KEK CP-080

Complete Lagrangian of MSSM*

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Abstract

A brief derivation of the lagrangian of the minimal supersymmetric theory is given and the complete expression of the lagrangian in terms of mass eigenstates is presented.

1. Introduction

Theories of supersymmetry (SUSY) draw much attentions in the past decades as a realistic possibility of the physics beyond the Standard Model (SM)[1]. Due to a large number of particles and interactions involved in any of SUSY theories, the actual calculation of the production rates or decay rates of supersymmetric particles, which are predicted but not yet discovered, is very complicated. Consequently, it is highly desirable to have a system of automatic computation of such processes. The Minami-Tateya collaboration at KEK has already developed a system called `GRACE` [2] which generates automatically the tree amplitudes of the Standard Model. Implementing SUSY interactions in `GRACE` with some additional modifications, necessary for the treatment of Majorana particles and fermion number clashing vertices, they are upgrading `GRACE` so that they can use it to compute SUSY processes automatically. As a prototype of SUSY theories, this group has chosen MSSM, the minimal supersymmetric extension of the standard model, which is the smallest but the most basic model of SUSY that includes the SM, and they have coded its interactions in the model file of `GRACE`.

Although the MSSM lagrangian is given in several papers [3,4], we need the self-contained and full expression including ghost interactions and gauge-fixing terms. In this paper I will present the complete MSSM lagrangian which is written in terms of mass eigenstates. The model files of `GRACE` for SUSY are coded based on this lagrangian, which also defines the phase convention of physical

* This work is partially supported by the Ministry of Education, Science and Culture, Japan, under the Grant-in-Aid for basic research program C (no.08640391).

particles. A package of MSSM processes, though limited to twenty-three processes, was generated by `GRACE` and is already released as `SUSY23`[5].

The paper is organized as follows. The superfields and their component fields used in MSSM are introduced in section 2, where the physical states such as fermions, gauge bosons etc. are defined in terms of the component fields. In section 3, the lagrangian is represented by superfields and then decomposed into the component fields. The complete expression of MSSM lagrangian is given in Appendix C in terms of mass eigenstates, except for the case of sfermion self-interactions, in which the lagrangian is given in a form with $\tilde{f}_L$ and $\tilde{f}_R$. For simplicity we consider fermions only in the first generation. Inclusion of the second and the third generations is trivial except for the four-sfermion interactions, in which the inter-generation interactions occur.

Notations, conventions and several important formulae are compiled in Appendix A. In Appendix B, the structure of the F-term and D-term is discussed. In Appendix D, the products of sfermion, which are expressed in Appendix C by $\tilde{f}_L$ and $\tilde{f}_R$ are converted to the mass eigenstates $\tilde{f}_1$ and $\tilde{f}_2$. In Appendix E, for the sake of those who are consulting the Hikasa's manuscript [4], his notation is compared with mine. It is confirmed that upon adjusting the conventions the lagrangian presented in this paper fully agrees with ref.[4] up to some trivial misprints in it.

2. Superfields and physical states

The MSSM, the minimal supersymmetric extension of the standard model which is based on the gauge group $SU(2)_L \times U(1) \times SU(3)_c$, consists of three gauge-superfields, V^a, V and V_s^α for gauge bosons, five left-handed chiral-superfields*, $\mathbf{\Phi}_\ell$, Φ_e, $\mathbf{\Phi}_q$, Φ_u, Φ_d, for spinors of each generation, and two left-handed chiral superfields, $\mathbf{\Phi_{H1}}$ and $\mathbf{\Phi_{H2}}$ for Higgs particles. The model contains three gauge coupling constants, g, g' and g_s, and one Higgs coupling constant, μ, and in addition to the fermion masses which I don't count as free parameters, $6 + 8N_G$ free parameters of the mass dimension for soft SUSY-breaking terms.

The chiral superfields represented by the bold letters are $SU(2)_L$ doublet, while non-bold superfields are $SU(2)_L$ singlet. The gauge superfield V^a is $SU(2)_L$ triplet, while the gauge superfield V is $SU(2)_L$ singlet. The gauge superfield V_s^α is $SU(3)_c$ octet. We use the index $a, b \cdots$ for $SU(2)_L$ and the index $\alpha, \beta \cdots$ for $SU(3)_c$.

Since we use only the left-handed chiral superfields subject to the condition

$$\bar{\mathcal{D}}_L \mathbf{\Phi} \equiv -(\frac{\partial}{\partial \bar{\theta}} + i\theta\sigma^\mu\partial_\mu)\mathbf{\Phi} = 0, \tag{2.1}$$

with the four-dimensional σ^μ being defined by (A.3), we consider Φ_e, Φ_u and Φ_d as the superfields for the left-handed antifermions which contain right-handed fermions; for example, the superfield Φ_e has a positive charge, and its hypercharge is given by $Y = 2$. For gauge-superfields, we work

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* Assume that the neutrinos are massless, we don't introduce the superfields corresponding to the right-handed singlet neutrino fields.

	$SU(2)_L$	$U(1)$	particle content
V^a	**3**	1	W^a_μ, λ^a, D^a
V	**1**	0	B_μ, λ, D
$\mathbf{\Phi}_\ell$	**2**	-1	$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$, $\begin{pmatrix} A(\nu_L) \\ A(e_L) \end{pmatrix}$, $\begin{pmatrix} F(\nu_L) \\ F(e_L) \end{pmatrix}$
Φ_e	**1**	2	e_R, $A(e_R)$, $F(e_R)$
$\mathbf{\Phi_q}$	**2**	$\frac{1}{3}$	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$, $\begin{pmatrix} A(u_L) \\ A(d_L) \end{pmatrix}$, $\begin{pmatrix} F(u_L) \\ F(d_L) \end{pmatrix}$
Φ_u	**1**	$-\frac{4}{3}$	u_R, $A(u_R)$, $F(u_R)$
Φ_d	**1**	$\frac{2}{3}$	d_R, $A(d_R)$, $F(d_R)$
$\mathbf{\Phi_{H_1}}$	**2**	-1	$\begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$, $\begin{pmatrix} \tilde{H}_1^0 \\ \tilde{H}_1^- \end{pmatrix}$, $\begin{pmatrix} F(H_1^0) \\ F(H_1^-) \end{pmatrix}$
$\mathbf{\Phi_{H_2}}$	**2**	1	$\begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$, $\begin{pmatrix} \tilde{H}_2^+ \\ \tilde{H}_2^0 \end{pmatrix}$, $\begin{pmatrix} F(H_2^+) \\ F(H_2^0) \end{pmatrix}$

	$SU(3)_c$	$SU(2)_L \times U(1)$	particle content
V_s^α	**8**	singlet	g^α_μ, $\tilde{g}^\alpha$, D^α

Table 1. Quantum numbers and component fields contained in each superfield appearing in MSSM

in the so-called Wess-Zumino gauge, in which several component fields contained in the gauge-superfield are gauged away and gauge-superfields consist of three component fields. The content of component fields and the quantum number of each superfield appearing in MSSM are listed in Table 1.

Upon shifting the vacuum expectation values, we define the Higgs scalar fields as follows,

$$\begin{aligned} \mathbf{H}_1 &\equiv \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} = \begin{pmatrix} (v_1 + \phi_1^0 - i\chi_1^0)/\sqrt{2} \\ -\phi_1^- \end{pmatrix}, \\ \mathbf{H}_2 &\equiv \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ (v_2 + \phi_2^0 + i\chi_2^0)/\sqrt{2} \end{pmatrix}. \end{aligned} \tag{2.2}$$

In terms of component fields the conventional spinors are expressed as

$$\begin{aligned} \Psi(e) &= \begin{pmatrix} \overline{e}_R \\ e_L \end{pmatrix}, \quad \Psi(\nu) = \begin{pmatrix} 0 \\ \nu_L \end{pmatrix}. \\ \Psi(u) &= \begin{pmatrix} \overline{u}_R \\ u_L \end{pmatrix}, \quad \Psi(d) = \begin{pmatrix} \overline{d}_R \\ d_L \end{pmatrix}. \end{aligned} \tag{2.3}$$

Here, the bar is on the upper component, since Φ_e is the left-handed chiral superfield for positron and the complex conjugate corresponds to the charge conjugated state.

Charged gauge bosons are defined as

$$W_\mu^\pm \equiv \frac{W_\mu^1 \mp iW_\mu^2}{\sqrt{2}}, \tag{2.4a}$$

while neutral gauge bosons are

$$\begin{pmatrix} Z_\mu \\ A_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \\ \sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} W_\mu^3 \\ B_\mu \end{pmatrix}. \tag{2.4b}$$

The gauge boson masses are given in terms of vacuum expectation values v_1 and v_2;

$$M_W^2 = \frac{1}{4} g^2 (v_1^2 + v_2^2), \qquad M_Z^2 = \frac{1}{4} (g^2 + g'^2)(v_1^2 + v_2^2). \tag{2.5}$$

Sfermions are defined as

$$\begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_f & \sin\theta_f \\ -\sin\theta_f & \cos\theta_f \end{pmatrix} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}, \qquad f = e, u, d, \tag{2.6}$$

where $\tilde{f}_L$ and $\tilde{f}_R$ are given in terms of the scalar component fields, $A(f_L)$, $A(f_R)$, listed in Table 1 as

$$\begin{aligned} \tilde{e}_L =& A(e_L), \quad \tilde{e}_R = A(e_R)^*, \\ \tilde{\nu}_L =& A(\nu_L), \\ \tilde{u}_L =& A(u_L), \quad \tilde{u}_R = A(u_R)^*, \\ \tilde{d}_L =& A(d_L), \quad \tilde{d}_R = A(d_R)^*, \end{aligned} \tag{2.7}$$

and the mixing angle is defined such that the mass matrix becomes diagonal with eigenvalues $m^2_{\tilde{f}_1}$ and $m^2_{\tilde{f}_2}$ $(m_{\tilde{f}_1} < m_{\tilde{f}_2})$:

$$\begin{aligned} &\begin{pmatrix} \cos\theta_f & \sin\theta_f \\ -\sin\theta_f & \cos\theta_f \end{pmatrix} \begin{pmatrix} m^2_{\tilde{f}_L} & m^2_{\tilde{f}_{LR}} \\ m^{2*}_{\tilde{f}_{LR}} & m^2_{\tilde{f}_R} \end{pmatrix} \begin{pmatrix} \cos\theta_f & -\sin\theta_f \\ \sin\theta_f & \cos\theta_f \end{pmatrix} \\ &= \begin{pmatrix} m^2_{\tilde{f}_1} & 0 \\ 0 & m^2_{\tilde{f}_2} \end{pmatrix}. \end{aligned} \tag{2.8}$$

The explicit form of the mass matrix is given in section 4.

As we see in section 3, charginos don't conserve fermion number. Therefore, the fermion number of charginos is not determined by interactions, but it is a matter of convention. We adopt the convention that the positively charged charginos are Dirac-particles. This convention is recommended by the LEP2 working group [6] and it is used also in the generator `SUSYGEN` [7]. There are two charginos which are made of four Weyl spinors, λ^+, λ^-, $\tilde{H}_1^-$ and $\tilde{H}_2^+$. The physical states with mass $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^\pm}$ are given by

$$\text{chargino}: \qquad \Psi(\tilde{\chi}_i^+) = \begin{pmatrix} \overline{\lambda_{iR}^-} \\ \lambda_{iL}^+ \end{pmatrix}, \qquad \Psi(\tilde{\chi}_i^-) \equiv \Psi(\tilde{\chi}_i^+)^c = \begin{pmatrix} \overline{\lambda_{iL}^+} \\ \lambda_{iR}^- \end{pmatrix}, \quad i = 1, 2 \tag{2.9}$$

where,

$$\begin{aligned} \begin{pmatrix} \lambda_{1R}^- \\ \lambda_{2R}^- \end{pmatrix} &= \begin{pmatrix} \cos\phi_R & \sin\phi_R \\ -\sin\phi_R & \cos\phi_R \end{pmatrix} \begin{pmatrix} \lambda^- \\ \tilde{H}_1^- \end{pmatrix}, \\ \begin{pmatrix} \lambda_{1L}^+ \\ \lambda_{2L}^+ \end{pmatrix} &= \begin{pmatrix} 1 & 0 \\ 0 & \epsilon_L \end{pmatrix} \begin{pmatrix} \cos\phi_L & \sin\phi_L \\ -\sin\phi_L & \cos\phi_L \end{pmatrix} \begin{pmatrix} \lambda^+ \\ \tilde{H}_2^+ \end{pmatrix}. \end{aligned} \tag{2.10}$$

Two orthogonal matrices in (2.10) diagonalizes the mass matrix,

$$\mathcal{M}_C \equiv \begin{pmatrix} M_2 & \sqrt{2} M_W \cos\beta \\ \sqrt{2} M_W \sin\beta & \mu \end{pmatrix}, \tag{2.11}$$

as

$$\begin{pmatrix} \cos\phi_L & \sin\phi_L \\ -\sin\phi_L & \cos\phi_L \end{pmatrix} \mathcal{M}_C \begin{pmatrix} \cos\phi_R & -\sin\phi_R \\ \sin\phi_R & \cos\phi_R \end{pmatrix} = \begin{pmatrix} m_{\tilde{c}_1} & 0 \\ 0 & m_{\tilde{c}_2} \end{pmatrix}, \tag{2.12}$$

where we set the ordering of the two charginos such that $|m_{\tilde{c}_1}| < |m_{\tilde{c}_2}|$. The parameter μ and M_2 are a Higgs-Higgs coupling constant and an SUSY breaking parameter as will be defined in (3.1) and (3.2). The mixing parameter $\cos\beta$ and $\sin\beta$ are related to the ratio of the two vacuum expectation values, v_1 and v_2,

$$\tan\beta = \frac{v_2}{v_1}, \qquad \cos\beta = \frac{v_1}{\sqrt{v_1^2+v_2^2}}, \qquad \sin\beta = \frac{v_2}{\sqrt{v_1^2+v_2^2}}. \tag{2.13}$$

The diagonal matrix with ϵ_L in (2.10) is to take care of the possible negative eigenvalue for $m_{\tilde{c}_2}$. (We can always choose the mixing parameters ϕ_R and ϕ_L such that $m_{\tilde{c}_1} > 0$). Practically, from (2.11) we find

$$\epsilon_L = \mathrm{sign}(M_2\mu - M_W^2 \sin 2\beta). \tag{2.14}$$

The physical masses of charginos are given by

$$m_{\tilde{\chi}_1^\pm} = m_{\tilde{c}_1}, \qquad m_{\tilde{\chi}_2^\pm} = \epsilon_L m_{\tilde{c}_2}, \tag{2.15}$$

with $\tilde{\chi}_1^\pm$ lighter than $\tilde{\chi}_2^\pm$. The mixing angles are given by

$$\begin{aligned}
\tan\phi_L =& \frac{m_{\tilde{\chi}_1^\pm}^2 - M_2^2 - 2M_W^2\cos^2\beta}{\sqrt{2}M_W(M_2\sin\beta+\mu\cos\beta)} = \frac{\sqrt{2}M_W(M_2\sin\beta+\mu\cos\beta)}{m_{\tilde{\chi}_1^\pm}^2 - \mu^2 - 2M_W^2\sin^2\beta}, \\
\tan\phi_R =& \frac{m_{\tilde{\chi}_1^\pm}^2 - M_2^2 - 2M_W^2\sin^2\beta}{\sqrt{2}M_W(M_2\cos\beta+\mu\sin\beta)} = \frac{\sqrt{2}M_W(M_2\cos\beta+\mu\sin\beta)}{m_{\tilde{\chi}_1^\pm}^2 - \mu^2 - 2M_W^2\cos^2\beta}.
\end{aligned} \tag{2.16}$$

From the four neutral Weyl spinors, λ, λ^0, $\tilde{H}_1^0$ and $\tilde{H}_2^0$, four Majorana particles are constructed. They are denoted by

$$\text{neutralino}: \qquad \Psi(\tilde{\chi}_i^0) \equiv \begin{pmatrix} \bar{\lambda}_i \\ \lambda_i \end{pmatrix}, \qquad i = 1 \sim 4, \tag{2.17}$$

where

$$\begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{pmatrix} = \begin{pmatrix} \eta_1 & 0 & 0 & 0 \\ 0 & \eta_2 & 0 & 0 \\ 0 & 0 & \eta_3 & 0 \\ 0 & 0 & 0 & \eta_4 \end{pmatrix} (\,\mathcal{O}_N) \begin{pmatrix} \lambda \\ \lambda^0 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix}. \tag{2.18}$$

The four-by-four matrix O_N diagonalizes the symmetric mass matrix $\mathcal{M}_N$ of the neutral Weyl spinors

$$\mathcal{M}_N \equiv \begin{pmatrix} M_1 & 0 & -M_Z\sin\theta_W\cos\beta & M_Z\sin\theta_W\sin\beta \\ * & M_2 & M_Z\cos\theta_W\cos\beta & -M_Z\cos\theta_W\sin\beta \\ * & * & 0 & -\mu \\ * & * & * & 0 \end{pmatrix}, \tag{2.19}$$

as

$$\mathcal{O}_N \mathcal{M}_N \mathcal{O}_N^T = \mathrm{diag}(m_{\tilde{n}_1}, \quad m_{\tilde{n}_2}, \quad m_{\tilde{n}_3}, \quad m_{\tilde{n}_4}), \tag{2.20}$$

where the eigenvalues are arranged such that $|m_{\tilde{n}_1}| < |m_{\tilde{n}_2}| < |m_{\tilde{n}_3}| < |m_{\tilde{n}_4}|$. Here M_1 is another SUSY breaking parameter(see (3.2)). In (2.18) a matrix with η_i is introduced in order to change the phase of the particle whose eigenvalue becomes negative by the diagonalization (2.20). Namely,

$$\eta_i = \begin{cases} 1, & m_{\tilde{n}_i} > 0, \\ i, & m_{\tilde{n}_i} < 0, \end{cases} \tag{2.21}$$

and

$$m_{\tilde{\chi}_i^0} = \eta_i^2 m_{\tilde{n}_i}, \tag{2.22}$$

with $\tilde{\chi}_1^0$ being the lightest neutralino.

Eight gluinos are colored Majorana particles with mass M_3 which comes from the SUSY breaking term in the lagrangian (3.2).

$$\text{gluino :} \qquad \Psi(\tilde{g}^\alpha) = \begin{pmatrix} \overline{\tilde{g}^\alpha} \\ \tilde{g}^\alpha \end{pmatrix}. \tag{2.23}$$

Next, we discuss the Higgs particles. As we see in detail in section 4, the mass eigenstate of the charged Higgs, $H^\pm$, is given by

$$\begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} \phi_1^\pm \\ \phi_2^\pm \end{pmatrix}, \tag{2.24}$$

where $\phi_1^+ = (\phi_1^-)^*$ and $\phi_2^- = (\phi_2^+)^*$ and $G^\pm$ is a massless Goldestone boson.

From the four neutral Higgs, we construct two real Higgs scalars with even CP, H^0, h^0, and one neutral Goldstone boson G^0 and one real Higgs A^0 which is CP odd,

$$\begin{aligned} \begin{pmatrix} H^0 \\ h^0 \end{pmatrix} &= \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix}, \\ \begin{pmatrix} G^0 \\ A^0 \end{pmatrix} &= \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \end{pmatrix}, \end{aligned} \tag{2.25}$$

where

$$\tan 2\alpha = \tan 2\beta \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2}, \quad -\frac{\pi}{2} < \alpha < 0. \tag{2.26}$$

The masses of Higgs particles are given at tree level by

$$\begin{aligned} M_A^2 &= m_1^2 + m_2^2 = -m_{12}^2(\tan\beta + \cot\beta), \\ M_{H^0,h^0}^2 &= \frac{1}{2}[M_A^2 + M_Z^2 \pm \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}], \\ M_{H^\pm}^2 &= M_A^2 + M_W^2, \end{aligned} \tag{2.27}$$

where m_1^2, m_2^2 and m_{12}^2 are defined in (4.9) by the parameters appearing in the MSSM lagrangian discussed in detail in the next section.

3. Lagrangian

In this section, first I show the lagrangian written by the superfields. By θ integrations and then eliminating the auxiliary fields by the equation of motion, I decompose the MSSM lagrangian in component fields. In Appendix C, the lagrangian is expressed in terms of physical states which are mass eigenstates and are related to the component fields as shown in section 2. The general form of the θ integration is given in Appendix B.

The basic lagrangian consists of two part, the supersymmetric part and softly breaking part.

$$
\begin{aligned}
\mathcal{L} = & \int d^2\theta \frac{1}{4}[2Tr(\mathbf{W}\mathbf{W}) + WW + 2Tr(\mathbf{W_s}\mathbf{W_s})] + h.c. && (3.1a)\\
& + \int d^2\theta d^2\bar{\theta} \mathbf{\Phi}_\ell{}^\dagger \exp[2(g\frac{\tau^a}{2}V^a + g'\frac{Y_\ell}{2}V)]\mathbf{\Phi}_\ell && (3.1b)\\
& + \int d^2\theta d^2\bar{\theta} \Phi_e^\dagger \exp(g'Y_e V)\Phi_e && (3.1c)\\
& + \int d^2\theta d^2\bar{\theta} \mathbf{\Phi_q}{}^\dagger \exp[2(g\frac{\tau^a}{2}V^a + g'\frac{Y_q}{2}V + g_s\frac{\lambda^\alpha}{2}V_s^\alpha)]\mathbf{\Phi_q} && (3.1d)\\
& + \int d^2\theta d^2\bar{\theta} \Phi_u^\dagger \exp(g'Y_u V - g_s\lambda^{\alpha *}V_s^\alpha)\Phi_u && (3.1e)\\
& + \int d^2\theta d^2\bar{\theta} \Phi_d^\dagger \exp(g'Y_d V - g_s\lambda^{\alpha *}V_s^\alpha)\Phi_d && (3.1f)\\
& + \int d^2\theta d^2\bar{\theta} \mathbf{\Phi_{H1}}{}^\dagger \exp[2(gT^aV^a + g'\frac{Y_{H1}}{2}V)]\mathbf{\Phi_{H1}} && (3.1g)\\
& + \int d^2\theta d^2\bar{\theta} \mathbf{\Phi_{H2}}{}^\dagger \exp[2(gT^aV^a + g'\frac{Y_{H2}}{2}V)]\mathbf{\Phi_{H2}} && (3.1h)\\
& + \frac{\sqrt{2}m_e}{v_1}\int d^2\theta \mathbf{\Phi_{H_1}}\mathbf{\Phi}_\ell\Phi_e + h.c. && (3.1i)\\
& - \frac{\sqrt{2}m_u}{v_2}\int d^2\theta \mathbf{\Phi_{H_2}}\mathbf{\Phi_q}\Phi_u + h.c. && (3.1j)\\
& + \frac{\sqrt{2}m_d}{v_1}\int d^2\theta \mathbf{\Phi_{H_1}}\mathbf{\Phi_q}\Phi_d + h.c. && (3.1k)\\
& - \mu\int d^2\theta \mathbf{\Phi_{H1}}\mathbf{\Phi_{H2}} + h.c. && (3.1\ell)\\
& + \mathcal{L}_{soft} && (3.1m)\\
& + \mathcal{L}_{gf} + \mathcal{L}_{ghost}, && (3.1n)
\end{aligned}
$$

where

$$
\begin{aligned}
\mathbf{W}_\alpha &= -\frac{1}{4}\bar{\mathcal{D}}\bar{\mathcal{D}}e^{-\mathbf{V}}\mathcal{D}_\alpha e^{\mathbf{V}}, \quad \text{with} \quad \mathbf{V} = \sum_1^3 \frac{\tau^a}{2}V^a, \qquad W_\alpha = -\frac{1}{4}\bar{\mathcal{D}}\bar{\mathcal{D}}\mathcal{D}_\alpha V,\\
\mathbf{W}_{s\alpha} &= -\frac{1}{4}\bar{\mathcal{D}}\bar{\mathcal{D}}e^{-\mathbf{V_s}}\mathcal{D}_\alpha e^{\mathbf{V_s}}, \quad \text{with} \quad \mathbf{V}_s = \sum_1^8 \frac{\lambda^\alpha}{2}V_s^\alpha,
\end{aligned} \tag{3.1o}
$$

and λ^α in (3.1d), (3.1e) and (3.1f) stands for the $SU(3)_c$ Gell-Mann matrix. Note the minus and "$*$" signs in the exponents of (3.1e) and (3.1f). This is due to the fact that Φ_u and Φ_d are the left-handed chiral superfields for $\bar{u}$- and $\bar{d}$-quark, respectively. The lagrangian (3.1a) gives the kinetic part of the gauge bosons and gauginos, while (3.1b)-(3.1f) give the kinetic part of the matter(fermions and sfermions) fields and their interaction lagrangians. (3.1i), (3.1j) and (3.1k) give the Yukawa interaction of matter fields with Higgs and higgsino fields. Note that in (3.1j) the overall sign is minus. Higgs kinetic part and Higgs interactions with gauge bosons and gauginos are obtained from (3.1g) and (3.1h), which also produce the gauge boson masses. (3.1ℓ) gives the higgsino off-diagonal mass. From the D-terms, we obtain the four scalar vertices, which include the quartic Higgs self-interaction terms in the Higgs potential. From the F-terms, we obtain another four scalar vertices, but they contain always at least two sfermions and they don't contribute to the Higgs potential. Instead, F-terms contribute to the Higgs masses (quadratic terms).

The soft SUSY breaking part(3.1m) has the following form* which contains as many as $6+8N_G$ parameters where $N_G = 3$ is a number of fermion generation,

$$
\begin{aligned}
\mathcal{L}_{soft} = &- \frac{1}{2} M_1 \lambda\lambda - \frac{1}{2} M_2 \lambda^a \lambda^a - \frac{1}{2} M_3 \tilde{g}^\alpha \tilde{g}^\alpha + h.c. \\
&- \tilde{m}_1^2 \mathbf{H}_1^* \mathbf{H}_1 - \tilde{m}_2^2 \mathbf{H}_2^* \mathbf{H}_2 - (\tilde{m}_{12}^2 \mathbf{H}_1 \mathbf{H}_2 + h.c.) - \sum_{\tilde{f}_i} \tilde{m}_{\tilde{f}_i}^2 \tilde{f}_i^* \tilde{f}_i \\
&- \frac{\sqrt{2} m_u}{v_2} A_u \mathbf{H_2} \mathbf{A}(q_L) A(u_R) + \frac{\sqrt{2} m_d}{v_1} A_d \mathbf{H_1} \mathbf{A}(q_L) A(d_R) + h.c. \\
&+ \frac{\sqrt{2} m_e}{v_1} A_e \mathbf{H_1} \mathbf{A}(\ell_L) A(e_R) + h.c.
\end{aligned}
\tag{3.2}
$$

where

$$
\begin{aligned}
\mathbf{H}_1^* \mathbf{H}_1 &= |H_1^0|^2 + |H_1^-|^2 = \frac{1}{2}(|v_1 + \phi_1^0|^2 + |\chi_1^0|^2) + |\phi_1^-|^2, \\
\mathbf{H}_1^* \mathbf{H}_2 &= H_1^{0*} H_2^+ + H_1^+ H_2^0, \\
\mathbf{H}_1 \mathbf{H}_2 &= H_1^0 H_2^0 - H_1^- H_2^+.
\end{aligned}
\tag{3.2a}
$$

and the summation is taken over all left-handed and right-handed sfermions. Note that $SU(2)$ invariance requires the common breaking parameters for the members of each left-handed doublet sfermions, e.g., $\tilde{m}_{\tilde{u}_L} = \tilde{m}_{\tilde{d}_L}$, $\tilde{m}_{\tilde{e}_L} = \tilde{m}_{\tilde{\nu}_L}$, etc.

The last two lagrangians in (3.1n) are for quantization. They represent the gauge fixing terms and the ghost interactions.

3.1 Matter gauge interactions

We start with the interaction lagrangians which come from (3.1b)-(3.1f) and from (3.1i)-(3.1k). Using

$$
\begin{aligned}
\frac{g}{2} \tau^a W_\mu^a + \frac{g'}{2} Y B_\mu = &\frac{g}{\sqrt{2}} \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} W_\mu^+ + \frac{g}{\sqrt{2}} \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} W_\mu^- \\
&+ g_Z (T_3 - s_W^2 Q) Z_\mu + e Q A_\mu,
\end{aligned}
\tag{3.3}
$$

with $g_Z = \frac{g}{c_W}$ and $s_W \equiv \sin\theta_W$, $c_W \equiv \cos\theta_W$, we obtain from the term** linear to the gauge

---

* One often includes the interaction (3.1ℓ) in the soft breaking part. This is because the coupling constant μ has a dimension of mass like the other soft breaking terms in (3.2). However, I don't classify it in the softly broken interaction since it is still supersymmetry invariant.

** Note that the sign convention of the gauge fields is fixed by the convention of the covariant derivatives given by (A.16).

couplings g, g' and g_s,

$$
\begin{aligned}
\mathcal{L}_{ffV} = & -\frac{g}{\sqrt{2}}\sum_{(f_\uparrow, f_\downarrow)}[\bar{\Psi}(f_\uparrow)\gamma^\mu L\Psi(f_\downarrow)W^+_\mu + \bar{\Psi}(f_\downarrow)\gamma^\mu L\Psi(f_\uparrow)W^-_\mu] \\
& - g_Z\sum_f \bar{\Psi}(f)\gamma^\mu[(T_{3f} - s_W^2 Q_f)L - s_W^2 Q_f R]\Psi(f)Z_\mu \\
& - e\sum_f Q_f\bar{\Psi}(f)\gamma^\mu\Psi(f)A_\mu \\
& - g_s\sum_q \bar{\Psi}(q)\gamma^\mu\frac{\lambda^\alpha}{2}\Psi(q)g^\alpha_\mu,
\end{aligned}
\tag{3.4}
$$

where $f_\uparrow$ and $f_\downarrow$ stand for the up and down components of $SU(2)_L$ fermion doublets, and the summation f is taken over the fermion species, $f = \nu, e, u$ and d, and the summation q is taken over all the quark species. We have used (A.9) and (A.13) in rewriting the interaction lagrangian in terms of the four-component spinors. Note the property,

$$
Q_{f_R} \equiv \frac{Y_R}{2} = -Q_{f_L} \equiv -[T_{3f_L} + \frac{Y_{f_L}}{2}], \qquad \text{for each } f \tag{3.5}
$$

which comes from the fact that the quantum numbers of f_R are those of the corresponding left-handed antiparticle. The lagrangian (3.3) agrees with the fermion-gauge boson interaction of SM. In a similar way we obtain

$$
\begin{aligned}
\mathcal{L}_{\tilde{f}\tilde{f}V} = & -i\frac{g}{\sqrt{2}}\sum_f(\tilde{f}^*_{\uparrow L}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\downarrow L}W^+_\mu + \tilde{f}^*_{\downarrow L}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\uparrow L}W^-_\mu) \\
& - ig_Z\sum_f[\tilde{f}^*_L\overset{\leftrightarrow}{\partial}{}^\mu(T_{3f} - s_W^2 Q_f)\tilde{f}_L - \tilde{f}^*_R\overset{\leftrightarrow}{\partial}{}^\mu(s_W^2 Q_f)\tilde{f}_R]Z_\mu \\
& - ie\sum_f Q_f[\tilde{f}^*_L\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_L + \tilde{f}^*_R\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_R]A_\mu \\
& - ig_s\sum_q(\tilde{q}^*_L\frac{\lambda^\alpha}{2}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{q}_L + \tilde{q}^*_R\frac{\lambda^\alpha}{2}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{q}_R)g^\alpha_\mu.
\end{aligned}
\tag{3.6}
$$

This confirms that $\tilde{e}_L$ and $\tilde{e}_R$ have indeed the same charge as electron.

