KA-TP-8-1995
hep-ph/9511250

Complete set of Feynman rules for the MSSM – *erratum*

Janusz Rosiek*
Institute of Theoretical Physics, Warsaw University
Hoża 69, 00-681 Warsaw, POLAND

November 6, 1995

Abstract

This erratum contains the full corrected version of the paper *Complete set of Feynman rules for the Minimal Supersymmetric Standard Model* [1]. The complete set of Feynman rules for the R-parity conserving MSSM is listed, including the most general form of flavour mixing. Propagators and vertices are computed in t'Hooft-Feynman gauge, convenient for perturbative calculations beyond the tree level.

Last update: 17 Sep 2004

*e-mail: janusz.rosiek@fuw.edu.pl

Instead of putting on the web next version of the *"erratum"*, with few more errors in the original paper corrected, I decided to resubmit the "integrated" version, i.e. full paper text with all necessary corrections included - it should be easier to use in this way. I also used this opportunity to correct the most irritating features of the notation used in the original *Phys. Rev.* **D** paper, making it, wherever possible, closer to commonly used naming conventions. However, I kept unchanged the "final" matrix notation for the interactions vertices in the mass eigenstates basis, as it proved to be very useful in compactifying many complicated loop calculations.

Most of the expressions for mass matrices, mixing angles and vertices listed in [1] have been checked during the calculations of the 1-loop radiative corrections in the gauge and Higgs sectors of the MSSM [2, 3] and in calculations of various CP violation/FCNC processes [4, 5, 6] The 1-loop corrections were calculated in on-shell renormalization scheme, which provide a very strict test of correctness of all formulae entering the expressions for the renormalized quantities: most of the errors in Feynman rules lead immediately to non-cancellation of the divergencies. Only the most exotic vertices like 4-sfermion couplings, several rarely used 2 Higgs boson-2 sfermion couplings were not used and did not pass this test yet. Other vertices can be with good probability considered as checked.

Formulae for diagonalization of mass matrices and most of the vertices listed in [1] are accessible also as the ready FORTRAN codes. They are part of the bigger library for calculation of the 1-loop radiative corrections in on-shell renormalization scheme to the MSSM neutral Higgs production and decay rates. This library can be found at:

http://www.fuw.edu.pl/~rosiek/physics/neutral_higgs.html

In order to avoid too many replacements in hep-ph archive, and to speed up the process of introducing further corrections if any were found, I will always put the most recent version of this collection of Feynman rules on my private web page. It will be available at:

http://www.fuw.edu.pl/~rosiek/physics/prd41.html

I will not update the hep-ph version of the *erratum* any more!

Acknowledgments

I wish to thank to P. Chankowski, A. Belayev, J. R. Espinosa, J. Hagelin, M.Laine, M. Misiak, P. Slavich, M. Rauch, J. Salomon and others who called my attention to some of the errors listed in this erratum. Especially, I would like to thank T. Ewerth for very careful reading of its integrated version.

Complete set of Feynman rules for the MSSM

published in *Phys. Rev.* **D41** (1990) 3464
Last update for errors and misprints: 27 Feb 2009

Janusz Rosiek

Institute of Theoretical Physics, Warsaw University
Hoża 69, 00-681 Warsaw, POLAND

Abstract

The complete set of Feynman rules for the R-parity conserving MSSM is listed, including the most general form of flavour mixing. Propagators and vertices are computed in t'Hooft-Feynman gauge, convenient for perturbative calculations beyond the tree level.

1 Introduction

Since many years the minimal supersymmetric extension of the standard model (MSSM) has been the subject of intensive studies. Practical calculations in the MSSM are usually tedious because of its complexity. For easier reference, in this paper we complete all Feynman rules for the MSSM in the t'Hooft-Feynman gauge, convenient for calculations of loop corrections. We put special emphasis on including the most general form of flavour mixing allowed in the R-parity conserving MSSM.

Some of the mass matrices and vertices given in the paper, mainly related to the Higgs and -inos sectors, has been listed in other papers (see e.g. [7, 8]). For completeness, we write down those formulae once again, in order to collect in one place and fixed convention the full set of rules needed to calculate any process in the frame of the MSSM. The spinor conventions used in the paper follow those given in [7].

The paper has the following structure. Section 2 contains short review of the rules of constructing SUSY Yang-Mills theories. In section 3 we define fields and parameters present in the MSSM Lagrangian. The physical content of the theory - the mass eigenstates fields are given in section 4. In section 5 we define the gauge used throughout the paper. Section 6 contains the MSSM Lagrangian expressed in terms of the physical fields. A short summary and comments on the choice of the parameters of the model are given in section 7. In Appendix A we write down the MSSM Lagrangian in terms of the initial fields, before the $SU(2) \times U(1)$ symmetry breaking. Appendix B contains the full set of Feynman rules corresponding to the Lagrangian of section 6.

2 General structure of the SUSY models

Supersymmetric Yang-Mills theories contain two basic types of fields - gauge multiplets (λ^a, V_μ^a) in the adjoint representation of a gauge group G and matter multiplets (A_i, ψ_i) in some chosen representations of G. By λ and ψ we denote here fermions in two-component notation, A_i are complex scalar fields and V_μ^a are spin-1 real vector fields (the spinor notation and conventions used in the paper are the same as those explained in Appendix A of ref. [7]). To construct the Lagrangian of such a theory we follow the rules given in ref. [7].

In the strictly supersymmetric case one has the following terms (summation convention is used unless stated otherwise):

1. Kinetic terms.

2. Self interaction of gauge multiplets: three- and four-gauge boson vertices plus additional interaction of gauginos and gauge fields:

$$ig f_{abc}\lambda^a\sigma^\mu\bar{\lambda}^b V^c_\mu$$

3. Interactions of the gauge and matter multiplets (T^a is the Hermitian group generator in the representation corresponding to the given multiplet):

$$\begin{gathered} -gT^a_{ij}V^a_\mu(\bar{\psi}_i\bar{\sigma}^\mu\psi_j + iA^\star_i\partial_\mu A_j), \\ ig\sqrt{2}T^a_{ij}(\lambda^a\psi_j A^\star_i - \bar{\lambda}^a\bar{\psi}_i A_j), \\ g^2(T^aT^b)_{ij}V^a_\mu V^{\mu b}A^\star_i A_j. \end{gathered}$$

4. Self interactions of the matter multiplets. For technical reasons it is convenient to define the so called "superpotential" W as at most cubic gauge-invariant polynomial which depends on scalar fields A_i, but not on $A^\star_i$ [7] (alternatively, the superpotential can be defined as a function of the superfields). Introducing two auxiliary functions:

$$F_i = \partial W/\partial A_i$$

$$D^a = gA^\star_i T^a_{ij}A_j$$

one can write the scalar supersymmetric potential as:

$$V = \frac{1}{2}D^aD^a + F^\star_i F_i$$

Yukawa interactions are given by:

$$-\frac{1}{2}\left(\frac{\partial^2 W}{\partial A_i\partial A_j}\psi_i\psi_j + \text{H.c.}\right)$$

In the case of semisimple groups $G = G_1 \times \ldots \times G_n$ in the expressions above one should substitute terms of the form gVT by sums $\Sigma g_i V_i T_i$ and similarly for gauginos. There are also n vertices $\lambda - \bar{\lambda} - V$ and n terms $\frac{1}{2}D^2$ in the scalar potential. For $U(1)$ factors there are no gaugino-gaugino-gauge interaction, and, by convention, the product $gT^a_{ij}V^a_\mu$ is replaced by $\frac{1}{2}gy_i\delta_{ij}V_\mu$ (no sum over i), where y_i is the $U(1)$ quantum number of the matter multiplet (A_i, ψ_i) (similarly for gauginos). In general the $U(1)$ D-field may be shifted by the so called Fayet-Iliopoulos term ξ [9]:

$$D = \frac{1}{2}gy_iA^\star_i A_i + \xi$$

$\xi \neq 0$ may introduce dangerous quadratic divergences into the theory. In most realistic models (including MSSM) this term is absent.

This completes the construction of a strictly supersymmetric theories. To build models which preserve the most important feature of such theories - absence of quadratic divergences - and which simultaneously are experimentally acceptable, it is necessary to add to the above Lagrangian explicit soft SUSY breaking terms. The most general form of appropriate expressions can be written down as [10]:

$$m_1 \Re A^2 + m_2 \Im A^2 + y(A^3 + \text{H.c.}) + m_3(\lambda^a \lambda^a + \text{H.c.})$$

A^2 and A^3 denote symbolically all possible gauge invariant combinations of scalar fields. These terms split the masses of scalars and fermions present in the SUSY multiplets and introduce new, non-supersymmetric trilinear scalar couplings.

3 MSSM field and coupling structure

To obtain the realistic supersymmetric version of the Standard Model one should extend the field content of the theory by adding appropriate scalar or fermionic partners to the ordinary matter and gauge fields. As stated in the previous section, the superpotential can only be constructed as a function of fields and not of their complex conjugates. Therefore it is not possible to give masses to all fermions using only one Higgs doublet - at least two with opposite $U(1)$ quantum numbers are necessary. The full field content of the MSSM is listed below:

1. Multiplets of the gauge group $SU(3) \times SU(2) \times U(1)$:
   - B_μ, λ_B - weak hypercharge gauge fields, coupling constant g_1
   - A^i_μ, λ^i_A - weak isospin gauge fields, coupling constant g_2
   - G^a_μ, λ^a_G - QCD gauge fields, coupling constant g_3
2. Matter multiplets - we assume that three matter generations exist, so the index I (and similarly all capital $I, J, K \ldots$ indices in the rest of the paper) runs from 1 to 3 (such notation can be immediately generalized to the case of N generations).

Scalars	Fermions	$U(1)$ charge
$L^I = \begin{pmatrix} \tilde{\nu}^I \\ \tilde{e}^{-I}_L \end{pmatrix}$	$\Psi^I_L = \begin{pmatrix} \nu^I \\ e^{-I} \end{pmatrix}_L$	-1
$R^I = \tilde{e}^{+I}_R$	$\Psi^I_R = (e^{-I}_L)^c$	2
$Q^I = \begin{pmatrix} \tilde{u}^I \\ \tilde{d}^I_L \end{pmatrix}$	$\Psi^I_Q = \begin{pmatrix} u^I \\ d^I \end{pmatrix}_L$	$\frac{1}{3}$
$D^I = \tilde{d}^{I\star}_R$	$\Psi^I_D = (d^I_L)^c$	$\frac{2}{3}$
$U^I = \tilde{u}^{I\star}_R$	$\Psi^I_U = (u^I_L)^c$	$-\frac{4}{3}$
$H^1 = \begin{pmatrix} H^1_1 \\ H^1_2 \end{pmatrix}$	$\Psi^1_H = \begin{pmatrix} \Psi^1_{H1} \\ \Psi^1_{H2} \end{pmatrix}$	-1
$H^2 = \begin{pmatrix} H^2_1 \\ H^2_2 \end{pmatrix}$	$\Psi^2_H = \begin{pmatrix} \Psi^2_{H1} \\ \Psi^2_{H2} \end{pmatrix}$	1

The $SU(3)$ indices are not written explicitly. We assume that Q quarks and squarks are QCD triplets, D and U fields - QCD antitriplets.

In order to define the theory we have to write down the superpotential and introduce the soft SUSY breaking terms (without them even using two Higgs doublets it is impossible to break spontaneously the gauge symmetry). The most general form of the superpotential which does not violate gauge invariance and the SM conservation laws is:

$$W = \mu\epsilon_{ij}H_i^1 H_j^2 + \epsilon_{ij}Y_l^{IJ}H_i^1 L_j^I R^J + \epsilon_{ij}Y_d^{IJ}H_i^1 Q_j^I D^J + \epsilon_{ij}Y_u^{IJ}H_i^2 Q_j^I U^J$$

Some bilinear and trilinear terms (e.g. $\varepsilon_L^I \epsilon_{ij} H_i^2 L_j^I$) are gauge invariant but break lepton and/or barion number conservation, so we do not include them. In general, presence of such terms can be forbidden by requiring the preservation of additional global symmetry of the model, so called R-parity (for review see e.g. [11]):

$$R = (-1)^{L+3B+2S}$$

Soft breaking terms can be divided into several classes:

1. Mass terms for the scalar fields.

$$\begin{aligned} -m_{H_1}^2 H_i^{1\star}H_i^1 - m_{H_2}^2 H_i^{2\star}H_i^2 - (m_L^2)^{IJ}L_i^{I\star}L_i^J - (m_R^2)^{IJ}R^{I\star}R^J \\ -(m_Q^2)^{IJ}Q_i^{I\star}Q_i^J - (m_D^2)^{IJ}D^{I\star}D^J - (m_U^2)^{IJ}U^{I\star}U^J \end{aligned}$$

2. Mass terms for gauginos.

$$\frac{1}{2}M_1\lambda_B\lambda_B + \frac{1}{2}M_2\lambda_A^i\lambda_A^i + \frac{1}{2}M_3\lambda_G^a\lambda_G^a + \text{H.c.}$$

3. Trilinear couplings of the scalar fields corresponding to the Yukawa terms in the superpotential.

$$m_{12}^2\epsilon_{ij}H_i^1 H_j^2 + \epsilon_{ij}A_l^{IJ}H_i^1 L_j^I R^J + \epsilon_{ij}A_d^{IJ}H_i^1 Q_j^I D^J + \epsilon_{ij}A_u^{IJ}H_i^2 Q_j^I U^J + \text{H.c.}$$

4. Trilinear couplings of the scalar fields, different in the from from the Yukawa terms in the superpotential (sometimes called "non-analytic terms" as they involve charge conjugated Higgs fields). Usually such couplings are not considered as they are not generated in the most popular SUSY-breaking models.

$$A_l^{\prime IJ}H_i^{2\star}L_i^I R^J + A_d^{\prime IJ}H_i^{2\star}Q_i^I D^J + A_u^{\prime IJ}H_i^{1\star}Q_i^I U^J + \text{H.c.}$$

In general constants μ, m_{12}^2, Yukawa matrices, squark and gaugino masses and the trilinear soft couplings may be complex. One can perform three operations which eliminate unphysical degrees of freedom. First, it is possible to change globally the phase of one of the Higgs multiplets in such a way, that the constant m_{12}^2 becomes a real number. Then the equations for the vacuum expectations values of the Higgs fields involve only real parameters (at least on the tree level). Second, one can redefine simultaneously the phases of all fermions in the model removing the complex phase from one of gaugino mass parameter (see e.g. [4]). Paralelly one should redefine the phases of other couplings to absorb the change of the phase of the Higgs multiplet. The last operation is the same as in the SM - by the rotation of the fields

$$
\begin{aligned}
&(Q_i^I, \Psi_{Qi}^I) \to V_{Qi}^{IJ}(Q_i^J, \Psi_{Qi}^J) && \text{(no sum over } i\text{)} \\
&(U^I, \Psi_U^I) \to V_U^{IJ}(U^J, \Psi_U^J) \\
&(D^I, \Psi_D^I) \to V_D^{IJ}(D^J, \Psi_D^J)
\end{aligned}
$$

and similarly for leptons, one can diagonalize the matrices Y_l^{IJ}, Y_u^{IJ} and Y_d^{IJ} obtaining Yukawa couplings of the form $\epsilon_{ij} Y_l^I H_i^1 L_j^I R^I$ etc. Simultaneous rotations of quark and squark fields lead to the so-called super-KM basis (see e.g. [5]). After the proper redefinition of the parameters the matrices V_Q, V_U, V_D, V_L and V_R disappear from the Lagrangian leaving as their trace the Kobayashi-Maskawa matrix K, appearing in many expressions containing both quarks and squarks:

$$K = V_{Q_1}^\dagger V_{Q_2}$$

Of course, sfermion mass matrices in the super-KM basis may be still non-diagonal, i.e. Yukawa and soft matrices need not to be diagonalized by the same rotations.

In the rest of the paper, in particular in section 4 and in Appendix A we use the *rotated* soft breaking parameters. For example, if the initial Yukawa and trilinear scalar couplings were $Y_u^{(0)}$ and $A_u^{(0)}$, respectively, the rotation of the quark and squark fields to the super-KM basis lead to diagonal Yukawa coupling $Y_u = V_{Q1}^\dagger Y_u^{(0)} V_U$ and new trilinear scalar coupling $A_u = V_{Q1}^\dagger A_u^{(0)} V_U$, which are then used in other expressions. The procedure of the redefinition of the squark mass matrices remains some freedom. We have chosen the redefined left squark mass matrix parameter in such a way that the Kobayashi-Maskawa matrix multiplies m_Q^2 in the up-squark mass matrix.

The full Lagrangian written in terms of the initial fields (before $SU(2)\times U(1)$ symmetry breaking) is given in Appendix A.

4 Physical spectrum of the MSSM

In the previous section we defined the field content and all parameters of the MSSM. To obtain the physical spectrum of particles present in the theory one should carry out the standard procedure of gauge symmetry breaking via vacuum expectation values of the neutral Higgs fields and find the eigenstates of the mass matrices for all fields. The VEV's of the Higgs fields satisfy the following equations (θ denotes the Weinberg angle, $s_W = \sin\theta$, $c_W = \cos\theta$, $e = g_2 s_W = g_1 c_W$):

$$< H^1 > = \frac{1}{\sqrt{2}} \begin{pmatrix} v_1 \\ 0 \end{pmatrix} \qquad\qquad < H^2 > = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_2 \end{pmatrix}$$

$$
\begin{aligned}
\left[\frac{e^2}{8 s_W^2 c_W^2}\left(v_1^2 - v_2^2\right) + m_{H_1}^2 + |\mu|^2\right] v_1 &= -m_{12}^2 v_2 \\
\left[-\frac{e^2}{8 s_W^2 c_W^2}\left(v_1^2 - v_2^2\right) + m_{H_2}^2 + |\mu|^2\right] v_2 &= -m_{12}^2 v_1
\end{aligned}
$$

Parameters of the above set of equations are constrained by the condition that v_1 and v_2 should reproduce the proper values of the gauge boson masses.

The physical fields of the MSSM can be identified as follows:

1. Gauge bosons. Eight gluons g^a_μ and the photon F_μ are massless, bosons $W^\pm_\mu$ and Z_μ have masses

$$
\begin{aligned}
M_Z &= \frac{e}{2s_W c_W}\left(v_1^2+v_2^2\right)^{\frac{1}{2}} \\
M_W &= \frac{e}{2s_W}\left(v_1^2+v_2^2\right)^{\frac{1}{2}}
\end{aligned}
$$

2. Charged Higgs scalars. Four charged Higgs scalars exist, two of them with the mass

$$M^2_{H_1^\pm} = M_W^2 + m^2_{H_1} + m^2_{H_2} + 2|\mu|^2$$

and the other two massless. In the physical (unitary) gauge $H_2^\pm(\equiv G^\pm)$ are eaten by W bosons and disappear from the Lagrangian. Fields H_1^+ and H_2^+ are related to the initial Higgs fields by the rotation matrix Z_H :

$$
\begin{pmatrix} H_2^{1\star} \\ H_1^2 \end{pmatrix} = Z_H \begin{pmatrix} H_1^+ \\ H_2^+ \end{pmatrix}
$$

$$
Z_H = \left(v_1^2+v_2^2\right)^{-\frac{1}{2}} \begin{pmatrix} v_2 & -v_1 \\ v_1 & v_2 \end{pmatrix}
$$

3. Neutral Higgs scalars. If the Lagrangian contains only real parameters the neutral Higgs particles have well defined CP eigenvalues - two of them are scalars, the other two are pseudoscalars. This is no longer true if some parameters are complex. Nevertheless, in both cases it is convenient to divide neutral Higgses into two classes.

   i) "Scalar" particles H_i^0 , $i=1,2$, defined as:

   $$\sqrt{2}\Re H_i^i = Z_R^{ij} H_j^0 + v_i \text{ (no sum over } i)$$

   The matrix Z_R and the masses of H_i^0 can be obtained by diagonalizing the M_R^2 matrix:

   $$
   Z_R^T \begin{pmatrix} -m^2_{12}\frac{v_2}{v_1} + \frac{e^2 v_1^2}{4s_W^2 c_W^2} & m^2_{12} - \frac{e^2 v_1 v_2}{4s_W^2 c_W^2} \\ m^2_{12} - \frac{e^2 v_1 v_2}{4s_W^2 c_W^2} & -m^2_{12}\frac{v_1}{v_2} + \frac{e^2 v_2^2}{4s_W^2 c_W^2} \end{pmatrix} Z_R = \begin{pmatrix} M^2_{H_1^0} & 0 \\ 0 & M^2_{H_2^0} \end{pmatrix}
   $$

   ii) "Pseudoscalar" particles A_i^0 , $i=1,2$:

   $$\sqrt{2}\Im H_i^i = Z_H^{ij} A_j^0 \text{ (no sum over } i)$$

   $A_1^0(\equiv A^0)$ has the mass $M_A^2 = m^2_{H_1} + m^2_{H_2} + 2|\mu|^2$, $A_2^0(\equiv G^0)$ is the massless Goldstone boson which disappears in the unitary gauge. The Z_H matrix is the same as in the case of the charged Higgs bosons.

