NMSDECAY: A Fortran Code for Supersymmetric Particle Decays in the Next-to-Minimal Supersymmetric Standard Model

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Abstract

The code NMSDECAY allows to compute widths and branching ratios of sparticle decays in the Next-to-Minimal Supersymmetric Standard Model. It is based on a generalization of SDECAY, to include the extended Higgs and neutralino sectors of the NMSSM. Slepton 3-body decays, possibly relevant in the case of a singlino-like lightest supersymmetric particle, have been added. NMSDECAY will be part of the NMSSMTools package, which computes Higgs, sparticle masses and Higgs decays in the NMSSM.
1 Introduction

The search for supersymmetric particles (sparticles) is one of the most exciting tasks of present and future experiments in particle physics, notably at the LHC [1,2]. These searches can only be successful if the possible signals of sparticles are known so that they can be simulated and be compared to the data. Sparticle signals are not unique, since they depend on the specific supersymmetric (SUSY) extension of the Standard Model (SM), i.e., on the particle content, couplings and spectrum, which determine the numerous possible decay cascades.

In recent years, SUSY decay cascades have been studied mostly in the framework of the Minimal Supersymmetric Standard Model (MSSM). In order to study the dependence of the decay cascades on the sparticle masses and couplings, it is very helpful to use numerical programs which perform the calculation of the large number of sparticle widths and possible branching ratios. The sparticle masses and couplings depend, in turn, on the parameters of the underlying Lagrangian. Therefore it is reasonable to interface programs for the sparticle decays with programs which compute the sparticle masses and couplings (so-called spectrum calculators).

In the case of the MSSM, one such interface is the program SUSY-HIT (SUspect-SdecaY-Hdecay-InTerface) [3]. It uses the program Suspect [4] for the calculation of the Higgs and sparticle spectra, SDECAY [5] for the sparticle branching ratios, and HDECAY [6] for the branching ratios of the Higgs sector. Another program including simultaneously the calculation of sparticle spectra and decays is SPheno [7,8].

However, the MSSM is not the only possible supersymmetric extension of the SM; it is just the one with a minimal Higgs sector, which in this case contains two SU(2) doublets $H_u$ (coupling to up-type quarks) and $H_d$ (coupling to down-type quarks and charged leptons). The price to pay for such a minimal Higgs content is a supersymmetric Higgs mass term $\mu$ in the MSSM superpotential, whose phenomenologically required order of magnitude (the weak or the SUSY breaking scale) is difficult to explain [9]. The $\mu$-problem of the MSSM can be solved in the Next-to-Minimal Supersymmetric Standard Model (NMSSM - for recent reviews see [10,11]). The Higgs sector of the NMSSM consists of two SU(2) doublets $H_u$ and $H_d$ (as in the MSSM), to which a gauge singlet superfield $S$ is added. Due to a $\lambda S H_u H_d$ coupling in the superpotential, the vacuum expectation value (vev) of $S$, $s$, generates a supersymmetric mass term $\mu_{\text{eff}} = \lambda s$ of the desired order of magnitude for $H_u$ and $H_d$. In its simplest $Z_3$ invariant version, the superpotential of the NMSSM is scale invariant; it is in fact the simplest phenomenologically acceptable supersymmetric extension of the SM with this property.

The new superfield $S$ implies various additional physical states when compared to the MSSM: a neutral CP-even Higgs boson, a CP-odd Higgs boson and a neutralino. These states can be relatively light; if the additional NMSSM-specific CP-even Higgs boson mixes very little with the Higgs bosons $H_u$ and $H_d$ of the MSSM, it will have very small couplings to SM gauge bosons, quarks and leptons and is hence much less constrained by the so far unsuccessful direct searches, notably at LEP [12]. In some regions of the parameter space of the NMSSM, CP-odd Higgs bosons can also be lighter than in the MSSM [13,14]. If they are light enough, any of the NMSSM-specific additional Higgs and neutralino states can have an important impact on sparticle decays, both as potential final states and/or as...
virtual intermediate states in 3-body decays. Notably in the case of the constrained NMSSM (with universal soft SUSY breaking terms at the GUT scale [15,16]), a very weakly coupled singlino-like neutralino can be the lightest supersymmetric particle (LSP), thus affecting the final states of all sparticle decay cascades.