The fermion-sfermion-gaugino interaction* is extracted from the remaining part of trilinear

---

* Here, I used the terminology "gaugino", since the lagrangian is still expressed in terms of Weyl spinors which are the partners of gauge bosons. Using (2.9), (2.10) and (2.17), we have to express (3.7) in terms of charginos and neutralinos which are mixtures of gauginos and higgsinos.

coupling in (3.1b)-(3.1f),

$$
\begin{aligned}
\mathcal{L}_{\tilde{f}f\tilde{V}} = & - g\sum_f [(*,\lambda^-)L\Psi(f_\uparrow)\tilde{f}^*_{\downarrow L} + (*,\lambda^+)L\Psi(f_\downarrow)\tilde{f}^*_{\uparrow L}] \\
& - \sqrt{2}\sum_f [\{g'(Q_f - T_{3fL})(*,\lambda) + gT_{3fL}(*,\lambda^0)\}L\Psi(f)\tilde{f}^*_L] \\
& + \sqrt{2}g'\sum_f Q_f(\bar{\lambda},*)R\Psi(f)\tilde{f}^*_R \\
& - \sqrt{2}g_s\sum_q [\overline{\Psi(q)}R\Psi(\tilde{g}^\alpha)\frac{\lambda^\alpha}{2}\tilde{q}_L - \overline{\Psi(q)}L\Psi(\tilde{g}^\alpha)\frac{\lambda^\alpha}{2}\tilde{q}_R] \\
& + h.c..
\end{aligned}
\tag{3.7}
$$

Here, "$*$" in the spinor means that the entry does not appear in the lagrangian and is not necessary to be specified at this stage. In the actual calculation, using (2.10), one obtains the lagrangian in terms of the mass eigenstates by replacing

$$
\begin{aligned}
(*,\lambda^-) &\rightarrow \cos\phi_R\bar{\Psi}(\tilde{\chi}^+_1) - \sin\phi_R\bar{\Psi}(\tilde{\chi}^+_2), \\
(*,\lambda^+) &\rightarrow \cos\phi_L\bar{\Psi}(\tilde{\chi}^-_1) - \epsilon_L\sin\phi_L\bar{\Psi}(\tilde{\chi}^-_2), \\
(*,\lambda) &\rightarrow (\mathcal{O}_N)_{j1}\eta^*_j\bar{\Psi}(\tilde{\chi}^0_j), \\
(\bar{\lambda},*) &\rightarrow (\mathcal{O}_N)_{j1}\eta_j\bar{\Psi}(\tilde{\chi}^0_j), \\
(*,\lambda^0) &\rightarrow (\mathcal{O}_N)_{j2}\eta^*_j\bar{\Psi}(\tilde{\chi}^0_j).
\end{aligned}
\tag{3.8}
$$

Therefore, depending on the convention of calling a positive chargino as a particle or a negative chargino, either one of the two terms of the first line of (3.7) violates the fermion number conservation, typical to the chargino interactions.

From the gauge coupling squared terms in the matter lagrangian, (3.1b)-(3.1f), we obtain the $\tilde{f}\tilde{f}VV$ interaction terms;

$$
\begin{aligned}
\mathcal{L}_{\tilde{f}\tilde{f}VV} = & \frac{g^2}{2}(\sum_f \tilde{f}^*_L\tilde{f}_L)W^+_\mu W^{-\mu} \\
& - \frac{gg_Z}{\sqrt{2}}s^2_W\sum_f Y_{fL}(\tilde{f}^*_{\uparrow L}\tilde{f}^*_{\downarrow L}W^+_\mu + \tilde{f}^*_{\downarrow L}\tilde{f}^*_{\uparrow L}W^-_\mu)Z^\mu \\
& + \frac{ge}{\sqrt{2}}\sum_f Y_{fL}(\tilde{f}^*_{\uparrow L}\tilde{f}^*_{\downarrow L}W^+_\mu + \tilde{f}^*_{\downarrow L}\tilde{f}^*_{\uparrow L}W^-_\mu)A^\mu \\
& + g^2_Z F_{ZZ}Z_\mu Z^\mu + 2eg_Z F_{ZA}Z_\mu A^\mu + e^2F_{AA}A_\mu A^\mu \\
& + g^2_s\sum_q(\tilde{q}^*_L\frac{\lambda^\alpha}{2}\frac{\lambda^\beta}{2}\tilde{q}_L + \tilde{q}^*_R\frac{\lambda^\alpha}{2}\frac{\lambda^\beta}{2}\tilde{q}_R)g^\alpha_\mu g^{\mu\beta} \\
& + \frac{g_sg}{\sqrt{2}}\{\tilde{u}^*_L\lambda^\alpha\tilde{d}_LW^{+\mu} + \tilde{d}^*_L\lambda^\alpha\tilde{u}_LW^{-\mu}\}g^\alpha_\mu \\
& + g_sg_Z\sum_q\{(T_{3q} - s^2_WQ_q)\tilde{q}_L\lambda^\alpha\tilde{q}_L - s^2_WQ_q\tilde{q}_R\lambda^\alpha\tilde{q}_R\}Z^\mu g^\alpha_\mu \\
& + g_se\sum_q Q_q(\tilde{q}_L\lambda^\alpha\tilde{q}_L + \tilde{q}_R\lambda^\alpha\tilde{q}_R)A^\mu g^\alpha_\mu,
\end{aligned}
\tag{3.9}
$$

where

$$
\begin{aligned}
F_{ZZ} &= \sum_f [\ (T_{3f} - s_W^2 Q_f)^2 \tilde{f}_L^* \tilde{f}_L + s_W^4 Q_f^2 \tilde{f}_R^* \tilde{f}_R\ ], \\
F_{ZA} &= \sum_f [\ Q_f (T_{3f} - s_W^2 Q_f) \tilde{f}_L^* \tilde{f}_L - s_W^2 Q_f^2 \tilde{f}_R^* \tilde{f}_R\ ], \\
F_{AA} &= \sum_f Q_f^2 (\tilde{f}_L^* \tilde{f}_L + \tilde{f}_R^* \tilde{f}_R).
\end{aligned} \tag{3.9a}
$$

From the Yukawa interaction of matter fields with Higgs fields, (3.1i), (3.1j) and (3.1k), we obtain the fermion mass terms and the following ffH interaction as well as $\tilde{f} f\ \tilde{H}$ interaction,

$$
\begin{aligned}
\mathcal{L}_{ffH} = &- \sum_f m_f \bar{\Psi}(f)\Psi(f) \\
&+ \frac{\sqrt{2} m_u}{v_2} \bar{\Psi}(u) L \Psi(d) \phi_2^+ - \frac{\sqrt{2} m_d}{v_1} \bar{\Psi}(u) R \Psi(d) \phi_1^+ + h.c. \\
&- \frac{\sqrt{2} m_e}{v_1} \bar{\Psi}(\nu) R \Psi(e) \phi_1^+ + h.c. \\
&- \frac{m_u}{v_2} [\bar{\Psi}(u)\Psi(u)\phi_2^0 - i\bar{\Psi}(u)\gamma_5\Psi(u)\chi_2^0] \\
&- \frac{m_d}{v_1} [\bar{\Psi}(d)\Psi(d)\phi_1^0 + i\bar{\Psi}(d)\gamma_5\Psi(d)\chi_1^0] \\
&- \frac{m_e}{v_1} [\bar{\Psi}(e)\Psi(e)\phi_1^0 + i\bar{\Psi}(e)\gamma_5\Psi(e)\chi_1^0],
\end{aligned} \tag{3.10a}
$$

$$
\begin{aligned}
\mathcal{L}_{\tilde{f}f\tilde{H}} = &\frac{\sqrt{2} m_u}{v_2} [\bar{\Psi}(u) L (*, \tilde{H}_2^+)^t \tilde{d}_L - \bar{\Psi}(u) L (*, \tilde{H}_2^0)^t \tilde{u}_L \\
&\qquad + (\bar{\Psi}(d) R (\overline{\tilde{H}_2^+}, *)^t - \bar{\Psi}(u) R (\overline{\tilde{H}_2^0}, *)^t) \tilde{u}_R] + h.c. \\
&- \frac{\sqrt{2} m_d}{v_1} [\bar{\Psi}(d) L (*, \tilde{H}_1^0)^t \tilde{d}_L - \bar{\Psi}(d) L (*, \tilde{H}_1^-)^t \tilde{u}_L \\
&\qquad + (\bar{\Psi}(d) R (\overline{\tilde{H}_1^0}, *)^t - \bar{\Psi}(u) R (\overline{\tilde{H}_1^-}, *)^t) \tilde{d}_R] + h.c. \\
&- \frac{\sqrt{2} m_e}{v_1} [\bar{\Psi}(e) L (*, \tilde{H}_1^0)^t \tilde{e}_L - \bar{\Psi}(e) L (*, \tilde{H}_1^-)^t \tilde{\nu}_L \\
&\qquad + (\bar{\Psi}(e) R (\overline{\tilde{H}_1^0}, *)^t - \bar{\Psi}(\nu) R (\overline{\tilde{H}_1^-}, *)^t) \tilde{e}_R] + h.c.,
\end{aligned} \tag{3.10b}
$$

where

$$
\begin{aligned}
(*, \tilde{H}_1^-)^t &= \sin\phi_R \Psi(\tilde{\chi}_1^-) + \cos\phi_R \Psi(\tilde{\chi}_2^-), \\
(*, \tilde{H}_2^+)^t &= \sin\phi_L \Psi(\tilde{\chi}_1^+) + \epsilon_L \cos\phi_L \Psi(\tilde{\chi}_2^+), \\
(\overline{\tilde{H}_1^-}, *)^t &= \sin\phi_R \Psi(\tilde{\chi}_1^+) + \cos\phi_R \Psi(\tilde{\chi}_2^+), \\
(\overline{\tilde{H}_2^+}, *)^t &= \sin\phi_L \Psi(\tilde{\chi}_1^-) + \epsilon_L \cos\phi_L \Psi(\tilde{\chi}_2^-), \\
(*, \tilde{H}_1^0)^t &= (\mathcal{O}_N)_{j3} \eta_j^* \Psi(\tilde{\chi}_j^0), \qquad (*, \tilde{H}_2^0)^t = (\mathcal{O}_N)_{j4} \eta_j^* \Psi(\tilde{\chi}_j^0), \\
(\overline{\tilde{H}_1^0}, *)^t &= (\mathcal{O}_N)_{j3} \eta_j \Psi(\tilde{\chi}_j^0), \qquad (\overline{\tilde{H}_2^0}, *)^t = (\mathcal{O}_N)_{j4} \eta_j \Psi(\tilde{\chi}_j^0).
\end{aligned} \tag{3.10c}
$$

3.2 F-terms and D-terms

The remaining interaction including matter fields come from the auxiliary fields $|F|^2$ and D^2. From (B.12) and (B.13), we find that the F-terms in the matter superfield provide supersymmetric sfermion mass terms, $\tilde{f}\tilde{f}H(G)$ and $\tilde{f}\tilde{f}HH$ interactions;

$$-\sum_{f_i} |F(f_i)|^2 = \mathcal{L}_{\tilde{f}\ mass} + \mathcal{L}_{\tilde{f}\tilde{f}H} + \mathcal{L}_{\tilde{f}\tilde{f}HH}. \tag{3.11}$$

The sfermion mass terms are given as

$$\mathcal{L}_{\tilde{f}\ mass} = -\sum_f m_f^2 (\tilde{f}_L^* \tilde{f}_L + \tilde{f}_R^* \tilde{f}_R), \tag{3.11a}$$

where the sum is over the matter fields, u_L, d_L, u_R, d_R, ν_L, e_L and e_R.

$$\begin{aligned}
\mathcal{L}_{\tilde{f}\tilde{f}H(G)} =& -2\frac{m_u^2}{v_2}(\tilde{u}_L^*\tilde{u}_L + \tilde{u}_R\tilde{u}_R)\phi_2^0 - 2\frac{m_d^2}{v_1}(\tilde{d}_L^*\tilde{d}_L + \tilde{d}_R\tilde{d}_R)\phi_1^0 \\
& - 2\frac{m_e^2}{v_1}(\tilde{e}_L^*\tilde{e}_L + \tilde{e}_R^*\tilde{e}_R)\phi_1^0 \\
& + \sqrt{2}g\frac{m_u m_d}{M_W \sin 2\beta}(\tilde{u}_R^*\tilde{d}_R H^+ + \tilde{d}_R^*\tilde{u}_R H^-) \\
& + \sqrt{2}\tilde{u}_L^*\tilde{d}_L(\frac{m_u^2}{v_2}\phi_2^+ - \frac{m_d^2}{v_1}\phi_1^+) - \sqrt{2}\frac{m_e^2}{v_1}\tilde{\nu}_L^*\tilde{e}_L\phi_1^+ + hc.,
\end{aligned} \tag{3.11b}$$

$$\begin{aligned}
\mathcal{L}_{\tilde{f}\tilde{f}HH} =& -\frac{m_u^2}{v_2^2}|\chi_2^0|^2(\tilde{u}_R^*\tilde{u}_R + \tilde{u}_L^*\tilde{u}_L) - \frac{m_d^2}{v_2^1}|\chi_1^0|^2(\tilde{d}_R^*\tilde{d}_R + \tilde{d}_L^*\tilde{d}_L) \\
& - \frac{m_e^2}{v_2^1}|\chi_1^0|^2(\tilde{e}_R^*\tilde{e}_R + \tilde{e}_L^*\tilde{e}_L) \\
& - \left|\frac{m_u}{v_2}\phi_2^0\tilde{u}_R^* + \sqrt{2}\frac{m_d}{v_1}\phi_1^-\tilde{d}_R^*\right|^2 - \left|\sqrt{2}\frac{m_u}{v_2}\phi_2^+\tilde{u}_R^* - \frac{m_d}{v_1}\phi_1^0\tilde{d}_R^*\right|^2 \\
& - \frac{m_u^2}{v_2^2}|\phi_2^0\tilde{u}_L^* - \sqrt{2}\phi_2^-\tilde{d}_L^*|^2 - \frac{m_d^2}{v_1^2}|\phi_1^0\tilde{d}_L^* + \sqrt{2}\phi_1^+\tilde{u}_L^*|^2 \\
& - \frac{m_e^2}{v_1^2}[2|\phi_1^-|^2 + (\phi_1^0)^2]\tilde{e}_R^*\tilde{e}_R - \frac{m_e^2}{v_1^2}|\phi_1^0\tilde{e}_L^* + \sqrt{2}\phi_1^+\tilde{\nu}_L^*|^2 \\
& - i\sqrt{2}(\frac{m_u^2}{v_2^2}\chi_2^0\phi_2^+ - \frac{m_d^2}{v_1^2}\chi_1^0\phi_1^+)(\tilde{u}_L^*\tilde{d}_L) + h.c. \\
& - i\sqrt{2}\frac{m_u m_d}{v_1 v_2}(\chi_2^0\phi_1^+ - \chi_1^0\phi_2^+)(\tilde{u}_R^*\tilde{d}_R) + h.c.
\end{aligned} \tag{3.11c}$$

From $\mathbf{F}(H_1)$ and $\mathbf{F}(H_2)$, one finds a part of the Higgs potential, $\tilde{f}_L\tilde{f}_R$ mixing terms and two kinds of interaction,

$$-\sum |F(H_i)|^2 = \mathcal{L}_{V(F)} + \mathcal{L}_{\tilde{f}_L\tilde{f}_R} + \mathcal{L}_{\tilde{f}\tilde{f}H(G)} + \mathcal{L}_{\tilde{f}\tilde{f}\tilde{f}\tilde{f}}, \tag{3.12}$$

where the suffix $V(F)$ of the first lagrangian on the right-hand side signifies that it is the Higgs potential contributed from the F terms.

$$\mathcal{L}_{V(F)} = -\mu^2(\mathbf{H}_1^*\mathbf{H}_1 + \mathbf{H}_2^*\mathbf{H}_2). \tag{3.12a}$$

$$\begin{aligned}\mathcal{L}_{\tilde{f}_L\tilde{f}_R} = &\quad m_u\ \mu\ \cot\beta(\tilde{u}_R^*\tilde{u}_L + \tilde{u}_L^*\tilde{u}_R)\\ &+ m_d\ \mu\ \tan\beta(\tilde{d}_R^*\tilde{d}_L + \tilde{d}_L^*\tilde{d}_R)\\ &+ m_e\ \mu\ \tan\beta(\tilde{e}_R^*\tilde{e}_L + \tilde{e}_L^*\tilde{e}_R),\end{aligned} \tag{3.12b}$$

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}H(G)} = &\frac{\mu}{v_1}[(m_d\tilde{d}_R^*\tilde{d}_L + m_e\tilde{e}_R^*\tilde{e}_L)(\phi_2^0 - i\chi_2^0)\\ &+ \sqrt{2}(m_d\tilde{d}_R^*\tilde{u}_L + m_e\tilde{e}_R^*\tilde{\nu}_L)\phi_2^-]\\ &+ \frac{m_u\mu}{v_2}[(\tilde{u}_R^*\tilde{u}_L)(\phi_1^0 + i\chi_1^0) - \sqrt{2}(\tilde{u}_R^*\tilde{d}_L)\phi_1^+]\\ &+ h.c.,\end{aligned} \tag{3.12c}$$

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}\tilde{f}\tilde{f}} = &-\frac{2}{v_1^2}|m_d\tilde{d}_R^*\tilde{d}_L + m_e\tilde{e}_R^*\tilde{e}_L|^2 - \frac{2}{v_1^2}|m_d\tilde{d}_R^*\tilde{u}_L + m_e\tilde{e}_R^*\tilde{\nu}_L|^2\\ &-\frac{2m_u^2}{v_2^2}(|\tilde{u}_R^*\tilde{d}_L|^2 + |\tilde{u}_R^*\tilde{u}_L|^2).\end{aligned} \tag{3.12d}$$

As three generations of fermions must be taken into account, we have to sum over the fermions in three generations before taking square in each term of (3.12d).

From the D-terms (B.18), we obtain a part of the Higgs potential, sfermion masses, $\tilde{f}\tilde{f}H(G)$, $\tilde{f}\tilde{f}HH$ as well as quartic sfermion interactions,

$$D\text{-terms} = -\frac{1}{2}\sum|D|^2 = \mathcal{L}_{V(D)} + \mathcal{L}_{\tilde{f}\tilde{f}} + \mathcal{L}_{\tilde{f}\tilde{f}H(G)} + \mathcal{L}_{\tilde{f}\tilde{f}HH} + \mathcal{L}_{\tilde{f}\tilde{f}\tilde{f}\tilde{f}}. \tag{3.13}$$

The contribution from the D-term to the Higgs potential, $\mathcal{L}_{V(D)}$ produces the Higgs self-interaction terms,

$$\begin{aligned}\mathcal{L}_{V(D)} = &-\frac{1}{8}(g^2 + g'^2)(\mathbf{H}_1^*\mathbf{H}_1 - \mathbf{H}_2^*\mathbf{H}_2)^2 - \frac{g^2}{2}|\mathbf{H}_1^*\mathbf{H}_2|^2\\ = &\ \text{constant} + \text{mass terms} + \mathcal{L}_{3H} + \mathcal{L}_{4H},\end{aligned} \tag{3.14}$$

where $\mathcal{L}_{3H}$ and $\mathcal{L}_{4H}$ are three body and four body Higgs and Goldstone boson self-interactions.

$$\begin{aligned}\mathcal{L}_{3H} = &-\frac{g}{4c}M_Z[\cos(\beta+\alpha)H^0 - \sin(\beta+\alpha)h^0]X\\ &- gM_W[\cos(\beta-\alpha)H^0H^+H^- + \sin(\beta-\alpha)h^0H^+H^-]\\ &- \frac{g}{2}M_W[\sin(\beta-\alpha)H^0 - \cos(\beta-\alpha)h^0](H^+G^- + H^-G^+)\\ &- i\frac{g}{2}M_W A^0(H^+G^- - H^-G^+),\end{aligned} \tag{3.14a}$$

where

$$\begin{aligned}X = &\cos 2\alpha((H^0)^2 - (h^0)^2) - 2\sin 2\alpha H^0h^0 - \cos 2\beta(2|H^+|^2 + (A^0)^2)\\ &- 2\sin 2\beta(G^0A^0 + H^+G^- + H^-G^+) + \cos 2\beta(2|G^+|^2 + (G^0)^2),\end{aligned} \tag{3.14b}$$

$$\begin{aligned}\mathcal{L}_{4H} = &-\frac{g^2}{32c^2}X^2\\ &-\frac{g^2}{4}[|\cos(\beta-\alpha)(H^0H^+ - h^0G^+) + \sin(\beta-\alpha)(H^0G^+ + h^0H^+)|^2\\ &\quad + |H^+G^0 - A^0G^+|^2]\\ &- i\frac{g^2}{4}(H^+G^- - H^-G^+)\\ &\quad[\cos(\beta-\alpha)(A^0H^0 - h^0G^0) - \sin(\beta-\alpha)(A^0h^0 + H^0G^0)].\end{aligned} \tag{3.14c}$$

The mass terms and the constant terms are calculated in section 4 when the full Higgs potential, resulted also from the SUSY breaking term and from the F terms, is taken into account.

$$\mathcal{L}_{\tilde{f}\tilde{f}} = -M_Z^2 \cos 2\beta[\ (T_{3f} - s_W^2 Q_f)\tilde{f}_L^* \tilde{f}_L + s_W^2 Q_f \tilde{f}_R^* \tilde{f}_R)\ ]. \tag{3.15}$$

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}H(G)} =& - g_Z M_Z (\cos(\beta+\alpha)H^0 - \sin(\beta+\alpha)h^0) \\ & \qquad [(T_{3f} - s_W^2 Q_f)\tilde{f}_L^* \tilde{f}_L + s_W^2 Q_f \tilde{f}_R^* \tilde{f}_R] \\ & + \frac{g}{\sqrt{2}} M_W (\cos 2\beta G^+ - \sin 2\beta H^+)\tilde{f}_{\uparrow L}^* \tilde{f}_{\downarrow L} + h.c.\end{aligned} \tag{3.16}$$

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}HH} =& - \frac{g_Z^2}{4}(\sum_f F_{LL}\tilde{f}_L^* \tilde{f}_L + F_{RR}\sum_f s^2 Q_f \tilde{f}_R^* \tilde{f}_R) \\ & - \frac{g^2}{2\sqrt{2}} F_{\uparrow\downarrow}^{(1)} \sum_f \tilde{f}_{\uparrow L}^* \tilde{f}_{\downarrow L} + i\frac{g^2}{2\sqrt{2}} F_{\uparrow\downarrow}^{(2)} \sum_f \tilde{f}_{\uparrow L}^* \tilde{f}_{\downarrow L} + h.c.,\end{aligned} \tag{3.17}$$

with

$$\begin{aligned}F_{LL} =&\ \{\cos 2\alpha((H^0)^2 - (h^0)^2) - 2\sin 2\alpha H^0 h^0 \\ & + \cos 2\beta((G^0)^2 - (A^0)^2) - 2\sin 2\beta G^0 A^0\}(T_{3f} - s^2 Q_f) \\ & - 2\{\cos 2\beta(|G^+|^2 - |H^+|^2) - \sin 2\beta(H^+G^- + H^-G^+)\}(T_{3f} + s^2 Q_{f'}), \\ F_{RR} =&\ \cos 2\alpha((H^0)^2 - (h^0)^2) - 2\sin 2\alpha H^0 h^0 \\ & + \cos 2\beta((G^0)^2 - (A^0)^2) - 2\sin 2\beta G^0 A^0 \\ & + 2\cos 2\beta(|G^+|^2 - |H^+|^2) + 2\sin 2\beta(H^+G^- + H^-G^+), \\ F_{\uparrow\downarrow}^{(1)} =& \cos(\beta+\alpha)(H^+h^0 - H^0G^+) + \sin(\beta+\alpha)(H^+H^0 + h^0G^+), \\ F_{\uparrow\downarrow}^{(2)} =& \cos 2\beta(A^0H^+ - G^+G^0) + \sin 2\beta(A^0G^+ + H^+G^0),\end{aligned} \tag{3.17a}$$

where f' is the $SU(2)_L$ partner of fermion f in the doublet. Four-sfermion interactions are given by (B.18),

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}\tilde{f}\tilde{f}} =& - \frac{g^2}{8}[4|\tilde{u}_L^* \tilde{d}_L + \tilde{\nu}^* \tilde{e}_L|^2 + |\tilde{u}_L^* \tilde{u}_L - \tilde{d}_L^* \tilde{d}_L + \tilde{\nu}^* \tilde{\nu} - \tilde{e}_L^* \tilde{e}_L|^2] \\ & - \frac{g'^2}{8}[-\tilde{\nu}_L^* \tilde{\nu}_L - \tilde{e}_L^* \tilde{e}_L + \frac{1}{3}(\tilde{u}_L^* \tilde{u}_L + \tilde{d}_L^* \tilde{d}_L) + 2\tilde{e}_R^* \tilde{e}_R - \frac{4}{3}\tilde{u}_R^* \tilde{u}_R + \frac{2}{3}\tilde{d}_R^* \tilde{d}_R]^2 \\ & - \frac{g_s^2}{8}\{\ \frac{4}{3}\sum_{q,i} |\tilde{q}_i^* \tilde{q}_i|^2 + 4\sum_{q<q',i} |\tilde{q}_i^* \tilde{q}_i'|^2 - \frac{4}{3}\sum_{q<q',i} (\tilde{q}_i^* \tilde{q}_i)(\tilde{q}_i'^* \tilde{q}_i')\} \\ & + \frac{g_s^2}{4}\{\ 2\sum_q |\tilde{q}_L^* \tilde{q}_R|^2 + 4\sum_{q<q'} |\tilde{q}_L^* \tilde{q}_R'|^2 - \frac{2}{3}\sum_{q,q'} (\tilde{q}_L^* \tilde{q}_L)(\tilde{q}_R'^* \tilde{q}_R')\},\end{aligned} \tag{3.18}$$

where for saving the space the strong interaction part proportional to g_s^2 is not explicitly expanded. Here again, as three generations of fermions are considered, following (B.18) one has to sum over the generations before taking squares at the g'^2 term, while in the g^2 term, according to (B.18) all the possible doublet combinations must be considered.

