Lightest Neutral Higgs Pair Production in Photon-photon Collisions in the Minimal Supersymmetric Standard Model

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Abstract

The cross sections for the lightest neutral Higgs pair production at the one-loop level in photon-photon collisions are calculated in the Minimal Supersymmetric Standard Model(MSSM). We find that the contributions to the lightest Higgs boson pair production cross sections arising from the genuine supersymmetric virtual particles dominate over that arising from the virtual particles in the two-Higgs-doublet model (2HDM) if there are mixing between the right- and left-handed stops, otherwise, the contributions from ones in the 2HDM are dominant. We present the detailed numerical results of the cross sections of the process $e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0$ in both beamstrahlung and laser back scattering photon modes at the Next Linear Collider (NLC). The cross sections are typically in the range of $10^{-3}fb$ to $10^5fb$ depending on the choice of the mass of the lightest neutral Higgs boson, $\tan\beta$ and photon collision modes, especially whether there are mixing between the stops.

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I. INTRODUCTION

The Higgs boson is the missing piece and also the least known one of the standard model (SM). Experimental data set a lower bound of 65.5 GeV at the 95% confidence level (CL) [1]. On the other hand, exploiting the sensitivity to the Higgs boson through quantum loops, a global fit to the latest electronweak precision data predicts \( m_H = 149^{+148}_{-82} \) GeV together with a 95% CL upper bound at 550 GeV in the SM [2].

Beyond the SM, the most intensively studied class of the theories as a possible candidate for new physics is the supersymmetry (SUSY), especially the minimal supersymmetric extension of the standard model (MSSM) [3] in which two Higgs doublets are necessary, giving masses separately to up- and down-type fermions and assuring cancellation of anomalies, which has the same Higgs sectors with the two-Higgs-doublet model (2HDM), i.e. so-called Model II, except the restrictions imposed by SUSY. In contrary to the SM in which there is just a single neutral Higgs boson, in the MSSM, there are three neutral and two charged Higgs bosons, \( h_0, H, A \) and \( H^\pm \) of which \( h_0 \) and \( H \) are \( CP \)–even and \( A \) is \( CP \)–odd. The masses and coupling of these Higgs bosons are controlled by two parameters, e.g., \( m_A \) and \( \tan \beta \), at tree level. The upper bound for the mass [4] for the lightest \( CP \)–even \( h_0 \) in MSSM is \( m_{h_0} < m_Z \) at tree level and \( m_{h_0} < m_Z + \epsilon(m_t, \tilde{m}) \) when including radiative corrections (\( \tilde{m} \) is the SUSY mass scale). The pursuit of the Higgs bosons predicted by the SM and the MSSM is one of the primary goals of the present and next generation of colliders.

The main processes of the neutral Higgs boson production at the LEP2 and LHC are \( e^+e^- \rightarrow Z h_0 \) [5] and \( gg \rightarrow (h_0, H, A) \) [6], respectively. However, the Next Linear Collider (NLC) operating at a center-of-mass energy of 500 – 2000 GeV with the luminosity of the order of \( 10^{33} \) cm\(^{-2}\) s\(^{-1}\) can also provide an ideal place to search for the Higgs boson, especially, it may produce a lightest neutral Higgs boson pair with an observable production rate, since the events would be much cleaner than in the LHC and the parameters of the Higgs boson would be easier to extracted. There are mainly two options for the photon sources at the NLC: laser back-scattering and beamstrahlung photons. These two kind of
photon sources are the options of turning the electron-positron collider into a laser photon collider with high energy and high luminosity which are expected to be comparable to that of the primary $e^+e^-$ collisions [4,8].

The primary mechanism of the neutral Higgs production in photon-photon collisions is $\gamma\gamma \rightarrow (h_0, H, A)$, but in order to study the triple and quadruple Higgs couplings at future high energy colliders, it is necessary to explore the Higgs boson pair production process. In the SM, the cross section for the neutral Higgs boson pair production in photon-photon collisions has been calculated by J.V. Jikia [9], and in the 2HDM, the process $\gamma\gamma \rightarrow H_0H_0$ has also been computed for a special case in Ref. [10]. In this paper, we present the complete calculations of the lightest neutral Higgs boson pair production cross section at one-loop level in the MSSM. In the MSSM, besides the loop diagrams arising from the SM and the 2HDM particles, there are also hundreds of additional loop diagrams arising from genuine SUSY particles, which make the calculations much more complicated than the case of the SM and the 2HDM.

The structure of this paper is as follows. In Sec. II we give the analytical results in terms of the well-known standard notation of the one-loop integrals. In Sec. III we present some numerical examples with discussions. The tedious expressions of the form factors in the amplitude are summarized in Appendix A, B and C, respectively.

II. CALCULATIONS

The process of

$$\gamma(p_1, \lambda_1) + \gamma(p_2, \lambda_2) \rightarrow h_0(k_1) + h_0(k_2)$$

is forbidden at the tree level but it can be induced through one-loop diagrams which are shown in Fig.1-Fig.5 (all relevant cross diagrams are not explicitly shown), where $\lambda_{1,2}$ denote the helicities of photons. In the center-of-mass system(CMS) the momenta read in terms of the beam energy $E$ of the incoming photons and the scattering angle $\theta$
\[ p_1^\mu = E(1, 0, 0, -1) \]
\[ p_2^\mu = E(1, 0, 0, 1) \]
\[ k_1^\mu = E(1, -\beta \sin \theta, 0, -\beta \cos \theta) \]
\[ k_2^\mu = E(1, \beta \sin \theta, 0, \beta \cos \theta) \] (2)

where \( \beta = \sqrt{1 - 4m_h^2/\hat{s}} \) is the velocity of the Higgs in the CMS. We define the Mandelstam variables as

\[ \hat{s} = (p_1 + p_2)^2 = (k_1 + k_2)^2 \]
\[ \hat{t} = (p_1 - k_1)^2 = (p_2 - k_2)^2 \]
\[ \hat{u} = (p_1 - k_2)^2 = (p_2 - k_1)^2 \] (3)

In order to calculate polarization cross section, we introduce the explicit polarization vectors of the helicities \( \lambda_1 \lambda_2 \) for photons as follows

\[ \epsilon_1^\mu(p_1, \lambda_1 = \pm 1) = -\frac{1}{\sqrt{2}}(0, 1, \mp i, 0) \]
\[ \epsilon_2^\mu(p_2, \lambda_2 = \pm 1) = \frac{1}{\sqrt{2}}(0, 1, \pm i, 0) \] (4)

This choice of polarization vectors for the photons implies

\[ \epsilon_i.p_j = 0, \quad (i, j = 1, 2) \] (5)

and by the momentum conservation,

\[ \epsilon_i.k_1 = -\epsilon_i.k_2, \quad (i = 1, 2). \] (6)

We perform the calculation in the ’t Hooft-Feynman gauge, the relevant Feynman rules can be found in Ref [3]. Because this process can only be induced through loop diagrams, we do not need to consider the renormalization at one-loop level, and the ultraviolet divergence should be canceled automatically if the calculation is right. The virtual particles which enter loops are the third family (top and bottom) quarks, \( W \) bosons, charged ghosts, charged Goldstone bosons, charged Higgs bosons, charginos, squarks and sleptons. As we will see
below, the transversality to photon momentum has been obviously kept. In order to ensure the correctness of our calculations, as a check, we have compared our results with Ref. [9], and found that our results in the case of the SM are agreement with theirs.

Because of the transversality of photons and our choices of the photons helicities, the general amplitude for the process $\gamma\gamma \rightarrow h_0h_0$ can be simply written as

$$M = M_1\epsilon_1\epsilon_2 + M_2\epsilon_1k_1\epsilon_2k_1 + eps(\epsilon_1, \epsilon_2, p_1, p_2)M_3$$

with

$$eps(\epsilon_1, \epsilon_2, p_1, p_2) = \epsilon_{\mu\nu\rho\sigma}\epsilon_1^\mu\epsilon_2^\nu\hat{p}_1^\rho\hat{p}_2^\sigma,$$

where $\epsilon_{\mu\nu\rho\sigma}$ is the total anti-symmetry tensor, and the $M_i (i = 1, 2, 3)$, which correspond to the factors of the $\epsilon_1\epsilon_2$, $\epsilon_1k_1\epsilon_2k_1$ and $eps(\epsilon_1, \epsilon_2, p_1, p_2)$, respectively, are given by

$$M_i = \sum_{j=1}^{12} f_i^{(j)} + (f_i^{(1)} + f_i^{(6)} + f_i^{(10)} + f_i^{(11)}) \left[ k_1 \leftrightarrow k_2, \hat{u} \leftrightarrow \hat{t} \right].$$

Here, the form factor $f_i^{(j)}$ represents the contributions arising from Feynman diagrams with the indices of $j$, and the $f_i^{(j)} \left[ k_1 \leftrightarrow k_2, \hat{u} \leftrightarrow \hat{t} \right]$ stands for the contributions from the cross diagrams of the corresponding diagrams with the indices of $j$. Among these form factors,

$$f_2^{(k)} = 0, \text{ for } (k = 3, 4, 5...9)$$

and

$$f_3^{(k)} = 0, \text{ for } (k = 3, 4, 6, 7, 8...12)$$

the explicit expressions of the other form factors are given in Appendix A, B and C, respectively. Note that the amplitude in Eqs. 7 does not have gauge-invariance due to dropping terms that vanish for our specific choice of polarization vectors. But we find that the amplitude has indeed the gauge-invariance after adding the dropping terms, which confirms again that our calculations are correct.

The polarization cross section and the cross section of subprocess $\gamma\gamma \rightarrow h_0h_0$ are given by
\[ \hat{\sigma}(\lambda_1 \lambda_2) = \int_{\hat{t}_{\text{min}}}^{\hat{t}_{\text{max}}} \frac{1}{32\pi \hat{s}^2} |M(\lambda_1 \lambda_2)|^2 \, d\hat{t}, \]

\[ \hat{\sigma} = \int_{\hat{t}_{\text{min}}}^{\hat{t}_{\text{max}}} \frac{1}{32\pi \hat{s}^2} \sum_{\text{spins}} |M|^2 \, d\hat{t}, \]  

(12) respectively, where the bar over the summation recalls average over initial spins, and

\[ \hat{t}_{\text{min}} = \left( m_{\gamma_0}^2 - \frac{\hat{s}}{2} \right) - \frac{\beta \hat{s}}{2}, \]

\[ \hat{t}_{\text{max}} = \left( m_{\gamma_0}^2 - \frac{\hat{s}}{2} \right) + \frac{\beta \hat{s}}{2}. \]  

(13)

The total cross section of \( e^+ e^- \rightarrow \gamma \gamma \rightarrow h_0 h_0 \) can be obtained by folding the \( \hat{\sigma} \), the cross section of the subprocess \( \gamma \gamma \rightarrow h_0 h_0 \), with the photon luminosity

\[ \sigma(s) = \int_{2m_{\gamma_0}/\sqrt{s}}^{x_{\text{max}}} \frac{dL_{\gamma\gamma}}{dz} \frac{d\hat{\sigma}(\gamma \gamma \rightarrow h_0 h_0 \text{at } \hat{s} = z^2 s)}{dz}, \]

where \( \sqrt{s} \) and \( \sqrt{\hat{s}} \) is the CMS energy of \( e^+ e^- \) and \( \gamma \gamma \) respectively and \( dL_{\gamma\gamma}/dz \) is the photon luminosity, defined as

\[ \frac{dL_{\gamma\gamma}}{dz} = 2z \int_{x_{\text{max}}}^{x_{\gamma_{\gamma}}(1)} \frac{dx}{x} f_{\gamma/e}(x) f_{\gamma/e}(z^2/x), \]

\( f_{\gamma/e}(x) \) is the photon structure function of the electron beam [12]. For a TeV collider with \( \sigma_x/\sigma_y = 25.5 \), the beamstrahlung photon structure function can be represented as [13]

\[ f_{\gamma/e}(x) = \begin{cases} 
2.25 - \sqrt{\frac{x}{0.166}} \left( \frac{1-x}{x} \right)^{2/3} & \text{for } x < 0.84, \\
0 & \text{for } x > 0.84,
\end{cases} \]

where \( x \) is the relative momentum of the radiated photon and the parent electron.

If we operate NLC as a mother machine of photon-photon collider in Compton back-scattering photon fusion mode with unpolarization initial electrons and laser, the energy spectrum of the photons is given by [14]

\[ f_{\gamma/e}(x) = \begin{cases} 
\frac{1}{1.8397} \left( 1 - x + \frac{1}{1-x} - \frac{4x}{x_i(1-x)} + \frac{4x^2}{x_i^2(1-x)^2} \right) & \text{for } x < 0.83, \ x_i = 2(1 + \sqrt{2}), \\
0 & \text{for } x > 0.83.
\]
III. NUMERICAL EXAMPLES AND CONCLUSIONS

In the following we present some numerical results of a lightest neutral Higgs boson pair production cross section in the process of $e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0$. In our numerical calculations, for the SM parameters, we choose $m_w = 80.33\, GeV$, $m_z = 91.187\, GeV$, $m_t = 176\, GeV$, $m_b = 4.5\, GeV$ and $\alpha = \frac{1}{128}$. Other parameters are determined as follows

(i) The Higgs boson masses $m_{h_0}$, $m_H$, $m_A$ and $m_{H^\pm}$ are given by

$$m_{h_0}^2 = \frac{1}{2} \left[ m_A^2 + m_z^2 + \epsilon - \sqrt{(m_A^2 + m_z^2 + \epsilon)^2 - 4m_A^2m_z^2\cos^2\beta - 4\epsilon(m_A^2\sin^2\beta + m_z^2\cos^2\beta)} \right],$$ \hspace{1cm} (14)

$$m_H^2 = m_A^2 + m_z^2 - m_{h_0}^2 + \epsilon,$$ \hspace{1cm} (15)

and

$$m_{H^\pm}^2 = m_A^2 + m_w^2$$ \hspace{1cm} (16)

with

$$\epsilon = \frac{3G_F}{\sqrt{2}\pi^2\sin^2\beta} \log(1 + \frac{m_S^2}{m_t^2}).$$ \hspace{1cm} (17)

Here we take $m_S = m_{\tilde{Q}} = m_{\tilde{U}} = m_{\tilde{D}}$, the definitions of which are given below. The mixing angle $\alpha$ is fixed by $\tan \beta$ and the Higgs boson mass $m_A$,

$$\tan 2\alpha = \tan 2\beta \frac{m_A^2 + m_z^2}{m_A^2 - m_z^2 + \epsilon/\cos 2\beta},$$ \hspace{1cm} (18)

where $-\frac{\pi}{2} < \alpha < 0$.

