PHYSICAL REVIEW D VOLUME 41, NUMBER 11 1 JUNE 1990

Complete set of Feynman rules for the minimal supersymmetric extension of the standard model

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(Received 31 July 1989)

This paper contains the complete set of Feynman rules for the minimal supersymmetric extension of the standard model. Propagators and vertices are computed in the 't Hooft–Feynman gauge, convenient for perturbative calculations beyond the tree level.

I. INTRODUCTION

In recent years intensive studies of the minimal supersymmetric extension of the standard model (MSSM) have been undertaken. It stands as the simplest soft broken-supersymmetry (SUSY) theory which contains all particles present in the standard model, and can be arranged so that it does not contradict the existing experimental data and is a good laboratory for testing various theoretical properties and experimental predictions of such theories. Although it is only the smallest realistic model, all practical calculations in the MSSM are very tedious because of its complexity. To make it easier, several papers containing Feynman rules for that model have been written.[1,2] They take into account only the tree-level interactions of the Higgs particles and those related to them (charginos and neutralinos). In this paper we complete all the Feynman rules for the MSSM in the 't Hooft–Feynman gauge, convenient for calculations of perturbative corrections. All rules are collected in a form which makes it easy to carry out systematic numerical or symbolic computations.

Part of the mass matrices and vertices considered in the paper, mainly related to the Higgs-boson and supersymmetric-fermion sectors, has been already investigated in other papers.[1,2] We write down those formulas once more, because our main aim is to collect in one place and in one fixed convention the full set of rules needed to calculate any process in the frame of the MSSM. The conventions used in the paper are the same as used by Haber and Kane.[1]

The plan of the paper is the following. Section II contains a short review of the technical rules of constructing SUSY Yang-Mills theories. In Sec. III we define the fields and the parameters existing in the MSSM. The physical content of the theory, the mass matrices eigenstates fields, are outlined in Sec. IV. In Sec. V we describe the gauge used in other calculations; Sec. VI contains the Lagrangian of the MSSM in terms of the physical fields. A short summary and comments on the choice of the parameters of the model are given in Sec. VII. In Appendix A we write down the same Lagrangian, but in terms of the initial fields; Appendix B consists of the full set of propagators and vertices corresponding to the Lagrangian of Sec. VI.

II. GENERAL STRUCTURE OF THE MODEL

Supersymmetric Yang-Mills theories contain two basic types of fields—gauge multiplets (λ^a, V^a_μ) in the adjoint representation of a gauge group G and matter multiplets (A_i, ψ_i) in some chosen representations of G. λ and ψ denote fermions in two-component notation, A_i are complex scalar fields, and V^a_μ 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. 1).

To construct the Lagrangian of such a theory we follow the rules given in Ref. 1. 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—the well-known three- and four-gauge-boson vertices—see, e.g., Ref. 3 and additional interaction of gauginos and gauge fields:

$$igf_{abc}\lambda^a\sigma^\mu\bar{\lambda}^b V^c_\mu .$$

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

$$-gT^a_{ij}V^a_\mu(\bar{\psi}_i\bar{\sigma}^\mu\psi_j + iA_i^*\partial^\mu A_j) ,$$

$$ig\sqrt{2}\,T^a_{ij}(\lambda^a\psi_j A_i^* - \bar{\lambda}^a\bar{\psi}_i A_j) ,$$

$$g^2(T^aT^b)_{ij}V^a_\mu V^{\mu b}A_i^* A_j .$$

(4) Self-interactions of the matter multiplets. For technical reasons it is convenient to define the so-called "superpotential" W as an at most cubic gauge-invariant polynomial which depends on scalar fields A_i, *but not on* A_i^* (Ref. 1) (usually the superpotential is defined as a function of the superfields). We need also two auxiliary functions:

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

$$D^a = gA_i^* T^a_{ij} A_j .$$

Now we can write the scalar supersymmetric potential as

$$V = \tfrac{1}{2}D^aD^a + F_i^* F_i .$$

Yukawa interactions are given by

$$-\tfrac{1}{2}(\partial^2 W/\partial A_i \partial A_j + \text{H.c.}) \ .$$

In the case of semisimple groups $G = G_1 \otimes \cdots \otimes G_n$ one should substitute in the above expressions sums of type $\sum g_i V_i T_i$ in place of gVT and the same for gauginos. There are also n $\lambda - \bar{\lambda} - V$ vertices and n $\frac{1}{2}D^2$ terms in the scalar potential. For the U(1) factor there is no gaugino-gaugino-gauge interaction, and 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:[4]

$$D = \tfrac{1}{2}gy_i A_i^* A_i + \xi \ .$$

A ξ different from zero may introduce dangerous quadratic divergences into the theory. In most realistic models (including the considered model) this constant is absent.

This completes the construction of a strictly supersymmetric theory. To construct models which keep the nice property of such a theory—lack of quadratic divergences—and which simultaneously are experimentally acceptable, it is necessary to add to the above Lagrangian explicit soft SUSY-breaking terms. All admissible expressions are listed below:[5]

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

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, nonsupersymmetric trilinear scalar couplings.

III. MINIMAL SUPERSYMMETRIC EXTENSION OF THE STANDARD MODEL

To obtain the 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. This is not enough—as stated in the previous paragraph, 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)⊗SU(2)⊗U(1):

A^i_μ, λ^i_A— weak isospin gauge fields,

coupling constant g_1 ;

B_μ, λ_B—weak hypercharge 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 (notation used can be immediately generalized to the case of N generations).

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

The SU(3) indices are not written explicitly. We understand that the 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 standard-model conservation laws is

$$W = h\epsilon_{ij}H^1_i H^2_j + \epsilon_{ij} l^{IJ} H^1_i L^I_j R^J + \epsilon_{ij} d^{IJ} H^1_i Q^I_j D^J + \epsilon_{ij} u^{IJ} H^2_i Q^I_j U^J \ .$$

Terms such as $a^I \epsilon_{ij} H^2_i L^I_j$ are gauge invariant but break lepton-number conservation, so we do not include them (similar problems appear for some products of squark fields).

Soft breaking terms can be divided into several classes.

(1) Mass terms for the scalar fields:

$$-m^2_{H_1} H^{1*}_i H^1_i - m^2_{H_2} H^{2*}_i H^2_i - (m^2_L)^{IJ} L^{I*}_i L^J_i - (m^2_R)^{IJ} R^{I*} R^J - (m^2_Q)^{IJ} Q^{I*}_i Q^J_i - (m^2_D)^{IJ} D^{I*} D^J - (m^2_U)^{IJ} U^{I*} U^J \ .$$

(2) Mass terms for gauginos:

$$m_1(\lambda^a_G \lambda^a_G + \text{H.c.}) + m_2(\lambda'^i_A \lambda'^i_A + \text{H.c.}) + m_3(\lambda_B \lambda_B + \text{H.c.}) \ .$$

(3) Yukawa-type couplings of the scalar fields corresponding to the suitable terms in the superpotential:

$$h_S \epsilon_{ij} H^1_i H^2_j + \epsilon_{ij} l^{IJ}_S H^1_i L^I_j R^J + \epsilon_{ij} d^{IJ}_S H^1_i Q^I_j D^J + \epsilon_{ij} u^{IJ}_S H^2_i Q^I_j U^J + \text{H.c.}$$

(4) Yukawa-type couplings of the scalar fields, which are *different from the terms permitted in the superpotential.* Usually such couplings are not considered but setting them to zero at the tree level is inconsistent; they are generated perturbatively:

$$k^{IJ}_S H^{2*}_i L^I_i R^J + e^{IJ}_S H^{2*}_i Q^I_i D^J + w^{IJ}_S H^{1*}_i Q^I_i U^J + \text{H.c.}$$

In general, constants h, h_S, matrices l^{IJ}, u^{IJ}, d^{IJ}, and the trilinear soft couplings may be complex. We can perform two operations which eliminate unnecessary degrees of freedom. First, it is possible to change globally the phase of one of the Higgs multiplets (H^2 for the example) in such a way that the constant h_S becomes a real number. Then the equations for the vacuum expectations values of the Higgs fields involve only real parameters. In parallel, one should redefine the constants of the trilinear couplings (such as u^{IJ}, u_S^{IJ} etc.) to absorb the change of the phase of the Higgs multiplet. The second operation is the same as in the standard model by the redefinition of the fields:

$$(Q_i^I,\Psi_{Qi}^I)\rightarrow V_{Qi}^{IJ}(Q_i^J,\Psi_{Qi}^J) \quad \text{(no sum over } i\text{)} ,$$

$$(U^I,\Psi_U^I)\rightarrow V_U^{IJ}(U^J,\Psi_U^J) ,$$

$$(D^I,\Psi_D^I)\rightarrow V_D^{IJ}(D^J,\Psi_D^J) ,$$

and similarly for leptons, one can diagonalize the matrices l^{IJ},u^{IJ}, and d^{IJ}, obtaining Yukawa couplings of the form $\epsilon_{ij}l^IH_i^1L_j^IR^I$, etc. Of course there is no reason for which soft terms would be diagonalized simultaneously. By a 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:

$$C=V_{Q_2}^\dagger V_{Q_1} .$$

This matrix appears in many different expressions containing quarks and squarks, much more often then in the standard model.

The full Lagrangian written in terms of the initial fields [before SU(2)-symmetry breaking] is given in Appendix A.

IV. PHYSICAL SPECTRUM OF THE MODEL

In the previous section we defined the field content and all the initial 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 (VEV's) 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, $e=g_1\sin\theta=g_2\cos\theta$):

$$\langle H^1\rangle=\frac{1}{\sqrt{2}}\begin{bmatrix} v_1 \\ 0 \end{bmatrix}, \quad \langle H^2\rangle=\frac{1}{\sqrt{2}}\begin{bmatrix} 0 \\ v_2 \end{bmatrix} ,$$

$$\left[\frac{e^2}{8\sin^2\theta\cos^2\theta}(v_1^2-v_2^2)+m_{H_1}^2+|h|^2\right]v_1=-h_Sv_2 ,$$

$$\left[-\frac{e^2}{8\sin^2\theta\cos^2\theta}(v_1^2-v_2^2)+m_{H_2}^2+|h|^2\right]v_2=-h_Sv_1 .$$

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

The mass eigenstates of the particles in the theory are the following.

(1) Gauge bosons. Eight gluons G_μ^a and the photon F_μ are massless, the bosons W_μ and Z_μ have masses

$$m_Z=\frac{e}{2\sin\theta\cos\theta}(v_1^2+v_2^2)^{1/2} ,$$

$$m_W=\frac{e}{2\sin\theta}(v_1^2+v_2^2)^{1/2} .$$

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

$$M_{H_1^\pm}^2=m_W^2+m_{H_1}^2+m_{H_2}^2+2|h|^2$$

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

$$\begin{bmatrix} H_2^{1*} \\ H_1^2 \end{bmatrix}=Z_H\begin{bmatrix} H_1^+ \\ H_2^+ \end{bmatrix} ,$$

$$Z_H=(v_1^2+v_2^2)^{-1/2}\begin{bmatrix} v_2 & -v_1 \\ v_1 & v_2 \end{bmatrix} .$$

(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, and the other two are pseudoscalars. This is no longer true if, for example, h is complex—one may find graphs which describe scalar-pseudoscalar transitions. Nevertheless, in both cases it is convenient to divide neutral Higgs bosons into two classes.

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

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

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

$$M_R=\begin{bmatrix} \alpha & \gamma \\ \gamma & \beta \end{bmatrix} ,$$

$$\alpha=-h_S\frac{v_2}{v_1}+\frac{e^2v_1^2}{4\sin^2\theta\cos^2\theta} ,$$

$$\beta=-h_S\frac{v_1}{v_2}+\frac{e^2v_2^2}{4\sin^2\theta\cos^2\theta} ,$$

$$\gamma=h_S-\frac{e^2v_1v_2}{4\sin^2\theta\cos^2\theta} ,$$

$$Z_R^TM_RZ_R=\begin{bmatrix} M_{H_1^0}^2 & 0 \\ 0 & M_{H_2^0}^2 \end{bmatrix} .$$

(ii) "Pseudoscalar" particles H_{i+2}^0, $i=1,2$:

$$\sqrt{2}\,\mathrm{Im}H_i^i=Z_H^{ij}H_{j+2}^0 \quad \text{(no sum over } i\text{)} .$$

H_3^0 has the mass $M_{H_3^0}^2=m_{H_1}^2+m_{H_2}^2+2|h|^2$, and H_4^0 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 seems to be convenient in the case of nonunitary gauge, when the Goldstone bosons are explicitly present in the Lagrangian and should be treated in the same way as the physical Higgs particles. In order to compare our expressions with those introduced in Refs. 1 and 2 one should substitute

$$Z_H=\begin{bmatrix}\sin\beta & -\cos\beta\\ \cos\beta & \sin\beta\end{bmatrix},\quad Z_R=\begin{bmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{bmatrix},$$

where

$$\tan\beta=\frac{v_2}{v_1},\quad \tan2\alpha=\tan2\beta\frac{M_{H_3^0}^2+m_Z^2}{M_{H_3^0}^2-m_Z^2}\ .$$

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

$$M_{H_1^+}^2=M_{H_3^0}^2+m_W^2\ ,$$

$$M_{H_1^0}^2+M_{H_2^0}^2=M_{H_3^0}^2+m_Z^2\ .$$

(4) Matter fermions (quarks and leptons) have of course the same masses as in the standard model:

$$m_\nu^1=0,\quad m_e^I=-\frac{1}{\sqrt{2}}v_1l^I\ ,$$

$$m_d^I=-\frac{1}{\sqrt{2}}v_1d^I,\quad m_u^I=\frac{1}{\sqrt{2}}v_2u^I\ .$$

(5) Charginos. Four two-component spinors $(\lambda_A^1,\lambda_A^2,\Psi_{H2}^1,\Psi_{H1}^2)$ combine to give two four-component Dirac fermions κ_1, κ_2 corresponding to two charginos. Also two mixing matrices Z^+ and Z^- appear in the Lagrangian. They are defined by the condition that the product $(Z^-)^TXZ^+$ should be diagonal:

$$X=\begin{bmatrix}2m_2 & \dfrac{ev_2}{\sqrt{2}\sin\theta}\\ \dfrac{ev_1}{\sqrt{2}\sin\theta} & h\end{bmatrix},$$

$$(Z^-)^TXZ^+=\begin{bmatrix}m_{\kappa_1} & 0\\ 0 & m_{\kappa_2}\end{bmatrix}.$$

The unitary matrices Z^+ and Z^- are not uniquely specified—by changing their relative phases and the order of the eigenvalues it is possible to choose m_{κ_i} positive and (if necessary) $m_{\kappa_1}>m_{\kappa_2}$. The fields κ_i are related to the initial spinors as below:

$$\Psi_{H2}^1=Z_{2i}^+\chi_i^+,\quad \Psi_{H1}^2=Z_{2i}^-\chi_i^-\ ,$$

$$\lambda_A^\pm=\frac{\lambda_A^1\mp i\lambda_A^2}{\sqrt{2}}=iZ_{1i}^\pm\chi_i^\pm,\quad \kappa_i=\begin{bmatrix}\chi_i^+\\ \bar{\chi}_i^-\end{bmatrix}\ .$$

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

$$\lambda_B=iZ_N^{1i}\chi_i^0,\quad \lambda_A^3=iZ_N^{2i}\chi_i^0\ ,$$

$$\Psi_{H1}^1=Z_N^{3i}\chi_i^0,\quad \Psi_{H2}^2=Z_N^{4i}\chi_i^0\ ,$$

$$\kappa_i^0=\begin{bmatrix}\chi_i^0\\ \bar{\chi}_i^0\end{bmatrix},\quad Z_N^TYZ_N=\begin{bmatrix}m_{\kappa_1^0} & & 0\\ & \ddots & \\ 0 & & m_{\kappa_4^0}\end{bmatrix},$$

$$Y=\begin{bmatrix}2m_3 & 0 & \dfrac{-ev_1}{2\cos\theta} & \dfrac{ev_2}{2\cos\theta}\\ 0 & 2m_2 & \dfrac{ev_1}{2\sin\theta} & \dfrac{-ev_2}{2\sin\theta}\\ \dfrac{-ev_1}{2\cos\theta} & \dfrac{ev_1}{2\sin\theta} & 0 & -h\\ \dfrac{ev_2}{2\cos\theta} & \dfrac{-ev_2}{2\sin\theta} & -h & 0\end{bmatrix}.$$

(7) SU(3) gauginos do not mix. In four-component notation we have eight gluinos Λ_G^a with masses $2m_1$:

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

(8) Three complex scalar fields L_1^I form three sneutrino mass eigenstates ν^I with masses given by diagonalization of a matrix M_ν:

$$L_1^I=Z_\nu^{IJ}\nu^J,\quad Z_\nu^\dagger M_\nu Z_\nu=\begin{bmatrix}M_{\nu_1}^2 & & 0\\ & \ddots & \\ 0 & & M_{\nu_3}^2\end{bmatrix},$$

$$M_\nu^{IJ}=-\frac{e^2(v_1^2-v_2^2)}{8\sin^2\theta\cos^2\theta}\delta^{IJ}+(m_L^2)^{IJ}\ .$$

Sneutrinos are neutral but *complex* scalars.

(9) Fields L_2^I and R^I mix to give six charged selectrons L_i, $i=1-6$:

$$L_2^I=Z_L^{Ii*}L_i^-,\quad R^I=Z_L^{(I+3)i}L_i^+\ ,$$

$$Z_L^\dagger\begin{bmatrix}A^T & C\\ C^\dagger & B\end{bmatrix}Z_L=\begin{bmatrix}M_{L_1}^2 & & 0\\ & \ddots & \\ 0 & & M_{L_6}^2\end{bmatrix},$$

$$A^{IJ}=-\frac{e^2(v_1^2-v_2^2)(1-2\cos^2\theta)}{8\sin^2\theta\cos^2\theta}\delta^{IJ}+(m_e^I)^2\delta^{IJ}+(m_L^2)^{IJ}\ ,$$

$$B^{IJ}=\frac{e^2(v_1^2-v_2^2)}{4\cos^2\theta}\delta^{IJ}+(m_e^I)^2\delta^{IJ}+(m_R^2)^{IJ}\ ,$$

$$C^{IJ}=\frac{1}{\sqrt{2}}[v_2(l^Ih^*\delta^{IJ}-k_S^{IJ})+v_1l_S^{IJ}]\ .$$

(10) Fields Q_1^I and U^I turn into six up squarks U_i:

$$Q_1^I = Z_U^{Ii} U_i^+ , \quad U^I = Z_U^{(I+3)i*} U_i^- ,$$

$$Z_U^\dagger \begin{bmatrix} A^\dagger & D^* \\ D^T & B^* \end{bmatrix} Z_U = \begin{bmatrix} M_{U_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{U_6}^2 \end{bmatrix} ,$$

$$A^{IJ} = \frac{e^2(v_1^2 - v_2^2)(1 - 4\cos^2\theta)}{24\sin^2\theta\cos^2\theta}\delta^{IJ} + (m_u^I)^2\delta^{IJ} + (m_Q^2)^{KL} C^{KI*} C^{LJ} ,$$

$$B^{IJ} = -\frac{e^2(v_1^2 - v_2^2)}{6\cos^2\theta}\delta^{IJ} + (m_u^I)^2\delta^{IJ} + (m_U^2)^{IJ} ,$$

$$D^{IJ} = -\frac{1}{\sqrt{2}}[v_1(w_S^{IJ} + u^I h^* \delta^{IJ}) + v_2 u_S^{IJ}] .$$

(11) There are six down squarks D_i composed from fields Q_2^I and D^I:

$$Q_2^I = Z_D^{Ii*} D_i^- , \quad D^I = Z_D^{(I+3)i} D_i^+ ,$$

$$Z_D^\dagger \begin{bmatrix} A^T & C \\ C^\dagger & B \end{bmatrix} Z_D = \begin{bmatrix} M_{D_1}^2 & & 0 \\ & \ddots & \\ 0 & & M_{D_6}^2 \end{bmatrix} ,$$

$$A^{IJ} = \frac{e^2(v_1^2 - v_2^2)(1 + 2\cos^2\theta)}{24\sin^2\theta\cos^2\theta}\delta^{IJ} + (m_d^I)^2\delta^{IJ} + (m_Q^2)^{IJ} ,$$

$$B^{IJ} = \frac{e^2(v_1^2 - v_2^2)}{12\cos^2\theta}\delta^{IJ} + (m_d^I)^2\delta^{IJ} + (m_D^2)^{IJ} ,$$

$$C^{IJ} = \frac{1}{\sqrt{2}}[v_2(d^I h^* \delta^{IJ} - e_S^{IJ}) + v_1 d_S^{IJ}] .$$

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

Photon	F_μ		
Gauge bosons	$Z_\mu, W_\mu^\pm$		
Gluons	G_μ^a	$a = 1-8$	
Gluinos	Λ_G^a	$a = 1-8$	(Majorana spinors)
Charginos	κ_i	$i = 1,2$	(Dirac spinors)
Neutralinos	κ_i^0	$i = 1-4$	(Majorana spinors)
Neutrinos	Ψ_ν^I	$I = 1-3$	(Dirac spinors)
Electrons	Ψ_e^I	$I = 1-3$	(Dirac spinors)
Quarks	q_u^I, q_d^I	$I = 1-3$	(Dirac spinors)
Sneutrinos	ν^I	$I = 1-3$	
Selectrons	$L_i^\pm$	$i = 1-6$	
Squarks	$U_i^\pm, D_i^\pm$	$i = 1-6$	
Higgs particles:			
charged		$H_1^\pm$	
neutral "scalar"		H_1^0, H_2^0	
neutral "pseudoscalar"		H_3^0	

The mass matrices are often quite complicated. Note that not for all the possible values of input parameters can one obtain reasonable sets of particle masses. There is no problem with fermions, but for some choices of the Higgs-sector data SU(2) symmetry would not be broken or, on the contrary, improper values of squark interaction constants can lead to negative values of their masses and, as a consequence, to color symmetry breaking. Demanding weak isospin symmetry breaking leads to the condition

$$m_{H_1}^2 + m_{H_2}^2 + 2|h|^2 > 2|h_S| ,$$

$$(m_{H_1}^2 + |h|^2)([m_{H_2}^2 + |h|^2) < h_S^2 .$$

A more detailed discussion of those questions, especially for the Higgs particles and gauginos, can be found for example in Refs. 1 and 2. The super-scalar sector parameters are very complicated and probably it is more convenient to check the positivity of physical tree masses already after diagonalization.