3.3 Higgs gauge interactions

From (3.1g), (3.1h) as well as from the D-terms, we obtain the various Higgs interaction terms. The D-terms provide the quartic part of the Higgs potentials shown in (B.18). From (3.1g) and (3.1h), we obtain the gaugino-higgsino mixing terms and the following four interactions.

$$\begin{aligned}
\mathcal{L}_{HHV} = &- \frac{g}{2} i[(v_1 \partial^\mu H_1^- - v_2 \partial^\mu H_2^-) W_\mu^+ - (v_1 \partial^\mu H_1^+ - v_2 \partial^\mu H_2^+) W_\mu^-] \\
&- \frac{g}{2c_W}(v_1 \partial^\mu \chi_1^0 + v_2 \partial^\mu \chi_2^0) Z_\mu \\
&+ \frac{g}{2} i[\cos(\beta - \alpha)(H^0 \overleftrightarrow{\partial}^\mu G^- + h^0 \overleftrightarrow{\partial}^\mu H^-) \\
&\quad - \sin(\beta - \alpha)(H^0 \overleftrightarrow{\partial}^\mu H^- - h^0 \overleftrightarrow{\partial}^\mu G^-) \\
&\quad + iG^0 \overleftrightarrow{\partial}^\mu G^- + iA^0 \overleftrightarrow{\partial}^\mu H^-] W_\mu^+ + h.c. \\
&+ \frac{g}{2c_W} i[(1 - 2s_W^2)(G^+ \overleftrightarrow{\partial}^\mu G^- + H^+ \overleftrightarrow{\partial}^\mu H^-) \\
&\quad - i\cos(\beta - \alpha)(G^0 \overleftrightarrow{\partial}^\mu H^0 + A^0 \overleftrightarrow{\partial}^\mu h^0) \\
&\quad - i\sin(\beta - \alpha)(G^0 \overleftrightarrow{\partial}^\mu h^0 - A^0 \overleftrightarrow{\partial}^\mu H^0)] Z_\mu \\
&+ ie[G^+ \overleftrightarrow{\partial}^\mu G^- + H^+ \overleftrightarrow{\partial}^\mu H^-] A_\mu.
\end{aligned} \tag{3.19}$$

Here, the first two lines can be removed by properly choosing the gauge fixing terms.

$$\begin{aligned}
\mathcal{L}_{\tilde{H}\tilde{H}V} = &+ \frac{g}{\sqrt{2}}[\tilde{H}_1^- \sigma^\mu \bar{\tilde{H}}_1^0 + \tilde{H}_2^0 \sigma^\mu \bar{\tilde{H}}_2^+] W_\mu^+ + h.c. \\
&+ \frac{g}{2c_W}[\tilde{H}_1^0 \sigma^\mu \bar{\tilde{H}}_1^0 - \tilde{H}_2^0 \sigma^\mu \bar{\tilde{H}}_2^0 \\
&\quad + (1 - 2s_W^2)(\tilde{H}_2^+ \sigma^\mu \bar{\tilde{H}}_2^+ - \tilde{H}_1^- \sigma^\mu \bar{\tilde{H}}_1^-)] Z_\mu \\
&- e[\tilde{H}_1^- \sigma^\mu \bar{\tilde{H}}_1^- - \tilde{H}_2^+ \sigma^\mu \bar{\tilde{H}}_2^+] A_\mu.
\end{aligned} \tag{3.20}$$

In (3.20) and in the following (3.22b), in the case of neutralino-neutralino interactions, $\tilde{\chi}_i^0 \tilde{\chi}_j^0 V$, $\tilde{\chi}_i^0 \tilde{\chi}_j^0 H$, $\tilde{\chi}_i^0 \tilde{\chi}_j^0 G$, one has to impose the Majorana condition for neutralinos in order to find the Feynman rule from the lagrangian. Namely, using

$$\overline{\Psi(\tilde{\chi}_i^0)} \Gamma \Psi(\tilde{\chi}_j^0) = \overline{\Psi(\tilde{\chi}_j^0)} \Gamma^c \Psi(\tilde{\chi}_i^0), \tag{3.21}$$

where

$$\Gamma^c = C \Gamma C^{-1}, \tag{3.21a}$$

with

$$C(1, \gamma_5, \gamma_\mu, \gamma_\mu \gamma_5, \sigma_{\mu\nu}) C^{-1} = (1, \gamma_5, -\gamma_\mu, \gamma_\mu \gamma_5, -\sigma_{\mu\nu}), \tag{3.21b}$$

the lagrangian must be put in the form,

$$\begin{aligned}
\mathcal{L} \sim \sum_{i,j} \overline{\Psi(\tilde{\chi}_i^0)} \Gamma(i,j) \Psi(\tilde{\chi}_j^0) = &\sum_i \overline{\Psi(\tilde{\chi}_i^0)} \Gamma(i,i) \Psi(\tilde{\chi}_i^0) \\
&+ \sum_{i<j} \overline{\Psi(\tilde{\chi}_i^0)} [\Gamma(i,j) + \Gamma(j,i)^c] \Psi(\tilde{\chi}_j^0).
\end{aligned} \tag{3.21c}$$

$$\mathcal{L}_{\tilde{H}\tilde{V}} = -\sqrt{2}M_W[\cos\beta\varphi(\tilde{H}_1^-)\varphi(\lambda^+) + \sin\beta\varphi(\tilde{H}_2^+)\varphi(\lambda^-)] + h.c.$$
$$- M_Z[\cos\beta\varphi(\tilde{H}_1^0) - \sin\beta\varphi(\tilde{H}_2^0)][c_W\varphi(\lambda^0) - s_W\varphi(\lambda)] + h.c. \tag{3.22a}$$

$$\begin{aligned}\mathcal{L}_{H\tilde{H}\tilde{V}} = & [g\varphi(\tilde{H}_1^0)\varphi(\lambda^-) - \frac{g}{\sqrt{2}}\varphi(\lambda^0)\varphi(\tilde{H}_1^-) - \frac{g'}{\sqrt{2}}\varphi(\lambda)\varphi(\tilde{H}_1^-)]\phi_1^+ \\ & - [g\varphi(\lambda^+)\varphi(\tilde{H}_2^0) + \frac{g}{\sqrt{2}}\varphi(\tilde{H}_2^+)\varphi(\lambda^0) + \frac{g'}{\sqrt{2}}\varphi(\tilde{H}_2^+)\varphi(\lambda)]\phi_2^- \\ & - [\frac{g}{\sqrt{2}}\varphi(\lambda^+)\varphi(\tilde{H}_1^-) + \frac{g}{2}\varphi(\tilde{H}_1^0)\varphi(\lambda^0) - \frac{g'}{2}\varphi(\tilde{H}_1^0)\varphi(\lambda)](\phi_1^0 + i\chi_1^0) \\ & - [\frac{g}{\sqrt{2}}\varphi(\tilde{H}_2^+)\varphi(\lambda^-) - \frac{g}{2}\varphi(\tilde{H}_2^0)\varphi(\lambda^0) + \frac{g'}{2}\varphi(\tilde{H}_2^0)\varphi(\lambda)](\phi_2^0 - i\chi_2^0) \\ & + h.c.\end{aligned} \tag{3.22b}$$

Using (2.9), (2.10), (2.14) and (2.15), we can easily rewrite the above lagrangian in terms of the mass eigenstates: the rule is simply to replace each product of two Weyl spinors according to the following rule,

$$\varphi(a)\varphi(b) \to \bar{\Psi}(a)L\Psi(b), \tag{3.22c}$$

where

$$\begin{aligned}\bar{\Psi}(a) &= \begin{cases} (\mathcal{O}_N)_{ia}\eta_i^*\bar{\Psi}(\tilde{\chi}_i^0), & \text{a= neutral} \\ (\mathcal{O}_{CR})_{ia}(\delta_{i1} + \epsilon_L\delta_{i2})\bar{\Psi}(\tilde{\chi}_i^-), & \text{a=positive}\end{cases} \\ \Psi(b) &= \begin{cases} (\mathcal{O}_N)_{ib}\eta_i^*\Psi(\tilde{\chi}_i^0), & \text{b= neutral} \\ (\mathcal{O}_{CL})_{ib}\Psi(\tilde{\chi}_i^-), & \text{b=negative}\end{cases}\end{aligned} \tag{3.22d}$$

with $\mathcal{O}_{CL}$ and $\mathcal{O}_{CR}$ being two orthogonal matrices appearing in (2.10).

From the (gauge coupling)^2 terms, we have

$$\mathcal{L}_{V mass} + \mathcal{L}_{H(G)VV} + \mathcal{L}_{HHVV}, \tag{3.23}$$

where

$$\mathcal{L}_{V mass} = \frac{g^2}{4}(v_1^2 + v_2^2)W_\mu^+W^{-\mu} + \frac{g_Z^2}{8}(v_1^2 + v_2^2)Z_\mu Z^\mu, \tag{3.23a}$$

$$\begin{aligned}\mathcal{L}_{H(G)VV} = & \ M_W G^-(eA^\mu - g_Z s_W^2 Z^\mu)W_\mu^+ + h.c. \\ & + gM_W(\cos(\beta-\alpha)H^0 + \sin(\beta-\alpha)h^0)W_\mu^+W^{-\mu} \\ & + \frac{g_Z}{2}M_Z(\cos(\beta-\alpha)H^0 + \sin(\beta-\alpha)h^0)Z_\mu Z^\mu,\end{aligned} \tag{3.23b}$$

$$\begin{aligned}\mathcal{L}_{HHVV} = & \frac{g^2}{4}W_\mu^+W^{-\mu}[(H^0)^2 + (h^0)^2 + (A^0)^2 + (G^0)^2 + 2|G^+|^2 + 2|H^+|^2] \\ & + \frac{g_Z^2}{8}Z_\mu Z^\mu[(H^0)^2 + (h^0)^2 + (A^0)^2 + (G^0)^2 \\ & \qquad + 2(1-2s_W^2)^2(|G^+|^2 + |H^+|^2)] \\ & + (c_W^2 - s_W^2)eg_Z Z_\mu A^\mu(|G^+|^2 + |H^+|^2) \\ & + e^2A_\mu A^\mu(|G^+|^2 + |H^+|^2) \\ & + \frac{ge}{2}W_\mu^+(A^\mu - \frac{s_W}{c_W}Z^\mu)F_W + h.c.,\end{aligned} \tag{3.23c}$$

where

$$F_W = \cos(\beta-\alpha)(H^0G^- + h^0H^-) + \sin(\beta-\alpha)(h^0G^- - H^0H^-) \\ + i(G^0G^- + A^0H^-). \tag{3.23d}$$

3.4 SUSY breaking interactions

The SUSY breaking lagrangian (3.1m) or (3.2) contributes to the mass terms as well as the Yukawa interaction terms which give the $\tilde{f}\tilde{f}H(G)$ interactions. From the third and fourth lines of (3.2) one obtains,

$$\begin{aligned}\mathcal{L}_{\tilde{f}\tilde{f}H(G)} =& m_u A_u \tilde{u}_R^* \tilde{u}_L + m_d A_d \tilde{d}_R^* \tilde{d}_L + m_e A_e \tilde{e}_R^* \tilde{e}_L + h.c. \\ &+ \frac{m_u}{v_2} A_u(-\sqrt{2}\phi_2^+ \tilde{u}_R^* \tilde{d}_L + (\phi_2^0 + i\chi_2^0)\tilde{u}_R^* \tilde{u}_L) + h.c. \\ &+ \frac{m_d}{v_1} A_d(\sqrt{2}\phi_1^- \tilde{d}_R^* \tilde{u}_L + (\phi_1^0 - i\chi_1^0)\tilde{d}_R^* \tilde{d}_L) + h.c. \\ &+ \frac{m_e}{v_1} A_e(\sqrt{2}\phi_1^- \tilde{e}_R^* \tilde{\nu}_L + (\phi_1^0 - i\chi_1^0)\tilde{e}_R^* \tilde{e}_L) + h.c.\end{aligned} \tag{3.24}$$

3.5 Kinetic term (3.1a)

From the lagrangian (3.1a) we obtain the (nonlinear) gauge boson kinetic terms which includes gauge boson self-interaction, gaugino kinetic terms and $\mathcal{L}_{\tilde{V}\tilde{V}V}$ interaction.

$$\begin{aligned}(3.1a) =& -\frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}g^\alpha_{\mu\nu}g^{\alpha\mu\nu} \\ &+ \mathcal{L}_{\tilde{V}\ kin} + \mathcal{L}_{\tilde{V}\tilde{V}V} + D\text{-terms}.\end{aligned} \tag{3.25}$$

The gauge boson kinetic part, the first line of (3.25), is the same as the SM. The gaugino kinetic part is given as

$$\begin{aligned}\mathcal{L}_{\tilde{V}\ kin} &= i\lambda^a\sigma^\mu\partial_\mu\overline{\lambda^a} + i\lambda\sigma^\mu\partial_\mu\overline{\lambda} + i\tilde{g}^\alpha\sigma^\mu\partial_\mu\overline{\tilde{g}}^\alpha \\ &= i\lambda^+\sigma^\mu\partial_\mu\overline{\lambda^+} + i\lambda^-\sigma^\mu\partial_\mu\overline{\lambda^-} + i\lambda^0\sigma^\mu\partial_\mu\overline{\lambda^0} + i\lambda\sigma^\mu\partial_\mu\overline{\lambda} + i\tilde{g}^\alpha\sigma^\mu\partial_\mu\overline{\tilde{g}}^\alpha.\end{aligned} \tag{3.25a}$$

Note that

$$\overline{\lambda^\pm} = \frac{\bar{\lambda}^1 \pm i\bar{\lambda}^2}{\sqrt{2}} = (\bar{\lambda})^\mp. \tag{3.25b}$$

$$\begin{aligned}\mathcal{L}_{\tilde{V}\tilde{V}V} =& g(\lambda^-\sigma^\mu\overline{\lambda^0} - \lambda^0\sigma^\mu\overline{\lambda^+})W^+_\mu + h.c. \\ &+ cg(\lambda^+\sigma^\mu\overline{\lambda^+} - \lambda^-\sigma^\mu\overline{\lambda^-})Z_\mu \\ &+ e(\lambda^+\sigma^\mu\overline{\lambda^+} - \lambda^-\sigma^\mu\overline{\lambda^-})A_\mu \\ &+ \frac{g_s}{2} i f^{\alpha\beta\gamma}\overline{\Psi(\tilde{g}^\alpha)}\gamma^\mu\Psi(\tilde{g}^\beta)g^\gamma_\mu.\end{aligned} \tag{3.25c}$$

Combining (3.25a) with the kinetic part of the fermions, sfermions Higgs and higgsino fields,

$$\begin{aligned}\mathcal{L}_{kinet} =& + i\sum_f \bar{\Psi}(f)\partial\!\!\!/\Psi(f) \\ &+ i\sum_i \bar{\Psi}(\tilde{\chi}_i^+)\partial\!\!\!/\Psi(\tilde{\chi}_i^+) + \frac{i}{2}\sum_i \bar{\Psi}(\tilde{\chi}_i^0)\partial\!\!\!/\Psi(\tilde{\chi}_i^0) + \frac{i}{2}\sum_\alpha \bar{\Psi}(\tilde{g}^\alpha)\partial\!\!\!/\Psi(\tilde{g}^\alpha) \\ &+ \sum_{f,i}(\partial^\mu \tilde{f}_i^*\partial_\mu \tilde{f}_i) \\ &+ \sum_H \partial^\mu H^*\partial_\mu H + \sum_G \partial^\mu G^*\partial_\mu G.\end{aligned} \tag{3.26}$$

Note that the factor $\frac{1}{2}$ is properly reproduced for neutralino and gluino kinetic terms.

3.6 Gauge fixing terms and ghost interacitons

Upon using (2.24)and (2.25) and partial integration, the first two lines of (3.19) reduces to

$$-iM_W G^- \partial^\mu W_\mu^+ + iM_W G^+ \partial^\mu W_\mu^- + M_Z G^0 \partial^\mu Z_\mu. \tag{3.27}$$

Therefore, the gauge fixing term can be chosen such that this part disappears from the lagrangian:

$$\mathcal{L}_{gf} = -\frac{1}{\xi_W} F^+ F^- - \frac{1}{2\xi_Z}|F^Z|^2 - \frac{1}{2\xi_\gamma}|F^\gamma|^2 - \frac{1}{2\xi_g}\sum_\alpha |F^{g\alpha}|^2, \tag{3.28}$$

where

$$\begin{aligned} F^\pm &= \partial^\mu W_\mu^\pm \pm iM_W \xi_W G^\pm, \\ F^Z &= \partial^\mu Z_\mu + M_Z \xi_Z G^0, \\ F^\gamma &= \partial^\mu A_\mu, \\ F^{g\alpha} &= \partial^\mu g_\mu^\alpha. \end{aligned} \tag{3.29}$$

This is exactly the same form as the SM gauge fixing terms, ensuring that the gauge boson propagators and the Goldstone boson propagators have the same form as the standard model.

Ghost interaction comes from the $SU(2)$ and $U(1)$ variation of the gauge fixing functions $F^\pm$ etc. First we note that the matter and gauge fields transform as*

$$\begin{aligned} SU(2)_L &: \begin{cases} \delta W_\mu^i = \epsilon^{ijk} u^j W_\mu^k + \frac{1}{g}\partial_\mu u^i, \\ \delta B_\mu = 0, \\ \delta(\mathbf{H}_i - < \mathbf{H}_i >_0) = -i\left(\frac{\vec{\tau}}{2}\cdot\vec{u}\right)\mathbf{H}_i, \end{cases} \\ U(1) &: \begin{cases} \delta W_\mu^i = 0, \\ \delta B_\mu = \frac{1}{g'}\partial_\mu \alpha, \\ \delta(\mathbf{H}_i - < \mathbf{H}_i >_0) = -iY_i \frac{\alpha}{2}\mathbf{H}_i, \end{cases} \\ SU(3)_c &: \quad \delta g_\mu^\alpha = f^{\alpha\beta\gamma} u^\beta g_\mu^\gamma + \frac{1}{g_s}\partial^\mu u_\mu^\alpha, \end{aligned} \tag{3.30}$$

where u^i and α are the gauge transformation parameters. Or, equivalently,

$$SU(2)_L : \begin{cases} \delta W_\mu^\pm = \pm i(W_\mu^3 u^\pm - W_\mu^\pm u^3) + \frac{1}{g}\partial_\mu u^\pm, \\ \delta Z_\mu = c_W[-iW_\mu^- u^+ + iW_\mu^+ u^- + \frac{1}{g}\partial_\mu u^3], \\ \delta A_\mu = s_W[-iW_\mu^- u^+ + iW_\mu^+ u^- + \frac{1}{g}\partial_\mu u^3], \end{cases} \tag{3.31}$$

* The non-Abelian gauge transformation is defined in my convention as

$$\mathbf{W}_\mu \equiv \sum \frac{\tau^a}{2} W_\mu^a \to U(x)\mathbf{W}_\mu U(x)^{-1} - \frac{i}{g} U(x)\partial_\mu U(x)^{-1},$$

with

$$U(x) \equiv \exp[-i\sum \frac{\tau^a}{2} u(x)^a].$$

where

$$u^{\pm} = \frac{u^1 \mp i u^2}{\sqrt{2}}. \tag{3.32}$$

The transformation of the gauge fixing functions $F^{\pm}$ etc is expressed as

$$\delta \begin{pmatrix} F^+ \\ F^- \\ F^Z \\ F^\gamma \end{pmatrix} = \begin{pmatrix} \tilde{\mathcal{M}}_1 & \tilde{\mathcal{M}}_2 \\ \tilde{\mathcal{M}}_3 & \tilde{\mathcal{M}}_4 \end{pmatrix} \begin{pmatrix} -u^+/g \\ -u^-/g \\ -u^3/g \\ -\alpha/g' \end{pmatrix}, \tag{3.33}$$

$$\delta F^{g\alpha} = [-\partial^\mu \partial_\mu \delta_{\alpha\beta} - g_s f^{\alpha\beta\gamma} \partial^\mu g^\gamma_\mu](-u^\beta/g_s).$$

Changing the base from u^3, α to u^z and u^γ by

$$\begin{pmatrix} u^z/g_Z \\ u^\gamma/e \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \\ \sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} u^3/g \\ \alpha/g' \end{pmatrix}, \tag{3.34}$$

so that the kinetic and mass terms become diagonal, and then separating the kinetic term and mass term one finds the final expression for the interaction lagrangian,

$$\begin{aligned} \mathcal{L}_{ghost} = {} & \partial_\mu \bar{\omega}_+ \partial_\mu \omega_+ - \xi_W M_W^2 \bar{\omega}_+ \omega_+ + \partial^\mu \bar{\omega}_- \partial_\mu \omega_- - \xi_W M_W^2 \bar{\omega}_- \omega_- \\ & + \partial^\mu \bar{\omega}_z \partial_\mu \omega_z - \xi_Z M_Z^2 \bar{\omega}_z \omega_z \quad + \partial^\mu \bar{\omega}_\gamma \partial_\mu \omega_\gamma \quad + \partial^\mu \bar{\omega}^\alpha \partial_\mu \omega^\alpha \\ & + (\bar{\omega}_+, \bar{\omega}_-, \bar{\omega}_z, \bar{\omega}_\gamma) \begin{pmatrix} \mathcal{M}_{int\ 1} & \mathcal{M}_{int\ 2} \\ \mathcal{M}_{int\ 3} & \mathcal{M}_{int\ 4} \end{pmatrix} \begin{pmatrix} \omega_+ \\ \omega_- \\ \omega_z \\ \omega_\gamma \end{pmatrix} \\ & + g_s f^{\alpha\beta\gamma} \partial^\mu \bar{\omega}^\alpha \omega^\beta g^\gamma_\mu, \end{aligned} \tag{3.35}$$

with

$$\begin{aligned} \begin{pmatrix} \mathcal{M}_{int\ 1} & \mathcal{M}_{int\ 2} \\ \mathcal{M}_{int\ 3} & \mathcal{M}_{int\ 4} \end{pmatrix} = {} & \begin{pmatrix} \tilde{\mathcal{M}}_1 & \tilde{\mathcal{M}}_2 \\ \tilde{\mathcal{M}}_3 & \tilde{\mathcal{M}}_4 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & c_W & s_W \\ 0 & 0 & -s_W & c_W \end{pmatrix} \\ & - (\text{kinetic terms}) - (\text{mass terms}). \end{aligned} \tag{3.36}$$

Here ω stands for the ghost particles which are scalar but behave as if they were fermion. The explicit form of the matrices $\mathcal{M}_{int\ 1}$ etc is given as follows,

$$\begin{aligned} \mathcal{M}_{int\ 1} = & - ig(c_W \partial^\mu Z_\mu + s_W \partial^\mu A_\mu) \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \\ & - \frac{g}{2} M_W \xi_W [\cos(\beta-\alpha) H^0 + \sin(\beta-\alpha) h^0] \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ & - i\frac{g}{2} M_W \xi_W G^0 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \end{aligned} \tag{3.37a}$$

$$\begin{aligned} \mathcal{M}_{int\ 2} = ig & \begin{pmatrix} c_W \partial^\mu W^+_\mu & s_W \partial^\mu W^+_\mu \\ -c_W \partial^\mu W^-_\mu & -s_W \partial^\mu W^-_\mu \end{pmatrix} \\ & - M_W \xi_W \begin{pmatrix} \frac{g_Z}{2}(c_W^2 - s_W^2) G^+ & e G^+ \\ \frac{g_Z}{2}(c_W^2 - s_W^2) G^- & e G^- \end{pmatrix}, \end{aligned} \tag{3.37b}$$

$$
\mathcal{M}_{int\ 3} = ig \begin{pmatrix} c_W \partial^\mu W_\mu^- & -c_W \partial^\mu W_\mu^+ \\ s_W \partial^\mu W_\mu^- & -s_W \partial^\mu W_\mu^+ \end{pmatrix} + \frac{g}{2} M_Z \xi_Z \begin{pmatrix} G^- & G^+ \\ 0 & 0 \end{pmatrix}, \tag{3.37c}
$$

$$
\mathcal{M}_{int\ 4} = -\frac{g_Z}{2} M_Z \xi_Z [\cos(\beta-\alpha) H^0 + \sin(\beta-\alpha) h^0] \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}. \tag{3.37d}
$$

They provide three interactions $\mathcal{L}_{\bar{\omega}\omega V}$, $\mathcal{L}_{\bar{\omega}\omega H}$ and $\mathcal{L}_{\bar{\omega}\omega G}$ where G stands for the Goldstone bosons.

$$
\begin{aligned}
\mathcal{L}_{\bar{\omega}\omega V} = & \, igc_W[\partial^\mu \bar{\omega}_+ \omega_+ - \partial^\mu \bar{\omega}_- \omega_-] Z_\mu \\
& + ie[\partial^\mu \bar{\omega}_+ \omega_+ - \partial^\mu \bar{\omega}_- \omega_-] A_\mu \\
& + ig[c_W(\partial^\mu \bar{\omega}_z \omega_- - \partial^\mu \bar{\omega}_+ \omega_z) + s_W(\partial^\mu \bar{\omega}_\gamma \omega_- - \partial^\mu \bar{\omega}_+ \omega_\gamma)] W_\mu^+ \\
& + ig[c_W(\partial^\mu \bar{\omega}_- \omega_z - \partial^\mu \bar{\omega}_z \omega_+) + s_W(\partial^\mu \bar{\omega}_- \omega_\gamma - \partial^\mu \bar{\omega}_\gamma \omega_+)] W_\mu^- \\
& + g_s f^{\alpha\beta\gamma} \partial \bar{\omega}^\alpha \omega^\beta g_\mu^\gamma .
\end{aligned} \tag{3.38}
$$

$$
\begin{aligned}
\mathcal{L}_{\bar{\omega}\omega H} = & -\frac{1}{2}[g M_W \xi_W (\bar{\omega}_+ \omega_+ + \bar{\omega}_- \omega_-) + g_Z M_Z \xi_Z \bar{\omega}_z \omega_z] \\
& [\cos(\beta-\alpha) H^0 + \sin(\beta-\alpha) h^0].
\end{aligned} \tag{3.39}
$$

$$
\begin{aligned}
\mathcal{L}_{\bar{\omega}\omega G} = & -i\frac{g}{2} M_W \xi_W [\bar{\omega}_+ \omega_+ - \bar{\omega}_- \omega_-] G^0 \\
& - (c_W^2 - s_W^2) \frac{g_Z}{2} M_W \xi_W [\bar{\omega}_+ \omega_z G^+ + \bar{\omega}_- \omega_z G^-] \\
& - e M_W \xi_W [\bar{\omega}_+ \omega_\gamma G^+ + \bar{\omega}_- \omega_\gamma G^-] \\
& + \frac{g}{2} M_Z \xi_Z [\bar{\omega}_z \omega_+ G^- + \bar{\omega}_z \omega_- G^+].
\end{aligned} \tag{3.40}
$$

4. Mass matrix

In this section, I will list the mass matrices of various particles, which are diagonalized by the orthogonal matrices as discussed in section 2.

(1)Fermion Their masses come from the interaction (3.1i), (3.1j), (3.1k) as explicitly shown in (3.10a).

(2)Gauge bosons Their masses come from (3.1g) and (3,1h) as shown in (3.23a). The mass term becomes

$$
\begin{aligned}
\mathcal{L}_m = & \frac{1}{4} g^2 (v_1^2 + v_2^2) W_\mu^+ W^{-\mu} \\
& + \frac{1}{8}(g^2 + g'^2)(v_1^2 + v_2^2) \begin{pmatrix} W_\mu^3, B_\mu \end{pmatrix} \begin{pmatrix} g^2 & -gg' \\ -gg' & g'^2 \end{pmatrix} \begin{pmatrix} W^{3\mu} \\ B^\mu \end{pmatrix},
\end{aligned} \tag{4.1}
$$

from which, we obtain the mass eigenvalues (2.5) and the mixing angle (2.4b). Photon and gluons remain massless.

(3)Sfermion The diagonal mass matrix elements come from the matter F-terms (3.11a) and the D-terms given by (3.15) while the off-diagonal elements come from the Higgs F-terms (3.12b) as well as from the soft breaking term (3.24).

$$\begin{pmatrix} m^2_{\tilde{f}_L} & m^2_{\tilde{f}_{LR}} \\ m^{2*}_{\tilde{f}_{LR}} & m^2_{\tilde{f}_R} \end{pmatrix}, \tag{4.2}$$

with

$$\begin{aligned} m^2_{\tilde{f}_L} &= \tilde{m}^2_{\tilde{f}_L} + m_f^2 + M_Z^2 \cos 2\beta (T_{3f} - Q_f s_W^2), \\ m^2_{\tilde{f}_R} &= \tilde{m}^2_{\tilde{f}_R} + m_f^2 + M_Z^2 \cos 2\beta Q_f s_W^2, \\ m^2_{\tilde{f}_{LR}} &= \begin{cases} -m_u(\mu \cot\beta + A_u^*), & f = u \\ -m_f(\mu \tan\beta + A_f^*), & f = d, e \end{cases} \end{aligned} \tag{4.3}$$

(4)Charginos They are mixture of gaugino $\lambda^{\pm}$ and higgsino $\tilde{H}_1^-$ and $\tilde{H}_2^+$. Higgsino mass comes from (3.1ℓ), which reads as

$$\begin{aligned} (3.1\ell) = &- \mu[\varphi(\tilde{H}_1^-)\varphi(\tilde{H}_2^+) + \bar{\varphi}(\tilde{H}_1^-)\bar{\varphi}(\tilde{H}_2^+) - \bar{\Psi}(\tilde{H}_1^0)\Psi(\tilde{H}_2^0)] \\ &+ F(H_i)\text{-terms}, \end{aligned} \tag{4.4}$$

while gauginos acquire masses only from the SUSY breaking interaction (3.1m). The gaugino higgsino mixing terms come from (3.22a). Collecting them all, we find, (see (2.11))

$$\mathcal{L}_m = -\left(\varphi(\lambda^+), \varphi(\tilde{H}_2^+)\right) \begin{pmatrix} M_2 & \sqrt{2} M_W \cos\beta \\ \sqrt{2} M_W \sin\beta & \mu \end{pmatrix} \begin{pmatrix} \varphi(\lambda^-) \\ \varphi(\tilde{H}_1^-) \end{pmatrix} + h.c. \tag{4.5}$$

The mass eigenvalues are

$$m^2_{\tilde{\chi}^{\pm}_{1,2}} = \frac{1}{2}(M_2^2 + \mu^2 + 2M_W^2 \mp \sqrt{C}), \tag{4.6}$$

where

$$C = (M_2^2 + \mu^2 + 2M_W^2)^2 - 4(M_2\mu - M_W^2 \sin 2\beta)^2. \tag{4.6a}$$

(5)Neutralinos They are mixture of neutral gauginos λ, λ^0 and neutral higgsinos $\tilde{H}_1^0$ and $\tilde{H}_2^0$. As in the case of charginos, gaugino acquires masses from SUSY breaking lagrangian while the higgsino mass comes from (4.4). The gaugino-higgsino mixing term come from (3.22a). Assembling them together, we find (see (2.19))

$$\begin{aligned} \mathcal{L}_m = &-\frac{1}{2} \begin{pmatrix} \lambda \\ \lambda^0 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix}^t \begin{pmatrix} M_1 & 0 & -M_Z\ s_W \cos\beta & M_Z\ s_W \sin\beta \\ * & M_2 & M_Z\ c_W \cos\beta & -M_Z\ c_W \sin\beta \\ * & * & 0 & -\mu \\ * & * & * & 0 \end{pmatrix} \begin{pmatrix} \lambda \\ \lambda^0 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix} \\ &+ h.c. \end{aligned} \tag{4.7}$$

(6)Gluinos Being a SUSY partner of gluons, gluinos are massless in the SUSY limit. Acquiring the contribution only from the SUSY breaking term (3.2), their mass is M_3.