(ii) In the MSSM the mass eigenstates $\tilde{q}_1$ and $\tilde{q}_2$ of the squarks are related to the current eigenstates $\tilde{q}_L$ and $\tilde{q}_R$ by

$$\begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} = R^{\tilde{q}} \begin{pmatrix} \tilde{q}_L \\ \tilde{q}_R \end{pmatrix} \quad \text{with} \quad R^{\tilde{q}} = \begin{pmatrix} \cos \theta_{\tilde{q}} & \sin \theta_{\tilde{q}} \\ -\sin \theta_{\tilde{q}} & \cos \theta_{\tilde{q}} \end{pmatrix}.$$ \hspace{1cm} (19)

For the squarks, the mixing angle $\theta_{\tilde{q}}$ and the masses $m_{\tilde{q}_{1,2}}$ can be calculated by diagonalizing the following mass matrices.
\[ M^2_q = \begin{pmatrix} M^2_{\text{LL}} & m_q M_{LR} \\ m_q M_{RL} & M^2_{\text{RR}} \end{pmatrix}, \]

\[ M^2_{\text{LL}} = m^2_Q + m^2_q + m^2_z \cos 2\beta (I^3_q - e_q \sin^2 \theta_w), \]

\[ M^2_{\text{RR}} = m^2_{\tilde{U}, \tilde{D}} + m^2_q + m^2_z \cos 2\beta e_q \sin^2 \theta_w, \]

\[ M_{LR} = M_{RL} = \begin{cases} A_t - \mu \cot \beta & (\tilde{q} = \tilde{t}) \\ A_b - \mu \tan \beta & (\tilde{q} = \tilde{b}) \end{cases}, \]

where \( m^2_Q, m^2_{\tilde{U}, \tilde{D}} \) are soft SUSY breaking mass terms of the left- and right-handed squark, respectively. Also, \( \mu \) is the coefficient of the \( H_1H_2 \) mixing term in the superpotential, \( A_t \) and \( A_b \) are the coefficient of the dimension-three trilinear soft SUSY-breaking term. \( I^3_q, e_q \) are the weak isospin and electric charge of the squark \( \tilde{q} \). From Eqs. \( 19 \) and \( 20 \), \( m_{\tilde{t}_{1,2}} \) and \( \theta_{\tilde{t}} \) can be derived as

\[ m^2_{\tilde{t}_{1,2}} = \frac{1}{2} \left[ M^2_{\text{LL}} + M^2_{\text{RR}} \mp \sqrt{(M^2_{\text{LL}} - M^2_{\text{RR}})^2 + 4m^2_t M^2_{LR}} \right], \]

\[ \tan \theta_{\tilde{t}} = \frac{m^2_{\tilde{t}} - M^2_{LR}}{m_t M_{LR}}. \]

Because of the small mass of the bottom quark, we will neglect the mixing between left- and right-sbottoms, thus \( \theta_b = 0 \). Similarly, we will neglect the mixing in the other light squarks. For simplicity, we shall assume the masses of all the light squarks (the superpartners of the first and the second family quarks) and all the sleptons (the superpartners of the three family leptons) are degenerate. For simplicity, we don’t show here the explicit expressions of the masses of mass-eigenstates of the sbottoms and the sleptons, which can be found in Ref. \[ 3 \]. In our numerical calculations, we choose \( m^2_Q = m^2_{\tilde{U}} = m^2_{\tilde{D}} = (1T\text{eV})^2 \).

(iii) For the parameters \( M, \tan \beta \) and \( \mu \) in the chargino matrix \[ 3 \], we put \( M = 100\text{GeV} \) and \( \mu = -300\text{GeV} \) unless otherwise stated, and \( \tan \beta \) remains a variable.

Some typical numerical calculations of the cross sections of the processes \( \gamma\gamma \to h_0h_0 \) and \( e^+e^- \to \gamma\gamma \to h_0h_0 \) are given in Figure \[ 3\text{--}10 \] and Figure \[ 11\text{--}14 \] respectively.

Figure \[ 3 \] shows the cross sections for the subprocess \( \gamma\gamma \to h_0h_0 \) as a function of the Higgs boson mass \( m_{h_0} \) for the opposite photon helicities \( \lambda_1 = -\lambda_2 = 1 \) in the MSSM, assuming...
\[ \tan \beta = 4 \text{ and } \sqrt{s} = 0.5, 1 \text{ and } 1.5 TeV. \]

In order to compare the contributions arising from different virtual particles, we also present the results of the cross section of the process in the 2HDM, of which the parameters space used in our numerical calculations only is the subset of the general 2HDM (Model II), where there are the relations between the Higgs boson masses (Eqs. 14-16) required by the MSSM. The figure shows that the cross section can increase from several \( fb \) to the order of \( 10^4 fb \) when \( m_{h_0} \) increases from 60 GeV to 120 GeV in the the mixing case of the stops. But it is only of the order of \( 10^{-1} fb \) in the no-mixing case of stops. The cross sections in the 2HDM are almost the same as that in the MSSM for no-mixing case.

Figure 7 and Figure 8 give the cross section of the subprocess as a function of the \( m_{h_0} \) for the equal photon helicities \( \lambda_1 = \lambda_2 = +1 \) and \( \lambda_1 = \lambda_2 = -1 \), respectively. From Figure 7 and Figure 8, one sees that the cross sections are smaller than that in the case of opposite photons helicities in the 2HDM and in the MSSM with the no-mixing case. And the cross sections for the mixing case of the stops are much larger than that for the no-mixing case of the stops and in the 2HDM. Figure 7 shows that the cross sections of the no-mixing case in the MSSM for the photon helicities \( \lambda_1 = \lambda_2 = +1 \) are almost the same as that in the 2HDM, but Figure 8 shows the cross sections for the photon helicities \( \lambda_1 = \lambda_2 = -1 \) are always bigger than that in the 2HDM. Such difference between the cross sections of the process for the photons helicities \( \lambda_1 = \lambda_2 = +1 \) and \( \lambda_1 = \lambda_2 = -1 \) is relative to the different contributions to the amplitude from the charginos.

In Figure 9 and 10, we present the cross sections of the subprocess \( \gamma \gamma \to h_0h_0 \) for the opposite and equal photon helicities as a function of the Higgs boson mass \( m_{h_0} \), respectively, assuming \( \tan \beta = 40 \). Because the difference between the cross sections of the process for the photons helicities \( \lambda_1 = \lambda_2 = +1 \) and \( \lambda_1 = \lambda_2 = -1 \) is negligibly small, we only present the results for the photons helicities \( \lambda_1 = \lambda_2 = +1 \). From Figure 9, we can see that the cross sections in the MSSM for the mixing case of stops are larger than that in the MSSM for the no-mixing case and in the 2HDM, especially for \( m_{h_0} > 90 GeV \), and the former can vary
from \( \sim 1fb \) to \( 10^4 fb \) when the Higgs mass is in the range of 60GeV to 130GeV, otherwise, the cross sections are only \( \sim 0.5fb \) and insensitive to the Higgs boson mass. Figure 10 shows that the cross sections in the MSSM for the mixing case of stops are much larger than that in the MSSM for the no-mixing and in the 2HDM for \( \sqrt{s} = 500GeV \), while for \( \sqrt{s} = 1000GeV \) and 1500GeV, the mixing effects of stops are only important for \( m_{h_0} > 120GeV \).

Figure 11 and Figure 12 give the total cross section for the process \( e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0 \) as the function of the Higgs boson mass \( m_{h_0} \) in beamstrahlung photon mode for \( \tan \beta = 4 \) and 40, respectively. From our calculations, we find that the contributions from the low energy cross section of the subprocess \( \gamma\gamma \rightarrow h_0h_0 \) are very important. In general, the total cross sections in the MSSM are greater than that in the 2HDM. We can see from Figure 11 that the total cross sections in the mixing case of stops are greatly enhanced, which are greater than \( 10^4 fb \) for all the Higgs boson masses in the range of 60 to 120GeV. But the total cross sections in the no-mixing case of stops and in the 2HDM are smaller than 1fb due to decoupling effects of the heavy squarks. From Figure 12 one sees that the cross sections for the mixing case of stops in the MSSM increase from order of 10fb to order of \( 10^4 fb \) with the increment of the mass of the Higgs boson, on the contrary, the total cross sections in the MSSM for the no-mixing case and in the 2HDM decrease.

In Figure 13 and Figure 14, we present the total cross sections of the process \( e^+e^-\gamma\gamma \rightarrow h_0h_0 \) in laser back-scattering photons mode as function of the Higgs boson mass \( m_{h_0} \) at \( e^+e^- \) CMS energy 500, 1000 and 1500GeV for \( \tan \beta = 4 \) and 40, respectively. The results given by these figures are similar to Figure 11 and 12 except that the total cross sections in the MSSM for the mixing case of stops decrease with increasing \( e^+e^- \) CMS energy.

To summarize, we have calculated the total cross sections of the process \( e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0 \) at one-loop level in the MSSM in both photon-photon collision mode of the laser back scattering and beamstrahlung. The results of numerical calculations for several typical parameter values show that the contributions to the total cross sections arising from the virtual particles in 2HDM play an important role when there are not mixing between the stops, otherwise, the genuine supersymmetric contributions to the total cross sections dominate.
over that arising from the ones in the 2HDM. The total cross sections of the process in the MSSM with the mixing case of the stops are much larger than that for the no-mixing case and in the 2HDM for both of $\tan \beta = 4$ and 40. Note that our numerical calculations indicate that the total cross sections are insensitive to the parameter $\mu$, and so we do not show the corresponding curves versus $\mu$. We conclude that the total cross section of the process $e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0$ varies from $10^{-3}\,fb$ to $10^5\,fb$ at $e^+e^-$ center-of-mass energy $\sqrt{s} = 500, 1000$ and $1500GeV$, mainly depending on the choice of the mass of the lightest neutral Higgs boson, $\tan \beta$ and photon collision modes, especially whether there are mixing between the stops.

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APPENDIX A

In this paper, all form factors are decomposed to two parts of contributions from the virtual particles in the 2HDM and the genuine SUSY, in which the contributions from the 2HDM include ones of the third generation quarks and the bosons in the SM as well as the additional bosons in the 2HDM.

The form factor $f_1^{(1)}$ is given by

$$f_1^{(1)} = f_1^{(1,2HDM)} + f_1^{(1,\text{charginos})} + f_1^{(1,\text{sfermions})}, \quad (22)$$

with

$$f_1^{(1,2HDM)} = f_1^{(1,\text{fermions})} + f_1^{(1,\text{bosons})}. \quad (23)$$