Matrix notation used in the paper is convenient in the case of non-unitary gauge, when the Goldstone bosons are explicitly present in the Lagrangian and enter the calculations together with the physical Higgs particles. In order to compare our expressions with the more commonly used notation one should substitute:

$$
Z_H = \begin{pmatrix} \sin\beta & -\cos\beta \\ \cos\beta & \sin\beta \end{pmatrix} \qquad Z_R = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}
$$

where:

$$\begin{aligned}\tan\beta &= \frac{v_2}{v_1}\\ \tan 2\alpha &= \tan 2\beta\frac{M_A^2+M_Z^2}{M_A^2-M_Z^2}\end{aligned}$$

It is also worth remembering that due to the SUSY structure of the model the Higgs boson masses fulfill two interesting tree-level relations:

$$\begin{aligned}M^2_{H_1^+} &= M_A^2+M_W^2\\ M^2_{H_1^0}+M^2_{H_2^0} &= M_A^2+M_Z^2\end{aligned}$$

4. Matter fermions (quarks and leptons) have masses (note that Y_l^I, Y_d^I are defined as negative):

$$m_\nu^I = 0 \qquad m_e^I = -\frac{v_1 Y_l^I}{\sqrt{2}}$$
$$m_d^I = -\frac{v_1 Y_d^I}{\sqrt{2}} \qquad m_u^I = \frac{v_2 Y_u^I}{\sqrt{2}}$$

5. Charginos. Four 2-component spinors $(\lambda_A^1, \lambda_A^2, \Psi_{H2}^1, \Psi_{H1}^2)$ combine to give two 4-component Dirac fermions χ_1, χ_2 corresponding to two physical charginos. The chargino mixing matrices Z_+ and Z_- are defined by the condition:

$$(Z_-)^T\begin{pmatrix} M_2 & \frac{ev_2}{\sqrt{2}s_W}\\ \frac{ev_1}{\sqrt{2}s_W} & \mu\end{pmatrix} Z_+ = \begin{pmatrix} M_{\chi_1} & 0\\ 0 & M_{\chi_2}\end{pmatrix}$$

The unitary matrices Z_-, Z_+ are not uniquely specified - by changing their relative phases and the ordering of the eigenvalues it is possible to choose M_{χ_i} to be positive and $M_{\chi_2} > M_{\chi_1}$. The fields χ_i are related to the initial spinors as below:

$$\begin{aligned}\Psi_{H1}^2 &= Z_+^{2i}\kappa_i^+\\ \Psi_{H2}^1 &= Z_-^{2i}\kappa_i^- \qquad\qquad \chi_i = \begin{pmatrix}\kappa_i^+\\ \bar\kappa_i^-\end{pmatrix}\\ \lambda_A^\pm &\equiv \frac{\lambda_A^1 \mp i\lambda_A^2}{\sqrt{2}} = iZ_\pm^{1i}\kappa_i^\pm\end{aligned}$$

6. Four 2-component spinors $(\lambda_B, \lambda_A^3, \Psi_{H1}^1, \Psi_{H2}^2)$ combine into four Majorana fermions χ_i^0, $i = 1\ldots 4$, called neutralinos. The formulas for mixing and mass matrices are the following:

$$Z_N^T\begin{pmatrix} M_1 & 0 & \frac{-ev_1}{2c_W} & \frac{ev_2}{2c_W}\\ 0 & M_2 & \frac{ev_1}{2s_W} & \frac{-ev_2}{2s_W}\\ \frac{-ev_1}{2c_W} & \frac{ev_1}{2s_W} & 0 & -\mu\\ \frac{ev_2}{2c_W} & \frac{-ev_2}{2s_W} & -\mu & 0\end{pmatrix} Z_N = \begin{pmatrix} M_{\chi_1^0} & & 0\\ & \ddots & \\ 0 & & M_{\chi_4^0}\end{pmatrix}$$

$$
\begin{aligned}
\lambda_B &= iZ_N^{1i}\kappa_i^0 \\
\lambda_A^3 &= iZ_N^{2i}\kappa_i^0 \\
\Psi_{H1}^1 &= Z_N^{3i}\kappa_i^0 \qquad\qquad \chi_i^0 = \begin{pmatrix} \kappa_i^0 \\ \bar{\kappa}_i^0 \end{pmatrix} \\
\Psi_{H2}^2 &= Z_N^{4i}\kappa_i^0
\end{aligned}
$$

7. $SU(3)$ gauginos do not mix. In four component notation one has eight gluinos Λ_G^a with masses $|M_3|$.

$$
\Lambda_G^a = \begin{pmatrix} -i\lambda_G^a \\ i\bar{\lambda}_G^a \end{pmatrix}
$$

8. Three complex scalar fields L_1^I form three sneutrino mass eigenstates $\tilde{\nu}^I$ with masses given by diagonalization of a matrix $\mathcal{M}_\nu^2$:

$$
\begin{aligned}
L_1^I &= Z_\nu^{IJ}\tilde{\nu}^J \\
Z_\nu^\dagger \mathcal{M}_\nu^2 Z_\nu &= \begin{pmatrix} M_{\nu_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{\nu_3}^2 \end{pmatrix} \\
\mathcal{M}_\nu^2 &= \frac{e^2(v_1^2 - v_2^2)}{8s_W^2 c_W^2}\hat{1} + m_L^2
\end{aligned}
$$

Sneutrinos are neutral but *complex* scalars.

9. Fields L_2^I and R^I mix to give six charged selectrons L_i, $i = 1 \ldots 6$:

$$
L_2^I = Z_L^{Ii\star} L_i^- \qquad\qquad R^I = Z_L^{(I+3)i} L_i^+
$$

$$
Z_L^\dagger \begin{pmatrix} (\mathcal{M}_L^2)_{LL} & (\mathcal{M}_L^2)_{LR} \\ (\mathcal{M}_L^2)_{LR}^\dagger & (\mathcal{M}_L^2)_{RR} \end{pmatrix} Z_L = \begin{pmatrix} M_{L_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{L_6}^2 \end{pmatrix}
$$

$$
\begin{aligned}
\left(\mathcal{M}_L^2\right)_{LL} &= \frac{e^2(v_1^2 - v_2^2)(1 - 2c_W^2)}{8s_W^2 c_W^2}\hat{1} + \frac{v_1^2 Y_l^2}{2} + (m_L^2)^T \\
\left(\mathcal{M}_L^2\right)_{RR} &= -\frac{e^2(v_1^2 - v_2^2)}{4c_W^2}\hat{1} + \frac{v_1^2 Y_l^2}{2} + m_R^2 \\
\left(\mathcal{M}_L^2\right)_{LR} &= \frac{1}{\sqrt{2}}\left(v_2(Y_l\mu^\star - A_l') + v_1 A_l\right)
\end{aligned}
$$

10. Fields Q_1^I and U^I turn into six up squarks U_i.

$$
Q_1^I = Z_U^{Ii} U_i^+ \qquad\qquad U^I = Z_U^{(I+3)i\star} U_i^-
$$

$$
Z_U^T \begin{pmatrix} (\mathcal{M}_U^2)_{LL} & (\mathcal{M}_U^2)_{LR} \\ (\mathcal{M}_U^2)_{LR}^\dagger & (\mathcal{M}_U^2)_{RR} \end{pmatrix} Z_U^\star = \begin{pmatrix} M_{U_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{U_6}^2 \end{pmatrix}
$$

$$\begin{aligned}
\left(\mathcal{M}_U^2\right)_{LL} &= -\frac{e^2(v_1^2-v_2^2)(1-4c_W^2)}{24s_W^2c_W^2}\hat{1} + \frac{v_2^2Y_u^2}{2} + (Km_Q^2K^\dagger)^T \\
\left(\mathcal{M}_U^2\right)_{RR} &= \frac{e^2(v_1^2-v_2^2)}{6c_W^2}\hat{1} + \frac{v_2^2Y_u^2}{2} + m_U^2 \\
\left(\mathcal{M}_U^2\right)_{LR} &= -\frac{1}{\sqrt{2}}\left(v_1(A_u^{'} + Y_u\mu^\star) + v_2A_u\right)
\end{aligned}$$

One should note that Z_U is defined with the complex conjugate comparing to definitions of Z_L (and Z_D below). With such a definition, all positively charged sfermion fields in the MSSM Lagrangian in section 4 are multiplied by Z_X^{ij}, negatively charged by $Z_X^{ij\star}$. This makes easier to control correctness of various calculations including complex parameters.

11. Finally one has six down-squarks D_i composed from fields Q_2^I and D^I:

$$Q_2^I = Z_D^{Ii\star}D_i^- \qquad\qquad D^I = Z_D^{(I+3)i}D_i^+$$

$$Z_D^\dagger \begin{pmatrix} (\mathcal{M}_D^2)_{LL} & (\mathcal{M}_D^2)_{LR} \\ (\mathcal{M}_D^2)_{LR}^\dagger & (\mathcal{M}_D^2)_{RR} \end{pmatrix} Z_D = \begin{pmatrix} M_{D_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{D_6}^2 \end{pmatrix}$$

$$\begin{aligned}
\left(\mathcal{M}_D^2\right)_{LL} &= -\frac{e^2(v_1^2-v_2^2)(1+2c_W^2)}{24s_W^2c_W^2}\hat{1} + \frac{v_1^2Y_d^2}{2} + (m_Q^2)^T \\
\left(\mathcal{M}_D^2\right)_{RR} &= -\frac{e^2(v_1^2-v_2^2)}{12c_W^2}\hat{1} + \frac{v_1^2Y_d^2}{2} + m_D^2 \\
\left(\mathcal{M}_D^2\right)_{LR} &= \frac{1}{\sqrt{2}}\left(v_2(Y_d\mu^\star - A_d^{'}) + v_1A_d\right)
\end{aligned}$$

We have now completely defined all the physical fields existing in the MSSM:

Photon	F_μ		
Gauge bosons	$Z_\mu^0, W_\mu^\pm$		
Gluons	g_μ^a	$a = 1\ldots 8$	
Gluinos	Λ_G^a	$a = 1\ldots 8$	(Majorana spinors)
Charginos	χ_i	$i = 1, 2$	(Dirac spinors)
Neutralinos	χ_i^0	$i = 1\ldots 4$	(Majorana spinors)
Neutrinos	ν^I	$I = 1\ldots 3$	(Dirac spinors)
Electrons	e^I	$I = 1\ldots 3$	(Dirac spinors)
Quarks	u^I, d^I	$I = 1\ldots 3$	(Dirac spinors)
Sneutrinos	$\tilde{\nu}^I$	$I = 1\ldots 3$	
Selectrons	$L_i^\pm$	$i = 1\ldots 6$	
Squarks	$U_i^\pm, D_i^\pm$	$i = 1\ldots 6$	
Higgs particles:			
charged	$H_1^\pm$ ($\equiv H^\pm$)		
neutral "scalar"	H_1^0, H_2^0 ($\equiv H, h$)		
neutral "pseudoscalar"	A_1^0 ($\equiv A^0$)		

Not for all the possible values of input parameters one can obtain reasonable sets of particle masses. For instance, for some choices of the Higgs sector data the $SU(2)\times U(1)$ symmetry would not be broken or, on the opposite, incorrect values of squark sector parameters can lead to negative values of their masses and in consequence to the color symmetry breaking [12]

5 Choice of the gauge

As long as one considers various processes in the spontaneously broken gauge theory in the tree approximation, the most natural and preferred choice is the unitary gauge in which the unphysical Goldstone bosons are absent from the Lagrangian and Feynman rules. When one wants to calculate higher order corrections, one must include the ghost loops suitable for the given gauge. In such case it is much more efficient to use the t'Hooft-Feynman gauge, in which the Goldstone fields appear explicitly in the calculations, but ghost vertices are relatively simple. For our model the appropriate choice for the gauge fixing terms is:

$$\begin{aligned}
L_{GF} &= -\frac{1}{2\kappa}\left(\partial^\mu G^a_\mu\right)^2 - \frac{1}{2\xi}\left(\partial^\mu A^3_\mu + \xi M_Z c_W G^0\right)^2 - \frac{1}{2\xi}\left(\partial^\mu B_\mu - \xi M_Z s_W G^0\right)^2 \\
&- \frac{1}{2\xi}\left(\partial^\mu A^1_\mu + \frac{i}{\sqrt{2}}\xi M_W (G^+ - G^-)\right)^2 - \frac{1}{2\xi}\left(\partial^\mu A^2_\mu - \frac{1}{\sqrt{2}}\xi M_W (G^+ + G^-)\right)^2 \\
&= -\frac{1}{2\kappa}\left(\partial^\mu G^a_\mu\right)^2 - \frac{1}{2\xi}\left(\partial^\mu Z_\mu\right)^2 - \frac{1}{2\xi}\left(\partial^\mu F_\mu\right)^2 - \frac{1}{\xi}\left(\partial^\mu W^+_\mu\right)\left(\partial^\mu W^-_\mu\right) \\
&- M_Z G^0 \partial^\mu Z_\mu - i M_W (G^+ \partial^\mu W^-_\mu - G^- \partial^\mu W^+_\mu) - \frac{1}{2}\xi M_Z^2 (G^0)^2 - \xi M_W^2 G^+ G^-
\end{aligned}$$

In some calculations it may be convenient to use even more complicated version of the above expression, with different gauge fixing parameters for various gauge groups (see e.g. [2]).

6 The interaction Lagrangian

Although we consider only the minimal extension of the standard model, the full set of Feynman rules for such a theory in the gauge described in section 5 is very complicated. In this section we write down the interaction part of the MSSM Lagrangian. The propagators and vertices suitable for the chosen gauge are collected in Appendix B. Of course, one can obtain from them rules for tree calculations in the unitary gauge by setting $H_2^\pm$ and A_2^0 to zero and neglecting the ghost terms.

It is convenient to divide all terms in the Lagrangian into classes corresponding to the different types of particles taking part in the interactions (the quark, squark and gluino vertices which contain the QCD coupling constant g_3 are collected together as the separate class).

We start from two technical remarks explaining the notation used through the rest of the paper. First, the expression "+H.c." always refers only to the line in which it was used. Second, after the diagonalization of the superpotential the Yukawa matrices $Y_l^{IJ}, Y_u^{IJ}, Y_d^{IJ}$ change into $Y_l^I\delta^{IJ}, Y_u^I\delta^{IJ}, Y_d^I\delta^{IJ}$ and simultaneously sums of the type $A^{IJ}Y_l^{JK}B^{KL}$ convert into $A^{IJ}Y_l^J B^{JL}$ etc., containing the capital indices $I, J, K\ldots$ more than twice; nevertheless, one should always use the summation convention in those cases. This should not lead to any misunderstandings.

1. Interactions of gauge bosons and superscalars.
i) quark-squark-gauge interactions (the color indices are not written explicitly):

$$- \frac{2}{3}e\bar{u}^I\gamma^\mu u^I F_\mu - \frac{2}{3}ie(U_i^- \overleftrightarrow{\partial^\mu} U_i^+)F_\mu + \frac{1}{3}e\bar{d}^I\gamma^\mu d^I F_\mu + \frac{1}{3}ie(D_i^+ \overleftrightarrow{\partial^\mu} D_i^-)F_\mu$$

$$
\begin{aligned}
&- \frac{e}{2s_Wc_W}\bar{u}^I\gamma^\mu(P_L-\frac{4}{3}s_W^2)u^IZ_\mu - \frac{ie}{2s_Wc_W}(Z_U^{Ii\star}Z_U^{Ij}-\frac{4}{3}s_W^2\delta^{ij})(U_i^-\overleftrightarrow{\partial^\mu}U_j^+)Z_\mu\\
&+ \frac{e}{2s_Wc_W}\bar{d}^I\gamma^\mu(P_L-\frac{2}{3}s_W^2)d^IZ_\mu + \frac{ie}{2s_Wc_W}(Z_D^{Ii}Z_D^{Ij\star}-\frac{2}{3}s_W^2\delta^{ij})(D_i^+\overleftrightarrow{\partial^\mu}D_j^-)Z_\mu\\
&- \frac{e}{\sqrt{2}s_W}K^{JI\star}\bar{d}^I\gamma^\mu P_Lu^JW_\mu^- - \frac{ie}{\sqrt{2}s_W}Z_D^{Ii}Z_U^{Jj}K^{JI\star}(D_i^+\overleftrightarrow{\partial^\mu}U_j^+)W_\mu^- + \text{H.c.}\\
&+ \frac{4}{9}e^2F_\mu F^\mu U_i^-U_i^+ + \frac{2e^2}{3s_Wc_W}(Z_U^{Ii\star}Z_U^{Ij}-\frac{4}{3}\delta^{ij}s_W^2)Z_\mu F^\mu U_i^-U_j^+\\
&+ \frac{e^2}{3c_W^2}\left[\frac{4}{3}\delta^{ij}s_W^2+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right]Z_\mu Z^\mu U_i^-U_j^+\\
&+ \frac{1}{9}e^2F_\mu F^\mu D_i^+D_i^- + \frac{e^2}{3s_Wc_W}(Z_D^{Ii}Z_D^{Ij\star}-\frac{2}{3}\delta^{ij}s_W^2)Z_\mu F^\mu D_i^+D_j^-\\
&+ \frac{e^2}{3c_W^2}\left[\frac{1}{3}\delta^{ij}s_W^2+\frac{3-4s_W^2}{4s_W^2}Z_D^{Ii}Z_D^{Ij\star}\right]Z_\mu Z^\mu D_i^+D_j^-\\
&+ \frac{e^2}{2s_W^2}Z_U^{Ii\star}Z_U^{Ij}W_\mu^+W^{-\mu}U_i^-U_j^+ + \frac{e^2}{2s_W^2}Z_D^{Ii}Z_D^{Ij\star}W_\mu^+W^{-\mu}D_i^+D_j^-\\
&- \frac{e^2\sqrt{2}}{6s_Wc_W}Z_D^{Ii}Z_U^{Jj}K^{JI\star}D_i^+U_j^+(Z^\mu s_W-F^\mu c_W)W_\mu^- + \text{H.c.}
\end{aligned}
$$

ii) lepton-slepton-gauge interactions

$$
\begin{aligned}
&- \frac{e}{2s_Wc_W}\bar{\nu}^I\gamma^\mu P_L\nu^IZ_\mu - \frac{ie}{2s_Wc_W}(\tilde{\nu}^{I\star}\overleftrightarrow{\partial^\mu}\tilde{\nu}^I)Z_\mu + e\bar{e}^I\gamma^\mu e^IF_\mu + ie(L_i^+\overleftrightarrow{\partial^\mu}L_i^-)F_\mu\\
&+ \frac{e}{2s_Wc_W}\bar{e}^I\gamma^\mu(P_L-2s_W^2)e^IZ_\mu + \frac{ie}{2s_Wc_W}(Z_L^{Ii}Z_L^{Ij\star}-2s_W^2\delta^{ij})(L_i^+\overleftrightarrow{\partial^\mu}L_j^-)Z_\mu\\
&- \frac{e}{\sqrt{2}s_W}\bar{\nu}^I\gamma^\mu P_Le^IW_\mu^+ - \frac{ie}{\sqrt{2}s_W}Z_\nu^{IJ}Z_L^{Ii}(L_i^+\overleftrightarrow{\partial^\mu}\tilde{\nu}^J)W_\mu^- + \text{H.c.}\\
&+ \frac{e^2}{4s_W^2c_W^2}Z_\mu Z^\mu\tilde{\nu}^{I\star}\tilde{\nu}^I + e^2F_\mu F^\mu L_i^-L_i^+ + \frac{e^2}{s_Wc_W}\left(Z_L^{Ii\star}Z_L^{Ij}-2\delta^{ij}s_W^2\right)F_\mu Z^\mu L_i^-L_j^+\\
&+ \frac{e^2}{c_W^2}\left(\delta^{ij}s_W^2+\frac{1-4s_W^2}{4s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right)Z_\mu Z^\mu L_i^-L_j^+\\
&+ \frac{e^2}{2s_W^2}W_\mu^+W^{-\mu}\tilde{\nu}^{I\star}\tilde{\nu}^I + \frac{e^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}W_\mu^+W^{-\mu}L_i^-L_j^+\\
&+ \frac{e^2}{\sqrt{2}s_Wc_W}Z_\nu^{IJ}Z_L^{Ii}\tilde{\nu}^JL_i^+W_\mu^-(Z^\mu s_W-F^\mu c_W) + \text{H.c.}
\end{aligned}
$$

2. Interactions of the Higgs particles and gauge bosons. For more concise notation, we define the auxiliary matrices

$$
A_M^{ij} = Z_R^{1i}Z_H^{1j} - Z_R^{2i}Z_H^{2j} \qquad\qquad C_R^i = v_1Z_R^{1i} + v_2Z_R^{2i} \tag{1}
$$

The Higgs-gauge interaction has the form:

$$
\begin{aligned}
&+ \frac{e}{2s_Wc_W}A_M^{ij}(H_i^0\overleftrightarrow{\partial^\mu}A_j^0)Z_\mu + \frac{ie}{2s_Wc_W}(H_i^+\overleftrightarrow{\partial^\mu}H_i^-)((c_W^2-s_W^2)Z_\mu+2s_Wc_WF_\mu)\\
&- \frac{ie}{2s_W}A_M^{ij}(H_i^0\overleftrightarrow{\partial^\mu}H_j^-)W_\mu^+ - \frac{e}{2s_W}(A_i^0\overleftrightarrow{\partial^\mu}H_i^-)W_\mu^+ + \text{H.c.}
\end{aligned}
$$

$$
\begin{aligned}
&+ \quad \frac{e^2}{2s_W^2} C_R^i (W_\mu^+ W^{-\mu} + \frac{1}{2c_W^2} Z_\mu Z^\mu) H_i^0 - \left(\frac{eM_W}{c_W} (Z^\mu s_W - F^\mu c_W) W_\mu^+ H_2^- + \text{H.c.} \right) \\
&+ \quad \frac{e^2}{4s_W^2 c_W^2} \left((c_W^2 - s_W^2)^2 Z_\mu Z^\mu + 4 s_W c_W (c_W^2 - s_W^2) Z_\mu F^\mu + 4 s_W^2 c_W^2 F_\mu F^\mu \right) H_i^+ H_i^- \\
&+ \quad \frac{e^2}{4s_W^2} (W_\mu^+ W^{-\mu} + \frac{1}{2c_W^2} Z_\mu Z^\mu)(H_i^0 H_i^0 + A_i^0 A_i^0) + \frac{e^2}{2s_W^2} W_\mu^+ W^{-\mu} H_i^+ H_i^- \\
&+ \quad \frac{e^2}{2s_W c_W} A_M^{ij} (Z^\mu s_W - F^\mu c_W) W_\mu^+ H_j^- H_i^0 - \frac{ie^2}{2s_W c_W} (Z^\mu s_W - F^\mu c_W) W_\mu^+ H_i^- A_i^0 + \text{H.c.}
\end{aligned}
$$

3. Higgs-lepton and Higgs-quark interactions.

$$
\begin{aligned}
&+ \quad \frac{1}{\sqrt{2}} Y_l^I Z_R^{1i} \bar{e}^I e^I H_i^0 - \frac{i}{\sqrt{2}} Y_l^I Z_H^{1i} \bar{e}^I \gamma_5 e^I A_i^0 - Y_l^I Z_H^{1i} (\bar{e}^I P_L \nu^I H_i^- + \text{H.c.}) \\
&+ \quad \frac{1}{\sqrt{2}} Y_d^I Z_R^{1i} \bar{d}^I d^I H_i^0 - \frac{1}{\sqrt{2}} Y_u^I Z_R^{2i} \bar{u}^I u^I H_i^0 - \frac{i}{\sqrt{2}} Y_d^I Z_H^{1i} \bar{d}^I \gamma_5 d^I A_i^0 + \frac{i}{\sqrt{2}} Y_u^I Z_H^{2i} \bar{u}^I \gamma_5 u^I A_i^0 \\
&+ \quad \bar{d}^I (-Y_d^I Z_H^{1i} P_L + Y_u^J Z_H^{2i} P_R) K^{JI\star} u^J H_i^- + \text{H.c.}
\end{aligned}
$$

4. Interactions of the charginos and neutralinos with the gauge bosons:

$$
\begin{aligned}
&- \quad e \bar{\chi}_i \gamma^\mu \chi_i F_\mu - \frac{e}{2s_W c_W} \bar{\chi}_i \gamma^\mu \left(Z_+^{1i\star} Z_+^{1j} P_L + Z_-^{1i} Z_-^{1j\star} P_R + (c_W^2 - s_W^2) \delta^{ij} \right) \chi_j Z_\mu \\
&+ \quad \frac{e}{s_W} \bar{\chi}_j \gamma^\mu \left[(Z_N^{2i} Z_+^{1j\star} - \frac{1}{\sqrt{2}} Z_N^{4i} Z_+^{2j\star}) P_L + (Z_N^{2i\star} Z_-^{1j} + \frac{1}{\sqrt{2}} Z_N^{3i\star} Z_-^{2j}) P_R \right] \chi_i^0 W_\mu^+ + \text{H.c.} \\
&+ \quad \frac{e}{4s_W c_W} \bar{\chi}_i^0 \gamma^\mu \left((Z_N^{4i\star} Z_N^{4j} - Z_N^{3i\star} Z_N^{3j}) P_L - (Z_N^{4i} Z_N^{4j\star} - Z_N^{3i} Z_N^{3j\star}) P_R \right) \chi_j^0 Z_\mu
\end{aligned}
$$