V. 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 in the Lagrangian and Feynman rules. When we want to calculate higher corrections, we must include the ghost loops suitable for the given gauge. Unfortunately the ghost part of the Lagrangian in the unitary gauge is complicated and difficult to deal with. In those cases it is much more efficient to use the so-called 't Hooft–Feynman gauge,[6] 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

$$\begin{aligned} L_{\mathrm{GF}} = & -\frac{1}{2\chi}(\partial^\mu G_\mu^a)^2 - \frac{1}{2\xi}(\partial^\mu A_\mu^3 + \xi m_Z \cos\theta H_4^0)^2 - \frac{1}{2\xi}(\partial^\mu B_\mu - \xi m_Z \sin\theta H_4^0)^2 \\ & - \frac{1}{2\xi}\left[\partial^\mu A_\mu^1 + \frac{i}{\sqrt{2}}\xi m_W (H_2^+ - H_2^-)\right]^2 - \frac{1}{2\xi}\left[\partial^\mu A_\mu^2 - \frac{1}{\sqrt{2}}\xi m_W (H_2^+ + H_2^-)\right]^2 \\ = & -\frac{1}{2\chi}(\partial^\mu G_\mu^a)^2 - \frac{1}{2\xi}(\partial^\mu Z_\mu)^2 - \frac{1}{2\xi}(\partial^\mu F_\mu)^2 - \frac{1}{\xi}(\partial^\mu W_\mu^+)(\partial^\mu W_\mu^-) \\ & - m_Z H_4^0 \partial^\mu Z_\mu - i m_W (H_2^+ \partial^\mu W_\mu^- - H_2^- \partial^\mu W_\mu^+) - \tfrac{1}{2}\xi m_Z^2 (H_4^0)^2 - \xi m_W^2 H_2^+ H_2^- . \end{aligned}$$

The first part of the above expression is identical to the usual gauge-fixing terms, the second cancels similar off-diagonal Higgs-boson–gauge-boson vertices remaining in the Lagrangian after symmetry breaking, and the third gives masses to the Goldstone bosons.

VI. 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 Sec. V is very complicated. In this section we describe the interaction Lagrangian of the model, 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 H_4^0 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 important only for special kinds of calculations, including strong corrections, so they are collected together as the separate, last class.

We must also give two technical remarks explaining the notation used. First, the expression "+ H.c." always refers only to the line in which it was used. Second, after the diagonalization of the superpotential the couplings l^{IJ}, u^{IJ}, d^{IJ} change into $l^I\delta^{IJ}$, $u^I\delta^{IJ}$, $d^I\delta^{IJ}$, and simultaneously sums of the type $A^{IJ}l^{JK}B^{KL}$ convert into $A^{IJ}l^JB^{JL}$, 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. In addition to the usual three-particle vertices with gradient coupling also somewhat surprising expressions containing two scalars and two gauge bosons appear.

(i) Quark-squark-gauge interactions (one should remember about the color indices, although they are not written explicitly):

$$-\tfrac{2}{3}e\bar{q}_u^I\gamma^\mu q_u^IF_\mu-\frac{e}{\sin\theta\cos\theta}\bar{q}_u^I\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\tfrac{2}{3}\sin^2\theta\right]q_u^IZ_\mu$$

$$+\tfrac{1}{3}e\bar{q}_d^I\gamma^\mu q_d^IF_\mu+\frac{e}{\sin\theta\cos\theta}\bar{q}_d^I\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\tfrac{1}{3}\sin^2\theta\right]q_d^IZ_\mu$$

$$-\frac{e}{\sqrt{2}\sin\theta}C^{IJ}\bar{q}_d^I\gamma^\mu\frac{1-\gamma_5}{2}q_u^JW_\mu^-+\text{H.c.}$$

$$-\tfrac{2}{3}ie(U_i^-\overleftrightarrow{\partial}^\mu U_i^+)F_\mu-\frac{ie}{\sin\theta\cos\theta}(\tfrac{1}{2}Z_U^{Ii*}Z_U^{Ij}-\tfrac{2}{3}\sin^2\theta\delta^{ij})(U_i^-\overleftrightarrow{\partial}^\mu U_j^+)Z_\mu$$

$$+\tfrac{1}{3}ie(D_i^+\overleftrightarrow{\partial}^\mu D_i^-)F_\mu+\frac{ie}{\sin\theta\cos\theta}(\tfrac{1}{2}Z_D^{Ii}Z_D^{ij*}-\tfrac{1}{3}\sin^2\theta\delta^{ij})(D_i^+\overleftrightarrow{\partial}^\mu D_j^-)Z_\mu$$

$$-\frac{ie}{\sqrt{2}\sin\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}(D_i^+\overleftrightarrow{\partial}^\mu U_j^+)W_\mu^-+\text{H.c.}$$

$$+\frac{e^2}{2\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}W_\mu^+W^{-\mu}U_i^-U_j^++\tfrac{4}{9}e^2F_\mu F^\mu U_i^-U_i^++\frac{2e^2}{3\sin\theta\cos\theta}(Z_U^{Ii*}Z_U^{Ij}-\tfrac{4}{3}\delta^{ij}\sin^2\theta)U_i^-U_j^+Z_\mu F^\mu$$

$$+e^2\left[\tfrac{4}{9}\delta^{ij}\tan^2\theta+\frac{3-8\sin^2\theta}{12\sin^2\theta\cos^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]Z_\mu Z^\mu U_i^-U_j^+\ +\frac{e^2}{2\sin^2\theta}Z_D^{Ii}Z_D^{Ij*}W_\mu^+W^{-\mu}D_i^+D_j^-+\tfrac{1}{9}e^2F_\mu F^\mu D_i^+D_i^-$$

$$+\frac{e^2}{3\sin\theta\cos\theta}(Z_D^{Ii}Z_D^{Ij*}-\tfrac{2}{3}\delta^{ij}\sin^2\theta)D_i^+D_j^-Z_\mu F^\mu\ +e^2\left[\tfrac{1}{9}\delta^{ij}\tan^2\theta+\frac{3-4\sin^2\theta}{12\sin^2\theta\cos^2\theta}Z_D^{Ii}Z_D^{Ij*}\right]Z_\mu Z^\mu D_i^+D_j^-$$

$$-\frac{e^2\sqrt{2}}{6\sin\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}D_i^+U_j^+(Z^\mu\tan\theta-F^\mu)W_\mu^-+\text{H.c.}$$

(ii) Lepton-slepton-gauge interactions:

$$+e\bar{\Psi}_e^I\gamma^\mu\Psi_e^IF_\mu+\frac{e}{\sin\theta\cos\theta}\bar{\Psi}_e^I\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\sin^2\theta\right]\Psi_e^IZ_\mu$$

$$-\frac{e}{2\sin\theta\cos\theta}\bar{\Psi}_\nu^I\gamma^\mu\frac{1-\gamma_5}{2}\Psi_\nu^IZ_\mu-\left[\frac{e}{\sqrt{2}\sin\theta}\bar{\Psi}_\nu^I\gamma^\mu\frac{1-\gamma_5}{2}\Psi_e^IW_\mu^++\text{H.c.}\right]$$

$$-\frac{ie}{2\sin\theta\cos\theta}(\nu^{I*}\overleftrightarrow{\partial}^\mu\nu^I)Z_\mu+ie(L_i^+\overleftrightarrow{\partial}^\mu L_i^-)F_\mu\ +\frac{ie}{\sin\theta\cos\theta}(\tfrac{1}{2}Z_L^{Ii}Z_L^{Ij*}-\sin^2\theta\delta^{ij})(L_i^+\overleftrightarrow{\partial}^\mu L_j^-)Z_\mu$$

$$-\frac{ie}{\sqrt{2}\sin\theta}Z_\nu^{IJ}Z_L^{Ii}(L_i^+\overleftrightarrow{\partial}^\mu\nu^J)W_\mu^-+\text{H.c.}$$

$$
\begin{aligned}
&+\frac{e^2}{2\sin^2\theta}\left[W_\mu^+W^{-\mu}+\frac{1}{2\cos^2\theta}Z_\mu Z^\mu\right]\nu^{I*}\nu^I+\frac{e^2}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}W_\mu^+W^{-\mu}L_i^-L_j^+\\
&+e^2\left[\delta^{ij}\tan^2\theta+\frac{1-4\sin^2\theta}{4\sin^2\theta\cos^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]Z_\mu Z^\mu L_i^-L_j^+ +e^2F_\mu F^\mu L_i^-L_i^+\\
&+e^2\left[\frac{1}{\sin\theta\cos\theta}Z_L^{Ii*}Z_L^{Ij}-2\delta^{ij}\tan\theta\right]F_\mu Z^\mu L_i^-L_j^+\\
&+\frac{e^2}{\sqrt{2}\sin\theta}Z_\nu^{IJ}Z_L^{Ii}\nu^JL_i^+W_\mu^-(Z^\mu\tan\theta-F^\mu)+\text{H.c.}
\end{aligned}
$$

(2) Interactions of the Higgs particles and gauge bosons. We define the auxiliary matrix A_M as

$$A_M^{ij}=Z_R^{1i}Z_H^{1j}-Z_R^{2i}Z_H^{2j}\ .$$

We have similar types of vertices as in the case of superscalars and additional two-gauge-boson–one-Higgs-particle couplings:

$$
\begin{aligned}
&+\frac{e}{2\sin\theta\cos\theta}A_M^{ij}(H_i^0\overleftrightarrow{\partial}^\mu H_{j+2}^0)Z_\mu+ie(Z_\mu\cot 2\theta+F_\mu)(H_i^+\overleftrightarrow{\partial}^\mu H_i^-)\\
&\quad-\frac{ie}{2\sin\theta}A_M^{ij}(H_i^0\overleftrightarrow{\partial}^\mu H_j^-)W_\mu^+-\frac{e}{2\sin\theta}(H_{i+2}^0\overleftrightarrow{\partial}^\mu H_i^-)W_\mu^+ +\text{H.c.}\\
&\quad+\frac{e^2}{2\sin^2\theta}v_iZ_R^{ij}\left[W_\mu^+W^{-\mu}+\frac{1}{2\cos^2\theta}Z_\mu Z^\mu\right]H_j^0\\
&\quad-em_W(Z^\mu\tan\theta-F^\mu)W_\mu^+H_2^- +\text{H.c.}\\
&\quad+e^2\left[\frac{1}{2\sin^2\theta}W_\mu^+W^{-\mu}+\cot^2 2\theta Z_\mu Z^\mu+2\cot 2\theta Z_\mu F^\mu+F_\mu F^\mu\right]H_i^+H_i^-\\
&\quad+\frac{e^2}{4\sin^2\theta}\left[W_\mu^+W^{-\mu}+\frac{1}{2\cos^2\theta}Z_\mu Z^\mu\right](H_i^0H_i^0+H_{i+2}^0H_{i+2}^0)\\
&\quad+\frac{e^2}{2\sin\theta}A_M^{ij}(Z^\mu\tan\theta-F^\mu)W_\mu^+H_j^-H_i^0-\frac{ie^2}{2\sin\theta}(Z^\mu\tan\theta-F^\mu)W_\mu^+H_i^-H_{i+2}^0+\text{H.c.}
\end{aligned}
$$

(3) Interactions of the charginos and neutralinos with the gauge bosons:

$$
\begin{aligned}
&-e\bar\kappa_i\gamma^\mu\kappa_iF_\mu-\frac{e}{2\sin\theta\cos\theta}\bar\kappa_i\gamma^\mu\left[Z_{1i}^{+*}Z_{1j}^+\frac{1-\gamma_5}{2}+Z_{1i}^-Z_{1j}^{-*}\frac{1+\gamma_5}{2}+2\delta^{ij}\cos 2\theta\right]\kappa_jZ_\mu\\
&\quad+\frac{e}{\sin\theta}\bar\kappa_j\gamma^\mu\left[\left[Z_N^{2i}Z_{1j}^{+*}-\frac{1}{\sqrt{2}}Z_N^{4i}Z_{2j}^{+*}\right]\frac{1-\gamma_5}{2}+\left[Z_N^{2i*}Z_{1j}^-+\frac{1}{\sqrt{2}}Z_N^{3i*}Z_{2j}^-\right]\frac{1+\gamma_5}{2}\right]\kappa_i^0W_\mu^+ +\text{H.c.}\\
&\quad+\frac{e}{2\sin\theta\cos\theta}\bar\kappa_i^0\gamma^\mu\left[Z_N^{4i*}Z_N^{4j}\frac{1-\gamma_5}{2}+Z_N^{3i}Z_N^{3j*}\frac{1+\gamma_5}{2}\right]\kappa_j^0Z_\mu\ .
\end{aligned}
$$

(4) Higgs-boson–lepton and Higgs-boson–quark interactions. They are of a form similar to the Weinberg-Salam model couplings, but complicated by the existence of two Higgs doublets:

$$
\begin{aligned}
&+\frac{1}{\sqrt{2}}l^IZ_R^{1i}\bar\Psi_e^I\Psi_e^IH_i^0-\frac{i}{\sqrt{2}}l^IZ_H^{1i}\bar\Psi_e^I\gamma_5\Psi_e^IH_{i+2}^0-l^IZ_H^{1i}\left[\bar\Psi_e^I\frac{1-\gamma_5}{2}\Psi_\nu^IH_i^- +\text{H.c.}\right]\\
&\quad+\frac{1}{\sqrt{2}}d^IZ_R^{1i}\bar q_d^Iq_d^IH_i^0-\frac{1}{\sqrt{2}}u^IZ_R^{2i}\bar q_u^Iq_u^IH_i^0-\frac{i}{\sqrt{2}}d^IZ_H^{1i}\bar q_d^I\gamma_5q_d^IH_{i+2}^0+\frac{i}{\sqrt{2}}u^IZ_H^{2i}\bar q_u^I\gamma_5q_u^IH_{i+2}^0\\
&\quad+\bar q_d^I\left[-d^IZ_H^{1i}\frac{1-\gamma_5}{2}+u^JZ_H^{2i}\frac{1+\gamma_5}{2}\right]C^{IJ}q_u^JH_i^- +\text{H.c.}
\end{aligned}
$$

(5) Interactions of the charginos and neutralinos with the superscalars.

(i) Interactions with squarks (superscript *C* denotes the charge-conjugated spinor):

$$\begin{aligned}
&+U_i^-\bar{\kappa}_j^0\left[\left[\frac{-e}{\sqrt{2}\sin\theta\cos\theta}Z_U^{Ii*}(\tfrac{1}{3}Z_N^{1j}\sin\theta+Z_N^{2j}\cos\theta)-u^IZ_U^{(I+3)i*}Z_N^{4j}\right]\frac{1-\gamma_5}{2}\right.\\
&\qquad\left.+\left[\frac{2e\sqrt{2}}{3\cos\theta}Z_U^{(I+3)i*}Z_N^{1j*}-u^IZ_U^{Ii*}Z_N^{4j*}\right]\frac{1+\gamma_5}{2}\right]q_u^I+\text{H.c.}\\
&+D_i^+\bar{\kappa}_j^0\left[\left[\frac{-e}{\sqrt{2}\sin\theta\cos\theta}Z_D^{Ii}(\tfrac{1}{3}Z_N^{1j}\sin\theta-Z_N^{2j}\cos\theta)+d^IZ_D^{(I+3)i}Z_N^{3j}\right]\frac{1-\gamma_5}{2}\right.\\
&\qquad\left.+\left[\frac{-e\sqrt{2}}{3\cos\theta}Z_D^{(I+3)i}Z_N^{1j*}+d^IZ_D^{Ii}Z_N^{3j*}\right]\frac{1+\gamma_5}{2}\right]q_d^I+\text{H.c.}
\end{aligned}$$

$$\begin{aligned}
&+U_i^+\bar{q}_d^I\left[\left[\frac{-e}{\sin\theta}Z_U^{Ji}Z_{1j}^{+*}+u^JZ_U^{(J+3)i}Z_{2j}^{+*}\right]\frac{1+\gamma_5}{2}-d^IZ_U^{Ji}Z_{2j}^-\frac{1-\gamma_5}{2}\right]C^{IJ}\kappa_j^C+\text{H.c.}\\
&-D_i^+\bar{\kappa}_j\left[\left[\frac{e}{\sin\theta}Z_D^{Ii}Z_{1j}^-+d^IZ_D^{(I+3)i}Z_{2j}^-\right]\frac{1-\gamma_5}{2}-u^JZ_D^{Ii}Z_{2j}^{+*}\frac{1+\gamma_5}{2}\right]C^{IJ}q_u^J+\text{H.c.}
\end{aligned}$$

(ii) Interactions with sleptons:

$$\begin{aligned}
&+\frac{e}{\sqrt{2}\sin\theta\cos\theta}Z_\nu^{IJ*}(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\nu^{J*}\bar{\kappa}_i^0\frac{1-\gamma_5}{2}\Psi_\nu^I+\text{H.c.}\\
&\quad+\bar{\kappa}_j^0\left[\left[\frac{e}{\sqrt{2}\sin\theta\cos\theta}Z_L^{Ii}(Z_N^{1j}\sin\theta+Z_N^{2j}\cos\theta)+l^IZ_L^{(I+3)i}Z_N^{3j}\right]\frac{1-\gamma_5}{2}\right.\\
&\qquad\left.+\left[\frac{-e\sqrt{2}}{\cos\theta}Z_L^{(I+3)i}Z_N^{1j*}+l^IZ_L^{Ii}Z_N^{3j*}\right]\frac{1+\gamma_5}{2}\right]\Psi_e^IL_i^++\text{H.c.}\\
&\quad-\bar{\kappa}_i^C\left[\frac{e}{\sin\theta}Z_{1i}^+\frac{1-\gamma_5}{2}+l^IZ_{2i}^{-*}\frac{1+\gamma_5}{2}\right]Z_\nu^{IJ*}\Psi_e^I\nu^{J*}+\text{H.c.}\\
&\quad-\left[\frac{e}{\sin\theta}Z_L^{Ii}Z_{1j}^-+l^IZ_L^{(I+3)i}Z_{2j}^-\right]\bar{\kappa}_j\frac{1-\gamma_5}{2}\Psi_\nu^IL_i^++\text{H.c.}
\end{aligned}$$

(6) Interactions of the charginos and neutralinos with the Higgs particles:

$$\begin{aligned}
&+\frac{e}{2\sin\theta\cos\theta}\bar{\kappa}_i^0\left[(Z_R^{1k}Z_N^{3j}-Z_R^{2k}Z_N^{4j})(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\frac{1-\gamma_5}{2}\right.\\
&\qquad\qquad\left.+(Z_R^{1k}Z_N^{3i*}-Z_R^{2k}Z_N^{4i*})(Z_N^{1j*}\sin\theta-Z_N^{2j*}\cos\theta)\frac{1+\gamma_5}{2}\right]\kappa_j^0H_k^0\\
&-\frac{ie}{2\sin\theta\cos\theta}\bar{\kappa}_i^0\left[(Z_H^{1k}Z_N^{3j}-Z_H^{2k}Z_N^{4j})(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\frac{1-\gamma_5}{2}\right.\\
&\qquad\qquad\left.-(Z_H^{1k}Z_N^{3i*}-Z_H^{2k}Z_N^{4i*})(Z_N^{1j*}\sin\theta-Z_N^{2j*}\cos\theta)\frac{1+\gamma_5}{2}\right]\kappa_j^0H_{k+2}^0\\
&-\frac{e}{\sqrt{2}\sin\theta}\bar{\kappa}_i\left[(Z_R^{1k}Z_{2i}^-Z_{1j}^++Z_R^{2k}Z_{1i}^-Z_{2j}^+)\frac{1-\gamma_5}{2}+(Z_R^{1k}Z_{2j}^{-*}Z_{1i}^{+*}+Z_R^{2k}Z_{1j}^{-*}Z_{2i}^{+*})\frac{1+\gamma_5}{2}\right]\kappa_jH_k^0\\
&+\frac{ie}{\sqrt{2}\sin\theta}\bar{\kappa}_i\left[(Z_H^{1k}Z_{2i}^-Z_{1j}^++Z_H^{2k}Z_{1i}^-Z_{2j}^+)\frac{1-\gamma_5}{2}-(Z_H^{1k}Z_{2j}^{-*}Z_{1i}^{+*}+Z_H^{2k}Z_{1j}^{-*}Z_{2i}^{+*})\frac{1+\gamma_5}{2}\right]\kappa_jH_{k+2}^0\\
&+\frac{e}{\sin\theta\cos\theta}\bar{\kappa}_j\left[Z_H^{1k}\left[\frac{1}{\sqrt{2}}Z_{2j}^-(Z_N^{1i}\sin\theta+Z_N^{2i}\cos\theta)-Z_{1j}^-Z_N^{3i}\cos\theta\right]\frac{1-\gamma_5}{2}\right.\\
&\qquad\qquad\left.-Z_H^{2k}\left[\frac{1}{\sqrt{2}}Z_{2j}^{+*}(Z_N^{1i*}\sin\theta+Z_N^{2i*}\cos\theta)+Z_{1j}^{+*}Z_N^{4i*}\cos\theta\right]\frac{1+\gamma_5}{2}\right]\kappa_i^0H_k^++\text{H.c.}
\end{aligned}$$