Here $f_1^{(1,\text{fermions})}$, $f_1^{(1,\text{bosons})}$, $f_1^{(1,\text{charginos})}$ and $f_1^{(1,\text{sfermions})}$ are
\[ f_{1}^{(1, \text{fermions})} = \]
\[
e^2 g^2 \frac{m_t^2 \cos(\alpha)^2 \csc(\beta)^2}{6m_w^2 \pi^2} \left[ 2B_0(0, m_t^2, m_t^2) + (m_{h_0}^2 + 4m_t^2 - \hat{t} - 2\hat{u})C_0^9 + 2m_t^2(\hat{s} + 2\hat{t})D_0^7 + (m_{h_0}^2 - \hat{u})C_1^9 + 2(m_{h_0}^2 + 4m_t^2)(m_{h_0}^2 + \hat{t})D_1^7 + 2\hat{s}C_2^9 + (m_{h_0}^4 + 2m_{h_0}^2\hat{t} + 8m_t^2\hat{t} - \hat{t}\hat{u})D_2^7 + 4m_{h_0}(\hat{t} + \hat{u})D_{11}^7 + 2(4m_{h_0}^2 - \hat{s})(m_{h_0}^2 + \hat{t})D_{12}^7 + (8m_{h_0}^4 - 4m_{h_0}^2\hat{s} + \hat{s}^2)D_{13}^7 + (m_{h_0}^2 + \hat{t})^2D_{22}^7 + 4(-4m_t^4 + \hat{t} + \hat{u})D_{001}^1 + 2(-m_{h_0}^2 + \hat{t})(-\hat{t} + \hat{u})D_{12}^1 + (-2m_{h_0}^4 + 2m_{h_0}^2\hat{t} - \hat{t}^2 + 2m_{h_0}^2\hat{u} - \hat{u}^2)D_{13}^4 - (m_{h_0}^2 + \hat{t})^2D_{22}^1 + 2(3m_{h_0}^2 + 2\hat{t} + \hat{u})D_{001}^1 + 8(-4m_{h_0}^2 + \hat{s})D_{001}^5 + 2(m_{h_0}^2 + 2\hat{t})D_{002}^4 - 8(m_{h_0}^2 + \hat{t})D_{002}^5 + e^2 g^2 \frac{\sin(\alpha - \beta)^2}{32\pi^2} \left( 2(-m_{h_0}^2 + \hat{t})(-m_{h_0}^2 + \hat{u})D_{11}^1 + 2(-m_{h_0}^2 + \hat{t})(-\hat{t} + \hat{u})D_{12}^1 + (-2m_{h_0}^4 + 2m_{h_0}^2\hat{t} - \hat{t}^2 + 2m_{h_0}^2\hat{u} - \hat{u}^2)D_{13}^1 - (m_{h_0}^2 + \hat{t})^2D_{22}^1 + 2(-13m_{h_0}^2 + 4\hat{s} + 2\hat{t} + \hat{u})D_{001}^1 - 2(3m_{h_0}^2 + 2\hat{t})D_{002}^4 + e^2 g^2 \frac{32\pi^2}{32\pi^2} \left( C_{00}^4(\cos(\alpha - \beta)^2 - 3\sin(\alpha - \beta)^2) - B_0(0, m_{w_{2}}^2, m_{w_{2}}^2) + (m_{h_0}^2 - \hat{u})C_1^1 - \hat{s}C_2^1 + \frac{e^2 g^2}{32\cos\theta_w^2\pi^2} \right) 4D_{00}^6(-2\cos\theta_w m_w \sin(\alpha - \beta) + m_z \cos(2\beta) \sin(\alpha + \beta))^2 + 2D_1^2 \sin(\alpha - \beta) (3 \cos\theta_w m_{h_0}^2 m_w \sin(\alpha - \beta) - \cos\theta_w m_{h_0}^2 \hat{t} \sin(\alpha - \beta) + \cos\theta_w \hat{t}^2 \sin(\alpha - \beta) + m_{h_0}^2 m_w m_z \cos(2\beta) \sin(\alpha + \beta) - m_w m_z \hat{t} \cos(2\beta) \sin(\alpha + \beta) + 2D_1^4 \sin(\alpha - \beta) (6 \cos\theta_w m_{h_0}^2 m_w^2 \sin(\alpha - \beta) - \cos\theta_w m_w^2 \hat{s} \sin(\alpha - \beta) + \cos\theta_w \hat{t}^2 \sin(\alpha - \beta) + 2 \cos\theta_w m_w^2 \hat{u} \sin(\alpha - \beta) - \cos\theta_w \hat{t} \hat{u} \sin(\alpha - \beta) - m_w m_z \hat{t} \cos(2\beta) \sin(\alpha + \beta) + m_w m_z \hat{u} \cos(2\beta) \sin(\alpha + \beta)) \]
\[ +2(-m_{h0}^2 + \hat{t}) \cos(\alpha - \beta)D_2^1(-\cos \theta_w m_{H^\pm}^2 \cos(\alpha - \beta)) + \cos \theta_w m_w^2 \cos(\alpha - \beta) + \cos \theta_w \hat{t} \cos(\alpha - \beta) - m_w m_z \sin(2\beta) \sin(\alpha + \beta)) \]
\[ + 2(-\hat{t} + \hat{u}) \cos(\alpha - \beta)D_1^1(\cos \theta_w m_{H^\pm}^2 \cos(\alpha - \beta) - \cos \theta_w m_w^2 \cos(\alpha - \beta) - \cos \theta_w \hat{t} \cos(\alpha - \beta) + m_w m_z \sin(2\beta) \sin(\alpha + \beta)) \]
\[ - D_0^1(\cos \theta_w m_{H^\pm}^2 \cos(\alpha - \beta) - \cos \theta_w m_w^2 \cos(\alpha - \beta) - \cos \theta_w \hat{t} \cos(\alpha - \beta) + m_w m_z \sin(2\beta) \sin(\alpha + \beta))^2 \]
\[ + C_0^1(-\cos \theta_w m_{H^\pm}^2 \cos(\alpha - \beta)^2) - \cos \theta_w m_{h0}^2 \cos(\alpha - \beta)^2 + \cos \theta_w m_w^2 \cos(\alpha - \beta)^2 \]
\[ + 3 \cos \theta_w \hat{t} \cos(\alpha - \beta)^2 - \cos \theta_w \hat{u} \cos(\alpha - \beta)^2 - \cos \theta_w m_{h0}^2 \sin(\alpha - \beta)^2 \]
\[ + 3 \cos \theta_w m_w^2 \sin(\alpha - \beta)^2 + 3 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 - \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 \]
\[ - 2m_w m_z \cos(2\beta) \sin(\alpha - \beta) - 2m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + D_{00}^1(8 \cos \theta_w^2 m_{h0}^2 \sin(\alpha - \beta)^2 + 48 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 - 17 \cos \theta_w^2 \hat{t} \sin(\alpha - \beta)^2 \]
\[ - 18 \cos \theta_w^2 \hat{u} \sin(\alpha - \beta)^2 + 6 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \]
\[ + 4m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2 + D_0^1(-16 \cos \theta_w^2 m_{h0}^2 m_w^2 \sin(\alpha - \beta)^2 \]
\[ - 4 \cos \theta_w^2 m_w^2 \hat{s} \sin(\alpha - \beta)^2 + 10 \cos \theta_w^2 m_w^2 \hat{t} \sin(\alpha - \beta)^2 \]
\[ - \cos \theta_w^2 \hat{t}^2 \sin(\alpha - \beta)^2 + 12 \cos \theta_w^2 m_w^2 \hat{u} \sin(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w^3 m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \]
\[ + 2 \cos \theta_w m_w m_z \hat{t} \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \]
\[ - m_w^2 m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2 + 4D_{00}^5(-2 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + m_z^2 \sin(2\beta) \sin(\alpha + \beta)^2 + D_{00}^4(\cos \theta_w^2 m_{H^\pm}^2 \cos(\alpha - \beta)^2 + 8 \cos \theta_w^2 m_{h0}^2 \cos(\alpha - \beta)^2 \]
\[ - \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 - 9 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 10 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 4m_z^2 \sin(2\beta) \sin(\alpha + \beta)^2 (\alpha + \beta)^2) \]
\[ -2a_3^2 m_{\chi_1}^2 + 2b_3^2 m_{\chi_1}^2 - 2a_3^2 m_{\chi_2}^2 m_{\chi_3}^2 - 2b_3^2 m_{\chi_1} m_{\chi_2}^2 + a_3^2 \bar{t} - b_3^2 \bar{t} + 2a_3^2 \bar{u} - 2b_3^2 \bar{u})C_{10}^{11} \\
+ 2m_{\chi_1} (a_3^2 m_{\chi_1}^2 - b_3^2 m_{\chi_1}^2 + a_3^2 m_{\chi_2}^2 + b_3^2 m_{\chi_2}^2) (-2m_{\chi_1}^2 - m_{\chi_1}^2 - \bar{s} - 2\bar{t})D_{10}^{12} \\
+ 2(a_3^2 - b_3^2) (-m_{\bar{h}_0}^2 + \bar{u})C_{11}^{1} \\
+ 4(-a_3^2 m_{\bar{h}_0}) + b_3^2 m_{\bar{h}_0} - 3a_3^2 m_{\bar{h}_0} m_{\chi_1}^2 + 3b_3^2 m_{\bar{h}_0} m_{\chi_1}^2 - 2a_3^2 m_{\bar{h}_0} m_{\chi_1}^2 m_{\chi_2}^2 \\
- 2b_3^2 m_{\bar{h}_0} m_{\chi_1}^2 m_{\chi_2}^2 + a_3^2 m_{\bar{h}_0} m_{\chi_2}^2 - b_3^2 m_{\bar{h}_0} m_{\chi_2}^2 - a_3^2 m_{\bar{h}_0} \bar{t} + b_3^2 m_{\bar{h}_0} \bar{t} \\
- 2a_3^2 m_{\chi_1}^2 \bar{t} + 2b_3^2 m_{\chi_1}^2 \bar{t} - 2a_3^2 m_{\chi_1} m_{\chi_2}^2 \bar{t} - 2b_3^2 m_{\chi_1} m_{\chi_2} \bar{t} - a_3^2 m_{\chi_2}^2 \bar{u} + b_3^2 m_{\chi_2}^2 \bar{u} \\
+ b_3^2 m_{\chi_1}^2 \bar{u} + a_3^2 m_{\chi_2}^2 \bar{u} + b_3^2 m_{\chi_2}^2 \bar{u})D_{11}^{12} + 4(-a_3^2 + b_3^2) \bar{s}C_{11}^{1} + 2(-a_3^2 m_{\bar{h}_0}) + b_3^2 m_{\bar{h}_0} \\
- 2a_3^2 m_{\bar{h}_0} m_{\chi_1}^2 + 2b_3^2 m_{\bar{h}_0} m_{\chi_2}^2 + 2a_3^2 m_{\bar{h}_0} m_{\chi_2}^2 - b_3^2 m_{\bar{h}_0} m_{\chi_2}^2 - a_3^2 m_{\bar{h}_0} \bar{t} \\
+ 2b_3^2 m_{\bar{h}_0} \bar{t} - 4a_3^2 m_{\chi_1}^2 \bar{t} + 4b_3^2 m_{\chi_1}^2 \bar{t} - 4a_3^2 m_{\chi_1} m_{\chi_2} \bar{t} - 4b_3^2 m_{\chi_1} m_{\chi_2} \bar{t} - a_3^2 \bar{u} - b_3^2 \bar{u})D_{12}^{12} \\
+ 8(a_3^2 - b_3^2)C_{00}^{11} + 8(a_3^2 m_{\chi_1}^2 - b_3^2 m_{\chi_1}^2 + 2a_3^2 m_{\chi_1} m_{\chi_2} + 2b_3^2 m_{\chi_1} m_{\chi_2} + a_3^2 m_{\chi_2}^2 - b_3^2 m_{\chi_2}^2 - a_3^2 \bar{t} \\
+ b_3^2 \bar{t} - a_3^2 \bar{u} + b_3^2 \bar{u})D_{00}^{12} + 8(-a_3^2 + b_3^2) m_{\bar{h}_0} (\bar{t} + \bar{u}) D_{11}^{12} + 4(a_3^2 - b_3^2) (-4m_{\bar{h}_0}^2 + \bar{s}) (m_{\bar{h}_0}^2 + \bar{t}) D_{12}^{12} \\
+ 2(a_3^2 - b_3^2) (-8m_{\bar{h}_0}^4 + 4m_{\bar{h}_0}^2 \bar{s} - \bar{s}^2) D_{13}^{12} + 2(-a_3^2 + b_3^2) (m_{\bar{h}_0}^2 + \bar{t})^2 D_{22}^{12} \\
+ [a_3 \rightarrow a_2, b_3 \rightarrow b_2, m_{\chi_1} \rightarrow m_{\chi_2}] + [a_3 \rightarrow a_1, b_3 \rightarrow b_1, m_{\chi_2} \rightarrow m_{\chi_1}] \\
+ [m_{\chi_1} \rightarrow m_{\chi_2}, m_{\chi_2} \rightarrow m_{\chi_1}] \right] \tag{26} \]

\[ f_{1,\text{fermions}}^{(1)} = -N_c \left[ \frac{e^2 \bar{t}^2}{2\pi^2} (\xi_3^2 D_{00}^{18} + \xi_3^2 D_{00}^{15} + \xi_3^2 D_{00}^{14} + \xi_3^2 D_{00}^{13}) \right] \\
- N_c \left[ e_{\ell} \rightarrow e_{\bar{b}}, \xi_{\ell_1} \rightarrow \xi_{\ell_1}, \xi_{\ell_2} \rightarrow \xi_{\ell_2}, \xi_{\ell_3} \rightarrow \xi_{\ell_3}, m_{\ell_1} \rightarrow m_{\ell_1}, m_{\ell_2} \rightarrow m_{\ell_2} \right] \\
- \left[ e_{\ell} \rightarrow e_{\tau}, \xi_{\ell_1} \rightarrow \xi_{\tau_1}, \xi_{\ell_2} \rightarrow \xi_{\tau_2}, \xi_{\ell_3} \rightarrow \xi_{\tau_3}, m_{\ell_1} \rightarrow m_{\tau_1}, m_{\ell_2} \rightarrow m_{\tau_2} \right] \tag{27} \]
\[
\begin{align*}
(m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2}), (m^2_{\tilde{t}_1}, m^2_{\bar{t}_1}, m^2_{t_1}), (m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2}), (m^2_{\tilde{t}_1}, m^2_{\bar{t}_1}, m^2_{t_1}), (m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2})
\end{align*}
\]

for \(C^i_m, C^i_{mm}, \) and

\[
\begin{align*}
(m^2_w, m^2_w, m^2_w, m^2_w), (m^2_H^\pm, m^2_H^\pm, m^2_w, m^2_w), (m^2_w, m^2_w, m^2_{H^\pm}, m^2_{H^\pm}), \\
(m^2_H^\pm, m^2_H^\pm, m^2_w, m^2_w), (m^2_w, m^2_H^\pm, m^2_H^\pm, m^2_{H^\pm}), (m^2_H^\pm, m^2_H^\pm, m^2_{H^\pm}, m^2_{H^\pm}), \\
(m^2_t, m^2_t, m^2_t, m^2_t), (m^2_{\tilde{t}_1}, m^2_{\tilde{t}_1}, m^2_{\tilde{t}_1}, m^2_{\tilde{t}_1}), (m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2}, m^2_{t_2}), \\
(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_1}, m^2_{\bar{t}_1}, m^2_{t_1}), (m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2}, m^2_{t_2}), (m^2_{\tilde{t}_1}, m^2_{\tilde{t}_1}, m^2_{\bar{t}_1}, m^2_{t_1}), (m^2_{\tilde{t}_2}, m^2_{\bar{t}_2}, m^2_{t_2}, m^2_{t_2}, m^2_{t_2})
\end{align*}
\]

for \(D^i_m, D^i_{mn}, D^{mn}_{mnt}.\) And \(a_i, b_i (i = 1, 2, 3)\) in Eqs. (26) are the coupling constants of the vertex \(h_0 - \chi^\pm_{1,2} - \chi^\mp_{1,2},\) which are given by

\[
\begin{align*}
a_1 &= \frac{ig}{2}((-Q^*_{11} + Q_{11}) \sin \alpha - (S^*_{11} + S_{11}) \cos \alpha) \\
b_1 &= \frac{ig}{2}((-Q^*_{11} + Q_{11}) \sin \alpha + (S^*_{11} - S_{11}) \cos \alpha) \\
a_2 &= \frac{ig}{2}((Q^*_{22} + Q_{22}) \sin \alpha - (S^*_{22} + S_{22}) \cos \alpha) \\
b_2 &= \frac{ig}{2}((-Q^*_{22} + Q_{22}) \sin \alpha + (S^*_{22} - S_{22}) \cos \alpha) \\
a_3 &= \frac{ig}{2}((Q^*_{21} + Q_{21}) \sin \alpha - (S^*_{21} + S_{21}) \cos \alpha) \\
b_3 &= \frac{ig}{2}((-Q^*_{21} + Q_{21}) \sin \alpha + (S^*_{21} - S_{21}) \cos \alpha),
\end{align*}
\]

where the details of the matrix \(Q\) and \(S\) can be found in Ref. [3]. In Eqs. (27) we only write down the contributions from the third generation sfermions, and \(N_c\) is the number of colors, \(e_t, e_b, e_\tau\) are the electric charge of the top quark, the bottom quark and the tau, respectively, the \(\xi_{ij}, \xi_{bj}, \xi_{\bar{j}j} (j = 1, 2, 3)\) are the coupling constants of the vertexes \(h_0 - \tilde{t} - \bar{t}, h_0 - \tilde{b} - \bar{b}, h_0 - \tilde{\tau} - \bar{\tau},\) respectively, which are given by (cf. Ref. [3])

\[
\begin{pmatrix}
\xi_{t1} & \xi_{t3} \\
\xi_{\bar{t}2} & \xi_{\bar{t}3}
\end{pmatrix} = ig R t A_t (R^t)^T
\]

