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SPheno, a program for calculating supersymmetric spectra, SUSY particle decays and SUSY particle production at e^+e^- colliders

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Abstract

SPheno is a program that accurately calculates the supersymmetric particle spectrum within a high scale theory, such as minimal supergravity, gauge mediated supersymmetry breaking, anomaly mediated supersymmetry breaking, or string effective field theories. An interface exists for an easy implementation of other models. The program solves the renormalization group equations numerically to two–loop order with user-specified boundary conditions. The complete one–loop formulas for the masses are used which are supplemented by two–loop contributions in case of the neutral Higgs bosons and the μ parameter. The obtained masses and mixing matrices are used to calculate decay widths and branching ratios of supersymmetric particles as well as of Higgs bosons, $b \to s\gamma$, $\Delta\rho$ and $(g-2)_\mu$. Moreover, the production cross sections of all supersymmetric particle as well as Higgs bosons at e^+e^- colliders can be calculated including initial state radiation and longitudinal polarization of the incoming electrons/positrons. The program is structured such that it can easily be extend to include non-minimal models and/or complex parameters.

Contents

1 Introduction

Supersymmetry (SUSY) [1, 2, 3] provides an attractive extension of the Standard Model (SM). It provides a qualitative understanding of various phenomena in particle physics: It stabilizes the gap between the Grand Unification scale / Planck scale and the electroweak scale [4]. It allows the unification of the three gauge couplings at a scale $M_U \simeq 2 \cdot 10^{16}$ GeV in a straight forward way [5]. The large top mass generates radiative electroweak symmetry breaking [6]. In addition it provides the lightest supersymmetric particle as a cold dark matter candidate [7]. Therefore, the search for supersymmetric particles is one of the main topics in the experimental program of present and future high energy colliders [8, 9, 10, 11].

The Minimal Supersymmetric Standard Model (MSSM) consists of taking the Standard Model and adding the corresponding supersymmetric partners [3]. In addition a second Higgs doublet is needed to obtain an anomaly–free theory. The second Higgs doublet is also needed to give mass to u-type quarks and down-type quarks at the same time. The MSSM in its most general from contains more than 100 unknown parameters [12] which are clearly to many for an exhaustive study. This number drastically reduces if one embeds the MSSM in a high scale theory, such as minimal supergravity theories [13], gauge mediated supersymmetry breaking[14], or anomaly mediated supersymmetry breaking[15]. There is not yet a theoretical preferred scheme for supersymmetry breaking. For this reason it is important to know whether the precision of on-going and future experiments is sufficient: (i) To distinguish between the various schemes. (ii) To which extend it is possible to reconstruct the underlying theory. It has been demonstrated that the expected experimental accuracies at future e^+e^- colliders complemented with data from the LHC allow for a successful reconstruct of such an underlying supersymmetric high scale theory [16]. Connected with these questions is the question if the theoretical accuracy matches the experimental one. The present version of the program `SPheno`[1] is thought as a further step in getting accurate theoretical results to match finally the experimental precision.

In the view of ongoing and future experiments it is highly desirable to have various and independent tools at hand performing the calculation of the supersymmetric spectrum, of decay widths, of branching ratios and of production cross sections. This allows for a cross check of the tools and by comparing the implemented methods and approximations one can also get a rough understanding of the theoretical error. `SPheno` is a program performing an accurate calculation of the supersymmetric spectrum, of the branching ratios of supersymmetric particles and the Higgs bosons and of the production cross sections of supersymmetric particles and the Higgs bosons in e^+e^- annihilation including longitudinal beam polarization. Moreover, the spectrum is used to calculate the branching of the rare decay $b \to s\gamma$, the supersymmetric contributions to the anomalous magnetic of the muon a_μ as well as supersymmetric contributions to the ρ parameter.

For the calculation of the spectrum the programs ISASUSY [17], SOFTSUSY [18] and SUSPECT [19] are widely used. A comparison of the results among these programs and with `SPheno` is given in [20]. The calculation of the branching ratios of supersymmetric particles as well as the production cross sections in e^+e^- annihilation can be done with `SPheno` , ISASUSY [17], SPYTHIA [21] and SUSYGEN [22]. A comparison of the results of these programs will be given in a future paper.

`SPheno` has been written in Fortran90. The main focus has been on accuracy and on stable numerical results and less on speed. However, on a modern PC a typical running time is in the order of one second. The calculation is done using two-loop renormalization group equations (RGEs) [23], complete one-loop correction to all SUSY and Higgs masses [24] supplemented by the 2-loop corrections to the neutral Higgs bosons [25, 26] and to the μ parameter[26]. The present version of `SPheno` does all calculations for real parameters neglecting the flavour structure in the fermion as well as in the sfermion sector. Decay widths and cross sections are calculated using tree-level formulas. However, the couplings involved are running couplings and thus important numerical effects of higher order corrections are

[1]SPheno stands for **S**upersymmetric **Pheno**menology

already taken into account. The program has been structured in such a way that the future inclusion of complex phases and mixing between the generations has already been considered in the design of the interfaces as well as in the definition of the various variables. Moreover, extensions of the MSSM, e.g. models with broken R-parity, can be implemented easily.

The aim of this paper is to provide a manual of the program, version 2.0, to describe the approximations used and to display the results of a run. In Sect. 2 we will summarize the MSSM parameters and we give the tree-level formulas for the supersymmetric particles. Moreover, a short summary of the implemented high scale models is given. In Sect. 3 we list the implemented decay modes of supersymmetric particles and the Higgs bosons. We also discuss shortly the approximations used. In Sect. 4 we present the implemented cross sections in e^+e^- annihilation. In Sect. 5 we discuss give details on the implemented low energy constraints. In Sect. 6 we discuss the implemented algorithm in some detail. In Sect. 7 the main program is presented in detail providing the necessary information so that this program can be easily adapted to the user's requirement. In the appendices we discuss the possible switches for influencing the program as well as a detailed discussion of possible input files. Moreover, we list the output of the program for a typical example. The source code as well as precompiled versions of the program can be obtained from the author via email: `porod@physik.unizh.ch`; or it can be downloaded from `http://www-theorie.physik.unizh.ch/~porod/SPheno.html`.

2 MSSM parameters, particle spectrum, and High Scale Models

In this section we fix our notation concerning the parameters and present the tree-level formulas for the masses as well as the mixing matrices. In the following we assume that the physical masses are ordered: $m_i \leq m_j$ if $i < j$ except for the sfermions as explained below. We also give a short overview over various high scale models which are implemented in the program.

2.1 Ingredients for the Lagrangian

The pure supersymmetric Lagrangian is specified by the Kähler potential giving the gauge interactions and by the Superpotential W giving the Yukawa interactions:

$$W = \epsilon_{ab} \left(Y^L_{ij} \hat{L}^a_i \hat{H}^b_1 \hat{E}^c_j + Y^D_{ij} \hat{Q}^a_i \hat{H}^b_1 \hat{D}^c_j + Y^U_{ij} \hat{Q}^b_i \hat{H}^a_2 \hat{U}^c_j - \mu \hat{H}^a_1 \hat{H}^b_2 \right) \tag{1}$$

where $\hat{L}$, $\hat{E}$, $\hat{Q}$, $\hat{D}$, and $\hat{U}$ denote the matter superfields. The $SU(2)_L$ representation indices are denoted by $a, b = 1, 2$ and the generation indices by $i, j = 1, 2, 3$; ϵ_{ab} is the totally antisymmetric tensor with $\epsilon_{12} = 1$. Note that the sign of μ is identical to the one in ISASUSY [17] and SOFTSUSY [18] but opposite to the convention in [24]. Presently, real Yukawas Y^L, Y^D, Y^U only are included. They and the gauge couplings g_i are $\overline{DR}$ quantities. g_1 is defined in the Grand Unification normalization $g_1 = \sqrt{5/3} g'$ where g' is the Standard Model hypercharge gauge coupling.

The next ingredient is the soft SUSY breaking Lagrangian, which is given by mass terms for the gauginos

$$L_{soft,1} = \frac{1}{2} \left(M_1 \tilde{B} \tilde{B} + M_2 \tilde{W}_a \tilde{W}^a + M_3 \tilde{g}_\alpha \tilde{g}^\alpha \right) + h.c. \ , \tag{2}$$

mass terms for scalar matter fields and Higgs fields

$$
\begin{aligned}
L_{soft,2} \;=\;& -M_{H_1}^2 H_{1a}^* H_1^a - M_{H_2}^2 H_{2a}^* H_2^a - M_{\tilde{L},ij}^2 \tilde{L}_{ia}^* \tilde{L}_j^a - M_{\tilde{E},ij}^2 \tilde{E}_i^* \tilde{E}_j \\
& -M_{\tilde{Q},ij}^2 \tilde{Q}_{ia}^* \tilde{Q}_j^a - M_{\tilde{U},ij}^2 \tilde{U}_i^* \tilde{U}_j - M_{\tilde{D},ij}^2 \tilde{D}_i^* \tilde{D}_j
\end{aligned} \tag{3}
$$

and trilinear couplings of scalar matter fields and Higgs fields

$$
\begin{aligned}
L_{soft,3} \;=\;& -\epsilon_{ab}\left(A_{ij}^L \tilde{L}_i^a H_1^b \tilde{E}_j^* + A_{ij}^D \tilde{Q}_i^a H_1^b \tilde{D}_j^* + A_{ij}^U \tilde{Q}_i^b H_2^a \tilde{U}_j^* - B\mu H_1^a H_2^b\right) \\
& +h.c.
\end{aligned} \tag{4}
$$

2.2 Masses and Mixing Matrices

The masses of the various particles are induced by the soft SUSY breaking parameters and the vacuum expectation values v_i of the neutral Higgs fields $v_i =< H_i^0 >$. The ratio of the vacuum expectation values is denoted by $\tan\beta = v_2/v_1$. The sum of the vacuum expectation values (vevs) squared is fixed by the gauge boson masses:

$$
m_W^2 = \frac{1}{4} g^2 (v_1^2 + v_2^2), \qquad m_Z^2 = \frac{1}{4}(g^2 + g'^2)(v_1^2 + v_2^2) \tag{5}
$$

Neglecting the mixing between different generations, the Standard Model fermion masses are given by:

$$
m_{u_i} = \frac{1}{\sqrt{2}} Y_{ii}^U v_2, \qquad m_{d_i} = \frac{1}{\sqrt{2}} Y_{ii}^D v_1, \qquad m_{l_i} = \frac{1}{\sqrt{2}} Y_{ii}^L v_1 \tag{6}
$$

for u-quarks, d-quarks and leptons, respectively.

The gluino mass is given by $m_{\tilde{g}} = |M_3|$. The charginos are combination of the charged winos $\tilde{w}^{\pm} = (\tilde{w}^1 \mp i\tilde{w}^2)/\sqrt{2}$ and the charged higgsinos $\tilde{h}_1^-, \tilde{h}_2^+$. The Lagrangian contains the chargino mass term $-(\tilde{\psi}^-)^T X \tilde{\psi}^+$ where $\psi^- = (-i\tilde{w}^-, \tilde{h}_1^-)^T$, $\psi^+ = (-i\tilde{w}^+, \tilde{h}_2^+)^T$ and

$$
X = \begin{pmatrix} M & \frac{g}{\sqrt{2}} v_2 \\ \frac{g}{\sqrt{2}} v_1 & \mu \end{pmatrix}. \tag{7}
$$

The matrix is diagonalized by two unitary matrices U and V:

$$
M_{D,\tilde{\chi}^{\pm}} = U^* X V^{-1}\,. \tag{8}
$$

The neutral gauginos $\tilde{b}, \tilde{w}^3$ as well as the neutral higgsinos $\tilde{h}_1^0, \tilde{h}_2^0$ form the neutralinos. In the basis $\tilde{\psi}^0 = (\tilde{b}, \tilde{w}^3, \tilde{h}_1^0, \tilde{h}_2^0)^T$ one finds the mass term $-(\tilde{\psi}^0)^T Y \tilde{\psi}^0$ with

$$
Y = \begin{pmatrix} M_1 & 0 & -\frac{g'}{2} v_1 & \frac{g'}{2} v_2 \\ 0 & M_2 & \frac{g}{2} v_1 & -\frac{g}{2} v_2 \\ -\frac{g'}{2} v_1 & \frac{g}{2} v_1 & 0 & -\mu \\ \frac{g'}{2} v_2 & -\frac{g}{2} v_2 & -\mu & 0 \end{pmatrix} \tag{9}
$$

This matrix is diagonalized by an unitary matrix N:

$$
M_{D,\tilde{\chi}^0} = N^* Y N^{\dagger}\,. \tag{10}
$$

The CP-even electroweak eigenstates (H_1^0, H_2^0) are rotated by the angle α into the Higgs mass eigenstates (h^0, H^0) as follows:

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} -\sin\alpha & \cos\alpha \\ \cos\alpha & \sin\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix} \tag{11}$$

with $m_{h^0} < m_{H^0}$. The CP-odd and the charged Higgs masses are given by

$$m_{A^0}^2 = B\,\mu\,(\tan\beta + \cot\beta)\,, \qquad m_{H^+}^2 = m_{A^0}^2 + m_W^2 \tag{12}$$

at tree level.

