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Feynman Rules for the Rational Part of One-loop QCD Corrections in the MSSM

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ABSTRACT: The complete set of Feynman rules for the rational part R of QCD corrections in the MSSM are calculated at the one-loop level, which can be very useful in the next-to-leading order calculations in supersymmetric models. Our results are expressed in the 't Hooft-Veltman regularization scheme and in the Four Dimensional Helicity scheme with non-anticommutating and anticommutating γ_5 strategies.

KEYWORDS: NLO, Supersymmetric models, Quantum chromodynamics.

Contents

1. Introduction

The calculations of multi-particle processes at next-to-leading order (NLO) level are particularly important for Large Hadron Collider (LHC) and International Linear Collider (ILC) physics, especially in hunting for Higgs boson(s) and New Physics (NP) signatures. Searching for the Higgs boson is one of the central tasks required for the operation of LHC. In order to solve some difficulties encountered in the Standard Model (SM), many New Physics models have been introduced. Most notable of them are the various supersymmetric (SUSY) models. The Minimal Supersymmetric extension of the Standard Model (MSSM)[1, 2, 3, 4, 5, 6, 7, 8], the simplest one, provides many new physics benchmark points to experimentalists to search the SUSY signatures at the LHC. However, both hunting for the Higgs boson(s) and searching for the New Physics signatures are often limited by overwhelming backgrounds. Cascade decays from heavy SUSY particles often result in multi-particle final states. Therefore, precise theoretical results of multi-leg processes are urgently needed with the enhancement of accumulated data at the LHC. To accomplish this task, a significant number of multileg processes should be calculated up to the NLO accuracy in SM and NP. Nevertheless, this task can be very challenging.

In general, a NLO calculation includes real-radiation corrections and virtual corrections with renormalization. The real corrections, without any loop integrals at NLO level, can be accomplished with many efficient algorithms, such as Berends-Giele recursion relations[9], Britto-Cachazo-Feng-Witten (BCFW) recursion relations [10, 11], etc. Programs such as MADGRAPH[12, 13], COMPHEP[14], AMEGIC++[15] ,ALPHA[16, 17, 18], HELAC[19, 20] and COMIX[21] are all efficient tree-level matrix elements generators. Accompanied with phase space slicing method[22] or subtraction terms[23, 24, 25, 26, 27, 28, 29, 30, 31], the automation of real-radiation part seems much straightforward to be realized[32, 27, 33, 34]. On the other hand, the automatic calculation of one-loop integrals is also a feasible task nowadays. Actually, the difficulties in one-loop calculation are relevant to the simplification of the lengthy Dirac structures and the reduction of one-loop integrals to standard master integrals. The latter issue can be resolved by many existing one-loop integrals reduction algorithms, such as Passarino-Veltman reduction procedure [35, 36, 37]. The former one encounters difficulties in making the expression more compact, because one should treat the Dirac matrices in $d = 4-2\epsilon$ dimensions when using dimensional regularization and dimensional reduction.

Recently, we have witnessed a new evolution of NLO techniques. Automatic one-loop calculations have become a feasible approach after several new and efficient algorithms are proposed. Some of the most notable methods are the Unitarity [38, 39, 40, 41, 42, 43] based techniques such as the Ossola, Papadopoulos, and Pittau (OPP) reduction method [44, 45, 46, 47, 48, 49], by reducing the computation of one-loop amplitudes to a problem of a tree level calculation. This method are able to control the computational complexity efficiently with remaining tree level recursion equations. However, when applying in 4 dimensions in OPP, one can extract the Cut Constructible(CC) part of the amplitudes, while the left piece rational terms should be derived separately [50]. With the known rational part R, efficient simplifications of the lengthy Dirac structures in 4 dimensions are possible at the Feynman amplitude level, which also make it possible to do a complicated one-loop computation about multi-particle processes in other reduction algorithms [51, 52, 53].

Fortunately, the rational part R (in OPP approach, it is called R_2) is proven to be guaranteed by the ultraviolet (UV) nature of one-loop amplitudes [52, 54],i.e. the only origin of R we considered here is from a combination of $\mathcal{O}(\epsilon)$ part in numerator of a loop integral and its UV divergence term $\mathcal{O}(\frac{1}{\epsilon_{UV}})$. Since the UV poles,in contrast to infrared divergence ones,do not depend on kinematical properties of external legs such as on-shell relations, one can establish the Feynman rules respect to the effective vertices. This fact also ensures four external legs enough.

The complete Feynman rules for R in SM under anticommutating γ_5 strategy in the 't Hooft-Feynman gauge, R_ξ gauge and Unitary gauge have been calculated [55, 56, 57]. Besides, their package R2SM written in FORM is also available [58]. The Feynman rules for the R in SM under the 't Hooft-Veltman γ_5 scheme have been calculated by us [59]. Moreover, some simplifications to extract rational terms were suggested recently [60, 61]. For supersymmetric amplitudes, one can track to the Cachazo-Svrcek-Witten Fenyman rules[62, 63, 64] to make some simplifications in the calculation of gluonic amplitudes.In the present paper, the complete set of Feynman Rules for rational part R of QCD corrections in the MSSM are calculated at the one-loop level with two γ_5 strategies. All of these Feynman rules can be implemented in NLO matrix element generators like MADLOOP[65, 66] and HELAC-NLO[67] and also be useful in the development of FEYNRULES[68] or in any other methods such as Open Loops [69] or GOSAM [70, 71].

The organization of the paper is as follows. In Section 2, the origin of rational part R is recalled. The dimensional regularization schemes and γ_5 schemes are fixed in Section 3. The complete set of Feynman rules are listed in Section 4. Finally, we make a conclusion.

2. Origin of Rational Part

In dimensional regularization procedure, one should treat integral momentum $\bar{q}$ in $d = 4-2\epsilon$ dimensions to maintain the gauge invariance. A generic N-point one-loop (sub-) amplitude reads as

$$\mathcal{A}_N = \int d^d\bar{q} \frac{\bar{N}(\bar{q})}{\bar{D}_1 \bar{D}_2 ... \bar{D}_N}, \tag{2.1}$$

where

$$\bar{D}_k = (\bar{q} + p_k)^2 - (m_k)^2, \quad \bar{q} = q + \tilde{q}. \tag{2.2}$$

Here a bar denotes d dimensional objects while a tilde means something living in $d-4$ dimensions.

The rational part R comes from the division of the above numerator $\bar{N}(\bar{q})$ into a 4-dimensional part and a $(d-4)$-dimensional part

$$\bar{N}(\bar{q}) = N(q) + \tilde{N}(\tilde{q}^2, \epsilon, q), \tag{2.3}$$

Apart from the process dependent $N(q)$, the remaining part $\tilde{N}(\tilde{q}^2, \epsilon, q) = \bar{N}(\bar{q}) - N(q)$ gives rise to rational part R

$$R \equiv \int d^d\bar{q} \frac{\tilde{N}(\tilde{q}^2, \epsilon, q)}{\bar{D}_1 \bar{D}_2 ... \bar{D}_N}, \tag{2.4}$$

To clarify the division and to avoid the possible ambiguities, we split $d = 4-2\epsilon$ dimensional objects in the tree like Feynman rules as follows

$$\bar{q}_{\bar{\mu}} = q_\mu + \tilde{q}_{\tilde{\mu}}, \;\; \bar{\gamma}_{\bar{\mu}} = \gamma_\mu + \tilde{\gamma}_{\tilde{\mu}}, \;\; \bar{g}_{\bar{\mu}\bar{\nu}} = g_{\mu\nu} + \tilde{g}_{\tilde{\mu}\tilde{\nu}}. \tag{2.5}$$

The effective vertices for R can be obtained from all possible one-particle irreducible Green functions, which is enough up to 4 external legs in the MSSM QCD, which is a renormalizable model. It's also worth reminding that the rational part R is not gauge invariance independently. Actually, in OPP framework, $R_1 + R_2$ is gauge invariant and preserves all the Ward identities of the theory [56].

3. Dimensional Regularization Schemes and γ_5 Schemes

In this section, the proposed regularization schemes and γ_5 schemes adopted in this paper are reviewed and an example of calculating rational term R is given.

First, the Feynman rules in two dimensional regularization schemes that maintain the advantages of the helicity method for loop calculation are reviewed. These schemes require all the quantities of external legs to be in four dimensions. The supersymmetry-preserving Dimensional Reduction (DRED)[72] has been proven to be equivalent to Dimensional Regularization (DREG) [73]. Thus, the Four-dimensional Helicity (FDH)[74, 75, 76, 77] and 't Hooft-Veltman (HV) [78] schemes were chosen in our results. In the FDH scheme, the only d dimensional object is the integral momentum $\bar{q}$, while in the HV scheme all the internal(unobserved) quantities such as the polarization of internal vectors are d dimensional objects, i.e.

$$\begin{aligned} R\Big|_{HV} &= \int d^d\bar{q}\frac{\tilde{N}(\tilde{q}^2,\epsilon,q)}{\bar{D}_1\bar{D}_2...\bar{D}_N}, \\ R\Big|_{FDH} &= \int d^d\bar{q}\frac{\tilde{N}(\tilde{q}^2,\epsilon=0,q)}{\bar{D}_1\bar{D}_2...\bar{D}_N}. \end{aligned} \tag{3.1}$$

When using dimensional regularization in both schemes, the common object to be analytically continued from 4 dimensions to $d = 4 - 2\epsilon$ dimensions is

$$q^2 \to q^2 + \tilde{q}^2. \tag{3.2}$$

Because of the nature of external legs in four dimensions, the contribution of $\tilde{q}$ to R has to be in $\tilde{q}^2$ forms.

As we known, there are two famous algebraic self-consistent γ_5 regularization schemes existing in the market. The first class, called 't Hooft-Veltman (HV) γ_5-regularization scheme, was proposed by 't Hooft and Veltman and systematized by Breitenlohner and Maison [78, 79, 80, 81, 82, 83, 84, 85, 86]. It is the first proven consistent γ_5 scheme [82, 83, 84, 85, 86]. It favors a non-vanishing anti-commutator $\{\gamma_5, \bar{\gamma}_{\bar{\mu}}\} \neq 0$. This scheme distinguishes 4-dimensional and $(d-4)$-dimensional objects to create correct spurious anomalies. Due to the non-anticommutation relation, the tree-like Feynman rules in the theory were modified as symmetric forms [87] in our calculations. The other practicable scheme was introduced by Kreimer, Körner, and Schilcher (KKS), *et al.* [88, 89, 90]. Instead of violating the anticommutation equation, they chose to preserve the anticommutation relationship $\{\gamma_5, \bar{\gamma}_{\bar{\mu}}\} = 0$ and prevented cyclic property in Dirac traces to avoid algebraic inconsistency. A projection on four-dimensional subspaces is needed in their redefinition of trace operation:

$$Tr(\gamma_5 \bar{\gamma}_{\bar{\mu}_1} ... \bar{\gamma}_{\bar{\mu}_{2k}}) \equiv tr(\mathcal{P}(\gamma_5) \bar{\gamma}_{\bar{\mu}_1} ... \bar{\gamma}_{\bar{\mu}_{2k}}), \tag{3.3}$$

where $\mathcal{P}(\gamma_5) \equiv \frac{i}{4!}\ \varepsilon_{\mu_1\mu_2\mu_3\mu_4}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3}\gamma^{\mu_4}$ with Lorentz indexes of $\varepsilon_{\mu_1\mu_2\mu_3\mu_4}$ all in 4 dimensions. To obtain the correct result in this scheme, a "special" vertex called "reading point" should be identified in the loops and all the γ_5 in Dirac structures should be removed to the vertex before performing projection. Generally, different treatments of "reading point" in each Feynman graph may generate a discrepancy proportional to the totally antisymmetric Levi-Civita tensor ε. In some computations of specific processes, different intermediate results may be derived if different regularization schemes are selected [91, 92].However, physical results should be the same in different regularization schemes as long as the unitarity is kept in the theory after some necessary renormalization[93, 94, 95, 96, 97, 98].

To describe the procedure more clearly, an illustrative example of deriving R from the gluon self-energy in MSSM QCD is provided. The corresponding Feynman diagrams are shown in Fig.1. The contribution of diagram (a) in Fig.1 is vanishing because it is a massless tadpole. For $(b) - (d)$, the internal scalar loops cannot give a non-vanishing contribution to the R of gluon self-energy because the vertices are always contracted to external polarization vectors. The nontrivial contributions are only from the last three diagrams. For the quark loop with two external gluons, the numerator can be read as

$$\bar{N}(\bar{q}) = -\frac{g_s^2}{(2\pi)^4}\frac{\delta_{ab}}{2} Tr[\gamma^{\mu}(\bar{\not{q}} + m_Q)\gamma^{\nu}(\bar{\not{q}} + \not{p} + m_Q)], \tag{3.4}$$

where external indices μ and ν have been taken in four dimensions. After performing some Dirac algebra, one arrive at

$$\tilde{N}(\tilde{q}^2) = 4\frac{g_s^2}{(2\pi)^4}\frac{\delta_{ab}}{2} g^{\mu\nu}\tilde{q}^2. \tag{3.5}$$

Integrating it with the help of any one-loop integral reduction algorithms, this quark loop contribution can be obtained. The last two diagrams are gluino loop and gluon loop. The same basic procedure is employed to deal with these loops.

4. Feynman Rules for the Rational Part

In this section, the complete list of the effective MSSM QCD vertices contributing to R in the 't Hooft-Feynman gauge are given. We use FEYNARTS [99] to generate all of the Feynman amplitudes. Therefore, the Feynman rules are following the

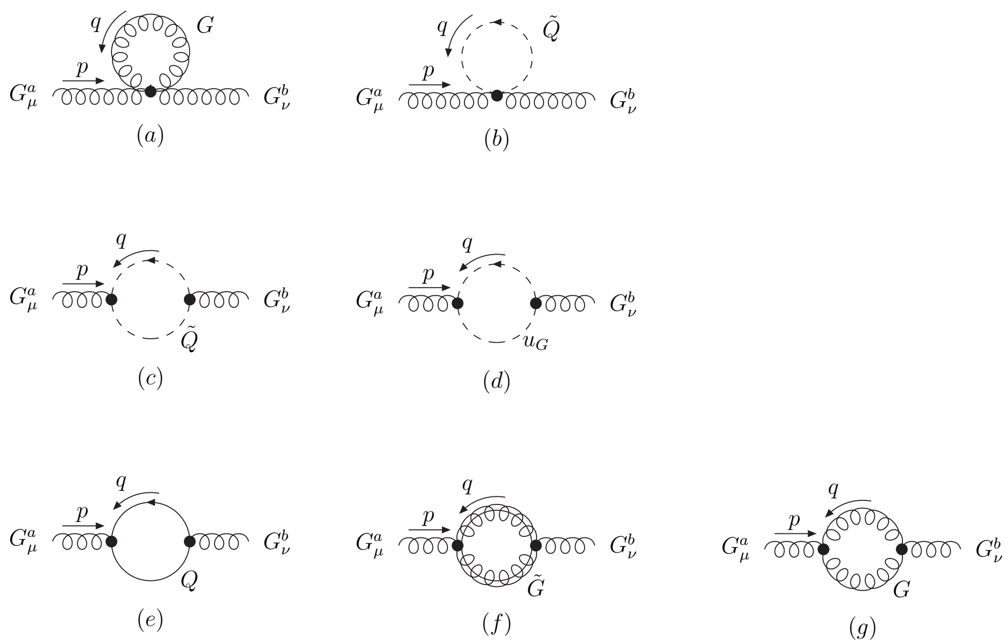


Figure 1: Diagrams contributing to the gluon self-energy in the MSSM QCD.

conventions of Refs.[100, 101, 102, 103]. In particular, fermion chains are concatenated following the algorithm in Ref.[104], which works also for Majorana fermions and the fermion-number-violating couplings.Two parameters λ_{HV} and $g5s$ are introduced in the formulae to denote the different dimensional regularization schemes and γ_5 schemes as in our previous paper [59]. Here, $\lambda_{HV} = 1$ corresponds to the 't Hooft-Veltman regularization scheme and $\lambda_{HV} = 0$ to the Four Dimensional Helicity scheme, while $g5s = 1$ corresponds to the KKS γ_5 scheme and $g5s = -1$ to the HV

γ_5 scheme. Our notations are as follows:

$$\begin{aligned}
L_1 = e, \quad L_2 = \mu, \quad L_3 = \tau, \\
L_4 = \nu_e, \quad L_5 = \nu_\mu, \quad L_6 = \nu_\tau, \\
Q_1 = u, \quad Q_2 = d, \quad Q_3 = s, \\
Q_4 = c, \quad Q_5 = b, \quad Q_6 = t, \\
\tilde{L}_{1,1} = \tilde{e}_1, \quad \tilde{L}_{1,2} = \tilde{e}_2, \quad \tilde{L}_{2,1} = \tilde{\mu}_1, \\
\tilde{L}_{2,2} = \tilde{\mu}_2, \quad \tilde{L}_{3,1} = \tilde{\tau}_1, \quad \tilde{L}_{3,2} = \tilde{\tau}_2, \\
\tilde{L}_4 = \tilde{\nu}_e, \quad \tilde{L}_5 = \tilde{\nu}_\mu, \quad \tilde{L}_6 = \tilde{\nu}_\tau, \\
\tilde{Q}_{1,1} = \tilde{u}_1, \quad \tilde{Q}_{1,2} = \tilde{u}_2, \quad \tilde{Q}_{2,1} = \tilde{d}_1, \\
\tilde{Q}_{2,2} = \tilde{d}_2, \quad \tilde{Q}_{3,1} = \tilde{s}_1, \quad \tilde{Q}_{3,2} = \tilde{s}_2, \\
\tilde{Q}_{4,1} = \tilde{c}_1, \quad \tilde{Q}_{4,2} = \tilde{c}_2, \quad \tilde{Q}_{5,1} = \tilde{b}_1, \\
\tilde{Q}_{5,2} = \tilde{b}_2, \quad \tilde{Q}_{6,1} = \tilde{t}_1, \quad \tilde{Q}_{6,2} = \tilde{t}_2.
\end{aligned} \tag{4.1}$$

In addition,

$$\begin{aligned}
e_1 = e, \quad e_2 = \mu, \quad e_3 = \tau, \\
\nu_1 = \nu_e, \quad \nu_2 = \nu_\mu, \quad \nu_3 = \nu_\tau, \\
U_1 = u, \quad U_2 = c, \quad U_3 = t, \\
D_1 = d, D_2 = s, D_3 = b, \\
\tilde{e}_{1,1} = \tilde{e}_1, \quad \tilde{e}_{1,2} = \tilde{e}_2, \quad \tilde{e}_{2,1} = \tilde{\mu}_1, \\
\tilde{e}_{2,2} = \tilde{\mu}_2, \quad \tilde{e}_{3,1} = \tilde{\tau}_1, \quad \tilde{e}_{3,2} = \tilde{\tau}_2, \\
\tilde{\nu}_1 = \tilde{\nu}_e, \quad \tilde{\nu}_2 = \tilde{\nu}_\mu, \quad \tilde{\nu}_3 = \tilde{\nu}_\tau, \\
\tilde{U}_{1,1} = \tilde{u}_1, \quad \tilde{U}_{1,2} = \tilde{u}_2, \quad \tilde{U}_{2,1} = \tilde{c}_1, \\
\tilde{U}_{2,2} = \tilde{c}_2, \quad \tilde{U}_{3,1} = \tilde{t}_1, \quad \tilde{U}_{3,2} = \tilde{t}_2, \\
\tilde{D}_{1,1} = \tilde{d}_1, \quad \tilde{D}_{1,2} = \tilde{d}_2, \quad \tilde{D}_{2,1} = \tilde{s}_1, \\
\tilde{D}_{2,2} = \tilde{s}_2, \quad \tilde{D}_{3,1} = \tilde{b}_1, \quad \tilde{D}_{3,2} = \tilde{b}_2.
\end{aligned} \tag{4.2}$$

N_c denotes the number of colors and V_{u_i,d_j} are CKM matrix elements. In MSSM, the following rotation matrices should be introduced too

$$\begin{pmatrix} \tilde{Q}_{l,1} \\ \tilde{Q}_{l,2} \end{pmatrix} = R_l \begin{pmatrix} \tilde{Q}_{l,L} \\ \tilde{Q}_{l,R} \end{pmatrix}, \begin{pmatrix} \tilde{U}_{l,1} \\ \tilde{U}_{l,2} \end{pmatrix} = RU_l \begin{pmatrix} \tilde{U}_{l,L} \\ \tilde{U}_{l,R} \end{pmatrix},$$
$$\begin{pmatrix} \tilde{D}_{l,1} \\ \tilde{D}_{l,2} \end{pmatrix} = RD_l \begin{pmatrix} \tilde{D}_{l,L} \\ \tilde{D}_{l,R} \end{pmatrix}, \begin{pmatrix} \tilde{e}_{l,1} \\ \tilde{e}_{l,2} \end{pmatrix} = RL_l \begin{pmatrix} \tilde{e}_{l,L} \\ \tilde{e}_{l,R} \end{pmatrix}.$$

Besides, matrices RN, CR, CL are the neutralino mixing matrix and the right-handed , left-handed chargino mixing matrices respectively, which is also following the convention of FEYNARTS. We denote the element of matrix M as M_{ij}, $M_{i,j}$ or $M_{(i,j)}$.