The impact of these NMSSM specific features on sparticle production and on cascade decays has already been addressed: sparticle decays into singlino-like neutralinos have been studied in [16–21], sparticle decays into neutralinos in [22], decays of stops, sbottoms and staus in [23], the associated production of a light CP-odd Higgs boson with a chargino pair in [24], neutralino decays into light Higgs bosons in [25], neutralino decays into soft leptons in [26], and neutralino and chargino decays into many leptons in [27].

The purpose of the code NMSDECAY is to compute all sparticle decays into all possible 2- and 3-body final states in the NMSSM: squarks, sleptons, gluino, neutralinos and charginos decaying into squarks, sleptons, gluino, neutralinos, charginos plus Higgs bosons, SM-like quarks, leptons and gauge bosons. R-parity is assumed to be conserved such that each sparticle can only decay into a lighter sparticle plus SM-like particles and/or Higgs bosons.

NMSDECAY is based on an extension of the MSSM-specific code SDECAY [5], generalized to include the NMSSM-specific extensions of the Higgs and neutralino sectors. QCD corrections, loop-induced and 3-body decays are included as in SDECAY. In the NMSSM, a singlino-like LSP can lead to dominant 3-body decays of sleptons, even if their 2-body decays are kinematically possible. Such 3-body decays of sleptons (which were omitted in SDECAY) have been added to NMSDECAY.

NMSDECAY is interfaced with NMSSMTools\(^1\), and is also written in FORTRAN 77. The installation and compilation of NMSSMTools is a fairly straightforward procedure, described in the manual README, which can be found on the web site. The package NMSSMTools includes: NMHDECAY [28,29], where the spectrum for the general NMSSM is computed and Higgs decays are calculated similar to HDECAY [6]; NMSPEC [30] where universal soft SUSY breaking terms at the GUT scale are assumed; a link to MicrOMEGAS [31,32], which allows for the calculation of the dark matter relic density and its detection cross sections. Sparticle decays of the NMSSM with gauge mediated SUSY breaking [33] are not yet included in NMSDECAY. Once NMSSMTools is compiled, the subroutines required for NMSDECAY are linked automatically to NMHDECAY and NMSPEC. However, the sparticle total widths and branching ratios are computed and written only if a corresponding flag in the input file \(\text{switch 13}\) is switched on.

In the next section we give the Lagrangian and the particle content of the NMSSM, and in Section 3 we describe how NMSDECAY is linked to NMSSMTools, as well as the various calculations performed in the different subroutines. In the Appendix we describe the arguments of the subroutines and \texttt{COMMON} statements, which have to be defined if NMSDECAY is called from another spectrum calculator.

\(^1\)Available on the web page \texttt{http://www.th.u-psud.fr/NMHDECAY/nmssmtools.html}
2 Lagrangian and Particle Content of the NMSSM

The NMSSM differs from the MSSM due to the presence of the gauge singlet superfield $S$. In the simplest $Z_3$ invariant realisation of the NMSSM, the Higgs mass term $\mu H_uH_d$ in the superpotential $W_{\text{MSSM}}$ of the MSSM is replaced by the coupling $\lambda$ of $S$ to $H_u$ and $H_d$, and a self-coupling $\kappa S^3$. Hence, in this simplest version the superpotential $W_{\text{NMSSM}}$ is scale invariant, and given by:

$$W_{\text{NMSSM}} = \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3 + h_t \hat{Q} \cdot \hat{H}_u \hat{T}_R + h_b \hat{H}_d \cdot \hat{Q} \hat{B}_R + h_\tau \hat{H}_d \cdot \hat{L} \hat{\tau}_R^c,$$  

(1)

where we have confined ourselves to the Yukawa couplings of $H_u$ and $H_d$ to the quarks $Q$, $T_R$, $B_R$ and leptons $L$, $\tau_R$ of the third generation. A sum over all generations is implicitly assumed. Once the scalar component of $S$ develops a vev $s$, the first term in $W_{\text{NMSSM}}$ generates an effective $\mu$-term

$$\mu_{\text{eff}} = \lambda s.$$  

(2)