(7)Higgs Their masses come from the quadratic part of the Higgs potential, which arises from the $F(H_i)$-terms,(3.12a), D-terms (3.14) and the SUSY breaking term (3.1m). It has the following form,

$$\begin{aligned} V = &\ m_1^2 \mathbf{H}_1^* \mathbf{H}_1 + m_2^2 \mathbf{H}_2^* \mathbf{H}_2 + (m_{12}^2 \mathbf{H}_1 \mathbf{H}_2 + h.c.) \\ &+ \frac{1}{8}(g^2 + g'^2)(\mathbf{H}_1^* \mathbf{H}_1 - \mathbf{H}_2^* \mathbf{H}_2)^2 + \frac{g^2}{2}|\mathbf{H}_1^* \mathbf{H}_2|^2, \end{aligned} \tag{4.8}$$

where

$$
\begin{aligned}
m_1^2 &= \tilde{m}_1^2 + |\mu|^2, \\
m_2^2 &= \tilde{m}_2^2 + |\mu|^2, \\
m_{12}^2 &= \tilde{m}_{12}^2.
\end{aligned}
\tag{4.9}
$$

and the product of two doublets is defined in (3.2a). Since the minimum of the above potential is realized by

$$
\mathbf{H}_1 = \begin{pmatrix} \frac{v_1}{\sqrt{2}} \\ 0 \end{pmatrix}, \qquad \mathbf{H}_2 = \begin{pmatrix} 0 \\ \frac{v_1}{\sqrt{2}} \end{pmatrix},
\tag{4.10}
$$

v_1, v_2 and m_1^2 etc are related at tree level as follows.

$$
\begin{aligned}
\frac{v_1 v_2}{v_1^2 + v_2^2} &= -\frac{m_{12}^2}{m_1^2 + m_2^2} (= \frac{1}{2}\sin 2\beta), \\
v_1^2 + v_2^2 &= -\frac{8}{g^2 + g'^2} \frac{m_1^2 \cos^2\beta - m_2^2 \sin^2\beta}{\cos 2\beta}.
\end{aligned}
\tag{4.11}
$$

Upon using (4.11), the Higgs potential (4.8) can be rewritten as

$$
\begin{aligned}
V = &\, m_1^2 \mathbf{H}_1^* \mathbf{H}_1 + m_2^2 \mathbf{H}_2^* \mathbf{H}_2 - (m_1^2 + m_2^2)\cos\beta \sin\beta (\mathbf{H}_1 \mathbf{H}_2 + h.c.) \\
&+ \frac{g^2 + g'^2}{8} (\mathbf{H}_1^* \mathbf{H}_1 - \mathbf{H}_2^* \mathbf{H}_2)^2 + \frac{g^2}{2} |\mathbf{H}_1^* \mathbf{H}_2|^2.
\end{aligned}
\tag{4.12}
$$

The straightforward calculation yields the following mass matrix for neutral Higgs,

$$
\begin{aligned}
\mathcal{L}_m = &- \frac{1}{2}(m_1^2 + m_2^2) \begin{pmatrix} \chi_1^0, \chi_2^0 \end{pmatrix} \begin{pmatrix} \sin^2\beta & -\sin\beta\cos\beta \\ -\sin\beta\cos\beta & \cos^2\beta \end{pmatrix} \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \end{pmatrix} \\
&- \frac{1}{2} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix}^t \begin{pmatrix} M_A^2 \sin^2\beta + M_Z^2 \cos^2\beta & -(M_A^2 + M_Z^2)\sin\beta\cos\beta \\ -(M_A^2 + M_Z^2)\sin\beta\cos\beta & M_A^2\cos^2\beta + M_Z^2 \sin^2\beta \end{pmatrix} \begin{pmatrix} \phi_1^0 \\ \phi_2^0 \end{pmatrix},
\end{aligned}
\tag{4.13}
$$

from which one obtains the masses of three neutral Higgses (see (2.27)),

$$
\begin{aligned}
M_A^2 &= m_1^2 + m_2^2 = -m_{12}^2(\tan\beta + \cot\beta), \\
M_{H^0,h^0}^2 &= \frac{1}{2}[M_A^2 + M_Z^2 \pm \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}], \\
M_{H^\pm}^2 &= M_A^2 + M_W^2.
\end{aligned}
\tag{4.14}
$$

The corresponding mixing angles are given in (2.25) with (2.26). For charged Higgs, we have

$$
\mathcal{L}_m = -(M_A^2 + M_W^2) \begin{pmatrix} \phi_1^+ & \phi_2^+ \end{pmatrix} \begin{pmatrix} \sin^2\beta & -\sin\beta\cos\beta \\ -\sin\beta\cos\beta & \cos^2\beta \end{pmatrix} \begin{pmatrix} \phi_1^- \\ \phi_2^- \end{pmatrix},
\tag{4.15}
$$

with the eigenvalue $M_{H^\pm}^2 = M_A^2 + M_W^2$ and the mixing matrix given by (2.24). The final form of the Higgs potential looks as follows,

$$
-V = \frac{g^2}{32c^2}(v_1^2 - v_2^2)^2 + (4.13) + (4.15) + (3.14a) + (3.14c).
\tag{4.16}
$$

5. Choice of input parameters

MSSM has four couplings, g, g', g_s and μ, and $6+8N_G$ free independent parameters for SUSY breaking, all together $10+8N_G$ parameters to be fixed. Among them, 8 parameters for each generation appear only in the sfermion mass matrix and their mixing. Therefore, it is more convenient to choose 5 physical masses and 3 mixing angles of sfermions in each generation as input parameters. From (2.8) one finds

$$
\begin{aligned}
m^2_{\tilde{f}_L} &= \cos^2\theta_f m^2_{\tilde{f}_1} + \sin^2\theta_f m^2_{\tilde{f}_2}, \\
m^2_{\tilde{f}_R} &= \sin^2\theta_f m^2_{\tilde{f}_1} + \cos^2\theta_f m^2_{\tilde{f}_2}, \\
m^2_{\tilde{f}_{LR}} &= \cos\theta_f \sin\theta_f (m^2_{\tilde{f}_1} - m^2_{\tilde{f}_2}).
\end{aligned} \tag{5.1}
$$

Using (4.2), (4.3) and (5.1), one can easily express the original parameters appearing in the lagrangian, $\tilde{m}^2_{\tilde{f}_L}$, $\tilde{m}^2_{\tilde{f}_R}$ and A_f, in terms of the physical input parameters (the physical masses and the mixing angles of sfermions). If we neglect a fermion mass ($m_f=0$), there is no mixing between $\tilde{f}_L$ and $\tilde{f}_R$. Consequently, we need one less parameter; we can discard the mixing angle θ_f, or equivalently A_f in terms of the parameter appearing in the lagrangian.

In case we neglect the masses of the fermions belonging to the first and second generations, the input parameters in sfermion sector are the following 20 quantities(5+5+8=18 independent quantities):

$$
\begin{gathered}
m^2_{\tilde{u}_L} = m^2_{\tilde{d}_L}, \quad m^2_{\tilde{\nu}e_L} = m^2_{\tilde{e}_L}, \quad m^2_{\tilde{u}_R}, \quad m^2_{\tilde{d}_R}, \quad m^2_{\tilde{e}_R}, \\
m^2_{\tilde{c}_L} = m^2_{\tilde{s}_L}, \quad m^2_{\tilde{\nu}\mu_L} = m^2_{\tilde{\mu}_L}, \quad m^2_{\tilde{c}_R}, \quad m^2_{\tilde{s}_R}, \quad m^2_{\tilde{\mu}_R}, \\
m^2_{\tilde{b}_1}, \quad m^2_{\tilde{b}_2}, \quad \theta_b, \quad m^2_{\tilde{t}_1}, \quad m^2_{\tilde{t}_2}, \quad \theta_t, \\
m^2_{\tilde{\tau}_1}, \quad m^2_{\tilde{\tau}_2}, \quad \theta_\tau, \quad m^2_{\tilde{\nu}\tau_L},
\end{gathered} \tag{5.2}
$$

with the constraints coming from the $SU(2)_L$ invariance of $\mathcal{L}_{soft}$, $\tilde{m}^2_{\tilde{f}_{L\uparrow}} = \tilde{m}^2_{\tilde{f}_{L\downarrow}}$,

$$
\begin{aligned}
\cos^2\theta_t m^2_{\tilde{t}_1} + \sin^2\theta_t m^2_{\tilde{t}_2} - m_t^2 &= \cos^2\theta_b m^2_{\tilde{b}_1} + \sin^2\theta_b m^2_{\tilde{b}_2} - m_b^2 + M_W^2\cos 2\beta, \\
m^2_{\tilde{\nu}\tau} &= \cos^2\theta_\tau m^2_{\tilde{\tau}_1} + \sin^2\theta_\tau m^2_{\tilde{\tau}_2} - m_\tau^2 + M_W^2\cos 2\beta.
\end{aligned} \tag{5.3}
$$

Concerning the remaining 10 parameters,

$$
g,\ g',\ g_s,\ \mu,\ M_1,\ M_2,\ M_3,\ \tilde{m}_1^2,\ \tilde{m}_2^2,\ \tilde{m}_{12}^2, \tag{5.4}
$$

it is customary to use, in place of $\tilde{m}_1^2$, $\tilde{m}_2^2$ and $\tilde{m}_{12}^2$, the pseudoscalar Higgs mass M_A^2 as given by (4.14) and two vacuum expectation values v_1 and v_2 which are defined by (4.11). This is because $\tilde{m}_1^2$, $\tilde{m}_2^2$ and $\tilde{m}_{12}^2$ appear only in the Higgs potential (4.8) through (4.9) and as we see from (4.12), (4.13) and (4.14), Higgs masses, mixing angles and Higgs potential are more naturally expressed in terms of M_A^2 and two vacuum expectation values. For reference sake, relations between the original three parameters and the M_A^2, v_1 and v_2 are shown here,

$$
\begin{aligned}
\tilde{m}_1^2 &= M_A^2\sin^2\beta - \frac{g^2+g'^2}{8}(v_1^2 - v_2^2) - \mu^2, \\
\tilde{m}_2^2 &= M_A^2\cos^2\beta + \frac{g^2+g'^2}{8}(v_1^2 - v_2^2) - \mu^2, \\
\tilde{m^2_{12}} &= -\frac{1}{2}M_A^2\sin 2\beta.
\end{aligned} \tag{5.5}
$$

Therefore, as far as the Higgs sector is concerned, MSSM contains only one more parameter than SM, for which we can take $\tan\beta$.

In place of g, g' and $v_1^2 + v_2^2$, more physical parameters can be used, namely, e, M_W and M_Z, which are related to the former parameters according to (2.5) and (A.15). Consequently, the input parameters we use are the following 10 quantities,

$$e, \quad g_s, \quad M_W, \quad M_Z, \quad \tan\beta, \quad M_A, \quad \mu, \quad M_1, \quad M_2, \quad M_3, \tag{5.6}$$

plus 20 sfermion parameters (5.2) under two constraints (5.3).

Acknowledgment

I would like to thank Prof. Y. Shimizu for useful discussions and for careful reading of the manuscript, and Dr. T. Ishikawa for pointing out mistypings in the equations of the manuscript.

Appendix A. Notations, Conventions and Mathematical formulae

In this note the Greek letters, Φ, φ, χ and Ψ are used in the following meaning,

$$\begin{array}{rl}
\Phi: & \text{left-handed chiral superfield} \\
\varphi,\ \chi: & \text{two component Weyl spinors} \\
\Psi: & \text{four component spinors} \\
 & \left(\begin{array}{c}\bar{\varphi}^{\dot{a}} \\ \chi_b\end{array}\right) \quad \text{Dirac fermion} \\
 & \left(\begin{array}{c}\bar{\varphi} \\ \varphi\end{array}\right) \quad \text{Majorana fermion.}
\end{array} \tag{A.1}$$

We use the convention of gamma matrices,

$$\gamma^\mu = \left(\begin{array}{cc} 0 & \bar{\sigma}^\mu \\ \sigma^\mu & 0 \end{array}\right), \tag{A.2}$$

where

$$\sigma^\mu = (1, \vec{\sigma}), \qquad \bar{\sigma}^\mu = (1, -\vec{\sigma}). \tag{A.3}$$

Note the following relation:

$$\chi\sigma^\mu\bar{\varphi} = -\bar{\varphi}\bar{\sigma}^\mu\chi. \tag{A.4}$$

The γ_5 is then given by

$$\gamma_5 = i\gamma^0\gamma^1\gamma^2\gamma^3 = \left(\begin{array}{cc} 1 & 0 \\ 0 & -1 \end{array}\right), \tag{A.5}$$

so that the right-handed and left-handed projections are given as follows;

$$R = \left(\begin{array}{cc} 1 & 0 \\ 0 & 0 \end{array}\right), \quad L = \left(\begin{array}{cc} 0 & 0 \\ 0 & 1 \end{array}\right), \quad \gamma^\mu R = \left(\begin{array}{cc} 0 & 0 \\ \sigma^\mu & 0 \end{array}\right), \quad \gamma^\mu L = \left(\begin{array}{cc} 0 & \bar{\sigma}^\mu \\ 0 & 0 \end{array}\right). \tag{A.6}$$

In this convention of the γ matrices, the charge conjugation matrix C, which must fulfill the following conditions (see, e.g. Appendix A of ref.[8].),

$$C^T = -C, \quad C^\dagger = C^{-1}(\text{unitarity}), \quad C\gamma_\mu^T C^{-1} = -\gamma_\mu, \tag{A.7}$$

is expressed as

$$C = -i\gamma^2\gamma^0 = -\left(\begin{array}{cc} i(\bar{\sigma}^2\sigma^0)^{\dot{\alpha}}{}_{\dot{\beta}} & 0 \\ 0 & i(\sigma^2\bar{\sigma}^0)_\alpha{}^\beta \end{array}\right) = \left(\begin{array}{cccc} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{array}\right). \tag{A.8}$$

Therefore, for a given spinor (with upper indices for anti-Weyl spinors and down indices for Weyl spinors),

$$\Psi = \left(\begin{array}{c} \bar{\varphi} \\ \chi \end{array}\right) = \left(\begin{array}{c} \bar{\varphi}^{\dot{1}} \\ \bar{\varphi}^{\dot{2}} \\ \chi_1 \\ \chi_2 \end{array}\right), \tag{A.9}$$

one finds

$$
\begin{aligned}
\bar{\Psi} &= (\,\bar{\chi}, \varphi\,) = (\,\bar{\chi}_{\dot{1}}, \bar{\chi}_{\dot{2}}, \varphi^1, \varphi^2\,)\,, \\
\Psi^c &= C(\bar{\Psi})^T = C \begin{pmatrix} \bar{\chi}_{\dot{1}} \\ \bar{\chi}_{\dot{2}} \\ \varphi^1 \\ \varphi^2 \end{pmatrix} = C \begin{pmatrix} -\bar{\chi}^{\dot{2}} \\ \bar{\chi}^{\dot{1}} \\ \varphi_2 \\ -\varphi_1 \end{pmatrix} = \begin{pmatrix} \bar{\chi} \\ \varphi \end{pmatrix}, \\
\overline{\Psi^c} &= -\,\Psi^T C^{-1} = (\bar{\varphi}, \chi),
\end{aligned} \tag{A.10}
$$

where the following properties

$$
\bar{\chi}^{\dot{\alpha}} = (\chi^{\alpha})^* = \epsilon^{\dot{\alpha}\dot{\beta}}\bar{\chi}_{\dot{\beta}}, \qquad \varphi_{\alpha} = (\bar{\varphi}_{\dot{\alpha}})^* = \epsilon_{\alpha\beta}\varphi^{\beta}, \tag{A.11}
$$

with

$$
\epsilon^{\alpha\beta} = \epsilon^{\dot{\alpha}\dot{\beta}} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \qquad \epsilon_{\alpha\beta} = \epsilon_{\dot{\alpha}\dot{\beta}} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}, \qquad \epsilon_{\alpha\beta}\epsilon^{\beta\gamma} = \delta_{\alpha}^{\gamma}, \tag{A.12}
$$

are used.

The bilinear of the four-component spinors are written in terms of two-component Weyl spinors as,

$$
\begin{aligned}
\bar{\Psi}_2\Psi_1 &= \bar{\chi}_2\bar{\varphi}_1 + \varphi_2\chi_1, \\
\bar{\Psi}_2\gamma^{\mu}\Psi_1 &= \bar{\chi}_2\bar{\sigma}^{\mu}\chi_1 + \varphi_2\sigma^{\mu}\bar{\varphi}_1 = \bar{\chi}_2\bar{\sigma}^{\mu}\chi_1 - \bar{\varphi}_1\bar{\sigma}^{\mu}\varphi_2, \\
\bar{\Psi}_2\gamma_5\Psi_1 &= \bar{\chi}_2\bar{\varphi}_1 - \varphi_2\chi_1, \\
\bar{\Psi}_2 R\Psi_1 &= \bar{\chi}_2\bar{\varphi}_1, \\
\bar{\Psi}_2 L\Psi_1 &= \varphi_2\chi_1, \\
\bar{\Psi}_2\gamma_{\mu}R\Psi_1 &= \varphi_2\sigma^{\mu}\bar{\varphi}_1 = -\bar{\varphi}_1\bar{\sigma}^{\mu}\varphi_2, \\
\bar{\Psi}_2\gamma_{\mu}L\Psi_1 &= \bar{\chi}_2\bar{\sigma}^{\mu}\chi_1.
\end{aligned} \tag{A.13}
$$

In particular,

$$
\begin{aligned}
\bar{\Psi}\Psi &= \bar{\varphi}\bar{\chi} + \varphi\chi, && \text{(mass term)} \\
\bar{\Psi}\partial\!\!\!/\Psi &= \chi\sigma^{\mu}\partial_{\mu}\bar{\chi} + \varphi\sigma^{\mu}\partial_{\mu}\bar{\varphi}, && \text{(kinetic term)}
\end{aligned} \tag{A.14}
$$

The gauge mixing angle θ_W and gauge couplings are related as follows, which is the same as the SM,

$$
\begin{aligned}
c_W \equiv \cos\theta_W &= \frac{g}{\sqrt{g^2 + g'^2}}, \qquad s_W \equiv \sin\theta_W = \frac{g'}{\sqrt{g^2 + g'^2}}, \\
e &= g\ s_W = g' c_W = \frac{gg'}{\sqrt{g^2 + g'^2}}.
\end{aligned} \tag{A.15}
$$

I use the following convention for the covariant derivative

$$
\mathcal{D}_{\mu} = \partial_{\mu} + ig\frac{\tau^a}{2}W_{\mu}^a + ig'\frac{Y}{2}B_{\mu} + ig_s\frac{\lambda^{\alpha}}{2}g_{\mu}^{\alpha}, \tag{A.16}
$$

where λ^{α} stands for the $SU(3)$ Gell-Mann matrix. Note that the signs of the coupling constants or gauge fields are opposite to the Kyoto convention [9] adopted in the SM part of `GRACE`.

Appendix B. θ integrals, F-terms and D-terms

In this Appendix, I show the general result of the θ integrals of each superfield interaction given in (3.1). First we note that the left-handed chiral superfield is given as,

$$
\begin{aligned}
y &= x - i\theta\sigma\bar{\theta}, \\
z &= x + i\theta\sigma\bar{\theta}, \\
\Phi &= A(y) + \sqrt{2}\theta\varphi(y) + \theta\theta F(y) \\
&= A(x) + \sqrt{2}\theta\varphi(x) + \theta\theta F(x) - i\theta\sigma^\mu\bar{\theta}\partial_\mu A(x) \\
&\quad + \frac{i}{\sqrt{2}}\theta\theta\partial_\mu\varphi(x)\sigma^\mu\bar{\theta} - \frac{1}{4}\theta\theta\bar{\theta}\bar{\theta}\partial_\mu\partial^\mu A(x), \\
\Phi^\dagger &= A^*(z) + \sqrt{2}\bar{\theta}\bar{\varphi}(z) + \bar{\theta}\bar{\theta}F^*(z) \\
&= A^*(x) + \sqrt{2}\bar{\theta}\bar{\varphi}(x) + \bar{\theta}\bar{\theta}F^*(x) + i\theta\sigma^\mu\bar{\theta}\partial_\mu A^*(x) \\
&\quad - \frac{i}{\sqrt{2}}\bar{\theta}\bar{\theta}\theta\sigma^\mu\partial_\mu\bar{\varphi}(x) - \frac{1}{4}\theta\theta\bar{\theta}\bar{\theta}\partial_\mu\partial^\mu A^*(x),
\end{aligned}
\tag{B.1}
$$

and the gauge superfield is decomposed in the Wess-Zumino gauge as,

$$
V(x,\theta,\bar{\theta}) = \theta\sigma^\mu\bar{\theta}V_\mu + \theta\theta\bar{\theta}\bar{\lambda} + \bar{\theta}\bar{\theta}\theta\lambda + \frac{1}{2}\theta\theta\bar{\theta}\bar{\theta}D. \tag{B.2}
$$

Here $F(x)$ and $D(x)$ are spurious fields, called auxiliary fields, and they are eliminated upon using the Euler's equation of motion.

The kinetic part of the gauge superfields becomes

$$
\begin{aligned}
(3.1a) = &\frac{1}{2}D^aD^a + i\lambda^a\sigma^\mu\mathcal{D}_\mu\bar{\lambda}^a - \frac{1}{4}V^a_{\mu\nu}V^{a\mu\nu} \\
&+\frac{1}{2}D^2 + i\lambda\sigma^\mu\partial_\mu\bar{\lambda} - \frac{1}{4}V_{\mu\nu}V^{\mu\nu} \\
&+\frac{1}{2}D^\alpha D^\alpha + i\tilde{g}^\alpha\sigma^\mu\mathcal{D}_\mu\bar{\tilde{g}}^\alpha - \frac{1}{4}g^\alpha_{\mu\nu}g^{\alpha\mu\nu},
\end{aligned}
\tag{B.3}
$$

where

$$
\begin{aligned}
\mathcal{D}_\mu\lambda^a &= \partial_\mu\lambda^a - g\epsilon^{abc}V^b_\mu\lambda^c, \\
V^a_{\mu\nu} &= \partial_\mu V^a_\nu - \partial_\nu V^a_\mu - g\epsilon^{abc}V^b_\mu V^c_\nu, \\
\mathcal{D}_\mu\tilde{g}^\alpha &= \partial_\mu\tilde{g}^\alpha - g_s f^{\alpha\beta\gamma}g^\beta_\mu\tilde{g}^\gamma, \\
g^\alpha_{\mu\nu} &= \partial_\mu g^\alpha_\nu - \partial_\nu g^\alpha_\mu - g_s f^{\alpha\beta\gamma}g^\beta_\mu g^\gamma_\nu,
\end{aligned}
\tag{B.4}
$$

with $\epsilon^{123} = 1$.

For the doublets,

$$\begin{aligned}
\int d^2\theta d^2\bar\theta \mathbf{\Phi}^\dagger \exp[2(g\frac{\tau^a}{2}V^a + \frac{g'}{2}YV + g_s\frac{\lambda^\alpha}{2}V_s^\alpha)]\mathbf{\Phi}& \\
= |\mathbf{F}|^2 + |\partial_\mu \mathbf{A}|^2 + i\varphi\sigma^\mu\partial_\mu\bar\varphi& \\
+ \frac{g}{2}[-(\bar\varphi\bar\sigma^\mu\tau^a\varphi + i\mathbf{A}^*\tau^a\partial^\mu\mathbf{A})W_\mu^a - \sqrt{2}(\bar\varphi\tau^a\mathbf{A}\bar\lambda^a + \mathbf{A}^*\tau^a\varphi\lambda^a)& \\
+ \mathbf{A}^*\tau^a\mathbf{A}D^a]& \\
+ \frac{g'}{2}Y[-(\bar\varphi\bar\sigma^\mu\varphi + i\mathbf{A}^*\partial^\mu\mathbf{A})B_\mu - \sqrt{2}(\bar\varphi\mathbf{A}\bar\lambda + \mathbf{A}^*\varphi\lambda)& \\
+ \mathbf{A}^*\mathbf{A}D]& \qquad (B.5)\\
+ \frac{g_s}{2}[-(\bar\varphi\bar\sigma^\mu\lambda^\alpha\varphi + i\mathbf{A}^*\lambda^\alpha\partial^\mu\mathbf{A})g_\mu^\alpha - \sqrt{2}(\bar\varphi\lambda^\alpha\mathbf{A}\overline{\tilde g^\alpha} + \mathbf{A}^*\lambda^\alpha\varphi\tilde g^\alpha)& \\
+ \mathbf{A}^*\lambda^\alpha\mathbf{A}D^\alpha]& \\
+ \frac{1}{4}[(g^2W_\mu^aW^{a\mu} + Y^2g'^2B^\mu B_\mu)\mathbf{A}^*\mathbf{A} + 2Ygg'W_\mu^aB^\mu(\mathbf{A}^*\tau^a\mathbf{A})]& \\
+ \frac{1}{4}[g_s^2g_\mu^\alpha g^{\mu\beta}\mathbf{A}^*(\lambda^\alpha\lambda^\beta)\mathbf{A} + 2Yg_sg'g_\mu^\alpha B^\mu(\mathbf{A}^*\lambda^\alpha\mathbf{A})& \\
+ 2g_sgg_\mu^\alpha W^{a\mu}\mathbf{A}^*(\tau^a\lambda^\alpha)\mathbf{A}].&
\end{aligned}$$

$$\begin{aligned}
\int d^2\theta d^2\bar\theta\Phi^\dagger \exp[g'YV + \lambda^\alpha V_s^\alpha]\Phi& \\
= |F|^2 + |\partial_\mu A|^2 + i\varphi\sigma^\mu\partial_\mu\bar\varphi& \\
+ \frac{g'}{2}Y[-(\bar\varphi\bar\sigma^\mu\varphi + iA^*\partial^\mu A)B_\mu - \sqrt{2}(\bar\varphi A\bar\lambda + A^*\varphi\lambda) + A^*AD]& \\
+ \frac{g_s}{2}[-(\bar\varphi\bar\sigma^\mu\lambda^\alpha\varphi + iA^*\lambda^\alpha\partial^\mu A)g_\mu^\alpha - \sqrt{2}(\bar\varphi\lambda^\alpha A\overline{\tilde g^\alpha} + A^*\lambda^\alpha\varphi\tilde g^\alpha)& \qquad (B.6)\\
+ A^*\lambda^\alpha AD^\alpha]& \\
+ \frac{1}{4}[Y^2g'^2B^\mu B_\mu(A^*A)]& \\
+ \frac{1}{4}[g_s^2g_\mu^\alpha g^{\mu\beta}A^*(\lambda^\alpha\lambda^\beta)A + 2Yg_sg'g_\mu^\alpha B^\mu(A^*\lambda^\alpha A)].&
\end{aligned}$$

Note that in (B.5), (B.6) as well as in (B.14), (B.15) below, λ^α with a Greek index α is the $SU(3)$ Gell-Mann matrix, while λ and λ^a with a Roman index a are the component fields of the gauge superfields. In (B.5) and (B.6) color indices are not explicitly shown. For example, in (B.5)

$$\mathbf{A}^*(\tau^a\lambda^\alpha)\mathbf{A} \equiv \sum_{i,j=1,2}\sum_{\rho,\sigma=1,3} A_{i,\rho}^*(\tau^a)_{ij}(\lambda^\alpha)_{\rho\sigma}A_{j,\sigma}.$$

In deriving the above expression, we have used the following formula,

$$(\bar\theta\bar\varphi)(\theta\sigma^\mu\bar\theta)(\theta\chi) = -\frac{1}{4}\theta\theta\bar\theta\bar\theta(\bar\varphi\bar\sigma^\mu\chi). \qquad (B.7)$$

The product of two chiral superfields becomes

$$\int d^2\theta\mathbf{\Phi}_1(y)\mathbf{\Phi}_2(y) = \mathbf{F}_1(y)\mathbf{A}_2(y) + \mathbf{A}_1(y)\mathbf{F}_2(y) - \varphi_1(y)\varphi_2(y), \qquad (B.8)$$

while the product of three chiral superfields becomes

$$\int d^2\theta \mathbf{\Phi}_1(y)\mathbf{\Phi}_2(y)\phi_3(y) = \mathbf{F}_1(y)\mathbf{A}_2(y)A_3(y) + \mathbf{A}_1(y)\mathbf{F}_2(y)A_3(y) + \mathbf{A}_1(y)\mathbf{A}_2(y)F_3(y) \\ - \mathbf{A}_1(y)\varphi_2(y)\varphi_3(y) - \varphi_1(y)\mathbf{A}_2(y)\varphi_3(y) - \varphi_1(y)\varphi_2(y)A_3(y). \tag{B.9}$$

The auxiliary fields F_i have a simple structure. They appear in the lagrangian always in the combination

$$\mathcal{L} \sim |F_i|^2 + F_i f_i(...) + F_i^* f_i^*(...), \tag{B.10}$$

where f_i is a function of scalar fields and is obtained from the superpotential W by differentiation,

$$f_i(...) = \frac{\partial W}{\partial A_i}. \tag{B.11}$$

The superpotential, W, is obtained from the Higgs-matter Yukawa coupling part of the lagrangian (from (3,1i) to (3.1k)) and the Higgs self-interaction (3.1ℓ) by replacing the superfields,Φ_i, by the corresponding scalar fields, A_i. Explicit expression of F_i is given as follows,

$$\begin{aligned}
F(u_L)^* =& - m_u(1+\frac{\phi_2^0 + i\chi_2^0}{v_2})\tilde{u}_R^* - \frac{\sqrt{2}m_d}{v_1}\phi_1^- \tilde{d}_R^*, \\
F(d_L)^* =& \frac{\sqrt{2}m_u}{v_2}\phi_2^+ \tilde{u}_R^* - m_d(1+\frac{\phi_1^0 - i\chi_1^0}{v_1})\tilde{d}_R^*, \\
F(u_R)^* =& \frac{\sqrt{2}m_u}{v_2}\phi_2^+ \tilde{d}_L - m_u(1+\frac{\phi_2^0 + i\chi_2^0}{v_2})\tilde{u}_L, \\
F(d_R)^* =& - m_d(1+\frac{\phi_1^0 - i\chi_1^0}{v_1})\tilde{d}_L, -\frac{\sqrt{2}m_d}{v_1}\phi_1^- \tilde{u}_L, \\
F(\nu_L)^* =& - \frac{\sqrt{2}m_e}{v_1}\phi_1^- \tilde{e}_R^*, \\
F(e_L)^* =& - m_e(1+\frac{\phi_1^0 - i\chi_1^0}{v_1})\tilde{e}_R^*, \\
F(e_R)^* =& - m_e(1+\frac{\phi_1^0 - i\chi_1^0}{v_1})\tilde{e}_L - \frac{\sqrt{2}m_e}{v_1}\phi_1^- \tilde{\nu}_L,
\end{aligned} \tag{B.12a}$$

$$\begin{aligned}
F(H_1^0)^* =& - \frac{\sqrt{2}m_d}{v_1}\tilde{d}_R^*\tilde{d}_L - \frac{\sqrt{2}m_e}{v_1}\tilde{e}_R^*\tilde{e}_L + \mu\frac{v_2 + \phi_2^0 + i\chi_2^0}{\sqrt{2}}, \\
F(H_1^-)^* =& + \frac{\sqrt{2}m_d}{v_1}\tilde{d}_R^*\tilde{u}_L + \frac{\sqrt{2}m_e}{v_1}\tilde{e}_R^*\tilde{\nu}_L - \mu\phi_2^+, \\
F(H_2^+)^* =& \frac{\sqrt{2}m_u}{v_2}\tilde{u}_R^*\tilde{d}_L + \mu\phi_1^-, \\
F(H_2^0)^* =& - \frac{\sqrt{2}m_u}{v_2}\tilde{u}_R^*\tilde{u}_L + \mu\frac{v_1 + \phi_1^0 - i\chi_1^0}{\sqrt{2}}.
\end{aligned} \tag{B.12b}$$

Upon eliminating F_i, the part of the lagrangian that contains F_i is given by

$$(B.10) = -\sum_i |F_i|^2 = -\left|\frac{\partial W}{\partial A_i}\right|^2. \tag{B.13}$$

From the F-terms of the matter fields, the masses of the sfermion as well as $\tilde{f}\tilde{f}H$ and $\tilde{f}\tilde{f}HH$ interactions are created, while from the F-terms of the Higgs fields, one obtains, above all, charged Higgs mass, neutral Higgs mass as well as $\tilde{f}_L\tilde{f}_R$ mixing terms.