To make the result readable, we introduce some notations for the following frequently used summations

$$
\begin{aligned}
SR1(l,m)_{s1,s2} &\equiv \sum_{k=1}^{2} R^*_{l,(s1,k)} R_{m,(s2,k)} = \left(R_m R_l^\dagger\right)_{s2,s1}, \\
SR2(l,m)_{s1,s2} &\equiv R^*_{l,(s1,1)} R_{m,(s2,2)} + R^*_{l,(s1,2)} R_{m,(s2,1)}, \\
SRU1(l,m)_{s1,s2} &\equiv \sum_{k=1}^{2} RU^*_{l,(s1,k)} RU_{m,(s2,k)} = \left(RU_m RU_l^\dagger\right)_{s2,s1}, \\
SRU2(l,m)_{s1,s2} &\equiv RU^*_{l,(s1,1)} RU_{m,(s2,2)} + RU^*_{l,(s1,2)} RU_{m,(s2,1)}, \\
SRD1(l,m)_{s1,s2} &\equiv \sum_{k=1}^{2} RD^*_{l,(s1,k)} RD_{m,(s2,k)} = \left(RD_m RD_l^\dagger\right)_{s2,s1}, \\
SRD2(l,m)_{s1,s2} &\equiv RD^*_{l,(s1,1)} RD_{m,(s2,2)} + RD^*_{l,(s1,2)} RD_{m,(s2,1)}.
\end{aligned}
$$

$\Omega^- \equiv \frac{1-\gamma_5}{2}$ and $\Omega^+ \equiv \frac{1+\gamma_5}{2}$ are two chiral projection operators with g_s, e coupling constants in QCD and QED respectively. For brevity, $t_\beta = \tan\beta, c_\beta = \cos\beta, s_\beta = \sin\beta, c_\alpha = \cos\alpha, s_\alpha = \sin\alpha, c_w = \cos\theta_w, s_w = \sin\theta_w$. Parameters μ and A_{Q_l} are the Higgs-doublet mixing parameter and the soft breaking A-parameters. In some cases, we also use notation $A = B(\alpha \to \beta)$, which means the expression A are obtained from B by all of the α in B replaced by the β.

4.1 Effective Vertices in Pure MSSM QCD

In this section, we give the complete list of the non-vanishing R effective vertices in pure MSSM QCD, with all external and internal legs MSSM QCD particles.

4.1.1 Pure MSSM QCD effective vertices with 2 external legs

All possible non-vanishing 2-point vertices in pure MSSM QCD are shown in Fig.2.

Squark-Squark vertices

There is no generation mixing in these vertices. The corresponding effective vertex is shown in Fig.2 (a) with their expressions as follows

$$
\begin{aligned}
\mathrm{Vert}(\tilde{Q}^i_{l,s1}, \tilde{Q}^j_{m,s2}) = \frac{ig_s^2}{24\pi^2}\, C_F\, \delta^{ij}\, \delta_{lm}\, \Bigg\{ &\left(3m^2_{\tilde{G}} + 3m^2_{Q_l} - p^2\right) \left[\frac{1+g5s}{2} SR1(l,l)_{s1,s2}\right. \\
&\left. - \frac{1-g5s}{2} SR2(l,l)_{s1,s2}\right] + \frac{\delta_{s1,s2}}{4}\left(3m^2_{\tilde{Q}_{l,s1}} - p^2\right)\Bigg\}. \qquad (4.3)
\end{aligned}
$$

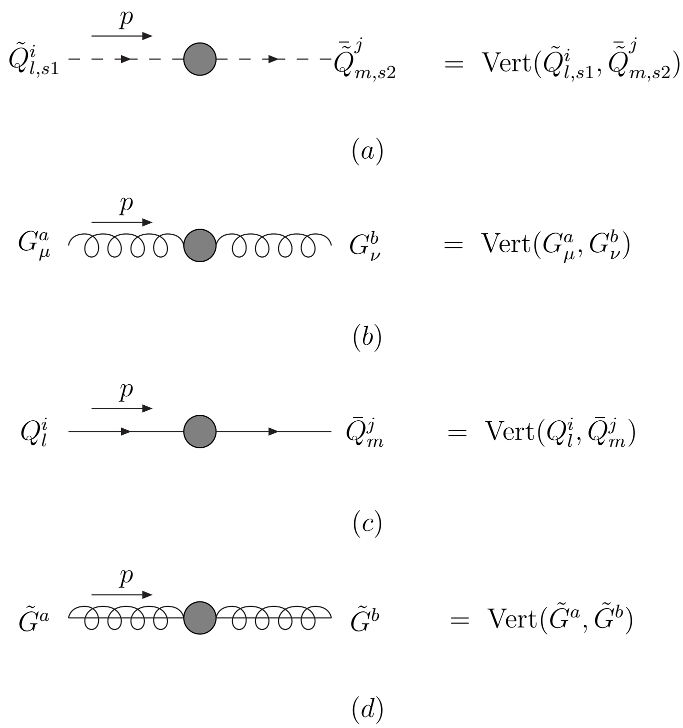


Figure 2: All possible non-vanishing 2-point vertices in pure MSSM QCD.

Gluon-Gluon vertex

The corresponding diagram is shown in Fig.2 (b) with its expression as follows

$$\begin{aligned}\text{Vert}(G^a_\mu, G^b_\nu) = \frac{ig_s^2}{48\pi^2}\; C_A\; \delta^{ab}\; &\left[\frac{p^2}{2} g_{\mu\nu} + \lambda_{HV}\left(g_{\mu\nu}p^2 - p_\mu p_\nu\right)\right. \\ &\left. + \sum_Q \left(\frac{p^2 - 6m_Q^2}{N_c} g_{\mu\nu}\right) + \left(p^2 - 6m_{\tilde{G}}^2\right) g_{\mu\nu}\right]. \end{aligned} \tag{4.4}$$

Quark-Quark vertices

The corresponding diagram is shown in Fig.2 (c) with its expression as follows

$$\text{Vert}(Q^i_l, \bar{Q}^j_m) = \frac{ig_s^2}{16\pi^2}\; C_F\; \delta^{ij}\; \delta_{lm}\; \left(-\not{p} + 2m_{Q_l}\right)\lambda_{HV}. \tag{4.5}$$

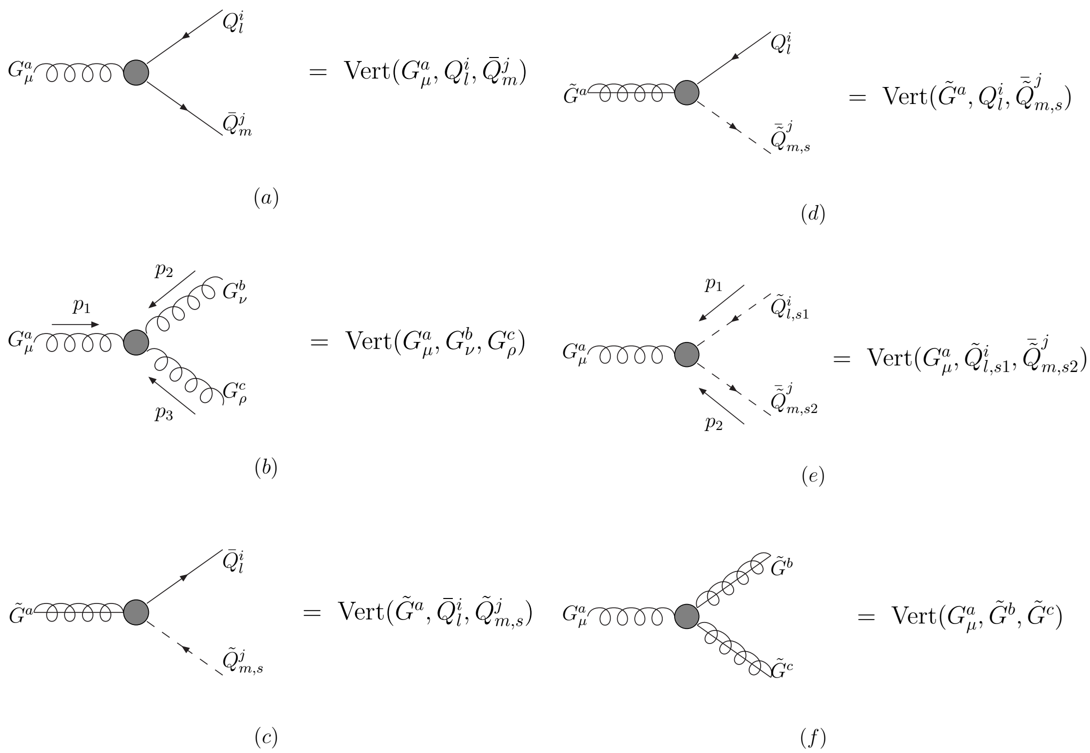


Figure 3: All possible non-vanishing 3-point vertices in pure MSSM QCD.

Gluino-Gluino vertex

The corresponding diagram is shown in Fig.2 (d) with its expression as follows

$$\mathrm{Vert}(\tilde{G}^a, \tilde{G}^b) = \frac{ig_s^2}{16\pi^2}\, C_A\, \delta^{ab}\, \left(-\not{p} + 2m_{\tilde{G}}\right) \lambda_{HV}. \tag{4.6}$$

4.1.2 Pure MSSM QCD effective vertices with 3 external legs

All possible non-vanishing 3-point vertices in pure MSSM QCD are shown in Fig.3.

Gluon-Quark-Quark vertices

The corresponding diagram is shown in Fig.3 (a) with its expression as follows

$$\mathrm{Vert}(G^a_\mu, Q^i_l, \bar{Q}^j_m) = \frac{ig_s^3}{16\pi^2}\, T^a_{ji}\, \delta_{lm} \left(C_- \Omega^- + C_+ \Omega^+\right) \gamma_\mu, \tag{4.7}$$

where

$$
\begin{aligned}
C_- &= (1+\lambda_{HV})\, C_F + \frac{N_c}{2} \left(R_l^\dagger R_l\right)_{2,2} \ , \\
C_+ &= (1+\lambda_{HV})\, C_F + \frac{N_c}{2} \left(R_l^\dagger R_l\right)_{1,1} \ . \qquad (4.8)
\end{aligned}
$$

Gluon-Gluon-Gluon vertex

The corresponding diagram is shown in Fig.3 (b) with its expression with only N_f flavor quarks as follows

$$
\mathrm{Vert}(G_\mu^a, G_\nu^b, G_\rho^c) = -\frac{g_s^3 N_c}{48\pi^2} \left(\frac{15}{4} + \lambda_{HV} + \frac{2N_f}{N_c}\right) f^{abc}\, V_{\mu\nu\rho}(p_1,p_2,p_3), \qquad (4.9)
$$

where

$$
V_{\mu\nu\rho}(p_1,p_2,p_3) = \ g_{\mu\nu}(p_2-p_1)_\rho + g_{\nu\rho}(p_3-p_2)_\mu + g_{\rho\mu}(p_1-p_3)_\nu . \qquad (4.10)
$$

Gluino-Quark-Squark vertices

The corresponding diagram are shown in Fig.3 (c,d) with their expressions as follows

$$
\begin{aligned}
\mathrm{Vert}(\tilde{G}^a, Q_l^i, \bar{\tilde{Q}}_{m,s}^j) &= \frac{i g_s^3}{\pi^2}\, T_{ji}^a\ \delta_{lm} \left(C_-\Omega^- + C_+\Omega^+\right), \\
\mathrm{Vert}(\tilde{G}^a, \bar{Q}_l^i, \tilde{Q}_{m,s}^j) &= \frac{i g_s^3}{\pi^2}\, T_{ij}^a\ \delta_{lm} \left(C_+^*\Omega^- + C_-^*\Omega^+\right), \qquad (4.11)
\end{aligned}
$$

where

$$
\begin{aligned}
C_- = \frac{1}{32\sqrt{2}N_c} \Bigg[&\left(R_{l,(s,1)} - \frac{1-g5s}{2}\, 4(1+\lambda_{HV}) R_{l,(s,2)} + \frac{1+g5s}{2}\, 4(1+\lambda_{HV}) R_{l,(s,1)} \right) N_c^2 \\
&- R_{l,(s,1)} - \frac{1-g5s}{2}\, 2R_{l,(s,1)} \left(R_l^\dagger R_l\right)_{2,1} + \frac{1+g5s}{2}\, 2R_{l,(s,2)} \left(R_l^\dagger R_l\right)_{2,1} \Bigg], \\
C_+ = -\frac{1}{32\sqrt{2}N_c} \Bigg[&\left(R_{l,(s,2)} - \frac{1-g5s}{2}\, 4(1+\lambda_{HV}) R_{l,(s,1)} + \frac{1+g5s}{2}\, 4(1+\lambda_{HV}) R_{l,(s,2)} \right) N_c^2 \\
&- R_{l,(s,2)} - \frac{1-g5s}{2}\, 2R_{l,(s,2)} \left(R_l^\dagger R_l\right)_{1,2} + \frac{1+g5s}{2}\, 2R_{l,(s,1)} \left(R_l^\dagger R_l\right)_{1,2} \Bigg]. \qquad (4.12)
\end{aligned}
$$

Gluon-Squark-Squark vertices

The corresponding diagram is shown in Fig.3 (e) with its expression as follows

$$\begin{aligned}\mathrm{Vert}(G^a_\mu, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}) = \frac{ig_s^3}{12\pi^2}\ T^a_{ji}\ \delta_{lm}\ \Bigg[\ & \frac{6N_c^2-1}{16N_c}\delta_{s1,s2} \\ & +\frac{1+g5s}{2}\ C_F\ SR1(l,l)_{s1,s2} + \frac{1-g5s}{2}\ \frac{C_F}{2} \\ & (SR1(l,l)_{s1,s2} - SR2(l,l)_{s1,s2})\Big]\ (p_1-p_2)_\mu. \end{aligned} \tag{4.13}$$

Gluon-Gluino-Gluino vertex

The corresponding diagram is shown in Fig.3 (f) with its expression as follows

$$\mathrm{Vert}(G^a_\mu, \tilde{G}^b, \tilde{G}^c) = \frac{ig_s^3}{16\pi^2}\ \left(C_-\Omega^- + C_+\Omega^+\right)\ \gamma_\mu, \tag{4.14}$$

where

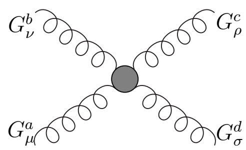
$$\begin{aligned} C_- &= 2N_c\left(Tr(T^aT^bT^c) - Tr(T^aT^cT^b)\right)(1+\lambda_{HV}) \\ &\quad + \left(Tr(T^aT^bT^c)\ \sum_l \left(R_l^\dagger R_l\right)_{1,1} - Tr(T^aT^cT^b)\ \sum_l \left(R_l^\dagger R_l\right)_{2,2}\right), \\ C_+ &= 2N_c\left(Tr(T^aT^bT^c) - Tr(T^aT^cT^b)\right)(1+\lambda_{HV}) \\ &\quad + \left(Tr(T^aT^bT^c)\ \sum_l \left(R_l^\dagger R_l\right)_{2,2} - Tr(T^aT^cT^b)\ \sum_l \left(R_l^\dagger R_l\right)_{1,1}\right). \end{aligned} \tag{4.15}$$

4.1.3 Pure MSSM QCD effective vertices with 4 external legs

All possible non-vanishing 4-point vertices in pure MSSM QCD are shown in Fig.4.