5. Interactions of the charginos and neutralinos with the superscalars.
i) interactions with squarks (superscript "C" denotes the charge conjugated spinor):

$$
\begin{aligned}
&+ \quad U_i^- \bar{\chi}_j^0 \left[\left(\frac{-e}{\sqrt{2} s_W c_W} Z_U^{Ii\star} (\frac{1}{3} Z_N^{1j} s_W + Z_N^{2j} c_W) - Y_u^I Z_U^{(I+3)i\star} Z_N^{4j} \right) P_L \right. \\
&\qquad\qquad\qquad \left. + \left(\frac{2e\sqrt{2}}{3c_W} Z_U^{(I+3)i\star} Z_N^{1j\star} - Y_u^I Z_U^{Ii\star} Z_N^{4j\star} \right) P_R \right] u^I + \text{H.c.} \\
&+ \quad D_i^+ \bar{\chi}_j^0 \left[\left(\frac{-e}{\sqrt{2} s_W c_W} Z_D^{Ii} (\frac{1}{3} Z_N^{1j} s_W - Z_N^{2j} c_W) + Y_d^I Z_D^{(I+3)i} Z_N^{3j} \right) P_L \right. \\
&\qquad\qquad\qquad \left. + \left(\frac{-e\sqrt{2}}{3c_W} Z_D^{(I+3)i} Z_N^{1j\star} + Y_d^I Z_D^{Ii} Z_N^{3j\star} \right) P_R \right] d^I + \text{H.c.} \\
&+ \quad U_i^+ \bar{d}^I \left[(\frac{-e}{s_W} Z_U^{Ji} Z_+^{1j\star} + Y_u^J Z_U^{(J+3)i} Z_+^{2j\star}) P_R - Y_d^I Z_U^{Ji} Z_-^{2j} P_L \right] K^{JI\star} \chi_j^C + \text{H.c.} \\
&- \quad D_i^+ \bar{\chi}_j \left[(\frac{e}{s_W} Z_D^{Ii} Z_-^{1j} + Y_d^I Z_D^{(I+3)i} Z_-^{2j}) P_L - Y_u^J Z_D^{Ii} Z_+^{2j\star} P_R \right] K^{JI\star} u^J + \text{H.c.}
\end{aligned}
$$

ii) interactions with sleptons

$$
\begin{aligned}
&+ \quad \frac{e}{\sqrt{2} s_W c_W} Z_\nu^{IJ\star} (Z_N^{1i} s_W - Z_N^{2i} c_W) \tilde{\nu}^{J\star} \bar{\chi}_i^0 P_L \nu^I + \text{H.c.} \\
&+ \quad \bar{\chi}_j^0 \left[\left(\frac{e}{\sqrt{2} s_W c_W} Z_L^{Ii} (Z_N^{1j} s_W + Z_N^{2j} c_W) + Y_l^I Z_L^{(I+3)i} Z_N^{3j} \right) P_L \right.
\end{aligned}
$$

$$+\left(\frac{-e\sqrt{2}}{c_W}Z_L^{(I+3)i}Z_N^{1j\star}+Y_l^I Z_L^{Ii}Z_N^{3j\star}\right)P_R\Big]\, e^I L_i^+ + \text{H.c.}$$

$$- \quad \bar{\chi}_i^C\left(\frac{e}{s_W}Z_+^{1i}P_L + Y_l^I Z_-^{2i\star}P_R\right)Z_\nu^{IJ\star}e^I\tilde{\nu}^{J\star} + \text{H.c.}$$

$$- \quad \left(\frac{e}{s_W}Z_L^{Ii}Z_-^{1j} + Y_l^I Z_L^{(I+3)i}Z_-^{2j}\right)\bar{\chi}_j P_L \nu^I L_i^+ + \text{H.c.}$$

6. Interactions of the charginos and neutralinos with the Higgs particles.

$$\begin{aligned}
+ \quad & \frac{e}{2s_W c_W}\bar{\chi}_i^0\Big[(Z_R^{1k}Z_N^{3j} - Z_R^{2k}Z_N^{4j})(Z_N^{1i}s_W - Z_N^{2i}c_W)P_L \\
& \qquad + (Z_R^{1k}Z_N^{3i\star} - Z_R^{2k}Z_N^{4i\star})(Z_N^{1j\star}s_W - Z_N^{2j\star}c_W)P_R\Big]\chi_j^0 H_k^0 \\
- \quad & \frac{ie}{2s_W c_W}\bar{\chi}_i^0\Big[(Z_H^{1k}Z_N^{3j} - Z_H^{2k}Z_N^{4j})(Z_N^{1i}s_W - Z_N^{2i}c_W)P_L \\
& \qquad - (Z_H^{1k}Z_N^{3i\star} - Z_H^{2k}Z_N^{4i\star})(Z_N^{1j\star}s_W - Z_N^{2j\star}c_W)P_R\Big]\chi_j^0 A_k^0 \\
- \quad & \frac{e}{\sqrt{2}s_W}\bar{\chi}_i\Big[(Z_R^{1k}Z_-^{2i}Z_+^{1j} + Z_R^{2k}Z_-^{1i}Z_+^{2j})P_L + (Z_R^{1k}Z_-^{2j\star}Z_+^{1i\star} + Z_R^{2k}Z_-^{1j\star}Z_+^{2i\star})P_R\Big]\chi_j H_k^0 \\
+ \quad & \frac{ie}{\sqrt{2}s_W}\bar{\chi}_i\Big[(Z_H^{1k}Z_-^{2i}Z_+^{1j} + Z_H^{2k}Z_-^{1i}Z_+^{2j})P_L - (Z_H^{1k}Z_-^{2j\star}Z_+^{1i\star} + Z_H^{2k}Z_-^{1j\star}Z_+^{2i\star})P_R\Big]\chi_j A_k^0 \\
+ \quad & \frac{e}{s_W c_W}\bar{\chi}_j\left[Z_H^{1k}\left(\frac{1}{\sqrt{2}}Z_-^{2j}(Z_N^{1i}s_W + Z_N^{2i}c_W) - Z_-^{1j}Z_N^{3i}c_W\right)P_L\right. \\
& \left. \qquad - Z_H^{2k}\left(\frac{1}{\sqrt{2}}Z_+^{2j\star}(Z_N^{1i\star}s_W + Z_N^{2i\star}c_W) + Z_+^{1j\star}Z_N^{4i\star}c_W\right)P_R\right]\chi_i^0 H_k^+ + \text{H.c.}
\end{aligned}$$

7. Self-interactions of the gauge bosons.

$$\begin{aligned}
- \quad & ie\left(W_\mu^+W_\nu^-(\partial^\mu F^\nu - \partial^\nu F^\mu) + F_\mu(W_\nu^-\partial^\nu W^{+\mu} - W_\nu^+\partial^\nu W^{-\mu} + W_\nu^+\overleftrightarrow{\partial^\mu}W^{-\nu})\right) \\
- \quad & \frac{iec_W}{s_W}\left(W_\mu^+W_\nu^-(\partial^\mu Z^\nu - Z^\nu F^\mu) + Z_\mu(W_\nu^-\partial^\nu W^{+\mu} - W_\nu^+\partial^\nu W^{-\mu} + W_\nu^+\overleftrightarrow{\partial^\mu}W^{-\nu})\right) \\
+ \quad & \frac{e^2}{2s_W^2}(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho})W_\mu^+W_\lambda^+W_\nu^-W_\rho^- + e^2(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho})F_\mu F_\nu W_\lambda^+W_\rho^- \\
+ \quad & \frac{e^2c_W^2}{s_W^2}(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho})Z_\mu Z_\nu W_\lambda^+W_\rho^- + \frac{e^2c_W}{s_W}(g^{\mu\lambda}g^{\nu\rho} + g^{\mu\rho}g^{\nu\lambda} - 2g^{\mu\nu}g^{\lambda\rho})Z_\mu F_\nu W_\lambda^+W_\rho^-
\end{aligned}$$

8. Ghost terms.

$$\begin{aligned}
- \quad & \frac{ie}{s_W}(Z_\mu c_W + F_\mu s_W)[(\partial^\mu\bar{\eta}^-)\eta^- - (\partial^\mu\bar{\eta}^+)\eta^+] \\
+ \quad & \frac{ie}{s_W}W_\mu^+[(\partial^\mu\bar{\eta}_Z c_W + \partial^\mu\bar{\eta}_F s_W)\eta^- - (\partial^\mu\bar{\eta}^+)(\eta_Z c_W + \eta_F s_W)] \\
+ \quad & \frac{ie}{s_W}W_\mu^-[-(\partial^\mu\bar{\eta}_Z c_W + \partial^\mu\bar{\eta}_F s_W)\eta^+ + (\partial^\mu\bar{\eta}^-)(\eta_Z c_W + \eta_F s_W)] \\
- \quad & \frac{\xi e^2}{4s_W^2}v_i Z_R^{ij}\left(\frac{1}{c_W^2}\bar{\eta}_Z\eta_Z + \bar{\eta}^+\eta^+ + \bar{\eta}^-\eta^-\right)H_j^0 + \frac{ie\xi M_W}{2s_W}(\bar{\eta}^-\eta^- - \bar{\eta}^+\eta^+)A_2^0 \\
+ \quad & \frac{\xi e M_W}{2s_W c_W}(\bar{\eta}_Z\eta^- - (c_W^2 - s_W^2)\bar{\eta}^+\eta_Z - \bar{\eta}^+ 2s_W c_W\eta_F)H_2^+ \\
+ \quad & \frac{\xi e M_W}{2s_W c_W}(\bar{\eta}_Z\eta^+ - (c_W^2 - s_W^2)\bar{\eta}^-\eta_Z - \bar{\eta}^- 2s_W c_W\eta_F)H_2^-
\end{aligned}$$

9. Scalar potential of the Higgs particles. This is the first part of the huge and complicated quartic potential of the 27 scalar fields appearing in the theory. To streamline notation we define four further auxiliary matrices:

$$
\begin{aligned}
A_H^{ij} &= Z_H^{1i}Z_H^{1j} - Z_H^{2i}Z_H^{2j} & \qquad A_R^{ij} &= Z_R^{1i}Z_R^{1j} - Z_R^{2i}Z_R^{2j}\\
A_P^{ij} &= Z_R^{1i}Z_H^{2j} + Z_R^{2i}Z_H^{1j} & \qquad B_R^{i} &= v_1 Z_R^{1i} - v_2 Z_R^{2i}
\end{aligned}
$$

The Higgs potential is expressed as:

$$
\begin{aligned}
&- \frac{e^2}{8s_W^2c_W^2}A_R^{ij}B_R^kH_i^0H_j^0H_k^0 - \frac{e^2}{8s_W^2c_W^2}A_H^{ij}B_R^kA_i^0A_j^0H_k^0\\
&- \left(\frac{e^2}{4s_W^2c_W^2}A_H^{ij}B_R^k + \frac{eM_W}{2s_W}(A_P^{kj}\delta^{1i} + A_P^{ki}\delta^{1j})\right)H_i^+H_j^-H_k^0\\
&+ \frac{ieM_W}{2s_W}\epsilon_{ij}\delta^{1k}H_i^+H_j^-A_k^0 + \frac{ie^2}{4s_W^2}A_P^{ij}\epsilon_{kl}H_i^0A_j^0H_k^+H_l^-\\
&- \frac{e^2}{32s_W^2c_W^2}A_R^{ij}A_R^{kl}H_i^0H_j^0H_k^0H_l^0 - \frac{e^2}{32s_W^2c_W^2}A_H^{ij}A_H^{kl}A_i^0A_j^0A_k^0A_l^0\\
&- \frac{e^2}{16s_W^2c_W^2}A_R^{ij}A_H^{kl}H_i^0H_j^0A_k^0A_l^0 - \frac{e^2}{8s_W^2c_W^2}A_H^{ij}A_H^{kl}H_i^+H_k^+H_j^-H_l^-\\
&- \frac{e^2}{4s_W^2}\left(\frac{1}{2c_W^2}A_R^{ij}A_H^{kl} + A_P^{ik}A_P^{jl}\right)H_i^0H_j^0H_k^+H_l^-\\
&- \frac{e^2}{4s_W^2}\left(\frac{1}{2c_W^2}A_H^{ij}A_H^{kl} + \epsilon_{ik}\epsilon_{jl}\right)A_i^0A_j^0H_k^+H_l^-
\end{aligned}
$$

It is easy to see that the couplings $H_i^+H_j^-A_k^0$ and $H_i^+H_j^-A_k^0H_l^0$ disappear in the unitary gauge.

10. Interactions of the sleptons and Higgs bosons.

i) three scalar (two sleptons and one Higgs) couplings:

$$
\begin{aligned}
&- \frac{e^2}{4s_W^2c_W^2}B_R^i\tilde\nu^{I\star}\tilde\nu^IH_i^0\\
&+ Z_\nu^{IJ}\left(\frac{-\sqrt{2}e^2}{4s_W^2}v_kZ_H^{kj}Z_L^{Ii} + (A_l^{IK}Z_L^{(K+3)i} + \frac{v_1}{\sqrt2}(Y_l^I)^2Z_L^{Ii})Z_H^{1j}\right.\\
&\qquad\left. +(A_l^{\prime IK}Z_L^{(K+3)i} - \mu^\star Y_l^IZ_L^{(I+3)i})Z_H^{2j}\right)\tilde\nu^JL_i^+H_j^- + \text{H.c.}\\
&+ \frac{i}{\sqrt2}\left((A_l^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} - A_l^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j})Z_H^{1k} + (A_l^{\prime IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star}\right.\\
&\qquad\left. -A_l^{\prime IJ}Z_L^{Ii\star}Z_L^{(J+3)j})Z_H^{2k} + Y_l^I(\mu^\star Z_L^{Ii\star}Z_L^{(I+3)j} - \mu Z_L^{Ij}Z_L^{(I+3)i\star})Z_H^{2k}\right)L_i^-L_j^+A_k^0\\
&+ \left(\frac{e^2}{2c_W^2}B_R^k\left(\delta^{ij} + \frac{1-4s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right) - (Y_l^I)^2v_1Z_R^{1k}(Z_L^{Ii\star}Z_L^{Ij} + Z_L^{(I+3)i\star}Z_L^{(I+3)j})\right.\\
&\qquad -\frac{1}{\sqrt2}Z_R^{1k}(A_l^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} + A_l^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j})\\
&\qquad +\frac{1}{\sqrt2}Z_R^{2k}(A_l^{\prime IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} + A_l^{\prime IJ}Z_L^{Ii\star}Z_L^{(J+3)j})\\
&\qquad \left. -\frac{1}{\sqrt2}Y_l^IZ_R^{2k}(\mu^\star Z_L^{Ii\star}Z_L^{(I+3)j} + \mu Z_L^{Ij}Z_L^{(I+3)i\star})\right)L_i^-L_j^+H_k^0
\end{aligned}
$$

ii) two slepton–two Higgs couplings:

$$
\begin{aligned}
&- \frac{e^2}{8s_W^2c_W^2}A_R^{ij}\tilde{\nu}^{I\star}\tilde{\nu}^I H_i^0 H_j^0 - \frac{e^2}{8s_W^2c_W^2}A_H^{ij}\tilde{\nu}^{I\star}\tilde{\nu}^I A_i^0 A_j^0 \\
&+ Z_\nu^{KJ\star}Z_\nu^{KI}(e^2\frac{c_W^2-s_W^2}{4s_W^2c_W^2}A_H^{ij} - (Y_l^K)^2 Z_H^{1i}Z_H^{1j})\tilde{\nu}^{J\star}\tilde{\nu}^I H_i^- H_j^+ \\
&+ \frac{i}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\left(\frac{e^2}{2s_W^2}A_H^{jk} - (Y_l^I)^2 Z_H^{1j}Z_H^{1k}\right)\tilde{\nu}^J L_i^+ H_j^- A_k^0 + \text{H.c.} \\
&+ \frac{1}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\left(\frac{-e^2}{2s_W^2}(Z_H^{1j}Z_R^{1k} + Z_H^{2j}Z_R^{2k}) + (Y_l^I)^2 Z_H^{1j}Z_R^{1k}\right)\tilde{\nu}^J L_i^+ H_j^- H_k^0 + \text{H.c.} \\
&+ \left(\frac{e^2}{4c_W^2}A_H^{kl}\left(\delta^{ij} + \frac{1-4s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right)\right. \\
&\qquad\qquad \left. -\frac{1}{2}(Y_l^I)^2 Z_H^{1k}Z_H^{1l}(Z_L^{Ii\star}Z_L^{Ij} + Z_L^{(I+3)i\star}Z_L^{(I+3)j})\right) L_i^- L_j^+ A_k^0 A_l^0 \\
&+ \left(\frac{e^2}{4c_W^2}A_R^{kl}\left(\delta^{ij} + \frac{1-4s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right)\right. \\
&\qquad\qquad \left. -\frac{1}{2}(Y_l^I)^2 Z_R^{1k}Z_R^{1l}(Z_L^{Ii\star}Z_L^{Ij} + Z_L^{(I+3)i\star}Z_L^{(I+3)j})\right) L_i^- L_j^+ H_k^0 H_l^0 \\
&+ \left(\frac{e^2}{2c_W^2}A_H^{kl}\left(\delta^{ij} - \frac{1+2s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right) - (Y_l^I)^2 Z_H^{1k}Z_H^{1l}Z_L^{(I+3)i\star}Z_L^{(I+3)j}\right) L_i^- L_j^+ H_k^- H_l^+
\end{aligned}
$$

11. Interactions of the squarks and Higgs bosons:
i) three scalar couplings:

$$
\begin{aligned}
&+ \frac{i}{\sqrt{2}}\Big((A_u^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star} - A_u^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j})Z_H^{2k} + (A_u'^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j} \\
&\qquad - A_u'^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star})Z_H^{1k} + Y_u^I(\mu Z_U^{Ii\star}Z_U^{(I+3)j} - \mu^\star Z_U^{Ij}Z_U^{(I+3)i\star})Z_H^{1k}\Big) U_i^- U_j^+ A_k^0 \\
&+ \left(\frac{-e^2}{3c_W^2}\left(\delta^{ij} + \frac{3-8s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right) B_R^k - (Y_u^I)^2 v_2 Z_R^{2k}(Z_U^{Ii\star}Z_U^{Ij} + Z_U^{(I+3)i\star}Z_U^{(I+3)j})\right. \\
&\qquad\qquad + \frac{1}{\sqrt{2}}Z_R^{2k}(A_u^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j} + A_u^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star}) \\
&\qquad\qquad + \frac{1}{\sqrt{2}}Z_R^{1k}(A_u'^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j} + A_u'^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star}) \\
&\qquad\qquad \left. + \frac{1}{\sqrt{2}}Y_u^I Z_R^{1k}(\mu^\star Z_U^{Ij}Z_U^{(I+3)i\star} + \mu Z_U^{Ii\star}Z_U^{(I+3)j})\right) U_i^- U_j^+ H_k^0 \\
&+ \frac{i}{\sqrt{2}}\Big((A_d^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star} - A_d^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})Z_H^{1k} + (A_d'^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star} \\
&\qquad - A_d'^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})Z_H^{2k} + Y_d^I(\mu^\star Z_D^{Ii\star}Z_D^{(I+3)j} - \mu Z_D^{Ij}Z_D^{(I+3)i\star})Z_H^{2k}\Big) D_i^- D_j^+ A_k^0 \\
&+ \left(\frac{e^2}{6c_W^2}\left(\delta^{ij} + \frac{3-4s_W^2}{2s_W^2}Z_D^{Ii\star}Z_D^{Ij}\right) B_R^k - (Y_d^I)^2 v_1 Z_R^{1k}(Z_D^{Ii\star}Z_D^{Ij} + Z_D^{(I+3)i\star}Z_D^{(I+3)j})\right. \\
&\qquad\qquad - \frac{1}{\sqrt{2}}Z_R^{1k}(A_d^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star} + A_d^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j}) \\
&\qquad\qquad + \frac{1}{\sqrt{2}}Z_R^{2k}(A_d'^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star} + A_d'^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})
\end{aligned}
$$

$$
-\frac{1}{\sqrt{2}} Y_d^I Z_R^{2k} (\mu^\star Z_D^{Ii\star} Z_D^{(I+3)j} + \mu Z_D^{Ij} Z_D^{(I+3)i\star}) \Big) D_i^- D_j^+ H_k^0
$$

$$
\begin{aligned}
+ \quad & \Bigg[\frac{1}{\sqrt{2}} \left(\frac{-e^2}{2s_W^2} v_l Z_H^{lk} + v_1 (Y_d^I)^2 Z_H^{1k} + v_2 (Y_u^J)^2 Z_H^{2k} \right) K^{JI\star} Z_D^{Ij} Z_U^{Ji} \\
& - \frac{\sqrt{2} M_W s_W}{e} \delta^{1k} Y_u^J Y_d^I K^{JI\star} Z_D^{(I+3)j} Z_U^{(J+3)i} \\
& + \Big(Z_H^{1k} \mu Y_u^J K^{JI\star} + (Z_H^{1k} A_u'^{KJ\star} - Z_H^{2k} A_u^{KJ\star}) K^{KI\star} \Big) Z_U^{(J+3)i} Z_D^{Ij} \\
& + \Big((Z_H^{1k} A_d^{KI} + Z_H^{2k} A_d'^{KI}) K^{JK\star} - Z_H^{2k} \mu^\star Y_d^I K^{JI\star} \Big) Z_U^{Ji} Z_D^{(I+3)j} \Bigg] U_i^+ D_j^+ H_k^- + \text{H.c.}
\end{aligned}
$$

ii) four scalar couplings:

$$
\begin{aligned}
+ \quad & \Bigg(\frac{-e^2}{6c_W^2} A_H^{kl} \left(\delta^{ij} + \frac{3-8s_W^2}{4s_W^2} Z_U^{Ii\star} Z_U^{Ij} \right) \\
& \qquad - \frac{1}{2} (Y_u^I)^2 Z_H^{2k} Z_H^{2l} (Z_U^{Ii\star} Z_U^{Ij} + Z_U^{(I+3)i\star} Z_U^{(I+3)j}) \Bigg) U_i^- U_j^+ A_k^0 A_l^0 \\
+ \quad & \Bigg(\frac{-e^2}{6c_W^2} A_R^{kl} \left(\delta^{ij} + \frac{3-8s_W^2}{4s_W^2} Z_U^{Ii\star} Z_U^{Ij} \right) \\
& \qquad - \frac{1}{2} (Y_u^I)^2 Z_R^{2k} Z_R^{2l} (Z_U^{Ii\star} Z_U^{Ij} + Z_U^{(I+3)i\star} Z_U^{(I+3)j}) \Bigg) U_i^- U_j^+ H_k^0 H_l^0 \\
+ \quad & \Bigg(\frac{-e^2}{3c_W^2} A_H^{kl} \left(\delta^{ij} - \frac{3+2s_W^2}{4s_W^2} Z_U^{Ii\star} Z_U^{Ij} \right) \\
& - (Y_u^I)^2 Z_H^{2k} Z_H^{2l} Z_U^{(I+3)i\star} Z_U^{(I+3)j} - (Y_d^I)^2 Z_H^{1k} Z_H^{1l} K^{JI\star} K^{KI} Z_U^{Ki\star} Z_U^{Jj} \Bigg) U_i^- U_j^+ H_k^- H_l^+ \\
+ \quad & \Bigg(\frac{e^2}{12c_W^2} A_H^{kl} \left(\delta^{ij} + \frac{3-4s_W^2}{2s_W^2} Z_D^{Ii\star} Z_D^{Ij} \right) \\
& \qquad - \frac{1}{2} (Y_d^I)^2 Z_H^{1k} Z_H^{1l} (Z_D^{Ii\star} Z_D^{Ij} + Z_D^{(I+3)i\star} Z_D^{(I+3)j}) \Bigg) D_i^- D_j^+ A_k^0 A_l^0 \\
+ \quad & \Bigg(\frac{e^2}{12c_W^2} A_R^{kl} \left(\delta^{ij} + \frac{3-4s_W^2}{2s_W^2} Z_D^{Ii\star} Z_D^{Ij} \right) \\
& \qquad - \frac{1}{2} (Y_d^I)^2 Z_R^{1k} Z_R^{1l} (Z_D^{Ii\star} Z_D^{Ij} + Z_D^{(I+3)i\star} Z_D^{(I+3)j}) \Bigg) D_i^- D_j^+ H_k^0 H_l^0 \\
+ \quad & \Bigg(\frac{e^2}{6c_W^2} A_H^{kl} \left(\delta^{ij} - \frac{3-2s_W^2}{2s_W^2} Z_D^{Ii\star} Z_D^{Ij} \right) \\
& - (Y_d^I)^2 Z_H^{1k} Z_H^{1l} Z_D^{(I+3)i\star} Z_D^{(I+3)j} - (Y_u^K)^2 Z_H^{2k} Z_H^{2l} K^{KI\star} K^{KJ} Z_D^{Ji\star} Z_D^{Ij} \Bigg) D_i^- D_j^+ H_k^- H_l^+ \\
+ \quad & \frac{1}{\sqrt{2}} K^{JI\star} \Bigg(\frac{-e^2}{2s_W^2} (Z_H^{1k} Z_R^{1l} + Z_H^{2k} Z_R^{2l}) Z_U^{Ji} Z_D^{Ij} - A_P^{lk} Y_u^J Y_d^I Z_U^{(J+3)i} Z_D^{(I+3)j} \\
& \qquad + \Big((Y_u^J)^2 Z_H^{2k} Z_R^{2l} + (Y_d^I)^2 Z_H^{1k} Z_R^{1l} \Big) Z_U^{Ji} Z_D^{Ij} \Bigg) U_i^+ D_j^+ H_k^- H_l^0 + \text{H.c.} \\
+ \quad & \frac{i}{\sqrt{2}} K^{JI\star} \Bigg(\frac{e^2}{2s_W^2} A_H^{kl} Z_U^{Ji} Z_D^{Ij} - \epsilon_{kl} Y_u^J Y_d^I Z_U^{(J+3)i} Z_D^{(I+3)j} \\
& \qquad + \Big((Y_u^J)^2 Z_H^{2k} Z_H^{2l} - (Y_d^I)^2 Z_H^{1k} Z_H^{1l} \Big) Z_U^{Ji} Z_D^{Ij} \Bigg) U_i^+ D_j^+ H_k^- A_l^0 + \text{H.c.}
\end{aligned}
$$