The soft SUSY breaking terms consist of mass terms for the gauginos $\tilde{B}$ (bino), $\tilde{W}^a$ (winos) and $\tilde{G}^a$ (gluinos)

$$-\mathcal{L}_I = \frac{1}{2} \left[ M_1 \tilde{B} \tilde{B} + M_2 \sum_{a=1}^{3} \tilde{W}^a \tilde{W}_a + M_3 \sum_{a=1}^{8} \tilde{G}^a \tilde{G}_a \right] + \text{h.c.},$$  

(3)

as well as soft breaking terms for the Higgs bosons $H_u$, $H_d$ and $S$, squarks $\tilde{q} \equiv (\tilde{t}_L, \tilde{b}_L, \tilde{t}_R, \tilde{b}_R)$ and sleptons $\tilde{\ell} \equiv (\tilde{\nu}_L, \tilde{\tau}_L)$ and $\tilde{\tau}_R$ (again in a simplified notation corresponding only to the third generation),

$$-\mathcal{L}_0 = m_{\tilde{H}_u}^2 |H_u|^2 + m_{\tilde{H}_d}^2 |H_d|^2 + m_S^2 |S|^2 + m_{\tilde{q}}^2 |\tilde{q}|^2 + m_{\tilde{t}}^2 |\tilde{t}_R|^2 + m_{\tilde{b}}^2 |\tilde{b}_R|^2 + m_{\tilde{\ell}}^2 |\tilde{\ell}|^2 + m_{\tilde{\tau}}^2 |\tilde{\tau}_R|^2.$$  

(4)

Finally there are trilinear interactions involving the sfermion and the Higgs fields, also including the singlet field

$$-\mathcal{L}_{\text{tril}} = \left( h_t A_t Q \cdot H_u T_R^c + h_b A_b H_d \cdot Q B_R^c + h_\tau A_\tau H_d \cdot L \tau_R^c + \lambda A_\chi H_u \cdot H_d S + \frac{1}{3} \kappa A_\chi S^3 \right) + \text{h.c.}.$$  

(5)

After electroweak symmetry breaking, and once the mass matrices have been diagonalized, the above fields give rise to the following physical eigenstates:

- **Higgs sector (assuming CP-conservation):**
  - 3 neutral CP-even Higgs bosons $H_i$, which are mixtures of the CP-even components of the superfields $H_u$, $H_d$ and $S$;
  - 2 neutral CP-odd Higgs bosons $A_i$, which are mixtures of the CP-odd components of $H_u$, $H_d$ and $S$;
  - 1 charged Higgs boson $H^\pm$, a mixture of the charged components of $H_u$ and $H_d$.

- **5 neutralinos** $\tilde{\chi}_i^0$, which are mixtures of the bino $\tilde{B}$, the neutral wino $\tilde{W}^3$, the neutral higgsinos from the superfields $H_u$ and $H_d$, and the singlino from the superfield $S$.

- **2 charginos** $\tilde{\chi}_i^\pm$, which are mixtures of the charged winos $\tilde{W}^\pm$ and the charged higgsinos
from the superfields $H_u$ and $H_d$.

- Gluinos $\tilde{G}$, which correspond to physical eigenstates.

- 4 complex scalar quarks $\tilde{q}$ per generation, which can be separated into up-type and down-type squarks. For the first two squark generations, mass eigenstates correspond to the weak interaction eigenstates, which carry the quantum numbers of the corresponding left- and right-handed quarks. The squarks of the third generation have to be treated separately, since mixings proportional to the Yukawa couplings are relevant: for the third generation we have 2 stops $\tilde{t}_{1,2}$ (with $m_{\tilde{t}_2} > m_{\tilde{t}_1}$) and 2 sbottoms $\tilde{b}_{1,2}$ (likewise ordered in mass).

- 3 complex scalar leptons $\tilde{\ell}$ per generation, 2 of which are charged and one is neutral. As in the case of squarks, the slepton mass eigenstates of the first two generations correspond to the weak eigenstates with the quantum numbers of the corresponding left- and right-handed leptons (we only consider left-handed (s)neutrinos). For the third generation we have 2 staus $\tilde{\tau}_{1,2}$ (ordered in mass) and a sneutrino $\tilde{\nu}_r$.