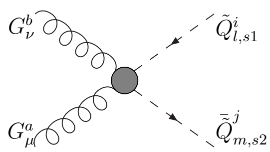
Gluon-Gluon-Gluon-Gluon vertex

The corresponding diagram is shown in Fig.4 (a) with its expression with only N_f flavors quarks as follows



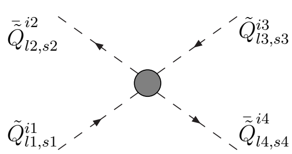
$= \text{Vert}\left(G^a_\mu, G^b_\nu, G^c_\rho, G^d_\sigma\right)$

(a)



$= \text{Vert}\left(G^a_\mu, G^b_\nu, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right)$

(b)



$= \text{Vert}\left(\tilde{Q}^{i1}_{l1,s1}, \bar{\tilde{Q}}^{i2}_{l2,s2}, \tilde{Q}^{i3}_{l3,s3}, \bar{\tilde{Q}}^{i4}_{l4,s4}\right)$

(c)

Figure 4: All possible non-vanishing 4-point vertices in pure MSSM QCD.

$$\text{Vert}\left(G^a_\mu, G^b_\nu, G^c_\rho, G^d_\sigma\right) = \frac{i g_s^4}{48\pi^2}\ \left(C_1\ g_{\mu\nu} g_{\rho\sigma} + C_2\ g_{\mu\rho} g_{\nu\sigma} + C_3\ g_{\mu\sigma} g_{\nu\rho}\right), \quad (4.16)$$

where

$$\begin{aligned}
C_1 &= Tr(\{T^a, T^b\}\{T^c, T^d\})\ \left(11N_c + 2\lambda_{HV} N_c + 6N_f\right) \\
&\quad - \left(Tr(T^a T^c T^b T^d) + Tr(T^a T^d T^b T^c)\right)\left(22N_c + 4\lambda_{HV} N_c + 10N_f\right)\ , \\
C_2 &= C_1(b \leftrightarrow c) = Tr(\{T^a, T^c\}\{T^b, T^d\})\ \left(11N_c + 2\lambda_{HV} N_c + 6N_f\right) \\
&\quad - \left(Tr(T^a T^b T^c T^d) + Tr(T^a T^d T^c T^b)\right)\left(22N_c + 4\lambda_{HV} N_c + 10N_f\right)\ , \\
C_3 &= C_1(b \leftrightarrow d) = Tr(\{T^a, T^d\}\{T^c, T^b\})\ \left(11N_c + 2\lambda_{HV} N_c + 6N_f\right) \\
&\quad - \left(Tr(T^a T^c T^d T^b) + Tr(T^a T^b T^d T^c)\right)\left(22N_c + 4\lambda_{HV} N_c + 10N_f\right)\ . \quad (4.17)
\end{aligned}$$

Gluon-Gluon-Squark-Squark vertices

The corresponding diagram is shown in Fig.4 (b) with its expression as follows

$$\mathrm{Vert}\left(G^a_\mu, G^b_\nu, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^4}{\pi^2}\ C\ g_{\mu\nu}. \tag{4.18}$$

where

$$\begin{aligned} C = &-\frac{1}{48}\ \delta_{lm}\ \left[\frac{1+g5s}{2}\ \left(3\ \delta^{ij}\ \delta^{ab} + 8\ C_F\ \left\{T^a, T^b\right\}_{ji}\right)\ SR1(l,l)_{s1,s2}\right. \\ &+\frac{1-g5s}{2}\ \left(2\ C_F\ \left\{T^a, T^b\right\}_{ji}\ \left(5\ SR1(l,l)_{s1,s2} + SR2(l,l)_{s1,s2}\right)\right. \\ &+\left.\delta^{ij}\ \delta^{ab}\ \left(7\ SR1(l,l)_{s1,s2} + 4\ SR2(l,l)_{s1,s2}\right)\right) \\ &\left.-\frac{\delta_{s1,s2}}{8}\left(\delta^{ij}\ \delta^{ab} - \frac{21N_c^2-2}{N_c}\ \left\{T^a, T^b\right\}_{ji}\right)\right]. \end{aligned} \tag{4.19}$$

Squark-Squark-Squark-Squark vertices

The corresponding diagram is shown in Fig.4 (c) with its expression as follows

$$\mathrm{Vert}\left(\tilde{Q}^{i1}_{l1,s1}, \bar{\tilde{Q}}^{i2}_{l2,s2}, \tilde{Q}^{i3}_{l3,s3}, \bar{\tilde{Q}}^{i4}_{l4,s4}\right) = \frac{ig_s^4}{\pi^2}\ \left(C_1\ \delta^{i1,i2}\delta^{i3,i4} + C_2\ \delta^{i1,i4}\delta^{i2,i3}\right) \tag{4.20}$$

where

$$\begin{aligned} C_1 = &-\frac{1}{384N_c^2}\ \left\{K1\left[\left(-\left(42+4\ g5s\right)N_c^3 + \left(78+8\ g5s\right)N_c\right)\delta_{l1,l4}\ \delta_{l2,l3}\right.\right. \\ &+\left.\left(6N_c^2 - \left(42+4\ g5s\right)\right)\ \delta_{l1,l2}\ \delta_{l3,l4}\right] + K2\ \left(-\left(42+4\ g5s\right)N_c^2 - \left(30+4\ g5s\right)\right) \\ &\delta_{l1,l2}\delta_{l3,l4} + K3\ \left(6N_c^3 + \left(66+8\ g5s\right)N_c\right)\ \delta_{l1,l4}\ \delta_{l2,l3} \\ &+\frac{1-g5s}{2}\ K4\ \left[\left(-8N_c^2-16\right)\ \delta_{l1,l2}\ \delta_{l3,l4} + \left(-8N_c^3+32N_c\right)\ \delta_{l1,l4}\ \delta_{l2,l3}\right] \\ &\left.+\left(12\lambda_{HV}-1\right)\left[\left(N_c^2+2\right)\delta_{s1,s2}\ \delta_{s3,s4}\ \delta_{l1,l2}\ \delta_{l3,l4} + \left(N_c^3-4N_c\right)\ \delta_{s1,s4}\ \delta_{s2,s3}\ \delta_{l1,l4}\ \delta_{l2,l3}\right]\right\}, \\ C_2 = &\ C_1\left(l2\leftrightarrow l4, s2\leftrightarrow s4\right). \end{aligned} \tag{4.21}$$

For brevity, we also introduce following notations

$$\begin{aligned} K1 &= \sum_{k=1}^{2}\left(R^*_{l1,(s1,k)}R_{l2,(s2,k)}R^*_{l3,(s3,k)}R_{l4,(s4,k)}\right), \\ K2 &= R^*_{l1,(s1,1)}R_{l2,(s2,1)}R^*_{l3,(s3,2)}R_{l4,(s4,2)} + R^*_{l1,(s1,2)}R_{l2,(s2,2)}R^*_{l3,(s3,1)}R_{l4,(s4,1)}, \\ K3 &= R^*_{l1,(s1,1)}R_{l2,(s2,2)}R^*_{l3,(s3,2)}R_{l4,(s4,1)} + R^*_{l1,(s1,2)}R_{l2,(s2,1)}R^*_{l3,(s3,1)}R_{l4,(s4,2)}, \\ K4 &= R^*_{l1,(s1,1)}R_{l2,(s2,2)}R^*_{l3,(s3,1)}R_{l4,(s4,2)} + R^*_{l1,(s1,2)}R_{l2,(s2,1)}R^*_{l3,(s3,2)}R_{l4,(s4,1)}. \end{aligned} \tag{4.22}$$

4.2 Effective Vertices in Mixed MSSM QCD

In this section, we give the complete set of the non-vanishing R effective vertices in mixed MSSM QCD, with all internal legs SUSY QCD particles and parts of external legs MSSM particles.

4.2.1 Mixed MSSM QCD effective vertices with 3 external legs

All possible non-vanishing 3-point vertices in mixed MSSM QCD are shown in Fig.5.

Scalar-Gluon-Gluon vertices

The generic effective vertex is shown in Fig.5 (a) with its expression as follows

$$\begin{aligned}
\mathrm{Vert}\left(h^0, G^a_\mu, G^b_\nu\right) &= -\frac{ig_s^2 e}{8\pi^2}\ \delta^{ab}\ g_{\mu\nu}\ \frac{1}{2m_W s_w}\left(\frac{c_\alpha}{s_\beta}\sum_U m_U^2 - \frac{s_\alpha}{c_\beta}\sum_D m_D^2\right),\\
\mathrm{Vert}\left(H^0, G^a_\mu, G^b_\nu\right) &= -\frac{ig_s^2 e}{8\pi^2}\ \delta^{ab}\ g_{\mu\nu}\ \frac{1}{2m_W s_w}\left(\frac{s_\alpha}{s_\beta}\sum_U m_U^2 + \frac{c_\alpha}{c_\beta}\sum_D m_D^2\right),\\
\mathrm{Vert}\left(A^0\ or\ \phi^0, G^a_\mu, G^b_\nu\right) &= 0.
\end{aligned} \tag{4.23}$$

Vector-Gluon-Gluon vertices

The generic effective vertex is shown in Fig.5 (b) with its expression as follows

$$\begin{aligned}
\mathrm{Vert}\left(Z_\mu, G^a_\nu, G^b_\rho\right) &= \frac{g_s^2 e}{12\pi^2}\ \delta^{ab}\ \varepsilon_{\mu\nu\rho(p1-p2)}\ \frac{1}{2c_w s_w}\ \sum_Q I_{3Q},\\
\mathrm{Vert}\left(A_\mu, G^a_\nu, G^b_\rho\right) &= 0.
\end{aligned} \tag{4.24}$$

Neutralino-Gluon-Gluino vertices

The generic effective vertex is shown in Fig.5 (c) with its expression as follows

$$\mathrm{Vert}\left(G^a_\mu, \tilde{G}^b, \tilde{\chi}^0_l\right) = \frac{ig_s^2 e}{\pi^2}\ \left(C_-\Omega^- + C_+\Omega^+\right)\ \gamma_\mu, \tag{4.25}$$

where

$$
\begin{aligned}
C_- =& \frac{\delta^{ab}}{192 m_W c_w s_w c_\beta s_\beta} \Bigg[m_W s_w c_\beta s_\beta RN^*_{l,1} (\sum_m \left(R^\dagger_m R_m\right)_{1,1} - 4 \sum_m \left(RU^\dagger_m RU_m\right)_{2,2} \\
&+2 \sum_m \left(RD^\dagger_m RD_m\right)_{2,2}) + 3 m_W c_w c_\beta s_\beta RN^*_{l,2} (\sum_m \left(RU^\dagger_m RU_m\right)_{1,1} \\
&- \sum_m \left(RD^\dagger_m RD_m\right)_{1,1}) + 6 c_w c_\beta RN^*_{l,4} \sum_m m_{U_m} \left(RU^\dagger_m RU_m\right)_{1,2} \\
&+6 c_w s_\beta RN^*_{l,3} \sum_m m_{D_m} \left(RD^\dagger_m RD_m\right)_{1,2} \Bigg], \\
C_+ =& -C_-^* \ .
\end{aligned}
\tag{4.26}
$$

Scalar-Gluino-Gluino vertices

The generic effective vertex is shown in Fig.5 (d) with its generic expression as follows

$$
\mathrm{Vert}\left(S, \tilde{G}^a, \tilde{G}^b\right) = \frac{i g_s^2 e}{\pi^2} \left(C_-^S \Omega^- + C_+^S \Omega^+\right). \tag{4.27}
$$

The actual values of S, C_-^S and C_+^S are

$$
\begin{aligned}
C_-^{h^0} &= \frac{\delta^{ab}}{32 m_W s_w c_\beta s_\beta} \left(c_\alpha c_\beta \sum_l m_{U_l} \left(RU^\dagger_l RU_l\right)_{2,1} - s_\alpha s_\beta \sum_l m_{D_l} \left(RD^\dagger_l RD_l\right)_{2,1} \right), \\
C_+^{h^0} &= (C_-^{h^0})^*, \\
C_\pm^{H^0} &= C_\pm^{h^0} \left(c_\alpha \to s_\alpha, s_\alpha \to -c_\alpha\right), \\
C_-^{A^0} &= g5s \frac{-i\delta^{ab}}{32 m_W s_w t_\beta} \left(\sum_l m_{U_l} \left(RU^\dagger_l RU_l\right)_{2,1} + t_\beta^2 \sum_l m_{D_l} \left(RD^\dagger_l RD_l\right)_{2,1} \right), \\
C_+^{A^0} &= (C_-^{A^0})^*, \\
C_-^{\phi^0} &= g5s \frac{i\delta^{ab}}{32 m_W s_w} \left(-\sum_l m_{U_l} \left(RU^\dagger_l RU_l\right)_{2,1} + \sum_l m_{D_l} \left(RD^\dagger_l RD_l\right)_{2,1} \right), \\
C_+^{\phi^0} &= (C_-^{\phi^0})^* \ .
\end{aligned}
\tag{4.28}
$$

Vector-Gluino-Gluino vertices

The generic effective vertex is shown in Fig.5 (e) with its generic expression as follows

$$\text{Vert}\left(V_\mu, \tilde{G}^a, \tilde{G}^b\right) = \frac{i g_s^2 e}{\pi^2}\ \left(C_-^V \Omega^- + C_+^V \Omega^+\right)\ \gamma_\mu. \tag{4.29}$$

The actual values of V, C_-^V and C_+^V are

$$\begin{aligned}
C_-^A &= \frac{\delta^{ab}}{96}\Bigg[2\ \sum_l \left(\left(RU_l^\dagger RU_l\right)_{1,1} - \left(RU_l^\dagger RU_l\right)_{2,2}\right) \\
&\quad - \sum_l \left(\left(RD_l^\dagger RD_l\right)_{1,1} - \left(RD_l^\dagger RD_l\right)_{2,2}\right)\Bigg], \\
C_+^A &= -C_-^A, \\
C_-^Z &= -\frac{\delta^{ab}}{192 c_w s_w}\Bigg\{\sum_l \Bigg[\left(4s_w^2 - \frac{1+g5s}{2}\ 3\right)\left(RU_l^\dagger RU_l\right)_{1,1} \\
&\quad - \left(4s_w^2 - \frac{1-g5s}{2}\ 3\right)\left(RU_l^\dagger RU_l\right)_{2,2}\Bigg] \\
&\quad - \sum_l \Bigg[\left(2s_w^2 - \frac{1+g5s}{2}\ 3\right)\left(RD_l^\dagger RD_l\right)_{1,1} \\
&\quad - \left(2s_w^2 - \frac{1-g5s}{2}\ 3\right)\left(RD_l^\dagger RD_l\right)_{2,2}\Bigg]\Bigg\}, \\
C_+^Z &= -C_-^Z\ .
\end{aligned} \tag{4.30}$$

Neutralino-Quark-Squark vertices

The generic effective vertices are shown in Fig.5 (f, g) with their generic expressions as follows

$$\begin{aligned}
\text{Vert}\left(\tilde{\chi}_n^0, Q_l^i, \bar{\tilde{Q}}_{m,s}^j\right) &= \frac{i g_s^2 e}{\pi^2}\ \delta_{lm}\ \left(C_-^{Q_l}\Omega^- + C_+^{Q_l}\Omega^+\right), \\
\text{Vert}\left(\tilde{\chi}_n^0, \bar{Q}_l^i, \tilde{Q}_{m,s}^j\right) &= \frac{i g_s^2 e}{\pi^2}\ \delta_{lm}\ \left(C_-^{\bar{Q}_l}\Omega^- + C_+^{\bar{Q}_l}\Omega^+\right).
\end{aligned} \tag{4.31}$$

The actual values of $\tilde{\chi}^0$, Q, $\tilde{Q}$, C_-^Q and C_+^Q are

$$
\begin{aligned}
C_-^{U_l} &= \frac{\delta^{ij}}{96\sqrt{2}m_W c_w s_w s_\beta}\ C_F\ \left[m_W s_w s_\beta RN^*_{n,1} RU_{l,(s,1)}\right. \\
&+3m_W c_w s_\beta RN^*_{n,2} RU_{l,(s,1)} + g5s\ 6m_{U_l} c_w RN^*_{n,4}\left(RU_l^\dagger RU_l\right)_{1,1} RU_{l,(s,\frac{3+g5s}{2})} \\
&-g5s\ 8m_W s_w s_\beta RN^*_{n,1}\left(RU_l^\dagger RU_l\right)_{2,1} RU_{l,(s,\frac{3+g5s}{2})} \\
&\left.+3c_w m_{U_l} RN^*_{n,4} RU_{l,(s,2)}\right], \\
C_+^{U_l} &= \frac{\delta^{ij}}{96\sqrt{2}m_W c_w s_w s_\beta}\ C_F\ \left[-4m_W s_w s_\beta RN_{n,1} RU_{l,(s,2)}\right. \\
&+3m_{U_l} c_w RN_{n,4} RU_{l,(s,1)} + g5s\ 2m_W s_w s_\beta RN_{n,1}\left(RU_l^\dagger RU_l\right)_{1,2} RU_{l,(s,\frac{3-g5s}{2})} \\
&+g5s\ 6m_W c_w s_\beta RN_{n,2}\left(RU_l^\dagger RU_l\right)_{1,2} RU_{l,(s,\frac{3-g5s}{2})} \\
&\left.+g5s\ 6m_{U_l} c_w RN_{n,4}\left(RU_l^\dagger RU_l\right)_{2,2} RU_{l,(s,\frac{3-g5s}{2})}\right], \\
C_-^{D_l} &= \frac{\delta^{ij}}{96\sqrt{2}m_W c_w s_w c_\beta}\ C_F\ \left[m_W s_w c_\beta RN^*_{n,1} RD_{l,(s,1)}\right. \\
&-3m_W c_w c_\beta RN^*_{n,2} RD_{l,(s,1)} + g5s\ 6m_{D_l} c_w RN^*_{n,3}\left(RD_l^\dagger RD_l\right)_{1,1} RD_{l,(s,\frac{3+g5s}{2})} \\
&+g5s\ 4m_W s_w c_\beta RN^*_{n,1}\left(RD_l^\dagger RD_l\right)_{2,1} RD_{l,(s,\frac{3+g5s}{2})} \\
&\left.+3m_{D_l} c_w RN^*_{n,3} RD_{l,(s,2)}\right], \\
C_+^{D_l} &= \frac{\delta^{ij}}{96\sqrt{2}m_W c_w s_w c_\beta}\ C_F\ \left[2m_W s_w c_\beta RN_{n,1} RD_{l,(s,2)}\right. \\
&+3m_{D_l} c_w RN_{n,3} RD_{l,(s,1)} + g5s\ 2m_W s_w c_\beta RN_{n,1}\left(RD_l^\dagger RD_l\right)_{1,2} RD_{l,(s,\frac{3-g5s}{2})} \\
&-g5s\ 6m_W c_w c_\beta RN_{n,2}\left(RD_l^\dagger RD_l\right)_{1,2} RD_{l,(s,\frac{3-g5s}{2})} \\
&\left.+g5s\ 6m_{D_l} c_w RN_{n,3}\left(RD_l^\dagger RD_l\right)_{2,2} RD_{l,(s,\frac{3-g5s}{2})}\right], \\
C_\pm^{\bar{U}_l} &= \left(C_\mp^{U_l}\right)^*\ , \\
C_\pm^{\bar{D}_l} &= \left(C_\mp^{D_l}\right)^*\ .
\end{aligned} \tag{4.32}
$$