12. Four-scalar interactions of four sleptons or two sleptons and two squarks.

$$
- \quad \frac{e^2}{8s_W^2 c_W^2} \tilde{\nu}^{I\star} \tilde{\nu}^{J\star} \tilde{\nu}^I \tilde{\nu}^J - \left(\frac{-e^2}{2c_W^2} \left(\delta^{ij} + \frac{1-4s_W^2}{2s_W^2} Z_L^{Ki\star} Z_L^{Kj} \right) \delta^{IJ} \right.
$$

$$
\begin{aligned}
&+\left(\frac{e^2}{2s_W^2}Z_L^{Ki\star}Z_L^{Lj}+Y_l^KY_l^LZ_L^{(K+3)i\star}Z_L^{(L+3)j}\right)Z_\nu^{LI}Z_\nu^{KJ\star}\Big)\tilde\nu^{J\star}\tilde\nu^IL_i^-L_j^+\\
-&\ \frac{e^2}{3c_W^2}\left(\delta^{ij}+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ji\star}Z_U^{Jj}\right)\tilde\nu^{I\star}\tilde\nu^IU_i^-U_j^+\\
+&\ \frac{e^2}{6c_W^2}\left(\delta^{ij}+\frac{3-4s_W^2}{2s_W^2}Z_D^{Ji\star}Z_D^{Jj}\right)\tilde\nu^{I\star}\tilde\nu^ID_i^-D_j^+\\
-&\ Z_\nu^{JI}Z_U^{Li\star}K^{LK}\left(\frac{e^2}{2s_W^2}Z_D^{Kj\star}Z_L^{Jk}+Y_l^JY_d^KZ_D^{(K+3)j\star}Z_L^{(J+3)k}\right)\tilde\nu^IU_i^-D_j^-L_k^++\mathrm{H.c.}\\
-&\ \left(\frac{e^2(1+8s_W^2)}{8s_W^2c_W^2}Z_L^{Ii\star}Z_L^{Jj\star}Z_L^{Jl}Z_L^{Ik}+\frac{e^2}{2c_W^2}\delta^{jl}(\delta^{ik}-3Z_L^{Ii\star}Z_L^{Ik})\right.\\
&\qquad\left.+Y_l^IY_l^JZ_L^{Jj\star}Z_L^{Ik}Z_L^{(I+3)i\star}Z_L^{(J+3)l}\right)L_i^-L_j^-L_k^+L_l^+\\
+&\ \frac{e^2}{6c_W^2}\left(\frac{3+12s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}Z_U^{Jk\star}Z_U^{Jl}-6\delta^{kl}Z_L^{Ii\star}Z_L^{Ij}-5\delta^{ij}Z_U^{Ik\star}Z_U^{Il}+4\delta^{ij}\delta^{kl}\right)L_i^-L_j^+U_k^-U_l^+\\
+&\ \left[\frac{e^2}{6c_W^2}\left(-\frac{3}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}Z_D^{Jk\star}Z_D^{Jl}+3\delta^{kl}Z_L^{Ii\star}Z_L^{Ij}+\delta^{ij}Z_D^{Ik\star}Z_D^{Il}-2\delta^{ij}\delta^{kl}\right)\right.\\
&\qquad\left.-Y_l^IY_d^J(Z_L^{(I+3)i\star}Z_L^{Ij}Z_D^{Jk\star}Z_D^{(J+3)l}+Z_L^{Ii\star}Z_L^{(I+3)j}Z_D^{(J+3)k\star}Z_D^{Jl})\right]L_i^-L_j^+D_k^-D_l^+
\end{aligned}
$$

13. Vertices containing the strong coupling constant g_3. There are two basic types of such interactions - couplings of the quarks and squarks with the gluons and gluinos and four squarks interactions. By Y^a we denote the matrices of the $SU(3)$ generators in **3** representation (generally $a, b, c\ldots$ are indices corresponding to **8** (adjoint) representation, $\alpha, \beta, \gamma\ldots$ - to **3** (basic) representation of the QCD gauge group).

$$
\begin{aligned}
-&\ g_3\bar d^IY^a\gamma^\mu d^Ig_\mu^a-ig_3(D_i^+Y^a\overleftrightarrow{\partial^\mu}D_i^-)g_\mu^a+g_3^2D_i^+Y^aY^bD_i^-g_\mu^ag^{b\mu}\\
-&\ \frac{2}{3}eg_3D_i^+Y^aD_i^-g_\mu^aF^\mu+\frac{eg_3}{s_Wc_W}(-Z_D^{Ii}Z_D^{Ij\star}+\frac{2}{3}\delta^{ij}s_W^2)D_i^+Y^aD_j^-g_\mu^aZ^\mu\\
-&\ g_3\bar u^IY^a\gamma^\mu u^Ig_\mu^a-ig_3(U_i^-Y^a\overleftrightarrow{\partial^\mu}U_i^+)g_\mu^a+g_3^2U_i^-Y^aY^bU_i^+g_\mu^ag^{b\mu}\\
+&\ \frac{4}{3}eg_3U_i^-Y^aU_i^+g_\mu^aF^\mu+\frac{eg_3}{s_Wc_W}(Z_U^{Ii\star}Z_U^{Ij}-\frac{4}{3}\delta^{ij}s_W^2)U_i^-Y^aU_j^+g_\mu^aZ^\mu\\
+&\ \frac{eg_3\sqrt2}{s_W}Z_U^{Jj}Z_D^{Ii}K^{JI\star}D_i^+Y^aU_j^+g_\mu^aW^{-\mu}+\mathrm{H.c.}\\
+&\ g_3\sqrt2U_i^-Y^a\bar\Lambda_G^a(-Z_U^{Ii\star}P_L+Z_U^{(I+3)i\star}P_R)u^I+\mathrm{H.c.}\\
+&\ g_3\sqrt2D_i^+Y^a\bar\Lambda_G^a(-Z_D^{Ii}P_L+Z_D^{(I+3)i}P_R)d^I+\mathrm{H.c.}\\
+&\ \frac{1}{2}ig_3f_{abc}\bar\Lambda_G^a\gamma^\mu\Lambda_G^bg_\mu^c+g_3f_{abc}(\partial^\mu\bar\eta_G^a)\eta_G^bg_\mu^c\\
+&\ \frac{1}{2}g_3f_{abc}(\partial_\mu g_\nu^a-\partial_\nu g_\mu^a)g^{b\mu}g^{c\nu}-\frac{1}{4}g_3^2f_{abc}f_{ade}g_\mu^bg^{d\mu}g_\nu^cg^{e\nu}
\end{aligned}
$$

In the next terms it is necessary to write down explicitly the color indices $\alpha, \beta, \gamma\ldots$ We also define following abbreviations:

$$
\begin{aligned}
R_U^{ij}&=Z_U^{Ii\star}Z_U^{Ij} & R_D^{ij}&=Z_D^{Ii}Z_D^{Ij\star}\\
X_U^{ij}&=\delta^{ij}-2R_U^{ij} & X_D^{ij}&=\delta^{ij}-2R_D^{ij}\\
Y_U^{ij}&=5R_U^{ij}-4\delta^{ij} & Y_D^{ij}&=2\delta^{ij}-R_D^{ij}\\
V_U^{ijkl}&=Y_u^IY_u^JZ_U^{(I+3)i\star}Z_U^{Ij}Z_U^{Jk\star}Z_U^{(J+3)l} & V_D^{ijkl}&=Y_d^IY_d^JZ_D^{(I+3)i}Z_D^{Ij\star}Z_D^{Jk}Z_D^{(J+3)l\star}
\end{aligned}
$$

$$
\begin{aligned}
&- \frac{1}{4}\left\{\left[\frac{g_3^2}{6}(3X_U^{il}X_U^{kj} - X_U^{ij}X_U^{kl}) + \frac{e^2}{4s_W^2}R_U^{ij}R_U^{kl} + \frac{e^2}{36c_W^2}Y_U^{ij}Y_U^{kl} + V_U^{ijkl} + V_U^{klij}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\right.\\
&+ \left.\left[\frac{g_3^2}{6}(3X_U^{ij}X_U^{kl} - X_U^{il}X_U^{kj}) + \frac{e^2}{4s_W^2}R_U^{il}R_U^{kj} + \frac{e^2}{36c_W^2}Y_U^{il}Y_U^{kj} + V_U^{ilkj} + V_U^{kjil}\right]\delta_{\alpha\delta}\delta_{\beta\gamma}\right\} U_{i\alpha}^- U_{k\gamma}^- U_{j\beta}^+ U_{l\delta}^+\\
&- \frac{1}{4}\left\{\left[\frac{g_3^2}{6}(3X_D^{il}X_D^{kj} - X_D^{ij}X_D^{kl}) + \frac{e^2}{4s_W^2}R_D^{ij}R_D^{kl} + \frac{e^2}{36c_W^2}Y_D^{ij}Y_D^{kl} + V_D^{ijkl} + V_D^{klij}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\right.\\
&+ \left.\left[\frac{g_3^2}{6}(3X_D^{ij}X_D^{kl} - X_D^{il}X_D^{kj}) + \frac{e^2}{4s_W^2}R_D^{il}R_D^{kj} + \frac{e^2}{36c_W^2}Y_D^{il}Y_D^{kj} + V_D^{ilkj} + V_D^{kjil}\right]\delta_{\alpha\delta}\delta_{\beta\gamma}\right\} D_{i\alpha}^+ D_{k\gamma}^+ D_{j\beta}^- D_{l\delta}^-\\
&- \left[\frac{g_3^2}{6}X_U^{ij}X_D^{kl}(3\delta_{\alpha\delta}\delta_{\beta\gamma} - \delta_{\alpha\beta}\delta_{\gamma\delta}) + \frac{e^2}{4s_W^2}(2K^{KI}K^{LJ\star}\delta_{\alpha\gamma}\delta_{\beta\delta} - \delta^{IJ}\delta^{KL}\delta_{\alpha\beta}\delta_{\gamma\delta})Z_U^{Ki\star}Z_U^{Lj}Z_D^{Jl\star}Z_D^{Ik}\right.\\
&\qquad + \frac{e^2}{36c_W^2}Y_U^{ij}Y_D^{kl}\delta_{\alpha\beta}\delta_{\gamma\delta} + (Y_d^IY_d^JK^{KI}K^{LJ\star}Z_U^{Ki\star}Z_U^{Lj}Z_D^{(I+3)l\star}Z_D^{(J+3)k}\\
&\qquad \left. + Y_u^IY_u^JK^{JL}K^{IK\star}Z_U^{(I+3)j}Z_U^{(J+3)i\star}Z_D^{Ll\star}Z_D^{Kk})\delta_{\alpha\delta}\delta_{\beta\gamma}\right] U_{i\alpha}^- U_{j\beta}^+ D_{k\gamma}^+ D_{l\delta}^-
\end{aligned}
$$

7 Summary

The model described in the previous sections contains a large number of free parameters which considerably limit its predictive power. There are some commonly used ways to reduce the number of free constants in this theory. The most often employed method is to obtain values of the parameters at the electroweak scale by RGE running from the coupling constants generated at high scale by some SUSY breaking scenario. Usually such theories are much more unified and contain typically only few free numbers. Of course, there are many constraints originating from experimental data. Obviously, the masses of the superpartners are bounded from below by negative result of direct SUSY searches in collider experiments. One can find also many indirect limits: for example, if the masses of the superscalars are not very high, then the non-diagonal soft Yukawa couplings $A_d^{IJ}, A_d^{\prime IJ}$ etc. can lead by loop corrections to too strong flavor changing neutral currents in the quark sector.

It is worth remembering that although in the superpotential one can have only three matrices of Yukawa couplings (four if right neutrino exists), six such matrices for the soft SUSY breaking terms are allowed, three additional ones describing interactions of the superscalars with the complex conjugated Higgs doublets. Those three new couplings can affect various processes, in particular they are present in the formulas for the scalar mass matrices. In most SUSY breaking scenarios such terms are not generated, but in principle they are not forbidden by MSSM symmetries.

Acknowledgments.

The author would like to thank professor S. Pokorski for many helpful discussions.

Appendix A MSSM Lagrangian before gauge symmetry breaking

In this Appendix we write down the Lagrangian of the MSSM in terms of the initial fields, before the $SU(2)$ symmetry breaking, but already after the redefinition of the coupling constants described in section 3. Expressions given below should help the reader to compare the conventions used here with other papers and eventually check calculations of the vertices expressed in terms of the mass eigenstate fields. In the formulas below we use the 2-component fermion notation. Transition to the 4-fermion notation can be done by substitution:

$$u^I = \begin{pmatrix} \Psi^I_{Q1} \\ \bar\Psi^I_U \end{pmatrix} \qquad d^I = \begin{pmatrix} \Psi^I_{Q2} \\ \bar\Psi^I_D \end{pmatrix}$$

and similarly for the leptons.
After the diagonalization of the Yukawa couplings the superpotential has the form (K is the Kobayashi-Maskawa matrix, $\epsilon_{12} = -\epsilon_{21} = -1$):

$$\begin{aligned} W &= \mu\epsilon_{ij} H^1_i H^2_j + Y^I_l \epsilon_{ij} H^1_i L^I_j R^I \\ &- Y^I_u (H^2_1 K^{IJ} Q^J_2 - H^2_2 Q^I_1) U^I - Y^I_d (H^1_1 Q^I_2 - H^1_2 K^{JI\star} Q^J_1) D^I \end{aligned}$$

The MSSM Lagrangian contains the following types of interactions:
1. Gauge boson-gaugino, gauge boson-gauge boson.

$$\begin{aligned} & ig_3 f_{abc} \lambda^a_G \sigma^\mu \bar\lambda^b_G G^c_\mu + ig_2 \epsilon_{ijk} \lambda^i_A \sigma^\mu \bar\lambda^j_A A^k_\mu \\ + & \frac{1}{2} g_3 f_{abc} (\partial_\mu G^a_\nu - \partial_\nu G^a_\mu) G^{b\mu} G^{c\nu} - \frac{1}{4} g^2_3 f_{abc} f_{ade} G^b_\mu G^{d\mu} G^c_\nu G^{e\nu} \\ + & \frac{1}{2} g_2 \epsilon_{ijk} (\partial_\mu A^i_\nu - \partial_\nu A^i_\mu) A^{j\mu} A^{k\nu} - \frac{1}{4} g^2_2 \epsilon_{ijk} \epsilon_{imn} A^j_\mu A^{m\mu} A^k_\nu A^{n\nu} \end{aligned}$$

2. Quark-squark-gauge. T^i are the $SU(2)$ generators, $T^i = \frac{1}{2}\tau^i$, where τ^i denote the Pauli matrices. Y^a and $\bar Y^a$ are the $SU(3)$ generators in the $\mathbf{3}$ and $\bar{\mathbf{3}}$ representations, respectively. $SU(3)$ and, wherever possible, also $SU(2)$ indices are suppressed. Finally, $A^\pm_\mu = A^1_\mu \pm iA^2_\mu = \sqrt{2} W^\mp_\mu$.

$$\begin{aligned} - & \bar\Psi^I_Q (g_3 Y^a G^a_\mu + g_2 T^3 A^3_\mu + \frac{1}{6} g_1 B_\mu) \bar\sigma^\mu \Psi^I_Q - iQ^{I\star} (g_3 Y^a G^a_\mu + g_2 T^3 A^3_\mu + \frac{1}{6} g_1 B_\mu) \overleftrightarrow{\partial^\mu_Q} Q^I \\ - & \frac{1}{2} g_2 K^{JI\star} (\bar\Psi^I_{Q2} \bar\sigma^\mu \Psi^J_{Q1} + iQ^{I\star}_2 \overleftrightarrow{\partial^\mu} Q^J_1) A^+_\mu + \text{H.c.} \\ + & i\sqrt{2} Q^{I\star} (g_3 Y^a \lambda^a_G + g_2 T^3 \lambda^3_A + \frac{1}{6} g_1 \lambda_B) \Psi^I_Q + \text{H.c.} \\ + & ig_2 (K^{JI\star} Q^{I\star}_2 \lambda^-_A \Psi^J_{Q1} + K^{JI} Q^{J\star}_1 \lambda^+_A \Psi^I_{Q2}) + \text{H.c.} \\ + & (Q_1, KQ_2)^{I\star} (g_3 Y^a G^a_\mu + g_2 T^i A^i_\mu + \frac{1}{6} g_1 B_\mu)(g_3 Y^b G^{b\mu} + g_2 T^j A^{j\mu} + \frac{1}{6} g_1 B^\mu) \begin{pmatrix} Q_1 \\ KQ_2 \end{pmatrix}^I \\ - & \bar\Psi^I_U (g_3 \bar Y^a G^a_\mu - \frac{2}{3} g_1 B_\mu) \bar\sigma^\mu \Psi^I_U - iU^{I\star} (g_3 \bar Y^a G^a_\mu - \frac{2}{3} g_1 B_\mu) \overleftrightarrow{\partial^\mu_U} U^I \\ + & U^{I\star} (g_3 \bar Y^a G^a_\mu - \frac{2}{3} g_1 B_\mu)(g_3 \bar Y^b G^{b\mu} - \frac{2}{3} g_1 B^\mu) U^I \\ - & \bar\Psi^I_D (g_3 \bar Y^a G^a_\mu + \frac{1}{3} g_1 B_\mu) \bar\sigma^\mu \Psi^I_D - iD^{I\star} (g_3 \bar Y^a G^a_\mu + \frac{1}{3} g_1 B_\mu) \overleftrightarrow{\partial^\mu_D} D^I \\ + & D^{I\star} (g_3 \bar Y^a G^a_\mu + \frac{1}{3} g_1 B_\mu)(g_3 \bar Y^b G^{b\mu} + \frac{1}{3} g_1 B^\mu) D^I \\ + & i\sqrt{2} U^{I\star} (g_3 \bar Y^a \lambda^a_G - \frac{2}{3} g_1 \lambda_B) \Psi^I_U + i\sqrt{2} D^{I\star} (g_3 \bar Y^a \lambda^a_G + \frac{1}{3} g_1 \lambda_B) \Psi^I_D + \text{H.c.} \end{aligned}$$

3. Lepton-slepton-gauge.

$$\begin{aligned}
&- \bar{\Psi}^I_L(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)\bar{\sigma}^\mu \Psi^I_L - iL^{I\star}(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)\overleftrightarrow{\partial^\mu_L} L^I \\
&+ L^{I\star}(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)(g_2 T^j A^{j\mu} - \frac{1}{2}g_1 B^\mu)L^I \\
&- g_1 \bar{\Psi}^I_R B_\mu \bar{\sigma}^\mu \Psi^I_R - ig_1 B_\mu (R^{I\star}\overleftrightarrow{\partial^\mu} R^I) + g_1^2 R^{I\star} R^I B_\mu B^\mu \\
&+ i\sqrt{2} L^{I\star}(g_2 T^i \lambda^i_A - \frac{1}{2}g_1 \lambda_B)\Psi^I_L + i\sqrt{2} g_1 R^{I\star}\lambda_B \Psi^I_R + \text{H.c.}
\end{aligned}$$

4. Higgs boson-Higgsino-gauge.

$$\begin{aligned}
&- \bar{\Psi}^1_H(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)\bar{\sigma}^\mu \Psi^1_H - iH^{1\star}(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)\overleftrightarrow{\partial^\mu_H} H^1 \\
&+ H^{1\star}(g_2 T^i A^i_\mu - \frac{1}{2}g_1 B_\mu)(g_2 T^j A^{j\mu} - \frac{1}{2}g_1 B^\mu)H^1 \\
&- \bar{\Psi}^2_H(g_2 T^i A^i_\mu + \frac{1}{2}g_1 B_\mu)\bar{\sigma}^\mu \Psi^2_H - iH^{2\star}(g_2 T^i A^i_\mu + \frac{1}{2}g_1 B_\mu)\overleftrightarrow{\partial^\mu_H} H^2 \\
&+ H^{2\star}(g_2 T^i A^i_\mu + \frac{1}{2}g_1 B_\mu)(g_2 T^j A^{j\mu} + \frac{1}{2}g_1 B^\mu)H^2 \\
&+ i\sqrt{2} H^{1\star}(g_2 T^i \lambda^i_A - \frac{1}{2}g_1 \lambda_B)\Psi^1_H + i\sqrt{2} H^{2\star}(g_2 T^i \lambda^i_A + \frac{1}{2}g_1 \lambda_B)\Psi^2_H + \text{H.c.}
\end{aligned}$$

5. Yukawa couplings.

$$\begin{aligned}
&- \mu\epsilon_{ij}\Psi^1_{Hi}\Psi^2_{Hj} - Y^I_l \epsilon_{ij}\Psi^1_{Hi}\Psi^I_{Lj}R^I - Y^I_l \epsilon_{ij}\Psi^1_{Hi}\Psi^I_R L^I_j - Y^I_l \epsilon_{ij}\Psi^I_R \Psi^I_{Lj} H^1_i + \text{H.c.} \\
&- Y^I_d(-\Psi^1_{H1}\Psi^I_{Q2} + K^{JI\star}\Psi^1_{H2}\Psi^J_{Q1})D^I - Y^I_d(-\Psi^1_{H1}Q^I_2 + K^{JI\star}\Psi^1_{H2}Q^J_1)\Psi^I_D + \text{H.c.} \\
&- Y^I_d(-H^1_1\Psi^I_{Q2} + K^{JI\star}H^1_2\Psi^J_{Q1})\Psi^I_D - Y^I_u(-K^{IJ}H^2_1\Psi^J_{Q2} + H^2_2\Psi^I_{Q1})\Psi^I_U + \text{H.c.} \\
&- Y^I_u(-K^{IJ}\Psi^2_{H1}\Psi^J_{Q2} + \Psi^2_{H2}\Psi^I_{Q1})U^I - Y^I_u(-K^{IJ}\Psi^2_{H1}Q^J_2 + \Psi^2_{H2}Q^I_1)\Psi^I_U + \text{H.c.}
\end{aligned}$$