Neglecting generation mixing, the sneutrino masses are given by:

$$M_{\tilde{\nu}_i}^2 \;=\; M_{\tilde{L}_i i}^2 + \frac{1}{2} m_Z^2 \cos 2\beta \tag{13}$$

The other sfermion mass matrices are 2×2 matrices:

$$M_{\tilde{l},i}^2 \;=\; \begin{pmatrix} M_{\tilde{L},ii}^2 - \left(\frac{1}{2} - s_W^2\right) c_{2\beta} m_Z^2 + m_{l,i}^2 & \frac{1}{\sqrt{2}}\left(v_1 (A_{ii}^L)^* - \mu Y_{ii}^L v_2\right) \\ \frac{1}{\sqrt{2}}\left(v_1 A_{ii}^L - (\mu Y_{ii}^L)^* v_2\right) & M_{\tilde{E},ii}^2 - s_W^2 c_{2\beta} m_Z^2 + m_{l,i}^2 \end{pmatrix} \tag{14}$$

$$M_{\tilde{u}}^2 \;=\; \begin{pmatrix} M_{\tilde{Q},ii}^2 + \left(\frac{1}{2} - \frac{2}{3} s_W^2\right) c_{2\beta} m_Z^2 + m_{u,i}^2 & \frac{1}{\sqrt{2}}\left(v_2 (A_{ii}^U)^* - \mu Y_{ii}^U v_1\right) \\ \frac{1}{\sqrt{2}}\left(v_2 A_{ii}^U - (\mu Y_{ii}^U)^* v_1\right) & M_{\tilde{U},ii}^2 + \frac{2}{3} s_W^2 c_{2\beta} m_Z^2 + m_{u,i}^2 \end{pmatrix} \tag{15}$$

$$M_{\tilde{d}}^2 \;=\; \begin{pmatrix} M_{\tilde{Q},ii}^2 - \left(\frac{1}{2} - \frac{1}{3} s_W^2\right) c_{2\beta} m_Z^2 + m_{d,i}^2 & \frac{1}{\sqrt{2}}\left(v_1 (A_{ii}^D)^* - \mu Y_{ii}^D v_2\right) \\ \frac{1}{\sqrt{2}}\left(v_1 A_{ii}^D - (\mu Y_{ii}^D)^* v_2\right) & M_{\tilde{D},ii}^2 - \frac{1}{3} s_W^2 c_{2\beta} m_Z^2 + m_{d,i}^2 \end{pmatrix} \tag{16}$$

where $c_{2\beta} = \cos\ 2\beta$ and $s_W^2 = \sin^2\theta_W$. These matrices are diagonalized by 2×2 matrices $R_{\tilde{f},i}$ with

$$m_{\tilde{f}}^2 = R_{\tilde{f}}^\dagger M_{\tilde{f}}^2 R_{\tilde{f}} \tag{17}$$

Sfermions are first ordered according to the generation and inside a generation according to their masses. For example, in the slepton sector the ordering is $\tilde{e}_1$, $\tilde{e}_2$, $\tilde{\mu}_1$, $\tilde{\mu}_2$, $\tilde{\tau}_1$, $\tilde{\tau}_2$ and similarly for squarks.

2.3 High scale models

In this section we summarize the key ingredients of the high scale models implemented in `SPheno`. We also present the formulas for the boundary conditions in the various models. In all cases the modulus $|\mu|$ is determined by requiring correct radiative symmetry breaking. At tree level the corresponding formula reads as:

$$|\mu|^2 = \frac{1}{2}\left[\tan 2\beta \left(M_{H_2}^2 \tan\beta - M_{H_1}^2 \cot\beta\right) - m_Z^2\right]. \tag{18}$$

Moreover, in all cases the high scale parameters are supplemented by the sign of μ and $\tan\beta$.

2.3.1 Minimal Supergravity

The minimal supergravity (mSUGRA) scenario is characterized by a set of universal parameters [13, 2] at the GUT scale M_{GUT}: the gaugino mass parameter $M_{1/2}$, the scalar mass parameter M_0, and the trilinear coupling A_0:

$$
\begin{aligned}
M_i(M_{GUT}) &= M_{1/2} && (19)\\
M^2_{\tilde{j}}(M_{GUT}) &= M_0^2 && (20)\\
A_i(M_{GUT}) &= A_0 Y_i(M_{GUT}) && (21)
\end{aligned}
$$

2.3.2 Minimal Supergravity including right handed neutrinos

In addition to the parameters of the mSUGRA model above the following parameters appear in this case: m_{ν_R}, a common mass for all right handed neutrinos, and m_{ν_i} ($i = 1, 2, 3$), the light neutrino masses. In this case the MSSM RGEs are run up to the scale m_{ν_R} where the neutrino Yukawa couplings are calculated using the formula $Y_{\nu,i} = \sqrt{m_{\nu_R} m_{\nu_i}}/v_2$. In the range between m_{ν_R} and M_{GUT} the effect of neutrino Yukawa couplings is included in the RGEs of gauge and Yukawa couplings. At the GUT-scale the right sneutrino mass parameters as well as the trilinear coupling $A_{\nu,i}$ are given by:

$$
\begin{aligned}
M^2_{\tilde{R}}(M_{GUT}) &= M_0^2 && (22)\\
A_{\nu,i}(M_{GUT}) &= A_0 Y_{\nu,i}(M_{GUT}) && (23)
\end{aligned}
$$

The corresponding RGEs are used in the running from M_{GUT} to m_{ν_R}. At the scale m_{ν_R} the neutrino Yukawa couplings $Y_{\nu,i}$, the trilinear couplings $A_{\nu,i}$ and the soft masses $M^2_{R,i}$ for the right sneutrinos are taken out of the RGEs and below the m_{ν_R} the usual set of MSSM RGEs are used.

2.3.3 Gauge Mediated Supersymmetry Breaking

Gauge mediated supersymmetry breaking [14, 27] (GMSB) is characterized by the mass $M_M \sim \langle S \rangle$ of the messenger fields and the mass scale $\Lambda = \langle F_S \rangle / \langle S \rangle$ setting the size of the gaugino and scalar masses. The gaugino masses

$$M_i(M_M) = (N_5 + 3N_{10}) g\left(\Lambda/M_M\right) \alpha_i(M_M)\Lambda \tag{24}$$

are generated by loops of scalar and fermionic messenger component fields; N_i is the multiplicity of messengers in the $5 + \overline{5}$ and $10 + \overline{10}$ vector-like multiplets, and

$$g(x) = \frac{1+x}{x^2}\log(1+x) + (x \to -x) \tag{25}$$

is the messenger–scale threshold function [28] which approaches unity for $\Lambda \ll M_M$. Masses of the scalar fields in the visible sector are generated by 2-loop effects of gauge/gaugino and messenger fields:

$$M^2_{\tilde{j}}(M_M) = 2(N_5 + 3N_{10}) f\left(\Lambda/M_M\right) \sum_{i=1}^{3} k_i C^i_j \alpha_i^2(M_M)\Lambda^2 \tag{26}$$

with $k_i = 1, 1, 3/5$ for $SU(3)$, $SU(2)$, and $U(1)$, respectively; the coefficients C^i_j are the quadratic Casimir invariants, being $4/3$, $3/4$, and $Y^2/4$ for the fundamental representations $\tilde{j}$

in the groups $i = SU(3), SU(2)$ and $U(1)$, with $Y = 2(Q - I_3)$ denoting the usual hypercharge; also the threshold function [28]

$$f(x) = \frac{1+x}{x^2}\left[\log(1+x) - 2\mathrm{Li}_2\left(\frac{x}{1+x}\right) + \frac{1}{2}\mathrm{Li}_2\left(\frac{2x}{1+x}\right)\right] + (x \to -x) \tag{27}$$

approaches unity for $\Lambda \ll M_M$. As evident from Eq. (26) scalar particles with identical Standard–Model charges squared have equal masses at the messenger scale M_M. In the minimal version of GMSB, the A parameters are generated at 3-loop level and they are practically zero at M_M. However, the program permits to set a value for A_0 different from zero but universal for all sfermions.

2.3.4 Anomaly Mediated Supersymmetry Breaking

In anomaly mediated supersymmetry breaking (AMSB) the SUSY breaking is transmitted from the hidden sector to the visible sector via the super–Weyl anomaly [15]. The soft SUSY breaking parameters are given by:

$$M_a = \frac{1}{g_a}\beta_a m_{3/2} \tag{28}$$

$$A_i = \beta_{Y_i} m_{3/2} \tag{29}$$

$$M_j^2 = \frac{1}{2}\dot{\gamma}_j m_{3/2}^2 \tag{30}$$

where β_a and β_{Y_i} are the beta functions of gauge and Yukawa couplings, respectively. The γ_j are the anomalous dimensions of the corresponding matter superfield and $m_{3/2}$ is the gravitino mass. Equation (30) leads to negative mass squared for the sleptons which is phenomenologically not acceptable. There are several possibilities to solve this problem [29] and the simplest one is to add a common scalar mass M_0 so that eq. (30) reads as

$$M_j^2 = M_0^2 + \frac{1}{2}\dot{\gamma}_j m_{3/2}^2 \tag{31}$$

This extension has been implemented in the program.

2.3.5 String Effective Field Theories

Four–dimensional strings naturally give rise to a minimal set of fields for inducing supersymmetry breaking; they play the rôle of the fields in the hidden sectors: the dilaton S and the moduli T_m chiral superfields which are generically present in large classes of 4–dimensional heterotic string theories. The vacuum expectation values of S and T_m, generated by genuinely non–perturbative effects, determine the soft supersymmetry breaking parameters [30, 31].

In the following we assume that all moduli fields get the same vacuum expectation values and that they couple in the same way to matter fields. Therefore, we omit the index m and take only one moduli field T. The properties of the supersymmetric theories are quite different for dilaton and moduli dominated scenarios as discussed in [30, 31]. The mass scale of the supersymmetry parameters is set by the gravitino mass $m_{3/2}$.

In the program we implemented the complete 1-loop formulas given in [31]. Three classes of models are implemented in the program: two versions of OII compactification defined by the sets A and B of boundary conditions in [31] as well as an OI compactification scheme. For the implementation of the OI compactification scheme we have used formulas Eqs. (3.21) – (3.23) of [31]:

$$
\begin{aligned}
M_i &= -g_i^2 m_{3/2}\Bigg\{\sqrt{3}\sin\theta + \Bigg[b_i + s\sqrt{3}\sin\theta g_s^2\Bigg(C_i - \sum_j C_i^j\Bigg) \\
&\qquad + 2\,t\cos\theta\, G_2(t)\Bigg(\delta_{\rm GS} + b_i - 2\sum_j C_i^j(1+n_j)\Bigg)\Bigg]/16\pi^2\Bigg\} && (32)\\
M_j^2 &= m_{3/2}^2\Bigg\{\Big(1+n_j\cos^2\theta\Big) + 2\sqrt{3}s\sin\theta\Bigg[\sum_i \gamma_j^i g_i^2 - \frac{1}{2s}\sum_{km}\gamma_j^{km}\Bigg] \\
&\qquad +\gamma_j + 2t\cos\theta\, G_2(t)\sum_{km}\gamma_j^{km}(n_j+n_k+n_m+3)\Bigg\} && (33)\\
A_{jkm} &= m_{3/2}\Big[-\sqrt{3}\sin\theta - 2t\cos\theta(n_j+n_k+n_m+3)G_2(t) + \gamma_j + \gamma_k + \gamma_m\Big] && (34)
\end{aligned}
$$

$s = \langle S\rangle$ is the vacuum expectation values of the dilaton field. $t = \langle T\rangle/m_{3/2}$ is the vacuum expectation value of the moduli field(s), and $G_2(t) = 2\zeta(t) + 1/2t$ is the non-holomorphic Eisenstein function with ζ denoting the Riemann zeta function. δ_{GS} is the parameter of the Green-Schwarz counterterm. γ_j are the anomalous dimensions of the matter fields, the γ_j^i and γ_j^{km} are their gauge and Yukawa parts, respectively. C_i, C_i^j are the quadratic Casimir operators for the gauge group G_i, respectively, in the adjoint representation and in the matter representation. The indices i, j, k denote H_1, H_2, $\tilde{E}$, $\tilde{L}$, $\tilde{D}$, $\tilde{U}$ and $\tilde{Q}$. The A-parameters are finally given by:

$$
\begin{aligned}
A_{e,n}(GUT) &= Y_{e,nn}(GUT)A_{\tilde{E}_n\tilde{L}_nH_1} && (35)\\
A_{d,n}(GUT) &= Y_{d,nn}(GUT)A_{\tilde{D}_n\tilde{Q}_nH_1} && (36)\\
A_{u,n}(GUT) &= Y_{u,nn}(GUT)A_{\tilde{U}_n\tilde{Q}_nH_2} && (37)
\end{aligned}
$$

where n denotes the generation.

In case of the OII compactification scheme the gaugino masses are given by Eqs. (3.11) of [31]:

$$
\begin{aligned}
M_i &= -g_i^2 m_{3/2}\Bigg\{\frac{\sqrt{3}\sin\theta}{2k_{s\bar{s}}^{1/2}} + \frac{1}{16\pi^2}\Bigg[2t\cos\theta G_2\left(\delta_{\rm GS}+b_i\right) + b_i \\
&\qquad + \frac{\sqrt{3}g_s^2\sin\theta}{2k_{s\bar{s}}^{1/2}}(C_i - \sum_j C_i^j)\Bigg]\Bigg\}. && (38)
\end{aligned}
$$

For the sfermion parameters we have implemented two sets of boundary conditions: set (A) is specified by formulas Eqs. (3.15) and (3.19) of [31]:

$$
\begin{aligned}
M_i^2 &= m_{3/2}^2\Bigg\{\sin^2\theta + \gamma_i + \frac{\sqrt{3}\sin\theta}{k_{s\bar{s}}^{1/2}}\Bigg[\sum_a \gamma_i^a g_a^2 + \frac{1}{2}\sum_{jk}\gamma_i^{jk}(k_s + k_{\bar{s}})\Bigg]\Bigg\}, && (39)\\
A_{ijk} &= m_{3/2}\Bigg\{\gamma_i + \gamma_j + \gamma_k - \frac{\sqrt{3}k_s\sin\theta}{k_{s\bar{s}}^{1/2}}\Bigg\} && (40)
\end{aligned}
$$

Set (B) is specified by formulas Eqs. (3.16) and (3.20) of [31]:

$$\begin{aligned}
M_i^2 &= m_{3/2}^2 \Big\{ \frac{\sqrt{3}\sin\theta}{k_{s\bar{s}}^{1/2}} \Big[1 + 2t\cos\theta G_2\Big] \Big[\sum_a g_a^2 \gamma_i^a + \frac{1}{2}\sum_{jk} \gamma_i^{jk} \left(k_s + k_{\bar{s}}\right)\Big] \\
&\quad + \sin^2\theta \Big[1 + \gamma_i + \ln\left[2t|\eta(t)|^4\right] \big(\sum_a \gamma_i^a + 2\sum_{jk}\gamma_i^{jk}\big) - \sum_a \gamma_i^a \ln(g_a^2)\Big] \\
&\quad - \frac{9\sin^2\theta}{k_{s\bar{s}}} \Big[\sum_a \gamma_i^a \left(\frac{g_a^4}{4}\right)\left(\ln(g_a^2) + \frac{5}{3}\right) \\
&\qquad + \ln\left[(t+\bar{t})|\eta(t)|^4\right] \big(\sum_a \gamma_i^a (\frac{g_a^4}{4}) + \frac{1}{3}\sum_{jk}\gamma_i^{jk} k_s k_{\bar{s}}\big)\Big]\Big\}, \qquad (41)
\end{aligned}$$

$$\begin{aligned}
A_{ijk} &= m_{3/2} \Big\{ (\gamma_i + \gamma_j + \gamma_k)\Big[1 + 2t\cos\theta G_2\Big] \\
&\quad + \frac{\sqrt{3}\sin\theta}{k_{s\bar{s}}^{1/2}} \Big[k_s + \sum_a \frac{g_a^2}{2}(\gamma_i^a + \gamma_j^a + \gamma_k^a)(1 - \ln(g_a^2)) \\
&\qquad - \ln\Big[(t+\bar{t})|\eta(t)|^4\Big] \big(\sum_a g_a^2 (\gamma_i^a + \gamma_j^a + \gamma_k^a) \\
&\qquad - \sum_{lm} k_s (\gamma_i^{lm} + \gamma_j^{lm} + \gamma_k^{lm})\big)\Big]\Big\}. \qquad (42)
\end{aligned}$$

In all three cases we have assumed that terms proportional to the $\log(\tilde{\mu}_i)$ can be neglected ($\tilde{\mu}_i$ denote the Pauli Villar masses).

