ZU-TH 01/03
LC-TOOL-2003-042

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

W. Porod

Institut für Theoretische Physik, Universität Zürich,
CH-8057 Zürich, Switzerland

March 12, 2014

arXiv:hep-ph/0301101v4 15 Mar 2004

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 high scale 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 ISAJET [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`, ISAJET [17], SPYTHIA [21], SUSYGEN [22] and SDECAY [23]. 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) [24], complete one-loop correction to all SUSY and Higgs masses [25] supplemented by the 2-loop corrections to the neutral Higgs bosons [26, 27] and to the μ parameter[27]. 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

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

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 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. This can be done using `SPheno` specific files or by using the SUSY Les Houches Accord (SLHA) [29]. Moreover, we list the output of the program for a typical example. The source code as well as precompiled a version 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 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 ISAJET [17] and SOFTSUSY [18] but opposite to the convention in [25]. 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

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

and trilinear couplings of scalar matter fields and Higgs fields

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

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

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

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:

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

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:

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

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 $M_{\tilde{R},i}^2$ 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, 30] (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

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

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

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

is the messenger–scale threshold function [31] 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:

$$M_{\tilde{j}}^2(M_M) = 2(N_5 + 3N_{10}) f\left(\Lambda/M_M\right) \sum_{i=1}^{3} k_i C_j^i \alpha_i^2(M_M)\Lambda^2 \qquad (26)$$

with $k_i = 1, 1, 3/5$ for $SU(3)$, $SU(2)$, and $U(1)$, respectively; the coefficients C_j^i 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 [31]

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

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 [32] 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 [33, 34].

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 [33, 34]. 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 [34]. 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 [34] 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 [34]:

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

$s = \langle S \rangle$ 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:

$$\begin{aligned} A_{e,n}(GUT) &= Y_{e,nn}(GUT) A_{\tilde{E}_n \tilde{L}_n H_1} \qquad (35) \\ A_{d,n}(GUT) &= Y_{d,nn}(GUT) A_{\tilde{D}_n \tilde{Q}_n H_1} \qquad (36) \\ A_{u,n}(GUT) &= Y_{u,nn}(GUT) A_{\tilde{U}_n \tilde{Q}_n H_2} \qquad (37) \end{aligned}$$

where n denotes the generation.

In case of the OII compactification scheme the gaugino masses are given by Eqs. (3.11) of [34]:

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

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 [34]:

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

Set (B) is specified by formulas Eqs. (3.16) and (3.20) of [34]:

$$
\begin{aligned}
M_i^2 &= m_{3/2}^2\Bigg\{\frac{\sqrt{3}\sin\theta}{k_{s\overline{s}}^{1/2}}\Big[1+2t\cos\theta G_2\Big]\Big[\sum_a g_a^2\gamma_i^a+\frac{1}{2}\sum_{jk}\gamma_i^{jk}\,(k_s+k_{\overline{s}})\Big] \\
&\quad +\sin^2\theta\Big[1+\gamma_i+\ln\left[2t|\eta(t)|^4\right](\sum_a\gamma_i^a+2\sum_{jk}\gamma_i^{jk})-\sum_a\gamma_i^a\ln(g_a^2)\Big] \\
&\quad -\frac{9\sin^2\theta}{k_{s\overline{s}}}\Big[\sum_a\gamma_i^a\left(\frac{g_a^4}{4}\right)\left(\ln(g_a^2)+\frac{5}{3}\right) \\
&\qquad +\ln\left[(t+\overline{t})|\eta(t)|^4\right](\sum_a\gamma_i^a(\frac{g_a^4}{4})+\frac{1}{3}\sum_{jk}\gamma_i^{jk}k_sk_{\overline{s}})\Big]\Bigg\}, \qquad (41)\\
A_{ijk} &= m_{3/2}\Bigg\{(\gamma_i+\gamma_j+\gamma_k)\Big[1+2t\cos\theta G_2\Big] \\
&\quad +\frac{\sqrt{3}\sin\theta}{k_{s\overline{s}}^{1/2}}\Big[k_s+\sum_a\frac{g_a^2}{2}(\gamma_i^a+\gamma_j^a+\gamma_k^a)(1-\ln(g_a^2)) \\
&\qquad -\ln\Big[(t+\overline{t})|\eta(t)|^4\Big](\sum_a g_a^2(\gamma_i^a+\gamma_j^a+\gamma_k^a) \\
&\qquad\quad -\sum_{lm}k_s(\gamma_i^{lm}+\gamma_j^{lm}+\gamma_k^{lm}))\Big]\Bigg\}. \qquad (42)
\end{aligned}
$$

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 [35] 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 [36]. This general model will be denoted by SUGRA.

2.3.7 General MSSM at low energies

Starting with version 2.2.0 there exists also the possibility to give the parameters at the low scale M_{EWSB} together with scale. In this case the parameters are taken as running parameters at the scale M_{EWSB} and the masses and mixing angles are calculated using these parameters which in turn serve as input for the calculation of decay widths and cross sections. The input parameter are: the electroweak gaugino mass parameters M_1 and M_2, the gluino mass $m_{\tilde{g}}$; the parameters describing the Higgs sector μ, $\tan\beta$, the mass of the pseudoscalar Higgs mass m_A; the sfermion mass parameters $M_{\tilde{E},ii}$, $M_{\tilde{L},ii}$, $M_{\tilde{D},ii}$, $M_{\tilde{U},ii}$, $M_{\tilde{Q},ii}$, $A_{u,ii}$, $A_{d,ii}$, and $A_{l,ii}$. This general model will be denoted by MSSM.

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

The following sfermion decays are calculated:

$$\begin{aligned}
\tilde{f}_i &\to f\,\tilde{\chi}_k^0,\ f'\,\tilde{\chi}_l^\pm && (43)\\
\tilde{f}_i &\to \tilde{f}_j\,Z^0,\ \tilde{f}_j'\,W^\pm && (44)\\
\tilde{f}_i &\to \tilde{f}_j\,(h^0, H^0, A^0),\ \tilde{f}_j'\,W^\pm && (45)
\end{aligned}$$

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 [38, 39, 40]:

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

where $l = e, \mu, \tau$. The corresponding widths are calculated within `SPheno` using the formulas given in [39]. 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 [30].

It is well known that the partial widths of sfermions can receive considerable radiative corrections [41]. However, the branching ratios are not that strongly affected [42]. 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:

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

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

$$\begin{aligned}
\tilde{\chi}_i^0 &\to f\,\bar{f}\,\tilde{\chi}_j^0,\ f\,f'\,\tilde{\chi}_k^{\mp} && (56)\\
\tilde{\chi}_i^0 &\to q\,\bar{q}\,\tilde{g} && (57)\\
\tilde{\chi}_k^+ &\to f\,\bar{f}\,\tilde{\chi}_s^+,\ f\,f'\,\tilde{\chi}_j^0 && (58)\\
\tilde{\chi}_k^+ &\to q\,q'\,\tilde{g} && (59)
\end{aligned}$$

In the calculation we have included all contributions from gauge bosons, sfermions and Higgs bosons [37, 43]. The Higgs contributions can be important in certain regions of parameter space [44]. In addition the loop induced decay s

$$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0\,\gamma \qquad (60)$$

are calculated [45] taking into account the left-right mixing of sfermions. 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

$$\begin{aligned}
\tilde{\chi}_1^0 &\to \gamma\ \tilde{G} && (61)\\
\tilde{\chi}_1^0 &\to Z^0\ \tilde{G} && (62)\\
\tilde{\chi}_1^0 &\to h^0\ \tilde{G} && (63)
\end{aligned}$$

Here we use the formulas given in [30].

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

$$\tilde{g} \to q\,\tilde{q}_i \qquad (64)$$

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

$$\begin{aligned}
\tilde{g} &\to \tilde{\chi}_i^0\,q\,\bar{q} && (65)\\
\tilde{g} &\to \tilde{\chi}_j^{\pm}\,q'\,\bar{q} && (66)\\
\tilde{g} &\to \bar{b}\,W^-\,\tilde{t}_1, b\,W^+\,\tilde{t}_1^* && (67)
\end{aligned}$$

Here we have implemented the formulas given in [46]. In addition the decays

$$\tilde{g} \to \tilde{\chi}_i^0\,\gamma \qquad (68)$$

are calculated [45, 47] taking into account the left-right mixing of sfermions.

In case of Higgs bosons the following decays are calculated:

$$\begin{aligned}
\phi &\to f\,\bar{f} && (69)\\
\phi &\to \tilde{f}_i\,\bar{\tilde{f}}_j && (70)\\
\phi &\to \tilde{\chi}_k^0\,\tilde{\chi}_l^0 && (71)\\
\phi &\to \tilde{\chi}_r^+\,\tilde{\chi}_s^- && (72)\\
H^0 &\to Z^0\,Z^0,\ W^+\,W^- && (73)\\
H^0 &\to h^0\,h^0 && (74)
\end{aligned}$$

$$A^0 \to h^0 Z^0 \quad (75)$$
$$H^+ \to f \bar{f}' \quad (76)$$
$$H^+ \to \tilde{f}_i \bar{\tilde{f}}'_j \quad (77)$$
$$H^+ \to \tilde{\chi}^0_k \tilde{\chi}^-_s \quad (78)$$
$$H^+ \to h^0 W^+ \quad (79)$$

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 [48, 49, 50]. In the present version only the gluonic QCD corrections for the decays into quarks [48] have been implemented. Therefore, the numbers provided by `SPheno` have to be taken with care and for refined analysis other programs, such as HDECAY [51] should be used.