6. The scalar potential (in the Lagrangian $-V$ appears):

$$V = \frac{1}{2}(D^a_G D^a_G + D^i_A D^i_A + D_B D_B) + F^\star_i F_i$$

For the $F^\star_{H1}F_{H1}$ and $F^\star_{H2}F_{H2}$ terms we explicitly write down $SU(3)$ indices in places where their contraction can be ambiguous ($\bar{Y}^a = -(Y^a)^T$).

$$\begin{aligned}
D^a_G &= g_3(Q^{I\star}_i Y^a Q^I_i + D^{I\star}\bar{Y}^a D^I + U^{I\star}\bar{Y}^a U^I) \\
D^i_A &= g_2[(Q_1, KQ_2)^{I\star} T^i \begin{pmatrix} Q_1 \\ KQ_2 \end{pmatrix}^I + L^{I\star}T^i L^I + H^{1\star}T^i H^1 + H^{2\star}T^i H^2] \\
D_B &= \frac{1}{2}g_1(\frac{1}{3}Q^{I\star}_i Q^I_i + \frac{2}{3}D^{I\star}D^I - \frac{4}{3}U^{I\star}U^I - L^{I\star}_i L^I_i + 2R^{I\star}R^I - H^{1\star}_i H^1_i + H^{2\star}_i H^2_i)
\end{aligned}$$

$$\begin{aligned}
F^\star_{H1}F_{H1} &= |\mu|^2 H^{2\star}_i H^2_i + Y^I_l Y^J_l L^{I\star}_i L^J_i R^{I\star}R^J + Y^I_d Y^J_d (K^{KI}K^{LJ\star}Q^{K\star}_{1\alpha}Q^L_{1\beta} + Q^{I\star}_{2\alpha}Q^J_{2\beta})D^{I\star}_\alpha D^J_\beta \\
&+ (Y^I_l \mu^\star H^{2\star}_i L^I_i R^I + Y^I_d \mu^\star (K^{JI\star}H^{2\star}_1 Q^J_1 + H^{2\star}_2 Q^I_2)D^I + \text{H.c.}) \\
&+ (Y^I_l Y^J_d (K^{KJ\star}L^{I\star}_1 Q^K_1 + L^{I\star}_2 Q^J_2)R^{I\star}D^J + \text{H.c.}) \\
F^\star_{H2}F_{H2} &= |\mu|^2 H^{1\star}_i H^1_i + Y^I_u Y^J_u (K^{IK\star}K^{JL}Q^{K\star}_{2\alpha}Q^L_{2\beta} + Q^{I\star}_{1\alpha}Q^J_{1\beta})U^{I\star}_\alpha U^J_\beta
\end{aligned}$$

$$
\begin{aligned}
& - && (Y_u^I \mu^\star (K^{IJ} H_2^{1\star} Q_2^J + H_1^{1\star} Q_1^I) U^I + \text{H.c.}) \\
F_{Li}^{I\star} F_{Li}^I & = && (Y_l^I)^2 H_i^{1\star} H_i^1 R^{I\star} R^I \\
F_R^{I\star} F_R^I & = && (Y_l^I)^2 \epsilon_{ij} \epsilon_{kl} H_i^{1\star} H_k^1 L_j^{I\star} L_l^I \\
F_{Qi}^{I\star} F_{Qi}^I & = && (Y_d^I)^2 H_i^{1\star} H_i^1 D^{I\star} D^I + (Y_u^I)^2 H_i^{2\star} H_i^2 U^{I\star} U^I + (Y_u^I Y_d^J K^{IJ} U^I D^{J\star} H_i^{1\star} H_i^2 + \text{H.c.}) \\
F_U^{I\star} F_U^I & = && (Y_u^I)^2 [K^{IJ\star} K^{IK} H_1^{2\star} H_1^2 Q_2^{J\star} Q_2^K + H_2^{2\star} H_2^2 Q_1^{I\star} Q_1^I - (K^{IJ\star} H_1^{2\star} H_2^2 Q_2^{J\star} Q_1^I + \text{H.c.})] \\
F_D^{I\star} F_D^I & = && (Y_d^I)^2 [H_1^{1\star} H_1^1 Q_2^{I\star} Q_2^I + K^{JI} K^{KI\star} H_2^{1\star} H_2^1 Q_1^{J\star} Q_1^K - (K^{JI\star} H_1^{1\star} H_2^1 Q_2^{I\star} Q_1^J + \text{H.c.})]
\end{aligned}
$$

7. The soft SUSY breaking terms.

$$
\begin{aligned}
- & \; m_{H_1}^2 H_i^{1\star} H_i^1 - m_{H_2}^2 H_i^{2\star} H_i^2 - (m_L^2)^{IJ} L_i^{I\star} L_i^J - (m_R^2)^{IJ} R^{I\star} R^J \\
- & \; (m_Q^2)^{IJ} [Q_2^{I\star} Q_2^J + K^{KI} K^{LJ\star} Q_1^{K\star} Q_1^L] - (m_D^2)^{IJ} D^{I\star} D^J - (m_U^2)^{IJ} U^{I\star} U^J \\
+ & \; \frac{1}{2} M_1 \lambda_B \lambda_B + \frac{1}{2} M_2 \lambda_A^i \lambda_A^i + \frac{1}{2} M_3 \lambda_G^a \lambda_G^a + \text{H.c.} \\
+ & \; m_{12}^2 \epsilon_{ij} H_i^1 H_j^2 + \epsilon_{ij} A_l^{IJ} H_i^1 L_j^I R^J + A_l^{\prime IJ} H_i^{2\star} L_i^I R^J + \text{H.c.} \\
+ & \; A_u^{IJ} (-K^{IK} H_1^2 Q_2^K + H_2^2 Q_1^I) U^J + A_u^{\prime IJ} (K^{IK} H_2^{1\star} Q_2^K + H_1^{1\star} Q_1^I) U^J + \text{H.c.} \\
+ & \; A_d^{IJ} (-H_1^1 Q_2^I + K^{KI\star} H_2^1 Q_1^K) D^J + A_d^{\prime IJ} (H_2^{2\star} Q_2^I + K^{KI\star} H_1^{2\star} Q_1^K) D^J + \text{H.c.}
\end{aligned}
$$

Appendix B Feynman rules

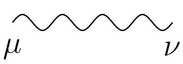
In this appendix we complete Feynman rules for the interactions described in section 6. For simplicity we write down the propagators and ghost terms for $\xi = 1$ - extension to the general case is straightforward . ξ-dependence of ghost vertices and Goldstone boson masses can be found in section 5 and section 6 point 7. All vertices are properly symmetrized.

B.1 Propagators

1. Scalar particles (Higgs boson or superscalar):

$$\frac{i}{p^2 - m^2}$$

2. Vector bosons:

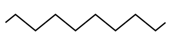


$$\frac{-i g_{\mu\nu}}{p^2 - m^2}$$

3. Fermions. Some of the MSSM fermions are Majorana spinors, what introduce additional complications into the calculations. The detailed discussion of the Feynman rules for the Majorana fermions can be found e.g. in [13].

$$\frac{i}{p_\mu \gamma^\mu - m}$$

4. Ghosts:

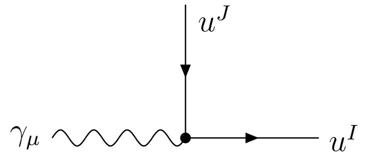


$$\frac{i}{p^2 - m^2}$$

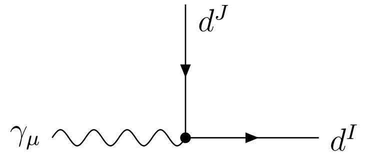
The propagators of the quarks, squarks and the color ghosts should be multiplied by the factor δ^{ab}, where a and b are as usual color indices.

B.2 Vertices

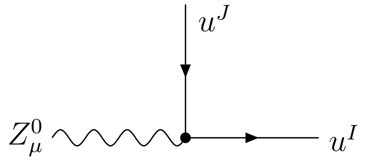
1. Quark-squark-gauge boson.



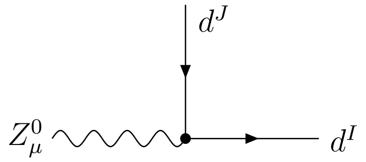
$$-\frac{2}{3}ie\gamma^\mu\delta^{IJ}$$



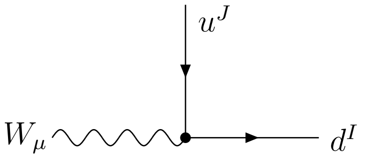
$$\frac{1}{3}ie\gamma^\mu\delta^{IJ}$$



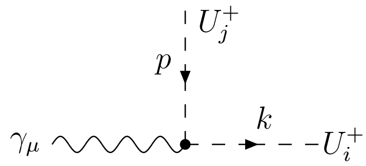
$$-\frac{ie}{2s_W c_W}\gamma^\mu(P_L-\frac{4}{3}s_W^2)\delta^{IJ}$$



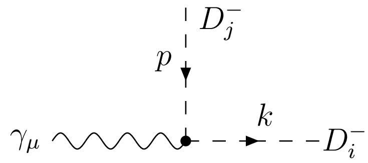
$$\frac{ie}{2s_W c_W}\gamma^\mu(P_L-\frac{2}{3}s_W^2)\delta^{IJ}$$



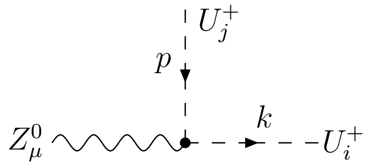
$$-\frac{ie}{\sqrt{2}s_W}K^{JI\star}\gamma^\mu P_L$$



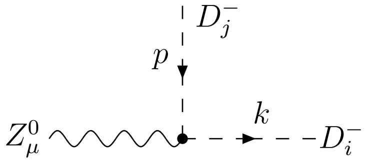
$$-\frac{2}{3}ie\delta^{ij}(p+k)^\mu$$



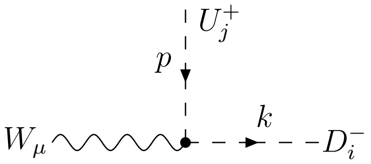
$$\frac{1}{3}ie\delta^{ij}(p+k)^\mu$$



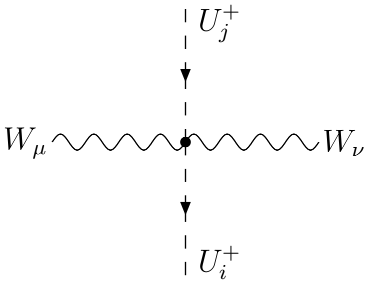
$$-\frac{ie}{2s_W c_W}(Z_U^{Ii\star}Z_U^{Ij}-\frac{4}{3}s_W^2\delta^{ij})(p+k)^\mu$$



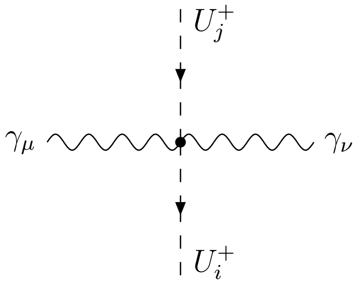
$$\frac{ie}{2s_W c_W}(Z_D^{Ii} Z_D^{Ij\star} - \frac{2}{3} s_W^2 \delta^{ij})(p+k)^\mu$$



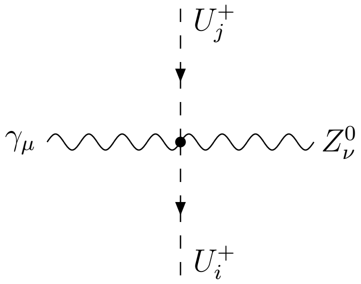
$$-\frac{ie}{\sqrt{2} s_W} Z_D^{Ii} Z_U^{Jj} K^{JI\star} (p+k)^\mu$$



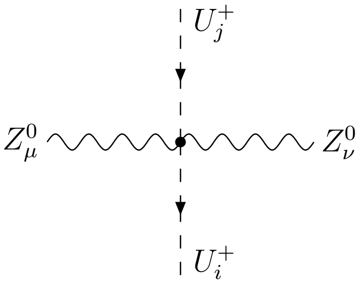
$$\frac{ie^2}{2s_W^2} Z_U^{Ii\star} Z_U^{Ij} g^{\mu\nu}$$



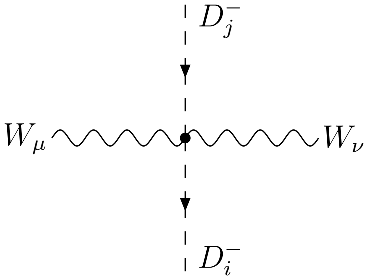
$$\frac{8}{9} ie^2 \delta^{ij} g^{\mu\nu}$$



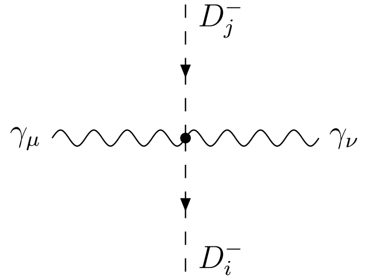
$$\frac{2ie^2}{3s_W c_W}(Z_U^{Ii\star} Z_U^{Ij} - \frac{4}{3} \delta^{ij} s_W^2) g^{\mu\nu}$$



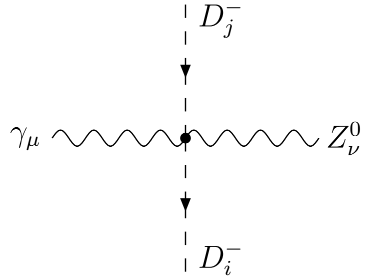
$$\frac{2ie^2}{3c_W^2}\left[\frac{4}{3}\delta^{ij} s_W^2 + \frac{3-8s_W^2}{4s_W^2} Z_U^{Ii\star} Z_U^{Ij}\right] g^{\mu\nu}$$



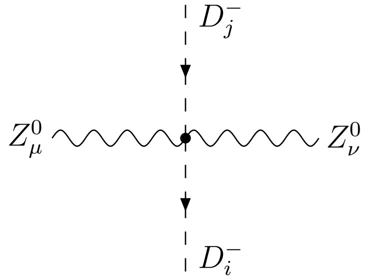
$$\frac{ie^2}{2s_W^2} Z_D^{Ii} Z_D^{Ij\star} g^{\mu\nu}$$



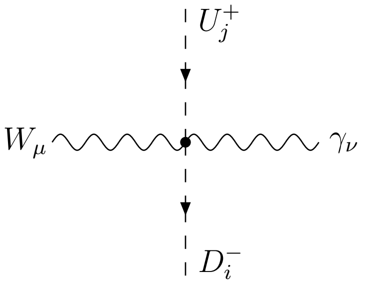
$$\frac{2}{9} ie^2 \delta^{ij} g^{\mu\nu}$$



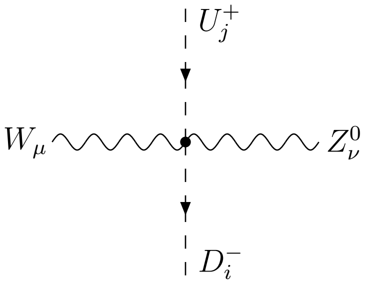
$$\frac{ie^2}{3s_W c_W}(Z_D^{Ii} Z_D^{Ij\star} - \frac{2}{3}\delta^{ij} s_W^2) g^{\mu\nu}$$



$$\frac{2ie^2}{3c_W^2}\left[\frac{1}{3}\delta^{ij} s_W^2 + \frac{3-4s_W^2}{4s_W^2} Z_D^{Ii} Z_D^{Ij\star}\right] g^{\mu\nu}$$

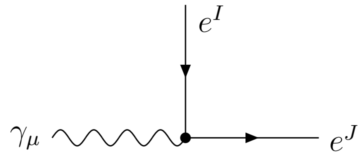


$$\frac{ie^2\sqrt{2}}{6s_W} Z_D^{Ii} Z_U^{Jj} K^{JI\star} g^{\mu\nu}$$

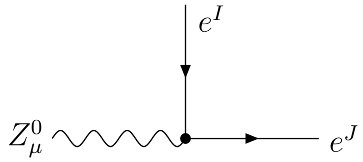


$$-\frac{ie^2\sqrt{2}}{6c_W} Z_D^{Ii} Z_U^{Jj} K^{JI\star} g^{\mu\nu}$$

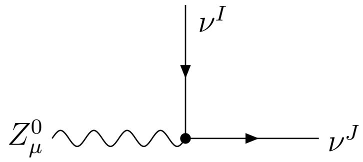
2. Lepton-slepton-gauge boson.



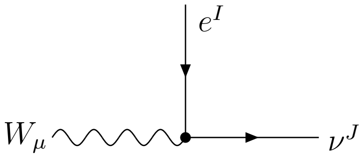
$$ie\gamma^\mu\delta^{IJ}$$



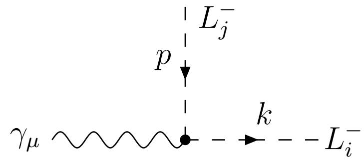
$$\frac{ie}{2s_Wc_W}\gamma^\mu(P_L - 2s^2_W)\delta^{IJ}$$



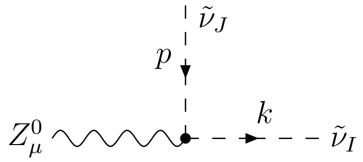
$$-\frac{ie}{2s_Wc_W}\gamma^\mu P_L\delta^{IJ}$$



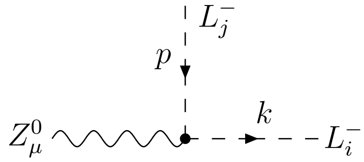
$$-\frac{ie}{\sqrt{2}s_W}\gamma^\mu P_L\delta^{IJ}$$



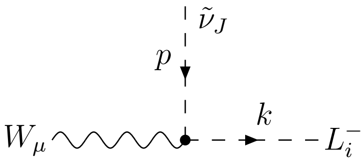
$$ie\delta^{ij}(p+k)^\mu$$



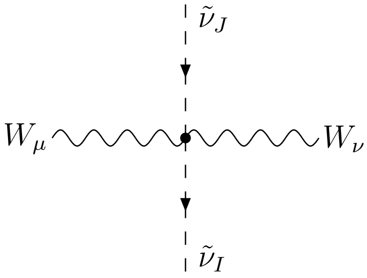
$$-\frac{ie}{2s_Wc_W}\delta^{IJ}(p+k)^\mu$$



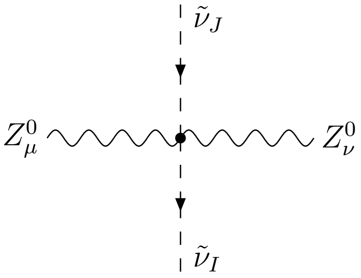
$$\frac{ie}{2s_Wc_W}(Z^{Ii}_L Z^{Ij\star}_L - 2s^2_W\delta^{ij})(p+k)^\mu$$



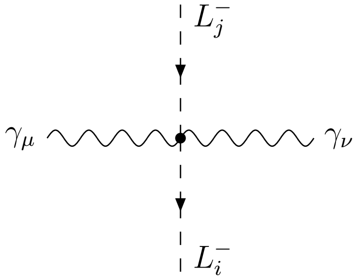
$$-\frac{ie}{\sqrt{2}s_W}Z^{IJ}_\nu Z^{Ii}_L(p+k)^\mu$$



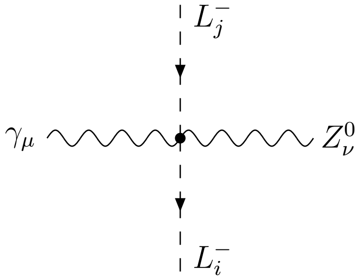
$$\frac{ie^2}{2s_W^2}\delta^{IJ}g^{\mu\nu}$$



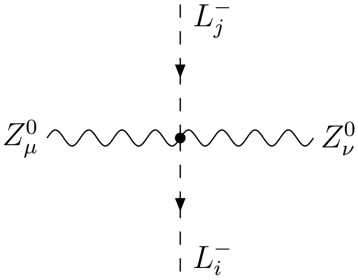
$$\frac{ie^2}{2s_W^2c_W^2}\delta^{IJ}g^{\mu\nu}$$



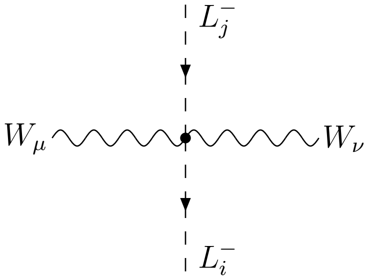
$$2ie^2\delta^{ij}g^{\mu\nu}$$



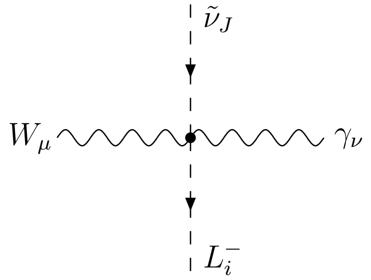
$$\frac{ie^2}{s_Wc_W}\left(Z_L^{Ii}Z_L^{Ij\star}-2\delta^{ij}s_W^2\right)g^{\mu\nu}$$



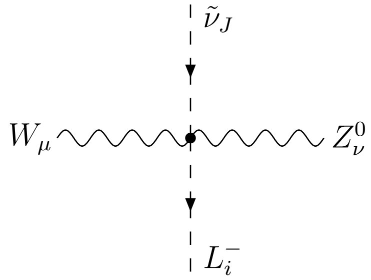
$$\frac{2ie^2}{c_W^2}\left[\delta^{ij}s_W^2+\frac{1-4s_W^2}{4s_W^2}Z_L^{Ii}Z_L^{Ij\star}\right]g^{\mu\nu}$$



$$\frac{ie^2}{2s_W^2}Z_L^{Ii}Z_L^{Ij\star}g^{\mu\nu}$$

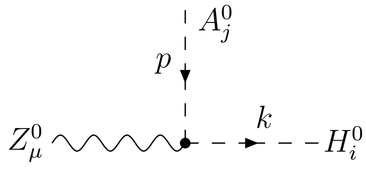


$$-\frac{ie^2}{\sqrt{2}s_W} Z_\nu^{IJ} Z_L^{Ii} g^{\mu\nu}$$

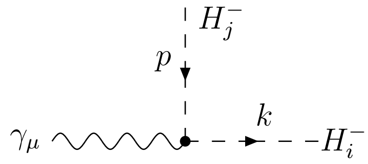


$$\frac{ie^2}{\sqrt{2}c_W} Z_\nu^{IJ} Z_L^{Ii} g^{\mu\nu}$$

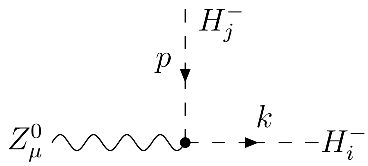
3. Higgs particle-gauge boson.