2.3.6 General High Scale Model

It is clear from the examples above that up to now there is no unique mechanism for supersymmetry breaking. Therefore, we have implemented the possibility to specify rather freely a high scale model. This model is specified by: a set of three in principal non–universal gaugino mass parameters $M_{1/2}[U(1)]$, $M_{1/2}[SU(2)]$, $M_{1/2}[SU(3)]$; a scalar mass for each type of sfermion, resulting in fifteen parameters: $M^0_{\tilde{E},ii}$, $M^0_{\tilde{L},ii}$, $M^0_{\tilde{D},ii}$, $M^0_{\tilde{U},ii}$, $M^0_{\tilde{Q},ii}$; two Higgs mass parameters $M^0_{H_1}$ and $M^0_{H_2}$; nine different A parameters $A_{0,e,ii}$, $A_{0,d,ii}$ and $A_{0,u,ii}$. Here ii denotes that only the diagonal entries can be set, because in the current version the effects of generation mixing is not taken into account. A model of this kind has been used in [32] for the study of low energy observables and the supersymmetric spectrum. It also can be used, for example, to set the boundary conditions for the gaugino mediated supersymmetry breaking [33]. This general model will be denoted by SUGRA.

3 Decays of supersymmetric particles and Higgs bosons

The programs calculates the most important two- and three-body decays of supersymmetric particles at tree level. In case of three-body decays the formulas are implemented such, that the effects of decay widths in the propagators are taken into account [34]. Therefore, it is possible to perform the calculation even in case that some of the intermediate particles are on-shell. This is useful in the case that the two–body decays have small phase space, because then the calculation of the three-body decays gives a more accurate result, e.g. $\Gamma(\tilde{\chi}^+_1 \to$

$\tilde{\chi}^0_1 W^+) \times \mathrm{BR}(W^+ \to \nu l^+)$ can be quite different from $\Gamma(\tilde{\chi}^+_1 \to \tilde{\chi}^0_1 \nu l^+)$ if the decay $\tilde{\chi}^+_1 \to \tilde{\chi}^0_1 W^+$ has only small phase space.

The following sfermion decays are calculated:

$$\tilde{f}_i \;\to\; f\,\tilde{\chi}^0_k,\;\; f'\,\tilde{\chi}^\pm_l \qquad (43)$$
$$\tilde{f}_i \;\to\; \tilde{f}_j\,Z^0,\;\; \tilde{f}'_j\,W^\pm \qquad (44)$$
$$\tilde{f}_i \;\to\; \tilde{f}_j\,(h^0, H^0, A^0),\;\; \tilde{f}'_j\,W^\pm \qquad (45)$$

In case of the lighter stop, it is possible that all two-body decays modes are kinematically forbidden at tree–level. In this case the following decay modes are important [35, 36, 37]:

$$\tilde{t}_1 \;\to\; c\,\tilde{\chi}^0_{1,2} \qquad (46)$$
$$\tilde{t}_1 \;\to\; W^+\,b\,\tilde{\chi}^0_1,\;\; H^+\,b\,\tilde{\chi}^0_1 \qquad (47)$$
$$\tilde{t}_1 \;\to\; b\,\nu\,\tilde{l}^+_i,\;\; b\,l^+\,\tilde{\nu} \qquad (48)$$

where $l = e, \mu, \tau$. The corresponding widths are calculated within SPheno using the formulas given in [36]. In case of GMSB models scenarios exist where the charged sleptons are next to lightest supersymmetric particles (NLSP) and the gravitino $\tilde{G}$ is the LSP. In this case the sleptons decay according to:

$$\tilde{l}_i \;\to\; l\,\tilde{G} \qquad (49)$$

Here we use the formulas given in [27].

It is well known that the partial widths of sfermions can receive considerable radiative corrections [38]. However, the branching ratios are not that strongly affected [39]. Therefore, for the moment being tree-level formulas are implemented. Some important numerical effects of higher order corrections are nevertheless implemented by using 1-loop corrected masses and running couplings in the formulas. The complete implementation of higher-order corrections is left for future versions of the program.

In case of charginos and neutralinos the following decay modes are calculated:

$$\tilde{\chi}^0_i \;\to\; Z^0\,\tilde{\chi}^0_j,\;\; W^\pm\,\tilde{\chi}^\mp_k \qquad (50)$$
$$\tilde{\chi}^0_i \;\to\; (h^0, H^0, A^0)\,\tilde{\chi}^0_j,\;\; H^\pm\,\tilde{\chi}^\mp_k \qquad (51)$$
$$\tilde{\chi}^0_i \;\to\; f\,\bar{\tilde{f}}_j,\;\; \bar{f}\,\tilde{f}_j \qquad (52)$$
$$\tilde{\chi}^+_k \;\to\; Z^0\,\tilde{\chi}^+_s,\;\; W^+\,\tilde{\chi}^0_j \qquad (53)$$
$$\tilde{\chi}^+_k \;\to\; (h^0, H^0, A^0)\,\tilde{\chi}^+_s,\;\; H^+\,\tilde{\chi}^0_j \qquad (54)$$
$$\tilde{\chi}^+_k \;\to\; f\,\tilde{f}'_i \qquad (55)$$

In case that all two body decay modes are kinematically forbidden the following three–body decays are calculated:

$$\tilde{\chi}^0_i \;\to\; f\,\bar{f}\,\tilde{\chi}^0_j,\;\; f\,f'\,\tilde{\chi}^\mp_k \qquad (56)$$
$$\tilde{\chi}^0_i \;\to\; q\,\bar{q}\,\tilde{g} \qquad (57)$$
$$\tilde{\chi}^+_k \;\to\; f\,\bar{f}\,\tilde{\chi}^+_s,\;\; f\,f'\,\tilde{\chi}^0_j \qquad (58)$$
$$\tilde{\chi}^+_k \;\to\; q\,q'\,\tilde{g} \qquad (59)$$

In the calculation we have included all contributions from gauge bosons, sfermions and Higgs bosons [34, 40]. The Higgs contributions can be important in certain regions of parameter space [41]. Similarly to case of the sleptons there exist parameter regions in GMSB models where the lightest neutralino is the NLSP and it decays according to

$$\tilde{\chi}^0_1 \rightarrow \gamma \ \tilde{G} \tag{60}$$
$$\tilde{\chi}^0_1 \rightarrow Z^0 \ \tilde{G} \tag{61}$$
$$\tilde{\chi}^0_1 \rightarrow h^0 \ \tilde{G} \tag{62}$$

Here we use the formulas given in [27].

In case of gluinos the following two–body decays are calculated:

$$\tilde{g} \rightarrow q \, \tilde{q}_i \tag{63}$$

with $q = u, d, c, s, t, b$. Again, in case that these decays are kinematically suppressed, the three-body decay modes are calculated:

$$\tilde{g} \rightarrow \tilde{\chi}^0_i \, q \, \bar{q} \tag{64}$$
$$\tilde{g} \rightarrow \tilde{\chi}^\pm_j \, q' \, \bar{q} \tag{65}$$
$$\tilde{g} \rightarrow \bar{b} \, W^- \, \tilde{t}_1, b \, W^+ \, \tilde{t}^*_1 \tag{66}$$

Here we have implemented the formulas given in [42].

In case of Higgs bosons the following decays are calculated:

$$\phi \rightarrow f \, \bar{f} \tag{67}$$
$$\phi \rightarrow \tilde{f}_i \, \bar{\tilde{f}}_j \tag{68}$$
$$\phi \rightarrow \tilde{\chi}^0_k \, \tilde{\chi}^0_l \tag{69}$$
$$\phi \rightarrow \tilde{\chi}^+_r \, \tilde{\chi}^-_s \tag{70}$$
$$H^0 \rightarrow Z^0 \, Z^0, \ W^+ \, W^- \tag{71}$$
$$H^0 \rightarrow h^0 \, h^0 \tag{72}$$
$$A^0 \rightarrow h^0 \, Z^0 \tag{73}$$
$$H^+ \rightarrow f \, \bar{f}' \tag{74}$$
$$H^+ \rightarrow \tilde{f}_i \, \bar{\tilde{f}}'_j \tag{75}$$
$$H^+ \rightarrow \tilde{\chi}^0_k \, \tilde{\chi}^-_s \tag{76}$$
$$H^+ \rightarrow h^0 \, W^+ \tag{77}$$

with $\phi = h^0, H^0, A^0$ and $f = \nu_i, e, \mu, \tau, u, d, c, s, t, b$. It is well known, that the widths as well as the branching ratios of the Higgs bosons can receive large one–loop corrections [43, 44, 45]. In the present version only the gluonic QCD corrections for the decays into quarks [43] have been implemented. Therefore, the numbers provided by SPheno have to be taken with care and for refined analysis other programs, such as HDECAY [46] should be used.

4 Production of supersymmetric particles and Higgs bosons

The program calculates the following cross sections:

$$e^+ \, e^- \rightarrow \tilde{f}_i \, \tilde{f}_j \qquad (f = l, \nu, q) \tag{78}$$

$$
\begin{aligned}
e^+ e^- &\to \tilde{\chi}^0_k \, \tilde{\chi}^0_n && (79)\\
e^+ e^- &\to \tilde{\chi}^+_r \, \tilde{\chi}^-_s && (80)\\
e^+ e^- &\to h^0 \, Z, \; H^0 Z && (81)\\
e^+ e^- &\to h^0 \, A^0, \; H^0 A^0 && (82)\\
e^+ e^- &\to H^+ H^- && (83)
\end{aligned}
$$

We haven taken the formulas of [47] for sfermion production, [48, 34] for production of charginos and neutralinos and [45] for Higgs boson production. Initial state radiation has been included using the formula given in [49]. In case of squarks in addition QCD corrections due to gluon exchange are included [49, 50]. Care has to be taken in case one calculates the cross sections near threshold because then higher order corrections are important to get reliable results [51] and, thus, the numbers obtained in the program have to be taken with care near the threshold. All cross sections are implemented such, that one can specify the degree of longitudinal polarization P_{e^-} of the incoming electron beam as well as the degree of longitudinal polarization P_{e^+} of the incoming positron beam. Here P_{e^-} is within the range $[-1, 1]$, where $\{-1, 0, 1\}$ denote 100% left-handed electrons, completely unpolarized electrons and 100% right-handed electrons, respectively. The same notation is used in case of positrons. For example, $P_{e^-} = -0.8$ ($P_{e^+} = -0.8$) means that 80% of the electrons (positrons) are left-polarized whereas the remaining 20% are unpolarized.

5 Low Energy Constraints

The supersymmetric parameters are constrained by direct searches at colliders and by loop-effects which supersymmetric particles induce observables of low energy experiments. Provided one neglects mixing between different sfermion generations the following quantities constrain several parameters of the MSSM: the rare decay $b \to s\,\gamma$, the anomalous magnetic moment of the muon a_μ and the supersymmetric contributions to the ρ parameter. These constraints are implemented in the program using the formulas given in [52, 53] for $b \to s\,\gamma$ supplemented by the QCD corrections as given in [54], [55] for a_μ and [56] for the sfermion contributions to the ρ parameter. In call cases we use the running couplings at m_Z for the calculation of the observables. The use of running couplings together with the correct implementation of supersymmetric threshold corrections for the couplings results in taking into account the most important higher oder corrections as has been pointed out e.g. in [57, 58] for the case of $b \to s\,\gamma$. The implementation of the supersymmetric threshold corrections to the couplings will be discussed in the next section.

6 Details of the Calculation

In this section we describe the algorithm used. It is schematically displayed in Fig. 1. The following standard model parameters are used as input: fermion and gauge boson pole masses, the fine structure constant α, the Fermi constant G_F and the strong coupling constant $\alpha_s(m_Z)$. It is assumed that $\alpha(m_Z)$ and $\alpha_s(m_Z)$ are given in the $\overline{MS}$ scheme.