4 Production of supersymmetric particles and Higgs bosons

The program calculates the following cross sections:

$$e^+ e^- \to \tilde{f}_i \tilde{f}_j \qquad (f = l, \nu, q) \quad (80)$$
$$e^+ e^- \to \tilde{\chi}^0_k \tilde{\chi}^0_n \quad (81)$$
$$e^+ e^- \to \tilde{\chi}^+_r \tilde{\chi}^-_s \quad (82)$$
$$e^+ e^- \to h^0 Z,\ H^0 Z \quad (83)$$
$$e^+ e^- \to h^0 A^0,\ H^0 A^0 \quad (84)$$
$$e^+ e^- \to H^+ H^- \quad (85)$$

We haven taken the formulas of [52] for sfermion production, [53, 37] for production of charginos and neutralinos and [50] for Higgs boson production. Initial state radiation has been included using the formula given in [54]. In case of squarks in addition QCD corrections due to gluon exchange are included [54, 55]. 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 [56] 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 [57, 58] for $b \to s\,\gamma$ supplemented by the QCD corrections as given in [59], [60] for a_μ and [61] 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 [62, 63] 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 masses, the Z-boson pole mass, the fine structure constant α, the Fermi constant G_F and the strong coupling constant $\alpha_s(m_Z)$. It is assumed that $\alpha_s(m_Z)$ is given in the $\overline{MS}$ scheme. We describe first the implementation of the high scale models and comment then on the case of the implemented MSSM model.

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. Afterward 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 [25]. The only difference is that we use an updated number for $\Delta\alpha_{lep} + \Delta\alpha_{had} = 0.06907$ [64]. The mass of the W-boson is calculated using the formula [65]

$$m_W^2 = m_Z^2\hat{\rho}\left(\frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\alpha^{\overline{DR}}(m_Z)\pi}{\sqrt{2}G_F m_Z^2\hat{\rho}(1-\Delta\hat{r})}}\right) \tag{86}$$

$$\hat{\rho} = \frac{1}{1-\Delta\hat{\rho}} \tag{87}$$

$$\Delta\hat{\rho} = Re\left(\frac{\Pi_{ZZ}^T(m_Z^2)}{\hat{\rho}m_Z^2} - \frac{\Pi_{WW}^T(m_W^2)}{m_W^2}\right) \tag{88}$$

$$\Delta\hat{r} = \hat{\rho}\frac{\Pi_{WW}^T(0)}{m_W^2} - \frac{\Pi_{ZZ}^T(m_Z^2)}{\hat{m}_Z^2} + \delta_{VB} \tag{89}$$

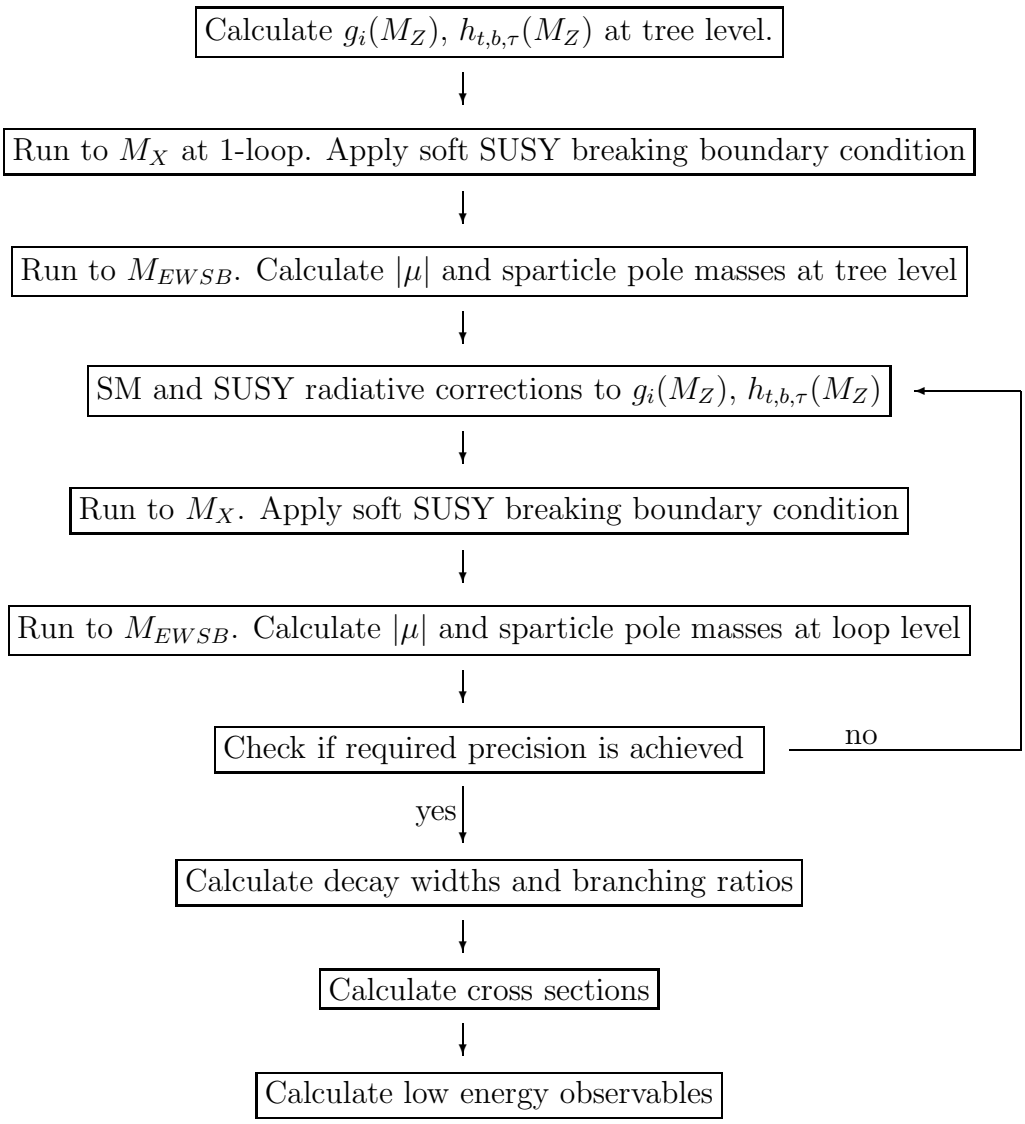

Figure 1: Algorithm used to calculate the SUSY spectrum, decay widths, production cross sections and low energy observables. Each step (represented by a box) is explained in the text. The initial step is the uppermost one. M_{EWSB} is the scale at which the EWSB conditions are imposed, and M_X is the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

where Π^T_{VV} is the transverse part of the vector boson self-energy and δ_{VB} contains non-universal corrections to the μ decay. In the computation we have included the leading SM two-loop corrections the formulas of [66] and adapting the Higgs contribution as in [25]. The formulas of the SUSY contribution to δ_{VB} are given in [67, 68]. All masses appearing in the loops are running except for the top-quark, because the 2-loop part is given for an on-shell definition of the top mass. Note here that also the gauge boson masses in the loops are running masses and thus an iteration has to be performed in practice.

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 [25]. In addition we have implemented the following improvements. The five light quarks and α_s are evolved to m_Z using 4-loop RGEs as given in [69] including threshold corrections at the low scale [70]. This evolution is done in the $\overline{MS}$ scheme. At m_Z the shift to the $\overline{DR}$ scheme is performed using the formulas given in [71, 72], e.g.:

$$m_{b',\overline{DR}}(m_Z) = m_{b,\overline{MS}}(m_Z)\left(1-\frac{\alpha_s}{3\pi}-\frac{23\alpha_s^2}{72\pi^2}+\frac{4g_2^2}{128\pi^2}-\frac{13g'^2}{1152\pi^2}\right) \tag{90}$$

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 [72]. We use the complete formulas given in Appendix D of [25] 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 resumed using [73]

$$m_{b,\overline{DR}}(m_Z) = \frac{m_{b',\overline{DR}}(m_Z)}{1-\frac{\Delta m_{b,SUSY}(m_Z)}{m_{b,\overline{DR}}(m_Z)}} \tag{91}$$

In the case of the top-quark a modified procedure has to be used due to its large mass. In this case we start from the pole mass m_t and use the formulas given in [25] to obtain $m_t^{\overline{DR}}(m_Z)$. The difference compared to [25] is in the 2-loop parts where we have taken the exact 2-loop formula given in [71]:

$$\Sigma_t^{2l} = -\left(\frac{\alpha_s(m_Z)}{\pi}\right)^2\left(\frac{8\pi^2}{9}+\frac{2011}{18}+\frac{16\pi^2\ln 2}{9}-\frac{8\zeta(3)}{3}+\frac{246}{3}L+22L^2\right) \tag{92}$$

$$L = \log\left(\frac{m_Z^2}{m_t^2}\right) \tag{93}$$

In the case of leptons we first calculate the running masses $m_l(m_l)$ at 1-loop level in the $\overline{MS}$ scheme. Afterward we use two-loop RGEs as given in [74] to evolve them to m_Z. Here we perform the shift to the $\overline{DR}$ scheme using the formula:

$$m_l^{\overline{DR},SM}(m_Z) = m_l^{\overline{MS},SM}(m_Z)\left(1-\frac{3(g'^2-g_2^2)}{128\pi^2}\right) \tag{94}$$

The analog of Eq. (91) is used to obtain the running mass including the SUSY threshold corrections.