Chargino-Quark-Squark vertices

The generic effective vertices are shown in Fig.5 (h, i) with their generic expressions as follows

$$
\begin{aligned}
\mathrm{Vert}\left(\tilde{\chi}_n^-, U_l^i, \bar{\tilde{D}}_{m,s}^j\right) &= \frac{ig_s^2 e}{\pi^2}\left(C_-^{U_l,\bar{\tilde{D}}_{m,s}}\Omega^- + C_+^{U_l,\bar{\tilde{D}}_{m,s}}\Omega^+\right),\\
\mathrm{Vert}\left(\tilde{\chi}_n^+, D_l^i, \bar{\tilde{U}}_{m,s}^j\right) &= \frac{ig_s^2 e}{\pi^2}\left(C_-^{D_l,\bar{\tilde{U}}_{m,s}}\Omega^- + C_+^{D_l,\bar{\tilde{U}}_{m,s}}\Omega^+\right),\\
\mathrm{Vert}\left(\tilde{\chi}_n^-, \bar{D}_l^i, \tilde{U}_{m,s}^j\right) &= \frac{ig_s^2 e}{\pi^2}\left(C_-^{\bar{D}_l,\tilde{U}_{m,s}}\Omega^- + C_+^{\bar{D}_l,\tilde{U}_{m,s}}\Omega^+\right),\\
\mathrm{Vert}\left(\tilde{\chi}_n^+, \bar{U}_l^i, \tilde{D}_{m,s}^j\right) &= \frac{ig_s^2 e}{\pi^2}\left(C_-^{\bar{U}_l,\tilde{D}_{m,s}}\Omega^- + C_+^{\bar{U}_l,\tilde{D}_{m,s}}\Omega^+\right),
\end{aligned}
\tag{4.33}
$$

where

$$
\begin{aligned}
C_-^{U_l,\bar{\tilde{D}}_{m,s}} &= \frac{\delta^{ij}}{64 m_W s_w c_\beta}\ C_F\ V^\dagger_{D_m,U_l}\ \Big[-2m_W c_\beta\ CR^*_{n,1} RD_{m,(s,1)}\\
&\quad +\sqrt{2} m_{D_m}\ CR^*_{n,2} RD_{m,(s,2)}\\
&\quad +g5s\ 2\sqrt{2} m_{D_m}\ CR^*_{n,2}\left(RU_l^\dagger RU_l\right)_{1,1} RD_{m,(s,\frac{3+g5s}{2})}\Big],\\
C_+^{U_l,\bar{\tilde{D}}_{m,s}} &= \frac{\delta^{ij}}{64 m_W s_w s_\beta}\ C_F\ V^\dagger_{D_m,U_l}\ \Big[\sqrt{2} m_{U_l}\ CL_{n,2} RD_{m,(s,1)}\\
&\quad +g5s\ 2\sqrt{2} m_{U_l}\ CL_{n,2}\left(RU_l^\dagger RU_l\right)_{2,2} RD_{m,(s,\frac{3-g5s}{2})}\\
&\quad -g5s\ 4 m_W s_\beta\ CL_{n,1}\left(RU_l^\dagger RU_l\right)_{1,2} RD_{m,(s,\frac{3-g5s}{2})}\Big],\\
C_-^{D_l,\bar{\tilde{U}}_{m,s}} &= \frac{\delta^{ij}}{64 m_W s_w s_\beta}\ C_F\ V_{U_m,D_l}\ \Big[2 m_W s_\beta\ CL^*_{n,1} RU_{m,(s,1)}\\
&\quad -\sqrt{2} m_{U_m}\ CL^*_{n,2} RU_{m,(s,2)}\\
&\quad -g5s\ 2\sqrt{2} m_{U_m}\ CL^*_{n,2}\left(RD_l^\dagger RD_l\right)_{1,1} RU_{m,(s,\frac{3+g5s}{2})}\Big],\\
C_+^{D_l,\bar{\tilde{U}}_{m,s}} &= \frac{\delta^{ij}}{64 m_W s_w c_\beta}\ C_F\ V_{U_m,D_l}\ \Big[-\sqrt{2} m_{D_l} CR_{n,2} RU_{m,(s,1)}\\
&\quad -g5s\ 2\sqrt{2} m_{D_l}\ CR_{n,2}\left(RD_l^\dagger RD_l\right)_{2,2} RU_{m,(s,\frac{3-g5s}{2})}\\
&\quad +g5s\ 4 m_W c_\beta\ CR_{n,1}\left(RD_l^\dagger RD_l\right)_{1,2} RU_{m,(s,\frac{3-g5s}{2})}\Big],\\
C_\pm^{\bar{U}_l,\tilde{D}_{m,s}} &= -\left(C_\mp^{U_l,\bar{\tilde{D}}_{m,s}}\right)^*\ ,\\
C_\pm^{\bar{D}_l,\tilde{U}_{m,s}} &= \left(C_\mp^{D_l,\bar{\tilde{U}}_{m,s}}\right)^*\ .
\end{aligned}
\tag{4.34}
$$

Scalar-Quark-Quark vertices

The generic effective vertex is shown in Fig.5 (j) with its generic expression as follows

$$\text{Vert}\left(S, Q_l^i, \bar{Q}_m^j\right) = -\frac{g_s^2}{8\pi^2}\, C_F\, \delta_{ij}\ \left(1+\lambda_{HV}\right)\left(v^{SQ_l\bar{Q}_m} + g5s\ a^{SQ_l\bar{Q}_m}\gamma_5\right). \quad (4.35)$$

The actual values of S, Q_l, $\bar{Q}_m$, $v^{SQ_l\bar{Q}_m}$ and $a^{SQ_l\bar{Q}_m}$ are

$$\begin{aligned}
v^{h^0U_l\bar{U}_m} &= -\frac{iec_\alpha m_{U_l}\delta_{lm}}{2m_W s_w s_\beta}, \qquad v^{h^0D_l\bar{D}_m} = \frac{ies_\alpha m_{D_l}\delta_{lm}}{2m_W s_w c_\beta},\\
a^{h^0Q_l\bar{Q}_m} &= 0,\\
v^{H^0U_l\bar{U}_m} &= -\frac{ies_\alpha m_{U_l}\delta_{lm}}{2m_W s_w s_\beta}, \qquad v^{H^0D_l\bar{D}_m} = -\frac{iec_\alpha m_{D_l}\delta_{lm}}{2m_W s_w c_\beta},\\
a^{H^0Q_l\bar{Q}_m} &= 0,\\
v^{A^0Q_l\bar{Q}_m} &= 0,\\
a^{A^0U_l\bar{U}_m} &= -\frac{em_{U_l}\delta_{lm}}{2m_W s_w t_\beta}, \qquad a^{A^0D_l\bar{D}_m} = -\frac{et_\beta m_{D_l}\delta_{lm}}{2m_W s_w},\\
v^{\phi^0Q_l\bar{Q}_m} &= 0,\\
a^{\phi^0U_l\bar{U}_m} &= -\frac{em_{U_l}\delta_{lm}}{2m_W s_w}, \qquad a^{\phi^0D_l\bar{D}_m} = \frac{em_{D_l}}{2m_W s_w},\\
v^{H^-U_l\bar{D}_m} &= V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_l}(t_\beta)^{-1} + m_{D_m}(t_\beta)\right),\\
a^{H^-U_l\bar{D}_m} &= V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_l}(t_\beta)^{-1} - m_{D_m}(t_\beta)\right),\\
v^{H^+D_l\bar{U}_m} &= V_{U_m,D_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_m}(t_\beta)^{-1} + m_{D_l}(t_\beta)\right),\\
a^{H^+D_l\bar{U}_m} &= -V_{U_m,D_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_m}(t_\beta)^{-1} - m_{D_l}(t_\beta)\right),\\
v^{\phi^-U_l\bar{D}_m} &= V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_l} - m_{D_m}\right),\\
a^{\phi^-U_l\bar{D}_m} &= V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_l} + m_{D_m}\right),\\
v^{\phi^+D_l\bar{U}_m} &= V_{U_m,D_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_m} - m_{D_l}\right),\\
a^{\phi^+D_l\bar{U}_m} &= -V_{U_m,D_l}\frac{ie}{2\sqrt{2}m_W s_w}\left(m_{U_m} + m_{D_l}\right).
\end{aligned} \quad (4.36)$$

Vector-Quark-Quark vertices

The generic effective vertex is shown in Fig.5 (k) with its generic expression as follows

$$\mathrm{Vert}\left(V_\mu, Q_l^i, \bar{Q}_m^j\right) = -\frac{g_s^2}{16\pi^2}\ C_F\ \delta^{ij}\ \ (1+\lambda_{HV})\left(v^{VQ_l\bar{Q}_m}\gamma_\mu + g5s\ a^{VQ_l\bar{Q}_m}\gamma_\mu\gamma_5\right) \tag{4.37}$$

The actual values of V, Q_l, $\bar{Q}_m$, $v^{VQ_l\bar{Q}_m}$ and $a^{VQ_l\bar{Q}_m}$ are

$$\begin{aligned}
v^{AQ_l\bar{Q}_m} &= -ieQ_{Q_l}\delta_{lm},\\
a^{AQ_l\bar{Q}_m} &= 0,\\
v^{ZQ_l\bar{Q}_m} &= \frac{ies_w}{c_w}\left(Q_{Q_l} - \frac{I_{3Q_l}}{2s_w^2}\right)\delta_{lm},\\
a^{ZQ_l\bar{Q}_m} &= \frac{ieI_{3Q_l}}{2s_wc_w}\delta_{lm},\\
v^{W^-U_l\bar{D}_m} &= -V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}s_w},\\
a^{W^-U_l\bar{D}_m} &= V^\dagger_{D_m,U_l}\frac{ie}{2\sqrt{2}s_w},\\
v^{W^+D_l\bar{U}_m} &= -V_{U_m,D_l}\frac{ie}{2\sqrt{2}s_w},\\
a^{W^+D_l\bar{U}_m} &= V_{U_m,D_l}\frac{ie}{2\sqrt{2}s_w}.
\end{aligned} \tag{4.38}$$

Scalar-Squark-Squark vertices

The generic effective vertex is shown in Fig.5 (l) with its generic expression as follows

$$\mathrm{Vert}\left(S, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^2e}{\pi^2}\ C^{S\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}. \tag{4.39}$$

The actual values of S, $\tilde{Q}_{l,s1}$, $\bar{\tilde{Q}}_{m,s2}$ and $C^{S\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}$ are

$$\begin{aligned}
C^{h^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} = \delta_{lm}&\frac{1}{192m_Ws_wc_ws_\beta}\ C_F\ \delta^{ij}\\
&\left\{\sum_{k=1}^{2}\left[\left(\left(18+12\ g5s\right)c_wc_\alpha m_{U_l}^2 + (-1)^{(k+1)}\ 4m_Wm_Zs_w^2s_\beta s_{\alpha+\beta}\right.\right.\right.\\
&\left.-\delta_{k,1}\ 3m_Wm_Zs_\beta s_{\alpha+\beta}\right)RU^*_{l,(s1,k)}RU_{l,(s2,k)}\Big]\\
&-3m_{U_l}c_w\left[\left(4c_\alpha m_{\tilde{G}} - \mu s_\alpha - c_\alpha A^*_{U_l} + \frac{1-g5s}{2}\ 8m_{U_l}c_\alpha\right)RU^*_{l,(s1,2)}RU_{l,(s2,1)}\right.\\
&\left.\left.+\left(4c_\alpha m_{\tilde{G}} - \mu^* s_\alpha - c_\alpha A_{U_l} + \frac{1-g5s}{2}\ 8m_{U_l}c_\alpha\right)RU^*_{l,(s1,1)}RU_{l,(s2,2)}\right]\right\},
\end{aligned}$$

$$
\begin{aligned}
C^{h^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\frac{1}{192 m_W s_w c_w c_\beta}\; C_F\; \delta^{ij} \\
&\left\{\sum_{k=1}^{2}\left[\left(\left(18+12\ g5s\right)c_w s_\alpha m_{D_l}^2 + (-1)^{(k+1)}\,2m_W m_Z s_w^2 c_\beta s_{\alpha+\beta}\right.\right.\right. \\
&-\ \delta_{k,1}\ 3m_W m_Z c_\beta s_{\alpha+\beta}\big)\, RD^*_{l,(s1,k)} RD_{l,(s2,k)}\Big] \\
&-3m_{D_l}c_w\left[\left(4s_\alpha m_{\tilde{G}} - \mu c_\alpha - s_\alpha A^*_{D_l} + \frac{1-g5s}{2}\ 8m_{D_l}s_\alpha\right) RD^*_{l,(s1,2)} RD_{l,(s2,1)}\right. \\
&\left.\left.+\ \left(4s_\alpha m_{\tilde{G}} - \mu^* c_\alpha - s_\alpha A_{D_l} + \frac{1-g5s}{2}\ 8m_{D_l}s_\alpha\right) RD^*_{l,(s1,1)} RD_{l,(s2,2)}\right]\right\}, \\
C^{H^0\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= C^{h^0\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}\left(s_\alpha \to -c_\alpha, c_\alpha \to s_\alpha, s_{\alpha+\beta} \to -c_{\alpha+\beta}, c_{\alpha+\beta} \to s_{\alpha+\beta}\right), \\
C^{A^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= -\delta_{lm}\frac{i}{64 m_W s_w}\; C_F\; \delta^{ij}\; m_{U_l}(t_\beta)^{-1} \\
&\left[\left(-g5s\ 4m_{\tilde{G}} + \mu(t_\beta) + \frac{1-g5s}{2}8m_{U_l} + A^*_{U_l}\right) RU^*_{l,(s1,2)} RU_{l,(s2,1)}\right. \\
&\left.-\ \left(-g5s\ 4m_{\tilde{G}} + \mu^*(t_\beta) + \frac{1-g5s}{2}8m_{U_l} + A_{U_l}\right) RU^*_{l,(s1,1)} RU_{l,(s2,2)}\right], \\
C^{A^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\frac{i}{64 m_W s_w}\; C_F\; \delta^{ij}\; m_{D_l}(t_\beta) \\
&\left[\left(-g5s\ 4m_{\tilde{G}} + \mu(t_\beta)^{-1} + \frac{1-g5s}{2}8m_{D_l} + A^*_{D_l}\right) RD^*_{l,(s1,2)} RD_{l,(s2,1)}\right. \\
&\left.-\ \left(-g5s\ 4m_{\tilde{G}} + \mu^*(t_\beta)^{-1} + \frac{1-g5s}{2}8m_{D_l} + A_{D_l}\right) RD^*_{l,(s1,1)} RD_{l,(s2,2)}\right], \\
C^{\phi^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\frac{i}{64 m_W s_w}\; C_F\; \delta^{ij}\; m_{U_l} \\
&\left[\left(g5s\ 4m_{\tilde{G}} + \mu(t_\beta)^{-1} - \frac{1-g5s}{2}8m_{U_l} - A^*_{U_l}\right) RU^*_{l,(s1,2)} RU_{l,(s2,1)}\right. \\
&\left.-\ \left(g5s\ 4m_{\tilde{G}} + \mu^*(t_\beta)^{-1} - \frac{1-g5s}{2}8m_{U_l} - A_{U_l}\right) RU^*_{l,(s1,1)} RU_{l,(s2,2)}\right], \\
C^{\phi^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\frac{i}{64 m_W s_w}\; C_F\; \delta^{ij}\; m_{D_l}(t_\beta) \\
&\left[\left(g5s\ 4m_{\tilde{G}} + \mu(t_\beta) - \frac{1-g5s}{2}8m_{D_l} - A^*_{D_l}\right) RD^*_{l,(s1,2)} RD_{l,(s2,1)}\right. \\
&\left.-\ \left(g5s\ 4m_{\tilde{G}} + \mu^*(t_\beta) - \frac{1-g5s}{2}8m_{D_l} - A_{D_l}\right) RD^*_{l,(s1,1)} RD_{l,(s2,2)}\right],
\end{aligned}
$$

$$
\begin{aligned}
C^{H^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} = & -\frac{1}{32\sqrt{2}m_W s_w t_\beta}\ C_F\ \delta^{ij}\ V^\dagger_{D_m,U_l}\ \Big\{(3+2g5s)\left(1+t_\beta^2\right)m_{U_l}m_{D_m} \\
& RU^*_{l,(s1,2)}RD_{m,(s2,2)} + \Bigg[\mu t_\beta m_{U_l} - \frac{1+g5s}{2}4m_{\tilde{G}}m_{U_l} \\
& -\frac{1-g5s}{2}\ 4m_{D_m}t_\beta^2\left(m_{U_l}+m_{D_m}+m_{\tilde{G}}\right)+m_{U_l}A^*_{U_l}\Bigg]RU^*_{l,(s1,2)}RD_{m,(s2,1)} \\
& +\left[(3+2g5s)\,m^2_{U_l}+(3+2g5s)\,m^2_{D_m}t_\beta^2-m_W^2t_\beta s_{2\beta}\right] \\
& RU^*_{l,(s1,1)}RD_{m,(s2,1)} + \Bigg[\mu^* m_{D_m}t_\beta + t_\beta^2 m_{D_m}\left(A_{D_m}-\frac{1+g5s}{2}4m_{\tilde{G}}\right) \\
& -\ \frac{1-g5s}{2}4m_{U_l}\left(m_{U_l}+m_{D_m}+m_{\tilde{G}}\right)\Bigg]RU^*_{l,(s1,1)}RD_{m,(s2,2)}\Bigg\}, \\
C^{H^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} = & -\frac{1}{32\sqrt{2}m_W s_w t_\beta}\ C_F\ \delta^{ij}\ V_{U_m,D_l}\ \Big\{(3+2g5s)\left(1+t_\beta^2\right)m_{U_m}m_{D_l} \\
& RD^*_{l,(s1,2)}RU_{m,(s2,2)} + \Bigg[\mu t_\beta m_{D_l} - \frac{1+g5s}{2}4m_{\tilde{G}}m_{D_l}t_\beta^2 \\
& -\frac{1-g5s}{2}\ 4m_{U_m}\left(m_{D_l}+m_{U_m}+m_{\tilde{G}}\right)+m_{D_l}A^*_{D_l}t_\beta^2\Bigg]RD^*_{l,(s1,2)}RU_{m,(s2,1)} \\
& +\left[(3+2g5s)\,m^2_{U_m}+(3+2g5s)\,m^2_{D_l}t_\beta^2-m_W^2t_\beta s_{2\beta}\right] \\
& RD^*_{l,(s1,1)}RU_{m,(s2,1)} + \Bigg[\mu^* m_{U_m}t_\beta + m_{U_m}\left(A_{U_m}-\frac{1+g5s}{2}4m_{\tilde{G}}\right) \\
& -\ \frac{1-g5s}{2}4m_{D_l}t_\beta^2\left(m_{D_l}+m_{U_m}+m_{\tilde{G}}\right)\Bigg]RU^*_{l,(s1,1)}RD_{m,(s2,2)}\Bigg\}, \\
C^{\phi^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} = & \frac{1}{32\sqrt{2}m_W s_w t_\beta}\ C_F\ \delta^{ij}\ V^\dagger_{D_m,U_l}\ \Bigg\{\Bigg[\mu m_{U_l} + \frac{1+g5s}{2}4m_{\tilde{G}}m_{U_l}t_\beta \\
& -\frac{1-g5s}{2}4m_{D_m}\left(m_{D_m}+m_{U_l}+m_{\tilde{G}}\right)t_\beta - A^*_{U_l}m_{U_l}t_\beta\Bigg]RU^*_{l,(s1,2)}RD_{m,(s2,1)} \\
& -t_\beta\left[-(3+2g5s)\,m^2_{D_m}+(3+2g5s)\,m^2_{U_l}+m_W^2c_{2\beta}\right]RU^*_{l,(s1,1)}RD_{m,(s2,1)} \\
& -t_\beta\Bigg[m_{D_m}\mu^* t_\beta + m_{D_m}\left(-A_{D_m}+\frac{1+g5s}{2}4m_{\tilde{G}}\right) \\
& -\ \frac{1-g5s}{2}4m_{U_l}\left(m_{U_l}+m_{D_m}+m_{\tilde{G}}\right)\Bigg]RU^*_{l,(s1,1)}RD_{m,(s2,2)}\Bigg\}, \\
C^{\phi^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} = & -\frac{1}{32\sqrt{2}m_W s_w t_\beta}\ C_F\ \delta^{ij}\ V_{U_m,D_l}\ \Bigg\{t_\beta\Bigg[\mu m_{D_l}t_\beta + \frac{1+g5s}{2}4m_{\tilde{G}}m_{D_l} \\
& -\frac{1-g5s}{2}4m_{U_m}\left(m_{U_m}+m_{D_l}+m_{\tilde{G}}\right) - A^*_{D_l}m_{D_l}\Bigg]RD^*_{l,(s1,2)}RU_{m,(s2,1)} \\
& +t_\beta\left[-(3+2g5s)\,m^2_{D_l}+(3+2g5s)\,m^2_{U_m}+m_W^2c_{2\beta}\right]RD^*_{l,(s1,1)}RU_{m,(s2,1)} \\
& +\Bigg[-m_{U_m}\mu^* + m_{U_m}\left(A_{U_m}-\frac{1+g5s}{2}4m_{\tilde{G}}\right)t_\beta \\
& +\ \frac{1-g5s}{2}4m_{D_l}\left(m_{D_l}+m_{U_m}+m_{\tilde{G}}\right)t_\beta\Bigg]RU^*_{l,(s1,1)}RD_{m,(s2,2)}\Bigg\}. \qquad (4.40)
\end{aligned}
$$