The auxiliary fields D contained in gauge superfields appear in the lagrangian as

$$\begin{aligned}
&\frac{1}{2}D^aD^a + \frac{1}{2}D^2 + \frac{1}{2}D^\alpha D^\alpha \\
&+\frac{g}{2}[\sum_{\text{doublet}} \mathbf{A}^*\tau^a\mathbf{A}]D^a + \frac{g'}{2}[\sum_{\text{doublet}} Y\mathbf{A}^*\mathbf{A} + \sum_{\text{singlet}} YA^*A]D \\
&+\frac{g_s}{2}[\sum_{\text{doublet}} \tilde{q}_L^*\lambda^\alpha\tilde{q}_L - \sum_{\text{singlet}} \tilde{q}_R^*\lambda^\alpha\tilde{q}_R]D^\alpha,
\end{aligned} \tag{B.14}$$

where Y is the hypercharge of the multiplet. From the equation of motion for D^a and D, one finds,

$$\begin{aligned}
D &= -\frac{g'}{2}[\sum_{\text{doublet}} Y\mathbf{A}^*\mathbf{A} + \sum_{\text{singlet}} YA^*A], \\
D^a &= -\frac{g}{2}[\sum_{\text{doublet}} \mathbf{A}^*\tau^a\mathbf{A}], \\
D^\alpha &= -\frac{g_s}{2}[\sum_{\text{doublet}} \tilde{q}_L^*\lambda^\alpha\tilde{q}_L - \sum_{\text{singlet}} \tilde{q}_R^*\lambda^\alpha\tilde{q}_R],
\end{aligned} \tag{B.15}$$

and (B.14) becomes simply

$$(B.14) = -\frac{1}{2}D^aD^a - \frac{1}{2}D^2 - \frac{1}{2}D^\alpha D^\alpha. \tag{B.16}$$

Using the property of generators of $SU(n)$,

$$\sum_{\alpha=1}^{n^2-1} \lambda^\alpha_{ab}\lambda^\alpha_{cd} = 2\delta_{ad}\delta_{bc} - \frac{2}{n}\delta_{ab}\delta_{cd}, \tag{B.17}$$

where $\lambda^\alpha = 2\times$(generator), namely $\lambda^\alpha = \tau^\alpha$ for $SU(2)$ and λ^α is the Gell-Mann matrix for $SU(3)$, one finds

$$\begin{aligned}
(B.14) = &-\frac{g^2}{8}\sum_a |\sum_{\text{doublet}} \mathbf{A}^*\tau^a\mathbf{A}|^2 \\
&-\frac{g'^2}{8}[\sum_{\text{doublet}} Y\mathbf{A}^*\mathbf{A} + \sum_{\text{singlet}} YA^*A]^2 \\
&-\frac{g_s^2}{8}\{\frac{4}{3}\sum_{q,i}|\tilde{q}_i^*\tilde{q}_i|^2 + 4\sum_{q<q',i}|\tilde{q}_i^*\tilde{q}_i'|^2 - \frac{4}{3}\sum_{q<q',i}(\tilde{q}_i^*\tilde{q}_i)(\tilde{q}_i'^*\tilde{q}_i')\} \\
&+\frac{g_s^2}{4}\{2\sum_q|\tilde{q}_L^*\tilde{q}_R|^2 + 4\sum_{q<q'}|\tilde{q}_L^*\tilde{q}_R'|^2 - \frac{2}{3}\sum_{q,q'}(\tilde{q}_L^*\tilde{q}_L)(\tilde{q}_R'^*\tilde{q}_R')\},
\end{aligned} \tag{B.18}$$

where in the third and fourth lines the sums are taken over $q, q' = u, d, \cdots$ and $i = R, L$. Extracting from the first two lines the terms which are quartic in Higgs fields $\mathbf{A} = \mathbf{H}_1$ and $\mathbf{A} = \mathbf{H}_2$, one obtains the SUSY part of the Higgs potential given in (4.8).

Appendix C. Explicit expression of the MSSM lagrangian in terms of mass eigenstates

The lagrangian derived in section 3 is not explicitly expressed on the basis of the mass eigenstates; they are still written in terms of two component Weyl spinors (in the case of charginos, neutralinos and gluinos) or in terms of unmixed states (in the case of sfermions). In this Appendix, the MSSM lagrangian is given explicitly in the mass eigenstates, so that we can easily read out the Feynman rule of MSSM from the lagrangian. For sfermions (except for (C.2)-(C.5)), in order to save the space I use the base $\tilde{f}_L$ and $\tilde{f}_R$ instead of $\tilde{f}_1$ and $\tilde{f}_2$.

Since the lagrangian consists of a huge number of terms, for the reference sake I first list in Table 2 the type of interactions and the corresponding equation numbers. Also listed in Table 2 are the equation numbers where the interactions are explained.

Gauge-boson-Fermion-Fermion

$$\begin{aligned}\mathcal{L} = &-\frac{g}{\sqrt{2}}\sum_{(f_\uparrow,f_\downarrow)}[\bar{f}_\uparrow\gamma^\mu\frac{1-\gamma_5}{2}f_\downarrow W^+_\mu + \bar{f}_\downarrow\gamma^\mu\frac{1-\gamma_5}{2}f_\uparrow W^-_\mu]\\ &- g_Z\sum_f \bar{f}\gamma^\mu[(T_{3f}-s_W^2Q_f)\frac{1-\gamma_5}{2} - s_W^2Q_f\frac{1+\gamma_5}{2}]fZ_\mu\\ &- e\sum_f Q_f\bar{f}\gamma^\mu f A_\mu\\ &- g_s\sum_q \bar{q}\gamma^\mu\frac{\lambda^\alpha}{2}q g^\alpha_\mu.\end{aligned} \tag{C.1}$$

W-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &-i\frac{g}{\sqrt{2}}\sum_{(f_\uparrow,f_\downarrow)}[c_{f_\uparrow}c_{f_\downarrow}(\tilde{f}^*_{\uparrow 1}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\downarrow 1}) - c_{f_\uparrow}s_{f_\downarrow}(\tilde{f}^*_{\uparrow 1}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\downarrow 2})\\ &- s_{f_\uparrow}c_{f_\downarrow}(\tilde{f}^*_{\uparrow 2}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\downarrow 1}) + s_{f_\uparrow}s_{f_\downarrow}(\tilde{f}^*_{\uparrow 2}\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_{\downarrow 2})]W^+_\mu + h.c.,\end{aligned} \tag{C.2}$$

where $f_\uparrow$ and $f_\downarrow$ stand for the up- and down-components of the fermion doublet, and $c_{f_\uparrow} \equiv \cos\theta_{f_\uparrow}$ and $s_{f_\uparrow} \equiv \sin\theta_{f_\uparrow}$ etc.

Z-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &-ig_Z\sum_f\{[T_{3f}c_f^2 - s_W^2Q_f](\tilde{f}^*_1\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_1)\\ &- T_{3f}c_fs_f[(\tilde{f}^*_1\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_2) + (\tilde{f}^*_2\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_1)]\\ &+ [T_{3f}s_f^2 - s_W^2Q_f](\tilde{f}^*_2\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_2)\}Z_\mu.\end{aligned} \tag{C.3}$$

γ-Sfermion-Sfermion

$$\mathcal{L} = -ie\sum_f Q_f[(\tilde{f}^*_1\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_1) + (\tilde{f}^*_2\overset{\leftrightarrow}{\partial}{}^\mu\tilde{f}_2)]A_\mu. \tag{C.4}$$

Gluon-Sfermion-Sfermion

	type	equation	explanation
Gauge coupl. (3-point)	Vff	(C.1)	(3.4)
	$V\tilde{f}\tilde{f}$	(C.2)-(C.5)	(3.6)
	$V\tilde{\chi}\tilde{\chi}$	(C.6)-(C.10)	(3.20)(3.25c)
	VHH	(C.11)	(3.19)
	VGH	(C.12)	(3.19)
	VGG	(C.13)	(3.19)
Higgs coupl. (3-point)	Hff	(C.14)(C.15)	(3.10a)
	HVV	(C.16)	(3.23b)
	$H\tilde{f}\tilde{f}$	(C.17)-(C.20)	(3.11b)(3.12c)(3.16)(3.24)
	$H\tilde{\chi}\tilde{\chi}$	(C.21)-(C.23)	(3.22b)
Goldstone (3-point)	Gff	(C.24)	(3.10a)
	GVV	(C.25)	(3.23b)
	$G\tilde{f}\tilde{f}$	(C.26)	(3.11b)(3.12c)(3.16)(3.24)
	$G\tilde{\chi}\tilde{\chi}$	(C.27)-(C.29)	(3.22b)
other 3-point	$\tilde{f}f\tilde{\chi}$	(C.30)-(C.32)	(3.7)(3.10b)
4-point coupling	$VV\tilde{f}\tilde{f}$	(C.33)-(C.37)	(3.9)
	$HHVV$	(C.38)	(3.23c)
	$HGVV$	(C.39)	(3.23c)
	$GGVV$	(C.40)	(3.23c)
	$\tilde{f}\tilde{f}HH$	(C.41)-(C.46)	(3.11c)(3.17)
	$\tilde{f}\tilde{f}GH$	(C.47)-(C.50)	(3.11c)(3.17)
	$\tilde{f}\tilde{f}GG$	(C.51)-(C.53)	(3.11c)(3.17)
	$\tilde{f}\tilde{f}\tilde{f}\tilde{f}$	(C.54)-(C.58)	(3.12d)(3.18)
Gauge selfinteraction	VVV	(C.59)	1st line of (3.25)
	$VVVV$	(C.60)	1st line of (3.25)
Higgs selfinteraction	HHH	(C.61)-(C.62)	(3.14a)
	$HHHH$	(C.63)-(C.65)	(3.14c)
Goldstone-Higgs interaction	HHG	(C.66)	(3.14a)
	HGG	(C.67)	(3.14a)
	$HHHG$	(C.68)	(3.14c)
	$HHGG$	(C.69)	(3.14c)
	$HGGG$	(C.70)	(3.14c)
	$GGGG$	(C.71)	(3.14c)
ghost	$\bar{\omega}\omega V$	(C.72)	(3.38)
	$\bar{\omega}\omega H$	(C.73)	(3.39)
	$\bar{\omega}\omega G$	(C.74)	(3.40)

Table 2. Type of interactions in MSSM.

$$\mathcal{L} = -ig_s \sum_q [(\tilde{q}_1^* \frac{\lambda^\alpha}{2} \overleftrightarrow{\partial}^\mu \tilde{q}_1) + (\tilde{q}_2^* \frac{\lambda^\alpha}{2} \overleftrightarrow{\partial}^\mu \tilde{q}_2)] g_\mu^\alpha. \tag{C.5}$$

W-Chargino-Neutralino

$$\mathcal{L} = +g \sum_{i,j} [\bar{\tilde{\chi}}_i^+ \gamma^\mu (\ell_{ij}^{+0} \frac{1-\gamma_5}{2} + r_{ij}^{+0} \frac{1+\gamma_5}{2}) \tilde{\chi}_j^0 W_\mu^+ + \bar{\tilde{\chi}}_i^0 \gamma^\mu (\ell_{ij}^{0+} \frac{1-\gamma_5}{2} + r_{ij}^{0+} \frac{1+\gamma_5}{2}) \tilde{\chi}_j^+ W_\mu^-], \tag{C.6}$$

where

$$\begin{aligned}
\ell_{i1}^{0+} &= \eta_i[(\mathcal{O}_N)_{i2}\cos\phi_L - \frac{1}{\sqrt{2}}(\mathcal{O}_N)_{i4}\sin\phi_L], \\
\ell_{i2}^{0+} &= \eta_i\epsilon_L[-(\mathcal{O}_N)_{i2}\sin\phi_L - \frac{1}{\sqrt{2}}(\mathcal{O}_N)_{i4}\cos\phi_L], \\
r_{i1}^{0+} &= \eta_i^*[(\mathcal{O}_N)_{i2}\cos\phi_R + \frac{1}{\sqrt{2}}(\mathcal{O}_N)_{i3}\sin\phi_R], \\
r_{i2}^{0+} &= \eta_i^*[-(\mathcal{O}_N)_{i2}\sin\phi_R + \frac{1}{\sqrt{2}}(\mathcal{O}_N)_{i3}\cos\phi_R],
\end{aligned} \tag{C.6a}$$

and $\ell_{ij}^{+0} = (\ell_{ji}^{0+})^*$, $r_{ij}^{+0} = (r_{ji}^{0+})^*$.

Z-Chargino-Chargino

$$\mathcal{L} = +g_Z \sum_{i,j} \bar{\tilde{\chi}}_i^+ \gamma^\mu (v_{ij}^+ + a_{ij}^+\gamma_5)\tilde{\chi}_j^+ Z_\mu, \tag{C.7}$$

where

$$\begin{aligned}
v_{11}^+ &= \frac{1}{4}(\sin^2\phi_R + \sin^2\phi_L) - c_W^2, \\
a_{11}^+ &= \frac{1}{4}(\sin^2\phi_R - \sin^2\phi_L), \\
v_{22}^+ &= \frac{1}{4}(\cos^2\phi_R + \cos^2\phi_L) - c_W^2, \\
a_{22}^+ &= \frac{1}{4}(\cos^2\phi_R - \cos^2\phi_L), \\
v_{12}^+ &= v_{21}^+ = \frac{1}{4}(\cos\phi_R\sin\phi_R + \epsilon_L\cos\phi_L\sin\phi_L), \\
a_{12}^+ &= a_{21}^+ = \frac{1}{4}(\cos\phi_R\sin\phi_R - \epsilon_L\cos\phi_L\sin\phi_L).
\end{aligned} \tag{C.7a}$$

γ-Chargino-Chargino

$$\mathcal{L} = -e(\bar{\tilde{\chi}}_1^+\gamma^\mu\tilde{\chi}_1^+ + \bar{\tilde{\chi}}_2^+\gamma^\mu\tilde{\chi}_2^+)A_\mu. \tag{C.8}$$

Z-Neutralino-Neutralino

$$\mathcal{L} = \frac{g_Z}{2}\sum_i a_{ii}^0 \overline{\tilde{\chi}_i^0}\gamma^\mu\gamma_5\tilde{\chi}_i^0 Z_\mu - g_Z\sum_{i<j}\overline{\tilde{\chi}_i^0}\gamma^\mu(v_{ij}^0 - a_{ij}^0\gamma_5)\tilde{\chi}_j^0 Z_\mu, \tag{C.9}$$

where

$$\begin{aligned}
v_{ij}^0 &= \frac{i}{2}\mathcal{I}m(\eta_i\eta_j^*)[(\mathcal{O}_N)_{i3}(\mathcal{O}_N)_{j3} - (\mathcal{O}_N)_{i4}(\mathcal{O}_N)_{j4}], \\
a_{ij}^0 &= \frac{1}{2}\mathcal{R}e(\eta_i\eta_j^*)[(\mathcal{O}_N)_{i3}(\mathcal{O}_N)_{j3} - (\mathcal{O}_N)_{i4}(\mathcal{O}_N)_{j4}].
\end{aligned} \tag{C.9a}$$

Gluon-Gluino-Gluino

$$\mathcal{L} = \frac{g_s}{2} i f^{\alpha\beta\gamma}\overline{\tilde{g}^\alpha}\gamma^\mu\tilde{g}^\beta g_\mu^\gamma. \tag{C.10}$$

Gauge-boson-Higgs-Higgs

$$\begin{aligned}\mathcal{L} =& + \frac{g}{2} i[\cos(\alpha-\beta)(h^0 \overleftrightarrow{\partial}^{\mu} H^-) + \sin(\alpha-\beta)(H^0 \overleftrightarrow{\partial}^{\mu} H^-)]W_\mu^+ + h.c. \\ & - \frac{g}{2}(A^0 \overleftrightarrow{\partial}^{\mu} H^-)W_\mu^+ + h.c. \\ & - \frac{g_Z}{2}[\cos(\alpha-\beta)(h^0 \overleftrightarrow{\partial}^{\mu} A^0) + \sin(\alpha-\beta)(H^0 \overleftrightarrow{\partial}^{\mu} A^0)]Z_\mu \\ & + ig_Z(\frac{1}{2} - s_W^2)(H^+ \overleftrightarrow{\partial}^{\mu} H^-)Z_\mu + ie(H^+ \overleftrightarrow{\partial}^{\mu} H^-)A_\mu.\end{aligned} \tag{C.11}$$

Gauge-boson-Higgs-Goldstone

$$\begin{aligned}\mathcal{L} =& - \frac{g}{2} i[\sin(\alpha-\beta)(h^0 \overleftrightarrow{\partial}^{\mu} G^-) - \cos(\alpha-\beta)(H^0 \overleftrightarrow{\partial}^{\mu} G^-)]W_\mu^+ + h.c. \\ & + \frac{g_Z}{2}[\sin(\alpha-\beta)(h^0 \overleftrightarrow{\partial}^{\mu} G^0) - \cos(\alpha-\beta)(H^0 \overleftrightarrow{\partial}^{\mu} G^0)]Z_\mu.\end{aligned} \tag{C.12}$$

Gauge-boson-Goldstone-Goldstone

$$\begin{aligned}\mathcal{L} =& - \frac{g}{2}[G^0 \overleftrightarrow{\partial}^{\mu} G^-)W_\mu^+ + (G^0 \overleftrightarrow{\partial}^{\mu} G^+)W_\mu^-] \\ & + ig_Z(\frac{1}{2} - s_W^2)(G^+ \overleftrightarrow{\partial}^{\mu} G^-)Z_\mu + ie(G^+ \overleftrightarrow{\partial}^{\mu} G^-)A_\mu.\end{aligned} \tag{C.13}$$

H^0(h^0, A^0)-Fermion-Fermion

$$\begin{aligned}\mathcal{L} =& + \frac{gm_e \sin\alpha}{2M_W \cos\beta}\bar{e}eh^0 - \frac{gm_e \cos\alpha}{2M_W\cos\beta}\bar{e}eH^0 + i\frac{gm_e}{2M_W}\tan\beta\bar{e}\gamma_5 eA^0 \\ & - \frac{gm_u\cos\alpha}{2M_W\sin\beta}\bar{u}uh^0 - \frac{gm_u\sin\alpha}{2M_W\sin\beta}\bar{u}uH^0 + i\frac{gm_u}{2M_W}\cot\beta\bar{u}\gamma_5 uA^0 \\ & + \frac{gm_d\sin\alpha}{2M_W\cos\beta}\bar{d}dh^0 - \frac{gm_d\cos\alpha}{2M_W\cos\beta}\bar{d}dH^0 + i\frac{gm_d}{2M_W}\tan\beta\bar{d}\gamma_5 dA^0.\end{aligned} \tag{C.14}$$

H$^\pm$-Fermion-Fermion

$$\mathcal{L} = \frac{g}{\sqrt{2}M_W}[m_e\tan\beta(\bar{\nu}\frac{1+\gamma_5}{2}e) + m_u\cot\beta(\bar{u}\frac{1-\gamma_5}{2}d) + m_d\tan\beta(\bar{u}\frac{1+\gamma_5}{2}d)]H^+ + h.c. \tag{C.15}$$

Higgs-Gauge-boson-Gauge-boson

$$\begin{aligned}\mathcal{L} =& + gM_W[\cos(\alpha-\beta)H^0 - \sin(\alpha-\beta)h^0]W_\mu^+W^{-\mu} \\ & + \frac{g_Z}{2}M_Z[\cos(\alpha-\beta)H^0 - \sin(\alpha-\beta)h^0]Z_\mu Z^\mu.\end{aligned} \tag{C.16}$$

In the following four equations (C.17), (C.18), (C.19) and (C.20), in order to avoid the complication of the equation I use $\tilde{f}_L$ and $\tilde{f}_R$ instead of the mass eigenstates $\tilde{f}_1$ and $\tilde{f}_2$. Using (2.6), one can easily find the proper interactions of the Higgs-sfermion-sfermion.

H^0-Sfermion-Sfermion

$$
\begin{aligned}
\mathcal{L} = &- \frac{g_Z}{2} M_Z \cos(\alpha+\beta) \tilde{\nu}^* \tilde{\nu} H^0 \\
&- (\frac{g m_e^2 \cos\alpha}{M_W \cos\beta} + g_Z M_Z \cos(\alpha+\beta)(-\frac{1}{2} + s_W^2)) \tilde{e}_L^* \tilde{e}_L H^0 \\
&- (\frac{g m_e^2 \cos\alpha}{M_W \cos\beta} - g_Z M_Z \cos(\alpha+\beta) s_W^2) \tilde{e}_R^* \tilde{e}_R H^0 \\
&+ \frac{g m_e}{2 M_W \cos\beta} (A_e \cos\alpha + \mu \sin\alpha)(\tilde{e}_L^* \tilde{e}_R H^0 + \tilde{e}_R^* \tilde{e}_L H^0) \\
\\
&- (\frac{g m_u^2 \sin\alpha}{M_W \sin\beta} + g_Z M_Z \cos(\alpha+\beta)(\frac{1}{2} - \frac{2}{3} s_W^2)) \tilde{u}_L^* \tilde{u}_L H^0 \\
&- (\frac{g m_u^2 \sin\alpha}{M_W \sin\beta} + \frac{2}{3} g_Z M_Z \cos(\alpha+\beta) s_W^2) \tilde{u}_R^* \tilde{u}_R H^0 \\
&+ \frac{g m_u}{2 M_W \sin\beta} (A_u \sin\alpha + \mu \cos\alpha)(\tilde{u}_L^* \tilde{u}_R H^0 + \tilde{u}_R^* \tilde{u}_L H^0) \\
\\
&- (\frac{g m_d^2 \cos\alpha}{M_W \cos\beta} + g_Z M_Z \cos(\alpha+\beta)(-\frac{1}{2} + \frac{1}{3} s_W^2)) \tilde{d}_L^* \tilde{d}_L H^0 \\
&- (\frac{g m_d^2 \cos\alpha}{M_W \cos\beta} - \frac{1}{3} g_Z M_Z \cos(\alpha+\beta) s_W^2) \tilde{d}_R^* \tilde{d}_R H^0 \\
&+ \frac{g m_d}{2 M_W \cos\beta} (A_d \cos\alpha + \mu \sin\alpha)(\tilde{d}_L^* \tilde{d}_R H^0 + \tilde{d}_R^* \tilde{d}_L H^0).
\end{aligned} \tag{C.17}
$$

$\mathbf{h}^0$-Sfermion-Sfermion

$$
\begin{aligned}
\mathcal{L} = &+ \frac{g_Z}{2} M_Z \sin(\alpha+\beta) \tilde{\nu}^* \tilde{\nu} h^0 \\
&+ (\frac{g m_e^2 \sin\alpha}{M_W \cos\beta} + g_Z M_Z \sin(\alpha+\beta)(-\frac{1}{2} + s_W^2)) \tilde{e}_L^* \tilde{e}_L h^0 \\
&+ (\frac{g m_e^2 \sin\alpha}{M_W \cos\beta} - g_Z M_Z \sin(\alpha+\beta) s_W^2) \tilde{e}_R^* \tilde{e}_R h^0 \\
&- \frac{g m_e}{2 M_W \cos\beta} (A_e \sin\alpha - \mu \cos\alpha)(\tilde{e}_L^* \tilde{e}_R h^0 + \tilde{e}_R^* \tilde{e}_L h^0) \\
\\
&- (\frac{g m_u^2 \cos\alpha}{M_W \sin\beta} - g_Z M_Z \sin(\alpha+\beta)(\frac{1}{2} - \frac{2}{3} s_W^2)) \tilde{u}_L^* \tilde{u}_L h^0 \\
&- (\frac{g m_u^2 \cos\alpha}{M_W \sin\beta} - \frac{2}{3} g_Z M_Z \sin(\alpha+\beta) s_W^2) \tilde{u}_R^* \tilde{u}_R h^0 \\
&+ \frac{g m_u}{2 M_W \sin\beta} (A_u \cos\alpha - \mu \sin\alpha)(\tilde{u}_L^* \tilde{u}_R h^0 + \tilde{u}_R^* \tilde{u}_L h^0) \\
\\
&+ (\frac{g m_d^2 \sin\alpha}{M_W \cos\beta} + g_Z M_Z \sin(\alpha+\beta)(-\frac{1}{2} + \frac{1}{3} s_W^2)) \tilde{d}_L^* \tilde{d}_L h^0 \\
&+ (\frac{g m_d^2 \sin\alpha}{M_W \cos\beta} - \frac{1}{3} g_Z M_Z \sin(\alpha+\beta) s_W^2) \tilde{d}_R^* \tilde{d}_R h^0 \\
&- \frac{g m_d}{2 M_W \cos\beta} (A_d \sin\alpha - \mu \cos\alpha)(\tilde{d}_L^* \tilde{d}_R h^0 + \tilde{d}_R^* \tilde{d}_L h^0).
\end{aligned} \tag{C.18}
$$

Note that (C.18) is obtained from (C.17) by the change

$$\sin\alpha \to \cos\alpha, \qquad \cos\alpha \to -\sin\alpha, \quad \sin(\alpha+\beta) \to \cos(\alpha+\beta), \quad \cos(\alpha+\beta) \to -\sin(\alpha+\beta). \quad (C.18a)$$

A^0-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &- i\frac{gm_e}{2M_W}(A_e\tan\beta-\mu)(\tilde{e}_L^*\tilde{e}_R A^0 - \tilde{e}_R^*\tilde{e}_L A^0)\\ &- i\frac{gm_u}{2M_W}(A_u\cot\beta-\mu)(\tilde{u}_L^*\tilde{u}_R A^0 - \tilde{u}_R^*\tilde{u}_L A^0)\\ &- i\frac{gm_d}{2M_W}(A_d\tan\beta-\mu)(\tilde{d}_L^*\tilde{d}_R A^0 - \tilde{d}_R^*\tilde{d}_L A^0).\end{aligned} \qquad (C.19)$$

H$^\pm$-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &- \frac{g}{\sqrt{2}M_W}[(M_W^2\sin 2\beta - m_e^2\tan\beta)\tilde{\nu}^*\tilde{e}_L + m_e(A_e\tan\beta-\mu)\tilde{\nu}^*\tilde{e}_R]H^+\\ &- \frac{g}{\sqrt{2}M_W}[M_W^2\sin 2\beta - m_d^2\tan\beta - m_u^2\cot\beta](\tilde{u}_L^*\tilde{d}_L H^+)\\ &+ \frac{\sqrt{2}gm_u m_d}{M_W\sin 2\beta}(\tilde{u}_R^*\tilde{d}_R H^+)\\ &- \frac{g}{\sqrt{2}M_W}[m_u(A_u\cot\beta-\mu)\tilde{u}_R^*\tilde{d}_L + m_d(A_d\tan\beta-\mu)\tilde{u}_L^*\tilde{d}_R]H^+\\ &+ h.c.\end{aligned} \qquad (C.20)$$

Higgs-Chargino-Chargino

$$\begin{aligned}\mathcal{L} = &-\frac{g}{\sqrt{2}}\{s_{11}^{CCh}\bar{\tilde{\chi}}_1^+\tilde{\chi}_1^+ h^0 + s_{22}^{CCh}\bar{\tilde{\chi}}_2^+\tilde{\chi}_2^+ h^0\\ &\quad+\bar{\tilde{\chi}}_1^+(\ell_{12}^{CCh}\ \frac{1-\gamma_5}{2} + r_{12}^{CCh}\ \frac{1+\gamma_5}{2})\tilde{\chi}_2^+ h^0 + \bar{\tilde{\chi}}_2^+(\ell_{21}^{CCh}\ \frac{1-\gamma_5}{2} + r_{21}^{CCh}\ \frac{1+\gamma_5}{2})\tilde{\chi}_1^+ h^0\\ &\quad+s_{11}^{CCH}\bar{\tilde{\chi}}_1^+\tilde{\chi}_1^+ H^0 + s_{22}^{CCH}\bar{\tilde{\chi}}_2^+\tilde{\chi}_2^+ H^0\\ &\quad+\bar{\tilde{\chi}}_1^+(\ell_{12}^{CCH}\ \frac{1-\gamma_5}{2} + r_{12}^{CCH}\ \frac{1+\gamma_5}{2})\tilde{\chi}_2^+ H^0 + \bar{\tilde{\chi}}_2^+(\ell_{21}^{CCH}\ \frac{1-\gamma_5}{2} + r_{21}^{CCH}\ \frac{1+\gamma_5}{2})\tilde{\chi}_1^+ H^0\}\\ &-\frac{ig}{\sqrt{2}}\{p_{11}^{CCA}\bar{\tilde{\chi}}_1^+\gamma_5\tilde{\chi}_1^+ A^0 + p_{22}^{CCA}\bar{\tilde{\chi}}_2^+\gamma_5\tilde{\chi}_2^+ A^0\\ &\quad+\bar{\tilde{\chi}}_1^+(\ell_{12}^{CCA}\ \frac{1-\gamma_5}{2} + r_{12}^{CCA}\ \frac{1+\gamma_5}{2})\tilde{\chi}_2^+ A^0 + \bar{\tilde{\chi}}_2^+(\ell_{21}^{CCA}\ \frac{1-\gamma_5}{2} + r_{21}^{CCA}\ \frac{1+\gamma_5}{2})\tilde{\chi}_1^+ A^0\},\end{aligned} \qquad (C.21)$$

where

$$
\begin{aligned}
s_{11}^{CCh} &= -\sin\alpha\cos\phi_L\sin\phi_R + \cos\alpha\sin\phi_L\cos\phi_R, \\
s_{22}^{CCh} &= \epsilon_L(\sin\alpha\sin\phi_L\cos\phi_R - \cos\alpha\cos\phi_L\sin\phi_R), \\
\ell_{12}^{CCh} &= \epsilon_L(\sin\alpha\sin\phi_L\sin\phi_R + \cos\alpha\cos\phi_L\cos\phi_R), \\
r_{12}^{CCh} &= -\sin\alpha\cos\phi_L\cos\phi_R - \cos\alpha\sin\phi_L\sin\phi_R, \\
\ell_{21}^{CCh} &= r_{12}^{CCh}, \\
r_{21}^{CCh} &= \ell_{12}^{CCh}, \\
s_{11}^{CCH} &= \cos\alpha\cos\phi_L\sin\phi_R + \sin\alpha\sin\phi_L\cos\phi_R, \\
s_{22}^{CCH} &= \epsilon_L(-\cos\alpha\sin\phi_L\cos\phi_R - \sin\alpha\cos\phi_L\sin\phi_R), \\
\ell_{12}^{CCH} &= \epsilon_L(-\cos\alpha\sin\phi_L\sin\phi_R + \sin\alpha\cos\phi_L\cos\phi_R), \\
r_{12}^{CCH} &= \cos\alpha\cos\phi_L\cos\phi_R - \sin\alpha\sin\phi_L\sin\phi_R, \\
\ell_{21}^{CCH} &= r_{12}^{CCH}, \\
r_{21}^{CCH} &= \ell_{12}^{CCH}, \\
p_{11}^{CCA} &= \sin\beta\cos\phi_L\sin\phi_R + \cos\beta\sin\phi_L\cos\phi_R, \\
p_{22}^{CCA} &= \epsilon_L(-\sin\beta\sin\phi_L\cos\phi_R - \cos\beta\cos\phi_L\sin\phi_R), \\
\ell_{12}^{CCA} &= \epsilon_L(\sin\beta\sin\phi_L\sin\phi_R - \cos\beta\cos\phi_L\cos\phi_R), \\
r_{12}^{CCA} &= \sin\beta\cos\phi_L\cos\phi_R - \cos\beta\sin\phi_L\sin\phi_R, \\
\ell_{21}^{CCA} &= -\, r_{12}^{CCA}, \\
r_{21}^{CCA} &= -\, \ell_{12}^{CCA}.
\end{aligned}
\tag{C.21a}
$$