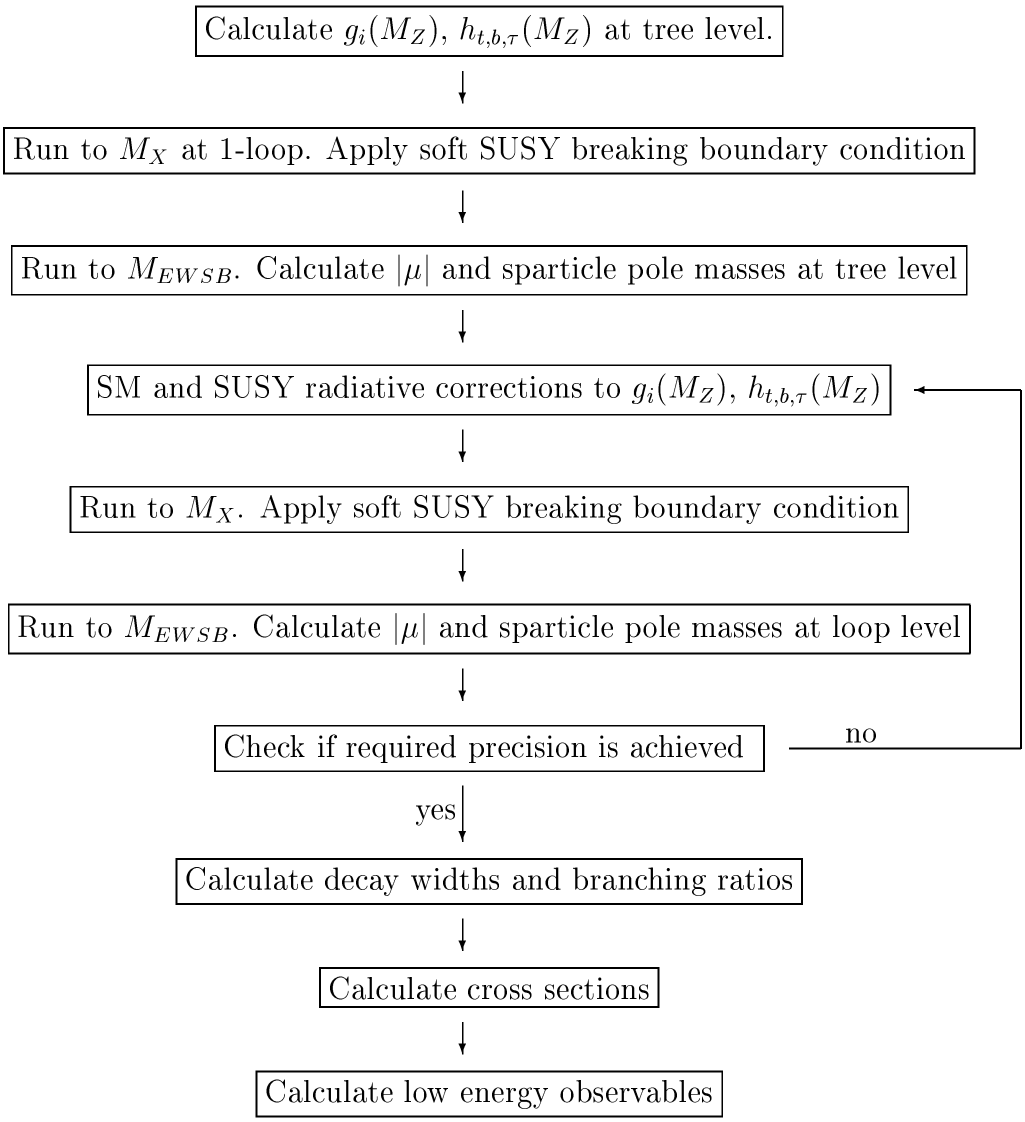

Figure 1: Algorithm used to calculate the SUSY spectrum, decay widths, production cross sections and low energy observables. Each step (represented by a box) is explained in the text. The initial step is the uppermost one. M_{EWSB} is the scale at which the EWSB conditions are imposed, and M_X is the scale at which the high energy SUSY breaking boundary conditions are imposed.

6.1 First rough calculation of SUSY and Higgs boson masses

In a first step, we calculate gauge and Yukawa couplings at m_Z scale using tree-level formulas. These are used as input for the one–loop RGEs to get the gauge and Yukawa couplings at the high scale where also the boundary conditions for the high scale model under study are imposed. Afterwards one–loop RGEs are used to get a first set of parameters at the electroweak scale. These parameters are used to get a first set of supersymmetric particle masses and Higgs masses using tree-level formulas except for the neutral CP-even Higgs bosons where one-loop effects due to (s)quarks of the third generation are taken into account. These masses are the starting point for the iterative loop which calculates the spectrum within the required precision as described below.

6.2 Main loop for the calculation of SUSY and Higgs boson masses

In the next step the gauge couplings and $\sin^2\theta_W$ are calculated at m_Z^2 in the $\overline{DR}$ scheme using the formulas given Appendix C of [24]. For the calculation of the Yukawa couplings we use the complete formulas for the fermion masses and the vacuum expectation values given in Appendix D of [24]. In case of third generation Yukawa couplings we use the following improvements. In case of the bottom quark we use 3-loop relationship between the pole mass and the $\overline{MS}$ mass $m_{b,\overline{MS}}(m_b)$ as given in [59]. The three–loop RGEs [60] are solved numerically to obtain $m_{b,\overline{MS}}(m_Z)$. Afterwards the shift from the $\overline{MS}$ scheme to the $\overline{DR}$ scheme arising from massless gauge bosons is calculated using the formula [61, 62]:

$$m_{b',\overline{DR}}(m_Z) = \left(1 - \frac{\alpha_s}{3\pi} - \frac{35\alpha_s^2}{72\pi^2}\right) m_{b,\overline{MS}}(m_Z) \tag{84}$$

where α_s is given in the $\overline{DR}$ scheme which is the reason for the different factor in front of α_s^2 compared to [62]. We use the complete formulas given in Appendix D of [24] to calculate the SUSY contribution denoted by $\Delta m_{b,SUSY}(m_Z)$. For the calculation we use running gauge and Yukawa couplings at m_Z. The SUSY contributions $\Delta m_{b,SUSY}(m_Z)$ are then resummed using [63]

$$m_{b,\overline{DR}}(m_Z) = \frac{m_{b',\overline{DR}}(m_Z)}{1 - \frac{\Delta m_{b,SUSY}(m_Z)}{m_{b,\overline{DR}}(m_Z)}} \tag{85}$$

The analogue resumation is done in case of the tau Yukawa coupling. In case of the top quark we take the complete formulas given in Appendix D of [24]. We also add the 2-loop contribution due to gluons in the $\overline{DR}$ scheme [61] which reads as:

$$\Delta m_t^{2-loop}(Q) = -m_t\alpha_s^2\left(0.538 - \frac{43}{24\pi^2}L + \frac{3}{8\pi^2}L^2\right) \tag{86}$$

where m_t is the on–shell top mass and $L = \ln(m_t^2/Q^2)$. The obtained gauge and Yukawa couplings are evolved to the high scale using two–loop RGEs [23]. The high scale can either be fixed or can be calculated from the requirement $g_1 = g_2$ at the high scale. The various cases are discussed in Sect. 7 and Appendix A. At the high scale the boundary conditions for the soft SUSY breaking parameters are set. The implemented models are summarized in Sect. 2.3; see also Appendix B.3. The complete set of two–loop RGEs [23] is used to evolve the parameters down to the electroweak scale $M_{EWSB} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ (there exists also the possibility to set M_{EWSB} by hand as explained in Appendix A).

The parameters are used as input to calculate the sparticle pole masses at one–loop order and in case of the neutral Higgs at two–loop order. Here we use the complete formulae given in the appendices of [24] for the one–loop contributions and for the 2-loop corrections $O(\alpha_s \alpha_t + \alpha_t^2 + \alpha_s \alpha_b)$ for the neutral Higgs boson the formulas given in [25, 26]. For the $O(\alpha_s \alpha_b)$ contributions we use the complete expressions which can be obtained from the $O(\alpha_s \alpha_t)$ contributions by appropriate replacements. In case of sfermions we have included in all cases left–right mixing. All gauge and Yukawa couplings are understood as $\overline{DR}$ quantities at M_{EWSB}. Also $\tan\beta$ and the vacuum expectation values are evaluated at M_{EWSB} to get a consistent set of input parameters. Note, that we express in all couplings the fermion masses and gauge boson masses by their corresponding expressions due to gauge couplings, Yukawa couplings and vacuum expectations values in the formulas of [24]. In all cases running masses are used as input for the loop integrals. In addition we have implemented the $O(\alpha_s \alpha_t + \alpha_t^2 + \alpha_s \alpha_b)$ corrections for the calculation of $|\mu|$ [26]. The numerical evolution of the one–loop integrals is based on the FF package [64] and the LoopTools package [65].

The masses obtained are used as input for the next iteration which starts again by calculating the SUSY contributions to gauge and Yukawa couplings at m_Z. In the case that during this iterative process an unphysical situation occurs, e.g. a pole mass squared being negative, the program terminates and it provides information on the exact reason for termination. The iteration is continued until all relative differences between the sparticle masses are smaller then the user imposed quantity δ:

$$\delta > \frac{|m_i - m_{i-1}|}{m_i} \tag{87}$$

for all sparticle masses; i denotes the i-th iteration. In most cases this achieved after three to four iterations. In the case that more than the maximal allowed number of iterations (user specified) are necessary, the program leaves the iteration giving a warning message.

6.3 Calculation of the other observables

The masses and mixing angles are then used to calculate the branching ratios and decay widths. Here two- and three body decays of supersymmetric particles are calculate. Note that we use the couplings as input which are renormalized at the scale M_{EWSB}. The user has the possibility to force the program to calculate three body decays even if one or more of the intermediate particles are on-shell. This possibility is useful in the case where the 2-body decay has only small phase because then the calculation of the three body decay width(s) give a more reliable result.

Afterwards the production cross sections at an e^+e^- collider of all supersymmetric particles as well as all Higgs bosons are calculated. Here the user has the possibility to specify the centre of mass energy as well as the degree of longitudinal polarization of the incoming beams. Moreover, the user can specify if initial state radiation shall be included in the calculation or not.

Finally, the low–energy constraints described in Section 5 are calculated: $BR(b \to s\gamma)$, SUSY contributions to a_μ and the sfermion contributions to $\Delta\rho$. For the the calculation of these quantities we evolve the gauge and Yukawa couplings from the scale M_{EWSB} down to m_Z. The couplings at m_Z are then used as input for the calculation of the low energy observables. For example in calculation of $BR(b \to s\gamma)$ the most important contributions to the C_7 coefficients are implemented as

$$
\begin{aligned}
C_7(W^+) &= -\frac{K_{ts}K_{tb}x_{tW}}{4\,m_W^2}\left(\frac{2}{3}F_1(x_{tW}) + F_2(x_{tW})\right) & (88)\\
C_7(H^+) &= -\frac{K_{ts}K_{tb}}{4\,m_{H^+}^2}\left[\frac{Y_t^2\cos^2\beta}{4}\left(\frac{2}{3}F_1(x_{tH^+}) + F_2(x_{tH^+})\right)\right.\\
&\qquad \left.-\frac{Y_bY_t\cos\beta\sin\beta m_t}{m_b}\left(\frac{2}{3}F_3(x_{tH^+}) + F_4(x_{tH^+})\right)\right] & (89)\\
C_7(\tilde{\chi}^+) &= \sum_{i,j=1}^{2}\frac{K_{ts}K_{tb}}{4\,m_{\tilde{t}_i}^2}\left[C_{R,ij}^2\left(\frac{2}{3}F_2(x_{\tilde{\chi}_j^+\tilde{t}_i}) + F_1(x_{\tilde{\chi}_j^+\tilde{t}_i})\right)\right.\\
&\qquad \left.-C_{L,ij}C_{R,ij}\left(\frac{2}{3}F_4(x_{\tilde{\chi}_j^+\tilde{t}_i}) + F_3(x_{\tilde{\chi}_j^+\tilde{t}_i})\right)\right] & (90)\\
C_{L,ij} &= Y_bR_{\tilde{t},i1}U_{j2} & (91)\\
C_{R,ij} &= -gR_{\tilde{t},i1}V_{j1} + Y_tR_{\tilde{t},i2}V_{j2} & (92)
\end{aligned}
$$

Here Y_i are the Yukawa couplings, U and V are the chargino matrices, K is the CKM matrix, $R_{\tilde{t}}$ is the stop mixing matrix and $x_{ab} = m_a^2/m_b^2$. The loop functions F_i are given in [52]. A similar replacement is done in the contributions to the C_8 coefficient. Moreover, in the program also the contributions from the first two generation of (s)fermions to $C_{7,8}$ are included for completeness. We then use [54] to obtain

$$
BR(b \to s\gamma) = 1.258 + 0.382r7^2 + 0.015r_8^2 + 1.395r_7 + 0.161r_8 + 0.083r_7r_8 \qquad (93)
$$

where $r_7 = C_7/C_7(W^+)$ and $r_8 = C_8/C_8(W^+)$. In this way important higher order corrections are taken into account, in particular the large $\tan\beta$ effects in case of $b \to s\gamma$ [58].

7 A sample example

In this section we discuss the executable statements of the main program given in the file `SPheno.f90`. In the first statements the required modules are loaded and the various variables are defined. Afterwards a series of initialization routines are called:

```
Call InitializeControl(11,"SPheno.out","SPheno")
Call InitializeLoopFunctions
Call InitializeStandardModel
```

The routine `InitialzeControl` opens the file `Messages.out` at channel 10 where all warnings and/or debugging informations are stored. In addition it reads the file `Control.in` if present. For the description of `Control.in` see Appendix B.1. Moreover, it opens the output file `SPheno.out` at channel 11. The last entry `"SPheno"` is the name of the calling program and is used for the initialization of the debugging system. The routine `InitializeLoopFunctions` initializes the routines for the calculation of the loop functions which are needed to calculated the loop corrected masses. The routine `InitializeStandardModel` reads data from the file `StandardModel.in`. In case that this file is not present, default values are used as described in Appendix B.4.