Vector-Squark-Squark vertices

The generic effective vertex is shown in Fig.5 (m) with its generic expression as follows

$$\mathrm{Vert}\left(V_\mu, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^2 e}{\pi^2}\; C^{V\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}. \tag{4.41}$$

The actual values of V, $\tilde{Q}_{l,s1}$, $\bar{\tilde{Q}}_{m,s2}$ and $C^{V\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}$ are

$$\begin{aligned}
C^{A\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= \delta_{lm}\;\frac{\delta^{ij}Q_{Q_l}}{96}\;C_F\;\left(\delta_{s1,s2} + \frac{1+g5s}{2}\;8SR1(l,l)_{s1,s2}\right.\\
&\left. + \frac{1-g5s}{2}\;4\left(SR1(l,l)_{s1,s2} - SR2(l,l)_{s1,s2}\right)\right)\;(p_1-p_2)_\mu\,,\\
C^{Z\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= -\delta_{lm}\;\frac{\delta^{ij}}{576c_w s_w}\;C_F\;\left[\frac{1+g5s}{2}\;9\sum_{k=1}^{2}\left(4s_w^2 - 3\delta_{k,1}\right)RU^*_{l,(s1,k)}RU_{l,(s2,k)}\right.\\
&(p_1-p_2)_\mu + \frac{1-g5s}{2}\;\left((p_1-p_2)_\mu\left(\sum_{k=1}^{2}\left(20s_w^2 - 3k^2\right)\right.\right.\\
&\left. RU^*_{l,(s1,k)}RU_{l,(s2,k)} - 16s_w^2\;SRU2(l,l)_{s1,s2}\right) + (p_1)_\mu\\
&\left(24RU^*_{l,(s1,1)}RU_{l,(s2,2)} - 12RU^*_{l,(s1,2)}RU_{l,(s2,1)}\right)\\
&\left.\left. -(p_2)_\mu\left(24RU^*_{l,(s1,2)}RU_{l,(s2,1)} - 12RU^*_{l,(s1,1)}RU_{l,(s2,2)}\right)\right)\right]\,,\\
C^{Z\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \delta_{lm}\;\frac{\delta^{ij}}{576c_w s_w}\;C_F\;\left[\frac{1+g5s}{2}\;9\sum_{k=1}^{2}\left(2s_w^2 - 3\delta_{k,1}\right)RD^*_{l,(s1,k)}RD_{l,(s2,k)}\right.\\
&(p_1-p_2)_\mu + \frac{1-g5s}{2}\;\left((p_1-p_2)_\mu\left(\sum_{k=1}^{2}\left(10s_w^2 - 3k^2\right)\right.\right.\\
&\left. RD^*_{l,(s1,k)}RD_{l,(s2,k)} - 8s_w^2\;SRD2(l,l)_{s1,s2}\right) + (p_1)_\mu\\
&\left(24RD^*_{l,(s1,1)}RD_{l,(s2,2)} - 12RD^*_{l,(s1,2)}RD_{l,(s2,1)}\right)\\
&\left.\left. -(p_2)_\mu\left(24RD^*_{l,(s1,2)}RD_{l,(s2,1)} - 12RD^*_{l,(s1,1)}RD_{l,(s2,2)}\right)\right)\right]\,,\\
C^{W^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \frac{\delta^{ij}}{96\sqrt{2}s_w}\;C_F\;V^\dagger_{D_m,U_l}\;\left[\frac{1+g5s}{2}9\,(p_1-p_2)_\mu\;RU^*_{l,(s1,1)}RD_{m,(s2,1)}\right.\\
&+\frac{1-g5s}{2}\left((p_1-p_2)_\mu\sum_{k=1}^{2}\left(k^2\;RU^*_{l,(s1,k)}RD_{m,(s2,k)}\right) + (p_1)_\mu\right.\\
&\left(4RU^*_{l,(s1,2)}RD_{m,(s2,1)} - 8RU^*_{l,(s1,1)}RD_{m,(s2,2)}\right) - (p_2)_\mu\\
&\left.\left.\left(4RU^*_{l,(s1,1)}RD_{m,(s2,2)} - 8RU^*_{l,(s1,2)}RD_{m,(s2,1)}\right)\right)\right]\,,
\end{aligned}$$

$$
\begin{aligned}
C^{W^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} = & \frac{\delta^{ij}}{96\sqrt{2}s_w}\ C_F\ V_{U_m,D_l}\ \left[\frac{1+g5s}{2}9\left(p_1-p_2\right)_\mu\ RD^*_{l,(s1,1)}RU_{m,(s2,1)}\right. \\
& +\frac{1-g5s}{2}\left(\left(p_1-p_2\right)_\mu\sum_{k=1}^{2}\left(k^2\ RD^*_{l,(s1,k)}RU_{m,(s2,k)}\right)+\left(p_1\right)_\mu\right. \\
& \left(4RD^*_{l,(s1,2)}RU_{m,(s2,1)}-8RD^*_{l,(s1,1)}RU_{m,(s2,2)}\right)-\left(p_2\right)_\mu \\
& \left.\left.\left(4RD^*_{l,(s1,1)}RU_{m,(s2,2)}-8RD^*_{l,(s1,2)}RU_{m,(s2,1)}\right)\right)\right]. \qquad (4.42)
\end{aligned}
$$

4.2.2 Mixed MSSM QCD effective vertices with 4 external legs

All possible non-vanishing 4-point vertices in mixed MSSM QCD are shown in Fig.6.

Vector-Gluon-Gluon-Gluon vertices

The generic effective vertex is shown in Fig.6 (a) with its expression as follows

$$
\mathrm{Vert}\left(V_\mu,G^a_\nu,G^b_\rho,G^c_\sigma\right)=\frac{ig_s^3e}{\pi^2}\ \left[C_1^V\left(g_{\mu\nu}g_{\rho\sigma}+g_{\mu\rho}g_{\sigma\nu}+g_{\mu\sigma}g_{\nu\rho}\right)+C_2^V\varepsilon_{\mu\nu\rho\sigma}\right] \qquad (4.43)
$$

The actual values of V, C_1^V and C_2^V are

$$
\begin{aligned}
C_1^A &= \frac{1}{24}\left(\sum_Q Q_Q\ Tr(T^a\left\{T^b,T^c\right\})\right), \\
C_2^A &= 0, \\
C_1^Z &= -\frac{s_w}{24c_w}\sum_Q\left(Q_Q-\frac{I_{3Q}}{2s_w^2}\right)Tr(T^a\left\{T^b,T^c\right\}), \\
C_2^Z &= -\frac{9i}{24c_ws_w}\sum_Q\frac{I_{3Q}}{2}Tr(T^a\left[T^b,T^c\right]). \qquad (4.44)
\end{aligned}
$$

Vector-Vector-Gluon-Gluon vertices

The generic effective vertex is shown in Fig.6 (b) with its expression as follows

$$\mathrm{Vert}\left(V_{1\mu}, V_{2\nu}, G^a_\rho, G^b_\sigma\right) = -\frac{ig_s^2}{24\pi^2}\,\delta^{ab}\,\left(g_{\mu\nu}g_{\rho\sigma} + g_{\mu\rho}g_{\sigma\nu} + g_{\mu\sigma}g_{\nu\rho}\right)$$
$$\sum_{l,m}\left(v^{V_1 Q_l \bar{Q}_m} v^{V_2 Q_m \bar{Q}_l} + a^{V_1 Q_l \bar{Q}_m} a^{V_2 Q_m \bar{Q}_l}\right), \quad (4.45)$$

where all non-vanish $v^{VQ_l\bar{Q}_m}$ and $a^{VQ_l\bar{Q}_m}$ are shown in Eq.(4.38).

Scalar-Scalar-Gluon-Gluon vertices

The generic effective vertex is shown in Fig.6 (c) with its expression as follows

$$\mathrm{Vert}\left(S_1, S_2, G^a_\mu, G^b_\nu\right) = \frac{ig_s^2}{8\pi^2}\,\delta^{ab}\,g_{\mu\nu}\,\sum_{l,m}\left(v^{S_1 Q_l \bar{Q}_m} v^{S_2 Q_m \bar{Q}_l} - a^{S_1 Q_l \bar{Q}_m} a^{S_2 Q_m \bar{Q}_l}\right) \quad (4.46)$$

where all non-vanish $v^{SQ_l\bar{Q}_m}$ and $a^{SQ_l\bar{Q}_m}$ are shown in Eq.(4.36).

Vector-Gluon-Squark-Squark vertices

The generic effective vertex is shown in Fig.6 (d) with its generic expression as follows

$$\mathrm{Vert}\left(V_\mu, G^a_\nu, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^3 e}{\pi^2}\,g_{\mu\nu}\,C^{V\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}. \quad (4.47)$$

The actual values of V, $\tilde{Q}$, $\bar{\tilde{Q}}$ and $C^{V\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}$ are

$$\begin{aligned}
C^{A\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= -\delta_{lm}\,\frac{Q_{Q_l}}{96N_c}\,T^a_{ji}\left[\left(6N_c^2-1\right)\delta_{s1,s2} + 2\left(5N_c^2-8\right)SR1(l,l)_{s1,s2}\right.\\
&\quad\left. -\frac{1-g5s}{2}\,4\,\left(N_c^2+1\right)\,\left(SR1(l,l)_{s1,s2}+SR2(l,l)_{s1,s2}\right)\right],\\
C^{Z\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\,\frac{1}{576c_w s_w N_c}\,T^a_{ji}\,\left\{\frac{1+g5s}{2}\,8\left(5N_c^2-7\right)s_w^2\,SRU1(l,l)_{s1,s2}\right.\\
&\quad + \left(51-48N_c^2\right)RU^*_{l,(s1,1)}RU_{l,(s2,1)} + 12\left(2N_c^2-1\right)s_w^2\delta_{s1,s2}\\
&\quad + \frac{1-g5s}{2}\left[-2\left(N_c^2+1\right)\left(8s_w^2-3\right)SRU2(l,l)_{s1,s2}\right.\\
&\quad\left.\left. +\;12\sum_{k=1}^{2}\left(\left(2\left(N_c^2-3\right)s_w^2 + N_c^2\delta_{k,1}+\delta_{k,2}\right)RU^*_{l,(s1,k)}RU_{l,(s2,k)}\right)\right]\right\},
\end{aligned}$$

$$
\begin{aligned}
C^{Z\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\ \frac{1}{576c_w s_w N_c}\ T^a_{ji}\ \left\{\frac{1+g5s}{2}\ 4\left(5N_c^2-7\right)s_w^2\ SRD1(l,l)_{s1,s2}\right.\\
&+\left(51-48N_c^2\right)RD^*_{l,(s1,1)}RD_{l,(s2,1)}+6\left(2N_c^2-1\right)s_w^2\delta_{s1,s2}\\
&+\frac{1-g5s}{2}\left[-2\left(N_c^2+1\right)\left(4s_w^2-3\right)SRD2(l,l)_{s1,s2}\right.\\
&\left.\left.+\ 12\sum_{k=1}^{2}\left(\left(\left(N_c^2-3\right)s_w^2+N_c^2\delta_{k,1}+\delta_{k,2}\right)RD^*_{l,(s1,k)}RD_{l,(s2,k)}\right)\right]\right\},\\
C^{W^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \frac{1}{96\sqrt{2}s_w N_c}\ T^a_{ji}\ V^\dagger_{D_m,U_l}\ \left\{\left(17-16N_c^2\right)RU^*_{l,(s1,1)}RD_{m,(s2,1)}\right.\\
&+\frac{1-g5s}{2}\left[4\sum_{k=1}^{2}\left(\left(N_c^2\delta_{k,1}+\delta_{k,2}\right)RU^*_{l,(s1,k)}RD_{m,(s2,k)}\right.\right.\\
&\left.\left.\left.+\ 2\left(N_c^2+1\right)\left(RU^*_{l,(s1,1)}RD_{m,(s2,2)}+RU^*_{l,(s1,2)}RD_{m,(s2,1)}\right)\right)\right]\right\},\\
C^{W^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \frac{1}{96\sqrt{2}s_w N_c}\ T^a_{ji}\ V_{U_m,D_l}\ \left\{\left(17-16N_c^2\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}\right.\\
&+\frac{1-g5s}{2}\left[4\sum_{k=1}^{2}\left(\left(N_c^2\delta_{k,1}+\delta_{k,2}\right)RD^*_{l,(s1,k)}RU_{m,(s2,k)}\right.\right.\\
&\left.\left.\left.+\ 2\left(N_c^2+1\right)\left(RD^*_{l,(s1,1)}RU_{m,(s2,2)}+RD^*_{l,(s1,2)}RU_{m,(s2,1)}\right)\right)\right]\right\}
\end{aligned}
\tag{4.48}
$$

Vector-Vector-Squark-Squark vertices

The generic effective vertex is shown in Fig.6 (e) with its generic expression as follows

$$
\text{Vert}\left(V_{1\mu},V_{2\nu},\tilde{Q}^i_{l,s1},\bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^2}{\pi^2}\ C^{V_1V_2\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}\ g_{\mu\nu}. \tag{4.49}
$$

The actual values of V_1, V_2, $\tilde{Q}$, $\bar{\tilde{Q}}$ and $C^{V_1V_2\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}$ are

$$
\begin{aligned}
C^{AA\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= -\delta_{lm}\ \frac{\delta^{ij}Q_{Q_l}^2e^2}{48}\ C_F\ \left[\delta_{s1,s2}+\frac{1+g5s}{2}16\ SR1(l,l)_{s1,s2}\right.\\
&\left.+\ \frac{1-g5s}{2}\left(20\ SR1(l,l)_{s1,s2}+4\ SR2(l,l)_{s1,s2}\right)\right],\\
C^{AZ\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{48}\ C_F\ \left\{\sum_{k=1}^{2}\left[17v^{AQ_l\bar{Q}_l}\left(v^{ZQ_l\bar{Q}_l}+(-1)^k a^{ZQ_l\bar{Q}_l}\right)\right.\right.\\
&\left.+\frac{1-g5s}{2}\ 4v^{AQ_l\bar{Q}_l}\left(v^{ZQ_l\bar{Q}_l}+(-1)^{(k+1)}a^{ZQ_l\bar{Q}_l}\right)\right]R^*_{l,(s1,k)}R_{l,(s2,k)}\\
&\left.+\ \frac{1-g5s}{2}\ 4v^{AQ_l\bar{Q}_l}v^{ZQ_l\bar{Q}_l}SR2(l,l)_{s1,s2}\right\},
\end{aligned}
$$

$$
\begin{aligned}
C^{ZZ\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= -\delta_{lm}\ \frac{\delta^{ij}}{48}\ C_F\ \left\{2\sum_{k=1}^{2}\sum_{r=1}^{2}\left[\left(v^{ZQ_l\bar{Q}_l}+(-1)^k a^{ZQ_l\bar{Q}_l}\right)\right.\right.\\
&\left.\left(v^{ZQ_l\bar{Q}_l}+(-1)^r a^{ZQ_l\bar{Q}_l}\right) R^*_{l,(s1,k)}R_{l,(s2,r)}\ \left(R_l^\dagger R_l\right)_{k,r}\right]\\
&-\sum_{k=1}^{2}\left[\left(19\left(v^{ZQ_l\bar{Q}_l}+(-1)^k a^{ZQ_l\bar{Q}_l}\right)^2\right.\right.\\
&\left.\left.+\ \frac{1-g5s}{2}\ 4\left(v^{ZQ_l\bar{Q}_l}+(-1)^{(k+1)} a^{ZQ_l\bar{Q}_l}\right)^2\right) R^*_{l,(s1,k)}R_{l,(s2,k)}\right]\\
&-\frac{1-g5s}{2}\ 4\left(\left(v^{ZQ_l\bar{Q}_l}+a^{ZQ_l\bar{Q}_l}\right)^2+3\left(v^{ZQ_l\bar{Q}_l}-a^{ZQ_l\bar{Q}_l}\right)\right)\\
&\left. SR2(l,l)_{s1,s2}\right\},\\
C^{W^-W^+\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= -\frac{\delta^{ij}}{96}\ C_F\ \left\{RU^*_{l,(s1,1)}RU_{m,(s2,1)}\left[2\sum_g\left(v^{W^-U_l\bar{D}_g}-a^{W^-U_l\bar{D}_g}\right)\right.\right.\\
&\left.\left(v^{W^+D_g\bar{U}_m}-a^{W^+D_g\bar{U}_m}\right)\left(\left(RD_g^\dagger RD_g\right)_{1,1}-8\right)-3\delta_{lm}\right]\\
&-\frac{1-g5s}{2}\ 4\sum_g\left(v^{W^-U_l\bar{D}_g}-a^{W^-U_l\bar{D}_g}\right)\left(v^{W^+D_g\bar{U}_m}-a^{W^+D_g\bar{U}_m}\right)\\
&\left.\left(SRD2(l,m)_{s1,s2}+RD^*_{l,(s1,2)}RD_{m,(s2,2)}\right)\right\},\\
C^{W^-W^+\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{\delta^{ij}}{96}\ C_F\ \left\{RD^*_{l,(s1,1)}RD_{m,(s2,1)}\left[2\sum_g\left(v^{W^+D_l\bar{U}_g}-a^{W^+D_l\bar{U}_g}\right)\right.\right.\\
&\left.\left(v^{W^-U_g\bar{D}_m}-a^{W^-U_g\bar{D}_m}\right)\left(\left(RU_g^\dagger RU_g\right)_{1,1}-8\right)-3\delta_{lm}\right]\\
&-\frac{1-g5s}{2}\ 4\sum_g\left(v^{W^+D_l\bar{U}_g}-a^{W^+D_l\bar{D}_g}\right)\left(v^{W^-U_g\bar{D}_m}-a^{W^-U_g\bar{D}_m}\right)\\
&\left.\left(SRU2(l,m)_{s1,s2}+RU^*_{l,(s1,2)}RU_{m,(s2,2)}\right)\right\},\\
C^{AW^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{i\delta^{ij}e}{144}\ C_F\ v^{W^-U_l\bar{D}_m}\left[17RU^*_{l,(s1,1)}RD_{m,(s2,1)}+\frac{1-g5s}{2}\right.\\
&\left(-4RU^*_{l,(s1,1)}RD_{m,(s2,2)}+8RU^*_{l,(s1,2)}RD_{m,(s2,1)}\right.\\
&\left.\left.+\ 4RU^*_{l,(s1,2)}RD_{m,(s2,2)}\right)\right],\\
C^{AW^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= -\frac{i\delta^{ij}e}{144}\ C_F\ v^{W^+D_l\bar{U}_m}\left[17RD^*_{l,(s1,1)}RU_{m,(s2,1)}+\frac{1-g5s}{2}\right.\\
&\left(-4RD^*_{l,(s1,2)}RU_{m,(s2,1)}+8RD^*_{l,(s1,1)}RU_{m,(s2,2)}\right.\\
&\left.\left.+\ 4RD^*_{l,(s1,2)}RU_{m,(s2,2)}\right)\right],
\end{aligned}
$$

$$
\begin{aligned}
C^{ZW^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} =& -\frac{i\delta^{ij}e}{144c_w s_w}\ C_F\ v^{W^- U_l \bar{D}_m}\Big[4s_w^2 RU^*_{l,(s1,2)}RD_{m,(s2,1)}\ \left(RU_l^\dagger RU_l\right)_{1,2}\\
&+\left(4s_w^2-3\right)RU^*_{l,(s1,1)}RD_{m,(s2,1)}\ \left(RU_l^\dagger RU_l\right)_{1,1}\\
&-\left(2s_w^2-3\right)RU^*_{l,(s1,1)}RD_{m,(s2,1)}\ \left(RD_m^\dagger RD_m\right)_{1,1}\\
&-2s_w^2 RU^*_{l,(s1,1)}RD_{m,(s2,2)}\ \left(RD_m^\dagger RD_m\right)_{2,1}-19s_w^2 RU^*_{l,(s1,1)}RD_{m,(s2,1)}\\
&+\frac{1-g5s}{2}\left(4s_w^2 RU^*_{l,(s1,1)}RD_{m,(s2,2)}-8s_w^2 RU^*_{l,(s1,2)}RD_{m,(s2,1)}\right.\\
&\left.-\ 4s_w^2 RU^*_{l,(s1,2)}RD_{m,(s2,2)}\right)\Big]\,,\\
C^{ZW^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} =& \frac{i\delta^{ij}e}{144c_w s_w}\ C_F\ v^{W^+ D_l \bar{U}_m}\Big[2s_w^2 RD^*_{l,(s1,2)}RU_{m,(s2,1)}\ \left(RD_l^\dagger RD_l\right)_{1,2}\\
&+\left(2s_w^2-3\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}\ \left(RD_l^\dagger RD_l\right)_{1,1}\\
&-\left(4s_w^2-3\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}\ \left(RU_m^\dagger RU_m\right)_{1,1}\\
&-4s_w^2 RD^*_{l,(s1,1)}RU_{m,(s2,2)}\ \left(RU_m^\dagger RU_m\right)_{2,1}+19s_w^2 RD^*_{l,(s1,1)}RU_{m,(s2,1)}\\
&+\frac{1-g5s}{2}\left(-4s_w^2 RD^*_{l,(s1,2)}RU_{m,(s2,1)}+8s_w^2 RD^*_{l,(s1,1)}RU_{m,(s2,2)}\right.\\
&\left.+\ 4s_w^2 RD^*_{l,(s1,2)}RU_{m,(s2,2)}\right)\Big]\,,
\end{aligned}
\tag{4.50}
$$

where the explicit expressions of $v^{VQ_l\bar{Q}_m}$ and $a^{VQ_l\bar{Q}_m}$ are given in Eq.(4.38).