(31)
with
\[
A_t = \left( \frac{m_f (1/2) - (2/3) \sin^2 \theta_w \sin(\alpha + \beta)}{\cos \theta_w} \right) - \frac{m_t^2 \cos(\alpha)}{m_w \sin(\beta)} \frac{m_t}{2m_w \sin(\beta)} (-A_t \cos \alpha - \mu \sin \alpha), \quad \text{(32)}
\]
and
\[
\begin{pmatrix}
\xi_{b1} & \xi_{b3} \\
\xi_{b3} & \xi_{b2}
\end{pmatrix} = \left( \frac{igm_z}{\cos \theta_w} \right) \begin{pmatrix}
(-1/2 + \sin^2 \theta_w) \sin(\alpha + \beta) & 0 \\
0 & -\sin^2 \theta_w \sin(\alpha + \beta)
\end{pmatrix}. \quad \text{(35)}
\]

The form factor \( f_1^{(2)} \) is given by
\[
f_1^{(2)} = f_1^{(2,2HDM)} + f_1^{(2,\text{charginos})} + f_1^{(2,\text{sfermions})}, \quad \text{(36)}
\]
with
\[
f_1^{(2,2HDM)} = f_1^{(2,\text{fermions})} + f_1^{(2,\text{bosons})}. \quad \text{(37)}
\]
Here the \( f_1^{(2,\text{fermions})}, f_1^{(2,\text{bosons})}, f_1^{(2,\text{charginos})} \) and \( f_1^{(2,\text{sfermions})} \) are
\[
f_1^{(2,\text{fermions})} = \frac{e^2 g^2 m_t^2 \cos(\alpha) \csc(\beta)^2}{12 m_w^2 \pi^2} \left[ -2 B_0 (0, m_t^2, m_t^2) + (m_{h_0}^2 - 2 \hat{\mu} - \hat{\mu}) C_0^9 + 2 m_t^2 s D_0^7 \\
+ (-4 m_{h_0}^2 + \hat{s}) C_1^9 - 2 (m_{h_0}^2 + \hat{t}) C_2^9 \right.
\]
\[
+ (m_{h_0}^4 - m_{h_0}^2 \hat{\mu} + \hat{s} \mu) D_2^7 + m_{h_0}^2 (m_{h_0}^2 - \hat{\mu}) D_3^7 + 2 (-m_{h_0}^2 - 8 m_t^2 + 2 \hat{\mu} + \hat{\mu}) D_{10}^7 \\
+ (-m_{h_0}^2 + \hat{t}) (-m_{h_0}^2 + \hat{\mu}) D_{12}^7 - (m_{h_0}^2 - \hat{\mu}) D_{13}^7 + (m_{h_0}^2 - \hat{\mu}) (m_{h_0}^2 + \hat{\mu}) D_{22}^7 \\
+ (m_{h_0}^4 + m_{h_0}^2 \hat{\mu} - 3 m_{h_0}^2 \hat{\mu} + \hat{s} \mu) D_{23}^7 + 2 m_{h_0}^2 (-m_{h_0}^2 + \hat{t}) D_{33}^7 \left. \\
+ \frac{e^2 g^2 m_t^2 \sin(\alpha)^2 \sec(\beta)^2}{48 m_w^2 \pi^2} [m_t \rightarrow m_b] \right), \quad \text{(38)}
\]
\[ f_1^{(2,\text{bosons})} = \]
\[
\frac{e^2 g^2 \cos(\alpha - \beta)^2}{16\pi^2} \left( \left( \hat{t} + \hat{u} \right) (D^2_{001} - D^3_{001}) + 2(m_{h_0}^2 + \hat{u})(D^2_{002} - D^3_{002}) \right) \\
+ \left( 4m_{h_0}^2 - \hat{s} \right) (D^2_{003} - D_{003}) + \frac{e^2 g^2}{16\cos\theta_w^2 \pi^2} \left( 2D^6_{00} (-2\cos\theta_w m_w \sin(\alpha - \beta) + m_z \cos(2\beta) \sin(\alpha + \beta))^2 \\
+ m_w^2 D^4_0 \sin(\alpha - \beta)(-12\cos\theta_w m_h^2 \sin(\alpha - \beta) - \cos\theta_w \hat{s} \sin(\alpha - \beta) \\
+ 7\cos\theta_w \hat{t} \sin(\alpha - \beta) + 7\cos\theta_w \hat{u} \sin(\alpha - \beta) - 2m_w m_z \cos(2\beta) \sin(\alpha + \beta)) \\
+ 2D^4_{00} (2\cos\theta_w m_h^2 \sin(\alpha - \beta)^2 + 12\cos\theta_w m_{h^2} \sin(\alpha - \beta)^2) \\
- 4\cos\theta_w^2 \hat{t} \sin(\alpha - \beta)^2 - 4\cos\theta_w^2 \hat{u} \sin(\alpha - \beta)^2 \\
+ 2\cos\theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2) \\
+ D^3_{00} \cos\theta_w^2 m_{h_0} \cos(\alpha - \beta)^2 - 4\cos\theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 5\cos\theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \\
- 2\cos\theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) \\
+ D^2_{00} (3\cos\theta_w^2 m_{h_0} \cos(\alpha - \beta)^2 - 4\cos\theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 3\cos\theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \\
- 2\cos\theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) \right) 
\]

\[ f_1^{(2,\text{charginos})} = \]
\[
\left[ \frac{e^2}{16\pi^2} \left( 8(a_3^2 - b_3^2) B_0 (0, m_{\tilde{\chi}^\pm_1}, m_{\tilde{\chi}^\pm_2}) + 2(a_3^2 - b_3^2)(-m_{h_0}^2 + 2m_{\tilde{\chi}^\pm_1}^2 - 2m_{\tilde{\chi}^\pm_2}^2 + 2\hat{t} + \hat{u})C_0^{13} \\
+ 2m_{\tilde{\chi}^\pm_1} (-a_3^2 m_{\tilde{\chi}^\pm_1}) + b_3^2 m_{\tilde{\chi}^\pm_2} - a_3^2 m_{\tilde{\chi}^\pm_2} - b_3^2 m_{\tilde{\chi}^\pm_1} \hat{s} D_0^{10} \\
+ 2(a_3^2 - b_3^2)(4m_{h_0}^2 - \hat{s})C_{14}^1 + 4(a_3^2 - b_3^2)(m_{h_0}^2 + \hat{t})C_{14}^2 + 2(a_3^2 - b_3^2)(-m_{h_0}^4 \\
- m_{h_0} m_{\tilde{\chi}^\pm_1}^2 + m_{h_0} m_{\tilde{\chi}^\pm_2}^2 + m_{h_0} \hat{u} + m_{\tilde{\chi}^\pm_1} \hat{u} - m_{\tilde{\chi}^\pm_2} \hat{u} - \hat{s} \hat{u}) D_{10}^2 \\
+ 2(a_3^2 - b_3^2)(-m_{h_0}^4 + m_{h_0} m_{\tilde{\chi}^\pm_1}^2 - m_{h_0} m_{\tilde{\chi}^\pm_2}^2 - m_{\tilde{\chi}^\pm_1} \hat{t}) \\
+ m_{\tilde{\chi}^\pm_1} \hat{t} + m_{h_0} \hat{u} D_{10}^3 + 4(a_3^2 m_{h_0}^2 - b_3^2 m_{h_0}^2 \\
+ 2a_3^2 m_{\tilde{\chi}^\pm_1}^2 - 2b_3^2 \hat{t} + a_3^2 \hat{t} + b_3^2 \hat{u} \hat{u}) D_{10}^1 + 2(a_3^2 - b_3^2)(m_{h_0}^2 + \hat{t})(-m_{h_0}^2 + \hat{u}) D_{12}^{10} \\
+ 2(a_3^2 - b_3^2)(m_{h_0}^2 + \hat{t}) D_{13}^{10} + 2(a_3^2 - b_3^2)(-m_{h_0}^2 + \hat{u})(m_{h_0}^2 + \hat{u}) D_{22}^{10} \\
+ 2(a_3^2 - b_3^2)(-m_{h_0}^4 - m_{h_0} \hat{u} - \hat{t} \hat{u}) D_{23}^{10} + 4(a_3^2 - b_3^2)m_{h_0}^2 m_{h_0} (m_{h_0}^2 + \hat{t}) D_{33}^{10} \right] 
\]
\[ f_1^{(2,sfermions)} = -N_c \left[ \frac{e^2 g^2}{2\pi^2} \left( \xi_{i3}^2 D_{00}^{16} + \xi_{i2}^2 D_{00}^{15} + \xi_{i1}^2 D_{00}^{14} + \xi_{i3}^2 D_{00}^{17} \right) \right] - N_c \left[ e_t \to e_b, \xi_{t1} \to \xi_{b1}, \xi_{t2} \to \xi_{b2}, \xi_{t3} \to \xi_{b3}, m_{i_t} \to m_{b_t}, m_{i_2} \to m_{b_2} \right] - \left[ e_t \to e_r, \xi_{t3} \to \xi_{r3}, m_{i_t} \to m_{r_t}, m_{i_2} \to m_{r_2} \right], \tag{41} \]

where \( C_{m}^{i}, C_{mn}^{i} \equiv C_{m}, C_{mn}(m_{h_0}^2, 0, t, i), C_{0}^{i} \equiv C_{0}(0, m_{h_0}^2, t, i) \) and \( D_{m}^{i}, D_{mn}^{i}, D_{mn}^{i} \equiv D_{m}, D_{mn}, D_{mnul}(0, m_{h_0}^2, 0, m_{h_0}^2, \bar{u}, \bar{t}, i) \). Here and below, the definition of \( i \) is the same with the case of \( f_1^{(1)} \), and their explicit expressions are given by Eqs. 28 and Eqs. 29.

The form factors \( f_1^{(3)} \) and \( f_1^{(4)} \) are given by

\[ f_1^{(3)} = f_1^{(4)} = \frac{e^2 g^2 m_Z m_Z B_0(0, m_Z^2, m_Z^2) \cos(\alpha - \beta)}{32 \cos \theta_w \pi^2 (m_H^2 - \hat{s})} (-\cos(2\alpha) \cos(\alpha + \beta) + 2 \sin(2\alpha) \sin(\alpha + \beta)) \]

\[ + \frac{3e^2 g^2 m_Z m_Z B_0(0, m_Z^2, m_Z^2) \cos(2\alpha) \sin(\alpha - \beta) \sin(\alpha + \beta)}{32 \cos \theta_w \pi^2 (m_{h_0}^2 + \hat{s})}. \tag{42} \]

The form factor \( f_1^{(5)} \) is given by

\[ f_1^{(5)} = f_1^{(5,2HDM)} + f_1^{(5,charginos)} + f_1^{(5,sfermions)}, \tag{43} \]

with

\[ f_1^{(5,2HDM)} = f_1^{(5,fermions)} + f_1^{(5,bosons)}. \tag{44} \]