(7) Self-interactions of the gauge bosons:

$$
\begin{aligned}
&-ie[W_\mu^+ W_\nu^- (\partial^\mu F^\nu - \partial^\nu F^\mu) + F_\mu (W_\nu^- \partial^\nu W^{+\mu} - W_\nu^+ \partial^\nu W^{-\mu} + W_\nu^+ \overleftrightarrow{\partial}^\mu W^{-\nu})] \\
&\quad -ie\cot\theta[W_\mu^+ W_\nu^- (\partial_\mu Z^\nu - \partial^\nu Z^\mu) + Z_\mu (W_\nu^- \partial^\nu W^{+\mu} - W_\nu^+ \partial^\nu W^{-\mu} + W_\nu^+ \overleftrightarrow{\partial}^\mu W^{-\nu})] \\
&\quad + \frac{e^2}{2\sin^2\theta}(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho}) W_\mu^+ W_\lambda^+ W_\nu^- W_\rho^- \\
&\quad + e^2(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho}) F_\mu F_\nu W_\lambda^+ W_\rho^- + e^2\cot^2\theta(g^{\mu\lambda}g^{\nu\rho} - g^{\mu\nu}g^{\lambda\rho}) Z_\mu Z_\nu W_\lambda^+ W_\rho^- \\
&\quad + e^2\cot\theta(g^{\mu\lambda}g^{\nu\rho} + g^{\mu\rho}g^{\nu\lambda} - 2g^{\mu\nu}g^{\lambda\rho}) Z_\mu F_\nu W_\lambda^+ W_\rho^- \ .
\end{aligned}
$$

(8) Ghost terms:

$$
\begin{aligned}
&-ie(Z_\mu\cot\theta + F_\mu)[(\partial^\mu\bar\eta^-)\eta^- - (\partial^\mu\bar\eta^+)\eta^+] + ieW_\mu^+[(\partial^\mu\bar\eta_Z\cot\theta + \partial^\mu\bar\eta_F)\eta^- - (\partial^\mu\bar\eta^+)(\eta_Z\cot\theta + \eta_F)] \\
&\quad + ieW_\mu^-[-(\partial^\mu\bar\eta_Z\cot\theta + \partial^\mu\bar\eta_F)\eta^+ + (\partial^\mu\bar\eta^-)(\eta_Z\cot\theta + \eta_F)] \\
&\quad - \frac{\xi e^2}{4\sin^2\theta} v_i Z_R^{ij} \left[\frac{1}{\cos^2\theta}\bar\eta_Z\eta_Z + \bar\eta^+\eta^+ + \bar\eta^-\eta^- \right] H_j^0 + \frac{ie\xi m_W}{2\sin\theta}(\bar\eta^-\eta^- - \bar\eta^+\eta^+) H_4^0 \\
&\quad + \frac{\xi e m_W}{2\sin\theta\cos\theta}(\bar\eta_Z\eta^- - \bar\eta^+\eta_Z\cos2\theta - \bar\eta^+\eta_F\sin2\theta) H_2^+ + \frac{\xi e m_W}{2\sin\theta\cos\theta}(\bar\eta_Z\eta^+ - \bar\eta^-\eta_Z\cos2\theta - \bar\eta^-\eta_F\sin2\theta) H_2^- \ .
\end{aligned}
$$

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

$$
A_H^{ij} = Z_H^{1i}Z_H^{1j} - Z_H^{2i}Z_H^{2j}, \quad A_R^{ij} = Z_R^{1i}Z_R^{1j} - Z_R^{2i}Z_R^{2j}, \quad A_P^{ij} = Z_R^{1i}Z_H^{2j} + Z_R^{2i}Z_H^{1j}, \quad B_R^i = v_1 Z_R^{1i} - v_2 Z_R^{2i} \ .
$$

The Higgs potential is expressed as

$$
\begin{aligned}
&-\frac{e^2}{8\sin^2\theta\cos^2\theta} A_R^{ij} B_R^k H_i^0 H_j^0 H_k^0 - \frac{e^2}{8\sin^2\theta\cos^2\theta} A_H^{ij} B_R^k H_{i+2}^0 H_{j+2}^0 H_k^0 \\
&\quad - \left[\frac{e^2}{4\sin^2\theta\cos^2\theta} A_H^{ij} B_R^k + \frac{em_W}{2\sin\theta}(A_P^{kj}\delta_{1i} + A_P^{ki}\delta_{1j}) \right] H_i^+ H_j^- H_k^0 \\
&\quad + \frac{iem_W}{2\sin\theta}\epsilon_{ij}\delta^{1k} H_i^+ H_j^- H_{k+2}^0 + \frac{ie^2}{4\sin^2\theta} A_P^{ij}\epsilon_{kl} H_i^0 H_{j+2}^0 H_k^+ H_l^- \\
&\quad - \frac{e^2}{32\sin^2\theta\cos^2\theta} A_R^{ij} A_R^{kl} H_i^0 H_j^0 H_k^0 H_l^0 - \frac{e^2}{32\sin^2\theta\cos^2\theta} A_H^{ij} A_H^{kl} H_{i+2}^0 H_{j+2}^0 H_{k+2}^0 H_{l+2}^0 \\
&\quad - \frac{e^2}{16\sin^2\theta\cos^2\theta} A_R^{ij} A_H^{kl} H_i^0 H_j^0 H_{k+2}^0 H_{l+2}^0 - \frac{e^2}{8\sin^2\theta\cos^2\theta} A_H^{ij} A_H^{kl} H_i^+ H_k^+ H_j^- H_l^- \\
&\quad - \frac{e^2}{4\sin^2\theta} \left[\frac{1}{2\cos^2\theta} A_R^{ij} A_H^{kl} + A_P^{ik} A_P^{jl} \right] H_i^0 H_j^0 H_k^+ H_l^- - \frac{e^2}{4\sin^2\theta} \left[\frac{1}{2\cos^2\theta} A_H^{ij} A_H^{kl} + \epsilon_{ik}\epsilon_{jl} \right] H_{i+2}^0 H_{j+2}^0 H_k^+ H_l^- \ .
\end{aligned}
$$

It is easy to see that the couplings $H_i^+ H_j^- H_{k+2}^0$ and $H_i^+ H_j^- H_{k+2}^0 H_l^0$ completely disappear in the unitary gauge.

(10) Interactions of the sleptons and Higgs bosons. One can naturally divide them into two groups.

(i) Three-scalar (two-slepton–one-Higgs-boson) couplings:

$$
\begin{aligned}
&-\frac{e^2}{4\sin^2\theta\cos^2\theta} B_R^i \nu^{I*}\nu^I H_i^0 \\
&\quad + Z_\nu^{IJ} \left[\frac{-\sqrt{2}e^2}{4\sin^2\theta} v_k Z_H^{kj} Z_L^{Ii} + (l_S^{IK} Z_L^{(K+3)i} - m_e^I l^I Z_L^{Ii}) Z_H^{1j} + (k_S^{IJ} Z_L^{(J+3)i} - h^* l^I Z_L^{(I+3)i}) Z_H^{2j} \right] \nu^J L_i^+ H_j^- + \mathrm{H.c.} \\
&\quad + \frac{i}{\sqrt{2}}[(l_S^{IJ*} Z_L^{Ij} Z_L^{(J+3)i*} - l_S^{IJ} Z_L^{Ii*} Z_L^{(J+3)j}) Z_H^{1k} + (k_S^{IJ*} Z_L^{Ij} Z_L^{(J+3)i*} - k_S^{IJ} Z_L^{Ii*} Z_L^{(J+3)j}) Z_H^{2k} \\
&\qquad + l^I(h^* Z_L^{Ii*} Z_L^{(I+3)j} - h Z_L^{Ij} Z_L^{(I+3)i*}) Z_H^{2k}] L_i^- L_j^+ H_{k+2}^0
\end{aligned}
$$

$$+\Bigg[\frac{e^2}{2\cos^2\theta}B_R^k\Bigg\{\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\Bigg\}-(l^I)^2v_1Z_R^{1k}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})$$

$$-\frac{1}{\sqrt{2}}Z_R^{1k}(l_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}+l_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})+\frac{1}{\sqrt{2}}Z_R^{2k}(k_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}+k_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})$$

$$-\frac{1}{\sqrt{2}}l^IZ_R^{2k}(h^*Z_L^{Ii*}Z_L^{(I+3)j}+hZ_L^{Ij}Z_L^{(I+3)i*})\Bigg]L_i^-L_j^+H_k^0\ .$$

(ii) Two-slepton–two-Higgs-boson couplings:

$$-\frac{e^2}{8\sin^2\theta\cos^2\theta}A_R^{ij}\nu^{I*}\nu^IH_i^0H_j^0-\frac{e^2}{8\sin^2\theta\cos^2\theta}A_H^{ij}\nu^{I*}\nu^IH_{i+2}^0H_{j+2}^0$$

$$+Z_\nu^{KJ*}Z_\nu^{KI}[e^2\cot^2\theta A_H^{ij}-(l^K)^2Z_H^{1j}]\nu^{J*}\nu^IH_i^-H_j^+$$

$$+\frac{i}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\Bigg\{\frac{e^2}{2\sin^2\theta}A_H^{jk}-(l^I)^2Z_H^{1j}Z_H^{1k}\Bigg\}\nu^JL_i^+H_j^-H_{k+2}^0+\text{H.c.}$$

$$+\frac{1}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\Bigg\{\frac{-e^2}{2\sin^2\theta}(Z_H^{1j}Z_R^{1k}+Z_H^{2j}Z_R^{2k})+(l^I)^2Z_H^{1j}Z_R^{1k}\Bigg\}\nu^JL_i^+H_j^-H_k^0+\text{H.c.}$$

$$+\Bigg[\frac{e^2}{4\cos^2\theta}A_H^{kl}\Bigg\{\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\Bigg\}-\tfrac{1}{2}(l^I)^2Z_H^{1k}Z_H^{1l}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})\Bigg]L_i^-L_j^+H_{k+2}^0H_{l+2}^0$$

$$+\Bigg[\frac{e^2}{4\cos^2\theta}A_R^{kl}\Bigg\{\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\Bigg\}-\tfrac{1}{2}(l^I)^2Z_R^{1k}Z_R^{1l}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})\Bigg]L_i^-L_j^+H_k^0H_l^0$$

$$+\Bigg[\frac{e^2}{2\cos^2\theta}A_H^{kl}\Bigg\{\delta^{ij}-\frac{1+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\Bigg\}-(l^I)^2Z_H^{1k}Z_H^{1l}Z_L^{(I+3)i*}Z_L^{(I+3)j}\Bigg]L_i^-L_j^+H_k^-H_l^+\ .$$

(11) Interactions of the squarks and Higgs bosons. We have the same two types of couplings as in the previous case.
(i) Three-scalar couplings:

$$+\frac{i}{\sqrt{2}}[(u_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*}-u_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j})Z_H^{2k}+(w_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}-w_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})Z_H^{1k}$$

$$+u^I(hZ_U^{Ii*}Z_U^{(I+3)j}-h^*Z_U^{Ij}Z_U^{(I+3)i*})Z_H^{1k}]U_i^-U_j^+H_{k+2}^0$$

$$+\Bigg[\frac{-e^2}{3\cos^2\theta}\Bigg\{\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\Bigg\}B_R^k-(u^I)^2v_2Z_R^{2k}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})$$

$$+\frac{1}{\sqrt{2}}Z_R^{2k}(u_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}+u_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})+\frac{1}{\sqrt{2}}Z_R^{1k}(w_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}+w_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})$$

$$+\frac{1}{\sqrt{2}}u^IZ_R^{1k}(h^*Z_U^{Ij}Z_U^{(I+3)i*}+hZ_U^{Ii*}Z_U^{(I+3)j})\Bigg]U_i^-U_j^+H_k^0$$

$$+\frac{i}{\sqrt{2}}[(d_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}-d_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})Z_H^{1k}+(e_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}-e_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})Z_H^{2k}$$

$$+d^I(h^*Z_D^{Ii*}Z_D^{(I+3)j}-hZ_D^{Ij}Z_D^{(I+3)i*})Z_H^{2k}]D_i^-D_j^+H_{k+2}^0$$

$$+\Bigg[\frac{e^2}{6\cos^2\theta}\Bigg\{\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\Bigg\}B_R^k-(d^I)^2v_1Z_R^{1k}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})$$

$$-\frac{1}{\sqrt{2}}Z_R^{1k}(d_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}+d_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})+\frac{1}{\sqrt{2}}Z_R^{2k}(e_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}+e_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})$$

$$-\frac{1}{\sqrt{2}}d^IZ_R^{2k}(h^*Z_D^{Ii*}Z_D^{(I+3)j}+hZ_D^{Ij}Z_D^{(I+3)i*})\Bigg]D_i^-D_j^+H_k^0$$

$$+\left[\frac{1}{\sqrt{2}}\left[\frac{-e^2}{2\sin^2\theta}v_l Z_H^{lk}+v_1(d^I)^2Z_H^{1k}+v_2(u^J)^2Z_H^{2k}\right]C^{IJ}Z_D^{Ij}Z_U^{Ji}\right.$$

$$-\frac{\sqrt{2}m_W\sin\theta}{e}\delta^{1k}u^Jd^IC^{IJ}Z_D^{(I+3)j}Z_U^{(J+3)i}+[Z_H^{1k}hu^JC^{IJ}+(Z_H^{1k}w_S^{KJ*}-Z_H^{2k}u_S^{KJ*})C^{IK}]Z_U^{(J+3)i}Z_D^{Ij}$$

$$\left.+[(Z_H^{1k}d_S^{KI}+Z_H^{2k}e_S^{KI})C^{KJ}-Z_H^{2k}h^*d^IC^{IJ}]Z_U^{Ji}Z_D^{(I+3)j}\right]U_i^+D_j^+H_k^-+\text{H.c.}$$

(ii) Four-scalar couplings:

$$+\left[\frac{-e^2}{6\cos^2\theta}A_H^{kl}\left[\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]\right.$$

$$\left.-\tfrac{1}{2}(u^I)^2Z_H^{2k}Z_H^{2l}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})\right]U_i^-U_j^+H_{k+2}^0H_{l+2}^0$$

$$+\left[\frac{-e^2}{6\cos^2\theta}A_R^{kl}\left[\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]-\tfrac{1}{2}(u^I)^2Z_R^{2k}Z_R^{2l}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})\right]U_i^-U_j^+H_k^0H_l^0$$

$$+\left[\frac{-e^2}{3\cos^2\theta}A_H^{kl}\left[\delta^{ij}-\frac{3+2\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]\right.$$

$$\left.-(u^I)^2Z_H^{2k}Z_H^{2l}Z_U^{(I+3)i*}Z_U^{(I+3)j}-(d^I)^2Z_H^{1k}Z_H^{1l}C^{IJ}C^{IK*}Z_U^{Ki*}Z_U^{Jj}\right]U_i^-U_j^+H_k^-H_l^+$$

$$+\left[\frac{e^2}{12\cos^2\theta}A_H^{kl}\left[\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]-\tfrac{1}{2}(d^I)^2Z_H^{1k}Z_H^{1l}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})\right]D_i^-D_j^+H_{k+2}^0H_{l+2}^0$$

$$+\left[\frac{e^2}{12\cos^2\theta}A_R^{kl}\left[\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]-\tfrac{1}{2}(d^I)^2Z_R^{1k}Z_R^{1l}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})\right]D_i^-D_j^+H_k^0H_l^0$$

$$+\left[\frac{e^2}{6\cos^2\theta}A_H^{kl}\left[\delta^{ij}-\frac{3-2\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]\right.$$

$$\left.-(d^I)^2Z_H^{1k}Z_H^{1l}Z_D^{(I+3)i*}Z_D^{(I+3)j}-(u^K)^2Z_H^{2k}Z_H^{2l}C^{IK}C^{JK*}Z_D^{Ji*}Z_D^{Ij}\right]D_i^-D_j^+H_k^-H_l^+$$

$$+\frac{i}{\sqrt{2}}C^{IJ}\left[\frac{e^2}{2\sin^2\theta}A_H^{kl}Z_U^{Ji}Z_D^{Ij}-\epsilon_{kl}u^Jd^IZ_U^{(J+3)i}Z_D^{(I+3)j}\right.$$

$$\left.+[(u^J)^2Z_H^{2k}Z_H^{2l}-(d^I)^2Z_H^{1k}Z_H^{1l}]Z_U^{Ji}Z_D^{Ij}\right]U_i^+D_j^+H_k^-H_{l+2}^0+\text{H.c.}$$

$$+\frac{1}{\sqrt{2}}C^{IJ}\left[\frac{-e^2}{2\sin^2\theta}(Z_H^{1k}Z_R^{1l}+Z_H^{2k}Z_R^{2l})Z_U^{Ji}Z_D^{Ij}-A_P^{lk}u^Jd^IZ_U^{(J+3)i}Z_D^{(I+3)j}\right.$$

$$\left.+[(u^J)^2Z_H^{2k}Z_R^{2l}+(d^I)^2Z_H^{1k}Z_R^{1l}]Z_U^{Ji}Z_D^{Ij}\right]U_i^+D_j^+H_k^-H_l^0+\text{H.c.}$$

(12) The last type of couplings which may be useful in calculations without strong corrections are the four scalar interactions of four sleptons or two sleptons and two squarks:

$$-\frac{e^2}{8\sin^2\theta\cos^2\theta}\nu^{I*}\nu^{J*}\nu^I\nu^J+\left[\frac{e^2}{2\cos^2\theta}\left[\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ki*}Z_L^{Kj}\right]\delta^{IJ}\right.$$

$$\left.-\left[\frac{e^2}{2\sin^2\theta}Z_L^{Ki*}Z_L^{Lj}+l^Kl^LZ_L^{(K+3)i*}Z_L^{(L+3)j}\right]Z_\nu^{LI}Z_\nu^{KJ*}\right]\nu^{J*}\nu^IL_i^-L_j^+$$

$$-\frac{e^2}{3\cos^2\theta}\left[\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ji*}Z_U^{Jj}\right]\nu^{I*}\nu^IU_i^-U_j^++\frac{e^2}{6\cos^2\theta}\left[\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ji*}Z_D^{Jj}\right]\nu^{I*}\nu^ID_i^-D_j^+$$

$$-Z_\nu^{JI}Z_U^{Li*}C^{KL*}\left[\frac{e^2}{2\sin^2\theta}Z_D^{Kj*}Z_L^{Jk}+l^Jd^KZ_D^{(K+3)j*}Z_L^{(J+3)k}\right]\nu^IU_i^-D_j^-L_k^++\text{H.c.}$$

$$+\left[-\frac{e^2(1+8\sin^2\theta)}{8\sin^2\theta\cos^2\theta}Z_L^{Ii*}Z_L^{Jj*}Z_L^{Jl}Z_L^{Ik}+\frac{e^2}{2\cos^2\theta}\delta^{jl}(3Z_L^{Ii*}Z_L^{Ik}-\delta^{ik})-l^Il^JZ_L^{Jj*}Z_L^{Ik}Z_L^{(I+3)i*}Z_L^{(J+3)l}\right]L_i^-L_j^-L_k^+L_l^+$$

$$+\frac{e^2}{6\cos^2\theta}\left[\frac{3+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}Z_U^{Jk*}Z_U^{Jl}-2\delta^{kl}Z_L^{Ii*}Z_L^{Ij}-5\delta^{ij}Z_U^{Ik*}Z_U^{Il}+4\delta^{ij}\delta^{kl}\right]L_i^-L_j^+U_k^-U_l^+$$

$$-\left[\frac{e^2}{6\cos^2\theta}\left[\frac{3+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}Z_D^{Jk*}Z_D^{Jl}-4\delta^{kl}Z_L^{Ii*}Z_L^{Ij}-\delta^{ij}Z_D^{Ik*}Z_D^{Il}+2\delta^{ij}\delta^{kl}\right]\right.$$

$$\left.+l^Id^J(Z_L^{(I+3)i*}Z_L^{Ij}Z_D^{Jk*}Z_D^{(J+3)l}+Z_L^{Ii*}Z_L^{(I+3)j}Z_D^{(J+3)k*}Z_D^{Jl})\right]L_i^-L_j^+D_k^-D_l^+ \; .$$