The obtained gauge and Yukawa couplings are evolved to the high scale using two–loop RGEs [24]. 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 [24] 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 fix M_{EWSB} to a constant value as described 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 [25] for the one–loop contributions and for the 2-loop corrections $O(\alpha_s(\alpha_t + \alpha_b) + (\alpha_t + \alpha_b)^2 + \alpha_\tau \alpha_b + \alpha_t^2 au)$ for the neutral Higgs boson the formulas given in [26, 27, 28]. 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 [25]. In all cases running masses are used as input for the loop integrals. In addition we have implemented the $O(\alpha_s(\alpha_t + \alpha_b) + (\alpha_t + \alpha_b)^2 + \alpha_\tau \alpha_b + \alpha_t^2 au)$ corrections for the calculation of $|\mu|$ [27, 28]. The numerical evolution of the one–loop integrals is based on the FF package [75] and the LoopTools package [76].

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:

$$\delta > \frac{|m_i - m_{i-1}|}{m_i} \tag{95}$$

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.

In the case of the MSSM model the running between M_{EWSB} and M_X is obviously omitted. In this model one has, however, to preform an iteration to get the Yukawa and gauge couplings correct because $\tan\beta$ is defined at M_{EWSB} instead of m_Z.

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.

Afterward 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 center 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

$$C_7(W^+) = -\frac{K_{ts}K_{tb}x_{tW}}{4\,m_W^2}\left(\frac{2}{3}F_1(x_{tW}) + F_2(x_{tW})\right) \tag{96}$$

$$C_7(H^+) = -\frac{K_{ts}K_{tb}}{4\,m_{H^+}^2}\left[\frac{Y_t^2\cos^2\beta}{4}\left(\frac{2}{3}F_1(x_{tH^+}) + F_2(x_{tH^+})\right) - \frac{Y_bY_t\cos\beta\sin\beta m_t}{m_b}\left(\frac{2}{3}F_3(x_{tH^+}) + F_4(x_{tH^+})\right)\right] \tag{97}$$

$$C_7(\tilde{\chi}^+) = \sum_{i,j=1}^{2}\frac{K_{ts}K_{tb}}{4\,m_{\tilde{t}_i}^2}\left[C_{R,ij}^2\left(\frac{2}{3}F_2(x_{\tilde{\chi}_j^+\tilde{t}_i}) + F_1(x_{\tilde{\chi}_j^+\tilde{t}_i})\right) - C_{L,ij}C_{R,ij}\left(\frac{2}{3}F_4(x_{\tilde{\chi}_j^+\tilde{t}_i}) + F_3(x_{\tilde{\chi}_j^+\tilde{t}_i})\right)\right] \tag{98}$$

$$C_{L,ij} = Y_bR_{\tilde{t},i1}U_{j2} \tag{99}$$

$$C_{R,ij} = -gR_{\tilde{t},i1}V_{j1} + Y_tR_{\tilde{t},i2}V_{j2} \tag{100}$$

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 [57]. 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 [59] to obtain

$$BR(b \to s\gamma) = 1.258 + 0.382r7^2 + 0.015r_8^2 + 1.395r_7 + 0.161r_8 + 0.083r_7r_8 \tag{101}$$

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 $b \to s\gamma$ [63].

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. Afterward the error system is initialized and the input data are read by calling:

```
Call ReadingData(kont)
```

The source code can be found in the file `SPheno.f90`. This routine checks first if the file `LesHouches.in` exists where the input data are provided according to SLHA (for a detailed description see Appendix C). If this file is absent, the routine checks if the files `Control.in`

Table 1: Variables for parameters and couplings. The parameters are defined in the module `MSSM_Data` and they 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)`

and/or `StandardModel.in` are present. The first one can be used to set various flags (see Appendix B.1) whereas the second one is used to set the SM input (see Appendix B.4). Standard values as described in the Appendix are used if any of these files is absent. Afterward the model specific information is read from the file `HighScale.in` which is described in Appendix B.3 (for a short description of the implemented models see Sect. 2.3). In all cases the file `Messages.out` is opened at channel 10 where all warnings and/or debugging informations are stored.

Before calling the subroutine `CalculateSpectrum`, which performs the calculation of the spectrum, 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
If (kont.Eq.0) Call CalculateSpectrum(n_run, delta, WriteOut, kont, tanb, 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, 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)
```

Table 2: Variables for masses and mixing matrices as given by the routine `CalculateSpectrum`. They are defined in the module `MSSM_Data` and 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)

The meaning of the various variables and their type is given in Tables 1 and 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 sneutrinos 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, 43 and 44 (55, 56, 65 and 66) entries specify the left–right mixing of smuons (staus). The squark mixing matrices have the same generation structure. This structure has been chosen to facilitate a later extension which includes flavour violating entries. Beside the variables given in Tables 1 and 2 the following variables 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 [25]. The exceptions are the masses of the neutral Higgs bosons (scalar and pseudo-scalar) as well as μ the two loop corrections due to α_s and all third generation Yukawa couplings are included [26, 27].

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_C, gT_C      &
    & , BR_C, gP_N, gT_N, BR_N, gP_G, gT_G, BR_G, 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.

Table 3: Correspondence between the indices for sfermion partial widths (branching ratios) and the modes. $\tilde{t}_1$ is listed extra because it can have three-body decay modes.

mode	$\tilde{l}$	$\tilde{\nu}$	$\tilde{d}$	$\tilde{u}$	$\tilde{t}_1$
$\tilde{f}_i \to f\tilde{\chi}^0_k$	1-4	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	5-6
$\tilde{f}_i \to f\tilde{g}$	-	-	7	7	7
$\tilde{f}_i \to W^\pm \tilde{f}'_j$	7	7-8	8-9	8-9	8-9
$\tilde{f}_i \to H^\pm \tilde{f}'_j$	8	9-10	10-11	10-11	10-11
$\tilde{f}_2 \to Z^0 \tilde{f}_1$	9	-	12	12	-
$\tilde{f}_2 \to A^0 \tilde{f}_1$	10	-	13	13	-
$\tilde{f}_2 \to h^0 \tilde{f}_1$	11	-	14	14	-
$\tilde{f}_2 \to H^0 \tilde{f}_1$	12	-	15	15	-
$\tilde{l}_1 \to l\tilde{G}$	13	-	-	-	-
$\tilde{t}_1 \to c\tilde{\chi}^0_{1,2}$	-	-	-	-	55-56
$\tilde{t}_1 \to W^+ \bar{b}\tilde{\chi}^0_1$	-	-	-	-	57
$\tilde{t}_1 \to \bar{b}e^+\tilde{\nu}_e$	-	-	-	-	58
$\tilde{t}_1 \to \bar{b}\mu^+\tilde{\nu}_\mu$	-	-	-	-	59
$\tilde{t}_1 \to \bar{b}\tau^+\tilde{\nu}_\tau$	-	-	-	-	60
$\tilde{t}_1 \to \bar{b}\nu_e\tilde{e}^+_{1,2}$	-	-	-	-	61-62
$\tilde{t}_1 \to \bar{b}\nu_\mu\tilde{\mu}^+_{1,2}$	-	-	-	-	63-64
$\tilde{t}_1 \to \bar{b}\nu_\tau\tilde{\tau}^+_{1,2}$	-	-	-	-	65-66

- `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.

- `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            &
```

Table 4: Correspondence between the second indices for chargino partial widths (branching ratios) and the decay modes.

mode	index of gP_C (BR_C)
$\tilde{\chi}_i^+ \to \tilde{l}_{m,k}^+ \nu_m$	1-6
$\tilde{\chi}_i^+ \to \tilde{\nu}_m l_m^+$	7-9
$\tilde{\chi}_i^+ \to \tilde{\bar{d}}_{m,k} u_m$	10-15
$\tilde{\chi}_i^+ \to \tilde{u}_{m,k} \bar{d}_m$	16-21
$\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 W^+$	22-25
$\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 H^+$	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
$\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 u_m d_m$	64-75
$\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 l_m^+ \nu_m$	76-87
$\tilde{\chi}_i^+ \to \tilde{g} u_m \bar{d}_m$	88-90
$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ u_m \bar{u}_m$	91-93
$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ d_m \bar{d}_m$	94-96
$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ l_m l_m^+$	97-99
$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ \nu_m \bar{\nu}_m$	100-102

```
          & , 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 center 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 [54]

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    &
```

Table 5: Correspondence between the second indices for neutralino partial widths (branching ratios) and the decay modes. Note, that also charge conjugated states are given.