Afterwards the routine `HighScaleInput` is called:

Table 1: Variables for parameters and couplings. The parameters are explained in Section 2. dp means double precision.

parameter/coupling	type & Fortran name
e^{φ_μ}	`complex(dp) :: phase_mu`
$\tan\beta$	`real(dp) :: tanb`
M_1, M_2, M_3	`complex(dp) :: Mi(3)`
M_E^2, M_L^2	`complex(dp), dimension(3,3) :: M2_E, M2_L`
M_D^2, M_Q^2, M_U^2	`complex(dp), dimension(3,3) :: M2_D, M2_Q, M2_U`
A_l, A_d, A_u	`complex(dp), dimension(3,3) :: A_l, A_d, A_u`
μ	`complex(dp) :: mu`
$B\mu$	`complex(dp) :: B`
M_H^2	`real(dp) :: M2_H(2)`
g', g	`real(dp) :: gp, g`
Y_l, Y_d, Y_u	`complex(dp), dimension(3,3) :: Y_l, Y_d, Y_u`
v_1, v_2	`real(dp) :: vevSM(2)`
g', g, g_s	`real(dp) :: gauge(3)`

```
Call HighScaleInput
```

The source code for this routine is given in the file `SPheno.f90`. This routine reads in the data from the file `HighScale.in` which specifies the model used as well as the high scale boundary conditions. A short description of the implemented models is given in Sect. 2.3 and details of the file `HighScale.in` are given in Appendix B.3. Afterwards a first rough estimate of the parameters and couplings is given by calling the routine `FirstGuess`:

```
Call FirstGuess(phase_mu, tanb, Mi, M2_E, M2_L, A_l, M2_D   &
         & , M2_Q, M2_U, A_d, A_u, mu, B, M2_H, gp, g, Y_l  &
         & , Y_d, Y_u, vevSM, mP02, mP0)
```

The meaning of the various variables and their type is given in Table 1 except for `mP02, mP0` which are given in Table 2. The parameters obtained are used to get the initial values for the spectrum at tree-level:

```
Call TreeMasses(gp, g, vevSM, Mi(1), Mi(2), Mi(3), mu, B     &
     &, tanb, M2_E, M2_L, A_l, Y_l, M2_D, M2_U, M2_Q, A_d    &
     &, A_u, Y_d, Y_u, mGlu, PhaseGlu, mC, mC2, U, V, mN     &
     &, mN2, N, mSneut, mSneut2, Rsneut, mSlepton, mSlepton2 &
     &, RSlepton, mSdown, mSdown2, RSdown, mSup, mSup2, RSup &
     &, mP0, mP02, RP0, mS0, mS02, RS0, mSpm, mSpm2, RSpm, kont)
```

The variables for the masses and mixing matrices are given in Table 2. Variable names ending with "2" indicate masses squared. The variables for the mixing matrices are already structured for a latter extension to include the effects of generation mixing and/or complex phases: the sfermion mixing matrices are 6×6 (except for sneutrions which is a 3×3 matrix). In the present release most of the entries are zero except for the diagonal 2×2 blocks which contain the left–right mixing for every species of sfermions. For example, the 11, 12, 21 and 22 entries in `Rslepton` specify the left–right mixing of selectrons, and similarly the 33, 34,

Table 2: Variables for masses and mixing matrices as given by the routine `Sugra`. Their connection to the parameters at tree–level is explained explained in Section 2. dp means double precision.

masses / mixing matrix	type & Fortran name
$m_{\tilde{g}}$	real(dp) :: mglu
$e^{\varphi_{\tilde{g}}}$	complex(dp) :: PhaseGlu
$m_{\tilde{\chi}_i^+}$	real(dp) :: mC(2)
U, V	complex(dp) :: U(2,2), V(2,2)
$m_{\tilde{\chi}_j^0}$	real(dp) :: N(4)
N	complex(dp) :: N(4,4)
m_{h^0}, m_{H^0}	real(dp) :: mS0(2)
R_α	real(dp) :: RS0(2,2)
m_{G^0}, m_{A^0}	real(dp) :: mP0(2)
R_β	real(dp) :: RP0(2,2)
m_{G^+}, m_{H^+}	real(dp) :: mSpm(2)
R'_β	complex(dp) :: RSpm(2,2)
$m_{\tilde{\nu}}$	real(dp) :: mSneut(3)
$R_{\tilde{\nu}}$	complex(dp) :: Rsneut(3,3)
$m_{\tilde{l}}$	real(dp) :: mSlepton(6)
$R_{\tilde{l}}$	complex(dp) :: Rslepton(6,6)
$m_{\tilde{u}}$	real(dp) :: mSup(6)
$R_{\tilde{u}}$	complex(dp) :: Rsup(6,6)
$m_{\tilde{d}}$	real(dp) :: mSdown(6)
$R_{\tilde{d}}$	complex(dp) :: Rsdown(6,6)
U_u^L, U_u^R	complex(dp) :: uU_L(3,3), uU_L(3,3)
U_d^L, U_d^R	complex(dp) :: uD_L(3,3), uD_L(3,3)
U_l^L, U_l^R	complex(dp) :: uL_L(3,3), uL_L(3,3)

43 and 44 (55, 56, 65 and 66) entries specifiy the left–right mixing of smuons (staus). The squark mixing matrices have the same generation structure.

These initial values serve as input for the more accurate calculation of the parameters including higher oder corrections. Before calling the subroutine Sugra, which performs these calculations, the user has the possibility to fix the high scale and/or the scale where the parameters and the loop corrected masses are calculated. For this purpose one or both of the following lines must be uncommented in the program:

```
! Call SetGUTScale(2.e16_dp)   ! please put the GUT scale
! Call SetRGEScale(1.e3_dp**2) ! please put the scale M_EWSB squared
```

The default is that these scales are calculated by the program. The high scale is computed from the requirement $g_1 = g_2$ (except in GMSB where the high scale is an input). The scale M_{EWSB} is given by $M_{EWSB} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$.

The accurate calculation of the SUSY parameters and the spectrum is done by the following call:

```
 delta = 1.e-3_dp
 WriteOut = .False.
 n_run = 20
 Call Sugra(delta, vevSM, mC, U, V, mN, N, mS0, mS02, RS0  &
    & , mP0, mP02, RP0, mSpm, mSpm2, RSpm, mSdown, mSdown2 &
    & , RSdown, mSup, mSup2, RSup, mSlepton, mSlepton2     &
    & , RSlepton, mSneut, mSneut2, RSneut, mGlu, PhaseGlu  &
    & , gauge, uL_L, uL_R, uD_L, uD_R, uU_L, uU_R, Y_l     &
    & , Y_d, Y_u, Mi, A_l, A_d, A_u, M2_E, M2_L, M2_D      &
    & , M2_Q, M2_U, M2_H, mu, B, m_GUT, kont, WriteOut, n_run)
```

The meaning of the various variables and their type is given in Tables 1 and 2. Note that the quantities uL_L, uL_R, uD_L, uD_R, uU_L, uU_R are 3×3 unit matrices in the present implementation. Also all SUSY parameters, Yukawa couplings and the sfermion masses are flavour diagonal. However, we have constructed the interface already in such a way that an extension to include mixing effects between the generations is facilitated. Compared to the previous calls of routines the following new variable appear:

- delta : specifies the required relative precision on the masses. If the maximal relative differences between the physical masses obtained between two runs is smaller than delta, the routine Sugra leaves the iteration loop.
- m_GUT : the value of the scale where the high energy boundary conditions are imposed.
- kont : A variable which is 0 provided everything is o.k. Otherwise either a numerical problem has occurred and/or the parameters belong to an unphysical region, e.g. a minimum of the potential where charge and/or colour breaking minima occur. In such a case the information is written to the file Messages.out.
- WriteOut : If it is set .True. then intermediate debugging information is written to the screen and the file Messages.out.

- n_run specifies the maximal number of iterations of the main loop. A warning will be given in the case that the required precision delta has not been reached within n_run iterations.

Note that the parameters are running parameters at the scale M_{EWSB}. The complete spectrum is calculated at 1–loop level using the formulas given in [24]. The exceptions are the masses of the neutral Higgs bosons (scalar and pseudo-scalar), where in addition the 2–loop corrections $O(\alpha_s\alpha_t + \alpha_t^2 + \alpha_s\alpha_b)$ are included [25, 26], and the μ parameter where also the $O(\alpha_s\alpha_t + \alpha_t^2 + \alpha_s\alpha_b)$ corrections [26] are included.

In the next part the branching ratios, the partial decay widths and the total decay widths are calculated provided that L_BR=.TRUE. and kont.eq.0:

```
If ((L_BR).and.(kont.eq.0)) then
 epsI = 1.e-5_dp
 deltaM = 1.e-3_dp
 CalcTBD = .False.
 ratioWoM = 1.e-4_dp
 If (HighScaleModel.Eq."GMSB")  Is_GMSB = .True.
 Call CalculateBR(gauge, mGlu, PhaseGlu, mC, U, V, mN, N   &
    & , mSneut, RSneut, mSlepton, RSlepton, mSup, RSup     &
    & , mSdown, RSdown, uL_L, uL_R, uD_L, uD_R, uU_L, uU_R &
    & , mS0, RS0, mP0, RP0, mSpm, RSpm, epsI, deltaM       &
    & , CalcTBD, kont, ratioWoM, Y_d, A_d, Y_l, A_l, Y_u   &
    & , A_u, mu, vevSM, Fgmsb, m32                         &
    & , gP_Sl, gT_Sl, BR_Sl, gP_Sn, gT_Sn, BR_Sn, gP_Sd    &
    & , gT_Sd, BR_Sd, gP_Su, gT_Su, BR_Su, gP_C2, gT_C     &
    & , BR_C2, gP_C3, BR_C3, gP_N2, gT_N, BR_N2, gP_N3     &
    & , BR_N3, gP_G2, gT_G, BR_G2, gP_G3, BR_G3, gP_P0     &
    & , gT_P0, BR_P0, gP_S0, gT_S0, BR_S0, gP_Spm, gT_Spm  &
    & , BR_Spm)
 end if
```

Variables starting with gP_, gT_ and BR_ indicate partial widths, total widths and branching ratios, respectively; they are Real(dp) vectors. The first index is the index of the decaying particle whereas the second one gives the mode. The correspondence between the second index and the modes is summarized for sfermions (variables ending Sl, Sn, Sd and Su for sleptons, sneutrino, d-squarks and u-squarks, respectively) in Table 3, for charginos in Table 4, for neutralinos in Table 5, for gluinos in Table 6 and for the Higgs bosons in Tables 7 and 8.

Here the following variables are new:

- epsI : gives the accuracy to which the phase space integrals in three body decays are calculated.

- deltaM : this variable affects the calculation of the phase space integrals in three body decays. In case that $m_i/(m-\sum_i m_i) <$ deltaM than m_i is set to zero in the calculation of the phase space integrals. m denotes here mass of the decaying particle and m_i (i=1,2,3) are the masses of the decay products.

- CalcTBD : if this variable is set .TRUE. then in all chargino-, neutralino- and gluino decays the three body modes will be calculated. This option has to be taken with care, because it can slow down the program considerably.

Table 3: Correspondence between the indices for sfermion partial widths (branching ratios) and the modes.

mode	$\tilde{l}$	$\tilde{\nu}$	$\tilde{d}$	$\tilde{u}$
$\tilde{f}_i \to f\,\tilde{\chi}^0_k$	1-4	1-4	1-4	1-4
$\tilde{f}_i \to f'\,\tilde{\chi}^\pm_j$	5-6	5-6	5-6	5-6
$\tilde{f}_i \to f\,\tilde{g}$	-	-	7	7
$\tilde{f}_i \to W^\pm \tilde{f}'_j$	7	7-8	8-9	8-9
$\tilde{f}_i \to H^\pm \tilde{f}'_j$	8	9-10	10-11	10-11
$\tilde{f}_2 \to Z^0 \tilde{f}_1$	9	11	12	12
$\tilde{f}_2 \to A^0 \tilde{f}_1$	10	12	13	13
$\tilde{f}_2 \to h^0 \tilde{f}_1$	11	13	14	14
$\tilde{f}_2 \to H^0 \tilde{f}_1$	12	14	15	15
$\tilde{l}_1 \to l\,\tilde{G}$	13	-	-	-

Table 4: Correspondence between the second indices for chargino partial widths (branching ratios) and the decay modes. In case of two body decays the variables are gP_C2 (BR_C2) and in case of three body decays gP_C3 (BR_C3).

mode	index of gP_C2 (BR_C2)	index of gP_C3 (BR_C3)
$\tilde{\chi}^+_i \to \tilde{l}^+_{m,k}\,\nu_m$	1-6	
$\tilde{\chi}^+_i \to \tilde{\nu}_m\,l^+_m$	7-9	
$\tilde{\chi}^+_i \to \bar{\tilde{d}}_{m,k}\,u_m$	10-15	
$\tilde{\chi}^+_i \to \tilde{u}_{m,k}\,\bar{d}_m$	16-21	
$\tilde{\chi}^+_i \to \tilde{\chi}^0_j\,W^+$	22-25	
$\tilde{\chi}^+_i \to \tilde{\chi}^0_j\,H^+$	26-29	
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,Z^0$	30	
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,A^0$	31	
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,h^0$	32	
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,H^0$	33	
$\tilde{\chi}^+_i \to \tilde{\chi}^0_j\,u_m\,\bar{d}_m$		1-12
$\tilde{\chi}^+_i \to \tilde{\chi}^0_j\,l^+_m\,\nu_m$		13-24
$\tilde{\chi}^+_i \to \tilde{g}\,u_m\,\bar{d}_m$		25-27
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,u_m\,\bar{u}_m$		28-30
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,d_m\,\bar{d}_m$		31-33
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,l_m\,l^+_m$		34-36
$\tilde{\chi}^+_2 \to \tilde{\chi}^+_1\,\sum_m \nu_m\,\bar{\nu}_m$		37

Table 5: Correspondence between the second indices for neutralino partial widths (branching ratios) and the decay modes. In case of two body decays the variables are gP_C2 (BR_C2) and in case of three body decays gP_C3 (BR_C3).