(13) At this point we complete all expressions containing the strong coupling constant g_3. We have two basic types of such interactions—first, couplings of the quarks and squarks with the gluons and gluinos and second, four squarks vertices in the superpotential. We include in this paragraph also other four-squark vertices with other couplings—placing them for example in the previous point would be unreasonable, because all realistic calculations including those expressions should also contain the strong corrections. By Y^a we denote the matrices of the SU(3) generators in the 3 representation [generally $a,b,c,\ldots$ are indices corresponding to the **8** (adjoint) representation, $\alpha,\beta,\gamma,\ldots$ to the **3** representation of the strong gauge group].

$$-g_3\bar{q}_u^IY^a\gamma^\mu q_u^IG_\mu^a-g_3\bar{q}_d^IY^a\gamma^\mu q_d^IG_\mu^a-ig_3(U_i^-Y^a\overleftrightarrow{\partial}^\mu U_i^+)G_\mu^a+g_3^2U_i^-Y^aY^bU_i^+G_\mu^aG^{b\mu}+\tfrac{4}{3}eg_3U_i^-Y^aU_i^+G_\mu^aF^\mu$$

$$+\frac{eg_3}{\sin\theta\cos\theta}(Z_U^{Ii*}Z_U^{Ij}-\tfrac{4}{3}\delta^{ij}\sin^2\theta)U_i^-Y^aU_j^+G_\mu^aZ^\mu$$

$$-ig_3(D_i^+Y^a\overleftrightarrow{\partial}^\mu D_i^-)G_\mu^a+g_3^2D_i^+Y^aY^bD_i^-G_\mu^aG^{b\mu}-\tfrac{2}{3}eg_3D_i^+Y^aD_i^-G_\mu^aF^\mu$$

$$+\frac{eg_3}{\sin\theta\cos\theta}(-Z_D^{Ii}Z_D^{Ij*}+\tfrac{2}{3}\delta^{ij}\sin^2\theta)D_i^+Y^aD_j^-G_\mu^aZ^\mu$$

$$+\frac{eg_3\sqrt{2}}{\sin\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}D_i^+Y^aU_j^+G_\mu^aW^{-\mu}+\text{H.c.}$$

$$+g_3\sqrt{2}U_i^-Y^a\bar{\Lambda}_G^a\left[-Z_U^{Ii*}\frac{1-\gamma_5}{2}+Z_U^{(I+3)i*}\frac{1+\gamma_5}{2}\right]q_u^I+\text{H.c.}$$

$$+g_3\sqrt{2}D_i^+Y^a\bar{\Lambda}_G^a\left[-Z_D^{Ii}\frac{1-\gamma_5}{2}+Z_D^{(I+3)i}\frac{1+\gamma_5}{2}\right]q_d^I+\text{H.c.}$$

$$+\tfrac{1}{2}ig_3f_{abc}\bar{\Lambda}_G^a\gamma^\mu\Lambda_G^bG_\mu^c+g_3f_{abc}(\partial^\mu\bar{\eta}_G^a)\eta_G^bG_\mu^c+\tfrac{1}{2}g_3f_{abc}(\partial_\mu G_\nu^a-\partial_\nu G_\mu^a)G^{b\mu}G^{c\nu}-\tfrac{1}{4}g_3^2f_{abc}f_{ade}G_\mu^bG^{d\mu}G_\nu^cG^{e\nu} \; .$$

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

$$+\left\{\tfrac{1}{12}g_3^2(\delta^{ij}-2Z_U^{Ii*}Z_U^{Ij})(\delta^{kl}-2Z_U^{Jk*}Z_U^{Jl})(3\delta_{\alpha\delta}\delta_{\beta\gamma}-\delta_{\alpha\beta}\delta_{\gamma\delta})\right.$$

$$+\left[\frac{e^2}{9\cos^2\theta}\left[2\delta^{ij}\delta^{kl}-5\delta^{ij}Z_U^{Ik*}Z_U^{Il}+\frac{9+16\sin^2\theta}{8\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}Z_U^{Jk*}Z_U^{Jl}\right]\right.$$

$$\left.\left.+u^Iu^JZ_U^{(I+3)i*}Z_U^{Ij}Z_U^{Jk*}Z_U^{(J+3)l}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\right\}U_{i\alpha}^-U_{k\gamma}^-U_{j\beta}^+U_{l\delta}^+$$

$$+\left\{\tfrac{1}{12}g_3^2(\delta^{ij}-2Z_D^{Ii*}Z_D^{Ij})(\delta^{kl}-2Z_D^{Jk*}Z_D^{Jl})(3\delta_{\alpha\delta}\delta_{\beta\gamma}-\delta_{\alpha\beta}\delta_{\gamma\delta})\right.$$

$$+\left[\frac{e^2}{18\cos^2\theta}\left[\delta^{ij}\delta^{kl}-\delta^{ij}Z_D^{Ik*}Z_D^{Il}+\frac{9-8\sin^2\theta}{4\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}Z_D^{Jk*}Z_D^{Jl}\right]\right.$$

$$\left.\left.+d^Id^JZ_D^{(I+3)j}Z_D^{Ii*}Z_D^{Jl}Z_D^{(J+3)k*}\right]\delta_{\alpha\beta}\delta_{\gamma\delta}\right\}D_{i\alpha}^-D_{k\gamma}^-D_{j\beta}^+D_{l\delta}^+$$

$$
\begin{aligned}
&+\Bigg[\tfrac{1}{12}g_3^2(\delta^{ij}-2Z_U^{Ii*}Z_U^{Ij})(\delta^{kl}-2Z_D^{Jk*}Z_D^{Jl})(3\delta_{\alpha\gamma}\delta_{\beta\delta}-2\delta_{\alpha\beta}\delta_{\gamma\delta})\\
&\quad-\frac{e^2}{18\cos^2\theta}\Bigg[4\delta^{ij}\delta^{kl}-2\delta^{ij}Z_D^{Ik*}Z_D^{Il}-5\delta^{kl}Z_U^{Ii*}Z_U^{Ij}+\frac{9-4\sin^2\theta}{2\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}Z_D^{Jk*}Z_D^{Jl}\Bigg]\delta_{\alpha\beta}\delta_{\gamma\delta}\\
&\quad+\Bigg[\frac{e^2}{2\sin^2\theta}Z_U^{Ii*}Z_U^{Jj}Z_D^{Kk*}Z_D^{Ll}+u^Iu^JZ_U^{(I+3)i*}Z_U^{(J+3)j}Z_D^{Kk*}Z_D^{Ll}\\
&\qquad+d^Kd^LZ_U^{Ii*}Z_U^{Jj}Z_D^{(K+3)k*}Z_D^{(L+3)l}\Bigg]C^{LJ}C^{KI*}\delta_{\alpha\gamma}\delta_{\beta\delta}\Bigg]U^-_{i\alpha}U^+_{j\beta}D^-_{k\gamma}D^+_{l\delta}\ .
\end{aligned}
$$

VII. SUMMARY

The model described in the previous sections contains a great 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 scale of the order of m_W by renormalization-group equations from the coupling constants of the supergravity theories investigated at the Planck mass. Usually such theories are much more unified and contain typically only few free numbers.[7] Of course, there are also many constraints originating from experimental data—first of all the masses of the superpartners are bounded from below by their absence in the present experiments, but one can find also many more subtle limits: for example, if the masses of the superscalars are not very high, then the nondiagonalness of the soft Yukawa couplings d_S^{IJ}, e_S^{IJ}, etc. can probably cause by loop corrections too strong flavor-changing neutral currents in the "normal" quark sector.

It is worth remembering that although in the superpotential we can have only three matrices of Yukawa couplings, 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 supergravity theories such terms are initially equal to zero, but it is easy to show graphs which generate them perturbatively. In all papers known to the author those couplings were neglected, which seems to be inconsistent.

Many of the vertices written down in Sec. VI, especially in the scalar potential, are very complicated. To minimize the possibility of mistakes a large part of them was computed with use of the symbolic calculation program REDUCE.

ACKNOWLEDGMENTS

The author would like to thank professor S. Pokorski for many helpful discussions. This work was supported in part by Polish Ministry of National Education, Research Program C.P.B.P. 01.03.

APPENDIX A

In this Appendix we write down the Lagrangian of the MSSM in terms of the initial fields, before SU(2)-symmetry breaking, but already after the redefinition of the coupling constants described in Sec. III. It 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 particles.

In the formulas below we use the two-component fermion notation.

After the diagonalization of the Yukawa couplings the superpotential has the form (C is the Kobayashi-Maskawa matrix, $\epsilon_{12}=-\epsilon_{21}=-1$)

$$
\begin{aligned}
W=&h\epsilon_{ij}H_i^1H_j^2+l^I\epsilon_{ij}H_i^1L_j^IR^I\\
&-u^I(H_1^2C^{JI*}Q_2^J-H_2^2Q_1^I)U^I\\
&-d^I(H_1^1Q_2^I-H_2^1C^{IJ}Q_1^J)D^I\ .
\end{aligned}
$$

The interaction Lagrangian contains the following types of interactions.

(1) Gauge-boson–gaugino, gauge-boson–gauge-boson:

$$
\begin{aligned}
&ig_3f_{abc}\lambda_G^a\sigma^\mu\bar{\lambda}_G^bG_\mu^c+ig_1\epsilon_{ijk}\lambda_A^i\sigma^\mu\bar{\lambda}_A^jA_\mu^k\ ,\\
&\tfrac{1}{2}g_3f_{abc}(\partial_\mu G_\nu^a-\partial_\nu G_\mu^a)G^{b\mu}G^{c\nu}-\tfrac{1}{4}g_3^2f_{abc}f_{ade}G_\mu^bG^{d\mu}G_\nu^cG^{e\nu}\ ,\\
&\tfrac{1}{2}g_1\epsilon_{ijk}(\partial_\mu A_\nu^i-\partial_\nu A_\mu^i)A^{j\mu}A^{k\nu}-\tfrac{1}{4}g_1^2\epsilon_{ijk}\epsilon_{imn}A_\mu^jA^{m\mu}A_\nu^kA^{n\nu}\ .
\end{aligned}
$$

(2) Quark-squark-gauge: T^i are the SU(2) group generators, $T^i=\frac{1}{2}\tau^i$, where τ^i denote the Pauli matrices and Y^a and $\bar{Y}^a$ the SU(3) generators in the 3 and $\bar{3}$ representations, respectively. SU(3) and, where possible, also SU(2) indices are not written explicitly:

$$-\overline{\Psi}{}^I_Q(g_3Y^aG^a_\mu+g_1T^3A^3_\mu+\tfrac{1}{6}g_2B_\mu)\overline{\sigma}{}^\mu\Psi^I_Q-iQ^{I*}(g_3Y^aG^a_\mu+g_1T^3A^3_\mu+\tfrac{1}{6}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_Q Q^I$$

$$-\tfrac{1}{2}g_1C^{IJ}(\overline{\Psi}{}^I_{Q2}\overline{\sigma}{}^\mu\Psi^J_{Q1}+iQ^{I*}_2\overleftrightarrow{\partial}{}^\mu Q^J_1)A^+_\mu+\text{H.c.}$$

$$+i\sqrt{2}Q^{I*}(g_3Y^a\lambda^a_G+g_1T^3\lambda^3_A+\tfrac{1}{6}g_2\lambda_B)\Psi^I_Q+\text{H.c.}$$

$$+ig_1(C^{IJ}Q^{I*}_2\lambda^-_A\Psi^J_{Q1}+C^{IJ*}Q^{J*}_1\lambda^+_A\Psi^I_{Q2})+\text{H.c.}$$

$$+(CQ_1,Q_2)^{I*}(g_3Y^aG^a_\mu+g_1T^iA^i_\mu+\tfrac{1}{6}g_2B_\mu)(g_3Y^bG^{b\mu}+g_1T^jA^{j\mu}+\tfrac{1}{6}g_2B_\mu)\begin{bmatrix}CQ_1\\ Q_2\end{bmatrix}^I$$

$$-\overline{\Psi}{}^I_U(g_3\overline{Y}{}^aG^a_\mu-\tfrac{2}{3}g_2B_\mu)\overline{\sigma}{}^\mu\Psi^I_U-iU^{I*}(g_3\overline{Y}{}^aG^a_\mu-\tfrac{2}{3}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_U U^I$$

$$+U^{I*}(g_3\overline{Y}{}^aG^a_\mu-\tfrac{2}{3}g_2B_\mu)(g_3\overline{Y}{}^bG^{b\mu}-\tfrac{2}{3}g_2B^\mu)U^I$$

$$-\overline{\Psi}{}^I_D(g_3\overline{Y}{}^aG^a_\mu+\tfrac{1}{3}g_2B_\mu)\overline{\sigma}{}^\mu\Psi^I_D-iD^{I*}(g_3\overline{Y}{}^aG^a_\mu+\tfrac{1}{3}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_D D^I$$

$$+D^{I*}(g_3\overline{Y}{}^aG^a_\mu+\tfrac{1}{3}g_2B_\mu)(g_3\overline{Y}{}^bG^{b\mu}+\tfrac{1}{3}g_2B^\mu)D^I$$

$$+i\sqrt{2}U^{I*}(g_3\overline{Y}{}^a\lambda^a_G-\tfrac{2}{3}g_2\lambda_B)\Psi^I_U+i\sqrt{2}D^{I*}(g_3\overline{Y}{}^a\lambda^a_G+\tfrac{1}{3}g_2\lambda_B)\Psi^I_D+\text{H.c.}$$

In the above formulas $A^\pm_\mu=A^1_\mu\pm iA^2_\mu=\sqrt{2}W^\mp_\mu$.

(3) Lepton-slepton-gauge:

$$-\overline{\Psi}{}^I_L(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)\overline{\sigma}{}^\mu\Psi^I_L-iL^{I*}(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_L L^I$$

$$+L^{I*}(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)(g_1T^jA^{j\mu}-\tfrac{1}{2}g_2B^\mu)L^I-g_2\overline{\Psi}{}^I_RB_\mu\overline{\sigma}{}^\mu\Psi^I_R-ig_2B_\mu(R^{I*}\overleftrightarrow{\partial}{}^\mu R^I)+g_2^2R^{I*}R^IB_\mu B^\mu$$

$$+i\sqrt{2}L^{I*}(g_1T^i\lambda^i_A-\tfrac{1}{2}g_2\lambda_B)\Psi^I_L+i\sqrt{2}g_2R^{I*}\lambda_B\Psi^I_R+\text{H.c.}$$

(4) Higgs-boson–Higgsino–gauge:

$$-\overline{\Psi}_{H1}(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)\overline{\sigma}{}^\mu\Psi_{H1}-iH^{1*}(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_H H^1$$

$$+H^{1*}(g_1T^iA^i_\mu-\tfrac{1}{2}g_2B_\mu)(g_1T^jA^{j\mu}-\tfrac{1}{2}g_2B^\mu)H^1$$

$$-\overline{\Psi}_{H2}(g_1T^iA^i_\mu+\tfrac{1}{2}g_2B_\mu)\overline{\sigma}{}^\mu\Psi_{H2}-iH^{2*}(g_1T^iA^i_\mu+\tfrac{1}{2}g_2B_\mu)\overleftrightarrow{\partial}{}^\mu_H H^2+H^{2*}(g_1T^iA^i_\mu+\tfrac{1}{2}g_2B_\mu)(g_1T^jA^{j\mu}+\tfrac{1}{2}g_2B^\mu)H^2$$

$$+i\sqrt{2}H^{1*}(g_1T^i\lambda^i_A-\tfrac{1}{2}g_2\lambda_B)\Psi_{H1}+i\sqrt{2}H^{2*}(g_1T^i\lambda^i_A+\tfrac{1}{2}g_2\lambda_B)\Psi_{H2}+\text{H.c.}$$

(5) Yukawa couplings:

$$-h\epsilon_{ij}\Psi^i_{H1}\Psi^j_{H2}-l^I\epsilon_{ij}\Psi^i_{H1}\Psi^I_{Lj}R^I-l^I\epsilon_{ij}\Psi^i_{H1}\Psi^I_RL^I_j-l^I\epsilon_{ij}\Psi^I_R\Psi^I_{Lj}H^1_i+\text{H.c.}$$

$$-d^I(-\Psi^1_{H1}\Psi^I_{Q2}+C^{IJ}\Psi^2_{H1}\Psi^J_{Q1})D^I-d^I(-\Psi^1_{H1}Q^I_2+C^{IJ}\Psi^2_{H1}Q^J_1)\Psi^I_D+\text{H.c.}$$

$$-d^I(-H^1_1\Psi^I_{Q2}+C^{IJ}H^1_2\Psi^J_{Q1})\Psi^I_D-u^I(-C^{JI*}H^2_1\Psi^J_{Q2}+H^2_2\Psi^I_{Q1})\Psi^I_U+\text{H.c.}$$

$$-u^I(-C^{JI*}\Psi^1_{H2}\Psi^J_{Q2}+\Psi^2_{H2}\Psi^I_{Q1})U^I-u^I(-C^{JI*}\Psi^1_{H2}Q^J_2+\Psi^2_{H2}Q^I_1)\Psi^I_U+\text{H.c.}$$

Passing to the four-fermion notation one should substitute

$$q^I_u=\begin{bmatrix}\Psi^I_{Q1}\\ \overline{\Psi}{}^I_U\end{bmatrix},\quad q^I_d=\begin{bmatrix}\Psi^I_{Q2}\\ \overline{\Psi}{}^I_D\end{bmatrix}$$

and similarly for the leptons.

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

$$V=\tfrac{1}{2}(D^a_GD^a_G+D^i_AD^i_A+D_BD_B)+F^*_iF_i\ .$$

For the $F^*_{H1}F_{H1}$ and $F^*_{H2}F_{H2}$ terms we present SU(3) indices explicitly in places where their contraction can be ambiguous:

$$D^a_G=g_3(Q^{I*}_iY^aQ^I_i+D^{I*}\overline{Y}{}^aD^I+U^{I*}\overline{Y}{}^aU^I)\ ,$$

$$D^i_A=g_1\left[(CQ_1,Q_2)^{I*}T^i\begin{bmatrix}CQ_1\\ Q_2\end{bmatrix}^I+L^{I*}T^iL^I+H^{1*}T^iH^1+H^{2*}T^iH^2\right]\ ,$$

$$D_B=\tfrac{1}{2}g_2(\tfrac{1}{3}Q^{I*}_iQ^I_i+\tfrac{2}{3}D^{I*}D^I-\tfrac{4}{3}U^{I*}U^I-L^{I*}_iL^I_i+2R^{I*}R^I-H^{1*}_iH^1_i+H^{2*}_iH^2_i)\ ,$$

$$F^*_{H1}F_{H1}=|h|^2H_i^{2*}H_i^2+l^Il^JL_i^{I*}L_i^JR^{I*}R^J+d^Id^J(C^{IK*}C^{JL}Q^{K*}_{1\alpha}Q^L_{1\beta}+Q^{I*}_{2\alpha}Q^J_{2\beta})D^{I*}_\alpha D^J_\beta$$
$$+[l^Ih^*H_i^{2*}L_i^IR^I+d^Ih^*(C^{IJ}H_1^{2*}Q_1^J+H_2^{2*}Q_2^I)D^I+\text{H.c.}]$$
$$+[l^Id^J(C^{JK}L_1^{I*}Q_1^K+L_2^{I*}Q_2^J)R^{I*}D^J+\text{H.c.}]\ ,$$
$$F^*_{H2}F_{H2}=|h|^2H_i^{1*}H_i^1+u^Iu^J(C^{KI}C^{LJ*}Q^{K*}_{2\alpha}Q^L_{2\beta}+Q^{I*}_{1\alpha}Q^J_{1\beta})U^{I*}_\alpha U^J_\beta$$
$$-[u^Ih^*(C^{JI*}H_2^{1*}Q_2^J+H_1^{1*}Q_1^I)U^I+\text{H.c.}]\ ,$$
$$F^{I*}_{Li}F^I_{Li}=(l^I)^2H_i^{1*}H_i^1R^{I*}R^I\ ,$$
$$F^{I*}_RF^I_R=(l^I)^2\epsilon_{ij}\epsilon_{kl}H_i^{1*}H_k^1L_j^{I*}L_l^I\ ,$$
$$F^{I*}_{Qi}F^I_{Qi}=(d^I)^2H_i^{1*}H_i^1D^{I*}D^I+(u^I)^2H_i^{2*}H_i^2U^{I*}U^I+(u^Id^JC^{JI*}U^ID^{J*}H_i^{1*}H_i^2+\text{H.c.})\ ,$$
$$F^{I*}_UF^I_U=(u^I)^2[C^{JI}C^{KI*}H_1^{2*}H_1^2Q_2^{J*}Q_2^K+H_2^{2*}H_2^2Q_1^{I*}Q_1^I-(C^{JI}H_1^{2*}H_2^2Q_2^{J*}Q_1^I+\text{H.c.})]\ ,$$
$$F^{I*}_DF^I_D=(d^I)^2[H_1^{1*}H_1^1Q_2^{I*}Q_2^I+C^{IJ*}C^{IK}H_2^{1*}H_2^1Q_1^{J*}Q_1^K-(C^{IJ}H_1^{1*}H_2^1Q_2^{I*}Q_1^J+\text{H.c.})]\ .$$

(7) The soft SUSY-breaking terms:

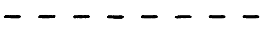
$$-m^2_{H_1}H_i^{1*}H_i^1-m^2_{H_2}H_i^{2*}H_i^2-(m_L^2)^{IJ}L_i^{I*}L_i^J-(m_R^2)^{IJ}R^{I*}R^J$$
$$-(m_Q^2)^{IJ}(Q_2^{I*}Q_2^J+C^{IK*}C^{JL}Q_1^{K*}Q_1^L)-(m_D^2)^{IJ}D^{I*}D^J-(m_U^2)^{IJ}U^{I*}U^J$$
$$+m_1\lambda^a_G\lambda^a_G+m_2\lambda^i{}_A\lambda^i{}_A+m_3\lambda_B\lambda_B+\text{H.c.}$$
$$+h_S\epsilon_{ij}H_i^1H_j^2+\epsilon_{ij}l_S^{IJ}H_i^1L_j^IR^J+k_S^{IJ}H_i^{2*}L_i^IR^J+\text{H.c.}$$
$$+u_S^{IJ}(-C^{KI*}H_1^2Q_2^K+H_2^2Q_1^I)U^J+w_S^{IJ}(C^{KI*}H_2^{1*}Q_2^K+H_1^{1*}Q_1^I)U^J+\text{H.c.}$$
$$+d_S^{IJ}(-H_1^1Q_2^I+C^{IK}H_2^1Q_1^K)D^J+e_S^{IJ}(H_2^{2*}Q_2^I+C^{IK}H_1^{2*}Q_1^K)D^J+\text{H.c.}$$

APPENDIX B

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

1. Propagators

(1) Scalar particles (Higgs boson or superscalar):



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

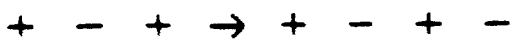
(2) Vector bosons:

$$\frac{-ig_{\mu\nu}}{p^2-m^2}\ .$$

(3) Fermions. Part of the fermions existing in the model are described by Majorana spinors, which introduce some additional complications into the calculations. The detailed discussion of the Feynman rules for the Majorana fermions can be found for example in Appendixes D and E of Ref. 1:

$$\frac{i}{\not p-m}\ .$$

(4) Ghosts:

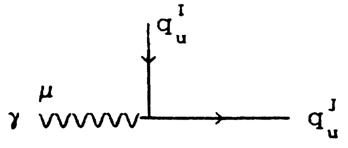


$$\frac{i}{p^2-m^2}\ .$$

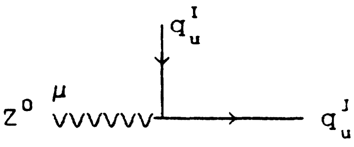
The propagators of the quarks, squarks, and the color ghosts should be multiplied by the factor δ^{ab}, where a and b are as usual color indices.