mode	index of gP_N (BR_N)
$\tilde{\chi}_i^0 \to \tilde{l}_{m,k}^+ \, l_m$	1-12
$\tilde{\chi}_i^0 \to \tilde{\nu}_m \, \nu_m$	13-18
$\tilde{\chi}_i^0 \to \tilde{\bar{u}}_{m,k} \, u_m$	19-30
$\tilde{\chi}_i^0 \to \tilde{d}_{m,k} \, \bar{d}_m$	31-42
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm \, W^\mp$	43-46
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm \, H^\mp$	47-50
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 \, Z^0$	51-(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)
$\tilde{\chi}_i^0 \to \gamma \, \tilde{G}$	63
$\tilde{\chi}_i^0 \to Z^0 \, \tilde{G}$	64
$\tilde{\chi}_i^0 \to h^0 \, \tilde{G}$	65
$\tilde{\chi}_i^0 \to \gamma \, \tilde{\chi}_j^0$	65 + j
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm \, q_m \, \bar{q}'_m$	69 - 80
$\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm \, l_m^\mp \, \nu_m$	81 - 92
$\tilde{\chi}_i^0 \to \tilde{G} \, u_m \, \bar{u}_m$	93 - 95
$\tilde{\chi}_i^0 \to \tilde{G} \, d_m \, \bar{d}_m$	96 - 98
$\tilde{\chi}_{i>1}^0 \to \tilde{\chi}_1^0 \, u_m \, \bar{u}_m$	99 - 101
$\tilde{\chi}_{i>1}^0 \to \tilde{\chi}_1^0 \, d_m \, \bar{d}_m$	102 - 104
$\tilde{\chi}_{i>1}^0 \to \tilde{\chi}_1^0 \, l_m^+ \, l_m^-$	105 - 107
$\tilde{\chi}_{i>1}^0 \to \tilde{\chi}_1^0 \, \nu_m \, \bar{\nu}_m$	108 - 110
$\tilde{\chi}_{i>2}^0 \to \tilde{\chi}_2^0 \, u_m \, \bar{u}_m$	111 - 113
$\tilde{\chi}_{i>2}^0 \to \tilde{\chi}_2^0 \, d_m \, \bar{d}_m$	114 - 116
$\tilde{\chi}_{i>2}^0 \to \tilde{\chi}_2^0 \, l_m^+ \, l_m^-$	117 - 119
$\tilde{\chi}_{i>2}^0 \to \tilde{\chi}_2^0 \, \nu_m \, \bar{\nu}_m$	120 - 122
$\tilde{\chi}_4^0 \to \tilde{\chi}_3^0 \, u_m \, \bar{u}_m$	123 - 125
$\tilde{\chi}_4^0 \to \tilde{\chi}_3^0 \, d_m \, \bar{d}_m$	126 - 128
$\tilde{\chi}_4^0 \to \tilde{\chi}_3^0 \, l_m^+ \, l_m^-$	129 - 131
$\tilde{\chi}_4^0 \to \tilde{\chi}_3^0 \, \nu_m \, \bar{\nu}_m$	132 - 134

Table 6: Correspondence between the indices for gluino partial widths (branching ratios) and the decay modes. Note, that also charge conjugated states are given.

mode	index of gP_G (BR_G)
$\tilde{g} \to \tilde{d}_{m,k}\, d_m$	1-12
$\tilde{g} \to \tilde{u}_{m,k}\, \bar{u}_m$	13-24
$\tilde{g} \to \tilde{t}_1\, \bar{c}$	25-26
$\tilde{g} \to \gamma\, \tilde{\chi}_j^0$	26 + j
$\tilde{g} \to \tilde{\chi}_1^0\, u_m\, \bar{u}_m$	31-33
$\tilde{g} \to \tilde{\chi}_1^0\, d_m\, \bar{d}_m$	34-36
$\tilde{g} \to \tilde{\chi}_2^0\, u_m\, \bar{u}_m$	37-39
$\tilde{g} \to \tilde{\chi}_2^0\, d_m\, \bar{d}_m$	40-42
$\tilde{g} \to \tilde{\chi}_3^0\, u_m\, \bar{u}_m$	43-45
$\tilde{g} \to \tilde{\chi}_3^0\, d_m\, \bar{d}_m$	46-48
$\tilde{g} \to \tilde{\chi}_4^0\, u_m\, \bar{u}_m$	49-51
$\tilde{g} \to \tilde{\chi}_4^0\, d_m\, \bar{d}_m$	52-54
$\tilde{g} \to \tilde{\chi}_i^\pm\, q_m\, \bar{q}'_m$	55-66
$\tilde{g} \to \tilde{t}_i\, W^-\, \bar{b}$	67-68

```
   & , 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
```

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.

Afterward 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

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_P0 (BR_P0) 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 m 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
$H^0 \to \tilde{e}_1^+ \, \tilde{e}_1^-$	-	10	-
$\phi \to \tilde{e}_1^\mp \, \tilde{e}_2^\pm$	-	11-12	11-12
$H^0 \to \tilde{e}_2^+ \, \tilde{e}_2^-$	-	13	-
$H^0 \to \tilde{\mu}_1^+ \, \tilde{\mu}_1^-$	-	14	-
$\phi \to \tilde{\mu}_1^\mp \, \tilde{\mu}_2^\pm$	-	15-16	15-16
$H^0 \to \tilde{\mu}_2^+ \, \tilde{\mu}_2^-$	-	17	-
$H^0 \to \tilde{\tau}_1^+ \, \tilde{\tau}_1^-$	-	18	-
$\phi \to \tilde{\tau}_1^\mp \, \tilde{\tau}_2^\pm$	-	19-20	19-20
$H^0 \to \tilde{\tau}_2^+ \, \tilde{\tau}_2^-$	-	21	-
$H^0 \to \tilde{\nu}_m \, \bar{\tilde{\nu}}_m$	-	21 + m	-
$H^0 \to \tilde{d}_1^+ \, \tilde{d}_1^-$	-	25	-
$\phi \to \tilde{d}_1^\mp \, \tilde{d}_2^\pm$	-	26-27	23-24
$H^0 \to \tilde{d}_2^+ \, \tilde{d}_2^-$	-	28	-
$H^0 \to \tilde{s}_1^+ \, \tilde{s}_1^-$	-	29	-
$\phi \to \tilde{s}_1^\mp \, \tilde{s}_2^\pm$	-	30-31	27-28
$H^0 \to \tilde{s}_2^+ \, \tilde{s}_2^-$	-	32	-
$H^0 \to \tilde{b}_1^+ \, \tilde{b}_1^-$	-	33	-
$\phi \to \tilde{b}_1^\mp \, \tilde{b}_2^\pm$	-	34-35	31-32
$H^0 \to \tilde{b}_2^+ \, \tilde{b}_2^-$	-	36	-
$H^0 \to \tilde{u}_1^+ \, \tilde{u}_1^-$	-	37	-
$\phi \to \tilde{u}_1^\mp \, \tilde{u}_2^\pm$	-	38-39	35-36
$H^0 \to \tilde{u}_2^+ \, \tilde{u}_2^-$	-	40	-
$H^0 \to \tilde{c}_1^+ \, \tilde{c}_1^-$	-	41	-
$\phi \to \tilde{c}_1^\mp \, \tilde{c}_2^\pm$	-	42-43	39-40
$H^0 \to \tilde{c}_2^+ \, \tilde{c}_2^-$	-	44	-
$H^0 \to \tilde{t}_1^+ \, \tilde{t}_1^-$	-	45	-
$\phi \to \tilde{t}_1^\mp \, \tilde{t}_2^\pm$	-	46-47	43-44
$H^0 \to \tilde{t}_2^+ \, \tilde{t}_2^-$	-	48	-
$\phi \to \tilde{\chi}_r^0 \, \tilde{\chi}_s^0 \; (r \le s)$	49-58	49-58	46-55
$\phi \to \tilde{\chi}_1^+ \, \tilde{\chi}_1^-$	59	59	56
$\phi \to \tilde{\chi}_1^\pm \, \tilde{\chi}_2^\mp$	60-61	60-61	57-58
$\phi \to \tilde{\chi}_2^+ \, \tilde{\chi}_2^-$	62	62	59
$H^0 \to Z^0 \, Z^0$	-	63	-
$H^0 \to W^+ \, W^-$	-	64	-
$H^0 \to h^0 \, h^0$	-	70	-
$A^0 \to h^0 \, Z^0$	-	-	63

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
$H^+ \to \tilde{u}_i \, \overline{\tilde{d}}_j$	12 + 2*(j-1) + i
$H^+ \to \tilde{c}_i \, \overline{\tilde{s}}_j$	16 + 2*(j-1) + i
$H^+ \to \tilde{t}_i \, \overline{\tilde{b}}_j$	20 + 2*(j-1) + i
$H^+ \to \tilde{\chi}_r^+ \, \tilde{\chi}_s^0$	24 + 4*(r-1) + s
$H^+ \to h^0 \, W^+$	34

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)
$e^+ e^- \to \tilde{\chi}_k^0 \, \tilde{\chi}_n^0$	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

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. Starting with version 2.2.0 `SPheno` allows for input and output according to the SUSY Les Houches accord [29].

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.