Scalar-Scalar-Squark-Squark vertices

The generic effective vertex is shown in Fig.6 (f) with its expression as follows

$$
\mathrm{Vert}\left(S_1, S_2, \tilde{Q}^i_{l,s1}, \bar{\tilde{Q}}^j_{m,s2}\right) = \frac{ig_s^2 e^2}{\pi^2}\ C^{S_1 S_2 \tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}. \tag{4.51}
$$

The actual values of S_1, S_2, $\tilde{Q}$, $\bar{\tilde{Q}}$ and $C^{S_1 S_2 \tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}$ are

$$
\begin{aligned}
C^{\tilde{\nu}_{n1},\bar{\tilde{\nu}}_{n2},\tilde{U}_{l,s1},\bar{\tilde{U}}_{m,s2}} =& \ \delta_{lm}\delta_{n1,n2}\ \frac{\delta^{ij}}{384c_w^2 s_w^2}\ C_F\ \left(4s_w^2 RU^*_{l,(s1,2)}RU_{l,(s2,2)}\right.\\
&\left.+\left(3c_w^2-s_w^2\right)RU^*_{l,(s1,1)}RU_{l,(s2,1)}\right),\\
C^{\tilde{\nu}_{n1},\bar{\tilde{\nu}}_{n2},\tilde{D}_{l,s1},\bar{\tilde{D}}_{m,s2}} =& -\delta_{lm}\delta_{n1,n2}\ \frac{\delta^{ij}}{384c_w^2 s_w^2}\ C_F\ \left(2s_w^2 RD^*_{l,(s1,2)}RD_{l,(s2,2)}\right.\\
&\left.+\left(2c_w^2+1\right)RD^*_{l,(s1,1)}RD_{l,(s2,1)}\right),
\end{aligned}
$$

$$
\begin{aligned}
C^{\tilde{e}_{n1,r1},\bar{\tilde{e}}_{n2,r2},\tilde{U}_{l,s1},\bar{\tilde{U}}_{m,s2}} &= -\delta_{lm}\delta_{n1,n2}\ \frac{\delta^{ij}}{384c_w^2s_w^2}\ C_F\ \ \Big[\left(2c_w^2+1\right)RU^*_{l,(s1,1)}RU_{l,(s2,1)} \\
&\quad RL^*_{n1,(r1,1)}RL_{n1,(r2,1)} - 4s_w^2RU^*_{l,(s1,2)}RU_{l,(s2,2)}RL^*_{n1,(r1,1)}RL_{n1,(r2,1)} \\
&\quad -2s_w^2RU^*_{l,(s1,1)}RU_{l,(s2,1)}RL^*_{n1,(r1,2)}RL_{n1,(r2,2)} \\
&\quad +8s_w^2RU^*_{l,(s1,2)}RU_{l,(s2,2)}RL^*_{n1,(r1,2)}RL_{n1,(r2,2)}\Big]\,, \\
C^{\tilde{e}_{n1,r1},\bar{\tilde{e}}_{n2,r2},\tilde{D}_{l,s1},\bar{\tilde{D}}_{m,s2}} &= \delta_{lm}\delta_{n1,n2}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2c_\beta^2}\ C_F\ \ \Big[4m_W^2s_w^2c_\beta^2RD^*_{l,(s1,2)}RD_{l,(s2,2)} \\
&\quad RL^*_{n1,(r1,2)}RL_{n1,(r2,2)} + 6m_{D_l}m_{e_{n1}}c_w^2RD^*_{l,(s1,1)}RD_{l,(s2,2)} \\
&\quad RL^*_{n1,(r1,2)}RL_{n1,(r2,1)} + 6m_{D_l}m_{e_{n1}}c_w^2RD^*_{l,(s1,2)}RD_{l,(s2,1)} \\
&\quad RL^*_{n1,(r1,1)}RL_{n1,(r2,2)} + 2m_W^2s_w^2c_\beta^2RD^*_{l,(s1,1)}RD_{l,(s2,1)} \\
&\quad RL^*_{n1,(r1,2)}RL_{n1,(r2,2)} + m_W^2\left(3c_w^2-s_w^2\right)c_\beta^2RD^*_{l,(s1,1)}RD_{l,(s2,1)} \\
&\quad RL^*_{n1,(r1,1)}RL_{n1,(r2,1)} - 2m_W^2s_w^2c_\beta^2RD^*_{l,(s1,2)}RD_{l,(s2,2)} \\
&\quad RL^*_{n1,(r1,1)}RL_{n1,(r2,1)}\Big]\,, \\
C^{\tilde{e}_{n1,r1},\bar{\tilde{\nu}}_{n2},\tilde{U}_{l,s1},\bar{\tilde{D}}_{m,s2}} &= \delta_{n1,n2}\ \frac{\delta^{ij}}{64s_w^2c_\beta^2}\ C_F\ V^\dagger_{D_m,U_l}\ RU^*_{l,(s1,1)}\left(m_W^2c_\beta^2RD_{m,(s2,1)}RL^*_{n1,(r1,1)}\right. \\
&\quad \left.+\,m_{D_m}m_{e_{n1}}RD_{m,(s2,2)}RL^*_{n1,(r1,2)}\right)\,, \\
C^{\tilde{\nu}_{n1},\bar{\tilde{e}}_{n2,r1},\tilde{D}_{l,s1},\bar{\tilde{U}}_{m,s2}} &= \delta_{n1,n2}\ \frac{\delta^{ij}}{64m_W^2s_w^2c_\beta^2}\ C_F\ V_{U_m,D_l}\ RU_{m,(s2,1)}\left(m_W^2c_\beta^2RD^*_{l,(s1,1)}RL_{n2,(r1,1)}\right. \\
&\quad \left.+\,m_{D_l}m_{e_{n2}}RD^*_{l,(s1,2)}RL_{n2,(r1,2)}\right)\,, \\
C^{h^0h^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2s_\beta^2}\ C_F\ \ \Big[\left(46m_{U_l}^2c_w^2c_\alpha^2+m_W^2\left(4s_w^2-3\right)c_{2\alpha}s_\beta^2\right) \\
&\quad RU^*_{l,(s1,1)}RU_{l,(s2,1)} + 2\left(23m_{U_l}^2c_w^2c_\alpha^2-2m_W^2s_w^2c_{2\alpha}s_\beta^2\right) \\
&\quad RU^*_{l,(s1,2)}RU_{l,(s2,2)} - \frac{1-g5s}{2}\ 8m_{U_l}^2c_w^2c_\alpha^2\left(SRU1(l,l)_{s1,s2}\right. \\
&\quad \left.+SRU2(l,l)_{s1,s2}\right)\Big]\,, \\
C^{h^0h^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2c_\beta^2}\ C_F\ \ \Big[\left(-46m_{D_l}^2c_w^2s_\alpha^2+m_W^2\left(2s_w^2-3\right)c_{2\alpha}c_\beta^2\right) \\
&\quad RD^*_{l,(s1,1)}RD_{l,(s2,1)} - 2\left(23m_{D_l}^2c_w^2s_\alpha^2+m_W^2s_w^2c_{2\alpha}c_\beta^2\right) \\
&\quad RD^*_{l,(s1,2)}RD_{l,(s2,2)} + \frac{1-g5s}{2}\ 8m_{D_l}^2c_w^2s_\alpha^2\left(SRD1(l,l)_{s1,s2}\right. \\
&\quad \left.+SRD2(l,l)_{s1,s2}\right)\Big]\,, \\
C^{H^0H^0\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}} &= C^{h^0h^0\tilde{Q}_{l,s1}\bar{\tilde{Q}}_{m,s2}}\left(s_\alpha\to -c_\alpha, c_\alpha\to s_\alpha, c_{2\alpha}\to -c_{2\alpha}\right)\,,
\end{aligned}
$$

$$
\begin{aligned}
C^{A^0A^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2t_\beta^2}\ C_F\ \ \left[\left(46m_{U_l}^2c_w^2+m_W^2\left(4s_w^2-3\right)c_{2\beta}t_\beta^2\right)\right.\\
&RU_{l,(s1,1)}^*RU_{l,(s2,1)}+2\left(23m_{U_l}^2c_w^2-2m_W^2s_w^2c_{2\beta}t_\beta^2\right)\\
&RU_{l,(s1,2)}^*RU_{l,(s2,2)}-\frac{1-g5s}{2}\ 8m_{U_l}^2c_w^2\left(SRU1(l,l)_{s1,s2}\right.\\
&\left.\left.-SRU2(l,l)_{s1,s2}\right)\right],\\
C^{A^0A^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2}\ C_F\ \ \left[\left(46m_{D_l}^2c_w^2t_\beta^2-m_W^2\left(2s_w^2-3\right)c_{2\beta}\right)\right.\\
&RD_{l,(s1,1)}^*RD_{l,(s2,1)}+2\left(23m_{D_l}^2c_w^2t_\beta^2+m_W^2s_w^2c_{2\beta}\right)\\
&RD_{l,(s1,2)}^*RD_{l,(s2,2)}-\frac{1-g5s}{2}\ 8m_{D_l}^2c_w^2t_\beta^2\left(SRD1(l,l)_{s1,s2}\right.\\
&\left.\left.-SRD2(l,l)_{s1,s2}\right)\right],\\
C^{\phi^0\phi^0\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2}\ C_F\ \ \left[\left(46m_{U_l}^2c_w^2-m_W^2\left(4s_w^2-3\right)c_{2\beta}\right)\right.\\
&RU_{l,(s1,1)}^*RU_{l,(s2,1)}+2\left(23m_{U_l}^2c_w^2+2m_W^2s_w^2c_{2\beta}\right)\\
&RU_{l,(s1,2)}^*RU_{l,(s2,2)}-\frac{1-g5s}{2}\ 8m_{U_l}^2c_w^2\left(SRU1(l,l)_{s1,s2}\right.\\
&\left.\left.-SRU2(l,l)_{s1,s2}\right)\right],\\
C^{\phi^0\phi^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2}\ C_F\ \ \left[\left(46m_{D_l}^2c_w^2+m_W^2\left(2s_w^2-3\right)c_{2\beta}\right)\right.\\
&RD_{l,(s1,1)}^*RD_{l,(s2,1)}+2\left(23m_{D_l}^2c_w^2-m_W^2s_w^2c_{2\beta}\right)\\
&RD_{l,(s1,2)}^*RD_{l,(s2,2)}-\frac{1-g5s}{2}\ 8m_{D_l}^2c_w^2\left(SRD1(l,l)_{s1,s2}\right.\\
&\left.\left.-SRD2(l,l)_{s1,s2}\right)\right],\\
C^{H^-H^+\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2t_\beta^2}\ C_F\ \ \left\{t_\beta^2\left[\left(2m_W^2c_w^2c_{2\beta}+m_W^2c_{2\beta}\right)\delta_{lm}\right.\right.\\
&\left.+\,46c_w^2t_\beta^2\sum_g m_{D_g}^2V_{D_g,U_l}^\dagger V_{U_m,D_g}\right]RU_{l,(s1,1)}^*RU_{m,(s2,1)}\\
&+2\left[\left(3c_w^2m_{U_l}m_{U_m}-2m_W^2s_w^2c_{2\beta}t_\beta^2\right)\delta_{lm}\right.\\
&\left.+\,20m_{U_l}m_{U_m}c_w^2\sum_g\left(V_{D_g,U_l}^\dagger V_{U_m,D_g}\right)\right]RU_{l,(s1,2)}^*RU_{m,(s2,2)}\\
&-\frac{1-g5s}{2}\ 8c_w^2\sum_g\left[V_{D_g,U_l}^\dagger V_{U_m,D_g}\left(t_\beta^2m_{D_g}RU_{l,(s1,1)}^*\right.\right.\\
&\left.\left.\left.+\,m_{U_m}RU_{l,(s1,2)}^*\right)\ \left(m_{D_g}t_\beta^2RU_{m,(s2,1)}+m_{U_l}RU_{m,(s2,2)}\right)\right]\right\},
\end{aligned}
$$

$$
\begin{aligned}
C^{H^-H^+\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} = & -\frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 t_\beta^2}\ C_F\ \Big\{\Big[\left(4 m_W^2 c_w^2 c_{2\beta} t_\beta^2 - m_W^2 c_{2\beta} t_\beta^2\right)\delta_{lm} \\
& - 46 c_w^2 \sum_g m_{U_g}^2 V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big] RD^*_{l,(s1,1)} RD_{m,(s2,1)} \\
& -2t_\beta^2\left[\left(3 c_w^2 t_\beta^2 m_{D_l} m_{D_m} + m_W^2 s_w^2 c_{2\beta}\right)\delta_{lm}\right. \\
& \left. + 20 m_{D_l} m_{D_m} c_w^2 t_\beta^2 \sum_g \left(V^\dagger_{D_m,U_g} V_{U_g,D_l}\right)\right] RD^*_{l,(s1,2)} RD_{m,(s2,2)} \\
& +\frac{1-g5s}{2}\ 8c_w^2 \sum_g \Big[V^\dagger_{D_m,U_g} V_{U_g,D_l}\left(t_\beta^2 m_{D_m} RD^*_{l,(s1,2)}\right. \\
& \left. + m_{U_g} RD^*_{l,(s1,1)}\right)\ \left(m_{D_l} t_\beta^2 RD_{m,(s2,2)} + m_{U_g} RD_{m,(s2,1)}\right)\Big]\Big\}\,, \\
C^{\phi^-\phi^+\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} = & -\frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2}\ C_F\ \Big\{\Big[\left(2 m_W^2 c_w^2 c_{2\beta} + m_W^2 c_{2\beta}\right)\delta_{lm} \\
& - 46 c_w^2 \sum_g m_{D_g}^2 V^\dagger_{D_g,U_l} V_{U_m,D_g}\Big] RU^*_{l,(s1,1)} RU_{m,(s2,1)} \\
& -2\left[\left(3 c_w^2 m_{U_l} m_{U_m} + 2 m_W^2 s_w^2 c_{2\beta}\right)\delta_{lm}\right. \\
& \left. + 20 m_{U_l} m_{U_m} c_w^2 \sum_g \left(V^\dagger_{D_g,U_l} V_{U_m,D_g}\right)\right] RU^*_{l,(s1,2)} RU_{m,(s2,2)} \\
& +\frac{1-g5s}{2}\ 8c_w^2 \sum_g \Big[V^\dagger_{D_g,U_l} V_{U_m,D_g}\left(m_{D_g} RU^*_{l,(s1,1)}\right. \\
& \left. - m_{U_m} RU^*_{l,(s1,2)}\right)\ \left(m_{D_g} RU_{m,(s2,1)} - m_{U_l} RU_{m,(s2,2)}\right)\Big]\Big\}\,, \\
C^{\phi^-\phi^+\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} = & \frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2}\ C_F\ \Big\{\Big[\left(4 m_W^2 c_w^2 c_{2\beta} - m_W^2 c_{2\beta}\right)\delta_{lm} \\
& + 46 c_w^2 \sum_g m_{U_g}^2 V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big] RD^*_{l,(s1,1)} RD_{m,(s2,1)} \\
& +2\left[\left(3 c_w^2 m_{D_l} m_{D_m} - m_W^2 s_w^2 c_{2\beta}\right)\delta_{lm}\right. \\
& \left. + 20 m_{D_l} m_{D_m} c_w^2 \sum_g \left(V^\dagger_{D_m,U_g} V_{U_g,D_l}\right)\right] RD^*_{l,(s1,2)} RD_{m,(s2,2)} \\
& -\frac{1-g5s}{2}\ 8c_w^2 \sum_g \Big[V^\dagger_{D_m,U_g} V_{U_g,D_l}\left(-m_{D_m} RD^*_{l,(s1,2)}\right. \\
& \left. + m_{U_g} RD^*_{l,(s1,1)}\right)\ \left(-m_{D_l} RD_{m,(s2,2)} + m_{U_g} RD_{m,(s2,1)}\right)\Big]\Big\}\,,
\end{aligned}
$$