mode	index of gP_C2 (BR_C2)	index of gP_C3 (BR_C3)
$\tilde{\chi}_i^0 \to \tilde{l}_{m,k}^+ \, l_m$	1-6	
$\tilde{\chi}_i^0 \to \tilde{\nu}_m \, l_m^+$	7-9	
$\tilde{\chi}_i^0 \to \bar{\tilde{u}}_{m,k} \, u_m$	10-15	
$\tilde{\chi}_i^0 \to \tilde{d}_{m,k} \, \bar{d}_m$	16-21	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^- \, W^+$	22-23	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^- \, H^+$	24-25	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, Z^0$	26-(24+i)	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, A^0$	(25+i)-(23+2 i)	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, h^0$	(26+i)-(22+3 i)	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, H^0$	(27+i)-(21+4 i)	
$\tilde{\chi}_1^0 \to \gamma \, \tilde{G}$	74	
$\tilde{\chi}_1^0 \to Z^0 \, \tilde{G}$	75	
$\tilde{\chi}_1^0 \to h^0 \, \tilde{G}$	76	
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, u_m \, \bar{u}_m$		1-(3*i-3)
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, d_m \, \bar{d}_m$		(3*i-2)-(6*i-6)
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, l_m^+ \, l_m^-$		(6*i-5)-(9*i-9)
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, \sum_n \nu_m \, \bar{\nu}_m$		(9*i-8)-(10*i-9)
$\tilde{\chi}_i^0 \to \tilde{G} \, u_m \, \bar{u}_m$		(10*i-8) - (10*i-6)
$\tilde{\chi}_i^0 \to \tilde{G} \, d_m \, \bar{d}_m$		(10*i-5) - (10*i-3)

Table 6: Correspondence between the indices for gluino partial widths (branching ratios) and the decay modes. In case of two body decays the variables are gP_G2 (BR_G2) and in case of three body decays gP_G3 (BR_G3).

mode	index of gP_C2 (BR_C2)	index of gP_C3 (BR_C3)
$\tilde{g} \to \bar{\tilde{d}}_{m,k} \, d_m$	1-6	
$\tilde{g} \to \tilde{u}_{m,k} \, \bar{u}_m$	7-12	
$\tilde{g} \to \tilde{\chi}_j^0 \, u_m \, \bar{u}_m$		1-12
$\tilde{g} \to \tilde{\chi}_j^0 \, d_m \, \bar{d}_m$		13-24
$\tilde{g} \to \tilde{\chi}_i^+ \, d_m \, \bar{u}_m$		25-30
$\tilde{g} \to \tilde{t}_i \, W^- \, \bar{b}$		31-32
$\tilde{g} \to \tilde{t}_1 \, \bar{c}$		33

Table 7: Correspondence between the indices for the partial widths (branching ratios) of the neutral Higgs bosons and the decay modes. The variables are gP_S0 (BR_S0) and gP_S0 (BR_S0) for the partial decay widths (branching ratios) of the CP-even Higgs bosons (h^0, H^0) and CP-odd Higgs boson (A^0). In case of gP_S0 (BR_S0) the first (second) index denotes decay modes of h^0 (H^0). Here ϕ stands for h^0, H^0 and A^0. The index runs from 1 to 3.

mode	h^0	H^0	A^0
$\phi \to l_m^+ \, l_m^-$	1-3	1-3	1-3
$\phi \to d_m \, \bar{d}_m$	4-6	4-6	4-6
$\phi \to u_m \, \bar{u}_m$	7-9	7-9	7-9
$H^0 \to \tilde{l}_{m,1}^+ \, \tilde{l}_{m,1}^-$	-	10 + 3*(m-1)	-
$\phi \to \tilde{l}_{m,1}^\mp \, \tilde{l}_{m,2}^\pm$	-	11 + 3*(m-1)	11 + 3*(m-1)
$H^0 \to \tilde{l}_{m,2}^+ \, \tilde{l}_{m,2}^-$	-	12 + 3*(m-1)	-
$H^0 \to \tilde{\nu}_m \, \bar{\tilde{\nu}}_m$	-	19 + m	-
$H^0 \to \tilde{d}_{m,1} \, \bar{\tilde{d}}_{m,1}$	-	22 + 3*(m-1)	-
$\phi \to \tilde{d}_{m,1} \, \bar{\tilde{d}}_{m,2}$	-	23 + 3*(m-1)	20 + 3*(m-1)
$H^0 \to \tilde{d}_{m,2} \, \bar{\tilde{d}}_{m,2}$	-	24 + 3*(m-1)	-
$H^0 \to \tilde{u}_{m,1} \, \bar{\tilde{u}}_{m,1}$	-	31 + 3*(m-1)	-
$\phi \to \tilde{u}_{m,1} \, \bar{\tilde{u}}_{m,2}$	-	32 + 3*(m-1)	29 + 3*(m-1)
$H^0 \to \tilde{u}_{m,2} \, \bar{\tilde{u}}_{m,2}$	-	33 + 3*(m-1)	-
$\phi \to \tilde{\chi}_r^0 \, \tilde{\chi}_s^0 \; (r \leq s)$	40-49	40-49	37-46
$\phi \to \tilde{\chi}_k^+ \, \tilde{\chi}_n^- \; (k \leq n)$	50-52	50-52	47-49
$H^0 \to Z^0 \, Z^0$	-	53	-
$H^0 \to W^+ \, W^-$	-	54	-
$H^0 \to h^0 \, h^0$	-	59	-
$A^0 \to h^0 \, Z^0$	-	-	52

Table 8: Correspondence between the indices for the partial widths (branching ratios) of the charged Higgs and the decay modes. The variables are gP_Spm (BR_Spm) and in case of partial decay widths (branching ratios).

mode	index
$H^+ \to l_m^+ \, \nu_m$	1-3
$H^+ \to u_m \, \bar{d}_m$	4-6
$H^+ \to \tilde{e}_i^+ \, \tilde{\nu}_e$	7-8
$H^+ \to \tilde{\mu}_i^+ \, \tilde{\nu}_\mu$	9-10
$H^+ \to \tilde{\tau}_i^+ \, \tilde{\nu}_\tau$	11-12
$H^+ \to \tilde{u}_i \, \bar{\tilde{d}}_j$	12 + 2*(i-1) + j
$H^+ \to \tilde{c}_i \, \bar{\tilde{s}}_j$	16 + 2*(i-1) + j
$H^+ \to \tilde{t}_i \, \bar{\tilde{b}}_j$	20 + 2*(i-1) + j
$H^+ \to \tilde{\chi}_r^+ \, \tilde{\chi}_s^0$	24 + 4*(r-1) + s
$H^+ \to h^0 \, W^+$	34

- `ratioWoM` : this variable is used to decide whether two body decays or three body decay modes are calculated in case of charginos, neutralino and gluino. The program tries first two-body decay modes. In the case that the ratio of the width Γ over the mass m of the decaying particle is small: $\Gamma/m <$ `ratioWoM`, then three body decay modes are calculated.

- `Fgmsb` and `m32` : the F parameter and the gravitino mass in the GMSB model. These parameters are calculated from the input and are set to huge numbers in all other models. They are needed for the calculation of the decay width(s) of the NLSP into a gravitino.

The next statements call the routine for the calculation of the cross sections provided `L_CS = .TRUE.` and `kont = 0`:

```
If ((L_CS).and.(kont.eq.0)) then
 Call InitializeCrossSections(Ecms, Pm, Pp, ISR)
 Call CalculateCrossSections(Ecms, Pm, Pp, ISR              &
          & , mSup, RSup, mf_u, mSdown, RSdown, mf_d, mglu  &
          & , SigSup, SigSdown, mSlepton, RSlepton          &
          & , mSneut, RSneut, SigSle, SigSn, mC, U, V, mN, N  &
          & , SigC, SigChi0, mS0, RS0, vevSM, mP0, RP0, mSpm  &
          & , RSpm, SigS0, SigSP, SigHp )
End If
```

Here the following additional input is needed:

- `Ecms` : the centre of mass energy of the collider

- `Pm`, `Pp` : degree of polarization of the incoming electron and positron, respectively

- `ISR` : logical variable, if `.TRUE.` then initial state radiation is taken into account using the formulas given in [49]

These variables can be set in the file `CrossSections.in`. The cross sections are stored in the variables starting with `Sig` which are summarized in Table 9. Please note, that in case of sfermions the structure of the variables is already put such that the case of generation mixing can easily be implemented. In the non–mixing case the cross sections are stored in the 2×2 diagonal blocks and they are sorted according to the generations as in the case of the sfermion mixing matrices.

Finally the low energy constraints $b \to s\gamma$, a_μ and $\Delta\rho$ are calculated provided that calculation of the spectrum had been performed successfully (`kont.eq.0`):

```
If (kont.eq.0) then
 Call CalculateLowEnergyConstraints(gauge, Y_l, Y_d, Y_u    &
   & , mSpm2, RSpm, mC, U, V, mN, N , mSup2, RSup, mSdown2  &
   & , RSdown, mSlepton2, RSlepton, mSneut2, RSneut         &
   & , BRbtosgamma, a_mu, Delta_Rho)
Else
 BRbtosgamma = 0._dp
 a_mu = 0._dp
 Delta_Rho = 0._dp
End If
```

Table 9: Correspondence between the production cross sections and the variables used in the program.

process	Fortran name and type
$e^+ e^- \to \tilde{u}_i \tilde{u}_j$	real(dp) :: SigSup(6,6)
$e^+ e^- \to \tilde{d}_i \tilde{d}_j$	real(dp) :: SigSdown(6,6)
$e^+ e^- \to \tilde{l}_i \tilde{l}_j$	real(dp) :: SigSle(6,6)
$e^+ e^- \to \tilde{\nu}_i \tilde{\nu}_j$	real(dp) :: SigSn(6,6)
$e^+ e^- \to \tilde{\chi}^0_k \tilde{\chi}^0_n$	real(dp) :: SigChi0(4,4)
$e^+ e^- \to \tilde{\chi}^+_r \tilde{\chi}^-_s$	real(dp) :: SigN(4,4)
$e^+ e^- \to h^0 Z,\ H^0 Z$	real(dp) :: SigS0(2)
$e^+ e^- \to h^0 A^0,\ H^0 A^0$	real(dp) :: SigSP(2)
$e^+ e^- \to H^+ H^-$	real(dp) :: SigHp

Here `BRbtosgamma`, `a_mu`, and `Delta_Rho` denote $10^4 \times \mathrm{BR}(b \to s\gamma)$, the SUSY contributions to a_μ and the sfermion contributions to $\Delta\rho$, respectively.

Afterwards the statement

```
Call WriteOutPut0(11, 1.e-6_dp, 1.e-3_dp)
```

is used to write all information to the file connected with unit 11 (first entry). The second entry puts a lower bound on the branching ratios to be written. In the case above, branching ratios smaller than 10^{-6} will not be given. The third entry gives the minimum value for the cross section in fb which will be written to the output file. In the example given above cross sections smaller than 10^{-3} will not be written to the output file.

The last statement closes all open files.

```
call closing() ! closes the files
```

8 Conclusions

We have described `SPheno`, a program calculating the spectrum, branching ratios and cross sections of supersymmetric particle in e^+e^- annihilation within the MSSM. The user can choose between the following high scale models: minimal supergravity, minimal supergravity including right handed neutrinos, gauge mediated supersymmetry breaking, anomaly mediated supersymmetry breaking, and string effective field theories based on OI and OII compactification. The calculation of the spectrum are done using two-loop renormalization group equations and the complete one-loop formulas for the SUSY masses. In case of the neutral Higgs bosons and the μ parameter leading two-loop effects are included. The masses and mixing angles are used to calculate the most important two body and three body decay modes. They are also used for the calculation of the SUSY production cross sections in e^+e^- annihilation. Here the effects of initial state radiation and longitudinal beam polarization is included. Finally the following low energy quantities are calculated: $BR(b \to s\gamma)$, the supersymmetric contributions to the anomalous magnetic moment of the muon a_μ and the sfermion contributions to the ρ parameter.

The program is set up in such a way that extensions can easily be included. The plans for upcoming versions are to include complex phases for the supersymmetric parameters, to include generation mixing, to include QCD and Yukawa corrections for various processes such as Sfermion and Higgs production and decays. In addition beam strahlung for various collider designs will be implemented.

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A Switches

In this appendix we describe the switches for influencing the behaviour of the program. Inside the main program one can set two scales:

1. The electroweak scale M_{EWSB}, which is the scale where the loop contributions to the masses and mixing matrices are calculated. The default is to calculate this scale from $M_{EWSB} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$. By calling

   ```
   Call SetRGEScale(1.e3_dp**2)
   ```

   M_{EWSB} will be set to the fixed value of 10^3 GeV in this example. Note that the input is the scale squared. In the case one uses a zero or a negative number as input for `SetRGEScale` then the scale will be calculated from the stop masses.

2. The high energy scale, where the boundary conditions of the model under study are set. Except for GMSB, where the scale is fixed by default, the high scale is calculated from the requirement $g_1 = g_2$. By calling

   ```
   Call SetGUTScale(2.e16_dp)
   ```

   M_{GUT} will be set to $2 \cdot 10^{16}$ GeV in this example. In the case one uses a zero or a negative number as input for `SetGUTScale` then the scale will be calculated from the requirement $g_1 = g_2$ except for GMSB.

In general the strong coupling g_s will be different from g_1 and g_2 in GUT theories if one works at the two loop level [66]. In case someone wants to enforce strict universality at the high scale, this can be done by using the following statement:

```
test = SetStrictUnification(.TRUE.)
```

where `test` is a logical variable to which the old value of SetStrictUnification is assigned. The same functions can also be used to set this option `.FALSE.`.

B Input files

In this section the input files are described. Among these files only the file `HighScale.in` has to be provided by the user. The other files `Control.in`, `CrossSections.in` and `StandardModel.in` can be used to change the default values which are given below in Appendices B.1, B.2 and B.4.

B.1 Control.in

This file contains three entries as shown below:

```
0              ! ErrorLevel
.True.         ! Calculation of branching ratios
.True.         ! Calculation of cross sections
```

The values given above are the default values inside the program and are used if the the file `Control.in` is not present. Here `ErrorLevel` is an integer in the range [-2,2] where the numbers correspond to the following behaviour of the program:

- -2 do not print severe warnings
- -1 do not print warnings
- 0 print every warning
- 1 abort in case of a severe warning
- 2 abort even in case of a warning

A warning is called severe if either a result is unphysical or if a numerical procedure gives an unreliable result.