Here \( f_1^{(5,fermions)}, f_1^{(5,bosons)}, f_1^{(5,charginos)} \) and \( f_1^{(5,sfermions)} \) are

\[ f_1^{(5,fermions)} = \]

\[ \left( -\cos(2\alpha) \cos(\alpha + \beta) + 2 \sin(2\alpha) \sin(\alpha + \beta) \right) \left( -\cos(2\alpha) \cos(\alpha + \beta) \right) \]

\[ \times \frac{e^2 g^2 m_Z}{48 \cos \theta_w m_W \pi^2 (m_H^2 - \hat{s})} \left( 4 m_t^2 \csc(\beta) \sin(\alpha) \left[ -2B_0(0, m_t^2, m_t^2) - \hat{s} C_0^0 - 2 \hat{s} C_2^0 + 8 C_{00}^0 \right] + m_t^2 \sec(\beta) \cos(\alpha) [m_t \to m_6] \right) \]

\[ + \frac{e^2 g^2 m_Z \cos(2\alpha) \sin(\alpha + \beta)}{16 \cos \theta_w m_W \pi^2 (m_{h_0}^2 + \hat{s})} \left( 4 m_t^2 \csc(\beta) \cos(\alpha) [m_t \to m_6] \right) \]

\[ \left[ 2B_0(0, m_t^2, m_t^2) + \hat{s} C_0^0 + 2 \hat{s} C_2^0 - 8 C_{00}^0 \right] - m_6^2 \sin(\alpha) \sec(\beta) [m_t \to m_6] \right) \right), \tag{45} \]
\[ f^{(5,\text{bosons})}_1 = \frac{(-\cos(2\alpha) \cos(\alpha + \beta) + 2 \sin(2\alpha) \sin(\alpha + \beta))(e^2 g^2 m_z m_w)}{32 \cos \theta_w \pi^2 (m_H^2 - \hat{s})} \left( \cos(\alpha - \beta)(4 - 2B_0(0, m_w^2, m_\mu^2) + \hat{s}C_0^1 - 2\hat{s}C_1^1 - 2\hat{s}C_2^1 + 8\hat{s}C_0^0 - 24C_0^{10} + \cos(2\beta) \cos(\alpha + \beta)(m_w^2 C_0^1 - 4C_0^{10} + 4C_0^{10}) \right) + \frac{3e^2 g^2 m_z m_w \cos(2\alpha) \sin(\alpha + \beta)}{32 \cos \theta_w \pi^2 (-m_{h_0}^2 + \hat{s})} \left( \sin(\alpha - \beta)(4 - 2B_0(0, m_w^2, m_\mu^2) + \hat{s}C_0^1 - 2\hat{s}C_1^1 - 2\hat{s}C_2^1 - 8\hat{s}C_0^{10} - 24C_0^{10} + \cos(2\beta) \sin(\alpha + \beta)(m_w^2 C_0^1 + 4C_0^{10} - 4C_0^{10}) \right), \] (46)

\[ f^{(5,\text{charginos})}_1 = \left[ \frac{e^2 \eta_2}{4\pi^2 (m_H^2 - \hat{s})} (2a_5 m_{x_2} \pm B_0(0, m_{x_2}^2, m_{x_2}^2) + a_5 m_{x_2} \pm \hat{s}C_0^1 + 2a_5 m_{x_2} \pm \hat{s}C_2^1 - 8a_5 m_{x_2} \pm C_0^{10} + (a_5 \rightarrow a_1, m_{x_2} \rightarrow m_{x_1}) \right] + [\eta_2 \rightarrow \eta_1, a_5 \rightarrow a_2, a_4 \rightarrow a_1, m_H \rightarrow m_{h_0}], \] (47)

\[ f^{(5,\text{sfermions})}_1 = N_c \left[ \frac{2e^2 e^2 \eta_1}{4\pi^2 (m_H^2 - \hat{s})} \left( (\xi_{t\bar{t}} C_{00}^{16} + \xi_{s\bar{t}} C_{00}^{17}) + \frac{2e^2 e^2 \eta_2}{4\pi^2 (m_H^2 - \hat{s})} (\xi_{t\bar{t}} C_{00}^{16} + \xi_{s\bar{t}} C_{00}^{17}) \right) \right] + N_c \left[ e_t \rightarrow e_b, \xi_{t\bar{t}} \rightarrow \xi_{b\bar{b}}, \xi_{s\bar{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{t\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{t\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{s\bar{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{s\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{s\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{t\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{t\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \xi_{s\tilde{t}} \rightarrow \xi_{b\tilde{b}}, \right] \] (48)

where \( C_{m}^{i}, C_{mn}^{i} \equiv C_{m}, C_{mn}(0, 0, \hat{s}, i) \), and \( \eta_1, \eta_2 \) are coupling constants of the vertexes \( h_0 - h_0 - h_0 \) and \( H - h_0 - h_0 \), respectively, which are given by

\[ \eta_1 = -\frac{3igm_z}{2 \cos \theta_w} \cos(2\alpha) \sin(\alpha + \beta) \]
\[ \eta_2 = -\frac{igm_z}{2 \cos \theta_w} (2 \sin(2\alpha) \sin(\alpha + \beta) - \cos(2\alpha) \cos(\alpha + \beta)), \] (49)

and \( a_4, a_5 \) are the coupling constants of the vertex \( H - \chi_{1,2}^\pm - \chi_{1,2}^\mp \), which are given by

\[ a_4 = -\frac{ig}{2} ((Q_{11}^* + Q_{11}) \cos \alpha + (S_{11}^* + S_{11}) \sin \alpha) \]
\[ a_5 = -\frac{ig}{2} ((Q_{22}^* + Q_{22}) \cos \alpha + (S_{22}^* + S_{22}) \sin \alpha). \] (50)

And \( \xi_{ti}, \xi_{bi}, \xi_{pi}, (i = 4, 5) \) are the coupling constants of the vertexes \( H - \tilde{t} - \tilde{t}, H - b - b \) and \( H - \tilde{\tau} - \tilde{\tau}, \) respectively, which are given by

\[ \begin{pmatrix} \xi_{t4} & \xi_{t6} \\ \xi_{b6} & \xi_{t5} \end{pmatrix} = (-ig) R^t A_{t}(R^t)^t. \] (51)
with
\[
A_t = \begin{pmatrix}
\frac{-m_t ((1/2)-(2/3)\sin^2 t_{\mu}) \cos (\alpha + \beta)}{\cos \theta_w} + \frac{m_t^2 \sin (\alpha)}{m_w \sin (\beta)} & \frac{m_t}{2m_w \sin (\beta)} & (A_t \sin \alpha - \mu \cos \alpha) \\
\frac{m_t}{2m_w \sin (\beta)} & \frac{-m_t (2/3)\sin^2 \theta_w \cos (\alpha + \beta)}{\cos \theta_w} + \frac{m_t^2 \sin \alpha}{m_w \sin (\beta)} & (A_t \sin \alpha - \mu \cos \alpha)
\end{pmatrix},
\] (52)

\[
\begin{pmatrix}
\xi_{b4} & \xi_{b6} \\
\xi_{b6} & \xi_{b5}
\end{pmatrix} = (ig) R^b A_b (R^b)^T
\] (53)

with
\[
A_b = \begin{pmatrix}
\frac{-m_b ((1/2)-(1/3)\sin^2 t_{\mu}) \cos (\alpha + \beta)}{\cos \theta_w} - \frac{m_b^2 \cos (\alpha)}{m_w \cos (\beta)} & \frac{m_b}{2m_w \cos (\beta)} & (-A_b \cos \alpha + \mu \sin \alpha) \\
\frac{m_b}{2m_w \cos (\beta)} & \frac{-m_b (1/3)\sin^2 \theta_w \cos (\alpha + \beta)}{\cos \theta_w} - \frac{m_b^2 \cos \alpha}{m_w \cos (\beta)} & (-A_b \cos \alpha + \mu \sin \alpha)
\end{pmatrix},
\] (54)

and
\[
\begin{pmatrix}
\xi_{\tilde{t}4} & \xi_{\tilde{t}6} \\
\xi_{\tilde{t}6} & \xi_{\tilde{t}5}
\end{pmatrix} = \left(\frac{igm_z \cos (\alpha + \beta)}{\cos \theta_w}\right) \begin{pmatrix} 1/2 - \sin^2 \theta_w & 0 \\
0 & \sin^2 \theta_w \end{pmatrix}.
\] (55)

The form factor \(f_1^{(6)}\) is given by
\[
f_1^{(6)} = -\frac{e^2 g^2}{32\pi^2} \left( B_0 (\hat{t}, m_{H^\pm}, m_{w^\pm}) \cos (\alpha - \beta)^2 + B_0 (\hat{t}, m_{w^\pm}, m_{w^\pm}) \sin (\alpha - \beta)^2 \right).
\] (56)

The form factor \(f_1^{(7)}\) is given by
\[
f_1^{(7)} = f_1^{(7,2HDM)} + f_1^{(7, sfermions)}.
\] (57)

with
\[
f_1^{(7,2HDM)} = e^2 g^2 / (32 \cos \theta_{w^2} \pi^2) \left(-4 \cos \theta_w \cos \theta_w B_0 (0, m_{w^2}, m_{w^2}) + \cos \theta_w \hat{s} C_1^1 + 4 \cos \theta_w \hat{s} C_2^1 + 4 C_{00}^6 \cos \theta_w \right)
\]
\[
+ \sin \theta_w \cos (2\alpha) \cos (2\beta) - \cos \theta_w \sin (2\alpha) \sin (2\beta))
\]
\[
+ 4 C_{00}^1 (6 \cos \theta_w - \sin \theta_w \cos (2\alpha) \cos (2\beta) + \cos \theta_w \sin (2\alpha) \sin (2\beta))
\]
\[
+ C_0^1 (\cos \theta_w m_{w^2} - 4 \cos \theta_w \hat{s} + m_{w^2} \sin \theta_w \cos (2\alpha) \cos (2\beta)
\]
\[
- \cos \theta_w m_{w^2} \sin (2\alpha) \sin (2\beta)),
\] (58)
The form factor \( f_{1}^{(7,sfermions)} \) is given by
\[
\begin{align*}
&f_{1}^{(7,sfermions)} = N_c \left[ \frac{ie^2 g^2}{2\pi^2} \left( \xi_{t1}^q C^{47} + \xi_{t1}^q D^{16} \right) \right] \\
&+ N_c \left[ e_t \rightarrow e_b, \xi_{t1}^q \rightarrow \xi_{b1}^q, \xi_{t2}^q \rightarrow \xi_{b2}^q, m_{t1} \rightarrow m_{b1}, m_{t2} \rightarrow m_{b2} \right] \\
&+ \left[ e_t \rightarrow e_\tau, \xi_{t1}^q \rightarrow \xi_{\tau1}^q, \xi_{t2}^q \rightarrow \xi_{\tau2}^q, m_{t1} \rightarrow m_{\tau1}, m_{t2} \rightarrow m_{\tau2} \right],
\end{align*}
\]
(59)

where \( C_{m}, C_{mn} \equiv C_{m}, C_{mn}(0, 0, \hat{s}, i) \) and \( \xi_{ti}^q, \xi_{bi}^q, \xi_{\tau i}^q \) \( (i = 1, 2) \) are the coupling constants of quadratic vertexes \( h_0 - h_0 - \tilde{t} - \tilde{t}, h_0 - h_0 - \tilde{b} - \tilde{b}, \) and \( h_0 - h_0 - \tilde{\tau} - \tilde{\tau}, \) respectively, which are given by

\[
\left( \begin{array}{c}
\xi_{ti}^q \\
\xi_{bi}^q
\end{array} \right) = \frac{ig^2}{2} R_t A_t^q (R_t)^T
\]
(60)

with

\[
A_t^q = \left( \begin{array}{cc}
\frac{((-1/2)-2(1/3) \sin^2 \theta_w) \cos(2\alpha)}{\cos^2 \theta_w} - \frac{m_t^2 \cos^2 \alpha}{m_t^2 \sin^2 \beta} & 0 \\
0 & (2/3) \tan^2 \theta_w \cos(2\alpha) - \frac{m_t^2 \cos^2 \alpha}{m_t^2 \sin^2 \beta}
\end{array} \right),
\]
(61)

\[
\left( \begin{array}{c}
\xi_{bi}^q \\
\xi_{b2}^q
\end{array} \right) = \frac{ig^2}{2} R_b A_b^q (R_b)^T
\]
(62)

with

\[
A_b^q = \left( \begin{array}{cc}
\frac{((-1/2)+1/3) \sin^2 \theta_w) \cos(2\alpha)}{\cos^2 \theta_w} - \frac{m_b^2 \sin^2 \alpha}{m_b^2 \cos^2 \beta} & 0 \\
0 & (-1/3) \tan^2 \theta_w \cos(2\alpha) - \frac{m_b^2 \sin^2 \alpha}{m_b^2 \cos^2 \beta}
\end{array} \right),
\]
(63)

and

\[
\left( \begin{array}{c}
\xi_{\tau i}^q \\
\xi_{\tau 2}^q
\end{array} \right) = \frac{ig^2}{2} \left( \begin{array}{c}
\frac{((-1/2)+\sin^2 \theta_w) \cos(2\alpha)}{\cos^2 \theta_w} \\
0
\end{array} \right)
\]
(64)

The form factor \( f_{1}^{(8)} \) is given by

\[
f_{1}^{(8)} = f_{1}^{(8,2HDM)} + f_{1}^{(8,sfermions)},
\]
(65)

with
\begin{align}
\mathcal{F}^{(8,2\text{HDM})}_1 &= \frac{e^2 g^2}{32 \cos \theta_w \pi^2} \left( 4 \cos \theta_w^2 + B_0(\hat{s}, m_{wH^\pm}^2, m_{H^\pm}^2)(-7 \cos \theta_w^2 + \sin \theta_w^2 \cos(2\alpha) \cos(2\beta) \\
&- \cos \theta_w^2 \sin(2\alpha) \sin(2\beta)) + B_0(\hat{s}, m_{H^\pm}^2, m_{H^\mp}^2)(- \cos \theta_w^2 \\
&- \sin \theta_w^2 \cos(2\alpha) \cos(2\beta) + \cos \theta_w^2 \sin(2\alpha) \sin(2\beta)) \right), \\
& \quad \text{(66)}
\end{align}

\begin{align}
\mathcal{F}^{(8,\text{sfermions})}_1 &= -N_c \left[ \frac{i e^2 e^2}{8 \pi^2} \left( \xi_{\tilde{t}_2} B_0(\hat{s}, m_{\tilde{t}_2}^2, m_{\tilde{t}_2}^2) + \xi_{\tilde{t}_1} B_0(\hat{s}, m_{\tilde{t}_1}^2, m_{\tilde{t}_1}^2) \right) \right] \\
& \quad - N_c \left[ \xi_t \to \xi_b, \xi_{\tilde{t}} \to \xi_{\tilde{b}}, \xi_{\tilde{b}_1} \to \xi_{\tilde{b}_2}, \xi_{\tilde{b}_2} \to \xi_{\tilde{b}_1}, m_{\tilde{t}_1} \to m_{\tilde{t}_2}, m_{\tilde{t}_2} \to m_{\tilde{t}_1} \right] \\
& \quad - \left[ \xi_t \to \xi_{\tilde{t}}, \xi_{\tilde{t}_1} \to \xi_{\tilde{t}_2}, \xi_{\tilde{t}_2} \to \xi_{\tilde{t}_1}, \xi_{\tilde{b}_1} \to \xi_{\tilde{b}_2}, \xi_{\tilde{b}_2} \to \xi_{\tilde{b}_1}, m_{\tilde{t}_1} \to m_{\tilde{t}_2}, m_{\tilde{t}_2} \to m_{\tilde{t}_1} \right]. \\
& \quad \text{(67)}
\end{align}