$$
\begin{aligned}
C^{h^0,H^0,\tilde{U}_{l,s1},\bar{\tilde{U}}_{m,s2}} &= \delta_{lm}\ \frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 s_\beta^2}\ C_F\ \left\{\left[m_{U_l}^2 c_w^2 \left(3 s_{2\alpha} + 40 c_\alpha s_\alpha\right)\right.\right. \\
&+ \left. m_W^2 \left(4 s_w^2 - 3\right) s_{2\alpha} s_\beta^2\right] RU^*_{l,(s1,1)} RU_{l,(s2,1)} \\
&+ \left[m_{U_l}^2 c_w^2 \left(3 s_{2\alpha} + 40 c_\alpha s_\alpha\right) - 4 m_W^2 s_w^2 s_{2\alpha} s_\beta^2\right] RU^*_{l,(s1,2)} RU_{l,(s2,2)} \\
&- \left.\frac{1-g5s}{2}\ 8 m_{U_l}^2 c_w^2 c_\alpha s_\alpha \left(SRU1(l,l)_{s1,s2} + SRU2(l,l)_{s1,s2}\right)\right\}, \\
C^{h^0,H^0,\tilde{D}_{l,s1},\bar{\tilde{D}}_{m,s2}} &= -\delta_{lm}\ \frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 c_\beta^2}\ C_F\ \left\{\left[m_{D_l}^2 c_w^2 \left(3 s_{2\alpha} + 40 c_\alpha s_\alpha\right)\right.\right. \\
&+ \left. m_W^2 \left(2 s_w^2 - 3\right) s_{2\alpha} c_\beta^2\right] RD^*_{l,(s1,1)} RD_{l,(s2,1)} \\
&+ \left[m_{D_l}^2 c_w^2 \left(3 s_{2\alpha} + 40 c_\alpha s_\alpha\right) - 2 m_W^2 s_w^2 s_{2\alpha} c_\beta^2\right] RD^*_{l,(s1,2)} RD_{l,(s2,2)} \\
&- \left.\frac{1-g5s}{2}\ 8 m_{D_l}^2 c_w^2 c_\alpha s_\alpha \left(SRD1(l,l)_{s1,s2} + SRD2(l,l)_{s1,s2}\right)\right\}, \\
C^{h^0 A^0 \tilde{U}_{l,s1} \bar{\tilde{U}}_{m,s2}} &= -\frac{1-g5s}{2}\ \delta_{lm}\ \frac{i\delta^{ij}}{48 m_W^2 s_w^2 s_\beta t_\beta}\ C_F\ m_{U_l}^2 c_\alpha \\
&\left(RU^*_{l,(s1,2)} RU_{l,(s2,1)} - RU^*_{l,(s1,1)} RU_{l,(s2,2)}\right), \\
C^{h^0 A^0 \tilde{D}_{l,s1} \bar{\tilde{D}}_{m,s2}} &= \frac{1-g5s}{2}\ \delta_{lm}\ \frac{i\delta^{ij}}{48 m_W^2 s_w^2 c_\beta}\ C_F\ m_{D_l}^2 s_\alpha t_\beta \\
&\left(RD^*_{l,(s1,2)} RD_{l,(s2,1)} - RD^*_{l,(s1,1)} RD_{l,(s2,2)}\right), \\
C^{h^0 \phi^0 \tilde{U}_{l,s1} \bar{\tilde{U}}_{m,s2}} &= -\frac{1-g5s}{2}\ \delta_{lm}\ \frac{i\delta^{ij}}{48 m_W^2 s_w^2 s_\beta}\ C_F\ m_{U_l}^2 c_\alpha \\
&\left(RU^*_{l,(s1,2)} RU_{l,(s2,1)} - RU^*_{l,(s1,1)} RU_{l,(s2,2)}\right), \\
C^{h^0 \phi^0 \tilde{D}_{l,s1} \bar{\tilde{D}}_{m,s2}} &= -\frac{1-g5s}{2}\ \delta_{lm}\ \frac{i\delta^{ij}}{48 m_W^2 s_w^2 c_\beta}\ C_F\ m_{D_l}^2 s_\alpha \\
&\left(RD^*_{l,(s1,2)} RD_{l,(s2,1)} - RD^*_{l,(s1,1)} RD_{l,(s2,2)}\right), \\
C^{H^0 A^0 \tilde{Q}_{l,s1} \bar{\tilde{Q}}_{m,s2}} &= C^{h^0 A^0 \tilde{Q}_{l,s1} \bar{\tilde{Q}}_{m,s2}} \left(s_\alpha \to -c_\alpha, c_\alpha \to s_\alpha\right), \\
C^{H^0 \phi^0 \tilde{Q}_{l,s1} \bar{\tilde{Q}}_{m,s2}} &= C^{h^0 G^0 \tilde{Q}_{l,s1} \bar{\tilde{Q}}_{m,s2}} \left(s_\alpha \to -c_\alpha, c_\alpha \to s_\alpha\right), \\
C^{A^0 \phi^0 \tilde{U}_{l,s1} \bar{\tilde{U}}_{m,s2}} &= \frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 s_\beta^2 t_\beta}\ C_F\ \left[\left(m_{U_l}^2 c_w^2 \left(40 s_\beta^2 + 3 s_{2\beta} t_\beta\right)\right.\right. \\
&+ \left. m_W^2 s_\beta^2 s_{2\beta} t_\beta \left(4 s_w^2 - 3\right)\right) RU^*_{l,(s1,1)} RU_{l,(s2,1)} \\
&+ \left(m_{U_l}^2 c_w^2 \left(40 s_\beta^2 + 3 s_{2\beta} t_\beta\right) - 4 m_W^2 s_w^2 s_\beta^2 s_{2\beta} t_\beta\right) \\
&RU^*_{l,(s1,2)} RU_{l,(s2,2)} - \frac{1-g5s}{2}\ 8 m_{U_l}^2 c_w^2 s_\beta^2 \\
&\left.\left(SRU1(l,l)_{s1,s2} - SRU2(l,l)_{s1,s2}\right)\right],
\end{aligned}
$$

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\begin{aligned}
C^{A^0\phi^0\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{\delta^{ij}}{384m_W^2c_w^2s_w^2c_\beta^2}\ C_F\ \left[\left(m_{D_l}^2c_w^2\left(40c_\beta^2t_\beta+3s_{2\beta}\right)\right.\right.\\
&\left.+\,m_W^2c_\beta^2s_{2\beta}\left(2s_w^2-3\right)\right)RD_{l,(s1,1)}^*RD_{l,(s2,1)}\\
&+\left(m_{D_l}^2c_w^2\left(40c_\beta^2t_\beta+3s_{2\beta}\right)-2m_W^2s_w^2c_\beta^2s_{2\beta}\right)\\
&RD_{l,(s1,2)}^*RD_{l,(s2,2)}-\frac{1-g5s}{2}\ 8m_{D_l}^2c_w^2c_\beta^2t_\beta\\
&\left.(SRD1(l,l)_{s1,s2}-SRD2(l,l)_{s1,s2})\right],\\
C^{h^0H^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{\delta^{ij}}{192\sqrt{2}m_W^2s_w^2c_\beta s_\beta^2t_\beta s_{2\beta}}\ C_F\ V_{D_m,U_l}^\dagger\left\{s_{2\beta}\left(m_{U_l}^2c_\alpha c_\beta\left(20s_\beta+3c_\beta t_\beta\right)\right.\right.\\
&\left.-m_{D_m}^2s_\alpha s_\beta t_\beta^2\left(20s_\beta+3c_\beta t_\beta\right)-3m_W^2s_\beta^2c_\beta t_\beta c_{\alpha+\beta}\right)\\
&RU_{l,(s1,1)}^*RD_{m,(s2,1)}+2m_{U_l}m_{D_m}s_\beta\left(10c_\alpha c_\beta s_{2\beta}t_\beta^2+3c_\beta s_\beta t_\beta s_{\beta-\alpha}\right.\\
&\left.-10s_\alpha s_\beta s_{2\beta}\right)RU_{l,(s1,2)}^*RD_{m,(s2,2)}-\frac{1-g5s}{2}\ 4s_\beta s_{2\beta}\\
&\left[\left(m_{U_l}^2c_\alpha c_\beta-m_{D_m}^2s_\alpha s_\beta t_\beta^2\right)RU_{l,(s1,1)}^*RD_{m,(s2,1)}\right.\\
&+\left(-m_{U_l}m_{D_m}s_\alpha s_\beta+m_{U_l}^2c_\alpha c_\beta\right)RU_{l,(s1,1)}^*RD_{m,(s2,2)}\\
&+\left(m_{U_l}m_{D_m}c_\alpha c_\beta t_\beta^2-m_{D_m}^2s_\alpha s_\beta t_\beta^2\right)RU_{l,(s1,2)}^*RD_{m,(s2,1)}\\
&\left.\left.+m_{U_l}m_{D_m}\left(c_\alpha c_\beta t_\beta^2-s_\alpha s_\beta\right)RU_{l,(s1,2)}^*RD_{m,(s2,2)}\right]\right\},\\
C^{h^0H^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= -\frac{\delta^{ij}}{192\sqrt{2}m_W^2s_w^2c_\beta s_\beta^2t_\beta s_{2\beta}}\ C_F\ V_{U_m,D_l}\left\{s_{2\beta}\left(m_{U_m}^2c_\alpha c_\beta\left(20s_\beta+3c_\beta t_\beta\right)\right.\right.\\
&\left.-m_{D_l}^2s_\alpha s_\beta t_\beta^2\left(20s_\beta+3c_\beta t_\beta\right)-3m_W^2s_\beta^2c_\beta t_\beta c_{\alpha+\beta}\right)\\
&RD_{l,(s1,1)}^*RU_{m,(s2,1)}+2m_{U_m}m_{D_l}s_\beta\left(10c_\alpha c_\beta s_{2\beta}t_\beta^2+3c_\beta s_\beta t_\beta s_{\beta-\alpha}\right.\\
&\left.-10s_\alpha s_\beta s_{2\beta}\right)RD_{l,(s1,2)}^*RU_{m,(s2,2)}-\frac{1-g5s}{2}\ 4s_\beta s_{2\beta}\\
&\left[\left(m_{U_m}^2c_\alpha c_\beta-m_{D_l}^2s_\alpha s_\beta t_\beta^2\right)RD_{l,(s1,1)}^*RU_{m,(s2,1)}\right.\\
&+\left(m_{U_m}m_{D_l}c_\alpha c_\beta t_\beta^2-m_{D_l}^2s_\alpha s_\beta t_\beta^2\right)RD_{l,(s1,1)}^*RU_{m,(s2,2)}\\
&+\left(-m_{D_l}m_{U_m}s_\alpha s_\beta+m_{U_m}^2c_\alpha c_\beta\right)RD_{l,(s1,2)}^*RU_{m,(s2,1)}\\
&\left.\left.+m_{U_m}m_{D_l}\left(c_\alpha c_\beta t_\beta^2-s_\alpha s_\beta\right)RD_{l,(s1,2)}^*RU_{m,(s2,2)}\right]\right\},\\
C^{H^0H^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= C^{h^0H^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}}\left(c_\alpha\to s_\alpha,s_\alpha\to -c_\alpha,c_{\alpha+\beta}\to s_{\alpha+\beta},\right.\\
&\left.s_{\alpha+\beta}\to -c_{\alpha+\beta},s_{\beta-\alpha}\to c_{\beta-\alpha},c_{\beta-\alpha}\to -s_{\beta-\alpha}\right),\\
C^{H^0H^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= C^{h^0H^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}}\left(c_\alpha\to s_\alpha,s_\alpha\to -c_\alpha,c_{\alpha+\beta}\to s_{\alpha+\beta},\right.\\
&\left.s_{\alpha+\beta}\to -c_{\alpha+\beta},s_{\beta-\alpha}\to c_{\beta-\alpha},c_{\beta-\alpha}\to -s_{\beta-\alpha}\right),
\end{aligned}
$$

$$
\begin{aligned}
C^{A^0 H^- \tilde{U}_{l,s1} \bar{\tilde{D}}_{m,s2}} &= \frac{i\delta^{ij}}{192\sqrt{2} m_W^2 s_w^2 t_\beta^2}\ C_F\ V^\dagger_{D_m,U_l}\ \Big[\Big(23 m_{D_m}^2 t_\beta^4 - 23 m_{U_l}^2 + 3 m_W^2 c_{2\beta} t_\beta^2\Big) \\
&\quad RU^*_{l,(s1,1)} RD_{m,(s2,1)} + \frac{1-g5s}{2}\ 4\left(m_{D_m} t_\beta^2 + m_{U_l}\right) \\
&\quad \Big(\left(m_{U_l} - m_{D_m} t_\beta^2\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)} + m_{D_m} t_\beta^2 RU^*_{l,(s1,2)} RD_{m,(s2,1)} \\
&\quad - m_{U_l} RU^*_{l,(s1,1)} RD_{m,(s2,2)}\Big)\Big]\,, \\
C^{A^0 H^+ \tilde{D}_{l,s1} \bar{\tilde{U}}_{m,s2}} &= -\frac{i\delta^{ij}}{192\sqrt{2} m_W^2 s_w^2 t_\beta^2}\ C_F\ V_{U_m,D_l}\ \Big[\Big(23 m_{D_l}^2 t_\beta^4 - 23 m_{U_m}^2 + 3 m_W^2 c_{2\beta} t_\beta^2\Big) \\
&\quad RD^*_{l,(s1,1)} RU_{m,(s2,1)} + \frac{1-g5s}{2}\ 4\left(m_{D_l} t_\beta^2 + m_{U_m}\right) \\
&\quad \Big(\left(m_{U_m} - m_{D_l} t_\beta^2\right) RD^*_{l,(s1,1)} RU_{m,(s2,1)} + m_{D_l} t_\beta^2 RD^*_{l,(s1,1)} RU_{m,(s2,2)} \\
&\quad - m_{U_m} RD^*_{l,(s1,2)} RU_{m,(s2,1)}\Big)\Big]\,, \\
C^{\phi^0 H^- \tilde{U}_{l,s1} \bar{\tilde{D}}_{m,s2}} &= -\frac{i\delta^{ij}}{192\sqrt{2} m_W^2 s_w^2 s_{2\beta} t_\beta}\ C_F\ V^\dagger_{D_m,U_l}\ \Big[s_{2\beta}\left(23 m_{D_m}^2 t_\beta^2 + 23 m_{U_l}^2 - 3 m_W^2 s_{2\beta} t_\beta\right) \\
&\quad RU^*_{l,(s1,1)} RD_{m,(s2,1)} - 2 m_{U_l} m_{D_m}\left(3 t_\beta + 10 s_{2\beta} t_\beta^2 + 10 s_{2\beta}\right) \\
&\quad RU^*_{l,(s1,2)} RD_{m,(s2,2)} - \frac{1-g5s}{2}\ 4 s_{2\beta} \\
&\quad \Big(\left(m_{U_l}^2 + m_{D_m}^2 t_\beta^2\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)} + \left(-m_{U_l}^2 + m_{U_l} m_{D_m}\right) \\
&\quad RU^*_{l,(s1,1)} RD_{m,(s2,2)} - \left(m_{D_m}^2 t_\beta^2 - m_{U_l} m_{D_m} t_\beta^2\right) RU^*_{l,(s1,2)} RD_{m,(s2,1)} \\
&\quad - \left(m_{U_l} m_{D_m} t_\beta^2 + m_{U_l} m_{D_m}\right) RU^*_{l,(s1,2)} RD_{m,(s2,2)}\Big)\Big]\,, \\
C^{\phi^0 H^+ \tilde{D}_{l,s1} \bar{\tilde{U}}_{m,s2}} &= -\frac{i\delta^{ij}}{192\sqrt{2} m_W^2 s_w^2 s_{2\beta} t_\beta}\ C_F\ V_{U_m,D_l}\ \Big[-s_{2\beta}\left(23 m_{D_l}^2 t_\beta^2 + 23 m_{U_m}^2 - 3 m_W^2 s_{2\beta} t_\beta\right) \\
&\quad RD^*_{l,(s1,1)} RU_{m,(s2,1)} + 2 m_{U_m} m_{D_l}\left(3 t_\beta + 10 s_{2\beta} t_\beta^2 + 10 s_{2\beta}\right) \\
&\quad RD^*_{l,(s1,2)} RU_{m,(s2,2)} + \frac{1-g5s}{2}\ 4 s_{2\beta} \\
&\quad \Big(\left(m_{U_m}^2 + m_{D_l}^2 t_\beta^2\right) RD^*_{l,(s1,1)} RU_{m,(s2,1)} + t_\beta^2\left(-m_{D_l}^2 + m_{D_l} m_{U_m}\right) \\
&\quad RD^*_{l,(s1,1)} RU_{m,(s2,2)} - \left(m_{U_m}^2 - m_{D_l} m_{U_m}\right) RD^*_{l,(s1,2)} RU_{m,(s2,1)} \\
&\quad - \left(m_{D_l} m_{U_m} t_\beta^2 + m_{D_l} m_{U_m}\right) RD^*_{l,(s1,2)} RU_{m,(s2,2)}\Big)\Big]\,,
\end{aligned}
$$

$$
\begin{aligned}
C^{h^0\phi^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= \frac{\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2 s_\beta c_\beta s_{2\beta}}\ C_F\ V^\dagger_{D_m,U_l}\ \left[-s_{2\beta}\left(23m_{U_l}^2 c_\alpha c_\beta + 23m_{D_m}^2 s_\alpha s_\beta\right.\right.\\
&\quad \left. -3m_W^2 s_\beta c_\beta s_{\alpha+\beta}\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)} + 2m_{U_l} m_{D_m}\left(10c_\alpha c_\beta s_{2\beta}\right.\\
&\quad \left. +10s_\alpha s_\beta s_{2\beta} + 3c_\beta s_\beta c_{\beta-\alpha}\right) RU^*_{l,(s1,2)} RD_{m,(s2,2)} + \frac{1-g5s}{2}\ 4s_{2\beta}\\
&\quad \left(\left(m_{U_l}^2 c_\alpha c_\beta + m_{D_m}^2 s_\alpha s_\beta\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)}\right.\\
&\quad + \left(m_{U_l}^2 c_\alpha c_\beta - m_{U_l} m_{D_m} s_\alpha s_\beta\right) RU^*_{l,(s1,1)} RD_{m,(s2,2)}\\
&\quad + \left(m_{D_m}^2 s_\alpha s_\beta - m_{U_l} m_{D_m} c_\alpha c_\beta\right) RU^*_{l,(s1,2)} RD_{m,(s2,1)}\\
&\quad \left.\left. -\ m_{U_l} m_{D_m}\left(c_\alpha c_\beta + s_\alpha s_\beta\right) RU^*_{l,(s1,2)} RD_{m,(s2,2)}\right)\right],\\
C^{h^0\phi^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \frac{\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2 s_\beta c_\beta s_{2\beta}}\ C_F\ V_{U_m,D_l}\ \left[-s_{2\beta}\left(23m_{U_m}^2 c_\alpha c_\beta + 23m_{D_l}^2 s_\alpha s_\beta\right.\right.\\
&\quad \left. -3m_W^2 s_\beta c_\beta s_{\alpha+\beta}\right) RD^*_{l,(s1,1)} RU_{m,(s2,1)} + 2m_{D_l} m_{U_m}\left(10c_\alpha c_\beta s_{2\beta}\right.\\
&\quad \left. +10s_\alpha s_\beta s_{2\beta} + 3c_\beta s_\beta c_{\beta-\alpha}\right) RD^*_{l,(s1,2)} RU_{m,(s2,2)} + \frac{1-g5s}{2}\ 4s_{2\beta}\\
&\quad \left(\left(m_{U_m}^2 c_\alpha c_\beta + m_{D_l}^2 s_\alpha s_\beta\right) RD^*_{l,(s1,1)} RU_{m,(s2,1)}\right.\\
&\quad + \left(m_{D_l}^2 s_\alpha s_\beta - m_{D_l} m_{U_m} c_\alpha c_\beta\right) RD^*_{l,(s1,1)} RU_{m,(s2,2)}\\
&\quad + \left(m_{U_m}^2 c_\alpha c_\beta - m_{D_l} m_{U_m} s_\alpha s_\beta\right) RD^*_{l,(s1,2)} RU_{m,(s2,1)}\\
&\quad \left.\left. -\ m_{D_l} m_{U_m}\left(c_\alpha c_\beta + s_\alpha s_\beta\right) RD^*_{l,(s1,2)} RU_{m,(s2,2)}\right)\right],\\
C^{H^0\phi^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= C^{h^0G^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}}\left(c_\alpha \to s_\alpha, s_\alpha \to -c_\alpha, c_{\alpha+\beta} \to s_{\alpha+\beta},\right.\\
&\quad \left. s_{\alpha+\beta} \to -c_{\alpha+\beta}, s_{\beta-\alpha} \to c_{\beta-\alpha}, c_{\beta-\alpha} \to -s_{\beta-\alpha}\right),\\
C^{H^0\phi^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= C^{h^0G^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}}\left(c_\alpha \to s_\alpha, s_\alpha \to -c_\alpha, c_{\alpha+\beta} \to s_{\alpha+\beta},\right.\\
&\quad \left. s_{\alpha+\beta} \to -c_{\alpha+\beta}, s_{\beta-\alpha} \to c_{\beta-\alpha}, c_{\beta-\alpha} \to -s_{\beta-\alpha}\right),\\
C^{A^0\phi^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{i\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2 s_{2\beta} t_\beta}\ C_F\ V^\dagger_{D_m,U_l}\ \left[s_{2\beta}\left(23m_{U_l}^2 + 23m_{D_m}^2 t_\beta^2\right.\right.\\
&\quad \left. -3m_W^2 t_\beta s_{2\beta}\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)} + 2m_{U_l} m_{D_m}\\
&\quad \left(3t_\beta + 10s_{2\beta} t_\beta^2 + 10s_{2\beta}\right) RU^*_{l,(s1,2)} RD_{m,(s2,2)} + \frac{1-g5s}{2}\\
&\quad 4s_{2\beta}\left(-\left(m_{U_l}^2 + m_{D_m}^2 t_\beta^2\right) RU^*_{l,(s1,1)} RD_{m,(s2,1)}\right.\\
&\quad + \left(m_{U_l}^2 + m_{U_l} m_{D_m} t_\beta^2\right) RU^*_{l,(s1,1)} RD_{m,(s2,2)}\\
&\quad + \left(m_{D_m}^2 t_\beta^2 + m_{U_l} m_{D_m}\right) RU^*_{l,(s1,2)} RD_{m,(s2,1)}\\
&\quad \left.\left. -\ m_{U_l} m_{D_m}\left(1 + t_\beta^2\right) RU^*_{l,(s1,2)} RD_{m,(s2,2)}\right)\right],
\end{aligned}
$$