2. Vertices

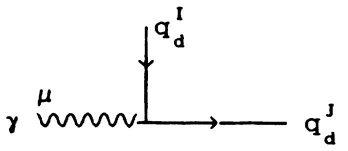
(1) Quarks–squarks–gauge-bosons:



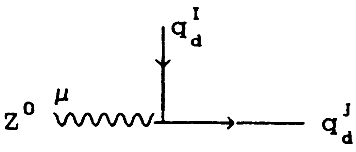
$$-\tfrac{2}{3}ie\gamma^\mu\delta^{IJ} ,$$



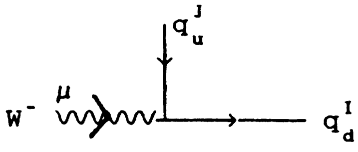
$$-\frac{ie}{\sin\theta\cos\theta}\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\tfrac{2}{3}\sin^2\theta\right]\delta^{IJ} ,$$



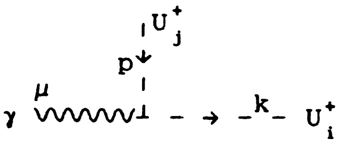
$$\tfrac{1}{3}ie\gamma^\mu\delta^{IJ} ,$$



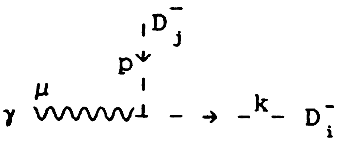
$$\frac{ie}{\sin\theta\cos\theta}\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\tfrac{1}{3}\sin^2\theta\right]\delta^{IJ} ,$$



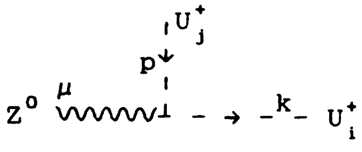
$$-\frac{ie}{\sqrt{2}\sin\theta}C^{IJ}\gamma^\mu\frac{1-\gamma_5}{2} ,$$



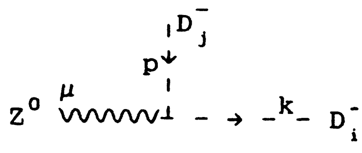
$$-\tfrac{2}{3}ie\delta^{ij}(p+k)^\mu ,$$



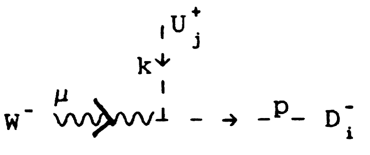
$$\tfrac{1}{3}ie\delta^{ij}(p+k)^\mu ,$$



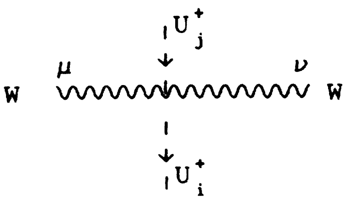
$$-\frac{ie}{\sin\theta\cos\theta}(\tfrac{1}{2}Z_U^{Ii*}Z_U^{Ij}-\tfrac{2}{3}\sin^2\theta\delta^{ij})(p+k)^\mu ,$$



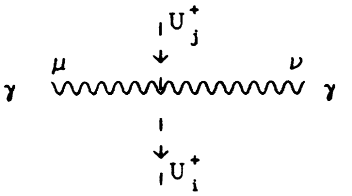
$$\frac{ie}{\sin\theta\cos\theta}(\tfrac{1}{2}Z_D^{Ii}Z_D^{Ij*}-\tfrac{1}{3}\sin^2\theta\delta^{ij})(p+k)^\mu ,$$



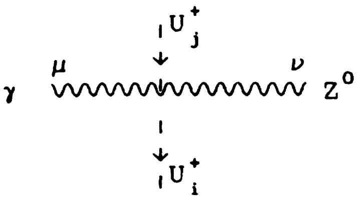
$$-\frac{ie}{\sqrt{2}\sin\theta} Z_D^{Ii} Z_U^{Jj} C^{IJ}(p+k)^\mu \ ,$$



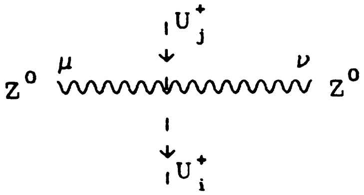
$$\frac{ie^2}{2\sin^2\theta} Z_U^{Ii*} Z_U^{Ij} g^{\mu\nu} \ ,$$



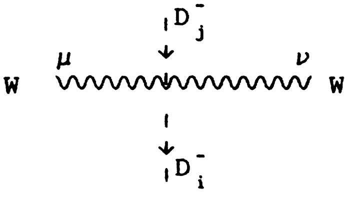
$$\tfrac{8}{9} ie^2 \delta^{ij} g^{\mu\nu} \ ,$$



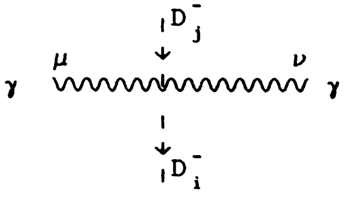
$$\frac{2ie^2}{3\sin\theta\cos\theta}(Z_U^{Ii*} Z_U^{Ij} - \tfrac{4}{3}\delta^{ij}\sin^2\theta) g^{\mu\nu} \ ,$$



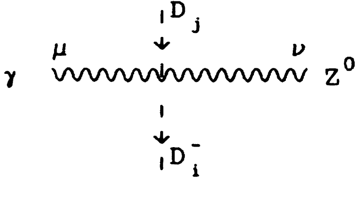
$$2ie^2 \left[\tfrac{4}{9}\delta^{ij}\tan^2\theta + \frac{3-8\sin^2\theta}{12\sin^2\theta\cos^2\theta} Z_U^{Ii*} Z_U^{Ij} \right] g^{\mu\nu} \ ,$$



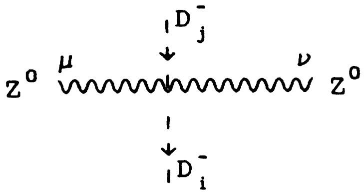
$$\frac{ie^2}{2\sin^2\theta} Z_D^{Ii} Z_D^{Ij*} g^{\mu\nu} \ ,$$



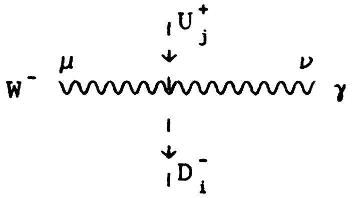
$$\tfrac{2}{9} ie^2 \delta^{ij} g^{\mu\nu} \ ,$$



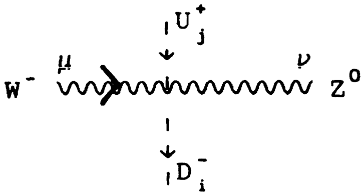
$$\frac{ie^2}{3\sin\theta\cos\theta}(Z_D^{Ii} Z_D^{Ij*} - \tfrac{2}{3}\delta^{ij}\sin^2\theta) g^{\mu\nu} \ ,$$



$$2ie^2\left[\tfrac{1}{9}\delta^{ij}\tan^2\theta+\frac{3-4\sin^2\theta}{12\sin^2\theta\cos^2\theta}Z_D^{Ii}Z_D^{Ij*}\right]g^{\mu\nu}\ ,$$

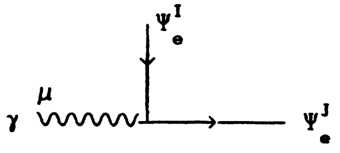


$$\frac{ie^2\sqrt{2}}{6\sin\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}g^{\mu\nu}\ ,$$

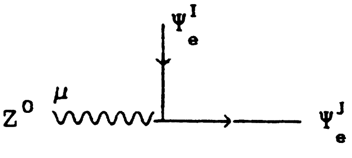


$$-\frac{ie^2\sqrt{2}}{6\cos\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}g^{\mu\nu}\ .$$

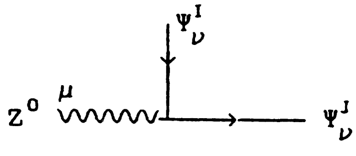
(2) Leptons–sleptons–gauge-bosons:



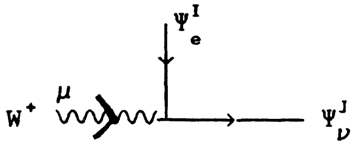
$$ie\gamma^\mu\delta^{IJ}\ ,$$



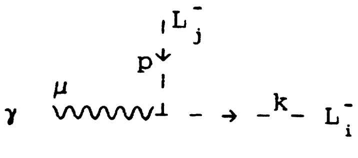
$$\frac{ie}{\sin\theta\cos\theta}\gamma^\mu\left[\frac{1}{2}\frac{1-\gamma_5}{2}-\sin^2\theta\right]\delta^{IJ}\ ,$$



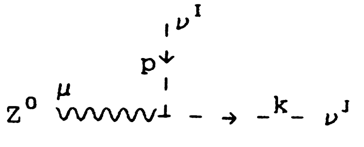
$$-\frac{ie}{2\sin\theta\cos\theta}\gamma^\mu\frac{1-\gamma_5}{2}\delta^{IJ}\ ,$$



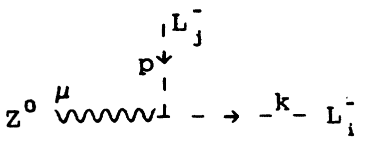
$$-\frac{ie}{\sqrt{2}\sin\theta}\gamma^\mu\frac{1-\gamma_5}{2}\delta^{IJ}\ ,$$



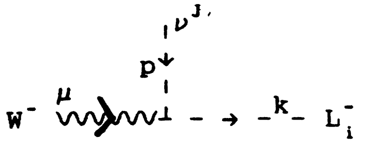
$$ie\delta^{ij}(p+k)^\mu\ ,$$



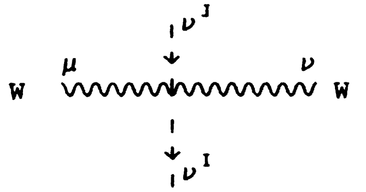
$$-\frac{ie}{2\sin\theta\cos\theta}\delta^{IJ}(p+k)^\mu\ ,$$



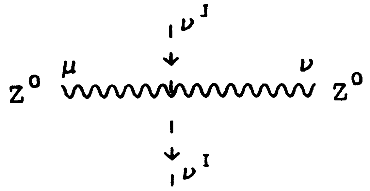
$$\frac{ie}{\sin\theta\cos\theta}\left(\tfrac{1}{2}Z_L^{Ii}Z_L^{Ij*}-\sin^2\theta\delta^{ij}\right)(p+k)^{\mu}\ ,$$



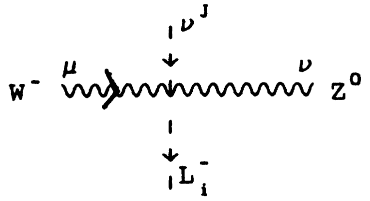
$$-\frac{ie}{\sqrt{2}\sin\theta}Z_{\nu}^{IJ}Z_L^{Ii}(p+k)^{\mu}\ ,$$



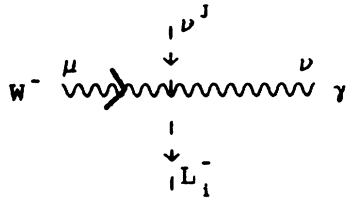
$$\frac{ie^2}{2\sin^2\theta}\delta^{IJ}g^{\mu\nu}\ ,$$



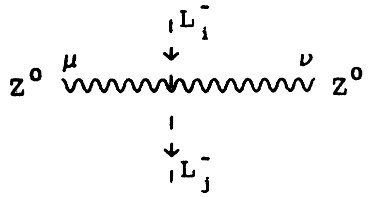
$$\frac{ie^2}{2\sin^2\theta\cos^2\theta}\delta^{IJ}g^{\mu\nu}\ ,$$



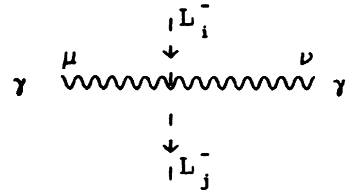
$$\frac{ie^2}{\sqrt{2}\cos\theta}Z_{\nu}^{IJ}Z_L^{Ii}g^{\mu\nu}\ ,$$



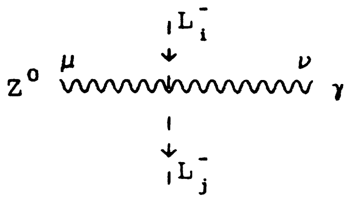
$$-\frac{ie^2}{\sqrt{2}\sin\theta}Z_{\nu}^{IJ}Z_L^{Ii}g^{\mu\nu}\ ,$$



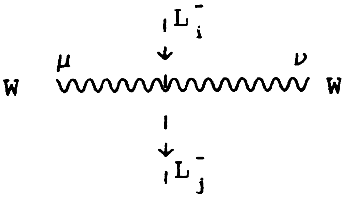
$$2ie^2\left[\delta^{ij}\tan^2\theta+\frac{1-4\sin^2\theta}{4\sin^2\theta\cos^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]g^{\mu\nu}\ ,$$



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

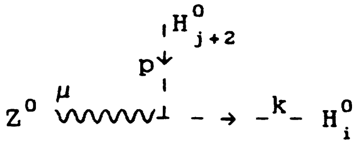


$$ie^2\left[\frac{1}{\sin\theta\cos\theta}Z_L^{Ii*}Z_L^{Ij}-2\delta^{ij}\tan\theta\right]g^{\mu\nu} ,$$

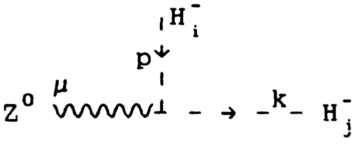


$$\frac{ie^2}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}g^{\mu\nu} .$$

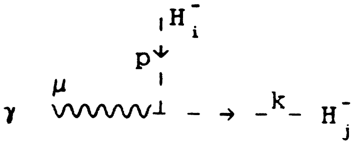
(3) Higgs-particle–gauge-boson:



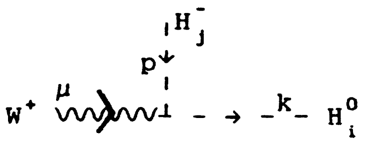
$$\frac{e}{2\sin\theta\cos\theta}A_M^{ij}(p+k)^\mu ,$$



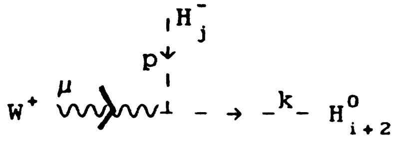
$$ie\delta^{ij}\cot2\theta(p+k)^\mu ,$$



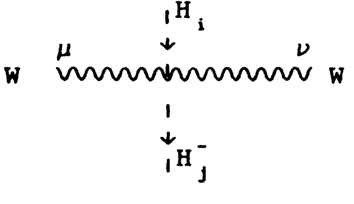
$$ie\delta^{ij}(p+k)^\mu ,$$



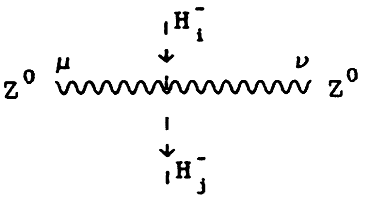
$$-\frac{ie}{2\sin\theta}A_M^{ij}(p+k)^\mu ,$$



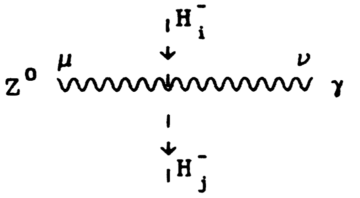
$$-\frac{e}{2\sin\theta}\delta^{ij}(p+k)^\mu ,$$



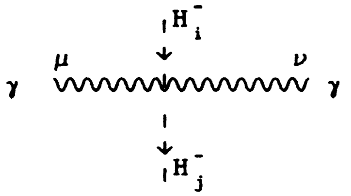
$$\frac{ie^2}{2\sin^2\theta}\delta^{ij}g^{\mu\nu} ,$$



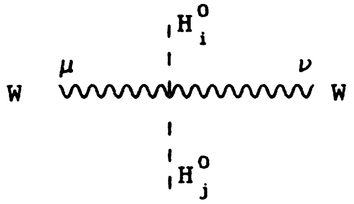
$2ie^2\cot^2 2\theta\delta^{ij}g^{\mu\nu}$,



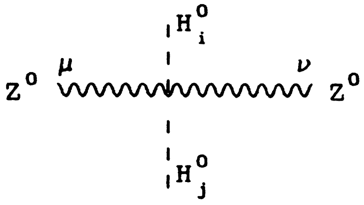
$2ie^2\cot 2\theta\delta^{ij}g^{\mu\nu}$,



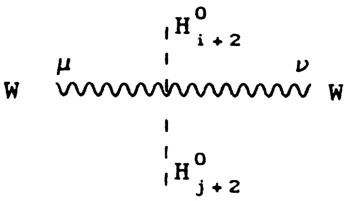
$2ie^2\delta^{ij}g^{\mu\nu}$,



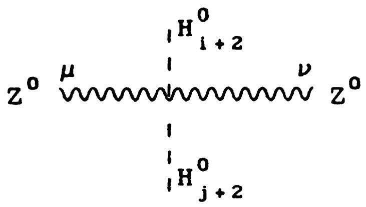
$\frac{ie^2}{2\sin^2\theta}\delta^{ij}g^{\mu\nu}$,



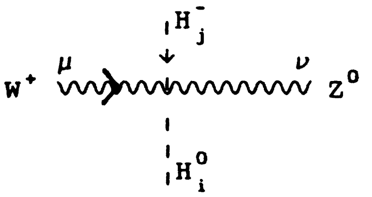
$\frac{ie^2}{2\sin^2\theta\cos^2\theta}\delta^{ij}g^{\mu\nu}$,



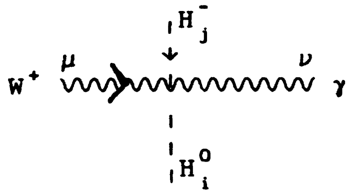
$\frac{ie^2}{2\sin^2\theta}\delta^{ij}g^{\mu\nu}$,



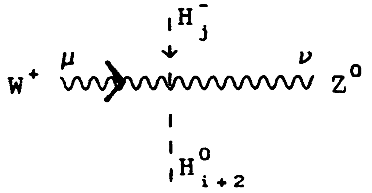
$\frac{ie^2}{2\sin^2\theta\cos^2\theta}\delta^{ij}g^{\mu\nu}$,



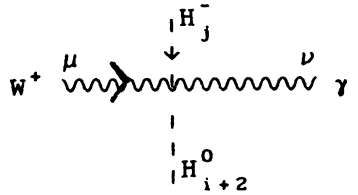
$$\frac{ie^2}{2\cos\theta} A_M^{ij} g^{\mu\nu} ,$$