The form factor \( \mathcal{F}^{(9)}_1 \) is given by

\begin{align}
\mathcal{F}^{(9)}_1 &= \mathcal{F}^{(9,2\text{HDM})}_1 + \mathcal{F}^{(9,\text{sfermions})}_1, \\
& \quad \text{(68)}
\end{align}

with

\begin{align}
\mathcal{F}^{(9,2\text{HDM})}_1 &= \frac{e^2 g^2 m_J m_w}{32 \cos \theta_w \pi^2 (-m_{H}^2 + \hat{s})} \left( 4 \cos(\alpha - \beta) - 2B_0(\hat{s}, m_{H^\pm}^2, m_{H^\pm}^2) \cos(\alpha - \beta) \\
&- 6B_0(\hat{s}, m_{wH^\pm}^2, m_{H^\pm}^2) \cos(\alpha - \beta) + B_0(\hat{s}, m_{H^\pm}^2, m_{H^\pm}^2) \cos(2\beta) \cos(\alpha + \beta) \\
&- B_0(\hat{s}, m_{wH^\pm}^2, m_{H^\pm}^2) \cos(2\beta) \cos(\alpha + \beta) - (\cos(2\alpha) \cos(\alpha + \beta) + 2 \sin(2\alpha) \cos(\alpha + \beta)) \\
&+ \frac{3 \epsilon^2 e^2 m_J m_w \cos(2\alpha) \sin(\alpha + \beta)}{32 \cos \theta_w \pi^2 (m_{J0}^2 - \hat{s})} \left( 4 \sin(\alpha - \beta) - 2B_0(\hat{s}, m_{H^\pm}^2, m_{H^\pm}^2) \sin(\alpha - \beta) \\
&- 6B_0(\hat{s}, m_{wH^\pm}^2, m_{H^\pm}^2) \sin(\alpha - \beta) + B_0(\hat{s}, m_{H^\pm}^2, m_{H^\pm}^2) \cos(2\beta) \sin(\alpha + \beta) \\
&- B_0(\hat{s}, m_{wH^\pm}^2, m_{H^\pm}^2) \cos(2\beta) \sin(\alpha + \beta) \right), \\
& \quad \text{(69)}
\end{align}

\begin{align}
\mathcal{F}^{(9,\text{sfermions})}_1 &= -N_c \left[ \frac{2 \eta_1 \epsilon^2 e^2}{8 \pi^2 (m_{H^\pm}^2 - \hat{s})} \left( \xi_{\tilde{b}_5} B_0(\hat{s}, m_{\tilde{b}_5}^2, m_{\tilde{b}_5}^2) + \xi_{\tilde{b}_4} B_0(\hat{s}, m_{\tilde{b}_4}^2, m_{\tilde{b}_4}^2) \right) \right] \\
& \quad + \frac{2 \eta_1 \epsilon^2 e^2}{8 \pi^2 (m_{J0}^2 - \hat{s})} \left( \xi_{\tilde{t}_2} B_0(\hat{s}, m_{\tilde{t}_2}^2, m_{\tilde{t}_2}^2) + \xi_{\tilde{t}_1} B_0(\hat{s}, m_{\tilde{t}_1}^2, m_{\tilde{t}_1}^2) \right) \\
& \quad - N_c \left[ \xi_t \to \xi_b, \xi_{\tilde{t}} \to \xi_{\tilde{b}}, \xi_{\tilde{b}_1} \to \xi_{\tilde{b}_2}, \xi_{\tilde{b}_2} \to \xi_{\tilde{b}_1}, m_{\tilde{t}_1} \to m_{\tilde{t}_2}, m_{\tilde{t}_2} \to m_{\tilde{t}_1} \right] \\
& \quad - \left[ \xi_t \to \xi_{\tilde{t}}, \xi_{\tilde{t}_1} \to \xi_{\tilde{t}_2}, \xi_{\tilde{t}_2} \to \xi_{\tilde{t}_1}, \xi_{\tilde{b}_1} \to \xi_{\tilde{b}_2}, \xi_{\tilde{b}_2} \to \xi_{\tilde{b}_1}, m_{\tilde{t}_1} \to m_{\tilde{t}_2}, m_{\tilde{t}_2} \to m_{\tilde{t}_1} \right]. \\
& \quad \text{(70)}
\end{align}

The form factor \( \mathcal{F}^{(10)}_1 \) is given by
\[ f_1^{(10)} = e^2 g^2 \cos(\alpha - \beta)^2/(32\pi^2)((m_{h_0}^2 - \hat{t})(C_1^1 + C_2^2) + C_{00}^2 + 2C_{00}^1) + e^2 g^2 \sin(\alpha - \beta)^2/(32\pi^2)((m_{h_0}^2 - \hat{t})(C_1^1 + C_2^2) + 3C_{00}^1) + e^2 g^2/(32 \cos \theta_w^2 \pi^2)(-\cos \theta_w^2 B_0(0, m_w^2, m_w^2) + C_0^1(1 - 3 \cos \theta_w m_w^2 \sin(\alpha - \beta) + \cos \theta_w \hat{t} \sin(\alpha - \beta) - m_w m_z \cos(2\beta) \sin(\alpha + \beta)) + \cos(\alpha - \beta)C_0^1(-\cos \theta_w m_w^2 \sin(\alpha - \beta)) + \cos \theta_w \hat{t} \sin(\alpha - \beta) - m_w m_z \cos(2\beta) \sin(\alpha + \beta)) + \cos \theta_w \hat{t} \cos(\alpha - \beta) - m_w m_z \sin(2\beta) \sin(\alpha + \beta)) \],

(71)

where \(C_m^i, C_{mn}^i \equiv C_m \equiv C_m(m_{h_0}^2, 0, \hat{t}, i)\) and \(C_0^i \equiv C_0(0, m_{h_0}^2, \hat{t}, i)\).

The form factor \(f_1^{(11)}\) is given by

\[ f_1^{(11)} = e^2 g^2 \cos(\alpha - \beta)^2/(32\pi^2)((m_{h_0}^2 - \hat{t})(C_1^1 + C_2^2) + C_{00}^2 + 2C_{00}^1) + e^2 g^2 \sin(\alpha - \beta)^2/(32\pi^2)((m_{h_0}^2 - \hat{t})(C_1^1 + C_2^2) + 3C_{00}^1) + e^2 g^2/(32 \cos \theta_w^2 \pi^2)(-\cos \theta_w^2 B_0(0, m_w^2, m_w^2) + C_0^1(1 - 3 \cos \theta_w m_w^2 \sin(\alpha - \beta) + \cos \theta_w \hat{t} \sin(\alpha - \beta) - m_w m_z \cos(2\beta) \sin(\alpha + \beta)) + \cos(\alpha - \beta)C_0^1(-\cos \theta_w m_w^2 \sin(\alpha - \beta)) + \cos \theta_w \hat{t} \sin(\alpha - \beta) - m_w m_z \cos(2\beta) \sin(\alpha + \beta)) + \cos \theta_w \hat{t} \cos(\alpha - \beta) - m_w m_z \sin(2\beta) \sin(\alpha + \beta)) \],

(72)

where \(C_m^i, C_{mn}^i \equiv C_m \equiv C_m(m_{h_0}^2, 0, \hat{t}, i)\) and \(C_0^i \equiv C_0(0, m_{h_0}^2, \hat{t}, i)\).

The form factor \(f_1^{(12)}\) is given by

\[ f_1^{(12)} = f_1^{(12,2HDM)} + f_1^{(12,sfermions)}, \]

(73)

with

\[ f_1^{(12,2HDM)} = e^2 g^2 \cos(\alpha - \beta)^2/(32\pi^2)(4B_0(m_{h_0}^2, m_{H^\pm}^2, m_w^2) - 2(\hat{t} + \hat{u})C_1^7 \]

23
+ (8m^2_{h_0} - s)C_1^s + 2sC_2^7 + 2sC_8^s - 2C_{00}^s) \\
+ e^2 g^2 \sin(\alpha - \beta)^2)/(32\pi^2)(4B_0(m^2_{h_0}, m_w^2, m_{h_0}^2) + (4m^2_{h_0} + s)C_1^t + 4sC_1^t - 2C_{00}^t) \\
+ e^2 g^2/(16 \cos \theta_w^2 \pi^2)(-C_0^s(-2 \cos \theta_w m_w \sin(\alpha - \beta) \\
+ m_z \cos(2\beta) \sin(\alpha + \beta) + C_1^s(5 \cos \theta_w m_{h_0}^2 \sin(\alpha - \beta)^2 \\
- 10 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 - 2 \cos \theta_w \hat{s} \sin(\alpha - \beta)^2 \\
- m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 + C_1^s(4 \cos \theta_w m_{h_0}^2 \cos(\alpha - \beta)^2 \\
- \cos \theta_w \hat{s} \sin(\alpha - \beta)^2 + 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \\
- m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 + C_1^s(\cos \theta_w m_{H^\pm}^2 \cos(\alpha - \beta)^2 \\
+ \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 \\
+ \cos \theta_w \hat{s} \sin(\alpha - \beta)^2 + 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \\
+ m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2), (74)

\begin{align*}
\mathsf{f}_2^{(1, s\text{fermions})} &= N_c \left[ \frac{e^2 g^2}{4\pi^2} \left( \xi_{l1}^2 C_{18}^s + \xi_{l2}^2 C_{17}^s + \xi_{l3}^2 C_{16}^s + \xi_{l3}^2 C_{19}^s \right) \right] \\
+ N_c \left[ e_t \rightarrow e_b, \xi_{l1} \rightarrow \xi_{b1}, \xi_{l2} \rightarrow \xi_{b2}, \xi_{l3} \rightarrow \xi_{b3}, m_{l_1} \rightarrow m_{b_1}, m_{l_2} \rightarrow m_{b_2} \right] \\
+ \left[ e_t \rightarrow e_\tau, \xi_{l1} \rightarrow \xi_{\tau1}, \xi_{l2} \rightarrow \xi_{\tau2}, \xi_{l3} \rightarrow \xi_{\tau3}, m_{l_1} \rightarrow m_{\tau1}, m_{l_2} \rightarrow m_{\tau2} \right], (75)
\end{align*}

where \( C_m, C_{mn} \equiv C_m, C_{mn}(m^2_{h_0}, m^2_{h_0}, \hat{s}, i) \).

**APPENDIX B**

The form factor \( f_2^{(1)} \) is given by

\[
\mathsf{f}_2^{(1)} = \mathsf{f}_2^{(1, s\text{fermions})} + \mathsf{f}_2^{(1, \text{charmios})} + \mathsf{f}_2^{(1, \text{bosons})},
\]

with

\[
\mathsf{f}_2^{(1, s\text{fermions})} = \mathsf{f}_2^{(1, \text{fermions})} + \mathsf{f}_2^{(1, \text{bosons})}.
\]

Here \( \mathsf{f}_2^{(1, \text{fermions})} \), \( \mathsf{f}_2^{(1, \text{bosons})} \), \( \mathsf{f}_2^{(1, \text{charmios})} \) and \( \mathsf{f}_2^{(1, s\text{fermions})} \) are
\[
\begin{align*}
\mathcal{f}_2^{(1,\text{fermions})} &= \\
&= \frac{e^2 g^2 m_w^2 \cos(\alpha)^2 \csc(\beta)^2}{6m_w^2 \pi^2} \left[ -8m_t D_0^7 - 4(m_{h_0}^2 + 8m_t^2) D_1^7 - (16m_t^2 + \hat{s} + 2\hat{t}) D_2^7 \\
&- 4D_{00}^7 - 4(m_{h_0}^2 + 4m_t^2)(D_{11}^7 + D_{13}^7) + 2(-4m_{h_0}^2 - 16m_t^2 - \hat{t} + \hat{u}) D_{12}^7 - (8m_t^2 + \hat{s} + 2\hat{t}) D_{22}^7 \right] \\
&+ \frac{e^2 g^2 m_w^2 \sin(\alpha)^2 \sec(\beta)^2}{24m_w^2 \pi^2} [m_t \rightarrow m_w], \quad (78)
\end{align*}
\]