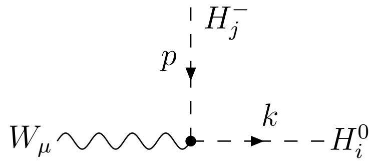
$$\frac{e}{2s_W c_W} A_M^{ij} (p+k)^\mu$$



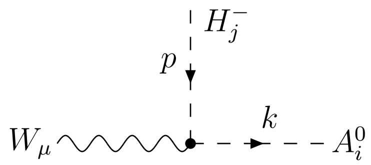
$$ie\delta^{ij}(p+k)^\mu$$



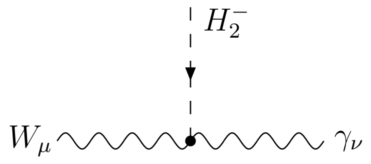
$$ie\delta^{ij}\frac{c_W^2 - s_W^2}{2s_W c_W}(p+k)^\mu$$



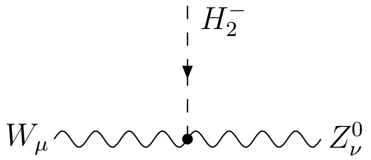
$$-\frac{ie}{2s_W} A_M^{ij}(p+k)^\mu$$



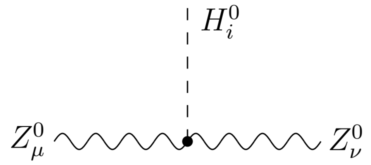
$$-\frac{e}{2s_W}\delta^{ij}(p+k)^\mu$$



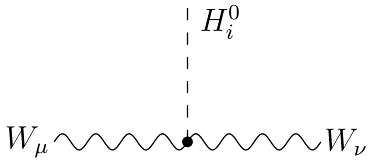
$$ieM_W g^{\mu\nu}$$



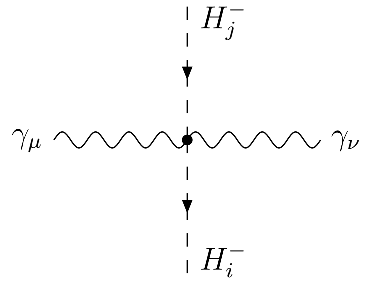
$$-ieM_W\frac{s_W}{c_W}g^{\mu\nu}$$



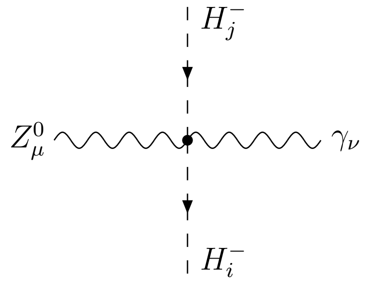
$$\frac{ie^2}{2s_W^2c_W^2}C_R^i g^{\mu\nu}$$



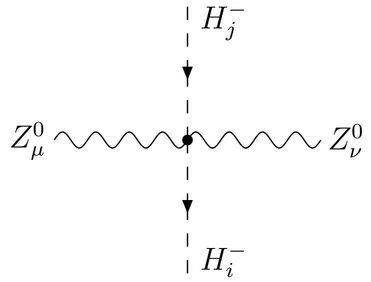
$$\frac{ie^2}{2s_W^2}C_R^i g^{\mu\nu}$$



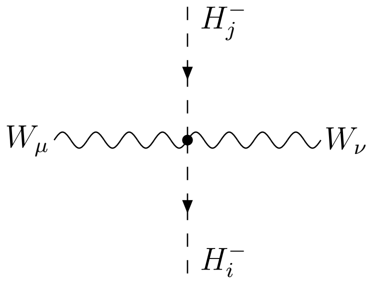
$$2ie^2\delta^{ij}g^{\mu\nu}$$



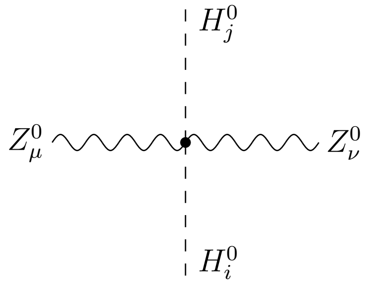
$$ie^2\frac{c_W^2-s_W^2}{s_Wc_W}\delta^{ij}g^{\mu\nu}$$



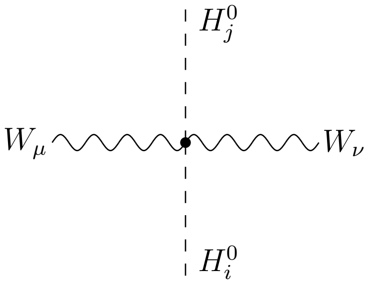
$$ie^2\frac{(c_W^2-s_W^2)^2}{2s_W^2c_W^2}\delta^{ij}g^{\mu\nu}$$



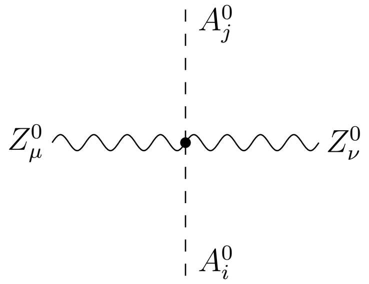
$$\frac{ie^2}{2s_W^2}\delta^{ij}g^{\mu\nu}$$



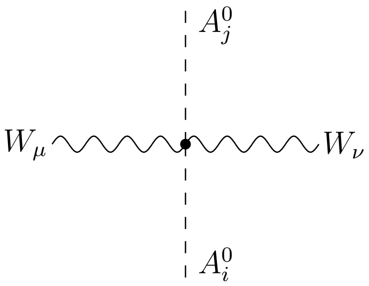
$$\frac{ie^2}{2s_W^2c_W^2}\delta^{ij}g^{\mu\nu}$$



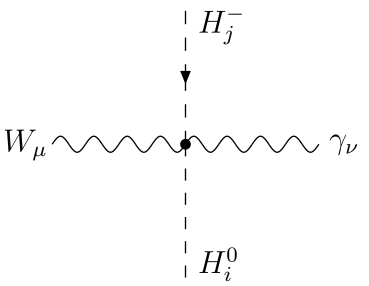
$$\frac{ie^2}{2s_W^2}\delta^{ij}g^{\mu\nu}$$



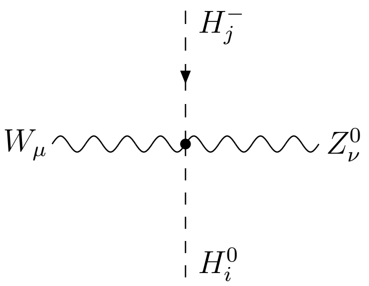
$$\frac{ie^2}{2s_W^2c_W^2}\delta^{ij}g^{\mu\nu}$$



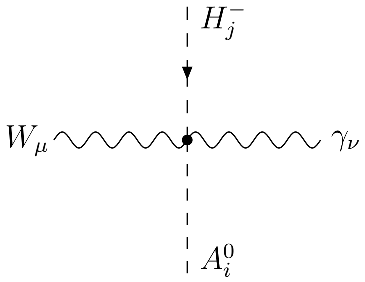
$$\frac{ie^2}{2s_W^2}\delta^{ij}g^{\mu\nu}$$



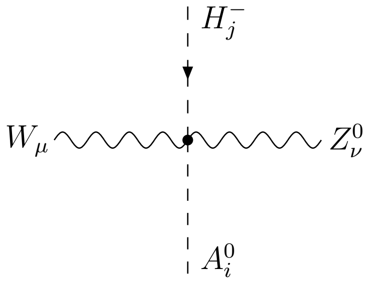
$$-\frac{ie^2}{2s_W}A_M^{ij}g^{\mu\nu}$$



$$\frac{ie^2}{2c_W}A_M^{ij}g^{\mu\nu}$$

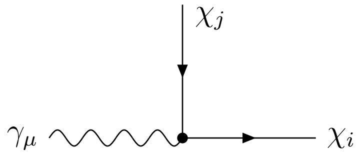


$$-\frac{e^2}{2s_W}\delta^{ij}g^{\mu\nu}$$

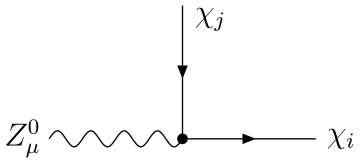


$$\frac{e^2}{2c_W}\delta^{ij}g^{\mu\nu}$$

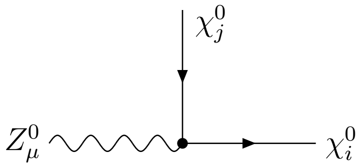
4. Chargino- and neutralino-gauge boson.



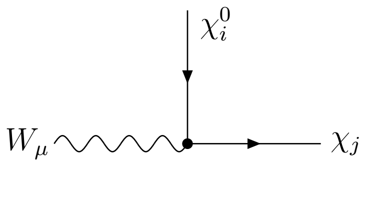
$$-ie\gamma^\mu\delta^{ij}$$



$$-\frac{ie}{2s_W c_W}\gamma^\mu\left(Z_+^{1i\star}Z_+^{1j}P_L + Z_-^{1i}Z_-^{1j\star}P_R + \delta^{ij}(c_W^2 - s_W^2)\right)$$

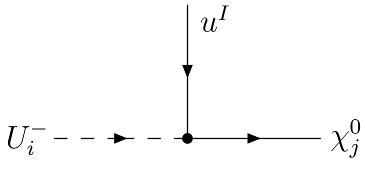


$$\frac{ie}{2s_W c_W}\gamma^\mu\left((Z_N^{4i\star}Z_N^{4j} - Z_N^{3i\star}Z_N^{3j})P_L - (Z_N^{4i}Z_N^{4j\star} - Z_N^{3i}Z_N^{3j\star})P_R\right)$$

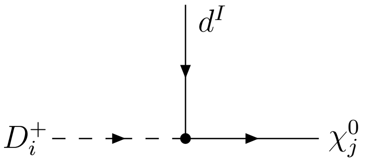


$$\frac{ie}{s_W}\gamma^\mu\left[\left(Z_N^{2i}Z_+^{1j\star} - \frac{1}{\sqrt{2}}Z_N^{4i}Z_+^{2j\star}\right)P_L + \left(Z_N^{2i\star}Z_-^{1j} + \frac{1}{\sqrt{2}}Z_N^{3i\star}Z_-^{2j}\right)P_R\right]$$

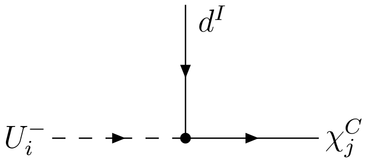
5. Chargino- and neutralino-quark and squark.



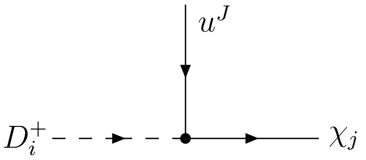
$$i\left[\left(\frac{-e}{\sqrt{2}s_W c_W}Z_U^{Ii\star}(\frac{1}{3}Z_N^{1j}s_W + Z_N^{2j}c_W) - Y_u^I Z_U^{(I+3)i\star}Z_N^{4j}\right)P_L + \left(\frac{2\sqrt{2}e}{3c_W}Z_U^{(I+3)i\star}Z_N^{1j\star} - Y_u^I Z_U^{Ii\star}Z_N^{4j\star}\right)P_R\right]$$



$$i\left[\left(\frac{-e}{\sqrt{2}s_W c_W}Z_D^{Ii}(\frac{1}{3}Z_N^{1j}s_W - Z_N^{2j}c_W) + Y_d^I Z_D^{(I+3)i}Z_N^{3j}\right)P_L + \left(\frac{-e\sqrt{2}}{3c_W}Z_D^{(I+3)i}Z_N^{1j\star} + Y_d^I Z_D^{Ii}Z_N^{3j\star}\right)P_R\right]$$

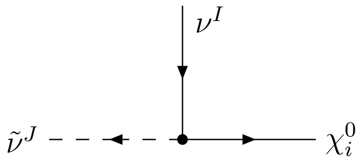


$$i\left[(\frac{-e}{s_W}Z_U^{Ji\star}Z_+^{1j} + Y_u^J Z_U^{(J+3)i\star}Z_+^{2j})P_L - Y_d^I Z_U^{Ji\star}Z_-^{2j\star}P_R\right]K^{JI}$$

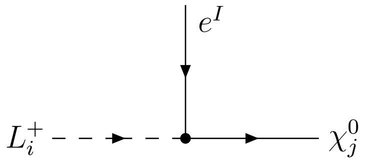


$$i\left[-(\frac{e}{s_W}Z_D^{Ii}Z_-^{1j} + Y_d^I Z_D^{(I+3)i}Z_-^{2j})P_L + Y_u^J Z_D^{Ii}Z_+^{2j\star}P_R\right]K^{JI\star}$$

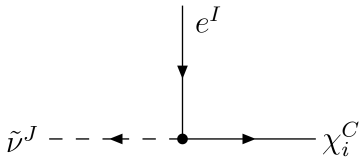
6. Charginos and neutralinos-leptons and sleptons.



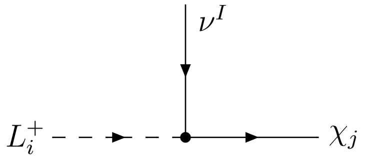
$$\frac{ie}{\sqrt{2}s_W c_W}Z_\nu^{IJ\star}(Z_N^{1i}s_W - Z_N^{2i}c_W)P_L$$



$$i\left[\left(\frac{e}{\sqrt{2}s_W c_W}Z_L^{Ii}(Z_N^{1j}s_W + Z_N^{2j}c_W) + Y_l^I Z_L^{(I+3)i}Z_N^{3j}\right)P_L + \left(\frac{-e\sqrt{2}}{c_W}Z_L^{(I+3)i}Z_N^{1j\star} + Y_l^I Z_L^{Ii}Z_N^{3j\star}\right)P_R\right]$$

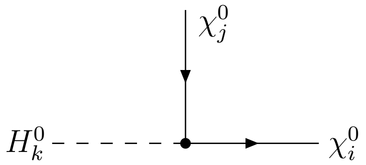


$$-i\left(\frac{e}{s_W}Z_+^{1i}P_L + Y_l^I Z_-^{2i\star}P_R\right)Z_\nu^{IJ\star}$$

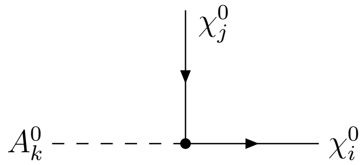


$$-i\left(\frac{e}{s_W}Z_L^{Ii}Z_-^{1j} + Y_l^I Z_L^{(I+3)i}Z_-^{2j}\right)P_L$$

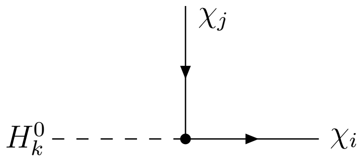
7. Chargino- and neutralino-Higgs boson.



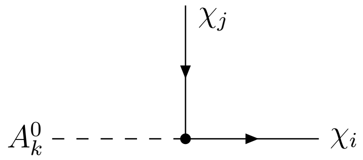
$$\frac{ie}{2s_W c_W}\Big[\Big((Z_R^{1k}Z_N^{3j} - Z_R^{2k}Z_N^{4j})(Z_N^{1i}s_W - Z_N^{2i}c_W) + (Z_R^{1k}Z_N^{3i} - Z_R^{2k}Z_N^{4i})(Z_N^{1j}s_W - Z_N^{2j}c_W)\Big)P_L + \Big((Z_R^{1k}Z_N^{3i\star} - Z_R^{2k}Z_N^{4i\star})(Z_N^{1j\star}s_W - Z_N^{2j\star}c_W) + (Z_R^{1k}Z_N^{3j\star} - Z_R^{2k}Z_N^{4j\star})(Z_N^{1i\star}s_W - Z_N^{2i\star}c_W)\Big)P_R\Big]$$



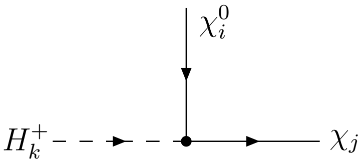
$$\frac{e}{2s_W c_W}\Big[\Big((Z_H^{1k}Z_N^{3j} - Z_H^{2k}Z_N^{4j})(Z_N^{1i}s_W - Z_N^{2i}c_W) \\ +(Z_H^{1k}Z_N^{3i} - Z_H^{2k}Z_N^{4i})(Z_N^{1j}s_W - Z_N^{2j}c_W)\Big)\,P_L \\ -\Big((Z_H^{1k}Z_N^{3i\star} - Z_H^{2k}Z_N^{4i\star})(Z_N^{1j\star}s_W - Z_N^{2j\star}c_W) \\ +(Z_H^{1k}Z_N^{3j\star} - Z_H^{2k}Z_N^{4j\star})(Z_N^{1i\star}s_W - Z_N^{2i\star}c_W)\Big)\,P_R\Big]$$



$$-\frac{ie}{\sqrt{2}s_W}\Big[(Z_R^{1k}Z_-^{2i}Z_+^{1j} + Z_R^{2k}Z_-^{1i}Z_+^{2j})P_L \\ +(Z_R^{1k}Z_-^{2j\star}Z_+^{1i\star} + Z_R^{2k}Z_-^{1j\star}Z_+^{2i\star})P_R\Big]$$

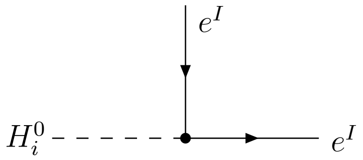


$$\frac{e}{\sqrt{2}s_W}\Big[-(Z_H^{1k}Z_-^{2i}Z_+^{1j} + Z_H^{2k}Z_-^{1i}Z_+^{2j})P_L \\ +(Z_H^{1k}Z_-^{2j\star}Z_+^{1i\star} + Z_H^{2k}Z_-^{1j\star}Z_+^{2i\star})P_R\Big]$$

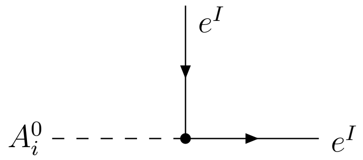


$$\frac{ie}{s_W c_W}\left[Z_H^{1k}\left(\frac{1}{\sqrt{2}}Z_-^{2j}(Z_N^{1i}s_W + Z_N^{2i}c_W) - Z_-^{1j}Z_N^{3i}c_W\right)P_L \\ -Z_H^{2k}\left(\frac{1}{\sqrt{2}}Z_+^{2j\star}(Z_N^{1i\star}s_W + Z_N^{2i\star}c_W) + Z_+^{1j\star}Z_N^{4i\star}c_W\right)P_R\right]$$

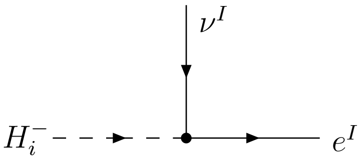
8. Leptons and quarks-Higgs particles.



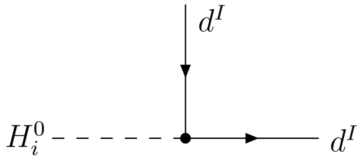
$$\frac{i}{\sqrt{2}}Y_l^I Z_R^{1i}$$



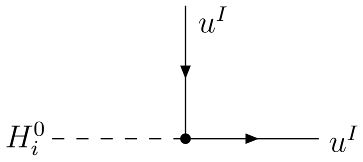
$$\frac{1}{\sqrt{2}}Y_l^I Z_H^{1i}\gamma_5$$



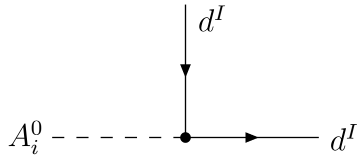
$$-iY_l^I Z_H^{1i}P_L$$



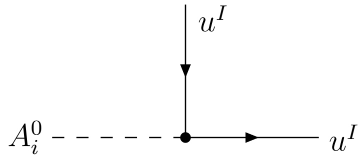
$$\frac{i}{\sqrt{2}}Y_d^I Z_R^{1i}$$



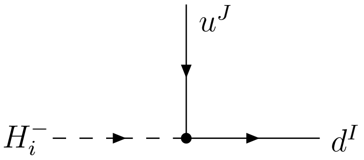
$$-\frac{i}{\sqrt{2}} Y_u^I Z_R^{2i}$$



$$\frac{1}{\sqrt{2}} Y_d^I Z_H^{1i} \gamma_5$$

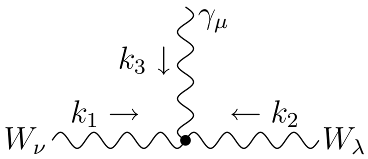


$$-\frac{1}{\sqrt{2}} Y_u^I Z_H^{2i} \gamma_5$$

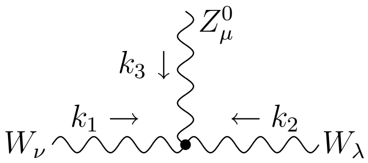


$$i(-Y_d^I Z_H^{1i} P_L + Y_u^J Z_H^{2i} P_R) K^{JI\star}$$

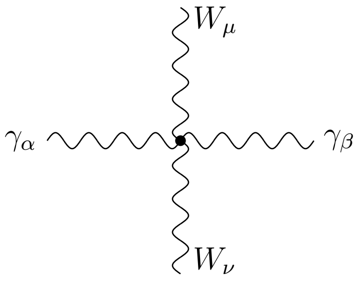
9. Self-interactions of gauge bosons.



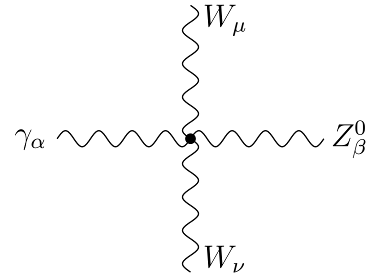
$$ie[g^{\nu\lambda}(k_1 - k_2)^\mu + g^{\lambda\mu}(k_2 - k_3)^\nu + g^{\mu\nu}(k_3 - k_1)^\lambda]$$



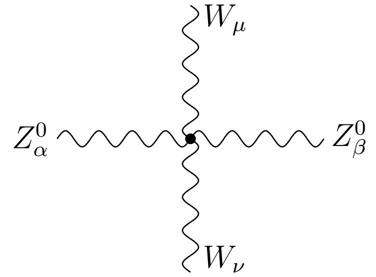
$$i\frac{ec_W}{s_W}[g^{\nu\lambda}(k_1 - k_2)^\mu + g^{\lambda\mu}(k_2 - k_3)^\nu + g^{\mu\nu}(k_3 - k_1)^\lambda]$$



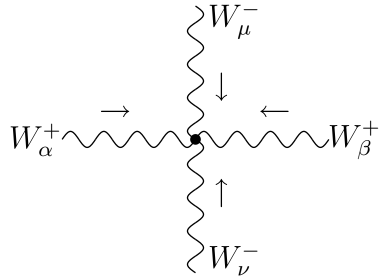
$$-ie^2(2g^{\alpha\beta}g^{\mu\nu} - g^{\alpha\mu}g^{\beta\nu} - g^{\alpha\nu}g^{\beta\mu})$$



$$-\frac{ie^2c_W}{s_W}(2g^{\alpha\beta}g^{\mu\nu} - g^{\alpha\mu}g^{\beta\nu} - g^{\alpha\nu}g^{\beta\mu})$$

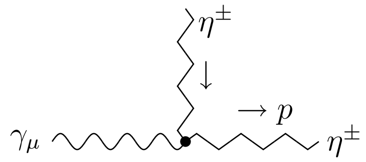


$$-\frac{ie^2c_W^2}{s_W^2}(2g^{\alpha\beta}g^{\mu\nu} - g^{\alpha\mu}g^{\beta\nu} - g^{\alpha\nu}g^{\beta\mu})$$

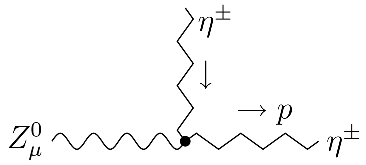


$$\frac{ie^2}{s_W^2}(2g^{\alpha\beta}g^{\mu\nu} - g^{\alpha\mu}g^{\beta\nu} - g^{\alpha\nu}g^{\beta\mu})$$

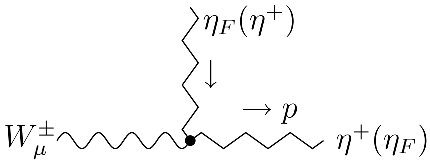
10. Ghost terms.