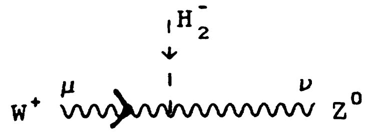
$$-\frac{ie^2}{2\sin\theta} A_M^{ij} g^{\mu\nu} ,$$



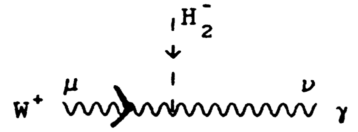
$$\frac{e^2}{2\cos\theta} \delta^{ij} g^{\mu\nu} ,$$



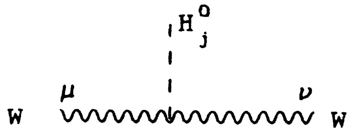
$$-\frac{e^2}{2\sin\theta} \delta^{ij} g^{\mu\nu} ,$$



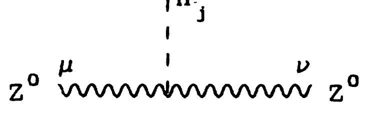
$$-iem_W \tan\theta g^{\mu\nu} ,$$



$$iem_W g^{\mu\nu} ,$$

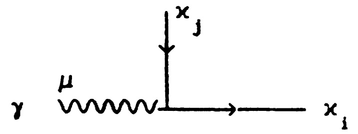


$$\frac{ie^2}{2\sin^2\theta} v_i Z_R^{ij} g^{\mu\nu} ,$$

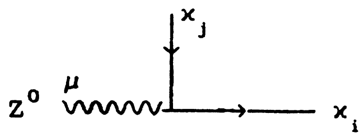


$$\frac{ie^2}{2\sin^2\theta\cos^2\theta} v_i Z_R^{ij} g^{\mu\nu} .$$

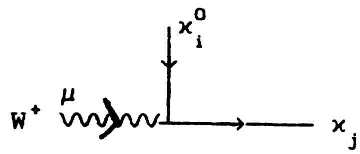
(4) Charginos–neutralinos–gauge-bosons:



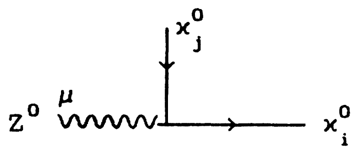
$$-ie\gamma^\mu\delta^{ij} ,$$



$$-\frac{ie}{2\sin\theta\cos\theta}\gamma^\mu\left[Z^{+}_{1i}{}^{*}Z^{+}_{1j}\frac{1-\gamma_5}{2}+Z^{-}_{1i}Z^{-}_{1j}{}^{*}\frac{1+\gamma_5}{2}+2\delta^{ij}\cos2\theta\right] ,$$

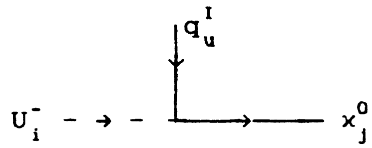


$$\frac{ie}{\sin\theta}\gamma^\mu\left[\left[Z_N^{2i}Z^{+}_{1j}{}^{*}-\frac{1}{\sqrt{2}}Z_N^{4i}Z^{+}_{2j}{}^{*}\right]\frac{1-\gamma_5}{2}\right.$$
$$\left.+\left[Z_N^{2i*}Z^{-}_{1j}+\frac{1}{\sqrt{2}}Z_N^{3i*}Z^{-}_{2j}\right]\frac{1+\gamma_5}{2}\right] ,$$

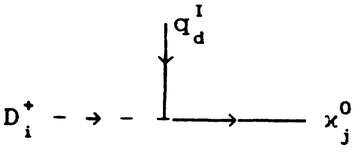


$$\frac{ie}{2\sin\theta\cos\theta}\gamma^\mu\left[Z_N^{4i*}Z_N^{4j}\frac{1-\gamma_5}{2}+Z_N^{3i}Z_N^{3j*}\frac{1+\gamma_5}{2}\right] .$$

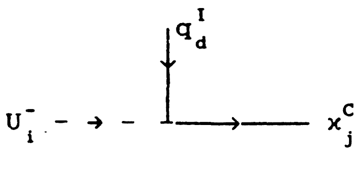
(5) Charginos-neutralinos-quarks-squarks:



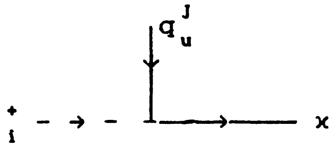
$$i\left[\left[\frac{-e}{\sqrt{2}\sin\theta\cos\theta}Z_U^{Ii*}(\tfrac{1}{3}Z_N^{1j}\sin\theta+Z_N^{2j}\cos\theta)\;-u^IZ_U^{(I+3)i*}Z_N^{4j}\right]\frac{1-\gamma_5}{2}\right.$$
$$\left.+\left[\frac{2\sqrt{2}e}{3\cos\theta}Z_U^{(I+3)i*}Z_N^{1j*}-u^IZ_U^{Ii*}Z_N^{4j*}\right]\frac{1+\gamma_5}{2}\right] ,$$



$$i\left[\left[\frac{-e}{\sqrt{2}\sin\theta\cos\theta}Z_D^{Ii}(\tfrac{1}{3}Z_N^{1j}\sin\theta-Z_N^{2j}\cos\theta)+d^IZ_D^{(I+3)i}Z_N^{3j}\right]\frac{1-\gamma_5}{2}\right.$$
$$\left.+\left[\frac{-e\sqrt{2}}{3\cos\theta}Z_D^{(I+3)i}Z_N^{1j*}+d^IZ_D^{Ii}Z_N^{3j*}\right]\frac{1+\gamma_5}{2}\right] ,$$

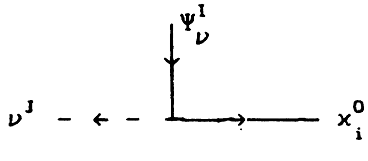


$$i\left[\left[\frac{-e}{\sin\theta}Z_U^{Ii*}Z^{+}_{1j}+u^JZ_U^{(J+3)i*}Z^{+}_{2j}\right]\frac{1-\gamma_5}{2}\;-d^IZ_U^{Ji*}Z^{-}_{2j}{}^{*}\frac{1+\gamma_5}{2}\right]C^{IJ*} ,$$

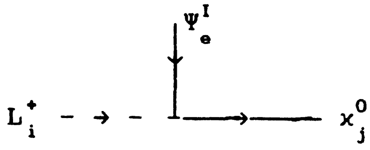


$$i\left[-\left[\frac{e}{\sin\theta}Z_D^{Ii}Z^-_{1j}+d^I Z_D^{(I+3)i}Z^-_{2j}\right]\frac{1-\gamma_5}{2}\;+u^J Z_D^{Ii}Z^{+*}_{2j}\frac{1+\gamma_5}{2}\right]C^{IJ}\,.$$

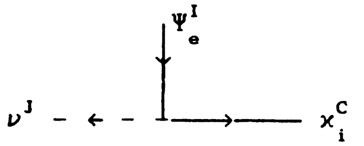
(6) Charginos-neutralinos-leptons-sleptons:



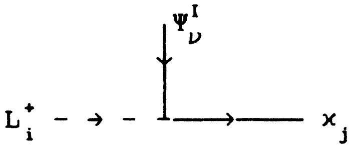
$$\frac{ie}{\sqrt{2}\sin\theta\cos\theta}Z_\nu^{IJ*}(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\frac{1-\gamma_5}{2}\;,$$



$$i\left[\left[\frac{e}{\sqrt{2}\sin\theta\cos\theta}Z_L^{Ii}(Z_N^{1j}\sin\theta+Z_N^{2j}\cos\theta)\;+l^I Z_L^{(I+3)i}Z_N^{3j}\right]\frac{1-\gamma_5}{2}\right.$$
$$\left.+\left[\frac{-e\sqrt{2}}{\cos\theta}Z_L^{(I+3)i}Z_N^{1j*}+l^I Z_L^{Ii}Z_N^{3j*}\right]\frac{1+\gamma_5}{2}\right]\,,$$

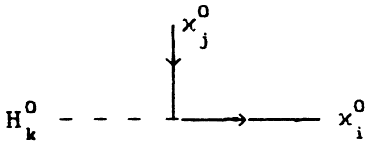


$$-i\left[\frac{e}{\sin\theta}Z^+_{1i}\frac{1-\gamma_5}{2}+l^I Z^{-*}_{2i}\frac{1+\gamma_5}{2}\right]Z_\nu^{IJ*}\;,$$

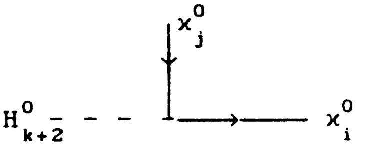


$$-i\left[\frac{e}{\sin\theta}Z_L^{Ii}Z^-_{1j}+l^I Z_L^{(I+3)i}Z^-_{2j}\right]\frac{1-\gamma_5}{2}\;.$$

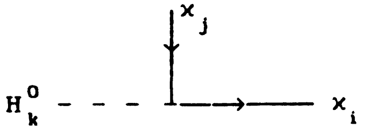
(7) Charginos–neutralinos–Higgs-particles:



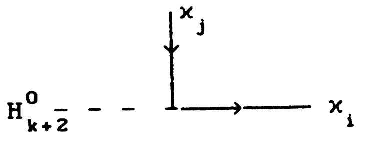
$$\frac{ie}{2\sin\theta\cos\theta}\left[(Z_R^{1k}Z_N^{3j}-Z_R^{2k}Z_N^{4j})(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\frac{1-\gamma_5}{2}\right.$$
$$\left.+(Z_R^{1k}Z_N^{3i*}-Z_R^{2k}Z_N^{4i*})(Z_N^{1j*}\sin\theta-Z_N^{2j*}\cos\theta)\frac{1+\gamma_5}{2}\right]\,,$$



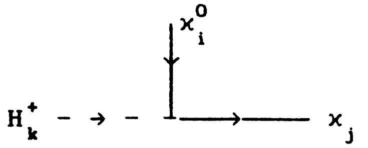
$$\frac{e}{2\sin\theta\cos\theta}\left[(Z_H^{1k}Z_N^{3j}-Z_H^{2k}Z_N^{4j})(Z_N^{1i}\sin\theta-Z_N^{2i}\cos\theta)\frac{1-\gamma_5}{2}\right.$$
$$\left.-(Z_H^{1k}Z_N^{3i*}-Z_H^{2k}Z_N^{4i*})(Z_N^{1j*}\sin\theta-Z_N^{2j*}\cos\theta)\frac{1+\gamma_5}{2}\right]\,,$$



$$-\frac{ie}{\sqrt{2}\sin\theta}\left[(Z_R^{1k}Z^-_{2i}Z^+_{1j}+Z_R^{2k}Z^-_{1i}Z^+_{2j})\frac{1-\gamma_5}{2}\right.$$
$$\left.+(Z_R^{1k}Z^{-*}_{2j}Z^{+*}_{1i}+Z_R^{2k}Z^{-*}_{1j}Z^{+*}_{2i})\frac{1+\gamma_5}{2}\right]\,,$$

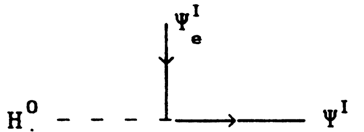


$$\frac{e}{\sqrt{2}\sin\theta}\left[-(Z_H^{1k}Z_{2i}^{-}Z_{1j}^{+}+Z_H^{2k}Z_{1i}^{-}Z_{2j}^{+})\frac{1-\gamma_5}{2}\right.$$
$$\left.+(Z_H^{1k}Z_{2j}^{-*}Z_{1i}^{+*}+Z_H^{2k}Z_{1j}^{-*}Z_{2i}^{+*})\frac{1+\gamma_5}{2}\right],$$

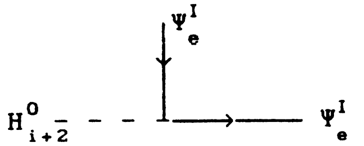


$$\frac{ie}{\sin\theta\cos\theta}\left[Z_H^{1k}\left[\frac{1}{\sqrt{2}}Z_{2j}^{-}(Z_N^{1i}\sin\theta+Z_N^{2i}\cos\theta)-Z_{1j}^{-}Z_N^{3i}\cos\theta\right]\frac{1-\gamma_5}{2}\right.$$
$$\left.-Z_H^{2k}\left[\frac{1}{\sqrt{2}}Z_{2j}^{+*}(Z_N^{1i*}\sin\theta+Z_N^{2i*}\cos\theta)+Z_{1j}^{+*}Z_N^{4i*}\cos\theta\right]\frac{1+\gamma_5}{2}\right].$$

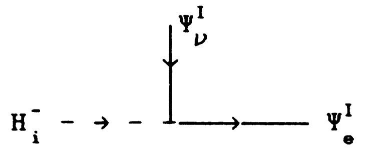
(8) Leptons–quarks–Higgs-particles:



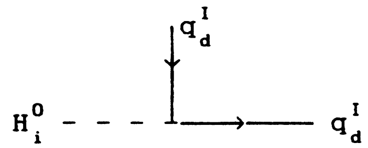
$$\frac{i}{\sqrt{2}}l^I Z_R^{1i},$$



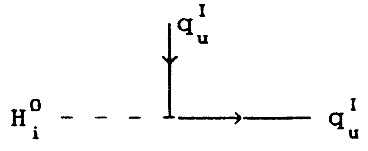
$$\frac{1}{\sqrt{2}}l^I Z_H^{1i}\gamma_5,$$



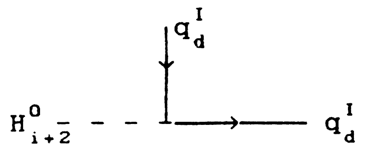
$$-il^I Z_H^{1i}\frac{1-\gamma_5}{2},$$



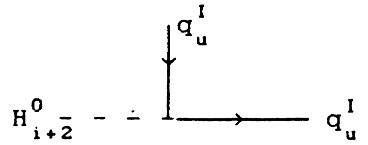
$$\frac{i}{\sqrt{2}}d^I Z_R^{1i},$$



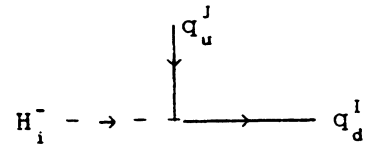
$$-\frac{i}{\sqrt{2}}u^I Z_R^{2i},$$



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

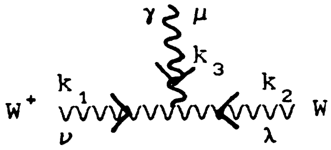


$$-\frac{1}{\sqrt{2}}u^I Z_H^{2i}\gamma_5,$$

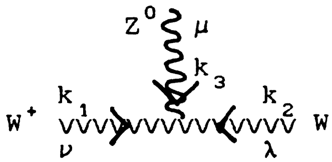


$$i\left[-d^I Z_H^{1i}\frac{1-\gamma_5}{2}+u^J Z_H^{2i}\frac{1+\gamma_5}{2}\right]C^{IJ} .$$

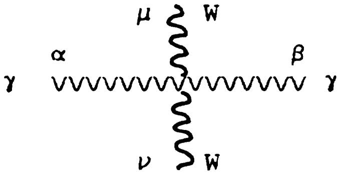
(9) Self-interactions of the gauge bosons:



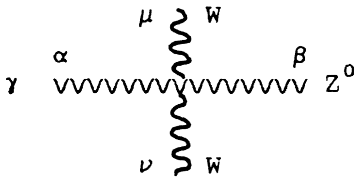
$$ie[g^{\nu\lambda}(k_1-k_2)^\mu+g^{\lambda\mu}(k_2-k_3)^\nu+g^{\mu\nu}(k_3-k_1)^\lambda] ,$$



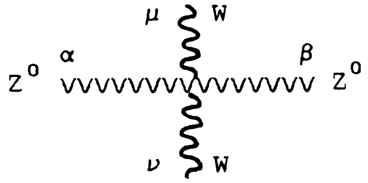
$$ie\cot\theta[g^{\nu\lambda}(k_1-k_2)^\mu+g^{\lambda\mu}(k_2-k_3)^\nu+g^{\mu\nu}(k_3-k_1)^\lambda] ,$$



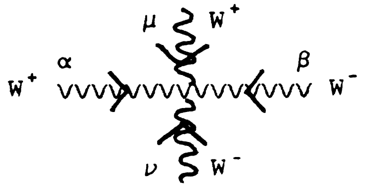
$$-ie^2(2g^{\alpha\beta}g^{\mu\nu}-g^{\alpha\mu}g^{\beta\nu}-g^{\alpha\nu}g^{\beta\mu}) ,$$



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

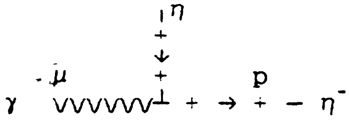


$$-ie^2\cot^2\theta(2g^{\alpha\beta}g^{\mu\nu}-g^{\alpha\mu}g^{\beta\nu}-g^{\alpha\nu}g^{\beta\mu}) ,$$

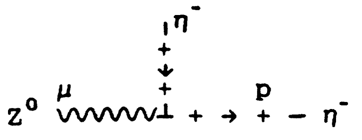


$$\frac{ie^2}{\sin^2\theta}(2g^{\alpha\mu}g^{\beta\nu}-g^{\alpha\nu}g^{\beta\mu}-g^{\alpha\beta}g^{\mu\nu}) .$$

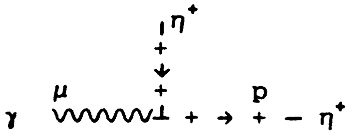
(10) Ghost terms:



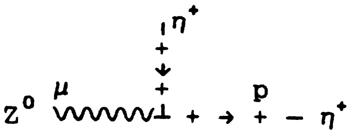
$$-iep^\mu ,$$



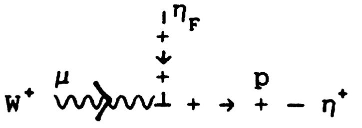
$-ie\cot\theta p^{\mu}$,



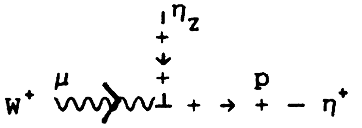
iep^{μ} ,



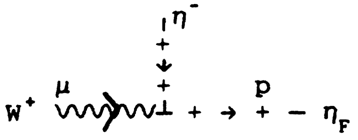
$ie\cot\theta p^{\mu}$,



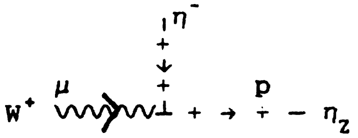
$-iep^{\mu}$,



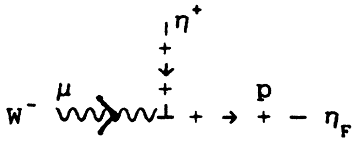
$-ie\cot\theta p^{\mu}$,



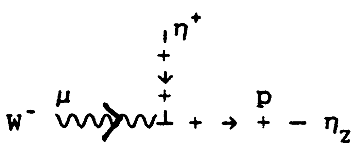
iep^{μ} ,



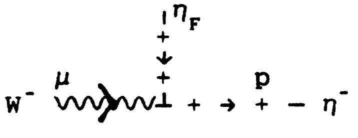
$ie\cot\theta p^{\mu}$,



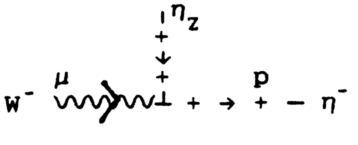
$-iep^{\mu}$,



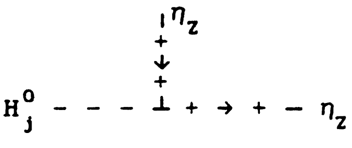
$-ie\cot\theta p^{\mu}$,



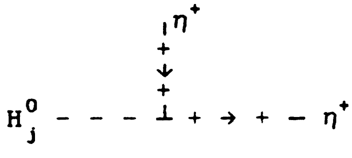
iep^{μ} ,



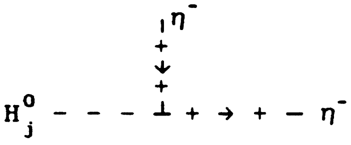
$ie\cot\theta p^{\mu}$,



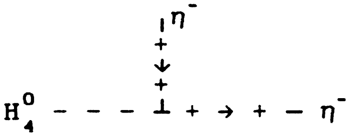
$-\frac{ie^2}{4\sin^2\theta\cos^2\theta}v_iZ_R^{ij}$,



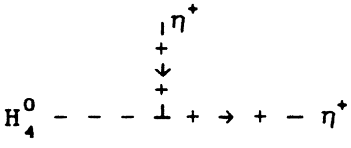
$-\frac{ie^2}{4\sin^2\theta}v_iZ_R^{ij}$,



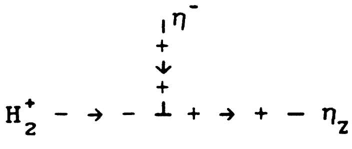
$-\frac{ie^2}{4\sin^2\theta}v_iZ_R^{ij}$,



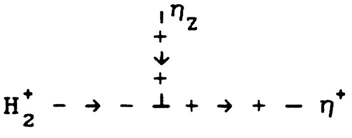
$-\frac{em_W}{2\sin\theta}$,



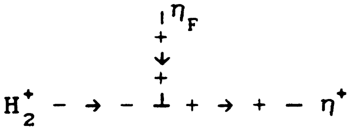
$\frac{em_W}{2\sin\theta}$,



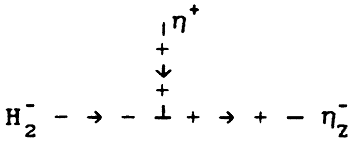
$\frac{iem_W}{2\sin\theta\cos\theta}$,



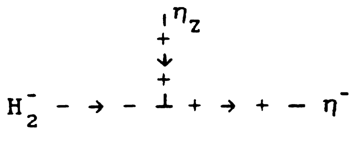
$-iem_W\cot2\theta$,



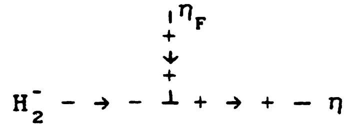
$-iem_W$,



$\frac{iem_W}{2\sin\theta\cos\theta}$,

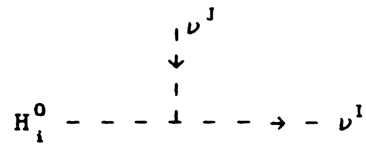


$-iem_W\cot2\theta$,

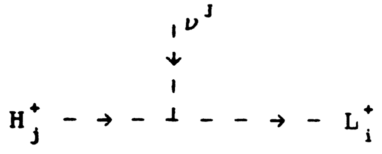


iem_W .