\[
\mathcal{f}_2^{(1,\text{bosons})} = \\
\frac{e^2 g^2 \cos(\alpha - \beta)}{16\pi^2} \left( 10D_{00}^4 - 16D_{00}^5 + 12D_{001}^4 - 32D_{001}^5 + 6D_{002}^4 - 16D_{002}^5 \\
+ (3m_{h_0}^2 + 2\hat{t} + \hat{u})(D_{111}^4 + 3D_{113}^4) + 4(-4m_{h_0}^2 + \hat{s})(D_{111}^5 + 3D_{113}^5) + 2(4m_{h_0}^2 + 4\hat{t} + \hat{u})(D_{112}^4 + D_{123}^4) \\
- 8(3m_{h_0}^2 + 2\hat{t} + \hat{u})(D_{112}^5 + D_{123}^5) + (7m_{h_0}^2 + 10\hat{t} + \hat{u}) D_{122}^4 - 4(6m_{h_0}^2 + 5\hat{t} + \hat{u}) D_{122}^5 \\
+ \hat{u} D_{122}^5 + (m_{h_0}^2 + 2\hat{t}) D_{122}^4 - 4(m_{h_0}^2 + \hat{t}) D_{122}^5 + \frac{e^2 g^2 \sin(\alpha - \beta)^2}{16\pi^2} \left( -6D_{00}^1 - 20D_{001}^1 - 10D_{002}^1 \\
+ (-13m_{h_0}^2 + 4\hat{s} + 2\hat{t} + \hat{u})(D_{111}^1 + 3D_{113}^1) - 2(8m_{h_0}^2 + 4\hat{t} + 3\hat{u})(D_{112}^1 + D_{123}^1) \\
- (17m_{h_0}^2 + 10\hat{t} + 3\hat{u}) D_{122}^1 - (3m_{h_0}^2 + 2\hat{t}) D_{122}^2 \right) \\
- \frac{e^2 g^2 C_0^2}{8\pi^2} + \frac{e^2 g^2}{8 \cos \theta_w \pi^2} (-2 \cos \theta_w m_w \sin(\alpha - \beta) \\
+ m_z \cos(2\beta) \sin(\alpha + \beta)^2 (D_0^6 + 4D_1^6 + 2D_2^6 + 2D_1^6 + 4D_1^6 + 2D_{13}^6 + D_{22}^6) \\
+ \frac{e^2 g^2}{32 \cos \theta_w \pi^2} \left( 2D_1^2 (-5 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 + 48 \cos \theta_w m_w \sin(\alpha - \beta)^2 \\
- 11 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 - 8 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 + 4m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2) \\
+ D_0^1 (48 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 - 7 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 - 8 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 \\
- 6 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + 4m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2) \\
+ 4D_1^1 \left( -\cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 + 48 \cos \theta_w m_w \sin(\alpha - \beta)^2 - 21 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 \\
- 17 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 + 6 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + 4m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2) \\
+ D_2^1 (-16 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 + 48 \cos \theta_w m_w \sin(\alpha - \beta)^2 + 8 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 \\
- 15 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 - 8 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 + 6 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \\
+ 4m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2) + 2(D_{11}^1 + D_{13}^1)(-34 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 \\
+ 48 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 + 16 \cos \theta_w \hat{t} \sin(\alpha - \beta)^2 - 3 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 - 2 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 \\
+ 6 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + 4m_z^2 \cos(2\beta) \sin(\alpha + \beta)^2) \\
+ 2D_{11}^1 (-49 \cos \theta_w m_{h_0} \sin(\alpha - \beta)^2 + 96 \cos \theta_w m_w \sin(\alpha - \beta)^2 + 20 \cos \theta_w \hat{u} \sin(\alpha - \beta)^2
\right).
\]
\[ + \cos \theta_w \hat{u} \sin(\alpha - \beta)^2 + 8m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + 8(D_{11}^5 + D_{13}^5)(-12 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 + 4 \cos \theta_w^2 \hat{s} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + 16D_{12}^5(-4 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - 5 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 3 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + 4D_{22}^5(-4 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - 6 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + 8D_2^5(-(\cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2) - 3 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[ - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + 4D_0^5(-2 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) + 8D_1^5(-12 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 \]
\[ + 5 \cos \theta_w^2 \hat{s} \cos(\alpha - \beta)^2 - 4 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[ + D_0^4(-11 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 + 11 \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 + \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 \]
\[ - 14 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 4m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) \]
\[ + 2D_2^4(-3 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 + 3 \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 \]
\[ + \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 8 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + 4m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) + D_{22}^4(\cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 \]
\[ + 8 \cos \theta_w^2 \hat{s} \cos(\alpha - \beta)^2 + 9 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + 4m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) + 4D_{12}^4(\cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 \]
\[ + 15 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 \]
\[ - 5 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 4m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) \]
\[ + 2(D_{11}^4 + D_{13}^4)(\cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 + 14 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 \]
\[ - 3 \cos \theta_w^2 \hat{i} \cos(\alpha - \beta)^2 - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 - 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) \]
\[ + 4m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2) + 2D_1^4(-6 \cos \theta_w^2 m_{h_0}^2 \cos(\alpha - \beta)^2 \]

\[ f_2^{(1,\text{charginos})} = \]
\[
\left[ \frac{e^2}{2\pi^2} (4m_{\tilde{\chi}^+}^2 a^2 m_{\tilde{\chi}^+} - b^2 m_{\tilde{\chi}^+} + a^2 m_{\tilde{\chi}^+} + b^2 m_{\tilde{\chi}^+}) D_0^{12} \right.
\]
\[
+ 4(a_3^2 m_{h_0}^2 - b_3^2 m_{h_0}^2 + 3a_3^2 m_{\chi_1}^2 - 3b_3^2 m_{\chi_1}^2 + 4a_3^2 m_{\chi_1}^2 m_{\tilde{\chi}^+}^2 + 4b_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + a_3^2 m_{\chi_2}^2 - b_3^2 m_{\chi_2}^2) D_1^{12} \]
\[
+ (6a_3^2 m_{\chi_1}^2 - 6b_3^2 m_{\chi_1}^2 + 8a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 8b_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 2a_3^2 m_{\chi_2}^2 - 2b_3^2 m_{\chi_2}^2 + a_3^2 s - b_3^2 s \\
+ 2a_3^2 t - 2b_3^2 t D_2^{12} + 4(a_3^2 - b_3^2) D_{10}^{12} + 4(a_3^2 m_{h_0}^2 - b_3^2 m_{h_0}^2 + a_3^2 m_{\chi_1}^2 - b_3^2 m_{\chi_1}^2 + 2a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 2b_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + a_3^2 m_{\chi_2}^2 - b_3^2 m_{\chi_2}^2) D_{11}^{12} \\
+ 2(4a_3^2 m_{h_0}^2 - 4b_3^2 m_{h_0}^2 + 4a_3^2 m_{\chi_1}^2 - 4b_3^2 m_{\chi_1}^2 + 8a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 8b_3^2 m_{\chi_1}^2 m_{\chi_2}^2) D_{12}^{12} \\
+ 8a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 4a_3^2 m_{\chi_2}^2 - 4b_3^2 m_{\chi_1}^2 + a_3^2 t - b_3^2 t - a_3^2 u + b_3^2 u) D_{13}^{12} \\
+ 4(a_3^2 m_{h_0}^2 - b_3^2 m_{h_0}^2 + a_3^2 m_{\chi_1}^2 - b_3^2 m_{\chi_1}^2 + 2a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 2b_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + a_3^2 m_{\chi_2}^2 - b_3^2 m_{\chi_2}^2) D_{14}^{12} \\
+ (2a_3^2 m_{\chi_1}^2 - 2b_3^2 m_{\chi_1}^2 + 4a_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 4b_3^2 m_{\chi_1}^2 m_{\chi_2}^2 + 2a_3^2 m_{\chi_2}^2 - 2b_3^2 m_{\chi_2}^2 \\
+ a_3^2 s - b_3^2 s + 2a_3^2 t - 2b_3^2 t D_{22}^{12}) \right] + \left[ a_3 \rightarrow a_2, b_3 \rightarrow b_2, m_{\chi_1} \rightarrow m_{\chi_2} \right] \\
+ \left[ a_3 \rightarrow a_1, b_3 \rightarrow b_1, m_{\chi_2} \rightarrow m_{\chi_1} \right] + \left[ m_{\chi_1} \rightarrow m_{\chi_2}, m_{\chi_2} \rightarrow m_{\chi_1} \right],
\]

\[
f_2^{(1,\text{sfermions})} = -N_c \left[ \frac{e^2 e^2}{2\pi^2} \left( \xi_5^2 (D_0^{18} + 4D_1^{18} + 2D_2^{18} + 2D_3^{18} + 4D_1^{18} + 2D_3^{18} \\
+ D_2^{12}) + \xi_5^2 (18 \rightarrow 15) + \xi_5^2 (18 \rightarrow 14) + \xi_5^2 (18 \rightarrow 19) \right) \right] \\
- N_c \left[ e_t \rightarrow e_b, \xi_1 \rightarrow \xi_2, \xi_2 \rightarrow \xi_1, \xi_3 \rightarrow \xi_4, m_{\tilde{t}} \rightarrow m_{\tilde{b}}, m_{\tilde{b}} \rightarrow m_{\tilde{t}} \right] \left[ e_t \rightarrow e_\tau, \xi_1 \rightarrow \xi_\tau, \xi_2 \rightarrow \xi_\tau, \xi_3 \rightarrow \xi_\tau, m_{\tilde{t}} \rightarrow m_{\tilde{\tau}}, m_{\tilde{\tau}} \rightarrow m_{\tilde{t}} \right],
\]

where \( C_m, C_m^i \equiv C_m, C_m(0, 0, s, i) \) and \( D_x \equiv D_x(m_{h_0}^2, 0, 0, m_{h_0}^2, \tilde{t}, \tilde{s}, i) \).

The form factor \( f_2^{(2)} \) is given by

\[
f_2^{(2)} = f_2^{(2, \text{2HDM})} + f_2^{(2, \text{charginos})} + f_2^{(2, \text{sfermions})},
\]

with
\[ f_2^{(2,2HDM)} = f_2^{(2,\text{fermions})} + f_2^{(2,\text{bosons})}. \]  

(82)

Here \( f_2^{(2,\text{fermions})}, f_2^{(2,\text{bosons})}, f_2^{(2,\text{charginos})} \) and \( f_2^{(2,\text{sfermions})} \) are

\[
\begin{align*}
  f_2^{(2,\text{fermions})} &= \\
  &= \frac{e^2 g^2 m_t^2 \cos(\alpha)\csc(\beta)^2}{6m_w^2 \pi^2} \left[ 2C_0^0 - (8m_t^2 + \hat{s})D_2^7 \\
  &\quad - 8m_t^2 D_3^7 - 4D_{00}^7 + (\hat{t} - \hat{u})(D_{12}^7 + D_{13}^7) - (8m_t^2 + \hat{s} + 2\hat{u})D_{22}^7 \\
  &\quad + (-4m_h^2 - 16m_t^2 + \hat{t} - \hat{u})D_{23}^7 - 2(m_h^2 + 4m_t^2)D_{33}^7 \right] \\
  &\quad + \frac{e^2 g^2 m_t^2 \sin(\alpha)^2 \sec(\beta)^2}{24m_w^2 \pi^2} \left[ m_t \to m_0 \right],
\end{align*}
\]

(83)

\[
\begin{align*}
  f_2^{(2,\text{bosons})} &= \\
  &= \frac{e^2 g^2 \cos(\alpha - \beta)^2}{16 \pi^2} \left( 4C_0^5 - 4C_1^2 + 4C_1^3 + 2(-\hat{t} + \hat{u})D_1^3 \\
  &\quad - 4C_2^2 + 4C_2^3 + 4D_{00}^3 + 4D_{00}^3 + (-\hat{t} + \hat{u})(D_{12}^3 + D_{13}^3 + D_{13}^3 + D_{13}^3) + 8(D_{00}^2 - D_{00}^2 + D_{00}^3 - D_{00}^3) \\
  &\quad + (-\hat{t} + \hat{u})(D_{12}^3 - D_{12}^3 + 2D_{12}^3 - 2D_{12}^3 - D_{12}^3 - D_{12}^3 + 2(m_h^2 + \hat{u})(D_{22}^3 - D_{22}^3) \\
  &\quad + (6m_h^2 + \hat{t} + 5\hat{u})(D_{22}^3 - D_{23}^3) + 2(3m_h^2 + \hat{t} + 2\hat{u})(D_{23}^3 - D_{23}^3 + 4m_h^2 - \hat{s})(D_{33}^3 - D_{33}^3) \right) \\
  &\quad + \frac{e^2 g^2 \sin(\alpha - \beta)^2}{8 \pi^2} \left( 2C_0^1 + (-\hat{t} + \hat{u})(D_1^1 + D_{12}^1 + D_{13}^1) + 4D_{10}^1 \right) \\
  &\quad + \frac{e^2 g^2}{16 \cos \theta_w^2 \pi^2} \left( 2(-2 \cos \theta_w m_w \sin(\alpha - \beta) + m_z \cos(2\beta) \sin(\alpha + \beta))^2(D_6^0 + D_6^3 + D_6^3 + 2D_{22}^3 + D_{33}^3) \\
  &\quad + 2D_{10}^1 \sin(\alpha - \beta)(3 \cos \theta_w m_h^2 \cos(\alpha - \beta) - 2 \cos \theta_w \hat{t} \sin(\alpha - \beta) \\
  &\quad - \cos \theta_w \hat{u} \sin(\alpha - \beta) + 2m_w m_z \cos(2\beta) \sin(\alpha + \beta)) \\
  &\quad + 2 \cos(\alpha - \beta)D_0^3(3 \cos \theta_w m_h^2 \cos(\alpha - \beta) - 2 \cos \theta_w \hat{t} \cos(\alpha - \beta) \\
  &\quad - \cos \theta_w \hat{u} \cos(\alpha - \beta) + 2m_w m_z \sin(2\beta) \sin(\alpha + \beta)) \right) \\
  &\quad + 2D_1^1(4 \cos \theta_w^2 m_h^2 \sin(\alpha - \beta)^2 + 12 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 \\
  &\quad - 4 \cos \theta_w^2 \hat{t} \sin(\alpha - \beta)^2 + 2 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \\
  &\quad + m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 + 2D_1^1(4 \cos \theta_w^2 m_h^2 \sin(\alpha - \beta)^2 \\
  &\quad + 12 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 - 3 \cos \theta_w^2 \hat{t} \sin(\alpha - \beta)^2 - 3 \cos \theta_w^2 \hat{u} \sin(\alpha - \beta)^2 \\
  &\quad + 2 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2) \\
  &\quad + 2D_{22}^1(4 \cos \theta_w^2 m_h^2 \sin(\alpha - \beta)^2 + 12 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 - 4 \cos \theta_w^2 \hat{t} \sin(\alpha - \beta)^2
\end{align*}
\]

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\[-2 \cos \theta_w^2 \hat{u} \sin(\alpha - \beta)^2 + 2 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ 2 D_3^1 (6 \cos \theta_w^2 m_h^2 \sin(\alpha - \beta)^2 + 12 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 - 4 \cos \theta_w^2 t \sin(\alpha - \beta)^2 \]
\[-2 \cos \theta_w^2 \hat{u} \sin(\alpha - \beta)^2 + 2 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) + m_w^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_2^3 (6 \cos \theta_w^2 m_h^2 \sin(\alpha - \beta)^2 + 48 \cos \theta_w^2 m_w^2 \sin(\alpha - \beta)^2 + 5 \cos \theta_w^2 \hat{s} \sin(\alpha - \beta)^2 \]
\[-9 \cos \theta_w^2 \hat{t} \sin(\alpha - \beta)^2 - 5 \cos \theta_w^2 \hat{u} \sin(\alpha - \beta)^2 + 8 \cos \theta_w m_w m_z \cos(2\beta) \sin(\alpha - \beta) \sin(\alpha + \beta) \]
\[+ 4 m_z^2 \cos(2\beta)^2 \sin(\alpha + \beta)^2 + (D_2^1 + D_3^1) (-4 \cos \theta_w^2 m_{H^\pm} \cos(\alpha - \beta)^2 \]
\[-\cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 + 4 \cos \theta_w^2 m_w^2 \cos(\alpha - \beta)^2 + \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[+ 6 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_3^3 (5 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 5 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 4 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[-2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_2^2 (7 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 4 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 3 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[-2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_3^3 (3 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 2 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[-2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_2^2 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 4 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[-2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_3^3 (13 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 8 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 5 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[+ 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_2^3 (9 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 8 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[+ 2 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 2 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_2^2 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 4 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 4 m_z^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \]
\[+ D_3^3 (6 \cos \theta_w^2 m_h^2 \cos(\alpha - \beta)^2 - 9 \cos \theta_w^2 \hat{t} \cos(\alpha - \beta)^2 - 5 \cos \theta_w^2 \hat{u} \cos(\alpha - \beta)^2 \]
\[-4 \cos \theta_w m_w m_z \cos(\alpha - \beta) \sin(2\beta) \sin(\alpha + \beta) + 4 m_w^2 \sin(2\beta)^2 \sin(\alpha + \beta)^2 \} \right),
\]

\[f_2^{(2\text{charginos})} = \]