$$C^{A^0\phi^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} = \frac{i\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2 s_{2\beta}t_\beta}\ C_F\ V_{U_m,D_l}\ \Big[s_{2\beta}\left(23m_{U_m}^2+23m_{D_l}^2t_\beta^2\right.$$
$$\left.-3m_W^2 t_\beta s_{2\beta}\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}+2m_{U_m}m_{D_l}$$
$$\left(3t_\beta+10s_{2\beta}t_\beta^2+10s_{2\beta}\right)RD^*_{l,(s1,2)}RU_{m,(s2,2)}-\frac{1-g5s}{2}$$
$$4s_{2\beta}\left(\left(m_{U_m}^2+m_{D_l}^2t_\beta^2\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}\right.$$
$$-\left(m_{D_l}^2t_\beta^2+m_{U_m}m_{D_l}\right)RD^*_{l,(s1,1)}RU_{m,(s2,2)}$$
$$-\left(m_{U_m}^2+m_{U_m}m_{D_l}t_\beta^2\right)RD^*_{l,(s1,2)}RU_{m,(s2,1)}$$
$$\left.+\ m_{D_l}m_{U_m}\left(1+t_\beta^2\right)RD^*_{l,(s1,2)}RU_{m,(s2,2)}\right)\Big],$$
$$C^{\phi^0\phi^-\tilde{U}_{l,s1}\bar{\tilde{D}}_{m,s2}} = -\frac{i\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2}\ C_F\ V^\dagger_{D_m,U_l}\ \Big[\left(23m_{U_l}^2-23m_{D_m}^2\right.$$
$$\left.+3m_W^2c_{2\beta}\right)RU^*_{l,(s1,1)}RD_{m,(s2,1)}+\frac{1-g5s}{2}$$
$$4\left(m_{D_m}-m_{U_l}\right)\left(\left(m_{U_l}+m_{D_m}\right)RU^*_{l,(s1,1)}RD_{m,(s2,1)}\right.$$
$$\left.-\ m_{U_l}RU^*_{l,(s1,1)}RD_{m,(s2,2)}-m_{D_m}RU^*_{l,(s1,2)}RD_{m,(s2,1)}\right)\Big],$$
$$C^{\phi^0\phi^+\tilde{D}_{l,s1}\bar{\tilde{U}}_{m,s2}} = -\frac{i\delta^{ij}}{192\sqrt{2}m_W^2 s_w^2}\ C_F\ V_{U_m,D_l}\ \Big[\left(23m_{U_m}^2-23m_{D_l}^2\right.$$
$$\left.+3m_W^2c_{2\beta}\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}+\frac{1-g5s}{2}$$
$$4\left(m_{D_l}-m_{U_m}\right)\left(\left(m_{U_m}+m_{D_l}\right)RD^*_{l,(s1,1)}RU_{m,(s2,1)}\right.$$
$$\left.-\ m_{D_l}RD^*_{l,(s1,1)}RU_{m,(s2,2)}-m_{U_m}RD^*_{l,(s1,2)}RU_{m,(s2,1)}\right)\Big],$$
$$C^{H^+\phi^-\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} = \frac{\delta^{ij}}{384m_W^2c_w^2s_w^2t_\beta}\ C_F\ \Big[t_\beta\left(\left(2m_W^2c_w^2s_{2\beta}+m_W^2s_{2\beta}\right)\delta_{lm}\right.$$
$$\left.-\ 46c_w^2t_\beta\sum_g\left(m_{D_g}^2V^\dagger_{D_g,U_l}V_{U_m,D_g}\right)\right)RU^*_{l,(s1,1)}RU_{m,(s2,1)}$$
$$+2\left(\left(3m_{U_l}^2c_w^2-2m_W^2s_w^2s_{2\beta}t_\beta\right)\delta_{lm}\right.$$
$$\left.+\ 20m_{U_l}m_{U_m}c_w^2\sum_g\left(V^\dagger_{D_g,U_l}V_{U_l,D_g}\right)\right)RU^*_{l,(s1,2)}RU_{m,(s2,2)}$$
$$+\frac{1-g5s}{2}\ 8c_w^2\ \sum_g\left(V^\dagger_{D_g,U_l}V_{U_m,D_g}\right)\left(m_{D_g}t_\beta^2RU^*_{l,(s1,1)}\right.$$
$$\left.+\ m_{U_m}RU^*_{l,(s1,2)}\right)\left(m_{D_g}RU_{m,(s2,1)}-m_{U_l}RU_{m,(s2,2)}\right)\Big],$$

$$
\begin{aligned}
C^{H^+\phi^-\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 t_\beta}\ C_F\ \Big[\Big(\big(4 m_W^2 c_w^2 s_{2\beta} t_\beta - m_W^2 s_{2\beta} t_\beta\big)\,\delta_{lm} \\
&- 46 c_w^2 \sum_g \Big(m_{U_g}^2 V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\Big)\, RD^*_{l,(s1,1)} RD_{m,(s2,1)} \\
&+2 t_\beta\, \Big(\big(3 m_{D_l}^2 c_w^2 t_\beta - m_W^2 s_w^2 s_{2\beta}\big)\,\delta_{lm} \\
&+ 20 m_{D_l} m_{D_m} c_w^2 t_\beta \sum_g \Big(V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\Big)\, RD^*_{l,(s1,2)} RD_{m,(s2,2)} \\
&+\frac{1-g5s}{2}\ 8 c_w^2\ \sum_g \Big(V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\,\big(m_{U_g} RD^*_{l,(s1,1)} \\
&- m_{D_m} RD^*_{l,(s1,2)}\big)\,\big(m_{U_g} RD_{m,(s2,1)} + m_{D_l} t_\beta^2 RD_{m,(s2,2)}\big)\Big]\,, \\
C^{H^-\phi^+\tilde{U}_{l,s1}\bar{\tilde{U}}_{m,s2}} &= \frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 t_\beta}\ C_F\ \Big[t_\beta\, \Big(\big(2 m_W^2 c_w^2 s_{2\beta} + m_W^2 s_{2\beta}\big)\,\delta_{lm} \\
&- 46 c_w^2 t_\beta \sum_g \Big(m_{D_g}^2 V^\dagger_{D_g,U_l} V_{U_m,D_g}\Big)\Big)\, RU^*_{l,(s1,1)} RU_{m,(s2,1)} \\
&+2\, \Big(\big(3 m_{U_l}^2 c_w^2 - 2 m_W^2 s_w^2 s_{2\beta} t_\beta\big)\,\delta_{lm} \\
&+ 20 m_{U_l} m_{U_m} c_w^2 \sum_g \Big(V^\dagger_{D_g,U_l} V_{U_l,D_g}\Big)\Big)\, RU^*_{l,(s1,2)} RU_{m,(s2,2)} \\
&+\frac{1-g5s}{2}\ 8 c_w^2\ \sum_g \Big(V^\dagger_{D_g,U_l} V_{U_m,D_g}\Big)\,\big(m_{D_g} RU^*_{l,(s1,1)} \\
&- m_{U_m} RU^*_{l,(s1,2)}\big)\,\big(m_{D_g} RU_{m,(s2,1)} + m_{U_l} t_\beta^2 RU_{m,(s2,2)}\big)\Big]\,, \\
C^{H^-\phi^+\tilde{D}_{l,s1}\bar{\tilde{D}}_{m,s2}} &= -\frac{\delta^{ij}}{384 m_W^2 c_w^2 s_w^2 t_\beta}\ C_F\ \Big[\Big(\big(4 m_W^2 c_w^2 s_{2\beta} t_\beta - m_W^2 s_{2\beta} t_\beta\big)\,\delta_{lm} \\
&- 46 c_w^2 \sum_g \Big(m_{U_g}^2 V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\Big)\, RD^*_{l,(s1,1)} RD_{m,(s2,1)} \\
&+2 t_\beta\, \Big(\big(3 m_{D_l}^2 c_w^2 t_\beta - m_W^2 s_w^2 s_{2\beta}\big)\,\delta_{lm} \\
&+ 20 m_{D_l} m_{D_m} c_w^2 t_\beta \sum_g \Big(V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\Big)\, RD^*_{l,(s1,2)} RD_{m,(s2,2)} \\
&+\frac{1-g5s}{2}\ 8 c_w^2\ \sum_g \Big(V^\dagger_{D_m,U_g} V_{U_g,D_l}\Big)\,\big(m_{U_g} RD^*_{l,(s1,1)} \\
&+ m_{D_m} t_\beta^2 RD^*_{l,(s1,2)}\big)\,\big(m_{U_g} RD_{m,(s2,1)} - m_{D_l} RD_{m,(s2,2)}\big)\Big]\,. \qquad (4.52)
\end{aligned}
$$

All of the other effective vertices which don't appear above are zero. We have checked that if we include all of the quarks and squarks, the terms proportional to totally antisymmetry tensor $\varepsilon_{\mu\nu\rho\sigma}$ are vanishing due to the cancelation of gauge anomaly in MSSM QCD.

5. Summary

Given the data accumulated at the LHC, searching the supersymmetry signatures seems feasible, which has been attracted a lot of interests from both theoretical and experimental sides. It is important to note that ATLAS and CMS are mainly focused on the MSSM to interpret what they have observed (or not observed). To be more specifically, a special theoretical model the so-called constrained MSSM was often used to reduce the number of unknow parameters from dozens to four-and-a-half[105, 106, 107, 108, 109, 110]. Hence, phenomenologically, MSSM plays a special role in discovering or excluding supersymmetry. As a consequence of R-parity conservation, a pair of gluino or squarks are produced dominantly at the LHC and then cascade decays into multi QCD particles. Its irreducible background are mainly multijets final states, and it may also be background of other interesting processes. Therefore, higher order corrections especially including SUSY QCD corrections are predominantly in investigating SUSY phenomenology.

In the paper, we have given a complete list of Feynman rules for the rational part of one-loop amplitudes in the MSSM QCD. The numerators of one-loop amplitudes can be simplified in four-dimensions if the corresponding rational terms are added correctly. It makes the NLO SUSY QCD calculation in multi-particle processes much easier than before. With the nature of rational part R described above, the regularization scheme dependence is included in the expressions of R. Therefore, γ_5 problems in dimensional regularization can be clarified with the investigation of R in supersymmetric models. To meet the needs of practical NLO calculation, the results are expressed in two dimensional regularization schemes and two γ_5 schemes. The usefulness of our results will be shown in analyzing SUSY phenomenology up to NLO SUSY QCD corrections.

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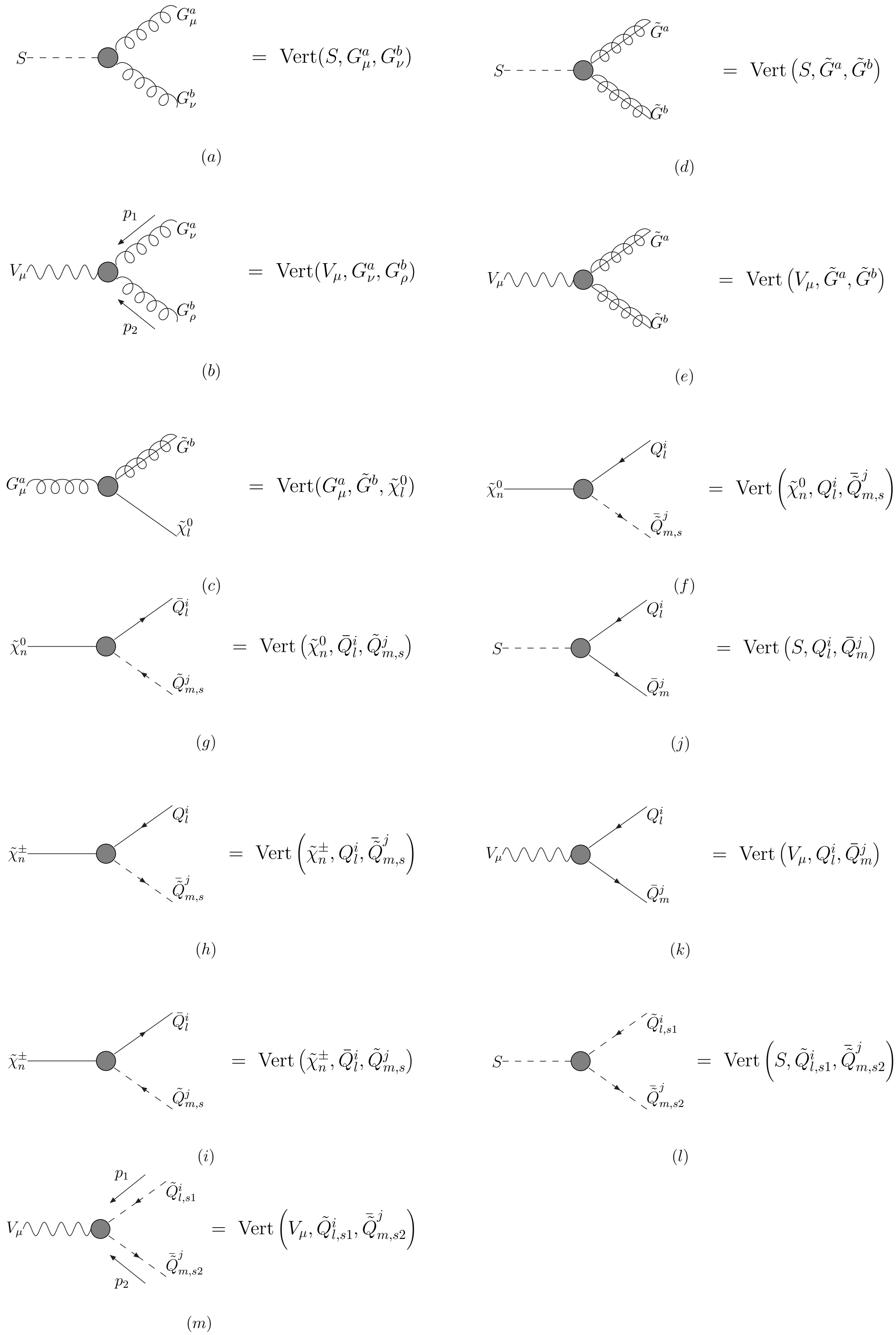

Figure 5: All possible non-vanishing 3-point vertices in mixed MSSM QCD.

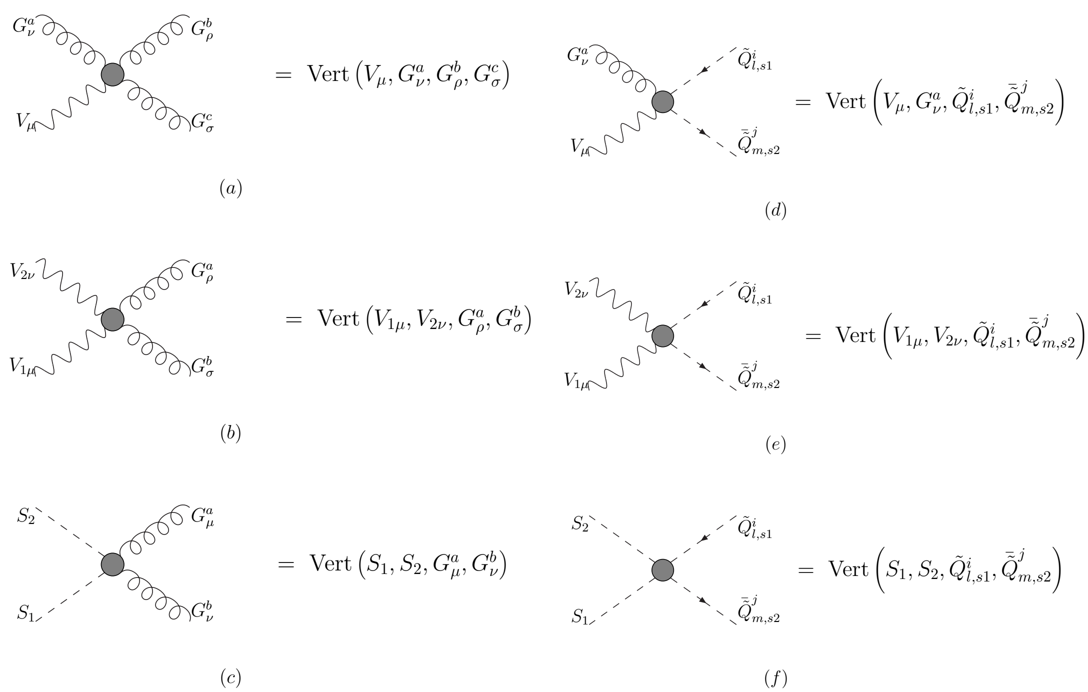

Figure 6: All possible non-vanishing 4-point vertices in mixed SUSY QCD (MSSM).