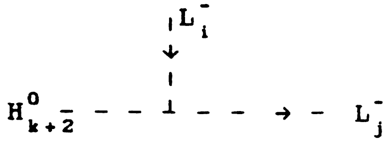
(11) Interactions of the sleptons and the Higgs particles:



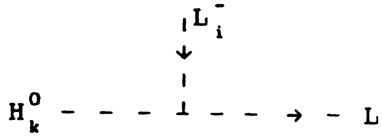
$$-\frac{ie^2}{4\sin^2\theta\cos^2\theta}B_R^i\delta^{IJ} ,$$



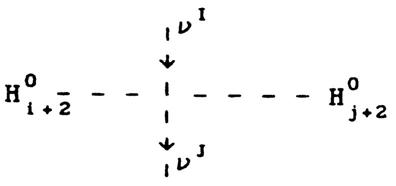
$$iZ_\nu^{IJ*}\left[-\frac{\sqrt{2}e^2}{4\sin^2\theta}v_k Z_H^{kj}Z_L^{Ii*}-Z_H^{1j}(m_e^I l^I Z_L^{Ii*}-l_S^{IK*}Z_L^{(K+3)i*})\right.$$
$$\left.+Z_H^{2j}(k_S^{IK*}Z_L^{(K+3)i*}-hl^I Z_L^{(I+3)i*})\right] ,$$



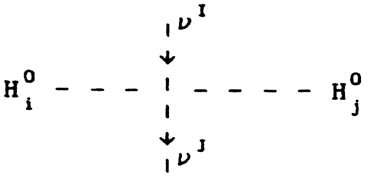
$$-\frac{1}{\sqrt{2}}[(l_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}-l_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})Z_H^{1k}$$
$$+(k_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}-k_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})Z_H^{2k}$$
$$+l^I(h^*Z_L^{Ii*}Z_L^{(I+3)j}-hZ_L^{Ij}Z_L^{(I+3)i*})Z_H^{2k}] ,$$



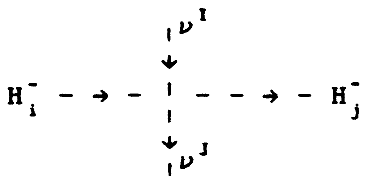
$$i\left[\frac{e^2}{2\cos^2\theta}B_R^k\left[\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]\right.$$
$$-(l^I)^2v_1Z_R^{1k}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})$$
$$-\frac{1}{\sqrt{2}}Z_R^{1k}(l_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}+l_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})$$
$$+\frac{1}{\sqrt{2}}Z_R^{2k}(k_S^{IJ*}Z_L^{Ij}Z_L^{(J+3)i*}+k_S^{IJ}Z_L^{Ii*}Z_L^{(J+3)j})$$
$$\left.-\frac{1}{\sqrt{2}}l^IZ_R^{2k}(h^*Z_L^{Ii*}Z_L^{(I+3)j}+hZ_L^{Ij}Z_L^{(I+3)i*})\right] ,$$



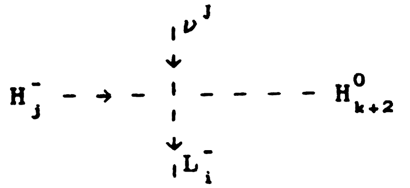
$$-\frac{ie^2}{4\sin^2\theta\cos^2\theta}A_H^{ij}\delta^{IJ} ,$$



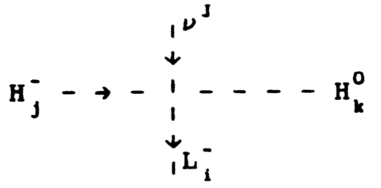
$$-\frac{ie^2}{4\sin^2\theta\cos^2\theta}A_R^{ij}\delta^{IJ} ,$$



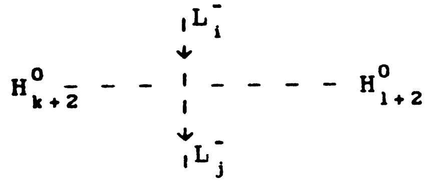
$$iZ_\nu^{KJ*}Z_\nu^{KI}(e^2\cot^2\theta A_H^{ij}-(l^K)^2Z_H^{1i}Z_H^{1j}) ,$$



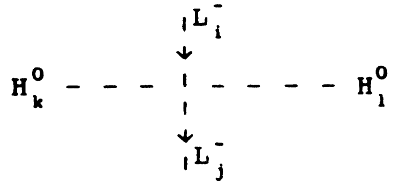
$$-\frac{1}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\left[\frac{e^2}{2\sin^2\theta}A_H^{jk}-(l^I)^2Z_H^{1j}Z_H^{1k}\right] ,$$



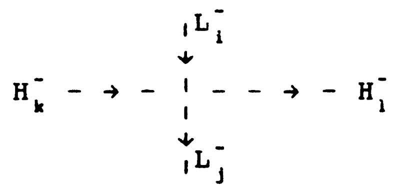
$$\frac{i}{\sqrt{2}}Z_L^{Ii}Z_\nu^{IJ}\left[\frac{-e^2}{2\sin^2\theta}(Z_H^{1j}Z_R^{1k}+Z_H^{2j}Z_R^{2k})+(l^I)^2Z_H^{1j}Z_R^{1k}\right] ,$$



$$i\left[\frac{e^2}{2\cos^2\theta}A_H^{kl}\left[\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]\right.$$
$$\left.-(l^I)^2Z_H^{1k}Z_H^{1l}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})\right] ,$$

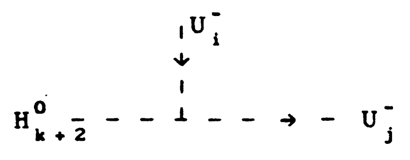


$$i\left[\frac{e^2}{2\cos^2\theta}A_R^{kl}\left[\delta^{ij}+\frac{1-4\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]\right.$$
$$\left.-(l^I)^2Z_R^{1k}Z_R^{1l}(Z_L^{Ii*}Z_L^{Ij}+Z_L^{(I+3)i*}Z_L^{(I+3)j})\right] ,$$

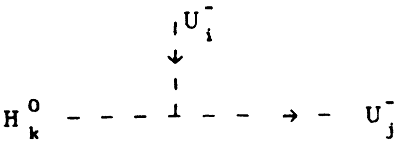


$$i\left[\frac{e^2}{2\cos^2\theta}A_H^{kl}\left[\delta^{ij}-\frac{1+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}\right]\right.$$
$$\left.-(l^I)^2Z_H^{1k}Z_H^{1l}Z_L^{(I+3)i*}Z_L^{(I+3)j}\right] .$$

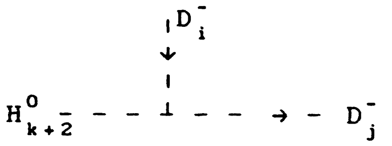
(12) Interactions of the squarks and the Higgs particles:



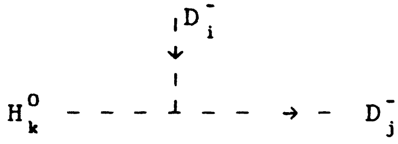
$$-\frac{1}{\sqrt{2}}[u^I(hZ_U^{Ii*}Z_U^{(I+3)j}-h^*Z_U^{Ij}Z_U^{(I+3)i*})Z_H^{1k}$$
$$+(u_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*}-u_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j})Z_H^{2k}$$
$$+(w_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}-w_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})Z_H^{1k}] ,$$



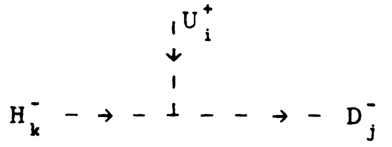
$$\begin{aligned} i\bigg[&\frac{-e^2}{3\cos^2\theta}B_R^k\left(\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right)\\ &-(u^I)^2v_2Z_R^{2k}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})\\ &+\frac{1}{\sqrt{2}}Z_R^{2k}(u_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}+u_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})\\ &+\frac{1}{\sqrt{2}}Z_R^{1k}(w_S^{IJ*}Z_U^{Ii*}Z_U^{(J+3)j}+w_S^{IJ}Z_U^{Ij}Z_U^{(J+3)i*})\\ &+\frac{1}{\sqrt{2}}u^IZ_R^{1k}(h^*Z_U^{Ij}Z_U^{(I+3)i*}+hZ_U^{Ii*}Z_U^{(I+3)j})\bigg]\,, \end{aligned}$$



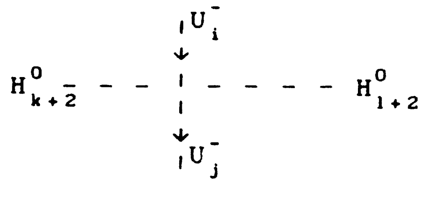
$$\begin{aligned} -\frac{1}{\sqrt{2}}[&(d_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}-d_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})Z_H^{1k}\\ &+(e_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}-e_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})Z_H^{2k}\\ &+d^I(h^*Z_D^{Ii*}Z_D^{(I+3)j}-hZ_D^{Ij}Z_D^{(I+3)i*})Z_H^{2k}]\,, \end{aligned}$$



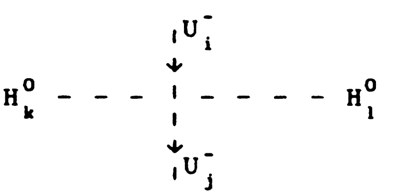
$$\begin{aligned} i\bigg[&\frac{e^2}{6\cos^2\theta}B_R^k\left(\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right)\\ &-(d^I)^2v_1Z_R^{1k}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})\\ &-\frac{1}{\sqrt{2}}Z_R^{1k}(d_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}+d_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})\\ &+\frac{1}{\sqrt{2}}Z_R^{2k}(e_S^{IJ*}Z_D^{Ij}Z_D^{(J+3)i*}+e_S^{IJ}Z_D^{Ii*}Z_D^{(J+3)j})\\ &-\frac{1}{\sqrt{2}}d^IZ_R^{2k}(h^*Z_D^{Ii*}Z_D^{(I+3)j}+hZ_D^{Ij}Z_D^{(I+3)i*})\bigg]\,, \end{aligned}$$



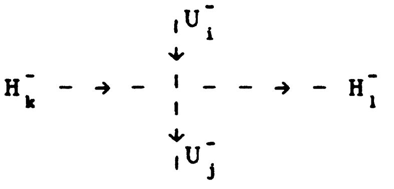
$$\begin{aligned} i\bigg[&\frac{1}{\sqrt{2}}\left(-\frac{e^2}{2\sin^2\theta}v_lZ_H^{lk}+v_1(d^I)^2Z_H^{1k}+v_2(u^J)^2Z_H^{2k}\right)C^{IJ*}Z_D^{Ij*}Z_U^{Ji*}\\ &-\frac{\sqrt{2}m_W\sin\theta}{e}\delta^{1k}u^Jd^IC^{IJ*}Z_D^{(I+3)j*}Z_U^{(J+3)i*}\\ &+[Z_H^{1k}h^*u^JC^{IJ*}+(Z_H^{1k}w_S^{KJ}-Z_H^{2k}u_S^{KJ})C^{IK*}]Z_U^{(J+3)i*}Z_D^{Ij*}\\ &+[(Z_H^{1k}d_S^{KI*}+Z_H^{2k}e_S^{KI*})C^{KJ*}-Z_H^{2k}hd^IC^{IJ*}]Z_U^{Ji*}Z_D^{(I+3)j*}\bigg]\,, \end{aligned}$$



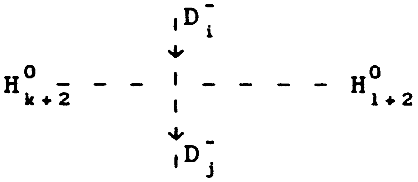
$$\begin{aligned} i\bigg[&\frac{-e^2}{3\cos^2\theta}A_H^{kl}\left(\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right)\\ &-(u^I)^2Z_H^{2k}Z_H^{2l}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})\bigg]\,, \end{aligned}$$



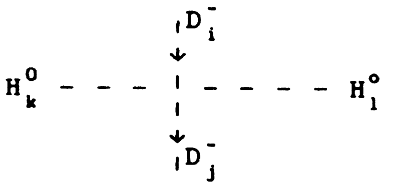
$$i\left[\frac{-e^2}{3\cos^2\theta}A_R^{kl}\left[\delta^{ij}+\frac{3-8\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]\right.$$
$$\left.-(u^I)^2Z_R^{2k}Z_R^{2l}(Z_U^{Ii*}Z_U^{Ij}+Z_U^{(I+3)i*}Z_U^{(I+3)j})\right],$$



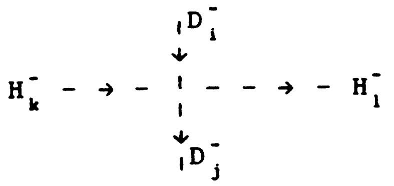
$$i\left[\frac{-e^2}{3\cos^2\theta}A_H^{kl}\left[\delta^{ij}-\frac{3+2\sin^2\theta}{4\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}\right]\right.$$
$$\left.-(u^I)^2Z_H^{2k}Z_H^{2l}Z_U^{(I+3)i*}Z_U^{(I+3)j}-(d^I)^2Z_H^{1k}Z_H^{1l}C^{IJ}C^{IK*}Z_U^{Ki*}Z_U^{Jj}\right],$$



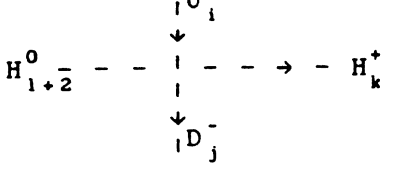
$$i\left[\frac{e^2}{6\cos^2\theta}A_H^{kl}\left[\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]\right.$$
$$\left.-(d^I)^2Z_H^{1k}Z_H^{1l}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})\right],$$



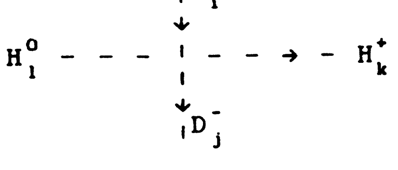
$$i\left[\frac{e^2}{6\cos^2\theta}A_R^{kl}\left[\delta^{ij}+\frac{3-4\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]\right.$$
$$\left.-(d^I)^2Z_R^{1k}Z_R^{1l}(Z_D^{Ii*}Z_D^{Ij}+Z_D^{(I+3)i*}Z_D^{(I+3)j})\right],$$



$$i\left[\frac{e^2}{6\cos^2\theta}A_H^{kl}\left[\delta^{ij}-\frac{3-2\sin^2\theta}{2\sin^2\theta}Z_D^{Ii*}Z_D^{Ij}\right]\right.$$
$$\left.-(d^I)^2Z_H^{1k}Z_H^{1l}Z_D^{(I+3)i*}Z_D^{(I+3)j}-(u^K)^2Z_H^{2k}Z_H^{2l}C^{IK}C^{JK*}Z_D^{Ii*}Z_D^{Ij}\right],$$

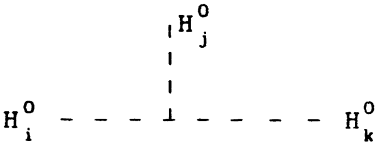


$$-\frac{1}{\sqrt{2}}C^{IJ}\left[\frac{e^2}{2\sin^2\theta}A_H^{kl}Z_U^{Ji}Z_D^{Ij}+[(u^J)^2Z_H^{2k}Z_H^{2l}-(d^I)^2Z_H^{1k}Z_H^{1l}]Z_U^{Ji}Z_D^{Ij}\right.$$
$$\left.-\epsilon_{kl}u^Jd^IZ_U^{(J+3)i}Z_D^{(I+3)j}\right],$$

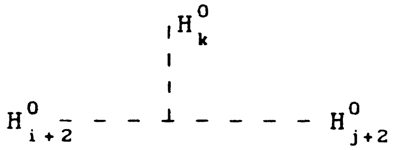


$$\frac{i}{\sqrt{2}}C^{IJ}\left[\frac{-e^2}{2\sin^2\theta}(Z_H^{1k}Z_R^{1l}+Z_H^{2k}Z_R^{2l})Z_U^{Ji}Z_D^{Ij}\right.$$
$$-A_P^{lk}u^Jd^IZ_U^{(J+3)i}Z_D^{(I+3)j}$$
$$\left.+[(u^J)^2Z_H^{2k}Z_R^{2l}+(d^I)^2Z_H^{1k}Z_R^{1l}]Z_U^{Ji}Z_D^{Ij}\right].$$

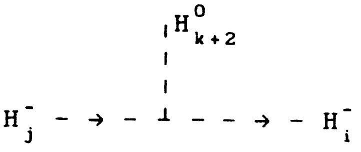
(13) Self-interactions of the Higgs particles:



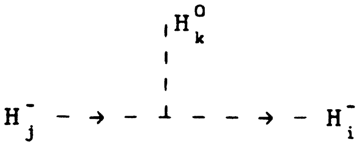
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}[3v_1Z_R^{1i}Z_R^{1j}Z_R^{1k}+3v_2Z_R^{2i}Z_R^{2j}Z_R^{2k}-v_2(Z_R^{1i}Z_R^{1j}Z_R^{2k}+Z_R^{1i}Z_R^{2j}Z_R^{1k}+Z_R^{2i}Z_R^{1j}Z_R^{1k})-v_1(Z_R^{2i}Z_R^{2j}Z_R^{1k}+Z_R^{2i}Z_R^{1j}Z_R^{2k}+Z_R^{1i}Z_R^{2j}Z_R^{2k})] ,$$



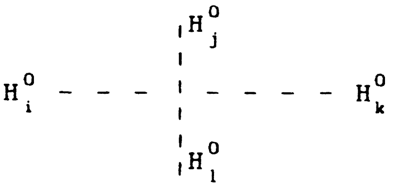
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}A_H^{ij}B_R^k ,$$



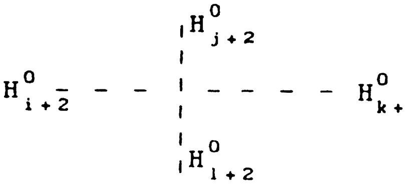
$$\frac{-em_W}{2\sin\theta}\epsilon_{ij}\delta^{1k} ,$$



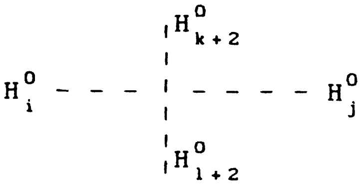
$$-i\left[\frac{e^2}{4\sin^2\theta\cos^2\theta}A_H^{ij}B_R^k+\frac{em_W}{2\sin\theta}(A_P^{kj}\delta_{1i}+A_P^{ki}\delta_{1j})\right] ,$$



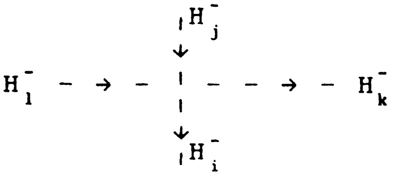
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}(3Z_R^{1i}Z_R^{1j}Z_R^{1k}Z_R^{1l}+3Z_R^{2i}Z_R^{2j}Z_R^{2k}Z_R^{2l}-Z_R^{1i}Z_R^{1j}Z_R^{2k}Z_R^{2l}-Z_R^{1i}Z_R^{2j}Z_R^{1k}Z_R^{2l}-Z_R^{1i}Z_R^{2j}Z_R^{2k}Z_R^{1l}-Z_R^{2i}Z_R^{1j}Z_R^{1k}Z_R^{2l}-Z_R^{2i}Z_R^{1j}Z_R^{2k}Z_R^{1l}-Z_R^{2i}Z_R^{2j}Z_R^{1k}Z_R^{1l}) ,$$