Higgs-Chargino-Neutralino

$$
\begin{aligned}
\mathcal{L} = &-g\sum_{i,j}\bar{\tilde{\chi}}_i^0(\ell_{ij}^{CNH}\ \frac{1-\gamma_5}{2} + r_{ij}^{CNH}\ \frac{1+\gamma_5}{2})\tilde{\chi}_j^+ H^- \\
&- g\sum_{i,j}\bar{\tilde{\chi}}_i^+((r_{ji}^{CNH})^*\frac{1-\gamma_5}{2} + (\ell_{ji}^{CNH})^*\frac{1+\gamma_5}{2})\tilde{\chi}_j^0 H^+,
\end{aligned}
\tag{C.22}
$$

where

$$
\begin{aligned}
\ell_{i1}^{CNH} &= \cos\beta[\cos\phi_L(\mathcal{O}_N)_{i4} + \frac{1}{\sqrt{2}}\sin\phi_L((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i^*, \\
r_{i1}^{CNH} &= \sin\beta[\cos\phi_R(\mathcal{O}_N)_{i3} - \frac{1}{\sqrt{2}}\sin\phi_R((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i, \\
\ell_{i2}^{CNH} &= \cos\beta\epsilon_L[-\sin\phi_L(\mathcal{O}_N)_{i4} + \frac{1}{\sqrt{2}}\cos\phi_L((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i^*, \\
r_{i2}^{CNH} &= \sin\beta[-\sin\phi_R(\mathcal{O}_N)_{i3} - \frac{1}{\sqrt{2}}\cos\phi_R((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i.
\end{aligned}
\tag{C.22a}
$$

Higgs-Neutralino-Neutralino

$$
\begin{aligned}
\mathcal{L} =& -\frac{g}{4}\sum_i s_{ii}^{NNH}\overline{\tilde{\chi}_i^0}\tilde{\chi}_i^0 H^0 - \frac{g}{2}\sum_{i<j}\overline{\tilde{\chi}_i^0}(s_{ij}^{NNH} + ip_{ij}^{NNH}\gamma_5)\tilde{\chi}_j^0 H^0 \\
& -\frac{g}{4}\sum_i s_{ii}^{NNh}\overline{\tilde{\chi}_i^0}\tilde{\chi}_i^0 h^0 - \frac{g}{2}\sum_{i<j}\overline{\tilde{\chi}_i^0}(s_{ij}^{NNh} + ip_{ij}^{NNh}\gamma_5)\tilde{\chi}_j^0 h^0 \\
& -i\frac{g}{4}\sum_i p_{ii}^{NNA}\overline{\tilde{\chi}_i^0}\gamma_5\tilde{\chi}_i^0 A^0 - \frac{g}{2}\sum_{i<j}\overline{\tilde{\chi}_i^0}(-s_{ij}^{NNA} + ip_{ij}^{NNA}\gamma_5)\tilde{\chi}_j^0 A^0,
\end{aligned}
\tag{C.23}
$$

where

$$
\begin{aligned}
s_{ij}^{NNH} =& \mathcal{R}e(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][\cos\alpha(\mathcal{O}_N)_{j3} - \sin\alpha(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}, \\
p_{ij}^{NNH} =& \mathcal{I}m(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][\cos\alpha(\mathcal{O}_N)_{j3} - \sin\alpha(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}, \\
s_{ij}^{NNh} =& \mathcal{R}e(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][-\sin\alpha(\mathcal{O}_N)_{j3} - \cos\alpha(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}, \\
p_{ij}^{NNh} =& \mathcal{I}m(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][-\sin\alpha(\mathcal{O}_N)_{j3} - \cos\alpha(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}, \\
s_{ij}^{NNA} =& \mathcal{I}m(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][\sin\beta(\mathcal{O}_N)_{j3} - \cos\beta(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}, \\
p_{ij}^{NNA} =& \mathcal{R}e(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - (\mathcal{O}_N)_{i1}\tan\theta_W][\sin\beta(\mathcal{O}_N)_{j3} - \cos\beta(\mathcal{O}_N)_{j4}] \\
& + (i\leftrightarrow j)\}.
\end{aligned}
\tag{C.23a}
$$

Note the minus sign in front of s_{ij}^{NNA}. As in (C.16) and (C.17), s_{ij}^{NNh} and p_{ij}^{NNh} are obtained from s_{ij}^{NNH} and p_{ij}^{NNH} by

$$
\sin\alpha \to \cos\alpha, \qquad \cos\alpha \to -\sin\alpha, \tag{C.23b}
$$

while s_{ij}^{NNA} and p_{ij}^{NNA} are obtained from p_{ij}^{NNH} and s_{ij}^{NNH} by

$$
\cos\alpha \to \sin\beta, \qquad \sin\alpha \to \cos\beta. \tag{C.23c}
$$

Goldstone-Fermion-Fermion

$$
\begin{aligned}
\mathcal{L} =& -i\frac{g}{2M_W}[m_e\bar{e}\gamma_5 eG^0 - m_u\bar{u}\gamma_5 uG^0 + m_d\bar{d}\gamma_5 dG^0] \\
& -\frac{g}{\sqrt{2}M_W}[m_e\bar{\nu}\frac{1+\gamma_5}{2}eG^+ - m_u\bar{u}\frac{1-\gamma_5}{2}dG^+ + m_d\bar{u}\frac{1+\gamma_5}{2}dG^+] + h.c.
\end{aligned}
\tag{C.24}
$$

Goldstone-Gauge-boson-Gauge-boson

$$
\mathcal{L} = -g_Z M_W s_W^2(G^- W_\mu^+ Z^\mu) + eM_W(G^- W_\mu^+ A^\mu) + h.c. \tag{C.25}
$$

Goldstone-Sfermion-Sfermion

$$
\begin{aligned}
\mathcal{L} =&+ \frac{g}{\sqrt{2}M_W}[(M_W^2\cos 2\beta - m_e^2)\tilde{\nu}^*\tilde{e}_L G^+ + (M_W^2\cos 2\beta + m_u^2 - m_d^2)\tilde{u}_L^*\tilde{d}_L G^+] \\
&+ \frac{g}{\sqrt{2}M_W}[m_e(A_e + \mu\tan\beta)\tilde{\nu}^*\tilde{e}_R G^+ - m_u(A_u + \mu\cot\beta)\tilde{u}_R^*\tilde{d}_L G^+ \\
&\qquad + m_d(A_d + \mu\tan\beta)\tilde{u}_L^*\tilde{d}_R G^+] \\
&+ i\frac{g}{2M_W}[m_e(A_e + \mu\tan\beta)\tilde{e}_L^*\tilde{e}_R G^0 - m_u(A_u + \mu\cot\beta)\tilde{u}_L^*\tilde{u}_R G^0 \\
&\qquad + m_d(A_d + \mu\tan\beta)\tilde{d}_L^*\tilde{d}_R G^0] \\
&+ h.c.
\end{aligned}
\tag{C.26}
$$

G^0-Chargino-Chargino

$$
\begin{aligned}
\mathcal{L} = \frac{ig}{\sqrt{2}}\{&p_{11}^{CCG}\bar{\tilde{\chi}}_1^+\gamma_5\tilde{\chi}_1^+ G^0 + p_{22}^{CCG}\bar{\tilde{\chi}}_2^+\gamma_5\tilde{\chi}_2^+ G^0 \\
&+\bar{\tilde{\chi}}_1^+(\ell_{12}^{CCG}\frac{1-\gamma_5}{2} + r_{12}^{CCG}\frac{1+\gamma_5}{2})\tilde{\chi}_2^+ G^0 + \bar{\tilde{\chi}}_2^+(\ell_{21}^{CCG}\frac{1-\gamma_5}{2} + r_{21}^{CCG}\frac{1+\gamma_5}{2})\tilde{\chi}_1^+ G^0\},
\end{aligned}
\tag{C.27}
$$

where

$$
\begin{aligned}
p_{11}^{CCG} &= \cos\beta\cos\phi_L\sin\phi_R - \sin\beta\sin\phi_L\cos\phi_R, \\
p_{22}^{CCG} &= \epsilon_L(-\cos\beta\sin\phi_L\cos\phi_R + \sin\beta\cos\phi_L\sin\phi_R), \\
\ell_{12}^{CCG} &= \epsilon_L(\cos\beta\sin\phi_L\sin\phi_R + \sin\beta\cos\phi_L\cos\phi_R), \\
r_{12}^{CCG} &= \cos\beta\cos\phi_L\cos\phi_R + \sin\beta\sin\phi_L\sin\phi_R, \\
\ell_{21}^{CCG} &= -\, r_{12}^{CCG}, \\
r_{21}^{CCG} &= -\, \ell_{12}^{CCG}.
\end{aligned}
\tag{C.27a}
$$

G^0-Neutralino-Neutralino

$$
\mathcal{L} = i\frac{g}{4}\sum_i p_{ii}^{NNG}\overline{\tilde{\chi}_i^0}\gamma_5\tilde{\chi}_i^0 G^0 + \frac{g}{2}\sum_{i<j}\overline{\tilde{\chi}_i^0}(-s_{ij}^{NNG} + ip_{ij}^{NNG}\gamma_5)\tilde{\chi}_j^0 G^0,
\tag{C.28}
$$

where

$$
\begin{aligned}
s_{ij}^{NNG} &= \mathcal{I}m(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}][\cos\beta(\mathcal{O}_N)_{j3} + \sin\beta(\mathcal{O}_N)_{j4}] \\
&\qquad + (i \leftrightarrow j)\}, \\
p_{ij}^{NNG} &= \mathcal{R}e(\eta_i\eta_j)\{[(\mathcal{O}_N)_{i2} - \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}][\cos\beta(\mathcal{O}_N)_{j3} + \sin\beta(\mathcal{O}_N)_{j4}] \\
&\qquad + (i \leftrightarrow j)\}.
\end{aligned}
\tag{C.28a}
$$

G$^\pm$-Chargino-Neutralino

$$
\begin{aligned}
\mathcal{L} = &+g\sum_{i,j}\bar{\tilde{\chi}}_i^0(\ell_{ij}^{CNG}\ \frac{1-\gamma_5}{2} + r_{ij}^{CNG}\ \frac{1+\gamma_5}{2})\tilde{\chi}_j^+ G^- \\
&+g\sum_{i,j}\bar{\tilde{\chi}}_i^+((r_{ji}^{CNG})^*\frac{1-\gamma_5}{2} + (\ell_{ji}^{CNG})^*\frac{1+\gamma_5}{2})\tilde{\chi}_j^0 G^+,
\end{aligned}
\tag{C.29}
$$

where

$$
\begin{aligned}
\ell_{i1}^{CNG} &= \sin\beta[-\cos\phi_L(\mathcal{O}_N)_{i4} - \frac{1}{\sqrt{2}}\sin\phi_L((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i^*, \\
r_{i1}^{CNG} &= \cos\beta[\cos\phi_R(\mathcal{O}_N)_{i3} - \frac{1}{\sqrt{2}}\sin\phi_R((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i, \\
\ell_{i2}^{CNG} &= \sin\beta\epsilon_L[\sin\phi_L(\mathcal{O}_N)_{i4} - \frac{1}{\sqrt{2}}\cos\phi_L((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i^*. \\
r_{i2}^{CNG} &= \cos\beta[-\sin\phi_R(\mathcal{O}_N)_{i3} - \frac{1}{\sqrt{2}}\cos\phi_R((\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1})]\eta_i.
\end{aligned}
\tag{C.29a}
$$

Chargino-Fermion-Sfermion

$$
\begin{aligned}
\mathcal{L} = &+\overline{\tilde{\chi}_1^-}(-g\cos\phi_L\frac{1-\gamma_5}{2} + g\frac{m_e\sin\phi_R}{\sqrt{2}M_W\cos\beta}\frac{1+\gamma_5}{2})e\tilde{\nu}^* \\
&+\overline{\tilde{\chi}_2^-}(g\epsilon_L\sin\phi_L\frac{1-\gamma_5}{2} + g\frac{m_e\cos\phi_R}{\sqrt{2}M_W\cos\beta}\frac{1+\gamma_5}{2})e\tilde{\nu}^* \\
&-g\cos\phi_R\overline{\tilde{\chi}_1^+}\frac{1-\gamma_5}{2}\nu\tilde{e}_L^* + g\sin\phi_R\overline{\tilde{\chi}_2^+}\frac{1-\gamma_5}{2}\nu\tilde{e}_L^* \\
&+\frac{gm_e\sin\phi_R}{\sqrt{2}M_W\cos\beta}\overline{\tilde{\chi}_1^+}\frac{1-\gamma_5}{2}\nu\tilde{e}_R^* + \frac{gm_e\cos\phi_R}{\sqrt{2}M_W\cos\beta}\overline{\tilde{\chi}_2^+}\frac{1-\gamma_5}{2}\nu\tilde{e}_R^* \\
\\
&+\overline{\tilde{\chi}_1^+}(-g\cos\phi_R\frac{1-\gamma_5}{2} + g\frac{m_u\sin\phi_L}{\sqrt{2}M_W\sin\beta}\frac{1+\gamma_5}{2})u\tilde{d}_L^* \\
&+\overline{\tilde{\chi}_2^+}(g\sin\phi_R\frac{1-\gamma_5}{2} + g\frac{m_u\epsilon_L\cos\phi_L}{\sqrt{2}M_W\sin\beta}\frac{1+\gamma_5}{2})u\tilde{d}_L^* \\
&+\frac{gm_d\sin\phi_R}{\sqrt{2}M_W\cos\beta}\overline{\tilde{\chi}_1^+}\frac{1-\gamma_5}{2}u\tilde{d}_R^* + g\frac{m_d\cos\phi_R}{\sqrt{2}M_W\cos\beta}\overline{\tilde{\chi}_2^+}\frac{1-\gamma_5}{2}u\tilde{d}_R^* \\
&+\overline{\tilde{\chi}_1^-}(-g\cos\phi_L\frac{1-\gamma_5}{2} + g\frac{m_d\sin\phi_R}{\sqrt{2}M_W\cos\beta}\frac{1+\gamma_5}{2})d\tilde{u}_L^* \\
&+\overline{\tilde{\chi}_2^-}(g\epsilon_L\sin\phi_L\frac{1-\gamma_5}{2} + g\frac{m_d\cos\phi_R}{\sqrt{2}M_W\cos\beta}\frac{1+\gamma_5}{2})d\tilde{u}_L^* \\
&+\frac{gm_u\sin\phi_L}{\sqrt{2}M_W\sin\beta}\overline{\tilde{\chi}_1^-}\frac{1-\gamma_5}{2}d\tilde{u}_R^* + g\frac{m_u\epsilon_L\cos\phi_L}{\sqrt{2}M_W\sin\beta}\overline{\tilde{\chi}_2^-}\frac{1-\gamma_5}{2}d\tilde{u}_R^* \\
&+h.c.
\end{aligned}
\tag{C.30}
$$

Neutralino-Fermion-Sfermion

$$
\begin{aligned}
\mathcal{L} = &-\frac{g}{\sqrt{2}}\sum_i\{\overline{\tilde{\chi}_i^0}(\ell_i^{NfL}\frac{1-\gamma_5}{2} + r_i^{NfL}\frac{1+\gamma_5}{2})f\tilde{f}_L^* + \overline{\tilde{\chi}_i^0}(\ell_i^{NfR}\frac{1-\gamma_5}{2} + r_i^{NfR}\frac{1+\gamma_5}{2})f\tilde{f}_R^*\} \\
&+h.c.,
\end{aligned}
\tag{C.31}
$$

where

$$
\begin{aligned}
\ell_i^{N\nu L} &= \ \eta_i^*[(\mathcal{O}_N)_{i2} - \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}], \\
\ell_i^{NeL} &= -\ \eta_i^*[(\mathcal{O}_N)_{i2} + \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}], \\
\ell_i^{NuL} &= \ \eta_i^*[(\mathcal{O}_N)_{i2} + \frac{s_W}{3c_W}(\mathcal{O}_N)_{i1}], \\
\ell_i^{NdL} &= -\ \eta_i^*[(\mathcal{O}_N)_{i2} - \frac{s_W}{3c_W}(\mathcal{O}_N)_{i1}], \\
r_i^{N\nu L} &= 0, \\
r_i^{NeL} &= \eta_i \frac{m_e}{M_W \cos\beta}(\mathcal{O}_N)_{i3}, \\
r_i^{NuL} &= \eta_i \frac{m_u}{M_W \sin\beta}(\mathcal{O}_N)_{i4}, \\
r_i^{NdL} &= \eta_i \frac{m_d}{M_W \cos\beta}(\mathcal{O}_N)_{i3}, \\
\ell_i^{N\nu R} &= 0, \\
\ell_i^{NeR} &= \eta_i^* \frac{m_e}{M_W \cos\beta}(\mathcal{O}_N)_{i3}, \\
\ell_i^{NuR} &= \eta_i^* \frac{m_u}{M_W \sin\beta}(\mathcal{O}_N)_{i4}, \\
\ell_i^{NdR} &= \eta_i^* \frac{m_d}{M_W \cos\beta}(\mathcal{O}_N)_{i3}, \\
r_i^{N\nu R} &= 0, \\
r_i^{NeR} &= 2\eta_i \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}, \\
r_i^{NuR} &= -\ \frac{4}{3}\eta_i \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}, \\
r_i^{NdR} &= \frac{2}{3}\eta_i \frac{s_W}{c_W}(\mathcal{O}_N)_{i1}.
\end{aligned}
\tag{C.31a}
$$

Gluino-Quark-Squark

$$
\mathcal{L} = -\sqrt{2} g_s \sum_q [\bar{q}\frac{1+\gamma_5}{2}\tilde{g}^\alpha \frac{\lambda^\alpha}{2}\tilde{q}_L - \bar{q}\frac{1-\gamma_5}{2}\tilde{g}^\alpha \frac{\lambda^\alpha}{2}\tilde{q}_R] + h.c. \tag{C.32}
$$

W-W-Sfermion-Sfermion

$$
\mathcal{L} = \frac{g^2}{2}(\tilde{u}_L^* \tilde{u}_L + \tilde{d}_L^* \tilde{d}_L + \tilde{\nu}^* \tilde{\nu} + \tilde{e}_L^* \tilde{e}_L) W_\mu^+ W^{-\mu}. \tag{C.33}
$$

W-Z(γ)-Sfermion-Sfermion

$$
\begin{aligned}
\mathcal{L} = &- \frac{g g_Z}{\sqrt{2}} \sin^2\theta_W \sum_f Y_{f_L}(\tilde{f}_{\uparrow L}^* \tilde{f}_{\downarrow L} W_\mu^+ + \tilde{f}_{\downarrow L}^* \tilde{f}_{\uparrow L} W_\mu^-) Z^\mu, \\
&+ \frac{ge}{\sqrt{2}} \sum_f Y_{f_L}(\tilde{f}_{\uparrow L}^* \tilde{f}_{\downarrow L} W_\mu^+ + \tilde{f}_{\downarrow L}^* \tilde{f}_{\uparrow L} W_\mu^-) A^\mu.
\end{aligned}
\tag{C.34}
$$

The hypercharge Y_{f_L} of the left-handed fermion doublets is defined as $Q_f = T_{3f} + \frac{Y_{f_L}}{2}$ and its value is given in Table 1.

(Z,γ)-(Z,γ)-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &+ g_Z^2 \sum_f [\ (T_{3f} - s_W^2 Q_f)^2 \tilde{f}_L^* \tilde{f}_L + s_W^4 Q_f^2 \tilde{f}_R^* \tilde{f}_R\ ] Z_\mu Z^\mu \\ &+ 2 e g_Z \sum_f [\ Q_f (T_{3f} - s_W^2 Q_f) \tilde{f}_L^* \tilde{f}_L - s_W^2 Q_f^2 \tilde{f}_R^* \tilde{f}_R\ ] Z_\mu A^\mu \\ &+ e^2 \sum_f Q_f^2 (\tilde{f}_L^* \tilde{f}_L + \tilde{f}_R^* \tilde{f}_R) A_\mu A^\mu .\end{aligned} \tag{C.35}$$

Gluon-Gluon-Squark-Squark

$$\mathcal{L} = + g_s^2 \sum_q (\tilde{q}_L^* \frac{\lambda^\alpha}{2} \frac{\lambda^\beta}{2} \tilde{q}_L + \tilde{q}_R^* \frac{\lambda^\alpha}{2} \frac{\lambda^\beta}{2} \tilde{q}_R) g_\mu^\alpha g^{\mu\beta} . \tag{C.36}$$

Gluon-(W,Z,γ)-Squark-Squark

$$\begin{aligned}\mathcal{L} = &+ \frac{g_s g}{\sqrt{2}} \{ \tilde{u}_L^* \lambda^\alpha \tilde{d}_L W^{+\mu} + \tilde{d}_L^* \lambda^\alpha \tilde{u}_L W^{-\mu} \} g_\mu^\alpha \\ &+ g_s g_z \sum_q \{ (T_{3q} - s_W^2 Q_q) \tilde{q}_L^* \lambda^\alpha \tilde{q}_L - s_W^2 Q_q \tilde{q}_R^* \lambda^\alpha \tilde{q}_R \} Z^\mu g_\mu^\alpha \\ &+ g_s e \sum_q Q_q (\tilde{q}_L^* \lambda^\alpha \tilde{q}_L + \tilde{q}_R^* \lambda^\alpha \tilde{q}_R) A^\mu g_\mu^\alpha .\end{aligned} \tag{C.37}$$

Higgs-Higgs-Gauge-boson-Gauge-boson

$$\begin{aligned}\mathcal{L} = &+ \frac{g^2}{4} W_\mu^+ W^{-\mu} [(H^0)^2 + (h^0)^2 + (A^0)^2 + 2 H^+ H^-] \\ &+ \frac{g_Z^2}{8} Z_\mu Z^\mu [(H^0)^2 + (h^0)^2 + (A^0)^2 + 2(1 - 2 s_W^2)^2 H^+ H^-] \\ &+ e g_Z (1 - 2 s_W^2) Z_\mu A^\mu H^+ H^- + e^2 A_\mu A^\mu H^+ H^- \\ &- \frac{g g_Z}{2} s_W^2 W_\mu^+ Z^\mu [\cos(\alpha - \beta) h^0 H^- + \sin(\alpha - \beta) H^0 H^- + i A^0 H^-] + h.c. \\ &+ \frac{g e}{2} W_\mu^+ A^\mu [\cos(\alpha - \beta) h^0 H^- + \sin(\alpha - \beta) H^0 H^- + i A^0 H^-] + h.c.\end{aligned} \tag{C.38}$$

Higgs-Goldstone-Gauge-boson-Gauge-boson

$$\mathcal{L} = \frac{g e}{2} W_\mu^+ (A^\mu - \frac{s_W}{c_W} Z^\mu) . [\cos(\alpha - \beta) H^0 G^- - \sin(\alpha - \beta) h^0 G^-] + h.c. \tag{C.39}$$

Goldstone-Goldstone-Gauge-boson-Gauge-boson

$$\begin{aligned}\mathcal{L} = &+ \frac{g^2}{4} W_\mu^+ W^{-\mu} [(G^0)^2 + 2 G^+ G^-] \\ &+ \frac{g_z^2}{8} Z_\mu Z^\mu [(G^0)^2 + 2(1 - 2 s_W^2)^2 G^+ G^-] \\ &+ (c_W^2 - s_W^2) e g_Z Z_\mu A^\mu G^+ G^- + e^2 A_\mu A^\mu G^+ G^- \\ &+ i \frac{g e}{2} W_\mu^+ (A^\mu - \frac{s_W}{c_W} Z^\mu) G^0 G^- + h.c.\end{aligned} \tag{C.40}$$

$\mathbf{H^0}$-$\mathbf{H^0}$-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &- \frac{1}{4} g_Z^2 (T_{3\nu}) \cos 2\alpha \tilde{\nu}^* \tilde{\nu} (H^0)^2 \\ &- [\frac{g^2 m_e^2 \cos^2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{4} g_Z^2 (T_{3e} - s_W^2 Q_e) \cos 2\alpha] \tilde{e}_L^* \tilde{e}_L (H^0)^2 \\ &- [\frac{g^2 m_e^2 \cos^2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{4} g_Z^2 s_W^2 Q_e \cos 2\alpha] \tilde{e}_R^* \tilde{e}_R (H^0)^2 \\ &- [\frac{g^2 m_u^2 \sin^2\alpha}{4M_W^2 \sin^2\beta} + \frac{1}{4} g_Z^2 (T_{3u} - s_W^2 Q_u) \cos 2\alpha] \tilde{u}_L^* \tilde{u}_L (H^0)^2 \\ &- [\frac{g^2 m_u^2 \sin^2\alpha}{4M_W^2 \sin^2\beta} + \frac{1}{4} g_Z^2 s_W^2 Q_u \cos 2\alpha] \tilde{u}_R^* \tilde{u}_R (H^0)^2 \\ &- [\frac{g^2 m_d^2 \cos^2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{4} g_Z^2 (T_{3d} - s_W^2 Q_d) \cos 2\alpha] \tilde{d}_L^* \tilde{d}_L (H^0)^2 \\ &- [\frac{g^2 m_d^2 \cos^2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{4} g_Z^2 s_W^2 Q_d \cos 2\alpha] \tilde{d}_R^* \tilde{d}_R (H^0)^2 . \end{aligned} \tag{C.41}$$

$\mathbf{h^0}$-$\mathbf{h^0}$-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &+ \frac{1}{4} g_Z^2 (T_{3\nu}) \cos 2\alpha \tilde{\nu}^* \tilde{\nu} (h^0)^2 \\ &- [\frac{g^2 m_e^2 \sin^2\alpha}{4M_W^2 \cos^2\beta} - \frac{1}{4} g_Z^2 (T_{3e} - s_W^2 Q_e) \cos 2\alpha] \tilde{e}_L^* \tilde{e}_L (h^0)^2 \\ &- [\frac{g^2 m_e^2 \sin^2\alpha}{4M_W^2 \cos^2\beta} - \frac{1}{4} g_Z^2 s_W^2 Q_e \cos 2\alpha] \tilde{e}_R^* \tilde{e}_R (h^0)^2 \\ &- [\frac{g^2 m_u^2 \cos^2\alpha}{4M_W^2 \sin^2\beta} - \frac{1}{4} g_Z^2 (T_{3u} - s_W^2 Q_u) \cos 2\alpha] \tilde{u}_L^* \tilde{u}_L (h^0)^2 \\ &- [\frac{g^2 m_u^2 \cos^2\alpha}{4M_W^2 \sin^2\beta} - \frac{1}{4} g_Z^2 s_W^2 Q_u \cos 2\alpha] \tilde{u}_R^* \tilde{u}_R (h^0)^2 \\ &- [\frac{g^2 m_d^2 \sin^2\alpha}{4M_W^2 \cos^2\beta} - \frac{1}{4} g_Z^2 (T_{3d} - s_W^2 Q_d) \cos 2\alpha] \tilde{d}_L^* \tilde{d}_L (h^0)^2 \\ &- [\frac{g^2 m_d^2 \sin^2\alpha}{4M_W^2 \cos^2\beta} - \frac{1}{4} g_Z^2 s_W^2 Q_d \cos 2\alpha] \tilde{d}_R^* \tilde{d}_R (h^0)^2 . \end{aligned} \tag{C.42}$$

The interaction (C.42) is obtained from (C.41) by the interchange

$$\sin\alpha \to -\cos\alpha, \qquad \cos\alpha \to \sin\alpha, \qquad \cos 2\alpha \to -\cos 2\alpha. \tag{C.42a}$$

$\mathbf{H^0}$-$\mathbf{h^0}$-Sfermion-Sfermion

$$\begin{aligned}\mathcal{L} = &+ \frac{1}{2} g_Z^2 (T_{3\nu}) \sin 2\alpha \tilde{\nu}^* \tilde{\nu} H^0 h^0 \\ &+ [\frac{g^2 m_e^2 \sin 2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{2} g_Z^2 (T_{3e} - s_W^2 Q_e) \sin 2\alpha] \tilde{e}_L^* \tilde{e}_L H^0 h^0 \\ &+ [\frac{g^2 m_e^2 \sin 2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{2} g_Z^2 s_W^2 Q_e \sin 2\alpha] \tilde{e}_R^* \tilde{e}_R H^0 h^0 \end{aligned}$$

$$
\begin{aligned}
&-[\frac{g^2 m_u^2 \sin 2\alpha}{4M_W^2 \sin^2\beta} - \frac{1}{2}g_Z^2(T_{3u} - s_W^2 Q_u)\sin 2\alpha]\tilde{u}_L^*\tilde{u}_L H^0 h^0 \\
&-[\frac{g^2 m_u^2 \sin 2\alpha}{4M_W^2 \sin^2\beta} - \frac{1}{2}g_Z^2 s_W^2 Q_u \sin 2\alpha]\tilde{u}_R^*\tilde{u}_R H^0 h^0 \\
&+[\frac{g^2 m_d^2 \sin 2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{2}g_Z^2(T_{3d} - s_W^2 Q_d)\sin 2\alpha]\tilde{d}_L^*\tilde{d}_L H^0 h^0 \\
&+[\frac{g^2 m_d^2 \sin 2\alpha}{4M_W^2 \cos^2\beta} + \frac{1}{2}g_Z^2 s_W^2 Q_d \sin 2\alpha]\tilde{d}_R^*\tilde{d}_R H^0 h^0,
\end{aligned}
\qquad (C.43)
$$

where (C.43) is obtained from (C.41) by the following replacement,

$$
\cos 2\alpha \to -\sin 2\alpha, \qquad \sin^2\alpha \to \sin 2\alpha, \qquad \cos^2\alpha \to -\sin 2\alpha. \qquad (C.43a)
$$