Acknowledgments

I would like to thank B. Allanach, A. Djouadi and S. Kraml for discussions on higher order corrections to the Yukawa couplings. Special thanks go to: (i) P. Slavich for discussions on 2-loop corrections of the neutral Higgs boson masses and the μ parameter as well as for providing a Fortran code performing these calculations. (ii) M. Mühlleitner for a detailed comparison of various decay branching ratios. I would like to thank G. Blair and P. Zerwas for an enjoyable and fruitful collaboration from which the work on this program originated. This work is supported by the Erwin Schrödinger fellowship No. J2095 of the 'Fonds zur Förderung der wissenschaftlichen Forschung' of Austria and partly by the Swiss 'Nationalfonds'.

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 [77]. 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.`.

Starting with version 2.2.0 it also possible to set these values using the SUSY Les Houches accord as described in Appendix C.

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. An alternative way to provide `SPheno` with input is by the SUSY Les Houches accord as described in Appendix C.

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 [78]. In Appendix D 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 counterterm 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 [34], 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.3.8 MSSM

This input file serves for the cases that one wants to start with low energy parameters for the calculation of masses, decays and/or production rates. The input consists of the electroweak gaugino mass parameters M_1 and M_2, the gluino mass $m_{\tilde{g}}$, 15 sfermion mass parameters $M_{\tilde{E},ii}$, $M_{\tilde{L},ii}$, $M_{\tilde{D},ii}$, $M_{\tilde{U},ii}$, $M_{\tilde{Q},ii}$, 9 trilinear parameters $A_{e,ii}$, $A_{d,ii}$, $A_{u,ii}$; $\tan\beta$. Moreover, one has to specify the renormalisation scale Q where all the parameters are given as well as μ and the mass of the pseudoscalar Higgs m_A.

```
MSSM
99.13 192.74 580.51                          ! M_1 M_2 m_gluino
136.23 136.23 133.55                         ! M_E_i
196.64 196.64 195.75                         ! M_L_i
519.53 519.53 516.86                         ! M_D_i
539.86 539.86 495.91                         ! M_Q_i
521.66 521.66 424.83                         ! M_U_i
0. 0. -510.01                                ! A_u
0. 0. -772.66                                ! A_d
0. 0. -254.20                                ! A_e
10. 454.65                                   ! tan(beta) Q
352.39  393.63                               ! mu m_A
```

In the case that the keyword `MSSMtree` is used instead of `MSSM` the masses are calculated using tree-level formulas instead of loop corrected masses. The renormalisation scale Q is absent in this case, e.g. the two last line read as

```
10.                                          ! tan(beta)
352.39  393.63                               ! mu m_A
```

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:

```
91.1876                 ! m_Z
2.4952                  ! Gamma_Z
0.0336 0.0336 0.037     ! Br(Z -> l l)
0.2                     ! Br(Z -> invisible)
2.118                   ! Gamma_W
0.1  0.1  0.1           ! Br(W -> l nu)
```

```
0.51099890e-3             ! m_e
0.105658357               ! m_mu
1.7770                    ! m_tau
2.00             ! scale Q where the masses of the light quarks u,d,s,c are given
0.003            ! m_u(Q)
1.2              ! m_c(Q)
175.0            ! m_t, pole mass
0.007            ! m_d(Q)
0.12             ! m_s(Q)
4.25             ! m_b(m_b)
137.0359998      ! 1./ alpha
0.1172           ! alpha_s(m_Z)
1.16639e-5       !  G_F, Fermi constant
0.224            ! s12 of CKM particle data book 1998, 90%, 0.217-0.222
0.0413           ! s23 of CKM 0.036-0.042
0.00363           ! s13 of CKM 0.0018 - 0.0044
0.               ! phase of CKM   0.-2 Pi
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 Implementation of SUSY Les Houches Accord

Starting with version 2.2.0 `SPheno` allows for input and output according to the SUSY Les Houches accord [29]. The name of the input file is `LesHouches.in` and the output will be written to the file `SPheno.spc`. In the following we summarize unsupported features as well extensions of this standard. The unsupported features are:

- $\alpha^1_{em}(m_Z)^{\overline{MS}}$ of the block `SMINPUTS` is ignored as input. Instead the value $\alpha_{em}(0)$ can be changed in the block `SPhenoInput` described below. The corresponding value for the output will be given.

- In block `EXTPAR` the entries 51–53 are ignored as the corresponding formulas are not (yet) implemented in `SPheno`.

- Currently there is no information concerning warnings and errors in block `SPINFO`. This will be changed within the one of the next versions. Please check the file `Messages.out` for this information.

The current implementation requires that the block `MODSEL` is read in before the block `EXTPAR` is read in. In the case that an unknown entry appears, a warning message is printed and SPheno tries to proceed. SPheno stops execution in the case that the model input is not complete.

For the `SPheno` specific input the block `SPhenoInput` has to be used. In this block switches can be set, SM input beside the one of the block `SMINPUTS` can be set. Moreover, the information for the cross section calculation can be given here. Within this block the

following flags and parameters can be set, with general structure `id value`:

1	:	setting the error level as described Appendix B.1
11	:	if value=1 (0) then (no) branching ratios are calculated
12	:	only branching ratios larger than value are written out
21	:	if value=1 (0) then (no) cross sections are calculated
22	:	cms energy for e^+e^- annihilation
23	:	value gives degree of polarisation for e^- beam
24	:	value gives degree of polarisation for e^+ beam
25	:	only cross sections larger than value (in fb) are written out
31	:	a fixed value for the GUT scale is used if value is larger than 0
32	:	if value=0 then $g_3(m_{GUT})$ can be different from $g_1(m_{GUT}) = g_2(m_{GUT})$; if value=1 then strict unification $g_1(m_{GUT}) = g_2(m_{GUT}) = g_3(m_{GUT})$ is enforced
33	:	a fixed value for the renormalization scale Q_{EWSB} is used if value is larger than 0
41	:	sets value of Z-boson width
42	:	sets value of W-boson width
51	:	sets value of electron mass
52	:	sets value of muon mass
61	:	sets scale where the running masses for light quarks (u, d, s, c) are defined
62	:	sets value of u-quark mass
63	:	sets value of c-quark mass
64	:	sets value of d-quark mass
65	:	sets value of s-quark mass

Here is an example for this block with the default values of `SPheno`

```
Block SPhenoInput       # SPheno specific input
 1  -1                  # error level
11   1                  # calculate branching ratios
12   1.00000000E-04     # write only branching ratios larger than this value
21   1                  # calculate cross section
22   5.00000000E+02     # cms energy in GeV
23   0.00000000E+00     # polarisation of incoming e- beam
24   0.00000000E+00     # polarisation of incoming e+ beam
25   1.00000000E-04     # write only cross sections larger than this value [fb]
31  -1.00000000E+00     # m_GUT, if < 0 than it determined via g_1=g_2
32   0                  # require strict unification g_1=g_2=g_3 if '1' is set
33  -1.00000000E+00     # Q_EWSB, if < 0 than  Q_EWSB=sqrt(m_~t1 m_~t2)
41   2.49520000E+00     # width of the Z-boson
42   2.11800000E+00     # width of the W-boson
51   5.10998900E-04     # electron mass
52   1.05658357E-01     # muon mass
61   2.00000000E+00     # scale where quark masses of first 2 gen. are defined
62   3.00000000E-03     # m_u(Q)
63   1.20000000E+00     # m_c(Q)
64   7.00000000E-03     # m_d(Q)
65   1.20000000E-01     # m_s(Q)
```

For the output the extensions below have been defined. The information concerning the cross section is written out using a `SPheno` specific block called `SPhenoCrossSections`. The

first line of this block gives the information on the cms energy, the polarization of the incoming beams as well if ISR is included or not, for example for $\sqrt{s} = 500$ GeV and unpolarized beams:

```
Block SPhenoCrossSections  # cross sections
XS 11 -11   500.0  0.00  0.00  1  # e+ e- XS, Pe-, Pe+,  including ISR
```

The FORTRAN format is in this case:

```
Format("XS 11 -11 ",F7.1," ",F5.2," ",F5.2," ",A)
```

The cross sections (in fb) themself are written as

```
#      Sigma [fb]        NDA         ID1     ID2
     2.83574498E+02    2     2000011  -2000011    # ~e_R-      ~e_R+
```

Here the first entry gives the cross section in fb, the second entry specifies the number of produced particles, the subsequent two integers give the PDG code of the particles. We have used the FORTRAN format

```
Format(3x,1P,e16.8,0p,3x,I2,3x,2(i9,1x),2x," # ",A)
```

As an example we give the cross sections for the SPS1a scenario at an 500 GeV e^+e^- linear collider with unpolarized beams:

```
Block SPhenoCrossSections  # cross sections
XS 11 -11   500.0  0.00  0.00  1  # e+ e- XS, Pe-, Pe+,  including ISR
#      Sigma [fb]        NDA         ID1     ID2
     2.83574498E+02    2     2000011  -2000011    # ~e_R-      ~e_R+
     7.79728001E+01    2     2000011  -1000011    # ~e_R-      ~e_L+
     4.57495061E+01    2     1000011  -1000011    # ~e_L-      ~e_L+
     5.47916441E+01    2     2000013  -2000013    # ~mu_R-     ~mu_R+
     6.00045490E-03    2     2000013  -1000013    # ~mu_R-     ~mu_L+
     1.90114309E+01    2     1000013  -1000013    # ~mu_L-     ~mu_L+
     5.96228076E+01    2     1000015  -1000015    # ~tau_1-    ~tau_1+
     1.26426385E+00    2     1000015  -2000015    # ~tau_1-    ~tau_2+
     1.59684572E+01    2     2000015  -2000015    # ~tau_2-    ~tau_2+
     4.52889205E+02    2     1000012  -1000012    # ~nu_eL     ~nu_eL*
     1.36168303E+01    2     1000014  -1000014    # ~nu_muL    ~nu_muL*
     1.39168830E+01    2     1000016  -1000016    # ~nu_tauL   ~nu_tauL*
     2.75869582E+02    2     1000022   1000022    # chi_10 chi_10
     6.56937491E+01    2     1000022   1000023    # chi_10 chi_20
     7.10141133E+00    2     1000022   1000025    # chi_10 chi_30
     8.27993814E-01    2     1000022   1000035    # chi_10 chi_40
     6.90281358E+01    2     1000023   1000023    # chi_20 chi_20
     1.60903760E+02    2     1000024  -1000024    # chi_1- chi_1+
     2.47077869E+01    2          25        23    # h0 Z
```

The information concerning the value of low energy observables ($BR(b \to s\gamma)$, SUSY contribution to $(g-2)_\mu$ and $\Delta(\rho)$) is written out using a `SPheno` specific block called `SPhenoLowEnergy`. We use the following identifier:

1 : BR($b \to s\gamma$)
2 : SUSY contribtutions to $(g-2)_\mu$
3 : SUSY contribtutions to $\Delta(\rho)$

As an example we give here the output for the SPS1a scenario:

```
Block SPhenoLowEnergy  # low energy observables
    1    4.55809155E+00   # BR(b -> s gamma)
    2    5.42193822E-09   # (g-2)_muon
    3    1.97608480E-04   # Delta(rho)
```

D 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`.

```
SPheno output file
Version 2.2.0 ,  created: 11.03.2004,  21:06

 mSugra input at the GUT scale   2.3626654756304632E+16
 M_1/2     :    2.5000000000000000E+02
 M_0       :    1.0000000000000000E+02
 A_0       :   -1.0000000000000000E+02
 tan(beta) at m_Z :   10.0000000000000000
 phase(mu) :    1.0000000000000000

 Parameters at the scale    4.8391963443672887E+02

       g'             g             g_3
 3.61193779E-01  6.46479958E-01  1.09493111E+00

      Y_e            Y_mu          Y_tau
 2.88471294E-05  5.96467232E-03  1.00322460E-01

      Y_u            Y_c            Y_t
 8.84695152E-06  3.53878053E-03  8.92107505E-01

      Y_d            Y_s            Y_b
 1.91375025E-04  3.28071453E-03  1.37357260E-01

 Gaugino mass parameters
   1.0165957170339030E+02   1.9176076501787236E+02   5.8493277901867339E+02

 mu, B
   3.5735299500991079E+02   1.6699996261573800E+04

 Slepton mass parameters
```

```
A_l
 -2.5325613989602988E+02  -2.5325004783357019E+02  -2.5153292012959056E+02
M2_E
  1.8440768268311054E+04   1.8438451866710398E+04   1.7787517468332015E+04
M2_L
  3.8191007905480838E+04   3.8189867711691244E+04   3.7869523746231192E+04

Squark mass parameters
A_d
 -8.5467574322023552E+02  -8.5467228770510383E+02  -7.9058921072895021E+02
A_u
 -6.7949078243535337E+02  -6.7948707229660602E+02  -4.9657599289477690E+02
M2_D
  2.7447722422748851E+05   2.7447520834575844E+05   2.7114817843756522E+05
M2_U
  2.7672441991504660E+05   2.7672246826518845E+05   1.7613291366656474E+05
M2_Q
  2.9674725559000188E+05   2.9674529488349473E+05   2.4602686847035179E+05

Higgs mass parameters
  3.2530345774801379E+04  -1.2784263452390164E+05

Masses and mixing matrices
Gluino :    6.0402198802780606E+02   1.0000000000000000

Charginos
  1.7973283139106542E+02   3.8228031192319548E+02
  U
        -0.91793         0.39673
         0.39673         0.91793
  V
        -0.97122         0.23819
         0.23819         0.97122

Neutralinos
 97.1655612758851674   1.8073254909635224E+02   3.6466658683987458E+02   3.81926175864457
  N
   1   1  (        -0.98576,         0.00000)
   1   2  (         0.05614,         0.00000)
   1   3  (        -0.14885,         0.00000)
   1   4  (         0.05449,         0.00000)
   2   1  (        -0.10391,         0.00000)
   2   2  (        -0.94275,         0.00000)
   2   3  (         0.27483,         0.00000)
   2   4  (        -0.15776,         0.00000)
   3   1  (         0.00000,         0.06048)
   3   2  (        -0.00000,        -0.09026)
```

```
   3   3  (        -0.00000,        -0.69484)
   3   4  (        -0.00000,        -0.71091)
   4   1  (         0.11757,         0.00000)
   4   2  (        -0.31610,         0.00000)
   4   3  (        -0.64770,         0.00000)
   4   4  (         0.68319,         0.00000)

e-sneutrino mass   :    1.9127930364369408E+02
mu-sneutrino mass  :    1.9127614461238977E+02
tau-sneutrino mass :    1.9038540593550744E+02

selectron masses
  1.4393792438692086E+02   2.0712432781915908E+02
 R_e
         0.00009         1.00000
        -1.00000         0.00009

smuon masses
  1.4390451752393614E+02   2.0713856716885780E+02
 R_mu
         0.01790         0.99984
        -0.99984         0.01790

stau masses
  1.3484343437971901E+02   2.1068049221898704E+02
 R_tau
         0.26425         0.96445
        -0.96445         0.26425

u-squark masses
  5.4756917879839784E+02   5.6524131281347229E+02
 R_u
         0.00006         1.00000
        -1.00000         0.00006

c-squark masses
  5.4755738858800510E+02   5.6524965433179352E+02
 R_c
         0.02389         0.99971
        -0.99971         0.02389

t-squark masses
  3.9945389533787068E+02   5.8628028438847809E+02
 R_t
         0.55340         0.83291
        -0.83291         0.55340
```

```
d-squark masses
  5.4730506514994352E+02   5.7064687850962798E+02
 R_d
         0.00058          1.00000
        -1.00000          0.00058

s-squark masses
  5.4730068877040878E+02   5.7064721260745614E+02
 R_s
         0.01000          0.99995
        -0.99995          0.01000

b-squark masses
  5.1512514815767906E+02   5.4710587491028832E+02
 R_b
         0.94697          0.32132
        -0.32132          0.94697

m_A0, m_H+
  3.9942973783298265E+02   4.0772744504014719E+02

m_h0, m_H0
  1.1080888761166447E+02   3.9980703384665037E+02
 R_S0
         0.11371          0.99351
        -0.99351          0.11371


Low energy constraints
 10^4 Br(b -> s gamma) :   0.4558514E+01
 Delta(a_mu)           :   0.5415330E-08
 Delta(rho)            :   0.1959489E-03


 Anti particles are marked with a * in case of
 (s)neutrinos and (s)quarks in the decay section.
                    Decay widths (GeV) and branching ratios

 Selectron_1
  Neutralino_1 e               0.21510088  100.00000000
 Total width :                 0.21510088


 Selectron_2
  Neutralino_1 e               0.12813720   48.21320960
  Neutralino_2 e               0.04910231   18.47535119
  Chargino_1 neutrino          0.08853247   33.31143921
```

```
Total width :                0.26577199


Smuon_1
 Neutralino_1 mu             0.21484110  100.00000000
Total width :                0.21484110


Smuon_2
 Neutralino_1 mu             0.12829264   48.23209605
 Neutralino_2 mu             0.04912578   18.46902142
 Chargino_1 neutrino         0.08857176   33.29888253
Total width :                0.26599018


Stau_1
 Neutralino_1 tau            0.15075247  100.00000000
Total width :                0.15075247


Stau_2
 Neutralino_1 tau            0.16323638   51.63787855
 Neutralino_2 tau            0.05485389   17.35237248
 Chargino_1 neutrino         0.09802725   31.00974897
Total width :                0.31611751


e-Sneutrino
 Neutralino_1 neutrino       0.16123722   85.32866208
 Neutralino_2 neutrino       0.00715724    3.78769424
 Chargino_1 e                0.02056576   10.88364368
Total width :                0.18896022


mu-Sneutrino
 Neutralino_1 neutrino       0.16123086   85.33568036
 Neutralino_2 neutrino       0.00715318    3.78600969
 Chargino_1 mu               0.02055318   10.87830995
Total width :                0.18893721


tau-Sneutrino
 Neutralino_1 neutrino       0.15943476   87.31209427
 Neutralino_2 neutrino       0.00605108    3.31378333
 Chargino_1 tau              0.01711746    9.37412241
Total width :                0.18260329
```