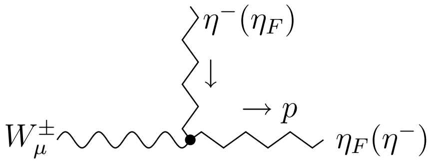
$$\pm iep^\mu$$



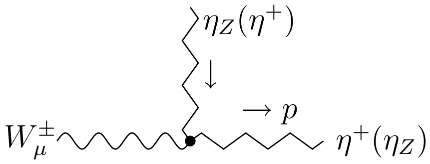
$$\pm\frac{iec_W}{s_W}p^\mu$$



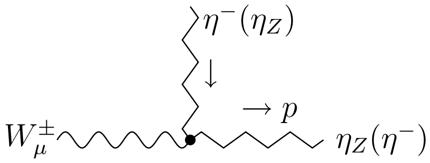
$$-iep^\mu$$



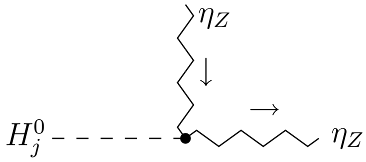
$$iep^\mu$$



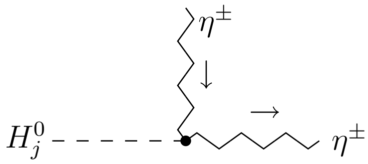
$$-\frac{iec_W}{s_W}p^\mu$$



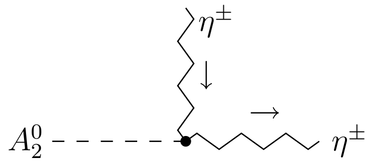
$$\frac{iec_W}{s_W}p^\mu$$



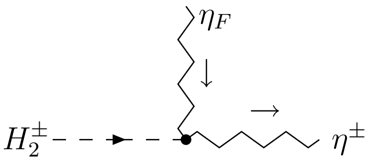
$$-\frac{ie^2}{4s_W^2c_W^2}v_iZ_R^{ij}$$



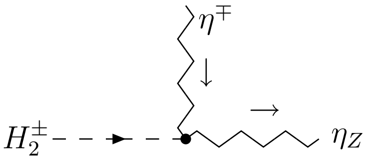
$$-\frac{ie^2}{4s_W^2}v_iZ_R^{ij}$$



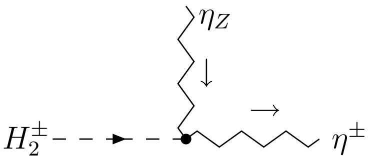
$$\pm\frac{eM_W}{2s_W}$$



$$\mp ieM_W$$

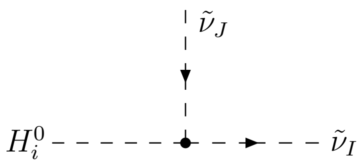


$$\frac{ieM_W}{2s_Wc_W}$$

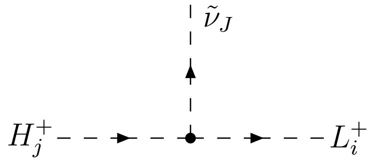


$$-ieM_W\frac{c_W^2-s_W^2}{2s_Wc_W}$$

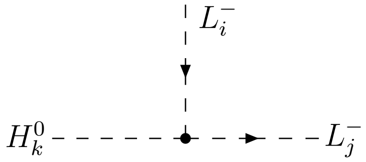
11. Slepton-Higgs boson.



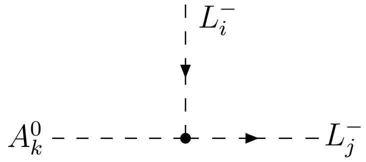
$$-\frac{ie^2}{4s_W^2c_W^2}B_R^i\delta^{IJ}$$



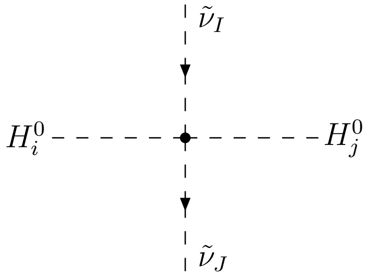
$$iZ_\nu^{IJ\star}\left(-\frac{\sqrt{2}e^2}{4s_W^2}\upsilon_k Z_H^{kj} Z_L^{Ii\star} + Z_H^{1j}\left(\frac{\upsilon_1}{\sqrt{2}}(Y_l^I)^2 Z_L^{Ii\star} + A_l^{IK\star} Z_L^{(K+3)i\star}\right) + Z_H^{2j}\left(A_l'^{IK\star} Z_L^{(K+3)i\star} - \mu Y_l^I Z_L^{(I+3)i\star}\right)\right)$$



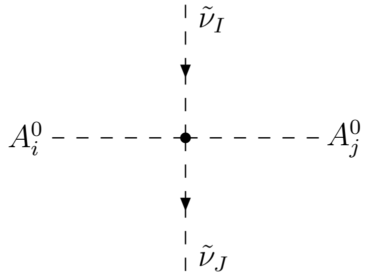
$$i\left(\frac{e^2}{2c_W^2}B_R^k\left(\delta^{ij} + \frac{1-4s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}\right) - (Y_l^I)^2\upsilon_1 Z_R^{1k}(Z_L^{Ii\star}Z_L^{Ij} + Z_L^{(I+3)i\star}Z_L^{(I+3)j}) - \frac{1}{\sqrt{2}}Z_R^{1k}(A_l^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} + A_l^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j}) + \frac{1}{\sqrt{2}}Z_R^{2k}(A_l'^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} + A_l'^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j}) - \frac{1}{\sqrt{2}}Y_l^I Z_R^{2k}(\mu^\star Z_L^{Ii\star}Z_L^{(I+3)j} + \mu Z_L^{Ij}Z_L^{(I+3)i\star})\right)$$



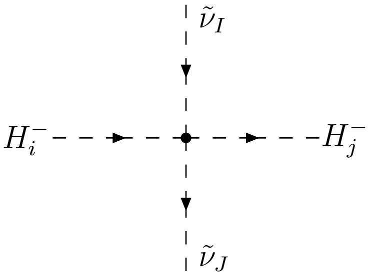
$$-\frac{1}{\sqrt{2}}\left((A_l^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} - A_l^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j})Z_H^{1k} + (A_l'^{IJ\star}Z_L^{Ij}Z_L^{(J+3)i\star} - A_l'^{IJ}Z_L^{Ii\star}Z_L^{(J+3)j})Z_H^{2k} + Y_l^I(\mu^\star Z_L^{Ii\star}Z_L^{(I+3)j} - \mu Z_L^{Ij}Z_L^{(I+3)i\star})Z_H^{2k}\right)$$



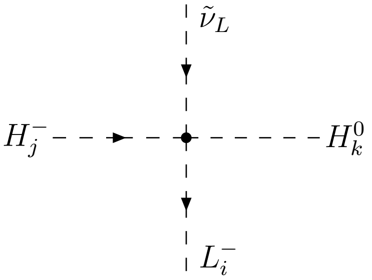
$$-\frac{ie^2}{4s_W^2c_W^2}A_R^{ij}\delta^{IJ}$$



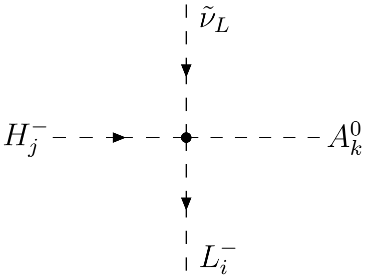
$$-\frac{ie^2}{4s_W^2c_W^2}A_H^{ij}\delta^{IJ}$$



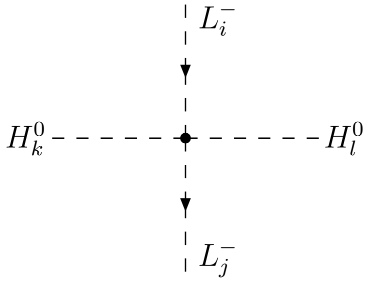
$$iZ_\nu^{KJ\star}Z_\nu^{KI}\left(e^2\frac{c_W^2 - s_W^2}{4s_W^2c_W^2}A_H^{ij} - (Y_l^K)^2 Z_H^{1i}Z_H^{1j}\right)$$



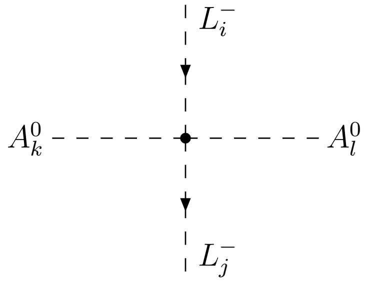
$$\frac{i}{\sqrt{2}} Z_L^{Ii} Z_\nu^{IL} \left(\frac{-e^2}{2s_W^2} (Z_H^{1j} Z_R^{1k} + Z_H^{2j} Z_R^{2k}) + (Y_l^I)^2 Z_H^{1j} Z_R^{1k} \right)$$



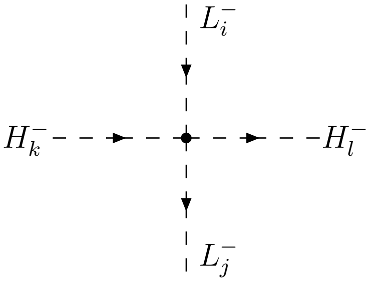
$$-\frac{1}{\sqrt{2}} Z_L^{Ii} Z_\nu^{IL} \left(\frac{e^2}{2s_W^2} A_H^{jk} - (Y_l^I)^2 Z_H^{1j} Z_H^{1k} \right)$$



$$i \left(\frac{e^2}{2c_W^2} A_R^{kl} \left(\delta^{ij} + \frac{1 - 4s_W^2}{2s_W^2} Z_L^{Ii\star} Z_L^{Ij} \right) \right.$$
$$\left. -(Y_l^I)^2 Z_R^{1k} Z_R^{1l} (Z_L^{Ii\star} Z_L^{Ij} + Z_L^{(I+3)i\star} Z_L^{(I+3)j}) \right)$$

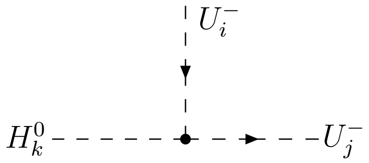


$$i \left(\frac{e^2}{2c_W^2} A_H^{kl} \left(\delta^{ij} + \frac{1 - 4s_W^2}{2s_W^2} Z_L^{Ii\star} Z_L^{Ij} \right) \right.$$
$$\left. -(Y_l^I)^2 Z_H^{1k} Z_H^{1l} (Z_L^{Ii\star} Z_L^{Ij} + Z_L^{(I+3)i\star} Z_L^{(I+3)j}) \right)$$

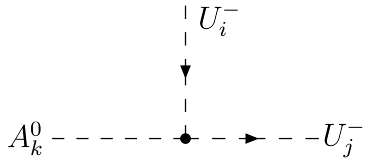


$$i \left(\frac{e^2}{2c_W^2} A_H^{kl} \left(\delta^{ij} - \frac{1 + 2s_W^2}{2s_W^2} Z_L^{Ii\star} Z_L^{Ij} \right) \right.$$
$$\left. -(Y_l^I)^2 Z_H^{1k} Z_H^{1l} Z_L^{(I+3)i\star} Z_L^{(I+3)j} \right)$$

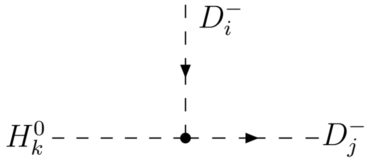
12. Interactions of the squarks and the Higgs particles.



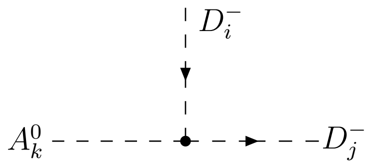
$$
\begin{aligned}
&i\left(\frac{-e^2}{3c_W^2}B_R^k\left(\delta^{ij}+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right)\right.\\
&-v_2(Y_u^I)^2Z_R^{2k}(Z_U^{Ii\star}Z_U^{Ij}+Z_U^{(I+3)i\star}Z_U^{(I+3)j})\\
&+\frac{1}{\sqrt{2}}Z_R^{2k}(A_u^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j}+A_u^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star})\\
&+\frac{1}{\sqrt{2}}Z_R^{1k}(A_u'^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j}+A_u'^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star})\\
&\left.+\frac{1}{\sqrt{2}}Y_u^IZ_R^{1k}(\mu^\star Z_U^{Ij}Z_U^{(I+3)i\star}+\mu Z_U^{Ii\star}Z_U^{(I+3)j})\right)
\end{aligned}
$$



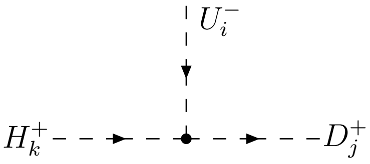
$$
\begin{aligned}
&-\frac{1}{\sqrt{2}}\left(Y_u^I(\mu Z_U^{Ii\star}Z_U^{(I+3)j}-\mu^\star Z_U^{Ij}Z_U^{(I+3)i\star})Z_H^{1k}\right.\\
&+(A_u^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star}-A_u^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j})Z_H^{2k}\\
&\left.+(A_u'^{IJ\star}Z_U^{Ii\star}Z_U^{(J+3)j}-A_u'^{IJ}Z_U^{Ij}Z_U^{(J+3)i\star})Z_H^{1k}\right)
\end{aligned}
$$



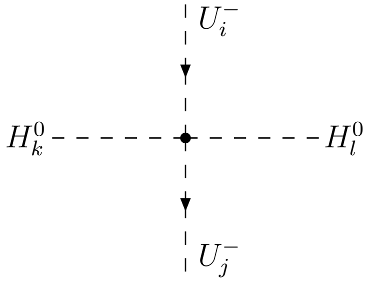
$$
\begin{aligned}
&i\left(\frac{e^2}{6c_W^2}B_R^k\left(\delta^{ij}+\frac{3-4s_W^2}{2s_W^2}Z_D^{Ii\star}Z_D^{Ij}\right)\right.\\
&-v_1(Y_d^I)^2Z_R^{1k}(Z_D^{Ii\star}Z_D^{Ij}+Z_D^{(I+3)i\star}Z_D^{(I+3)j})\\
&-\frac{1}{\sqrt{2}}Z_R^{1k}(A_d^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star}+A_d^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})\\
&+\frac{1}{\sqrt{2}}Z_R^{2k}(A_d'^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star}+A_d'^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})\\
&\left.-\frac{1}{\sqrt{2}}Y_d^IZ_R^{2k}(\mu^\star Z_D^{Ii\star}Z_D^{(I+3)j}+\mu Z_D^{Ij}Z_D^{(I+3)i\star})\right)
\end{aligned}
$$



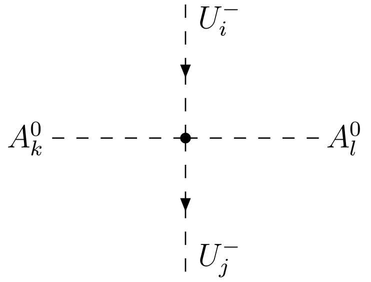
$$
\begin{aligned}
&-\frac{1}{\sqrt{2}}\left((A_d^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star}-A_d^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})Z_H^{1k}\right.\\
&+(A_d'^{IJ\star}Z_D^{Ij}Z_D^{(J+3)i\star}-A_d'^{IJ}Z_D^{Ii\star}Z_D^{(J+3)j})Z_H^{2k}\\
&\left.+Y_d^I(\mu^\star Z_D^{Ii\star}Z_D^{(I+3)j}-\mu Z_D^{Ij}Z_D^{(I+3)i\star})Z_H^{2k}\right)
\end{aligned}
$$



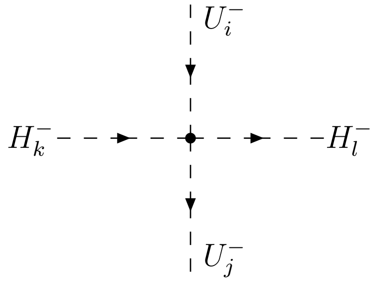
$$
\begin{aligned}
&i\left[\frac{1}{\sqrt{2}}\left(\frac{-e^2}{2s_W^2}v_lZ_H^{lk}+v_1(Y_d^I)^2Z_H^{1k}+v_2(Y_u^J)^2Z_H^{2k}\right)K^{JI}Z_D^{Ij\star}Z_U^{Ji\star}\right.\\
&-\frac{\sqrt{2}M_Ws_W}{e}\delta^{1k}Y_u^JY_d^IK^{JI}Z_D^{(I+3)j\star}Z_U^{(J+3)i\star}\\
&+[Z_H^{1k}\mu^\star Y_u^JK^{JI}+(Z_H^{1k}A_u'^{KJ}-Z_H^{2k}A_u^{KJ})K^{KI}]Z_U^{(J+3)i\star}Z_D^{Ij\star}\\
&\left.+[(Z_H^{1k}A_d^{KI\star}+Z_H^{2k}A_d'^{KI\star})K^{JK}-Z_H^{2k}\mu Y_d^IK^{JI}]Z_U^{Ji\star}Z_D^{(I+3)j\star}\right]
\end{aligned}
$$



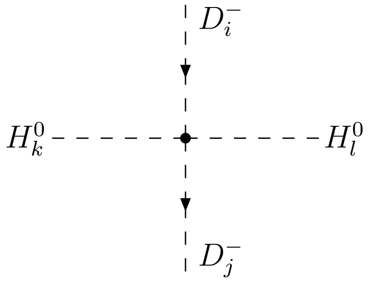
$$i\left(\frac{-e^2}{3c_W^2}A_R^{kl}\left(\delta^{ij}+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right)\right.$$
$$\left.-(Y_u^I)^2 Z_R^{2k}Z_R^{2l}(Z_U^{Ii\star}Z_U^{Ij}+Z_U^{(I+3)i\star}Z_U^{(I+3)j})\right)$$



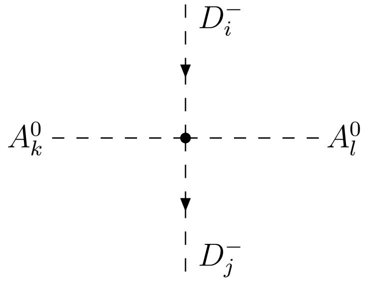
$$i\left(\frac{-e^2}{3c_W^2}A_H^{kl}\left(\delta^{ij}+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right)\right.$$
$$\left.-(Y_u^I)^2 Z_H^{2k}Z_H^{2l}(Z_U^{Ii\star}Z_U^{Ij}+Z_U^{(I+3)i\star}Z_U^{(I+3)j})\right)$$



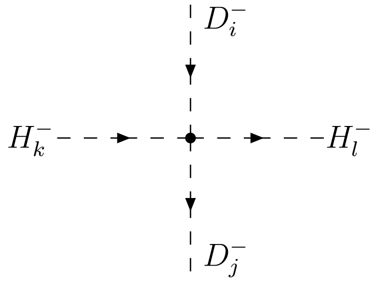
$$i\left(\frac{-e^2}{3c_W^2}A_H^{kl}\left(\delta^{ij}-\frac{3+2s_W^2}{4s_W^2}Z_U^{Ii\star}Z_U^{Ij}\right)\right.$$
$$-(Y_u^I)^2 Z_H^{2k}Z_H^{2l}Z_U^{(I+3)i\star}Z_U^{(I+3)j}$$
$$\left.-(Y_d^I)^2 Z_H^{1k}Z_H^{1l}K^{JI\star}K^{KI}Z_U^{Ki\star}Z_U^{Jj}\right)$$



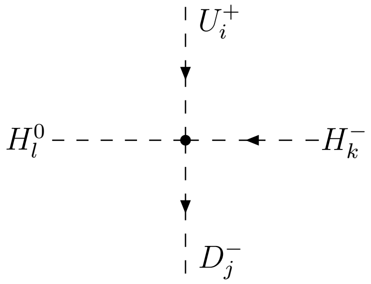
$$i\left(\frac{e^2}{6c_W^2}A_R^{kl}\left(\delta^{ij}+\frac{3-4s_W^2}{2s_W^2}Z_D^{Ii\star}Z_D^{Ij}\right)\right.$$
$$\left.-(Y_d^I)^2 Z_R^{1k}Z_R^{1l}(Z_D^{Ii\star}Z_D^{Ij}+Z_D^{(I+3)i\star}Z_D^{(I+3)j})\right)$$



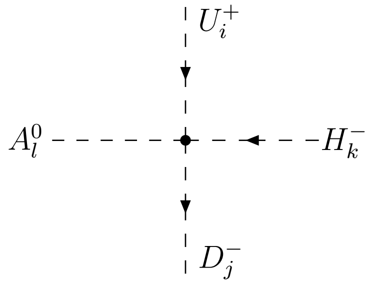
$$i\left(\frac{e^2}{6c_W^2}A_H^{kl}\left(\delta^{ij}+\frac{3-4s_W^2}{2s_W^2}Z_D^{Ii\star}Z_D^{Ij}\right)\right.$$
$$\left.-(Y_d^I)^2 Z_H^{1k}Z_H^{1l}(Z_D^{Ii\star}Z_D^{Ij}+Z_D^{(I+3)i\star}Z_D^{(I+3)j})\right)$$



$$i\left(\frac{e^2}{6c_W^2}A_H^{kl}\left(\delta^{ij}-\frac{3-2s_W^2}{2s_W^2}Z_D^{Ii\star}Z_D^{Ij}\right)\right.$$
$$-(Y_d^I)^2 Z_H^{1k}Z_H^{1l}Z_D^{(I+3)i\star}Z_D^{(I+3)j}$$
$$\left.-(Y_u^K)^2 Z_H^{2k}Z_H^{2l}K^{KI\star}K^{KJ}Z_D^{Ji\star}Z_D^{Ij}\right)$$

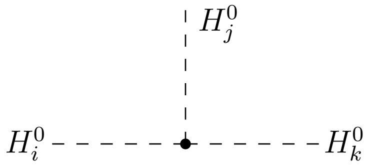


$$\frac{i}{\sqrt{2}}K^{JI\star}\left(\frac{-e^2}{2s_W^2}(Z_H^{1k}Z_R^{1l}+Z_H^{2k}Z_R^{2l})Z_U^{Ji}Z_D^{Ij} -A_P^{lk}Y_u^JY_d^IZ_U^{(J+3)i}Z_D^{(I+3)j} +[(Y_u^J)^2Z_H^{2k}Z_R^{2l}+(Y_d^I)^2Z_H^{1k}Z_R^{1l}]Z_U^{Ji}Z_D^{Ij}\right)$$

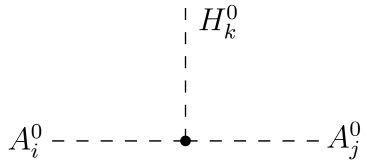


$$-\frac{1}{\sqrt{2}}K^{JI\star}\left(\frac{e^2}{2s_W^2}A_H^{kl}Z_U^{Ji}Z_D^{Ij}+[(Y_u^J)^2Z_H^{2k}Z_H^{2l} -(Y_d^I)^2Z_H^{1k}Z_H^{1l}]Z_U^{Ji}Z_D^{Ij}-\epsilon_{kl}Y_u^JY_d^IZ_U^{(J+3)i}Z_D^{(I+3)j}\right)$$

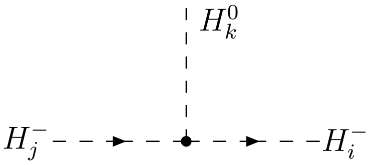
13. Self-interactions of the Higgs particles.