B.2 CrossSections.in

This file contains four entries as shown below:

```
500.           ! c.m.s. energy in GeV
0.             ! degree of longitudinal polarization of electrons
0.             ! degree of longitudinal polarization of positrons
.True.         ! calculation of initial state radiation if .TRUE.
```

The values given above are the default values inside the program and are used if the the file `CrossSections.in` is not present.

B.3 HighScale.in

In this section we describe the input file for the high scale boundary conditions. The package contains several files starting with `Highscale.in` and ending in the models described below. One has to rename the model file to the name `Highscale.in` to use it as input for `SPheno`. Note that in all examples below the value of A_0 given below will be multiplied by the Yukawas coupling at the high scale and that this product enters the RGEs. For most of the examples below we have used the so-called SPS points defined in [67]. In Appendix C we display the output for the point SPS1a.

B.3.1 mSUGRA

The minimal SUGRA version is defined by four parameters and the sign of the μ parameter. The parameters are the gaugino mass parameter $M_{1/2}$, the scalar mass parameter M_0, the trilinear parameter A_0 as well as $\tan\beta$. The file reads for example

```
mSugra
 250.                          ! M_1/2
 100.                          ! M_0
-100.                          ! A_0
  10.                          ! tan(beta)
   1.                          ! sign of mu
.TRUE.                         ! if 2-loop RGEs should be used
```

B.3.2 mSUGRA including right handed neutrinos

In this case one needs four more input values compared to the case of mSUGRA described above: a common right handed neutrino mass m_{ν_R} and the light neutrino masses m_{ν_i} ($i = 1, 2, 3$). The file reads for example

```
mSugra
 250.                          ! M_1/2
 100.                          ! M_0
-100.                          ! A_0
  10.                          ! tan(beta)
   1.                          ! sign of mu
1.e14                          ! m_nu_R
1.e-14 3.e-12 0.06e-9          ! m_nu_i
.TRUE.                         ! if 2-loop RGEs should be used
```

B.3.3 GMSB

The GMSB scenario is characterized by two mass parameters M_M and Λ; the multiplicity N_5 and N_{10} of messengers in the $5+\overline{5}$ and $10+\overline{10}$ vector-like multiplets, respectively; $\tan\beta$ and the sign of μ as described in Sect. 2.3.3. In addition one can set a common value for the A parameters at the scale M_M. Note, however, that in the minimal model this value is practically zero. The file reads for example

```
GMSB
100000.                         ! Lambda
200000.                         ! M_M
1                               ! N_5
0                               ! N_10
0.                              ! A0
15.                             ! tan(beta)
1.                              ! sign of mu
.TRUE.                          ! if 2-loop RGEs should be used
```

B.3.4 AMSB

The implemented AMSB scenario is characterized by the gravitino mass $m_{3/2}$, a common scalar mass M_0, $\tan\beta$ and the sign of μ. The file reads for example

```
AMSB            ! model
60000.          ! M_3/2
450.            ! M_0
10.             ! tan(beta)
1.              ! sign of mu
.TRUE.          ! if 2-loop RGEs should be used
```

B.3.5 String I

This scenario is characterized by the gravitino mass $m_{3/2}$, the common vev $< t >$ of the moduli fields, the string coupling squared g_s^2, the sine squared of the mixing angle between the dilaton fields and moduli fields $\sin^2\theta$, the parameter δ_{GS} of the Green–Schwarz counter-term, the modular weights n_i characterizing the couplings between moduli fields and matter fields, which are assumed to be generation independent in the current implementation. Moreover, one needs to specify $\tan\beta$ and the sign of μ. The file reads for example as

```
String_OI
180.                       ! M_3/2
14.0                       ! <t>
0.5                        ! g_s^2
0.9                        ! sin^2(theta)
 0.                        ! delta_GS
-1 -3                      ! n_E n_L
 1 -2 0                    ! n_D n_U n_Q
-1 -1                      ! n_H1 n_H2
10.                        ! tan(beta)
-1.                        ! phase(mu)
.TRUE.                     ! if 2-loop RGEs should be used
```

B.3.6 String II

This scenario is characterized by the gravitino mass $m_{3/2}$, the common vev of the moduli fields $< t >$, the string coupling squared g_s^2, the sine squared of the mixing angle between the dilaton fields and moduli fields $\sin^2\theta$, the parameter of the Green–Schwarz counter-term δ_{GS}. Moreover, one needs to specify $\tan\beta$ and the sign of μ. There are two different scenarios implemented denoted as `String_OIIa` and `String_OIIb` corresponding to boundary conditions (A) and (B) of [31], respectively. The files read for example as

```
String_OIIa
300.                       ! M_3/2
14.6                       ! <t>
0.5                        ! g_s^2
0.9                        ! sin^2(theta)
0.                         ! delta_GS
```

```
5.                          ! tan(beta)
1.                          ! phase(mu)
.TRUE.                      ! if 2-loop RGEs should be used
```

and

```
String_OIIb
300.                        ! M_3/2
14.6                        ! <t>
0.5                         ! g_s^2
0.9                         ! sin^2(theta)
0.                          ! delta_GS
5.                          ! tan(beta)
1.                          ! phase(mu)
.TRUE.                      ! if 2-loop RGEs should be used
```

B.3.7 SUGRA

This input files serves as interface for more general models with gauge couplings unification. Here the user can specify non-universal gaugino masses at the high scale $M_{1/2}[U(1)]$, $M_{1/2}[SU(2)]$, $M_{1/2}[SU(3)]$, 15 different values of the sfermion mass parameters for every type of sfermions: $M^0_{\tilde{E},ii}$, $M^0_{\tilde{L},ii}$, $M^0_{\tilde{D},ii}$, $M^0_{\tilde{U},ii}$, $M^0_{\tilde{Q},ii}$; two Higgs mass parameters $M^0_{H_1}$ and $M^0_{H_2}$; nine different A parameters $A_{0,e,ii}$, $A_{0,d,ii}$ and $A_{0,u,ii}$. Here ii denotes that only the diagonal entries can be set.

```
Sugra
480. 300. 300.         ! M_1/2_i
150. 150. 150.         ! M0_E_ii
150. 150. 150.         ! M0_L_ii
150. 150. 150.         ! M0_D_ii
150. 150. 150.         ! M0_Q_ii
150. 150. 150.         ! M0_U_ii
150. 150.              ! M0_H_i
0. 0. 0.               ! A0_u_ii
0. 0. 0.               ! A0_d_ii
0. 0. 0.               ! A0_e_ii
10.                    ! tan(beta)
1.                     ! phase(mu)
.TRUE.                 ! if 2-loop RGEs should be used
```

B.4 StandardModel.in

This file contains the values of the Standard Model parameters and must include all lines given below. Otherwise the default values given in the listing below are used:

```
91.187                      ! Z boson mass
2.490                       ! width of Z-boson
0.14 0.14 0.14 0.14 0.14    ! Br(Z -> q q) q=u,d,c,s,b
0.035 0.035 0.03            ! Br(Z -> l l) l=e, mu, tau
```

```
0.2                          ! Br(Z -> invisible)
80.41                        ! W boson mass
2.06                         ! widht of W-boson
0.35 0.35                    ! Br(W -> q q)
0.1  0.1 0.1                 ! Br(W -> l nu)
0.51099906e-3                ! electron mass
0.105658                     ! muon mass
1.7771                       ! tau mass
0.004                        ! u-quark mass
1.4                          ! c-quark mass
174.3                        ! t-quark mass
0.01                         ! d-quark mass
0.15                         ! s-quark mass
4.62                         ! b-quark mass
0.2315                       ! sin(theta_W) squared
137.0359895                  ! 1 / Alpha
127.9                        ! 1 / Alpha at m_Z
0.119                        ! Alpha_s at m_Z
1.16639e-5                   !  G_F, Fermi constant
0.220           ! s12 of CKM, parametrized as particle data book
0.039           ! s23 of CKM
0.0031          ! s13 of CKM
0.              ! phase of CKM
2.19709e-6      ! life time of muon
3.4e-13         ! life time of tau
```

All masses are given in GeV and Br denotes "branching ratio" in the list above.

C Sample output

Here we give the content of the file `SPheno.out` provided one uses the content of `HighScale.in` for the mSUGRA scenario described in Appendix B.3.1 and the default values of the files `Control.in`, `CrossSections.in` and `StandardModel.in`.

```
 mSugra input at the GUT scale   1.8193751412503776E+16
 M_1/2     :    2.5000000000000000E+02
 M_0       :    1.0000000000000000E+02
 A_0       :   -1.0000000000000000E+02
 tan(beta) :   10.0000000000000000
 phase(mu) :    1.0000000000000000

 Parameters at the scale    4.8387163690920886E+02

 Gaugino mass parameters
   1.0256160300628754E+02   1.9230453743751079E+02   5.8695416971423458E+02

 tan(beta), mu, B
```

```
 10.0000000000000000   3.5489208425079283E+02   1.5675353981646900E+04

Slepton mass parameters
A_l
 -7.2960260902552873E-03  -1.5085451901504909 -25.2233192083639537
M2_E
  1.8409373246520361E+04   1.8407069022083171E+04   1.7758366624396785E+04
M2_L
  3.7890957725749206E+04   3.7889823466403272E+04   3.7570561651708413E+04

Squark mass parameters
A_d
 -0.2294422308452373  -3.4416136998921720  -1.0705947183168641E+02
A_u
 -7.4845500397144014E-03  -2.6195690984405484  -4.4984080721097047E+02
M2_D
  2.7694850270662527E+05   2.7694564371571731E+05   2.7392874700277165E+05
M2_U
  2.7918011844082910E+05   2.7917785219910560E+05   1.7963017265859758E+05
M2_Q
  2.9890503958833648E+05   2.9890250621627242E+05   2.4881821604275642E+05

Higgs mass parameters
  3.2728705451079368E+04  -1.2647888724841128E+05

Masses and mixing matrices
Gluino :    5.9431308258414890E+02   1.0000000000000000

Charginos
  1.8128399897496990E+02   3.7972508491362004E+02
  U
  -0.915146173   0.403122168
   0.403122168   0.915146173
  V
  -0.969411416   0.245441450
   0.245441450   0.969411416

Neutralinos
 97.6301037960382843   1.8286658240938323E+02   3.6169325535757582E+02
 3.7956517886694593E+02
  N
   1   1  (  -0.985173736,   0.000000000)
   1   2  (   0.055759050,   0.000000000)
   1   3  (  -0.152169890,   0.000000000)
   1   4  (   0.056284663,   0.000000000)
   2   1  (  -0.105870636,   0.000000000)
   2   2  (  -0.939909692,   0.000000000)
```

```
   2   3  (   0.280773631,   0.000000000)
   2   4  (  -0.162872183,   0.000000000)
   3   1  (   0.000000000,   0.061494809)
   3   2  (  -0.000000000,  -0.091193095)
   3   3  (  -0.000000000,  -0.694530579)
   3   4  (  -0.000000000,  -0.711005965)
   4   1  (   0.120176983,   0.000000000)
   4   2  (  -0.324259957,   0.000000000)
   4   3  (  -0.644699749,   0.000000000)
   4   4  (   0.681744238,   0.000000000)

e-sneutrino mass   :    1.9045601012611243E+02
mu-sneutrino mass  :    1.9045285310250864E+02
tau-sneutrino mass :    1.8956097209694545E+02

selectron masses
  1.4386950800164570E+02   2.0663378686036157E+02
 R_e
   0.000088274   0.999999996
  -0.999999996   0.000088274

smuon masses
  1.4383537094841918E+02   2.0664861475069350E+02
 R_mu
   0.018241899   0.999833603
  -0.999833603   0.018241899

stau masses
  1.3457995016660027E+02   2.1033431394260100E+02
 R_tau
   0.268468657   0.963288420
  -0.963288420   0.268468657

u-squark masses
  5.4780614315239006E+02   5.6490633570208024E+02
 R_u
   0.000077527   0.999999997
  -0.999999997   0.000077527

c-squark masses
  5.4779164376198435E+02   5.6491659043591176E+02
 R_c
   0.027104541   0.999632604
  -0.999632604   0.027104541

t-squark masses
  3.9757274604952244E+02   5.8855899352335769E+02
```

```
 R_t
   0.554536381   0.832159481
  -0.832159481   0.554536381

d-squark masses
  5.4761741237742456E+02   5.6953755385412876E+02
 R_d
   0.000836413   0.999999650
  -0.999999650   0.000836413

s-squark masses
  5.4761111206790952E+02   5.6953840728628120E+02
 R_s
   0.012543035   0.999921333
  -0.999921333   0.012543035

b-squark masses
  5.1664747823588539E+02   5.4745980835840328E+02
 R_b
   0.951026325   0.309109898
  -0.309109898   0.951026325

m_A0, m_H+
  3.9716087636273568E+02   4.0654002309066368E+02

m_h0, m_H0
  1.1166181009637616E+02   3.9789685848133115E+02
 R_S0
   0.113896390   0.993492633
  -0.993492633   0.113896390


Low energy constraints
 10^4 Br(b -> s gamma) :   0.3838177E+01
 Delta(a_mu)           :   0.5447498E-08
 Delta(rho)            :   0.1829291E-03


                    Decay widths (GeV) and branching ratios

 Selectron_1
  Neutralino_1 e               0.21131224  100.00000000
 Total width :                 0.21131224


 Selectron_2
  Neutralino_1 e               0.12712238   52.26317145
```

```
 Neutralino_2 e              0.04013733   16.50145248
 Chargino_1 neutrino         0.07597540   31.23537607
Total width :                0.24323511


Smuon_1
 Neutralino_1 mu             0.21104744  100.00000000
Total width :                0.21104744


Smuon_2
 Neutralino_1 mu             0.12728238   52.28029028
 Neutralino_2 mu             0.04016202   16.49625242
 Chargino_1 neutrino         0.07601710   31.22345730
Total width :                0.24346150


Stau_1
 Neutralino_1 tau            0.14597684  100.00000000
Total width :                0.14597684


Stau_2
 Neutralino_1 tau            0.16310412   55.22030445
 Neutralino_2 tau            0.04619971   15.64130946
 Chargino_1 neutrino         0.08606600   29.13838609
Total width :                0.29536983


e-Sneutrino
 Neutralino_1 neutrino       0.15829938   90.39621196
 Neutralino_2 neutrino       0.00372885    2.12934196
 Chargino_1 e                0.01308905    7.47444608
Total width :                0.17511727


mu-Sneutrino
 Neutralino_1 neutrino       0.15829302   90.40278693
 Neutralino_2 neutrino       0.00372587    2.12788095
 Chargino_1 mu               0.01307861    7.46933212
Total width :                0.17509749


tau-Sneutrino
 Neutralino_1 neutrino       0.15649412   92.23051574
 Neutralino_2 neutrino       0.00292840    1.72586668
 Chargino_1 tau              0.01025464    6.04361757
```

```
Total width :                 0.16967717


Sdown_1
 Neutralino_1 d-quark         0.28784101   98.48847777
 Neutralino_2 d-quark         0.00280074    0.95830889
 Neutralino_3 d-quark         0.00038028    0.13011842
 Neutralino_4 d-quark         0.00123347    0.42204919
 Chargino_1 u-quark           0.00000306    0.00104559
Total width :                 0.29225857


Sdown_2
 Neutralino_1 d-quark         0.12768972    2.43021937
 Neutralino_2 d-quark         1.60529969   30.55242392
 Neutralino_3 d-quark         0.00884812    0.16839948
 Neutralino_4 d-quark         0.08754132    1.66610595
 Chargino_1 u-quark           3.18849528   60.68415751
 Chargino_2 u-quark           0.23637246    4.49869376
Total width :                 5.25424660


S-strange_1
 Neutralino_1 s-quark         0.28785440   98.14255868
 Neutralino_2 s-quark         0.00313853    1.07006608
 Neutralino_3 s-quark         0.00039188    0.13360864
 Neutralino_4 s-quark         0.00123018    0.41942337
 Chargino_1 c-quark           0.00068723    0.23430866
 Chargino_2 c-quark           0.00000010    0.00003458
Total width :                 0.29330232


S-strange_2
 Neutralino_1 s-quark         0.12767855    2.43041977
 Neutralino_2 s-quark         1.60496370   30.55122040
 Neutralino_3 s-quark         0.00888876    0.16920168
 Neutralino_4 s-quark         0.08758857    1.66728859
 Chargino_1 c-quark           3.18774099   60.68011250
 Chargino_2 c-quark           0.23649323    4.50175707
Total width :                 5.25335380


Sbottom_1
 Neutralino_1 b-quark         0.16184398    4.11945668
 Neutralino_2 b-quark         1.32661019   33.76655332
 Neutralino_3 b-quark         0.01759582    0.44787087
 Neutralino_4 b-quark         0.04615410    1.17477226
```

```
 Chargino_1 t-quark          1.71616072   43.68188400
 Stop_1 W-                   0.66040512   16.80946286
Total width :                3.92876992


Sbottom_2
 Neutralino_1 b-quark        0.24397318   33.44230042
 Neutralino_2 b-quark        0.08601743   11.79072502
 Neutralino_3 b-quark        0.03700740    5.07274017
 Neutralino_4 b-quark        0.05304386    7.27091758
 Chargino_1 t-quark          0.11582889   15.87709181
 Stop_1 W-                   0.19366391   26.54622500
Total width :                0.72953467


Sup_1
 Neutralino_1 u-quark        1.15181264   98.48926332
 Neutralino_2 u-quark        0.01120273    0.95792374
 Neutralino_3 u-quark        0.00152307    0.13023466
 Neutralino_4 u-quark        0.00494195    0.42257635
 Chargino_1 d-quark          0.00000002    0.00000193
Total width :                1.16948041


Sup_2
 Neutralino_1 u-quark        0.03620866    0.66423008
 Neutralino_2 u-quark        1.72553982   31.65418423
 Neutralino_3 u-quark        0.00517093    0.09485826
 Neutralino_4 u-quark        0.06407609    1.17544453
 Chargino_1 d-quark          3.53559056   64.85867992
 Chargino_2 d-quark          0.08463583    1.55260297
Total width :                5.45122190


S-charm_1
 Neutralino_1 c-quark        1.15098392   98.14036844
 Neutralino_2 c-quark        0.01253940    1.06919075
 Neutralino_3 c-quark        0.00158298    0.13497525
 Neutralino_4 c-quark        0.00492241    0.41971639
 Chargino_1 s-quark          0.00276378    0.23565786
 Chargino_2 s-quark          0.00000107    0.00009130
Total width :                1.17279356


S-charm_2
 Neutralino_1 c-quark        0.03701501    0.67941726
 Neutralino_2 c-quark        1.72415946   31.64725980
```