```
Sdown_1
 Neutralino_1 d-quark          0.28770802   98.55660629
 Neutralino_2 d-quark          0.00270653    0.92714381
 Neutralino_3 d-quark          0.00035708    0.12232218
 Neutralino_4 d-quark          0.00114841    0.39339795
 Chargino_1 u-quark            0.00000154    0.00052910
Total width :                  0.29192159


Sdown_2
 Neutralino_1 d-quark          0.12854555    2.41263613
 Neutralino_2 d-quark          1.63736438   30.73124285
 Neutralino_3 d-quark          0.00855909    0.16064329
 Neutralino_4 d-quark          0.08259529    1.55020837
 Chargino_1 u-quark            3.24403336   60.88637215
 Chargino_2 u-quark            0.22691457    4.25889723
Total width :                  5.32801224


S-strange_1
 Neutralino_1 s-quark          0.28771851   98.32632702
 Neutralino_2 s-quark          0.00292980    1.00124494
 Neutralino_3 s-quark          0.00036645    0.12523375
 Neutralino_4 s-quark          0.00114683    0.39192166
 Chargino_1 c-quark            0.00045378    0.15507723
 Chargino_2 c-quark            0.00000057    0.00019540
Total width :                  0.29261594


S-strange_2
 Neutralino_1 s-quark          0.12853671    2.41273081
 Neutralino_2 s-quark          1.63714210   30.73039024
 Neutralino_3 s-quark          0.00858872    0.16121673
 Neutralino_4 s-quark          0.08262979    1.55102333
 Chargino_1 c-quark            3.24352858   60.88347439
 Chargino_2 c-quark            0.22701084    4.26116451
Total width :                  5.32743673


Sbottom_1
 Neutralino_1 b-quark          0.16674913    4.31705130
 Neutralino_2 b-quark          1.34234704   34.75269181
 Neutralino_3 b-quark          0.01963712    0.50839523
 Neutralino_4 b-quark          0.04237541    1.09707817
 Chargino_1 t-quark            1.72934949   44.77199120
 Stop_1 W-                     0.56211179   14.55279229
```

```
Total width :                3.86256998


Sbottom_2
 Neutralino_1 b-quark        0.23969032   31.70912297
 Neutralino_2 b-quark        0.09310073   12.31648674
 Neutralino_3 b-quark        0.04221537    5.58475713
 Neutralino_4 b-quark        0.05849015    7.73778189
 Chargino_1 t-quark          0.12448615   16.46852800
 Stop_1 W-                   0.19792061   26.18332328
Total width :                0.75590333


Sup_1
 Neutralino_1 u-quark        1.15145952   98.55637070
 Neutralino_2 u-quark        0.01083087    0.92704170
 Neutralino_3 u-quark        0.00143110    0.12249171
 Neutralino_4 u-quark        0.00460431    0.39409473
Total width :                1.16832581


Sup_2
 Neutralino_1 u-quark        0.03594243    0.65176659
 Neutralino_2 u-quark        1.75313101   31.79062555
 Neutralino_3 u-quark        0.00499759    0.09062447
 Neutralino_4 u-quark        0.06006824    1.08925513
 Chargino_1 d-quark          3.58197347   64.95417438
 Chargino_2 d-quark          0.07850353    1.42355387
Total width :                5.51461627


S-charm_1
 Neutralino_1 c-quark        1.15081537   98.28078206
 Neutralino_2 c-quark        0.01188610    1.01508491
 Neutralino_3 c-quark        0.00147943    0.12634444
 Neutralino_4 c-quark        0.00458850    0.39186267
 Chargino_1 s-quark          0.00217691    0.18591022
Total width :                1.17094649


S-charm_2
 Neutralino_1 c-quark        0.03656941    0.66343674
 Neutralino_2 c-quark        1.75204300   31.78529687
 Neutralino_3 c-quark        0.00499658    0.09064717
 Neutralino_4 c-quark        0.06014129    1.09107406
 Chargino_1 s-quark          3.57978849   64.94397663
 Chargino_2 s-quark          0.07857902    1.42556852
```

```
Total width :                5.51211779


Stop_1
 Neutralino_1 t-quark        0.39740101   19.20680823
 Neutralino_2 t-quark        0.24141364   11.66777483
 Chargino_1 b-quark          1.39258046   67.30487641
 Chargino_2 b-quark          0.02117232    1.02328034
 c-quark neutralino_1        0.00039523    0.01910206
 c-quark neutralino_2        0.01609207    0.77774681
 W b-quark neutralino_1      0.00000851    0.00041131
Total width :                2.06906324


Stop_2
 Neutralino_1 t-quark        0.22065736    3.00862752
 Neutralino_2 t-quark        0.63812557    8.70073930
 Neutralino_3 t-quark        0.31053610    4.23410966
 Neutralino_4 t-quark        1.44635779   19.72085545
 Chargino_1 b-quark          1.59111038   21.69453369
 Chargino_2 b-quark          1.47358454   20.09208783
 Stop_1  Z                   1.38482788   18.88190500
 Stop_1  h0                  0.26895379    3.66714154
Total width :                7.33415341


Chargino_1
 Smuon_1 neutrino            0.00003886    0.28387005
 Stau_1 neutrino             0.01301743   95.10376372
 Neutralino_1 W              0.00055115    4.02662386
 neutralino_1 d^* u          0.00000003    0.00020879
 neutralino_1 s^* c          0.00000003    0.00020863
 neutralino_1 e^+    nu      0.00002675    0.19544840
 neutralino_1 mu^+   nu      0.00002675    0.19544086
 neutralino_1 tau^+  nu      0.00002661    0.19442906
Total width :                0.01368761

Chargino_2
 Selectron_2 neutrino        0.12483567    5.01198171
 Smuon_2 neutrino            0.12487681    5.01363320
 Stau_1 neutrino             0.00129050    0.05181199
 Stau_2 neutrino             0.13608583    5.46366024
 e-sneutrino e               0.05066962    2.03431606
 mu-sneutrino mu             0.05073214    2.03682600
 tau-sneutrino tau           0.06846536    2.74879077
 Neutralino_1 W              0.17054406    6.84711094
 Neutralino_2 W              0.71196465   28.58440836
```

```
 Chargino_1 Z                0.60191556   24.16608771
 Chargino_1 h0               0.44847615   18.00570494
 neutralino_1 b^* t          0.00028615    0.01148873
 neutralino_2 d^* u          0.00000457    0.00018361
 neutralino_2 s^* c          0.00000457    0.00018367
 neutralino_2 b^* t          0.00002663    0.00106920
 chargino_1 u u^*            0.00001046    0.00041986
 chargino_1 c c^*            0.00001045    0.00041949
 chargino_1 d d^*            0.00000445    0.00017860
 chargino_1 s s^*            0.00000446    0.00017891
 chargino_1 b b^*            0.00052754    0.02117995
Total width :                2.49074476

Neutralino_1 : stable

Neutralino_2
 Selectron^-_1 e^+           0.00067750    3.46314577
 Selectron^+_1 e^-           0.00067750    3.46314577
 Smuon^-_1 mu^+              0.00070088    3.58266441
 Smuon^+_1 mu^-              0.00070088    3.58266441
 Stau^-_1 tau^+              0.00836773   42.77287626
 Stau^+_1 tau^-              0.00836773   42.77287626
 Neutralino_1 photon         0.00000004    0.00019852
 neutralino_1 u u^*          0.00000350    0.01786695
 neutralino_1 c c^*          0.00000349    0.01784001
 neutralino_1 d d^*          0.00000463    0.02368626
 neutralino_1 s s^*          0.00000463    0.02368617
 neutralino_1 b b^*          0.00000476    0.02435045
 neutralino_1 nu_e   nu_e^   0.00001156    0.05908396
 neutralino_1 nu_mu  nu_mu   0.00001156    0.05909905
 neutralino_1 nu_tau nu_ta   0.00001244    0.06357803
 neutralino_1 e^-    e^+     0.00000506    0.02584007
 neutralino_1 mu^-   mu^+    0.00000505    0.02582376
 neutralino_1 tau^-  tau^+   0.00000422    0.02157388
Total width :                0.01956317


Neutralino_3
 Selectron^-_1 e^+           0.00246761    0.12381862
 Selectron^+_1 e^-           0.00246761    0.12381862
 Selectron^-_2 e^+           0.00110911    0.05565227
 Selectron^+_2 e^-           0.00110911    0.05565227
 Smuon^-_1 mu^+              0.00249046    0.12496504
 Smuon^+_1 mu^-              0.00249046    0.12496504
 Smuon^-_2 mu^+              0.00115204    0.05780683
 Smuon^+_2 mu^-              0.00115204    0.05780683
 Stau^-_1 tau^+              0.01021462    0.51254502
```