3 The Structure of NMSDECAY

3.1 Compilation, Input and Output

From version NMSSMTools 3.0.0 onwards, the required files for NMSDECAY are included in the directory sources of NMSSMTools. Once the commands make init and make are typed in the main directory, these files are compiled and linked automatically to the routines nmhdecay and nmspec. The compilation is managed by the routine getFlags inside micromegas/CalcHEP_src, which checks automatically for the available compilers: the default for Linux is gfortran, but g77 and ifort could also be used. (In the latter case the corresponding flags in getFlags have to be set by the user.)

The input files have to be named according to the convention #inp#, where the prefix and suffix of the input file can be chosen at will by the user (at least one of the # must be non-vanishing). The format of the input files has to follow the conventions specified in the SUSY Les Houches Accord 2 [34], and include a BLOCK MODSEL where the switch 3 (choice of particle content) must be set to 3 (NMSSM). In order to allow NMSDECAY to run, switch 1 (choice of SUSY breaking model) must be set to 0 (general NMSSM) or 1 (mSUGRA = NMSPEC). Additional switches inside the BLOCK MODSEL specify the activation of various subroutines, and the switch 13 must be set to 1 in order to activate NMSDECAY. No additional action by the user is required.

Once NMSDECAY is activated and the input file is run (typing ./ run #inp#), the sparticle decay widths and branching ratios are appended to the output file #decay#, where the prefix and suffix correspond to the name of the input file. (This file always contains the various Higgs decay widths and branching ratios.) The format of the output also follows the SUSY Les Houches Accord [35], with particle codes for the NMSSM as specified in [34]. If scans are activated, the user has to define the format of the output in the subroutines OUTPUT using the branching ratios made available in the various COMMON statements (see Section 3.3).
3.2 Contents of NMSDECAY_INTERFACE

The main routines in the files main/nmhdecay.f and main/nmspec.f only call the subroutine NMSDECAY_INTERFACE in the file sources/NMSDECAY.f. The subroutine NMSDECAY_INTERFACE serves to: (i) translate parameters, masses, mixing angles and couplings from NMSSMTools into the conventions used in the other sparticle-specific subroutines; (ii) call these subroutines; (iii) call the subroutine NS_output.

At the beginning of NMSDECAY_INTERFACE, various flags are set to 1: flagqcd for QCD corrections to 2-body decays, and flagmulti and flagloop for the activation of 3-body and loop-induced decays, respectively. In case the user is not interested in QCD corrections and/or the latter decays (e.g. in order to speed up the running), these flags can be set to 0. Then, make init and make must be typed again for re-compilation.

The parameter multilim (default: multilim=0.01) specifies under which condition 3-body branching ratios are taken into account (after they have been computed). Only if a the total 3-body decay width is larger than multilim times the total 2-body decay width, 3-body branching ratios will be included in the sparticle widths and in the output file. (Otherwise a dominant part of the output file can contain a lengthy list of very small 3-body branching ratios, which adds little information.)

The QCD corrections depend on the scale $Q^2$ at which the couplings and masses (notably the strong coupling $\alpha_s$) of the tree level vertices are defined. This scale (amuref) is set equal to the SUSY scale, computed in terms of the squark masses of the first two generations in the routine sources/runpar. Alternatively, the SUSY scale can be specified in the input file. Note that various input parameters are implicitely defined at the SUSY scale. Hence, a change of $Q^2$ in the input file will lead implicitly to a different choice for these input parameters (SUSY breaking terms and NMSSM-specific parameters which affect, in turn, masses and mixing angles), and not just to a change of scale of the couplings of the tree level vertices. In any case, the $Q^2$ dependence of the QCD corrections of the 2-body decays involving strongly interacting (s)particles compensates the dominant $Q^2$ dependence of the tree level vertices, if the latter is due to the running of the strong coupling constant.

Couplings, masses and mixing angles at the SUSY scale are read from various COMMON statements, which are initialised in various other subroutines in NMSSMTools. For convenience, these COMMON statements - together with the arguments PAR of the subroutine NMSDECAY_INTERFACE(PAR) corresponding to NMSSM-specific input parameters - are listed in the Appendix. The numerous couplings among sparticles and SM-like particles are written into several NMSDECAY-specific COMMON statements, which carry a NS_ prefix.