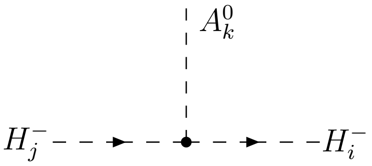
$$-\frac{ie^2}{4s_W^2c_W^2}(A_R^{ij}B_R^k+A_R^{jk}B_R^i+A_R^{ki}B_R^j)$$



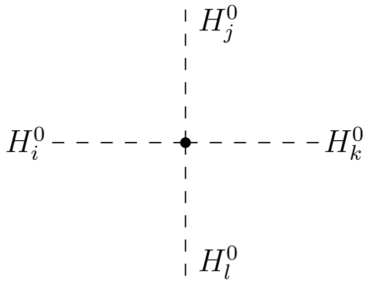
$$-\frac{ie^2}{4s_W^2c_W^2}A_H^{ij}B_R^k$$



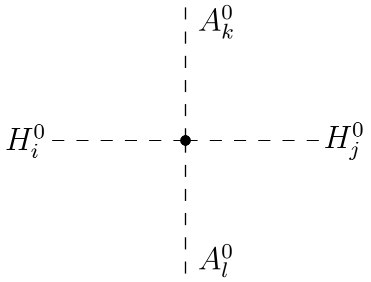
$$-i\left(\frac{e^2}{4s_W^2c_W^2}A_H^{ij}B_R^k+\frac{eM_W}{2s_W}(A_P^{kj}\delta^{1i}+A_P^{ki}\delta^{1j})\right)$$



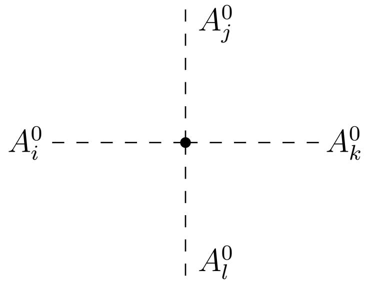
$$-\frac{eM_W}{2s_W}\epsilon_{ij}\delta^{1k}$$



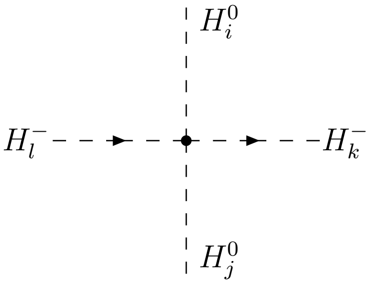
$$-\frac{ie^2}{4s_W^2c_W^2}(A_R^{ij}A_R^{kl}+A_R^{ik}A_R^{jl}+A_R^{il}A_R^{jk})$$



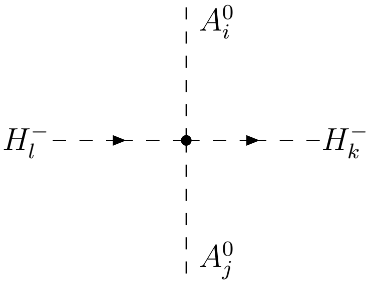
$$-\frac{ie^2}{4s_W^2c_W^2}A_R^{ij}A_H^{kl}$$



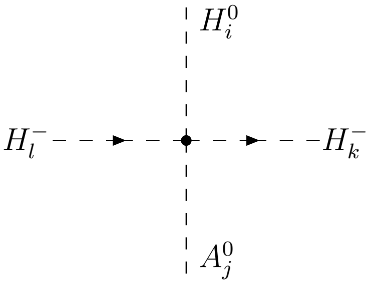
$$-\frac{ie^2}{4s_W^2c_W^2}(A_H^{ij}A_H^{kl}+A_H^{ik}A_H^{jl}+A_H^{il}A_H^{jk})$$



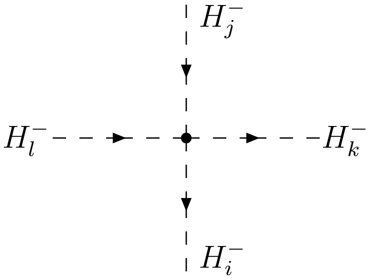
$$-\frac{ie^2}{4s_W^2}\left(\frac{1}{c_W^2}A_R^{ij}A_H^{kl}+A_P^{ik}A_P^{jl}+A_P^{il}A_P^{jk}\right)$$



$$-\frac{ie^2}{4s_W^2}\left(\frac{1}{c_W^2}A_H^{ij}A_H^{kl}+\epsilon_{ik}\epsilon_{jl}+\epsilon_{il}\epsilon_{jk}\right)$$

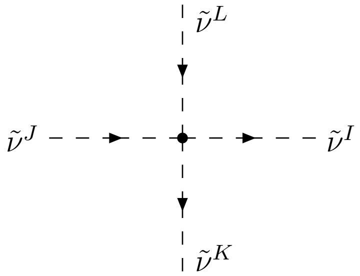


$$-\frac{e^2}{4s_W^2}A_P^{ij}\epsilon_{kl}$$

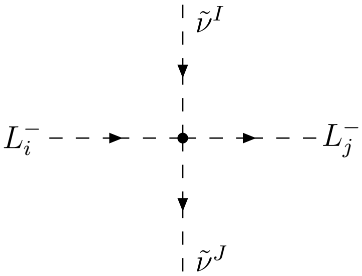


$$-\frac{ie^2}{4s_W^2c_W^2}(A_H^{ij}A_H^{kl}+A_H^{il}A_H^{jk})$$

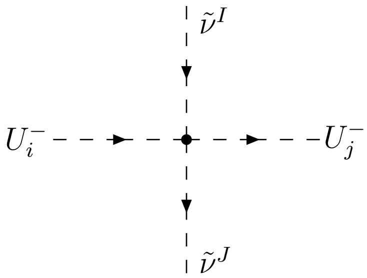
14. Interactions of four sleptons or two sleptons and two squarks:



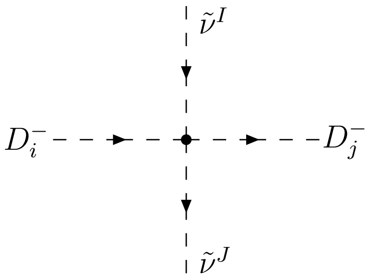
$$-\frac{ie^2}{4s_W^2c_W^2}(\delta^{IJ}\delta^{KL}+\delta^{IL}\delta^{KJ})$$



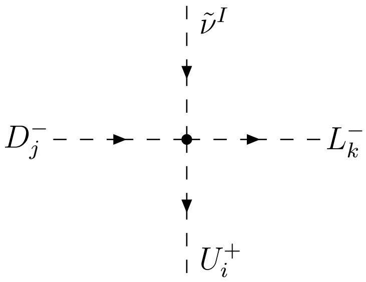
$$-i\left(\frac{-e^2}{2c_W^2}\left(\delta^{ij}+\frac{1-4s_W^2}{2s_W^2}Z_L^{Ki\star}Z_L^{Kj}\right)\delta^{IJ}\right.$$
$$\left.+\left(\frac{e^2}{2s_W^2}Z_L^{Ki\star}Z_L^{Lj}+Y_l^KY_l^LZ_L^{(K+3)i\star}Z_L^{(L+3)j}\right)Z_\nu^{LI}Z_\nu^{KJ\star}\right)$$



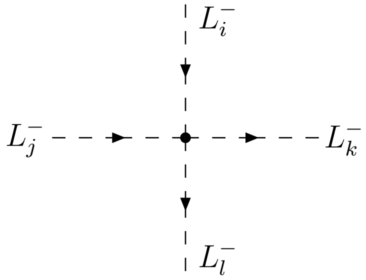
$$-\frac{ie^2}{3c_W^2}\left(\delta^{ij}+\frac{3-8s_W^2}{4s_W^2}Z_U^{Ki\star}Z_U^{Kj}\right)\delta^{IJ}$$



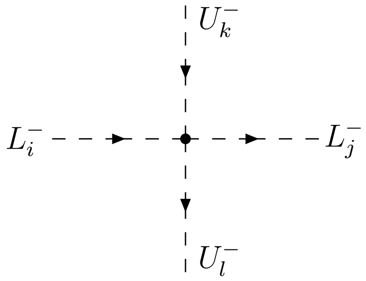
$$\frac{ie^2}{6c_W^2}\left(\delta^{ij}+\frac{3-4s_W^2}{2s_W^2}Z_D^{Ki\star}Z_D^{Kj}\right)\delta^{IJ}$$



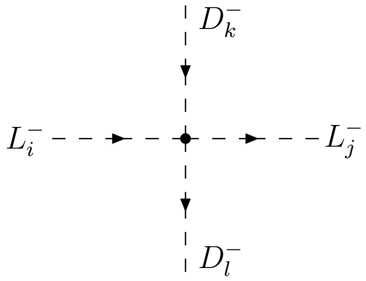
$$-iZ_\nu^{JI}Z_U^{Li\star}K^{LK}\left(\frac{e^2}{2s_W^2}Z_D^{Kj\star}Z_L^{Jk}+Y_l^JY_d^KZ_D^{(K+3)j\star}Z_L^{(J+3)k}\right)$$



$$-i\left(\frac{e^2}{c_W^2}(\delta^{il}\delta^{jk}+\delta^{ik}\delta^{jl})\right.$$
$$-\frac{3e^2}{2c_W^2}(\delta^{il}Z_L^{Ij\star}Z_L^{Ik}+\delta^{ik}Z_L^{Ij\star}Z_L^{Il}+\delta^{jl}Z_L^{Ii\star}Z_L^{Ik}+\delta^{jk}Z_L^{Ii\star}Z_L^{Il})$$
$$+\frac{e^2(1+8s_W^2)}{4s_W^2c_W^2}(Z_L^{Ii\star}Z_L^{Jj\star}Z_L^{Jk}Z_L^{Il}+Z_L^{Ii\star}Z_L^{Jj\star}Z_L^{Jl}Z_L^{Ik})$$
$$\left.+Y_l^IY_l^J(Z_L^{(I+3)i\star}Z_L^{Jj\star}+Z_L^{(I+3)j\star}Z_L^{Ji\star})(Z_L^{Il}Z_L^{(J+3)k}+Z_L^{Ik}Z_L^{(J+3)l})\right)$$

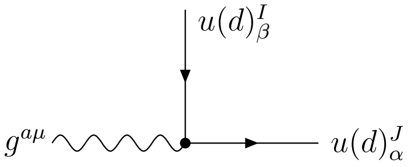


$$\frac{ie^2}{6c_W^2}\left(\frac{3+12s_W^2}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}Z_U^{Jk\star}Z_U^{Jl}\right.$$
$$\left.-6\delta^{kl}Z_L^{Ii\star}Z_L^{Ij}-5\delta^{ij}Z_U^{Ik\star}Z_U^{Il}+4\delta^{ij}\delta^{kl}\right)$$

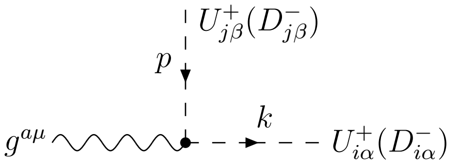


$$i\left[\frac{e^2}{6c_W^2}\left(-\frac{3}{2s_W^2}Z_L^{Ii\star}Z_L^{Ij}Z_D^{Jk\star}Z_D^{Jl}\right.\right.$$
$$\left.+3\delta^{kl}Z_L^{Ii\star}Z_L^{Ij}+\delta^{ij}Z_D^{Ik\star}Z_D^{Il}-2\delta^{ij}\delta^{kl}\right)$$
$$\left.-Y_l^IY_d^J(Z_L^{(I+3)i\star}Z_L^{Ij}Z_D^{Jk\star}Z_D^{(J+3)l}+Z_L^{Ii\star}Z_L^{(I+3)j}Z_D^{(J+3)k\star}Z_D^{Jl})\right]$$

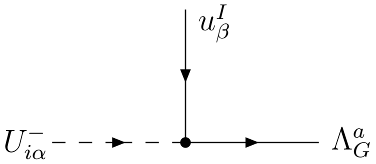
15. Strong interactions of the quarks, squarks, gluons and gluinos.



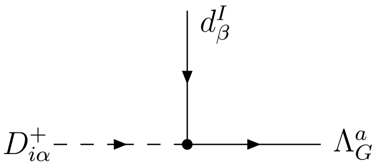
$$-ig_3Y^a_{\alpha\beta}\gamma^\mu\delta^{IJ}$$



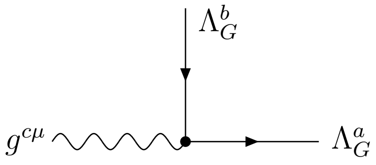
$$-ig_3(p+k)^\mu Y^a_{\alpha\beta}\delta^{ij}$$



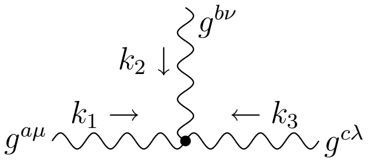
$$ig_3\sqrt{2}Y^a_{\alpha\beta}(-Z_U^{Ii\star}P_L+Z_U^{(I+3)i\star}P_R)$$



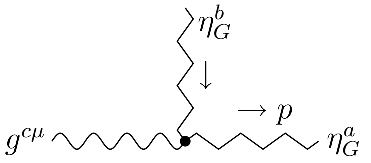
$$ig_3\sqrt{2}Y^a_{\alpha\beta}(-Z_D^{Ii}P_L+Z_D^{(I+3)i}P_R)$$



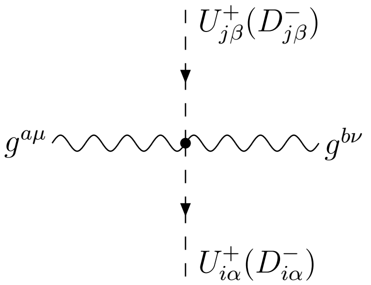
$$-g_3 f_{abc}\gamma^\mu$$



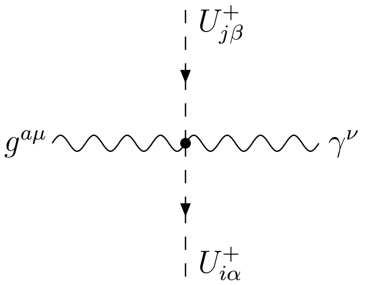
$$-g_3 f_{abc}[g^{\mu\nu}(k_1-k_2)^\lambda + g^{\nu\lambda}(k_2-k_3)^\mu + g^{\mu\lambda}(k_3-k_1)^\nu]$$



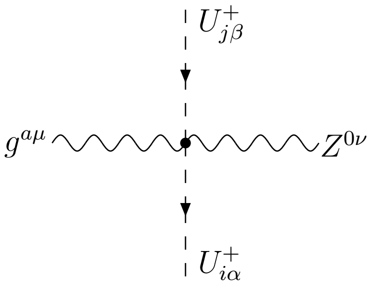
$$g_3 f_{abc} p^\mu$$



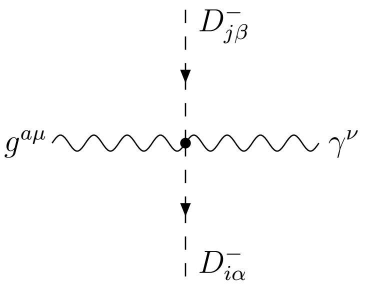
$$ig_3^2(Y^aY^b+Y^bY^a)_{\alpha\beta}g^{\mu\nu}\delta^{ij}$$



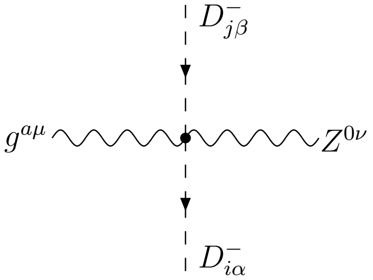
$$\frac{4}{3}ieg_3 Y^a_{\alpha\beta}g^{\mu\nu}\delta^{ij}$$



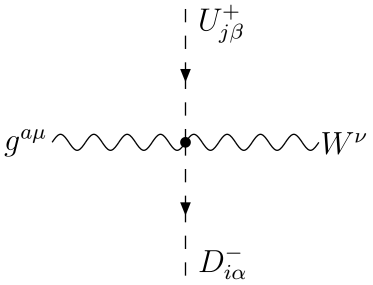
$$\frac{ieg_3}{s_W c_W}(Z_U^{Ii\star}Z_U^{Ij} - \frac{4}{3}\delta^{ij}s_W^2)Y^a_{\alpha\beta}g^{\mu\nu}$$



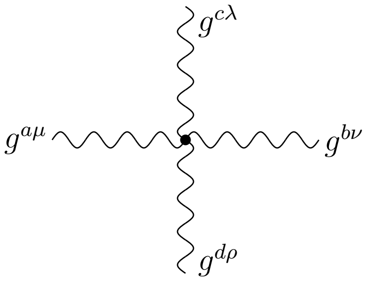
$$-\frac{2}{3}ieg_3 Y^a_{\alpha\beta}g^{\mu\nu}\delta^{ij}$$



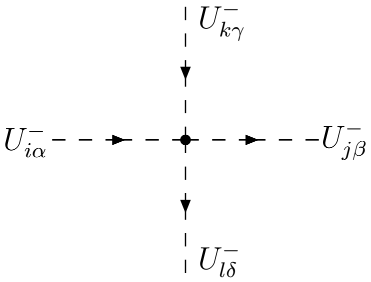
$$\frac{ieg_3}{s_W c_W}(-Z_D^{Ii}Z_D^{Ij\star} + \frac{2}{3}\delta^{ij}s_W^2)Y^a_{\alpha\beta}g^{\mu\nu}$$



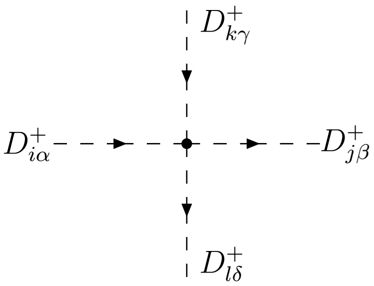
$$\frac{ieg_3\sqrt{2}}{s_W}Z_D^{Ii}Z_U^{Jj}K^{JI\star}Y^a_{\alpha\beta}g^{\mu\nu}$$



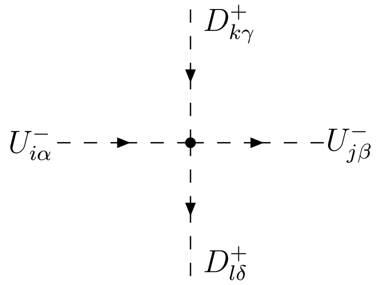
$$\begin{aligned}&-ig_3^2[f_{abe}f_{cde}(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\rho}g^{\nu\lambda}) + f_{ade}f_{bce}(g^{\mu\nu}g^{\lambda\rho} - g^{\mu\lambda}g^{\nu\rho})\\ &+f_{ace}f_{dbe}(g^{\mu\rho}g^{\lambda\nu} - g^{\mu\nu}g^{\lambda\rho})]\end{aligned}$$



$$\begin{aligned}&-i\left\{\left[\frac{g_3^2}{6}(3X_U^{il}X_U^{kj} - X_U^{ij}X_U^{kl}) + \frac{e^2}{4s_W^2}R_U^{ij}R_U^{kl}\right.\right.\\ &\left.+\ \frac{e^2}{36c_W^2}Y_U^{ij}Y_U^{kl} + V_U^{ijkl} + V_U^{klij}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\\ &+\left[\frac{g_3^2}{6}(3X_U^{ij}X_U^{kl} - X_U^{il}X_U^{kj}) + \frac{e^2}{4s_W^2}R_U^{il}R_U^{kj}\right.\\ &\left.\left.+\ \frac{e^2}{36c_W^2}Y_U^{il}Y_U^{kj} + V_U^{ilkj} + V_U^{kjil}\right]\delta_{\alpha\delta}\delta_{\beta\gamma}\right\}\end{aligned}$$



$$\begin{aligned}&-i\left\{\left[\frac{g_3^2}{6}(3X_D^{il}X_D^{kj} - X_D^{ij}X_D^{kl}) + \frac{e^2}{4s_W^2}R_D^{ij}R_D^{kl}\right.\right.\\ &\left.+\ \frac{e^2}{36c_W^2}Y_D^{ij}Y_D^{kl} + V_D^{ijkl} + V_D^{klij}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\\ &+\left[\frac{g_3^2}{6}(3X_D^{ij}X_D^{kl} - X_D^{il}X_D^{kj}) + \frac{e^2}{4s_W^2}R_D^{il}R_D^{kj}\right.\\ &\left.\left.+\ \frac{e^2}{36c_W^2}Y_D^{il}Y_D^{kj} + V_D^{ilkj} + V_D^{kjil}\right]\delta_{\alpha\delta}\delta_{\beta\gamma}\right\}\end{aligned}$$



$$
\begin{aligned}
&-i\left[\frac{g_3^2}{6}X_U^{ij}X_D^{kl}(3\delta_{\alpha\delta}\delta_{\beta\gamma}-\delta_{\alpha\beta}\delta_{\gamma\delta})\right.\\
&+\frac{e^2}{4s_W^2}(2K^{KI}K^{LJ\star}\delta_{\alpha\gamma}\delta_{\beta\delta}-\delta^{IJ}\delta^{KL}\delta_{\alpha\beta}\delta_{\gamma\delta})Z_U^{Ki\star}Z_U^{Lj}Z_D^{Jl\star}Z_D^{Ik}\\
&+\frac{e^2}{36c_W^2}Y_U^{ij}Y_D^{kl}\delta_{\alpha\beta}\delta_{\gamma\delta}+(Y_d^IY_d^JK^{KI}K^{LJ\star}Z_U^{Ki\star}Z_U^{Lj}Z_D^{(I+3)l\star}Z_D^{(J+3)k}\\
&\left.+\,Y_u^IY_u^JK^{JL}K^{IK\star}Z_U^{(I+3)j}Z_U^{(J+3)i\star}Z_D^{Ll\star}Z_D^{Kk})\delta_{\alpha\delta}\delta_{\beta\gamma}\right]
\end{aligned}
$$

For definitions of symbols X_U, X_D, R_U, R_D etc. see section 6.

References

[1] J. Rosiek, *Phys. Rev.* **D41** (1990) 3464.

[2] P. Chankowski, S. Pokorski, J. Rosiek *Nucl. Phys.* **B423** (1994) 437; *Nucl. Phys.* **B423** (1994) 497; V. Driesen, W. Hollik, J. Rosiek, *Zeit. Phys.* **C71** (1996) 259; S. Heinemeyer, W. Hollik, J. Rosiek, G. Weiglein, *Eur.Phys.J.* **C19** (2001) 535-546.

[3] P. Chankowski et al. *Nucl. Phys.* **B417** (1994) 101.

[4] S. Pokorski, J. Rosiek, C. Savoy *Nucl. Phys.* **B570** (2000) 81-116.

[5] M. Misiak, S. Pokorski, J. Rosiek *"Supersymmetry and the FCNC effects"*, *hep-ph*/9703442, published in *Adv.Ser.Direct.High Energy Phys.* **15** (1998) 795-828.

[6] A. Buras, P. Chankowski, J. Rosiek, Ł. Sławianowska, *Nucl.Phys.* **B619** (2001) 434-466.

[7] H. E. Haber and G. L. Kane, *Phys. Rep.* **117** (1985) 75.

[8] J. F. Gunion and H. E. Haber, *Nucl. Phys.* **B272** (1986) 1.

[9] P. Fayet and J. Iliopoulos, *Phys. Lett.* **51B** (1974) 461.

[10] L. Girardello and M. T. Grisaru, *Nucl. Phys.* **B194** (1982) 65.

[11] H. Dreiner, *"An Introduction to explicit R-parity violation"*, *hep-ph*/9707435, published in *Kane, G.L. (ed.): Perspectives on supersymmetry* 462-479.

[12] J. A. Casas, *"Charge and color breaking"*, *hep-ph*/9707475, published in *Kane, G.L. (ed.): Perspectives on supersymmetry* 378-401.

[13] A. Denner , H. Eck, O. Hahn, J. Kublbeck, *Phys.Lett.* **B291** (1992) 278-280; A. Denner, H. Eck, O. Hahn, J. Kublbeck, *Nucl.Phys.* **B387** (1992) 467-484.