```
 Stau^+_1 tau^-              0.01021462    0.51254502
 Stau^-_2 tau^+              0.01218195    0.61126086
 Stau^+_2 tau^-              0.01218195    0.61126086
 e-sneutrino nu_e^*          0.00612932    0.30755439
 e-sneutrino^* nu_e          0.00612932    0.30755439
 mu-sneutrino nu_mu^*        0.00612947    0.30756211
 mu-sneutrino^* nu_mu        0.00612947    0.30756211
 tau-sneutrino nu_tau^*      0.00617278    0.30973532
 tau-sneutrino^* nu_tau      0.00617278    0.30973532
 Chargino^+_1 W^-            0.59455684   29.83342506
 Chargino^-_1 W^+            0.59455684   29.83342506
 Neutralino_1 Z              0.22190910   11.13486222
 Neutralino_2 Z              0.41946063   21.04752045
 Neutralino_1 h0             0.04208191    2.11156877
 Neutralino_2 h0             0.02422138    1.21537033
 Neutralino_2 photon         0.00002024    0.00101568
 neutralino_1 b b^*          0.00000772    0.00038719
 neutralino_2 b b^*          0.00000522    0.00026192
Total width :                1.99292182


Neutralino_4
 Selectron^-_1 e^+           0.01008587    0.38204392
 Selectron^+_1 e^-           0.01008587    0.38204392
 Selectron^-_2 e^+           0.02480502    0.93959259
 Selectron^+_2 e^-           0.02480502    0.93959259
 Smuon^-_1 mu^+              0.01007017    0.38144944
 Smuon^+_1 mu^-              0.01007017    0.38144944
 Smuon^-_2 mu^+              0.02486868    0.94200385
 Smuon^+_2 mu^-              0.02486868    0.94200385
 Stau^-_1 tau^+              0.00789319    0.29898723
 Stau^+_1 tau^-              0.00789319    0.29898723
 Stau^-_2 tau^+              0.04123849    1.56207842
 Stau^+_2 tau^-              0.04123849    1.56207842
 e-sneutrino nu_e^*          0.06494620    2.46010577
 e-sneutrino^* nu_e          0.06494620    2.46010577
 mu-sneutrino nu_mu^*        0.06494764    2.46016018
 mu-sneutrino^* nu_mu        0.06494764    2.46016018
 tau-sneutrino nu_tau^*      0.06535235    2.47549054
 tau-sneutrino^* nu_tau      0.06535235    2.47549054
 Chargino^+_1 W^-            0.67613622   25.61145377
 Chargino^-_1 W^+            0.67613622   25.61145377
 Neutralino_1 Z              0.05545958    2.10076061
 Neutralino_2 Z              0.04990974    1.89053781
 Neutralino_1 h0             0.18282528    6.92526289
 Neutralino_2 h0             0.37096704   14.05190972
 Neutralino_2 photon         0.00002906    0.00110069
```

```
 chargino^+_1 d u^*          0.00000417    0.00015812
 chargino^-_1 d^* u          0.00000417    0.00015812
 chargino^+_1 s c^*          0.00000418    0.00015820
 chargino^-_1 s^* c          0.00000418    0.00015820
 chargino^+_1 b t^*          0.00001489    0.00056401
 chargino^-_1 b^* t          0.00001489    0.00056401
 neutralino_1 b b^*          0.00000829    0.00031410
 neutralino_2 u u^*          0.00000460    0.00017408
 neutralino_2 c c^*          0.00000459    0.00017392
 neutralino_2 d d^*          0.00000530    0.00020077
 neutralino_2 s s^*          0.00000530    0.00020085
 neutralino_2 b b^*          0.00001293    0.00048988
Total width :                2.63997596


Gluino
 Sup_1 u^*                   0.22870900    4.94258582
 Sup_1^* u                   0.22870900    4.94258582
 Sup_2 u^*                   0.11126815    2.40459439
 Sup_2^* u                   0.11126815    2.40459439
 S-charm_1 c^*               0.22850951    4.93827473
 S-charm_1^* c               0.22850951    4.93827473
 S-charm_2 c^*               0.11134187    2.40618760
 S-charm_2^* c               0.11134187    2.40618760
 Stop_1 t^*                  0.23793220    5.14190657
 Stop_1^* t                  0.23793220    5.14190657
 Sdown_1 d^*                 0.23074812    4.98665276
 Sdown_1^* d                 0.23074812    4.98665276
 Sdown_2 d^*                 0.08317483    1.79747505
 Sdown_2^* d                 0.08317483    1.79747505
 S-strange_1 s^*             0.23077130    4.98715370
 S-strange_1^* s             0.23077130    4.98715370
 S-strange_2 s^*             0.08317883    1.79756163
 S-strange_2^* s             0.08317883    1.79756163
 Sbottom_1 b^*               0.51851488   11.20552447
 Sbottom_1^* b               0.51851488   11.20552447
 Sbottom_2 b^*               0.24263650    5.24357028
 Sbottom_2^* b               0.24263650    5.24357028
 Stop_1 c^*                  0.00530170    0.11457405
 Stop_1^* c                  0.00530170    0.11457405
 neutralino_1 gluon          0.00002680    0.00057923
 neutralino_2 gluon          0.00022135    0.00478362
 neutralino_3 gluon          0.00033270    0.00718998
 neutralino_4 gluon          0.00038117    0.00823738
 neutralino_1 t t^*          0.00008962    0.00193684
 neutralino_2 t t^*          0.00009374    0.00202577
 chargino^+_1 t^* b          0.00066796    0.01443507
```

```
  chargino^-_1 t b^*          0.00066796    0.01443507
  chargino^+_2 t^* b          0.00032981    0.00712747
  chargino^-_2 t b^*          0.00032981    0.00712747
 Total width :                4.62731469

h0
  muons                       0.00000101    0.04633093
  taus                        0.00028643   13.08657852
  d-quark                     0.00000000    0.00016098
  s-quark                     0.00000104    0.04730787
  b-quark                     0.00180832   82.62040292
  c-quark                     0.00009191    4.19919143
 Total width :                0.00218871


H0
  muons                       0.00027932    0.03671913
  taus                        0.07900846   10.38638120
  d-quark                     0.00000098    0.00012915
  s-quark                     0.00028872    0.03795547
  b-quark                     0.50606084   66.52630492
  c-quark                     0.00000440    0.00057844
  t-quark                     0.03284785    4.31814858
  Selectron 1 1               0.00038588    0.05072782
  Smuon 1 1                   0.00039320    0.05168917
  Smuon 1 2                   0.00001885    0.00247807
  Smuon 2 1                   0.00001885    0.00247807
  Stau 1 1                    0.00420030    0.55216824
  Stau 1 2                    0.00406411    0.53426431
  Stau 2 1                    0.00406411    0.53426431
  e-Sneutrino                 0.00071373    0.09382650
  mu-Sneutrino                0.00071386    0.09384330
  tau-Sneutrino               0.00074895    0.09845649
  neutralino_1 neutralino_1   0.01640703    2.15685379
  neutralino_1 neutralino_2   0.04741210    6.23275196
  neutralino_2 neutralino_2   0.01321269    1.73692880
  chargino^+_1 chargino^-_1   0.03572858    4.69684775
  Z Z                         0.00145341    0.19106428
  W+ W-                       0.00311215    0.40912109
  h0 h0                       0.00955444    1.25601818
 Total width :                0.76069285


A0
  muons                       0.00027991    0.02394510
  taus                        0.07918234    6.77364982
```

```
 s-quark                      0.00028933    0.02475108
 b-quark                      0.50718753   43.38733581
 c-quark                      0.00000337    0.00028798
 t-quark                      0.10446570    8.93651435
 Smuon 1 2                    0.00001955    0.00167248
 Smuon 2 1                    0.00001955    0.00167248
 Stau 1 2                     0.00569243    0.48695874
 Stau 2 1                     0.00569243    0.48695874
 neutralino_1 neutralino_1    0.02519311    2.15514326
 neutralino_1 neutralino_2    0.10809913    9.24733561
 neutralino_2 neutralino_2    0.09248237    7.91140044
 chargino^+_1 chargino^-_1    0.23769243   20.33338946
 h0 Z                         0.00267578    0.22889978
Total width :                 1.16897596



H^+
 muon neutrino                0.00028573    0.04266509
 tau neutrino                 0.08082739   12.06922654
 d-quark u-quark              0.00000088    0.00013177
 s-quark c-quark              0.00026233    0.03917183
 b-quark t-quark              0.42729169   63.80362064
 Selectron_2 Sneutrino        0.00051866    0.07744696
 Smuon_1 Sneutrino            0.00005543    0.00827732
 Smuon_2 Sneutrino            0.00051472    0.07685861
 Stau_1 Sneutrino             0.01489058    2.22347616
 Stau_2 Sneutrino             0.00000817    0.00121960
 chargino_1 neutralino_1      0.14117172   21.07990203
 chargino_1 neutralino_2      0.00083132    0.12413279
 h0 W                         0.00303956    0.45386947
Total width :                 0.66969819


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     283.6216345 fb
 1   2      78.0199000 fb
 2   2      45.7859068 fb

smuons
 1   1      54.7929652 fb
 1   2       0.0059693 fb
 2   2      19.0224584 fb

staus
 1   1      59.6056340 fb
 1   2       1.2593673 fb
 2   2      15.9954658 fb


e-sneutrino
           453.2694763 fb

mu-sneutrino
            13.6239191 fb

tau-sneutrino
            13.9240765 fb


neutralinos
 1   1     275.7338081 fb
 1   2      65.7329474 fb
 1   3       7.2644701 fb
 1   4       0.9005054 fb
 2   2      69.0994560 fb


charginos
 1   1     161.0778560 fb


h^0 Z
            24.7411048 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
```

References

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