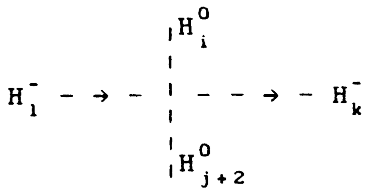
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}(3Z_H^{1i}Z_H^{1j}Z_H^{1k}Z_H^{1l}+3Z_H^{2i}Z_H^{2j}Z_H^{2k}Z_H^{2l}-Z_H^{1i}Z_H^{1j}Z_H^{2k}Z_H^{2l}-Z_H^{1i}Z_H^{2j}Z_H^{1k}Z_H^{2l}-Z_H^{1l}Z_H^{2j}Z_H^{2k}Z_H^{1l}-Z_H^{2i}Z_H^{1j}Z_H^{1k}Z_H^{2l}-Z_H^{2i}Z_H^{1j}Z_H^{2k}Z_H^{1l}-Z_H^{2i}Z_H^{2j}Z_H^{1k}Z_H^{1l}) ,$$



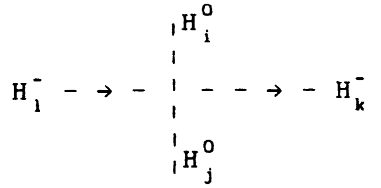
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}A_R^{ij}A_H^{kl} ,$$



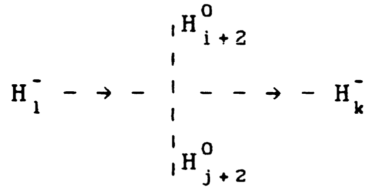
$$\frac{-ie^2}{4\sin^2\theta\cos^2\theta}[2Z_H^{1i}Z_H^{1j}Z_H^{1k}Z_H^{1l}+2Z_H^{2i}Z_H^{2j}Z_H^{2k}Z_H^{2l}-(Z_H^{1i}Z_H^{2k}+Z_H^{1k}Z_H^{2i})(Z_H^{1j}Z_H^{2l}+Z_H^{1l}Z_H^{2j})] ,$$



$$\frac{-e^2}{4\sin^2\theta} A_P^{ij} \epsilon_{kl} \ ,$$

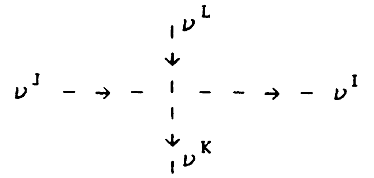


$$\frac{-ie^2}{2\sin^2\theta} \left[\frac{1}{2\cos^2\theta} A_R^{ij} A_H^{kl} + A_P^{jk} A_P^{jl} \right] ,$$

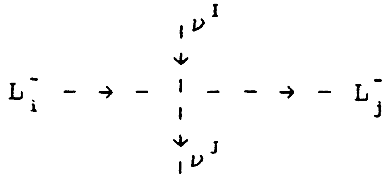


$$\frac{-ie^2}{2\sin^2\theta} \left[\frac{1}{2\cos^2\theta} A_H^{ij} A_H^{kl} + \epsilon_{ik} \epsilon_{jl} \right] .$$

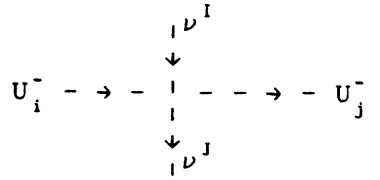
(14) Interactions of four sleptons or two sleptons and two squarks:



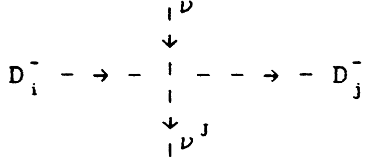
$$-\frac{ie^2}{4\sin^2\theta\cos^2\theta} (\delta^{IJ}\delta^{KL} + \delta^{IL}\delta^{KJ}) \ ,$$



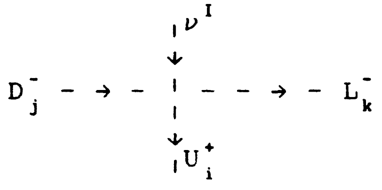
$$i \left[\frac{e^2}{2\cos^2\theta} \left[\delta^{ij} + \frac{1-4\sin^2\theta}{2\sin^2\theta} Z_L^{Ki*} Z_L^{Kj} \right] \delta^{IJ} \right.$$
$$\left. - \left[\frac{e^2}{2\sin^2\theta} Z_L^{Ki*} Z_L^{Lj} + l^K l^L Z_L^{(K+3)i*} Z_L^{(L+3)j} \right] Z_\nu^{LI} Z_\nu^{KJ*} \right] ,$$



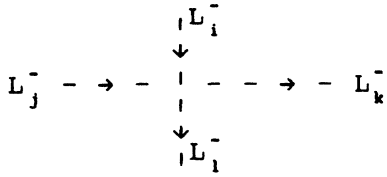
$$\frac{-ie^2}{3\cos^2\theta} \left[\delta^{ij} + \frac{3-8\sin^2\theta}{4\sin^2\theta} Z_U^{Ki*} Z_U^{Kj} \right] \delta^{IJ} ,$$



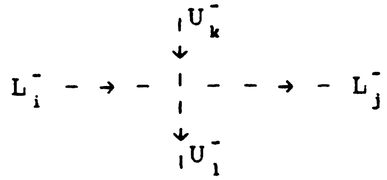
$$\frac{ie^2}{6\cos^2\theta} \left[\delta^{ij} + \frac{3-4\sin^2\theta}{2\sin^2\theta} Z_D^{Ki*} Z_D^{Kj} \right] \delta^{IJ} ,$$



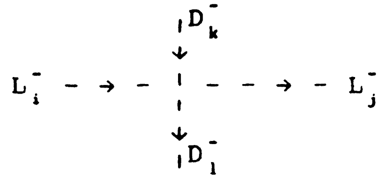
$$-iZ_\nu^{JI} Z_U^{Li*} C^{KL*} \left[\frac{e^2}{2\sin^2\theta} Z_D^{Kj*} Z_L^{Jk} + l^J d^K Z_D^{(K+3)j*} Z_L^{(J+3)k} \right] ,$$



$$i\left[\frac{-e^2}{\cos^2\theta}(\delta^{il}\delta^{jk}+\delta^{ik}\delta^{jl})\right.$$
$$+\frac{3e^2}{2\cos^2\theta}(\delta^{il}Z_L^{Ij*}Z_L^{Ik}+\delta^{ik}Z_L^{Ij*}Z_L^{Il}+\delta^{jl}Z_L^{Ii*}Z_L^{Ik}+\delta^{jk}Z_L^{Ii*}Z_L^{Il})$$
$$-\frac{e^2(1+8\sin^2\theta)}{4\sin^2\theta\cos^2\theta}(Z_L^{Ii*}Z_L^{Jj*}Z_L^{Jk}Z_L^{Il}+Z_L^{Ii*}Z_L^{Jj*}Z_L^{Jl}Z_L^{Ik})$$
$$\left.-l^Il^J(Z_L^{(I+3)i*}Z_L^{Jj*}+Z_L^{(I+3)j*}Z_L^{Ji*})(Z_L^{Il}Z_L^{(J+3)k}+Z_L^{Ik}Z_L^{(J+3)l})\right],$$

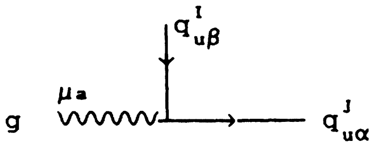


$$\frac{ie^2}{6\cos^2\theta}\left[\frac{3+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}Z_U^{Jk*}Z_U^{Jl}\right.$$
$$\left.-2\delta^{kl}Z_L^{Ii*}Z_L^{Ij}-5\delta^{ij}Z_U^{Ik*}Z_U^{Il}+4\delta^{ij}\delta^{kl}\right],$$

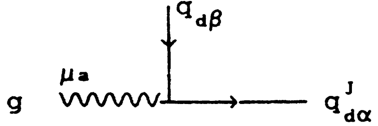


$$i\left[-\frac{e^2}{6\cos^2\theta}\left[\frac{3+2\sin^2\theta}{2\sin^2\theta}Z_L^{Ii*}Z_L^{Ij}Z_D^{Jk*}Z_D^{Jl}\right.\right.$$
$$\left.-4\delta^{kl}Z_L^{Ii*}Z_L^{Ij}-\delta^{ij}Z_D^{Ik*}Z_D^{Il}+2\delta^{ij}\delta^{kl}\right]$$
$$-l^Id^J(Z_L^{(I+3)i*}Z_L^{Ij}Z_D^{Jk*}Z_D^{(J+3)l}$$
$$\left.+Z_L^{Ii*}Z_L^{(I+3)j}Z_D^{(J+3)k*}Z_D^{Jl})\right].$$

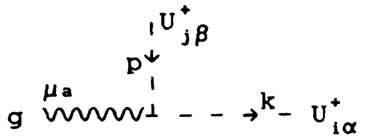
(15) Strong interactions of the quarks, squarks, gluons, and gluinos:



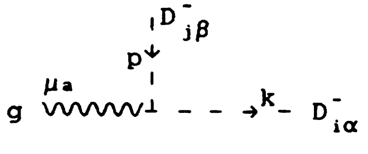
$$-ig_3Y^a_{\alpha\beta}\gamma^\mu\delta^{IJ},$$



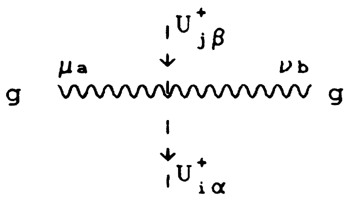
$$-ig_3Y^a_{\alpha\beta}\gamma^\mu\delta^{IJ},$$



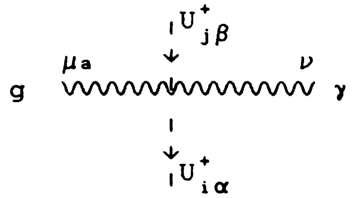
$$-ig_3(p+k)^\mu Y^a_{\alpha\beta}\delta^{ij},$$



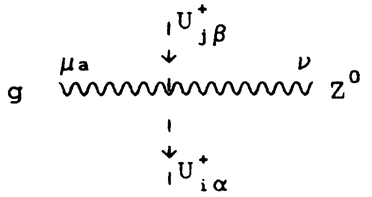
$$-ig_3(p+k)^\mu Y^a_{\alpha\beta}\delta^{ij},$$



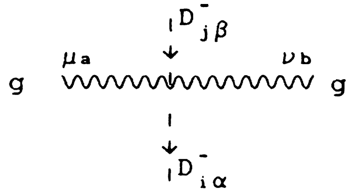
$2ig_3^2(Y^aY^b)_{\alpha\beta}g^{\mu\nu}\delta^{ij}$,



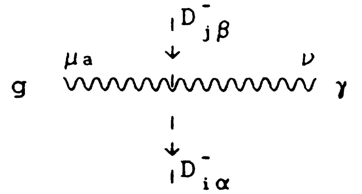
$\frac{4}{3}ieg_3Y^a_{\alpha\beta}g^{\mu\nu}\delta^{ij}$,



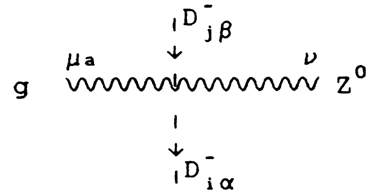
$\frac{ieg_3}{\sin\theta\cos\theta}(Z_U^{Ii*}Z_U^{Ij}-\frac{4}{3}\delta^{ij}\sin^2\theta)Y^a_{\alpha\beta}g^{\mu\nu}$,



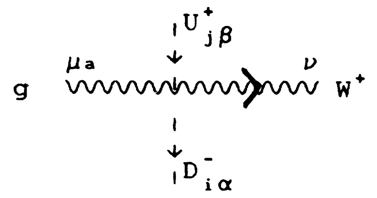
$2ig_3^2(Y^aY^b)_{\alpha\beta}g^{\mu\nu}\delta^{ij}$,



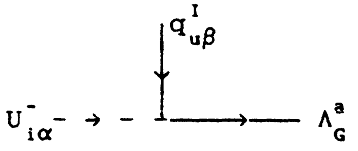
$-\frac{2}{3}ieg_3Y^a_{\alpha\beta}g^{\mu\nu}\delta^{ij}$,



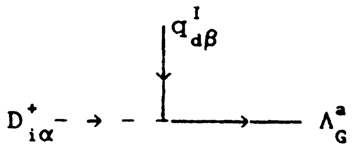
$\frac{ieg_3}{\sin\theta\cos\theta}(-Z_D^{Ii}Z_D^{Ij*}+\frac{2}{3}\delta^{ij}\sin^2\theta)Y^a_{\alpha\beta}g^{\mu\nu}$,



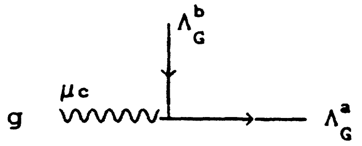
$\frac{ieg_3\sqrt{2}}{\sin\theta}Z_D^{Ii}Z_U^{Jj}C^{IJ}Y^a_{\alpha\beta}g^{\mu\nu}$,



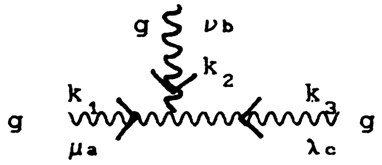
$$ig_3\sqrt{2}\,Y^a_{\alpha\beta}\left[-Z_U^{Ii*}\frac{1-\gamma_5}{2}+Z_U^{(I+3)i*}\frac{1+\gamma_5}{2}\right],$$



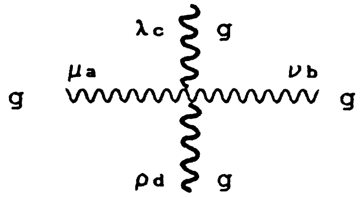
$$ig_3\sqrt{2}\,Y^a_{\alpha\beta}\left[-Z_D^{Ii}\frac{1-\gamma_5}{2}+Z_D^{(I+3)i}\frac{1+\gamma_5}{2}\right],$$



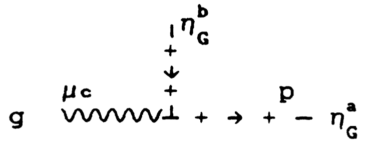
$$-\tfrac{1}{2}g_3 f_{abc}\gamma^{\mu},$$



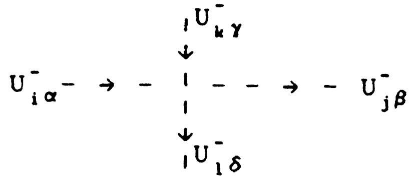
$$-g_3 f_{abc}[g^{\mu\nu}(k_1-k_2)^{\lambda}+g^{\nu\lambda}(k_2-k_3)^{\mu}+g^{\mu\lambda}(k_3-k_1)^{\nu}],$$



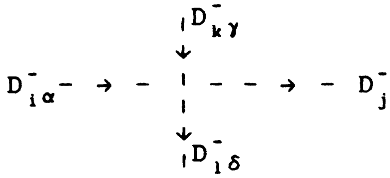
$$-ig_3^2[f_{abe}f_{cde}(g^{\nu\lambda}g^{\nu\rho}-g^{\mu\rho}g^{\nu\lambda})+f_{ade}f_{bce}(g^{\mu\nu}g^{\lambda\rho}-g^{\mu\lambda}g^{\nu\rho})$$
$$+f_{ace}f_{dbe}(g^{\mu\rho}g^{\nu\lambda}-g^{\mu\nu}g^{\lambda\rho})],$$



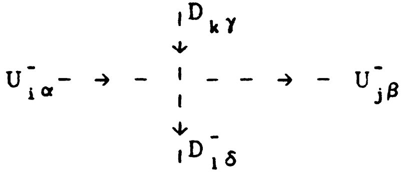
$$g_3 f_{abc}p^{\mu},$$



$$i\Bigg[\tfrac{1}{6}g_3^2(\delta^{ij}\delta^{kl}+\delta^{il}\delta^{jk}-2\delta^{ij}Z_U^{Ik*}Z_U^{Il}-2\delta^{il}Z_U^{Ik*}Z_U^{Ij}-2\delta^{kj}Z_U^{Ii*}Z_U^{Il}$$
$$-2\delta^{kl}Z_U^{Ii*}Z_U^{Ij}+Z_U^{Ii*}Z_U^{Ij}Z_U^{Jk*}Z_U^{Jl}+Z_U^{Ii*}Z_U^{Jj}Z_U^{Jk*}Z_U^{Il})$$
$$+\frac{2e^2}{9\cos^2\theta}\Bigg[\delta^{ij}\delta^{kl}+\delta^{il}\delta^{jk}-\tfrac{5}{4}(\delta^{ij}Z_U^{Ik*}Z_U^{Il}$$
$$+\delta^{il}Z_U^{Ik*}Z_U^{Ij}+\delta^{kj}Z_U^{Ii*}Z_U^{Il}+\delta^{kl}Z_U^{Ii*}Z_U^{Ij})$$
$$+\frac{9+16\sin^2\theta}{16\sin^2\theta}(Z_U^{Ii*}Z_U^{Ij}Z_U^{Jk*}Z_U^{Jl}+Z_U^{Ii*}Z_U^{Jj}Z_U^{Jk*}Z_U^{Il})\Bigg]$$
$$+\tfrac{1}{2}u^I u^J(Z_U^{(I+3)i*}Z_U^{Ij}Z_U^{Jk*}Z_U^{(J+3)l}+Z_U^{(I+3)i*}Z_U^{Il}Z_U^{Jk*}Z_U^{(J+3)j}$$
$$+Z_U^{(I+3)k*}Z_U^{Ij}Z_U^{Ji*}Z_U^{(J+3)l}$$
$$+Z_U^{(I+3)k*}Z_U^{Il}Z_U^{Ji*}Z_U^{(J+3)j})\Bigg](\delta_{\alpha\delta}\delta_{\beta\gamma}+\delta_{\alpha\beta}\delta_{\gamma\delta}),$$



$$
\begin{aligned}
i\biggl[&\tfrac{1}{6}g_3^2(\delta^{ij}\delta^{kl}+\delta^{il}\delta^{jk}-2\delta^{ij}Z_D^{Ik*}Z_D^{Il}-2\delta^{il}Z_D^{Ik*}Z_D^{Ij}-2\delta^{kj}Z_D^{Ii*}Z_D^{Il}\\
&\qquad-2\delta^{kl}Z_D^{Ii*}Z_D^{Ij}+Z_D^{Ii*}Z_D^{Ij}Z_D^{Jk*}Z_D^{Jl}+Z_D^{Ii*}Z_D^{Jj}Z_D^{Jk*}Z_D^{Il})\\
&+\frac{e^2}{18\cos^2\theta}\biggl[\delta^{ij}\delta^{kl}+\delta^{il}\delta^{jk}-\tfrac{1}{2}(\delta^{ij}Z_D^{Ik*}Z_D^{Il}\\
&\qquad\qquad+\delta^{il}Z_D^{Ik*}Z_D^{Ij}+\delta^{kj}Z_D^{Ii*}Z_D^{Il}+\delta^{kl}Z_D^{Ii*}Z_D^{Ij})\\
&\qquad+\frac{9-8\sin^2\theta}{4\sin^2\theta}(Z_D^{Ii*}Z_D^{Ij}Z_D^{Jk*}Z_D^{Jl}+Z_D^{Ii*}Z_D^{Jj}Z_D^{Jk*}Z_D^{Il})\biggr]\\
&+\tfrac{1}{2}d^Id^J(Z_D^{Ii*}Z_D^{(I+3)j}Z_D^{(J+3)k*}Z_D^{Jl}+Z_D^{Ii*}Z_D^{(I+3)l}Z_D^{(J+3)k*}Z_D^{Jj}\\
&\qquad+Z_D^{Ik*}Z_D^{(I+3)j}Z_D^{(J+3)i*}Z_D^{Jl}\\
&\qquad+Z_D^{Ik*}Z_D^{(I+3)l}Z_D^{(J+3)i*}Z_D^{Jj})\biggr](\delta_{\alpha\delta}\delta_{\beta\gamma}+\delta_{\alpha\beta}\delta_{\gamma\delta})\ ,
\end{aligned}
$$



$$
\begin{aligned}
i\biggl[&\tfrac{1}{12}g_3^2(\delta^{ij}-2Z_U^{Ii*}Z_U^{Ij})(\delta^{kl}-2Z_D^{Jk*}Z_D^{Jl})(3\delta_{\alpha\gamma}\delta_{\beta\delta}-2\delta_{\alpha\beta}\delta_{\gamma\delta})\\
&-\frac{e^2}{18\cos^2\theta}\biggl[4\delta^{ij}\delta^{kl}-2\delta^{ij}Z_D^{Ik*}Z_D^{Il}-5\delta^{kl}Z_U^{Ii*}Z_U^{Ij}\\
&\qquad+\frac{9-4\sin^2\theta}{2\sin^2\theta}Z_U^{Ii*}Z_U^{Ij}Z_D^{Jk*}Z_D^{Jl}\biggr]\delta_{\alpha\beta}\delta_{\gamma\delta}\\
&+\biggl[\frac{e^2}{2\sin^2\theta}Z_U^{Ii*}Z_U^{Jj}Z_D^{Kk*}Z_D^{Ll}+u^Iu^JZ_U^{(I+3)i*}Z_U^{(J+3)j}Z_D^{Kk*}Z_D^{Ll}\\
&\qquad+d^Kd^LZ_U^{Ii*}Z_U^{Jj}Z_D^{(K+3)k*}Z_D^{(L+3)l}\biggr]C^{LJ}C^{KI*}\delta_{\alpha\gamma}\delta_{\beta\delta}\biggr]\ .
\end{aligned}
$$

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