Sfermion-Sfermion-A^0-A^0

$$
\begin{aligned}
\mathcal{L} = &+\frac{1}{4}g_Z^2(T_{3\nu})\cos 2\beta\tilde{\nu}^*\tilde{\nu}(A^0)^2 \\
&-[\frac{g^2 m_e^2}{4M_W^2}\tan^2\beta - \frac{1}{4}g_Z^2(T_{3e} - s_W^2 Q_e)\cos 2\beta]\tilde{e}_L^*\tilde{e}_L(A^0)^2 \\
&-[\frac{g^2 m_e^2}{4M_W^2}\tan^2\beta - \frac{1}{4}g_Z^2 s_W^2 Q_e \cos 2\beta]\tilde{e}_R^*\tilde{e}_R(A^0)^2 \\
\\
&-[\frac{g^2 m_u^2}{4M_W^2}\cot^2\beta - \frac{1}{4}g_Z^2(T_{3u} - s_W^2 Q_u)\cos 2\beta]\tilde{u}_L^*\tilde{u}_L(A^0)^2 \\
&-[\frac{g^2 m_u^2}{4M_W^2}\cot^2\beta - \frac{1}{4}g_Z^2 s_W^2 Q_u \cos 2\beta]\tilde{u}_R^*\tilde{u}_R(A^0)^2 \\
&-[\frac{g^2 m_d^2}{4M_W^2}\tan^2\beta - \frac{1}{4}g_Z^2(T_{3d} - s_W^2 Q_d)\cos 2\beta]\tilde{d}_L^*\tilde{d}_L(A^0)^2 \\
&-[\frac{g^2 m_d^2}{4M_W^2}\tan^2\beta - \frac{1}{4}g_Z^2 s_W^2 Q_d \cos 2\beta]\tilde{d}_R^*\tilde{d}_R(A^0)^2.
\end{aligned}
\qquad (C.44)
$$

Note that (C.44) is obtained from (C.42)) by

$$
\sin\alpha \to \sin\beta, \qquad \cos\alpha \to \cos\beta. \qquad (C.44a)
$$

Sfermion-Sfermion-H$^+$-H$^-$

$$
\begin{aligned}
\mathcal{L} = &-[\frac{g^2 m_e^2}{2M_W^2}\tan^2\beta + \frac{1}{2}g_Z^2(T_{3\nu} + s_W^2 Q_e)\cos 2\beta]\tilde{\nu}^*\tilde{\nu}H^+H^- \\
&-\frac{1}{2}g_Z^2(T_{3e})\cos 2\beta\tilde{e}_L^*\tilde{e}_L H^+H^- \\
&-[\frac{g^2 m_e^2}{2M_W^2}\tan^2\beta - \frac{1}{2}g_Z^2 s_W^2 Q_e \cos 2\beta]\tilde{e}_R^*\tilde{e}_R H^+H^-
\end{aligned}
$$

$$
\begin{aligned}
&-[\frac{g^2 m_d^2}{2M_W^2}\tan^2\beta + \frac{1}{2}g_Z^2(T_{3u}+s_W^2 Q_d)\cos 2\beta]\tilde{u}_L^*\tilde{u}_L H^+H^- \\
&-[\frac{g^2 m_u^2}{2M_W^2}\cot^2\beta - \frac{1}{2}g_Z^2 s_W^2 Q_u\cos 2\beta]\tilde{u}_R^*\tilde{u}_R H^+H^- \\
&-[\frac{g^2 m_u^2}{2M_W^2}\cot^2\beta + \frac{1}{2}g_Z^2(T_{3d}+s_W^2 Q_u)\cos 2\beta]\tilde{d}_L^*\tilde{d}_L H^+H^- \\
&-[\frac{g^2 m_d^2}{2M_W^2}\tan^2\beta - \frac{1}{2}g_Z^2 s_W^2 Q_d\cos 2\beta]\tilde{d}_R^*\tilde{d}_R H^+H^-.
\end{aligned}
\tag{C.45}
$$

Sfermion-sfermion-Higgs^0-H$^\pm$

$$
\begin{aligned}
\mathcal{L} = &+\frac{g^2}{2\sqrt{2}M_W^2}[m_e^2\frac{\cos\alpha\sin\beta}{\cos^2\beta} - M_W^2\sin(\alpha+\beta)]\tilde{\nu}^*\tilde{e}_L H^0H^+ \\
&+\frac{g^2}{2\sqrt{2}M_W^2}[m_d^2\frac{\cos\alpha\sin\beta}{\cos^2\beta} + m_u^2\frac{\sin\alpha\cos\beta}{\sin^2\beta} - M_W^2\sin(\alpha+\beta)]\tilde{u}_L^*\tilde{d}_L H^0H^+ \\
&+g^2\frac{m_u m_d\cos(\alpha-\beta)}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R H^0H^+ \\
&-\frac{g^2}{2\sqrt{2}M_W^2}[m_e^2\frac{\sin\alpha\sin\beta}{\cos^2\beta} + M_W^2\cos(\alpha+\beta)]\tilde{\nu}^*\tilde{e}_L h^0H^+ \\
&-\frac{g^2}{2\sqrt{2}M_W^2}[m_d^2\frac{\sin\alpha\sin\beta}{\cos^2\beta} - m_u^2\frac{\cos\alpha\sin\beta}{\sin^2\beta} + M_W^2\cos(\alpha+\beta)]\tilde{u}_L^*\tilde{d}_L h^0H^+ \\
&-g^2\frac{m_u m_d\sin(\alpha-\beta)}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R h^0H^+ \\
&+i\frac{g^2}{2\sqrt{2}M_W^2}(m_e^2\tan^2\beta + M_W^2\cos 2\beta)\tilde{\nu}^*\tilde{e}_L A^0H^+ \\
&+i\frac{g^2}{2\sqrt{2}M_W^2}(m_d^2\tan^2\beta - m_u^2\cot^2\beta + M_W^2\cos 2\beta)\tilde{u}_L^*\tilde{d}_L A^0H^+ \\
&+h.c.
\end{aligned}
\tag{C.46}
$$

Sfermion-Sfermion-H$^\pm$-G^0

$$
\begin{aligned}
\mathcal{L} = &-i\frac{g^2}{2\sqrt{2}M_W^2}(m_e^2\tan\beta - M_W^2\sin 2\beta)\tilde{\nu}^*\tilde{e}_L H^+G^0 \\
&-i\frac{g^2}{2\sqrt{2}M_W^2}(m_d^2\tan\beta + m_u^2\cot\beta - M_W^2\sin 2\beta)\tilde{u}_L^*\tilde{d}_L H^+G^0 \\
&+i\frac{g^2 m_u m_d}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R H^+G^0 \\
&+h.c.
\end{aligned}
\tag{C.47}
$$

Sfermion-Sfermion-H$^\pm$-G$^\mp$

$$
\begin{aligned}
\mathcal{L} =& + (\frac{g^2 m_e^2}{2M_W^2}\tan\beta - \frac{1}{2}g_Z^2(T_{3\nu} + s_W^2 Q_e)\sin 2\beta)\tilde{\nu}^*\tilde{\nu} H^+ G^- \\
& - \frac{1}{2}g_Z^2(T_{3e})\sin 2\beta \tilde{e}_L^*\tilde{e}_L H^+ G^- \\
& + (\frac{g^2 m_e^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2 s_W^2 Q_e \sin 2\beta)\tilde{e}_R^*\tilde{e}_R H^+ G^- \\
& + (\frac{g^2 m_d^2}{2M_W^2}\tan\beta - \frac{1}{2}g_Z^2(T_{3u} + s_W^2 Q_d)\sin 2\beta)\tilde{u}_L^*\tilde{u}_L H^+ G^- \\
& - (\frac{g^2 m_u^2}{2M_W^2}\cot\beta - \frac{1}{2}g_Z^2 s_W^2 Q_u \sin 2\beta)\tilde{u}_R^*\tilde{u}_R H^+ G^- \\
& - (\frac{g^2 m_u^2}{2M_W^2}\cot\beta + \frac{1}{2}g_Z^2(T_{3d} + s_W^2 Q_u)\sin 2\beta)\tilde{d}_L^*\tilde{d}_L H^+ G^- \\
& + (\frac{g^2 m_d^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2 s_W^2 Q_d \sin 2\beta)\tilde{d}_R^*\tilde{d}_R H^+ G^- \\
& + h.c.
\end{aligned}
\tag{C.48}
$$

Sfermion-Sfermion-A^0-G^0

$$
\begin{aligned}
\mathcal{L} =& + \frac{1}{2}g_Z^2(T_{3\nu})\sin 2\beta \tilde{\nu}^*\tilde{\nu} A^0 G^0 \\
& + (\frac{g^2 m_e^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2(T_{3e} - s_W^2 Q_e)\sin 2\beta)\tilde{e}_L^*\tilde{e}_L A^0 G^0 \\
& + (\frac{g^2 m_e^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2 s_W^2 Q_e \sin 2\beta)\tilde{e}_R^*\tilde{e}_R A^0 G^0 \\
& - (\frac{g^2 m_u^2}{2M_W^2}\cot\beta - \frac{1}{2}g_Z^2(T_{3u} - s_W^2 Q_u)\sin 2\beta)\tilde{u}_L^*\tilde{u}_L A^0 G^0 \\
& - (\frac{g^2 m_u^2}{2M_W^2}\cot\beta - \frac{1}{2}g_Z^2 s_W^2 Q_u \sin 2\beta)\tilde{u}_R^*\tilde{u}_R A^0 G^0 \\
& + (\frac{g^2 m_d^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2(T_{3d} - s_W^2 Q_d)\sin 2\beta)\tilde{d}_L^*\tilde{d}_L A^0 G^0 \\
& + (\frac{g^2 m_d^2}{2M_W^2}\tan\beta + \frac{1}{2}g_Z^2 s_W^2 Q_d \sin 2\beta)\tilde{d}_R^*\tilde{d}_R A^0 G^0.
\end{aligned}
\tag{C.49}
$$

Sfermion-Sfermion-Higgs^0-G$^\pm$

$$
\begin{aligned}
\mathcal{L} =& - \frac{g^2}{2\sqrt{2}M_W^2}(m_e^2\frac{\cos\alpha}{\cos\beta} - M_W^2\cos(\alpha+\beta))\tilde{\nu}^*\tilde{e}_L H^0 G^+ \\
& - \frac{g^2}{2\sqrt{2}M_W^2}(m_d^2\frac{\cos\alpha}{\cos\beta} - m_u^2\frac{\sin\alpha}{\sin\beta} - M_W^2\cos(\alpha+\beta))\tilde{u}_L^*\tilde{d}_L H^0 G^+ \\
& - g^2\frac{m_u m_d \sin(\alpha-\beta)}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R H^0 G^+
\end{aligned}
$$

$$
\begin{aligned}
&+\frac{g^2}{2\sqrt{2}M_W^2}(m_e^2\frac{\sin\alpha}{\cos\beta}-M_W^2\sin(\alpha+\beta))\tilde{\nu}^*\tilde{e}_L h^0 G^+\\
&+\frac{g^2}{2\sqrt{2}M_W^2}(m_d^2\frac{\sin\alpha}{\cos\beta}+m_u^2\frac{\cos\alpha}{\sin\beta}-M_W^2\sin(\alpha+\beta))\tilde{u}_L^*\tilde{d}_L h^0 G^+\\
&-g^2\frac{m_u m_d\cos(\alpha-\beta)}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R h^0 G^+
\end{aligned}
$$

$$
\begin{aligned}
&-i\frac{g^2}{2\sqrt{2}M_W^2}(m_e^2\tan\beta-M_W^2\sin 2\beta)\tilde{\nu}^*\tilde{e}_L A^0 G^+\\
&-i\frac{g^2}{2\sqrt{2}M_W^2}(m_d^2\tan\beta+m_u^2\cot\beta-M_W^2\sin 2\beta)\tilde{u}_L^*\tilde{d}_L A^0 G^+\\
&-i\frac{g^2 m_u m_d}{\sqrt{2}M_W^2\sin 2\beta}\tilde{u}_R^*\tilde{d}_R A^0 G^+\\
&+h.c.
\end{aligned}
\tag{C.50}
$$

Sfermion-Sfermion-$\mathbf{G^+}$-$\mathbf{G^-}$

$$
\begin{aligned}
\mathcal{L}=&-(\frac{g^2 m_e^2}{2M_W^2}-\frac{1}{2}g_Z^2(T_{3\nu}+s_W^2 Q_e)\cos 2\beta)\tilde{\nu}^*\tilde{\nu}G^+G^-\\
&+\frac{1}{2}g_Z^2(T_{3e})\cos 2\beta\tilde{e}_L^*\tilde{e}_L G^+G^-\\
&-(\frac{g^2 m_e^2}{2M_W^2}+\frac{1}{2}g_Z^2 s_W^2 Q_e\cos 2\beta)\tilde{e}_R^*\tilde{e}_R G^+G^-
\end{aligned}
$$

$$
\begin{aligned}
&-(\frac{g^2 m_d^2}{2M_W^2}-\frac{1}{2}g_Z^2(T_{3u}+s_W^2 Q_d)\cos 2\beta)\tilde{u}_L^*\tilde{u}_L G^+G^-\\
&-(\frac{g^2 m_u^2}{2M_W^2}+\frac{1}{2}g_Z^2 s_W^2 Q_u\cos 2\beta)\tilde{u}_R^*\tilde{u}_R G^+G^-\\
&-(\frac{g^2 m_u^2}{2M_W^2}-\frac{1}{2}g_Z^2(T_{3d}+s_W^2 Q_u)\cos 2\beta)\tilde{d}_L^*\tilde{d}_L G^+G^-\\
&-(\frac{g^2 m_d^2}{2M_W^2}+\frac{1}{2}g_Z^2 s_W^2 Q_d\cos 2\beta)\tilde{d}_R^*\tilde{d}_R G^+G^-.
\end{aligned}
\tag{C.51}
$$

Sfermion-Sfermion-$\mathbf{G^0}$-$\mathbf{G^0}$

$$
\begin{aligned}
\mathcal{L}=&-\frac{1}{4}g_Z^2(T_{3\nu})\cos 2\beta\tilde{\nu}^*\tilde{\nu}(G^0)^2\\
&-(\frac{g^2 m_e^2}{4M_W^2}+\frac{1}{4}g_Z^2(T_{3e}-s_W^2 Q_e)\cos 2\beta)\tilde{e}_L^*\tilde{e}_L(G^0)^2\\
&-(\frac{g^2 m_e^2}{4M_W^2}+\frac{1}{4}g_Z^2 s_W^2 Q_e\cos 2\beta)\tilde{e}_R^*\tilde{e}_R(G^0)^2
\end{aligned}
$$

$$
\begin{aligned}
&-(\frac{g^2 m_u^2}{4M_W^2}+\frac{1}{4}g_Z^2(T_{3u}-s_W^2 Q_u)\cos 2\beta)\tilde{u}_L^*\tilde{u}_L(G^0)^2\\
&-(\frac{g^2 m_u^2}{4M_W^2}+\frac{1}{4}g_Z^2 s_W^2 Q_u\cos 2\beta)\tilde{u}_R^*\tilde{u}_R(G^0)^2\\
&-(\frac{g^2 m_d^2}{4M_W^2}+\frac{1}{4}g_Z^2(T_{3d}-s_W^2 Q_d)\cos 2\beta)\tilde{d}_L^*\tilde{d}_L(G^0)^2\\
&-(\frac{g^2 m_d^2}{4M_W^2}+\frac{1}{4}g_Z^2 s_W^2 Q_d\cos 2\beta)\tilde{d}_R^*\tilde{d}_R(G^0)^2.
\end{aligned}
\tag{C.52}
$$

Sfermion-Sfermion-$\mathbf{G^0}$-$\mathbf{G^\pm}$

$$
\begin{aligned}
\mathcal{L}=&+i\frac{g^2}{2\sqrt{2}M_W^2}(m_e^2-M_W^2\cos 2\beta)(\tilde{\nu}^*\tilde{e}_L G^0 G^+-\tilde{e}_L^*\tilde{\nu}G^0G^-)\\
&+i\frac{g^2}{2\sqrt{2}M_W^2}(m_d^2-m_u^2-M_W^2\cos 2\beta)(\tilde{u}_L^*\tilde{d}_L G^0G^+-\tilde{d}_L^*\tilde{u}G^0G^-).
\end{aligned}
\tag{C.53}
$$

Four-slepton interactions (same generation)

$$
\begin{aligned}
\mathcal{L}=&-\frac{g_Z^2}{8}[\tilde{\nu}^*\tilde{\nu}\tilde{\nu}^*\tilde{\nu}+2\tilde{\nu}^*\tilde{\nu}\tilde{e}_L^*\tilde{e}_L+\tilde{e}_L^*\tilde{e}_L\tilde{e}_L^*\tilde{e}_L+4s_W^2\tilde{e}_R^*\tilde{e}_R\tilde{e}_R^*\tilde{e}_R]\\
&+(\frac{1}{2}g_Z^2 s_W^2-\frac{g^2 m_e^2}{2M_W^2\cos^2\beta})[\tilde{\nu}^*\tilde{\nu}\tilde{e}_R^*\tilde{e}_R+\tilde{e}_L^*\tilde{e}_L\tilde{e}_R^*\tilde{e}_R].
\end{aligned}
\tag{C.54}
$$

Four-slepton interactions (intergeneration)

Below I show only the interactions between the first and second generations. It is straightforward to obtain the first-third and second-third intergeneration interactions.

$$
\begin{aligned}
\mathcal{L}=&-\frac{g_Z^2}{4}[\tilde{\nu}_e^*\tilde{\nu}_e\tilde{\nu}_\mu^*\tilde{\nu}_\mu+\tilde{e}_L^*\tilde{e}_L\tilde{\mu}_L^*\tilde{\mu}_L+2\cos^2\theta_W\tilde{\nu}_e^*\tilde{e}_L\tilde{\mu}_L^*\tilde{\nu}_\mu+2\cos^2\theta_W\tilde{e}_L^*\tilde{\nu}_e\tilde{\nu}_\mu^*\tilde{\mu}_L]\\
&+\frac{g_Z^2}{2}\sin^2\theta_W[\tilde{\nu}_e^*\tilde{\nu}_e\tilde{\mu}_R^*\tilde{\mu}_R+\tilde{\nu}_\mu^*\tilde{\nu}_\mu\tilde{e}_R^*\tilde{e}_R+\tilde{e}_L^*\tilde{e}_L\tilde{\mu}_R^*\tilde{\mu}_R+\tilde{e}_R^*\tilde{e}_R\tilde{\mu}_L^*\tilde{\mu}_L-2\tilde{e}_R^*\tilde{e}_R\tilde{\mu}_R^*\tilde{\mu}_R]\\
&+g_Z^2(\frac{1}{4}-\frac{1}{2}\sin^2\theta_W)[\tilde{\nu}_e^*\tilde{\nu}_e\tilde{\mu}_L^*\tilde{\mu}_L+\tilde{\nu}_\mu^*\tilde{\nu}_\mu\tilde{e}_L^*\tilde{e}_L]\\
&-\frac{g^2 m_e m_\mu}{2M_W^2\cos^2\beta}[\tilde{\nu}_e^*\tilde{e}_R\tilde{\mu}_R^*\tilde{\nu}_\mu+\tilde{e}_R^*\tilde{\nu}_e\tilde{\nu}_\mu^*\tilde{\mu}_R+\tilde{e}_R^*\tilde{e}_L\tilde{\mu}_L^*\tilde{\mu}_R+\tilde{e}_L^*\tilde{e}_R\tilde{\mu}_R^*\tilde{\mu}_L].
\end{aligned}
\tag{C.55}
$$

Two-slepton-Two-squark (same generation)

$$
\begin{aligned}
\mathcal{L}=&-g_Z^2(\frac{1}{4}-\frac{1}{2}s_W^2 Q_u)[\tilde{\nu}^*\tilde{\nu}\tilde{u}_L^*\tilde{u}_L+\tilde{e}_L^*\tilde{e}_L\tilde{d}_L^*\tilde{d}_L]\\
&-\frac{1}{2}g_Z^2 s_W^2 Q_u[\tilde{\nu}^*\tilde{\nu}\tilde{u}_R^*\tilde{u}_R+\tilde{e}_L^*\tilde{e}_L\tilde{u}_R^*\tilde{u}_R-2\tilde{e}_R^*\tilde{e}_R\tilde{u}_R^*\tilde{u}_R]\\
&+g_Z^2(\frac{1}{4}+\frac{1}{2}s_W^2 Q_d)[\tilde{\nu}^*\tilde{\nu}\tilde{d}_L^*\tilde{d}_L+\tilde{e}_L^*\tilde{e}_L\tilde{u}_L^*\tilde{u}_L]\\
&-\frac{1}{2}g_Z^2 s_W^2 Q_d[\tilde{\nu}^*\tilde{\nu}\tilde{d}_R^*\tilde{d}_R+\tilde{e}_L^*\tilde{e}_L\tilde{d}_R^*\tilde{d}_R-2\tilde{e}_R^*\tilde{e}_R\tilde{d}_R^*\tilde{d}_R]
\end{aligned}
$$

$$
\begin{aligned}
&- g_Z^2(Q_u - \frac{1}{2}) s_W^2 \tilde{e}_R^* \tilde{e}_R \tilde{u}_L^* \tilde{u}_L - g_Z^2(Q_d + \frac{1}{2}) s_W^2 \tilde{e}_R^* \tilde{e}_R \tilde{d}_L^* \tilde{d}_L] \\
&- \frac{1}{2} g^2 [\tilde{\nu}^* \tilde{e}_L \tilde{d}_L^* \tilde{u}_L + \tilde{e}_L^* \tilde{\nu} \tilde{u}_L^* \tilde{d}_L] \\
&- \frac{g^2 m_e m_d}{2M_W^2 \cos^2\beta} [\tilde{\nu}^* \tilde{e}_R \tilde{d}_R^* \tilde{u}_L + \tilde{e}_R^* \tilde{\nu} \tilde{u}_L^* \tilde{d}_R + \tilde{e}_L^* \tilde{e}_R \tilde{d}_R^* \tilde{d}_L + \tilde{e}_R^* \tilde{e}_L \tilde{d}_L^* \tilde{d}_R].
\end{aligned} \tag{C.56}
$$

Two-slepton-Two-squark (intergeneration)

Intergeneration interaction is obtained by either of the two ways: (1) replacement in the lepton sector, $\tilde{\nu}_e \to \tilde{\nu}_\mu$, $\tilde{e} \to \tilde{\mu}$ and $m_e \to m_\mu$; (2) replacement in the quark sector, $\tilde{u} \to \tilde{c}$, $\tilde{d} \to \tilde{s}$ and $m_d \to m_s$.

Four-squark interactions (same generation)

$$
\begin{aligned}
\mathcal{L} = &- [\frac{1}{6} g_s^2 + \frac{1}{2} g_Z^2 (\frac{1}{4} + s_W^2 Q_u Q_d)][(\tilde{u}_L^* \tilde{u}_L)^2 + (\tilde{d}_L^* \tilde{d}_L)^2] \\
&+ [\frac{1}{6} g_s^2 + g_Z^2 (\frac{1}{4} - (Q_u Q_d + \frac{1}{2}) s_W^2)](\tilde{u}_L^* \tilde{u}_L)(\tilde{d}_L^* \tilde{d}_L) \\
&- [\frac{1}{6} g_s^2 + \frac{1}{2} g_Z^2 s_W^2 Q_u^2](\tilde{u}_R^* \tilde{u}_R)^2 \\
&- [\frac{1}{6} g_s^2 + \frac{1}{2} g_Z^2 s_W^2 Q_d^2](\tilde{d}_R^* \tilde{d}_R)^2
\end{aligned}
$$

$$
\begin{aligned}
&- [\frac{1}{6} g_s^2 - g_Z^2 s_W^2 Q_u (Q_u - \frac{1}{2})](\tilde{u}_L^* \tilde{u}_L)(\tilde{u}_R^* \tilde{u}_R) \\
&- [\frac{1}{6} g_s^2 - g_Z^2 s_W^2 Q_d (Q_d + \frac{1}{2})](\tilde{d}_L^* \tilde{d}_L)(\tilde{d}_R^* \tilde{d}_R) \\
&- [\frac{1}{6} g_s^2 - g_Z^2 s_W^2 Q_d (Q_u - \frac{1}{2})](\tilde{u}_L^* \tilde{u}_L)(\tilde{d}_R^* \tilde{d}_R) \\
&- [\frac{1}{6} g_s^2 - g_Z^2 s_W^2 Q_u (Q_d + \frac{1}{2})](\tilde{d}_L^* \tilde{d}_L)(\tilde{u}_R^* \tilde{u}_R)
\end{aligned}
$$

$$
\begin{aligned}
&+ [\frac{1}{6} g_s^2 - g_Z^2 s_W^2 Q_u Q_d](\tilde{d}_R^* \tilde{d}_R)(\tilde{u}_R^* \tilde{u}_R) \\
&+ [\frac{1}{2} g_s^2 - \frac{g^2 m_u^2}{2M_W^2 \sin^2\beta}][(\tilde{u}_R^* \tilde{u}_L)(\tilde{u}_L^* \tilde{u}_R) + (\tilde{u}_R^* \tilde{d}_L)(\tilde{d}_L^* \tilde{u}_R)] \\
&+ [\frac{1}{2} g_s^2 - \frac{g^2 m_d^2}{2M_W^2 \cos^2\beta}](\tilde{d}_R^* \tilde{d}_L)(\tilde{d}_L^* \tilde{d}_R) + (\tilde{d}_R^* \tilde{u}_L)(\tilde{u}_L^* \tilde{d}_R)] \\
&- \frac{1}{2}(g_s^2 + g^2)(\tilde{u}_L^* \tilde{d}_L)(\tilde{d}_L^* \tilde{u}_L) - \frac{1}{2} g_s^2 (\tilde{u}_R^* \tilde{d}_R)(\tilde{d}_R^* \tilde{u}_R).
\end{aligned} \tag{C.57}
$$

Four-quark interactions (intergeneration)

$$
\begin{aligned}
\mathcal{L} = &+ [\frac{1}{6}g_s^2 - g_Z^2(\frac{1}{4} + s_W^2 Q_u Q_d)](\tilde{u}_L^*\tilde{u}_L)(\tilde{c}_L^*\tilde{c}_L) - \frac{1}{2}g_s^2(\tilde{u}_L^*\tilde{c}_L)(\tilde{c}_L^*\tilde{u}_L) \\
&+ [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u^2](\tilde{u}_R^*\tilde{u}_R)(\tilde{c}_R^*\tilde{c}_R) - \frac{1}{2}g_s^2(\tilde{u}_R^*\tilde{c}_R)(\tilde{c}_R^*\tilde{u}_R) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u(Q_u - \frac{1}{2})][(\tilde{u}_L^*\tilde{u}_L)(\tilde{c}_R^*\tilde{c}_R) + (\tilde{u}_R^*\tilde{u}_R)(\tilde{c}_L^*\tilde{c}_L)] \\
&+ \frac{1}{2}g_s^2[(\tilde{u}_L^*\tilde{c}_R)(\tilde{c}_R^*\tilde{u}_L) + (\tilde{u}_R^*\tilde{c}_L)(\tilde{c}_L^*\tilde{u}_R)] \\
&- \frac{g^2 m_u m_c}{2M_W^2 \sin^2\beta}[(\tilde{u}_R^*\tilde{u}_L)(\tilde{c}_L^*\tilde{c}_R) + (\tilde{u}_L^*\tilde{u}_R)(\tilde{c}_R^*\tilde{c}_L)] \\
&+ [\frac{1}{6}g_s^2 - g_Z^2(\frac{1}{4} + s_W^2 Q_u Q_d)](\tilde{d}_L^*\tilde{d}_L)(\tilde{s}_L^*\tilde{s}_L) - \frac{1}{2}g_s^2(\tilde{d}_L^*\tilde{s}_L)(\tilde{s}_L^*\tilde{d}_L) \\
&+ [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_d^2](\tilde{d}_R^*\tilde{d}_R)(\tilde{s}_R^*\tilde{s}_R) - \frac{1}{2}g_s^2(\tilde{d}_R^*\tilde{s}_R)(\tilde{s}_R^*\tilde{d}_R) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_d(Q_d + \frac{1}{2})][(\tilde{d}_L^*\tilde{d}_L)(\tilde{s}_R^*\tilde{s}_R) + (\tilde{d}_R^*\tilde{d}_R)(\tilde{s}_L^*\tilde{s}_L)] \\
&+ \frac{1}{2}g_s^2[(\tilde{d}_L^*\tilde{s}_R)(\tilde{s}_R^*\tilde{d}_L) + (\tilde{d}_R^*\tilde{s}_L)(\tilde{s}_L^*\tilde{d}_R)] \\
&- \frac{g^2 m_d m_s}{2M_W^2 \cos^2\beta}[(\tilde{d}_R^*\tilde{d}_L)(\tilde{s}_L^*\tilde{s}_R) + (\tilde{d}_L^*\tilde{d}_R)(\tilde{s}_R^*\tilde{s}_L)] \\
&+ [\frac{1}{6}g_s^2 + g_Z^2(\frac{1}{4} - (Q_u Q_d + \frac{1}{2})s_W^2)](\tilde{u}_L^*\tilde{u}_L)(\tilde{s}_L^*\tilde{s}_L) - \frac{1}{2}g_s^2(\tilde{u}_L^*\tilde{s}_L)(\tilde{s}_L^*\tilde{u}_L) \\
&+ [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u Q_d](\tilde{u}_R^*\tilde{u}_R)(\tilde{s}_R^*\tilde{s}_R) - \frac{1}{2}g_s^2(\tilde{u}_R^*\tilde{s}_R)(\tilde{s}_R^*\tilde{u}_R) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_d(Q_d + \frac{1}{2})](\tilde{u}_L^*\tilde{u}_L)(\tilde{s}_R^*\tilde{s}_R) + \frac{1}{2}g_s^2(\tilde{u}_L^*\tilde{s}_R)(\tilde{s}_R^*\tilde{u}_L) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u(Q_u - \frac{1}{2})](\tilde{u}_R^*\tilde{u}_R)(\tilde{s}_L^*\tilde{s}_L) + \frac{1}{2}g_s^2(\tilde{u}_R^*\tilde{s}_L)(\tilde{s}_L^*\tilde{u}_R) \\
&+ [\frac{1}{6}g_s^2 + g_Z^2(\frac{1}{4} - (Q_u Q_d + \frac{1}{2})s_W^2)](\tilde{d}_L^*\tilde{d}_L)(\tilde{c}_L^*\tilde{c}_L) - \frac{1}{2}g_s^2(\tilde{d}_L^*\tilde{c}_L)(\tilde{c}_L^*\tilde{d}_L) \\
&+ [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u Q_d](\tilde{d}_R^*\tilde{d}_R)(\tilde{c}_R^*\tilde{c}_R) - \frac{1}{2}g_s^2(\tilde{d}_R^*\tilde{c}_R)(\tilde{c}_R^*\tilde{d}_R) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_u(Q_u - \frac{1}{2})](\tilde{d}_L^*\tilde{d}_L)(\tilde{c}_R^*\tilde{c}_R) + \frac{1}{2}g_s^2(\tilde{d}_L^*\tilde{c}_R)(\tilde{c}_R^*\tilde{d}_L) \\
&- [\frac{1}{6}g_s^2 - g_Z^2 s_W^2 Q_d(Q_d + \frac{1}{2})](\tilde{d}_R^*\tilde{d}_R)(\tilde{c}_L^*\tilde{c}_L) + \frac{1}{2}g_s^2(\tilde{d}_R^*\tilde{c}_L)(\tilde{c}_L^*\tilde{d}_R) \\
&- \frac{1}{2}g^2[(\tilde{u}_L^*\tilde{d}_L)(\tilde{s}_L^*\tilde{c}_L) + (\tilde{d}_L^*\tilde{u}_L)(\tilde{c}_L^*\tilde{s}_L)] \\
&- \frac{g^2 m_u m_c}{2M_W^2 \sin^2\beta}[(\tilde{u}_R^*\tilde{d}_L)(\tilde{s}_L^*\tilde{c}_R) + (\tilde{d}_L^*\tilde{u}_R)(\tilde{c}_R^*\tilde{s}_L)] \qquad (C.58) \\
&- \frac{g^2 m_d m_s}{2M_W^2 \cos^2\beta}[(\tilde{u}_L^*\tilde{d}_R)(\tilde{s}_R^*\tilde{c}_L) + (\tilde{d}_R^*\tilde{u}_L)(\tilde{c}_L^*\tilde{s}_R)].
\end{aligned}
$$