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\[
\left[ \frac{e^2}{2\pi^2} \left( (4a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{1i}}^2 + 4a_3^2m_{\chi_{1i}m_{\chi_{2i}}} + 4b_3^2m_{\chi_{1i}m_{\chi_{2i}}} + a_3^2\hat{s} - b_3^2\hat{s})D_{10}^{10} + 4m_{\chi_{1i}}(a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{1i}}^2 + a_3^2m_{\chi_{2i}}^2 + b_3^2m_{\chi_{2i}}^2)D_{10}^{10} + (a_3^2 - b_3^2)(-2C_0^{13} + 4D_{00}^{10} + (-\hat{t} + \hat{u})(D_{12}^{10} + D_{13}^{10})) \right) \\
+ 2a_3^2\hat{u} - b_3^2\hat{u})D_{22}^{10} + (4a_3^2m_{h_0}^2 - 4b_3^2m_{h_0}^2 + 4a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{2i}}^2 + 8a_3^2m_{\chi_{1i}}m_{\chi_{2i}}^2 \\
+ 8b_3^2m_{\chi_{1i}m_{\chi_{2i}}} + 4a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{2i}}^2 - a_3^2\hat{t} + b_3^2\hat{t} + a_3^2\hat{u} - b_3^2\hat{u})D_{23}^{10} \\
+ 2(a_3^2m_{h_0}^2 - b_3^2m_{h_0}^2 + a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{2i}}^2 + 2a_3^2m_{\chi_{1i}m_{\chi_{2i}}} + 2b_3^2m_{\chi_{1i}}m_{\chi_{2i}} + a_3^2m_{\chi_{1i}}^2 - b_3^2m_{\chi_{2i}}^2)D_{33}^{10}) \right] \\
+ \left[ a_3 \rightarrow a_3, \ b_3 \rightarrow b_3, m_{\chi_{1i}} \rightarrow m_{\chi_{2i}}, m_{\chi_{2i}} \rightarrow m_{\chi_{1i}} \right] + \left[ a_3 \rightarrow a_3, \ b_3 \rightarrow b_3, m_{\chi_{1i}} \rightarrow m_{\chi_{2i}}, m_{\chi_{2i}} \rightarrow m_{\chi_{1i}} \right],
\]

(85)

\[
f_2^{(2,\text{fermions})} = -N_c \left[ \frac{e^2e_i^2}{2\pi^2} \left( \xi_{f_3}^2(D_{12}^{16} + D_{16}^{12} + D_{22}^{16} + D_{26}^{12}) \\
- \xi_{f_2}^2(16 \rightarrow 15) - \xi_{f_1}^2(16 \rightarrow 14) - \xi_{f_3}^2(16 \rightarrow 17) \right) \right] \\
- N_c \left[ e_t \rightarrow e_{\hat{t}}, \xi_{f_1} \rightarrow \xi_{\hat{f}_1}, \xi_{f_2} \rightarrow \xi_{\hat{f}_2}, \xi_{f_3} \rightarrow \xi_{\hat{f}_3}, m_{\hat{f}_1} \rightarrow m_{\hat{f}_2}, m_{\hat{f}_2} \rightarrow m_{\hat{f}_3} \right] \\
- \left[ e_t \rightarrow e_t, \xi_{f_1} \rightarrow \xi_{\hat{f}_1}, \xi_{f_2} \rightarrow \xi_{\hat{f}_2}, \xi_{f_3} \rightarrow \xi_{\hat{f}_3}, m_{\hat{f}_1} \rightarrow m_{\hat{f}_2}, m_{\hat{f}_2} \rightarrow m_{\hat{f}_3} \right],
\]

(86)

where \( D_{mn}^i, D_{mnm}^i, D_{mnm}^{i,md} \equiv D_m, D_{mn}, D_{mnl}(0, m_{h_0}^2, 0, m_{h_0}^2, \hat{u}, \hat{t}, i) \), \( C_m, C_{mn} \equiv C_m, C_{mn}(m_{h_0}^2, 0, \hat{t}, i) \) and \( C_0 \equiv C_0(0, m_{h_0}^2, \hat{t}, i) \).

The form factor \( f_2^{(10)} \) is given by

\[
f_2^{(10)} = \frac{e^2g^2 \cos(\alpha - \beta)^2}{32\pi^2} \left( 4C_0^{0} - C_0^{4} + 6C_0^{1} + 6C_0^{2} + C_0^{3} + 2C_0^{1} + 2C_0^{2} + 4C_0^{3} + 2C_0^{2} + 2C_0^{3} \right) \\
+ \frac{3e^2g^2 \sin(\alpha - \beta)^2}{32\pi^2} \left( C_0^{1} + 2C_0^{1} + 2C_0^{1} + C_0^{1} + 2C_0^{1} + 2C_0^{2} \right),
\]

(87)

where \( C_m, C_{mn} \equiv C_m, C_{mn}(m_{h_0}^2, 0, \hat{t}, i) \) and \( C_0 \equiv C_0(0, m_{h_0}^2, \hat{t}, i) \).

The form factor \( f_2^{(11)} \) is given by

\[
f_2^{(11)} = \frac{e^2g^2 \cos(\alpha - \beta)^2}{32\pi^2} \left( 4C_0^{0} - C_0^{4} + 6C_0^{1} + 6C_0^{2} + C_0^{3} + 2C_0^{1} + 2C_0^{2} + 4C_0^{3} + 2C_0^{2} + 2C_0^{3} \right) \\
+ \frac{3e^2g^2 \sin(\alpha - \beta)^2}{32\pi^2} \left( C_0^{1} + 2C_0^{1} + 2C_0^{1} + C_0^{1} + 2C_0^{1} + 2C_0^{2} \right),
\]

(88)

where \( C_m, C_{mn} \equiv C_m, C_{mn}(m_{h_0}^2, 0, \hat{t}, i) \) and \( C_0 \equiv C_0(0, m_{h_0}^2, \hat{t}, i) \).
The form factor $f_{2}^{(12)}$ is given by

$$f_{2}^{(12)} = \frac{e^{2}g^{2} \cos(\alpha - \beta)^{2}}{16\pi^{2}} \left(-4C_{0}^{8} - 4C_{1}^{8} - C_{11}^{8}\right) - \frac{e^{2}g^{2} \sin(\alpha - \beta)^{2}}{16\pi^{2}} \left(4C_{0}^{1} - 4C_{1}^{1} - C_{11}^{1}\right),$$  \hspace{1cm} (89)

where $C_{m}^{i}, C_{mn}^{i} \equiv C_{m}, C_{mn}(m_{h0}^{2}, m_{h0}^{2}, \hat{s}, i)$.

APPENDIX C

The form factor $f_{3}^{(1)}$ is given by

$$f_{3}^{(1)} = \left[ \frac{ie^{2}a_{3}b_{3}m_{\tilde{\chi}_{1}^{\pm}m_{\tilde{\chi}_{2}^{\pm}D_{0}^{12}}^{12}}}{\pi^{2}} \right] + \left[ a_{3} \rightarrow a_{2}, b_{3} \rightarrow b_{2}, m_{\tilde{\chi}_{1}^{\pm}} \rightarrow m_{\tilde{\chi}_{2}^{\pm}} \right]$$

$$+ \left[ a_{3} \rightarrow a_{1}, b_{3} \rightarrow b_{1}, m_{\tilde{\chi}_{2}^{\pm}} \rightarrow m_{\tilde{\chi}_{1}^{\pm}} \right] + \left[ m_{\tilde{\chi}_{1}^{\pm}} \rightarrow m_{\tilde{\chi}_{2}^{\pm}}, m_{\tilde{\chi}_{2}^{\pm}} \rightarrow m_{\tilde{\chi}_{1}^{\pm}} \right],$$  \hspace{1cm} (90)

where $D_{0}^{i} \equiv D_{0}(m_{h0}^{2}, 0, 0, m_{h0}^{2}, \hat{t}, \hat{s}, i)$.

The form factor $f_{3}^{(2)}$ is given by

$$f_{3}^{(2)} = \left[ \frac{ie^{2}a_{3}b_{3}m_{\tilde{\chi}_{1}^{\pm}m_{\tilde{\chi}_{2}^{\pm}D_{0}^{10}}^{10}}}{\pi^{2}} \right] + \left[ m_{\tilde{\chi}_{1}^{\pm}} \rightarrow m_{\tilde{\chi}_{2}^{\pm}}, m_{\tilde{\chi}_{2}^{\pm}} \rightarrow m_{\tilde{\chi}_{1}^{\pm}} \right]$$

$$+ \left[ a_{3} \rightarrow a_{2}, b_{3} \rightarrow b_{2}, m_{\tilde{\chi}_{2}^{\pm}} \rightarrow m_{\tilde{\chi}_{1}^{\pm}} \right] + \left[ a_{3} \rightarrow a_{1}, b_{3} \rightarrow b_{1}, m_{\tilde{\chi}_{1}^{\pm}} \rightarrow m_{\tilde{\chi}_{2}^{\pm}} \right],$$  \hspace{1cm} (91)

where $D_{0}^{i} \equiv D_{0}(0, m_{h0}^{2}, 0, m_{h0}^{2}, \hat{u}, \hat{t}, i)$.

The form factor $f_{3}^{(5)}$ is given by

$$f_{3}^{(5)} = \frac{-ie^{2}\eta_{2}(b_{3}m_{\tilde{\chi}_{1}^{\pm}}C_{0}^{11} + b_{4}m_{\tilde{\chi}_{1}^{\pm}}C_{0}^{10})}{2\pi^{2}(m_{H}^{2} - \hat{s})} + \frac{-ie^{2}\eta_{1}(b_{3}m_{\tilde{\chi}_{2}^{\pm}}C_{0}^{11} + b_{4}m_{\tilde{\chi}_{2}^{\pm}}C_{0}^{10})}{2\pi^{2}(m_{h0}^{2} - \hat{s})},$$  \hspace{1cm} (92)

where $C_{0}^{i} \equiv C_{0}(0, 0, \hat{s}, i)$. 

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FIG. 1. Feynman diagrams for the process γγ → h₀h₀, where the solid line, wavy line, dashed line and dotted line represent the fermions (the top and the bottom quark as well as the charginos), the gauge bosons (the photon and the W± boson), the scalars (the charged Higgs bosons, the charged Goldstone bosons, the squarks and the sleptons) and the charged ghosts, respectively.
FIG. 2. Same with Figure 1.
FIG. 3. Same with Figure 1
FIG. 4. Same with Figure 1.
FIG. 5. Same with Figure [1]
FIG. 6. The cross sections for the process $\gamma\gamma \rightarrow h_0h_0$ as a function of the lightest Higgs boson mass for the opposite photon helicities $\lambda_1 = -\lambda_2 = 1$ at $\sqrt{s} = 500, 1000, 1500 GeV$ and $\tan \beta = 4$. The numbers on the curves are the photon-photon center-of-mass energy $\sqrt{s}$. The dotted lines represent the cross sections of the process in the 2HDM and the dotted lines - in the MSSM with $A_t = \mu \cot \beta$ and $A_b = \mu \tan \beta$ (there does not exist mixing between the stops, we label it no-mixing), the solid lines - in the MSSM with the stops mixing (we label it mixing). We have taken $m_{\tilde{Q}}^2 = m_{\tilde{U}}^2 = m_{\tilde{D}}^2 = (1 TeV)^2$, and when the stops exist mixing, we choose the value of $A_t$ which make the mass of the lighter stop equal to 50 GeV. The other relevant SUSY parameters are $M = 100 GeV$ and $\mu = -300 GeV$. 
FIG. 7. Same with Figure 6 but for the equal photon helicities $\lambda_1 = \lambda_2 = 1$. 
FIG. 8. Same with Figure 8 but for the equal photon helicities $\lambda_1 = \lambda_2 = -1$. 
FIG. 9. The cross sections for the process $\gamma\gamma \rightarrow h_0 h_0$ as a function of the lightest Higgs boson mass for the opposite photon helicities $\lambda_1 = -\lambda_2 = 1$ at $\sqrt{s} = 500, 1000, 1500 \text{GeV}$ and $\tan \beta = 40$, the other parameters are the same with Figure 6.
FIG. 10. Same with Figure 9 but for the equal photon helicities $\lambda_1 = \lambda_2 = 1$. 
FIG. 11. The total cross sections for the process $e^+e^- \rightarrow \gamma\gamma \rightarrow h_0h_0$ as a function of the lightest Higgs boson mass for the beamstrahlung photons at $\sqrt{s} = 500, 1000$ and 1500 GeV, where $\tan\beta = 4$ and the other SUSY parameters are the same with Figure 8. The numbers on the curves are the $e^+e^-$ CMS energy.
FIG. 12. Same with Figure 11 but for $\tan \beta = 40$. 
FIG. 13. Same with Figure 11 but for laser back scattering photons.
FIG. 14. Same with Figure 13 but for $\tan \beta = 40$. 