Neutralino_3 c-quark	0.00516765	0.09485322
Neutralino_4 c-quark	0.06416446	1.17775023
Chargino_1 s-quark	3.53281680	64.84549368
Chargino_2 s-quark	0.08472953	1.55522582
Total width :	5.44805290	

Stop_1

Neutralino_1 t-quark	0.39250239	19.40691906
Neutralino_2 t-quark	0.22674584	11.21123908
Chargino_1 b-quark	1.38120247	68.29228464
Chargino_2 b-quark	0.02203615	1.08955722
Total width :	2.02248685	

Stop_2

Neutralino_1 t-quark	0.22161960	2.91852834
Neutralino_2 t-quark	0.62619038	8.24635720
Neutralino_3 t-quark	0.34624563	4.55973974
Neutralino_4 t-quark	1.54482109	20.34388720
Chargino_1 b-quark	1.54991244	20.41093566
Chargino_2 b-quark	1.51409588	19.93926416
Stop_1 Z	1.51313204	19.92657136
Stop_1 h0	0.27752232	3.65471634
Total width :	7.59353939	

Chargino_1

neutralino_1 d u	0.00033235	1.99860842
neutralino_1 s c	0.00033232	1.99844982
neutralino_1 e nu	0.00058806	3.53637657
neutralino_1 mu nu	0.00063093	3.79415091
neutralino_1 tau nu	0.01474527	88.67241428
Total width :	0.01662893	

Chargino_2

Selectron_2 neutrino	0.12652636	5.19161956
Smuon_1 neutrino	0.00000150	0.00006154
Smuon_2 neutrino	0.12656625	5.19325658
Stau_1 neutrino	0.00104893	0.04303979
Stau_2 neutrino	0.13749520	5.64169248
e-sneutrino e	0.05302870	2.17586926
mu-sneutrino mu	0.05309068	2.17841255
tau-sneutrino tau	0.07070699	2.90124380
Neutralino_1 W	0.17302320	7.09947452
Neutralino_2 W	0.67940247	27.87718885
Chargino_1 Z	0.58927646	24.17914547

```
 Chargino_1 h0              0.42696015   17.51899560
Total width :               2.43712690

Neutralino_1 : stable

Neutralino_2
 Selectron_1 e              0.00154723    7.10543425
 Smuon_1 mu                 0.00160018    7.34859632
 Stau_1 tau                 0.01862788   85.54596943
Total width :               0.02177529


Neutralino_3
 Selectron_1 e              0.00503923    0.26009421
 Selectron_2 e              0.00218588    0.11282149
 Smuon_1 mu                 0.00508346    0.26237682
 Smuon_2 mu                 0.00227146    0.11723867
 Stau_1 tau                 0.02025229    1.04529883
 Stau_2 tau                 0.02419151    1.24861727
 e-sneutrino neutrino       0.01234523    0.63718479
 mu-sneutrino neutrino      0.01234554    0.63720099
 tau-sneutrino neutrino     0.01243421    0.64177746
 Chargino_1 W               1.14827835   59.26707890
 Neutralino_1 Z             0.22657242   11.69427718
 Neutralino_2 Z             0.40462398   20.88420588
 Neutralino_1 h0            0.04071375    2.10139378
 Neutralino_2 h0            0.02112676    1.09043373
Total width :               1.93746405


Neutralino_4
 Selectron_1 e              0.02090064    0.79655160
 Selectron_2 e              0.05133031    1.95626710
 Smuon_1 mu                 0.02086555    0.79521429
 Smuon_2 mu                 0.05145801    1.96113393
 Stau_1 tau                 0.01565228    0.59652937
 Stau_2 tau                 0.08419943    3.20895348
 e-sneutrino neutrino       0.13486416    5.13985427
 mu-sneutrino neutrino      0.13486717    5.13996895
 tau-sneutrino neutrino     0.13571657    5.17234103
 Chargino_1 W               1.34016810   51.07560769
 Neutralino_1 Z             0.05567616    2.12189348
 Neutralino_2 Z             0.04779240    1.82143249
 Neutralino_1 h0            0.17892991    6.81925922
 Neutralino_2 h0            0.35146997   13.39499312
Total width :               2.62389066
```

```
 Gluino
  Sup_1 u-quark                0.32555602    9.88307192
  Sup_2 u-quark                0.13408883    4.07060373
  S-charm_1 c-quark            0.32506240    9.86808701
  S-charm_2 c-quark            0.13420743    4.07420414
  Stop_1 t-quark               0.35279908   10.71010362
  Sdown_1 d-quark              0.32809509    9.96015176
  Sdown_2 d-quark              0.09594182    2.91255533
  S-strange_1 s-quark          0.32815106    9.96185087
  S-strange_2 s-quark          0.09594849    2.91275775
  Sbottom_1 b-quark            0.82565254   25.06475973
  Sbottom_2 b-quark            0.34857445   10.58185414
 Total width :                 3.29407721

h0
  electrons                    0.00000000    0.00000125
  muons                        0.00000103    0.05351444
  taus                         0.00029239   15.14367767
  d-quark                      0.00000001    0.00031725
  s-quark                      0.00000138    0.07138010
  b-quark                      0.00152831   79.15466880
  u-quark                      0.00000000    0.00004556
  c-quark                      0.00010767    5.57639494
 Total width :                 0.00193079


H0
  muons                        0.00028014    0.04201232
  taus                         0.07938694   11.90538074
  d-quark                      0.00000168    0.00025219
  s-quark                      0.00037836    0.05674169
  b-quark                      0.42140146   63.19609693
  c-quark                      0.00000511    0.00076636
  t-quark                      0.03081125    4.62065503
  Selectron 1 1                0.00039974    0.05994791
  Smuon 1 1                    0.00040732    0.06108426
  Smuon 1 2                    0.00003734    0.00559954
  Stau 1 1                     0.00433734    0.65045550
  Stau 1 2                     0.00799437    1.19888731
  e-Sneutrino                  0.00073208    0.10978775
  mu-Sneutrino                 0.00073222    0.10980771
  tau-Sneutrino                0.00076881    0.11529554
  neutralino_1 neutralino_1    0.01687144    2.53015073
  neutralino_1 neutralino_2    0.04686601    7.02833048
  neutralino_2 neutralino_2    0.01058042    1.58670780
  chargino_1 chargino_1        0.03027976    4.54094909
```

```
  Z Z                            0.00153237    0.22980460
  W W                            0.00320663    0.48088662
  h0 h0                          0.00980485    1.47039879
 Total width :                   0.66681564



A0
  muons                          0.00028050    0.02631577
  taus                           0.07949301    7.45791191
  d-quark                        0.00000168    0.00015796
  s-quark                        0.00037883    0.03554126
  b-quark                        0.42198287   39.58978482
  c-quark                        0.00000389    0.00036525
  t-quark                        0.10032310    9.41215930
  Smuon 1 2                      0.00003869    0.00362993
  Stau 1 2                       0.01130912    1.06100403
  neutralino_1 neutralino_1      0.02607822    2.44661842
  neutralino_1 neutralino_2      0.10959778   10.28229529
  neutralino_2 neutralino_2      0.08682800    8.14606947
  chargino_1 chargino_1          0.22688237   21.28575532
  h0 Z                           0.00269020    0.25239056
 Total width :                   1.06588826



 H^+
  electron neutrino              0.00000001    0.00000109
  muon neutrino                  0.00028712    0.04644904
  tau neutrino                   0.08137042   13.16371935
  d-quark u-quark                0.00000151    0.00024435
  s-quark c-quark                0.00034333    0.05554153
  b-quark t-quark                0.37287242   60.32152442
  Selectron_2 Sneutrino          0.00053557    0.08664129
  Smuon_1 Sneutrino              0.00005577    0.00902161
  Smuon_2 Sneutrino              0.00053145    0.08597568
  Stau_1 Sneutrino               0.01497337    2.42231984
  Stau_2 Sneutrino               0.00000770    0.00124494
  chargino_1 neutralino_1        0.14336239   23.19248520
  chargino_1 neutralino_2        0.00074334    0.12025399
  h0 W                           0.00305719    0.49457746
 Total width :                   0.61814157


Total cross sections in fb for:
 E_cms :     500.0000000  GeV
 Degree of polarization: P_e- = 0.000000 P_e+ = 0.000000
```

```
Intial state radiation is included

u-squarks : kinematically not possible

c-squarks : kinematically not possible

t-squarks : kinematically not possible


d-squarks : kinematically not possible

s-squarks : kinematically not possible

b-squarks : kinematically not possible


selectrons
 1   1     290.9786253 fb
 1   2      81.1156881 fb
 2   2      43.5380487 fb

smuons
 1   1      57.2730680 fb
 1   2       0.0058106 fb
 2   2      18.4801616 fb

staus
 1   1      62.1659720 fb
 1   2       1.2151999 fb
 2   2      15.5585302 fb


e-sneutrino
           412.6967832 fb

mu-sneutrino
            12.9553932 fb

tau-sneutrino
            13.2367076 fb


neutralinos
 1   1     284.9858436 fb
 1   2      64.4974860 fb
 1   3       8.0550495 fb
 1   4       1.0888651 fb
```

```
  2   2      61.0982614 fb


 charginos
  1   1     142.6642433 fb


 h^0 Z
             23.1467991 fb

 H^0 Z : cross section below   1.0000000E-03 fb

 h^0 A^0 : kinematically not possible

 H^0 A^0 : kinematically not possible

 H^+ H^- : kinematically not possible
```

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