Gauge-boson-Gauge-boson-Gauge-boson

$$
\begin{aligned}
\mathcal{L} = &+ igc_W[(\partial_\mu W^-_\nu - \partial_\nu W^-_\mu)W^{+\mu}Z^\nu - (\partial_\mu W^+_\nu - \partial_\nu W^+_\mu)W^{-\mu}Z^\nu \\
&\qquad - (\partial_\mu Z_\nu - \partial_\nu Z_\mu)W^{+\mu}W^{-\nu}] \\
&+ ie[(\partial_\mu W^-_\nu - \partial_\nu W^-_\mu)W^{+\mu}A^\nu - (\partial_\mu W^+_\nu - \partial_\nu W^+_\mu)W^{-\mu}A^\nu \\
&\qquad - (\partial_\mu A_\nu - \partial_\nu A_\mu)W^{+\mu}W^{-\nu}] \\
&+ g_s f^{\alpha\beta\gamma}(\partial_\mu g^\alpha_\nu)g^\beta_\mu g^\gamma_\nu.
\end{aligned} \tag{C.59}
$$

Gauge-boson-Gauge-boson-Gauge-boson-Gauge-boson

$$
\begin{aligned}
\mathcal{L} = &+ \frac{g^2}{2}[(W^+_\mu W^{+\mu})(W^-_\nu W^{-\nu}) - (W^+_\mu W^{-\mu})^2] \\
&+ g^2 c_W^2[W^+_\mu W^-_\nu Z^\mu Z^\nu - W^+_\mu W^{-\mu} Z_\nu Z^\nu] \\
&+ g^2 c_W s_W[W^+_\mu W^-_\nu (Z^\mu A^\nu + Z^\nu A^\mu) - 2W^+_\mu W^{-\mu} Z_\nu A^\nu] \\
&+ e^2[W^+_\mu W^-_\nu A^\mu A^\nu - W^+_\mu W^{-\mu} A_\nu A^\nu] \\
&- \frac{1}{4}g_s^2 f^{\alpha\beta\gamma} f^{\rho\sigma\gamma} g^\alpha_\mu g^\beta_\nu g^\rho_\mu g^\sigma_\nu.
\end{aligned} \tag{C.60}
$$

Higgs^0-Higgs^0-Higgs^0

$$
\begin{aligned}
\mathcal{L} = &- \frac{g_Z}{4} M_Z \cos 2\alpha[\sin(\alpha+\beta)(h^0)^3 + \cos(\alpha+\beta)(H^0)^3] \\
&- \frac{g_Z}{4} M_Z \cos 2\beta[\sin(\alpha+\beta)h^0 - \cos(\alpha+\beta)H^0](A^0)^2 \\
&- \frac{g_Z}{4} M_Z[2\sin 2\alpha \sin(\alpha+\beta) - \cos 2\alpha \cos(\alpha+\beta)](h^0)^2 H^0 \\
&+ \frac{g_Z}{4} M_Z[2\sin 2\alpha \cos(\alpha+\beta) + \cos 2\alpha \sin(\alpha+\beta)](H^0)^2 h^0.
\end{aligned} \tag{C.61}
$$

H$^+$-H$^-$-Higgs^0

$$
\begin{aligned}
\mathcal{L} = &- [gM_W \cos(\alpha-\beta) - \frac{g_Z}{2} M_Z \cos(\alpha+\beta)\cos 2\beta]H^+H^-H^0 \\
&+ [gM_W \sin(\alpha-\beta) - \frac{g_Z}{2} M_Z \sin(\alpha+\beta)\cos 2\beta]H^+H^-h^0.
\end{aligned} \tag{C.62}
$$

Higgs^0-Higgs^0-Higgs^0-Higgs^0

$$
\begin{aligned}
\mathcal{L} = &- \frac{g_Z^2}{32}\cos^2 2\alpha (h^0)^4 - \frac{g_Z^2}{16}\sin 4\alpha (h^0)^3 H^0 \\
&- \frac{g_Z^2}{16}(3\sin^2 2\alpha - 1)(h^0)^2(H^0)^2 + \frac{g_Z^2}{16}\sin 4\alpha h^0 (H^0)^3 \\
&- \frac{g_Z^2}{32}\cos^2 2\alpha (H^0)^4 - \frac{g_Z^2}{32}\cos^2 2\beta (A^0)^4 \\
&- \frac{g_Z^2}{16}\cos 2\alpha \cos 2\beta (h^0)^2 (A^0)^2 - \frac{g_Z^2}{8}\sin 2\alpha \cos 2\beta h^0 H^0 (A^0)^2 \\
&+ \frac{g_Z^2}{16}\cos 2\alpha \cos 2\beta (H^0)^2 (A^0)^2.
\end{aligned} \tag{C.63}
$$

H$^+$-H$^-$-Higgs^0-Higgs^0

$$
\begin{aligned}
\mathcal{L} =& -[\frac{g^2}{4}\sin^2(\alpha-\beta)+\frac{g_Z^2}{8}\cos 2\alpha\cos 2\beta]H^+H^-(h^0)^2 \\
&+[\frac{g^2}{2}\sin(\alpha-\beta)\cos(\alpha-\beta)-\frac{g_Z^2}{4}\sin 2\alpha\cos 2\beta]H^+H^-h^0H^0 \\
&-[\frac{g^2}{4}\cos^2(\alpha-\beta)-\frac{g_Z^2}{8}\cos 2\alpha\cos 2\beta]H^+H^-(H^0)^2 \\
&-\frac{g_Z^2}{8}\cos^2 2\beta H^+H^-(A^0)^2.
\end{aligned}
\tag{C.64}
$$

$\mathbf{H^+}$-$\mathbf{H^-}$-$\mathbf{H^+}$-$\mathbf{H^-}$

$$
\mathcal{L} = -\frac{g_Z^2}{8}\cos^2 2\beta(H^+)^2(H^-)^2.
\tag{C.65}
$$

Higgs-Higgs-Goldstone

$$
\begin{aligned}
\mathcal{L} =& +\frac{g_Z}{2}M_Z\sin 2\beta[\cos(\alpha+\beta)H^0-\sin(\alpha+\beta)h^0]A^0G^0 \\
&+\frac{1}{2}(gM_W\sin(\alpha-\beta)+g_ZM_Z\cos(\alpha+\beta)\sin 2\beta)(H^0H^+G^-+H^0H^-G^+) \\
&+\frac{1}{2}(gM_W\cos(\alpha-\beta)-g_ZM_Z\sin(\alpha+\beta)\sin 2\beta)(h^0H^+G^-+h^0H^-G^+) \\
&+i\frac{1}{2}gM_W(A^0H^-G^+-A^0H^+G^-).
\end{aligned}
\tag{C.66}
$$

Higgs-Goldstone-Goldstone

$$
\begin{aligned}
\mathcal{L} =& -\frac{1}{4}g_ZM_Z\cos(\alpha+\beta)\cos 2\beta[H^0(G^0)^2+2H^0G^+G^-] \\
&+\frac{1}{4}g_ZM_Z\sin(\alpha+\beta)\cos 2\beta[h^0(G^0)^2+2h^0G^+G^-].
\end{aligned}
\tag{C.67}
$$

Higgs-Higgs-Higgs-Goldstone

$$
\begin{aligned}
\mathcal{L} =& +\frac{g_Z^2}{8}\sin 2\beta[\cos 2\alpha((H^0)^2-(h^0)^2)-2\sin 2\alpha H^0h^0]A^0G^0 \\
&-\frac{g_Z^2}{16}\sin 4\beta[(A^0)^3G^0+2H^+H^-A^0G^0] \\
&+\frac{1}{8}(g^2\sin 2(\alpha-\beta)+g_Z^2\cos 2\alpha\sin 2\beta)[H^+G^-+H^-G^+][(H^0)^2-(h^0)^2] \\
&+\frac{1}{4}(g^2\cos 2(\alpha-\beta)-g_Z^2\sin 2\alpha\sin 2\beta)[H^+G^-+H^-G^+]H^0h^0 \\
&-\frac{g_Z^2}{16}\sin 4\beta[H^+G^-+H^-G^+](A^0)^2 \\
&-i\frac{g^2}{4}[\cos(\alpha-\beta)H^0-\sin(\alpha-\beta)h^0][A^0H^+G^--A^0H^-G^+] \\
&-\frac{g_Z^2}{8}\sin 4\beta[(H^+)^2H^-G^-+(H^-)^2H^+G^+].
\end{aligned}
\tag{C.68}
$$

Higgs-Higgs-Goldstone-Goldstone

$$\begin{aligned}\mathcal{L} =& + \frac{g_Z^2}{16}[\cos 2\alpha \cos 2\beta ((h^0)^2 - (H^0)^2) + 2\sin 2\alpha \cos 2\beta H^0 h^0](G^0)^2 \\ & - \frac{g_Z^2}{16}(3\sin^2 2\beta - 1)(A^0)^2(G^0)^2 \\ & - (\frac{g^2}{4} - \frac{g_Z^2}{8}\cos^2 2\beta)H^+H^-(G^0)^2 \\ & - i\frac{g^2}{4}[\sin(\alpha-\beta)H^0 + \cos(\alpha-\beta)h^0][H^-G^+G^0 - H^+G^0G^-] \\ & + \frac{1}{4}(g^2 - g_Z^2\sin^2 2\beta)(A^0H^-G^+G^0 + A^0H^+G^-G^0) \\ & - \frac{1}{4}(g^2\sin^2(\alpha-\beta) + \frac{1}{2}g_Z^2\cos 2\alpha\cos 2\beta)(H^0)^2G^+G^- \\ & - \frac{1}{4}(g^2\cos^2(\alpha-\beta) - \frac{1}{2}g_Z^2\cos 2\alpha\cos 2\beta)(h^0)^2G^+G^- \\ & - \frac{1}{4}(g^2\sin 2(\alpha-\beta) - g_Z^2\sin 2\alpha\cos 2\beta)H^0h^0G^+G^- \\ & - (\frac{g^2}{4} - \frac{g_Z^2}{8}\cos^2 2\beta)(A^0)^2G^+G^- + \frac{g_Z^2}{4}\cos 4\beta H^+H^-G^+G^- \\ & - \frac{g_Z^2}{8}\sin^2 2\beta[(H^+)^2(G^-)^2 + (H^-)^2(G^+)^2].\end{aligned} \tag{C.69}$$

Higgs-Goldstone-Goldstone-Goldstone

$$\begin{aligned}\mathcal{L} =& \frac{g_Z^2}{16}\sin 4\beta[(G^0)^3A^0 + (G^0)^2G^+H^- + (G^0)^2G^-H^+ \\ & + 2G^+G^-G^0A^0 + 2(G^-)^2G^+H^+ + 2(G^+)^2G^-H^-].\end{aligned} \tag{C.70}$$

Goldstone-Goldstone-Goldstone-Goldstone

$$\mathcal{L} = -\frac{g_Z^2}{32}\cos^2 2\beta[(G^0)^4 + 4G^+G^-(G^0)^2 + 4(G^+)^2(G^-)^2]. \tag{C.71}$$

Ghost-Ghost-Gauge-boson

$$\begin{aligned}\mathcal{L} =& igc[\partial^\mu\bar{\omega}_+\omega_+ - \partial^\mu\bar{\omega}_-\omega_-]Z_\mu \\ & + ie[\partial^\mu\bar{\omega}_+\omega_+ - \partial^\mu\bar{\omega}_-\omega_-]A_\mu \\ & + ig[c(\partial^\mu\bar{\omega}_z\omega_- - \partial^\mu\bar{\omega}_+\omega_z) + s(\partial^\mu\bar{\omega}_\gamma\omega_- - \partial^\mu\bar{\omega}_+\omega_\gamma)]W_\mu^+ \\ & + ig[c(\partial^\mu\bar{\omega}_-\omega_z - \partial^\mu\bar{\omega}_z\omega_+) + s(\partial^\mu\bar{\omega}_-\omega_\gamma - \partial^\mu\bar{\omega}_\gamma\omega_+)]W_\mu^- \\ & + g_s f^{\alpha\beta\gamma}\partial\bar{\omega}^\alpha\omega^\beta g_\mu^\gamma.\end{aligned} \tag{C.72}$$

Ghost-Ghost-Higgs

$$\begin{aligned}\mathcal{L} =& -\frac{1}{2}[gM_W\xi_W(\bar{\omega}_+\omega_+ + \bar{\omega}_-\omega_-) + g_ZM_Z\xi_Z\bar{\omega}_z\omega_z] \\ & [\cos(\beta-\alpha)H^0 + \sin(\beta-\alpha)h^0].\end{aligned} \tag{C.73}$$

Ghost-Ghost-Goldstone

$$
\begin{aligned}
\mathcal{L} =& - i\frac{g}{2}M_W\xi_W[\bar{\omega}_+\omega_+ - \bar{\omega}_-\omega_-]G^0 \\
& - (\frac{1}{2} - s_W^2)g_Z M_W\xi_W[\bar{\omega}_+\omega_z G^+ + \bar{\omega}_-\omega_z G^-] \\
& - eM_W\xi_W[\bar{\omega}_+\omega_\gamma G^+ + \bar{\omega}_-\omega_\gamma G^-] \\
& + \frac{g}{2}M_Z\xi_Z[\bar{\omega}_z\omega_+ G^- + \bar{\omega}_z\omega_- G^+].
\end{aligned}
\tag{C.74}
$$

Appendix D. Sfermion expansion

In Appendix C, most of the interactions of sfermions are expressed in terms of the f_L and f_R, which are not mass eigenstates. In this Appendix, using sfermions in the first generation, $\tilde{\nu}$, $\tilde{e}_i$, $\tilde{u}_i$ and $\tilde{d}_j (i = 1, 2)$ as the representative, the product of two sfermions and of four sfermions are expanded by the mass eigenstates f_1 and f_2.

The mass eigenstates of sfermions are defined by (2.6). Using the reversed expression,

$$
\begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix} = \begin{pmatrix} c_f & -s_f \\ s_f & c_f \end{pmatrix} \begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix}, \tag{D.1}
$$

with $c_f = \cos\theta_f$ and $s_f = \sin\theta_f$ for $f = e, u, d$, one finds that the products of two sfermions are decomposed as

$$
\begin{aligned}
(\tilde{\nu}^*\tilde{e}_L) &= c_e\tilde{\nu}^*\tilde{e}_1 - s_e\tilde{\nu}^*\tilde{e}_2, \\
(\tilde{\nu}^*\tilde{e}_R) &= s_e\tilde{\nu}^*\tilde{e}_1 + c_e\tilde{\nu}^*\tilde{e}_2, \\
(\tilde{u}_L^*\tilde{u}_L) &= c_u^2\ \tilde{u}_1^*\tilde{u}_1 - c_u s_u\ \tilde{u}_1^*\tilde{u}_2 - s_u c_u\ \tilde{u}_2^*\tilde{u}_1 + s_u^2\ \tilde{u}_2^*\tilde{u}_2, \\
(\tilde{u}_R^*\tilde{u}_R) &= s_u^2\ \tilde{u}_1^*\tilde{u}_1 + s_u c_u\ \tilde{u}_1^*\tilde{u}_2 + c_u s_u\ \tilde{u}_2^*\tilde{u}_1 + c_u^2\ \tilde{u}_2^*\tilde{u}_2, \\
(\tilde{u}_L^*\tilde{u}_R) &= c_u s_u\ \tilde{u}_1^*\tilde{u}_1 + c_u^2\ \tilde{u}_1^*\tilde{u}_2 - s_u^2\ \tilde{u}_2^*\tilde{u}_1 - s_u c_u\ \tilde{u}_2^*\tilde{u}_2, \\
(\tilde{u}_R^*\tilde{u}_L) &= s_u c_u\ \tilde{u}_1^*\tilde{u}_1 - s_u^2\ \tilde{u}_1^*\tilde{u}_2 + c_u^2\ \tilde{u}_2^*\tilde{u}_1 - c_u s_u\ \tilde{u}_2^*\tilde{u}_2, \\
(\tilde{d}_L^*\tilde{u}_L) &= c_d c_u\ \tilde{d}_1^*\tilde{u}_1 - c_d s_u\ \tilde{d}_1^*\tilde{u}_2 - s_d c_u\ \tilde{d}_2^*\tilde{u}_1 + s_d s_u\ \tilde{d}_2^*\tilde{u}_2, \\
(\tilde{d}_R^*\tilde{u}_R) &= s_d s_u\ \tilde{d}_1^*\tilde{u}_1 + s_d c_u\ \tilde{d}_1^*\tilde{u}_2 + c_d s_u\ \tilde{d}_2^*\tilde{u}_1 + c_d c_u\ \tilde{d}_2^*\tilde{u}_2, \\
(\tilde{d}_L^*\tilde{u}_R) &= c_d s_u\ \tilde{d}_1^*\tilde{u}_1 + c_d c_u\ \tilde{d}_1^*\tilde{u}_2 - s_d s_u\ \tilde{d}_2^*\tilde{u}_1 - s_d c_u\ \tilde{d}_2^*\tilde{u}_2, \\
(\tilde{d}_R^*\tilde{u}_L) &= s_d c_u\ \tilde{d}_1^*\tilde{u}_1 - s_d s_u\ \tilde{d}_1^*\tilde{u}_2 + c_d c_u\ \tilde{d}_2^*\tilde{u}_1 - c_d s_u\ \tilde{d}_2^*\tilde{u}_2.
\end{aligned}
\tag{D.2}
$$

The product of four sfermions are decomposed as follows.

$$
\begin{aligned}
(\tilde{u}_L^*\tilde{u}_L)^2 =& + c_u^4(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_1) \\
& - 2c_u^3 s_u(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_2) - 2c_u^3 s_u(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
& + c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_1^*\tilde{u}_2) + c_u^2 s_u^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
& + 2c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_1) + 2c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
& - 2c_u s_u^3(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2) - 2c_u s_u^3(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
& + s_u^4(\tilde{u}_2^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2).
\end{aligned}
\tag{D.3}
$$

$$
\begin{aligned}
(\tilde{u}_R^*\tilde{u}_R)^2 = &+ s_u^4(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_1) \\
&+ 2c_u s_u^3(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_2) + 2c_u s_u^3(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
&+ c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_1^*\tilde{u}_2) + c_u^2 s_u^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
&+ 2c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_1) + 2c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
&+ 2c_u^3 s_u(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2) + 2c_u^3 s_u(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
&+ c_u^4(\tilde{u}_2^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2).
\end{aligned} \tag{D.4}
$$

$$
\begin{aligned}
|\tilde{u}_L^*\tilde{u}_R|^2 = &+ c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_1) \\
&+ c_u s_u(c_u^2 - s_u^2)(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_1^*\tilde{u}_2) + c_u s_u(c_u^2 - s_u^2)(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
&- c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_1^*\tilde{u}_2) - c_u^2 s_u^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_1) \\
&+ (c_u^4 + s_u^4)(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_1) - 2c_u^2 s_u^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
&- c_u s_u(c_u^2 - s_u^2)(\tilde{u}_1^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2) - c_u s_u(c_u^2 - s_u^2)(\tilde{u}_2^*\tilde{u}_1)(\tilde{u}_2^*\tilde{u}_2) \\
&+ c_u^2 s_u^2(\tilde{u}_2^*\tilde{u}_2)(\tilde{u}_2^*\tilde{u}_2).
\end{aligned} \tag{D.5}
$$

$$
\begin{aligned}
|\tilde{u}_L^*\tilde{d}_L|^2 = &+ c_u^2 c_d^2(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_1) \\
&- c_u s_u c_d^2(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_2) - c_u^2 c_d s_d(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_1) \\
&- c_u^2 c_d s_d(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_1) - c_u s_u c_d^2(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_1) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_2) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_1) \\
&+ c_u^2 s_d^2(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_1) + s_u^2 c_d^2(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_2) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_2) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_1) \\
&- c_u s_u s_d^2(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_1) - s_u^2 c_d s_d(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_2) \\
&- s_u^2 c_d s_d(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_2) - c_u s_u s_d^2(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_2) \\
&+ s_u^2 s_d^2(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_2).
\end{aligned} \tag{D.6}
$$

$$
\begin{aligned}
|\tilde{u}_R^*\tilde{d}_R|^2 = &+ s_u^2 s_d^2(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_1) \\
&+ c_u s_u s_d^2(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_2) + s_u^2 c_d s_d(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_1) \\
&+ s_u^2 c_d s_d(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_1) + c_u s_u s_d^2(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_1) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_2) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_1) \\
&+ s_u^2 c_d^2(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_1) + c_u^2 s_d^2(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_1^*\tilde{u}_2) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_2) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_1) \\
&+ c_u s_u c_d^2(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_1) + c_u^2 s_d c_d(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_1^*\tilde{u}_2) \\
&+ c_u^2 c_d s_d(\tilde{u}_2^*\tilde{d}_1)(\tilde{d}_2^*\tilde{u}_2) + c_u s_u c_d^2(\tilde{u}_1^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_2) \\
&+ c_u^2 c_d^2(\tilde{u}_2^*\tilde{d}_2)(\tilde{d}_2^*\tilde{u}_2).
\end{aligned} \tag{D.7}
$$

$$
\begin{aligned}
|\tilde{u}_L^* \tilde{d}_R|^2 = &+ c_u^2 s_d^2 (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_1) \\
&- c_u s_u s_d^2 (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_2) + c_u^2 c_d s_d (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_1) \\
&+ c_u^2 c_d s_d (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_1) - c_u s_u s_d^2 (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_1) \\
&- c_u s_u c_d s_d (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_2) - c_u s_u c_d s_d (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_1) \\
&+ c_u^2 c_d^2 (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_1) + s_u^2 s_d^2 (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_2) \\
&- c_u s_u c_d s_d (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_2) - c_u s_u c_d s_d (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_1) \\
&- c_u s_u c_d^2 (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_1) + s_u^2 c_d s_d (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_2) \\
&+ s_u^2 c_d s_d (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_2) - c_u s_u c_d^2 (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_2) \\
&+ s_u^2 c_d^2 (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_2).
\end{aligned} \tag{D.8}
$$

The expression of $|\tilde{u}_R^* \tilde{d}_L|^2$ is obtained from $|\tilde{u}_L^* \tilde{d}_R|^2$ by $u \leftrightarrow d$. Explicitly it is given as

$$
\begin{aligned}
|\tilde{u}_R^* \tilde{d}_L|^2 = &+ s_u^2 c_d^2 (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_1) \\
&+ c_u s_u c_d^2 (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_2) - s_u^2 c_d s_d (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_1) \\
&- s_u^2 c_d s_d (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_1) + c_u s_u c_d^2 (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_1) \\
&- c_u s_u c_d s_d (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_2) - c_u s_u c_d s_d (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_1) \\
&+ c_u^2 c_d^2 (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_1^* \tilde{u}_2) + s_u^2 s_d^2 (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_1) \\
&- c_u s_u c_d s_d (\tilde{u}_1^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_2) - c_u s_u c_d s_d (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_1) \\
&+ c_u s_u s_d^2 (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_1) - c_u^2 c_d s_d (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_1^* \tilde{u}_2) \\
&- c_u^2 c_d s_d (\tilde{u}_2^* \tilde{d}_1)(\tilde{d}_2^* \tilde{u}_2) + c_u s_u s_d^2 (\tilde{u}_1^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_2) \\
&+ c_u^2 s_d^2 (\tilde{u}_2^* \tilde{d}_2)(\tilde{d}_2^* \tilde{u}_2).
\end{aligned} \tag{D.9}
$$

Setting $\tilde{d} = \tilde{u}$ in the last four equations (D.6)-(D.9), one recovers the first three equations (D.3)-(D.5).

$$
\begin{aligned}
(\tilde{u}_L^* \tilde{u}_L)(\tilde{d}_L^* \tilde{d}_L) = &+ c_u^2 c_d^2 (\tilde{u}_1^* \tilde{u}_1)(\tilde{d}_1^* \tilde{d}_1) \\
&- c_u^2 c_d s_d (\tilde{u}_1^* \tilde{u}_1)(\tilde{d}_1^* \tilde{d}_2) - c_u^2 c_d s_d (\tilde{u}_1^* \tilde{u}_1)(\tilde{d}_2^* \tilde{d}_1) \\
&- c_u s_u c_d^2 (\tilde{u}_1^* \tilde{u}_2)(\tilde{d}_1^* \tilde{d}_1) - c_u s_u c_d^2 (\tilde{u}_2^* \tilde{u}_1)(\tilde{d}_1^* \tilde{d}_1) \\
&+ c_u s_u c_d s_d (\tilde{u}_1^* \tilde{u}_2)(\tilde{d}_1^* \tilde{d}_2) + c_u s_u c_d s_d (\tilde{u}_2^* \tilde{u}_1)(\tilde{d}_2^* \tilde{d}_1) \\
&+ c_u s_u c_d s_d (\tilde{u}_1^* \tilde{u}_2)(\tilde{d}_2^* \tilde{d}_1) + c_u s_u c_d s_d (\tilde{u}_2^* \tilde{u}_1)(\tilde{d}_1^* \tilde{d}_2) \\
&+ c_u^2 s_d^2 (\tilde{u}_1^* \tilde{u}_1)(\tilde{d}_2^* \tilde{d}_2) + s_u^2 c_d^2 (\tilde{u}_2^* \tilde{u}_2)(\tilde{d}_1^* \tilde{d}_1) \\
&- s_u^2 c_d s_d (\tilde{u}_2^* \tilde{u}_2)(\tilde{d}_2^* \tilde{d}_1) - s_u^2 c_d s_d (\tilde{u}_2^* \tilde{u}_2)(\tilde{d}_1^* \tilde{d}_2) \\
&- c_u s_u s_d^2 (\tilde{u}_2^* \tilde{u}_1)(\tilde{d}_2^* \tilde{d}_2) - c_u s_u s_d^2 (\tilde{u}_1^* \tilde{u}_2)(\tilde{d}_2^* \tilde{d}_2) \\
&+ s_u^2 s_d^2 (\tilde{u}_2^* \tilde{u}_2)(\tilde{d}_2^* \tilde{d}_2).
\end{aligned} \tag{D.10}
$$

$(\tilde{u}_R^* \tilde{u}_R)(\tilde{d}_R^* \tilde{d}_R)$ is obtained from $(\tilde{u}_L^* \tilde{u}_L)(\tilde{d}_L^* \tilde{d}_L)$,by

$$
c_u \to s_u, \quad s_u \to -c_u, \quad c_d \to s_d, \quad s_d \to -c_d. \tag{D.11}
$$

$$
\begin{aligned}
(\tilde{u}_R^*\tilde{u}_R)(\tilde{d}_R^*\tilde{d}_R) = &+ s_u^2 s_d^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_1) \\
&+ s_u^2 c_d s_d(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_2) + s_u^2 c_d s_d(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_1) \\
&+ c_u s_u s_d^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_1) + c_u s_u s_d^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_1) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_2) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_1) \\
&+ c_u s_u c_d s_d(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_1) + c_u s_u c_d s_d(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_2) \\
&+ s_u^2 c_d^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_2) + c_u^2 s_d^2(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_1) \\
&+ c_u^2 c_d s_d(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_1) + c_u^2 c_d s_d(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_2) \\
&+ c_u s_u c_d^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_2) + c_u s_u c_d^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_2) \\
&+ c_u^2 c_d^2(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_2).
\end{aligned} \tag{D.12}
$$

$$
\begin{aligned}
(\tilde{u}_L^*\tilde{u}_L)(\tilde{d}_R^*\tilde{d}_R) = &+ c_u^2 s_d^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_1) \\
&+ c_u^2 c_d s_d(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_2) + c_u^2 c_d s_d(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_1) \\
&- c_u s_u s_d^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_1) - c_u s_u s_d^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_1) \\
&- c_u s_u c_d s_d(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_2) - c_u s_u c_d s_d(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_1) \\
&- c_u s_u c_d s_d(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_1) - c_u s_u c_d s_d(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_1^*\tilde{d}_2) \\
&+ c_u^2 c_d^2(\tilde{u}_1^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_2) + s_u^2 s_d^2(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_1) \\
&+ s_u^2 c_d s_d(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_1) + s_u^2 c_d s_d(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_1^*\tilde{d}_2) \\
&- c_u s_u c_d^2(\tilde{u}_2^*\tilde{u}_1)(\tilde{d}_2^*\tilde{d}_2) - c_u s_u c_d^2(\tilde{u}_1^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_2) \\
&+ s_u^2 c_d^2(\tilde{u}_2^*\tilde{u}_2)(\tilde{d}_2^*\tilde{d}_2).
\end{aligned} \tag{D.13}
$$

Appendix E. Relation with Hikasa' convention

Here, I list the particles whose relative signs are differently defined in ref.[4] as well as some different notation for parameters.

this paper	Hikasa [4]
ϕ_1^-	$-H_1^-$
χ_1^0	$-\zeta_1$
G^0	$-\chi_0$(due to the relative sign of ζ_1)
$G^\pm$	$-\chi^\pm$(due to the relative sing of H_1^-)
g_μ^α	G_μ^α
ϕ_R	ϕ_L
ϕ_L	ϕ_R
ϵ_L	ϵ_R
$\tilde{m}_{12}^2$	$B\mu$

(E.1)

There are several trivial misprints in ref.[4], some of which were pointed out by T. Ishikawa. These are

· the first line of (6.96), h^0 should read H^0.

· the second term of the third line of (6.100), $\cos 2\alpha$ should read $\sin 2\alpha$.

· the second line after (6.107), $m_e \to m_s$ should read $m_d \to m_s$.
· the first two terms of (I.5) , multiply g^2.

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