3.3 Contents of Sparticle Decay Files

The sparticle decay files contain appropriate modifications of the corresponding subroutines of SDECAY, generalizing the neutral Higgs and neutralino sectors to include the particle content of the NMSSM. For each species of sparticles, separate subroutines in the files NS_name_of_sparticle are devoted to the calculation of the 2-body and 3-body widths and branching ratios. For 2-body decays, 1-loop QCD corrections have been included as in SDECAY (with the renormalisation scale $Q^2$ given by the SUSY scale, unless modified by the user - see above). In rare cases, 1-loop QCD corrections can be negative and larger...
in absolute value than the tree level branching ratio, for any choice of the renormalisation scale. Of course, this signals that higher order corrections would be relevant. In order to avoid negative branching ratios in such cases, we replace (provisionally) \((1 + \text{corr.})\) by \(1/(1 - \text{corr.})\) whenever the relative 1-loop correction \(\text{corr.}\) is less than -1.

If 2-body decay channels are not kinematically open or are strongly suppressed, 3-body decays can be relevant for sbottoms, stops, gluinos, neutralinos and charginos. (Strong suppressions of 2-body decays can occur in the case of a singlino-like LSP in the NMSSM.) Then, the virtual exchanged particles can be neutral and charged Higgs bosons, \(W^\pm, Z\), gluino, charginos, neutralinos, squarks, sleptons and the top quark. Interference terms for identical final states are taken into account.

Since the quarks of the first two generations and the leptons are light, in the MSSM it is usually assumed that the corresponding \(\bar{q} \to q + \text{LSP}\) and \(\tilde{\ell} \to \ell + \text{LSP}\) 2-body decays are kinematically allowed and dominant, so that 3-body decays can be safely neglected. This is not always true in the NMSSM, even if one requires a neutral LSP (for cosmological reasons): the LSP can be a singlino-like neutralino \((\tilde{\chi}_1^0 \approx \tilde{\chi}_s^0)\) with very small couplings to squarks and sleptons. Notably sleptons can be lighter than the lightest MSSM-like neutralino \((\tilde{\chi}_2^0)\) such that their decay into the singlino-like neutralino (plus the corresponding lepton) would represent the only kinematically allowed 2-body decay mode. Since this partial width would be very small, 3-body decays into the lightest slepton (assumed to be the \(\tilde{\tau}_1\)) can be dominant. These have been added to the decay modes already present in SDECAY. (We take care of a subtlety in the case where 2-body decays are in principle allowed, but subdominant: we ensure that a particle only mediates a 3-body decay if its mass is sufficiently large to prevent it from being produced in a 2-body decay; otherwise one would be generating double-countings in decay cascades, and the phase space integrals would typically diverge.)

In what follows we summarise the different NS\(_n\) decay subroutines, briefly describing the decays contained in each one:

**NSsquark.f:**
- \(\tilde{q}_{L,R}\) 2-body decays (first two generations) into \(q + \tilde{\chi}_i^0, q + \tilde{\chi}_i^\pm, q + \tilde{G}\).

**NSsbottom.f:**
- \(\tilde{b}_{1,2}\) 2-body decays into \(b + \tilde{\chi}_i^0, b + \tilde{G}, t + \tilde{\chi}_i^\pm, \tilde{t}_{1,2} + H^\pm, \tilde{t}_{1,2} + W^\pm;\)
- \(\tilde{b}_{1,2}\) 2-body decays into \(\tilde{b}_1 + H_i, \tilde{b}_1 + A_i, \tilde{b}_1 + Z;\)
- \(\tilde{b}_{1,2}\) 3-body decays into \(t + \ell + \tilde{\ell}', \tilde{t}_{1,2} + q + q', \tilde{t}_{1,2} + \ell + \tilde{\ell}';\)
- \(\tilde{b}_{2}\) 3-body decays into \(\tilde{b}_1 + q + \tilde{q}, \tilde{b}_1 + \ell + \tilde{\ell}\).

**NSstop.f:**
- \(\tilde{t}_{1,2}\) 2-body decays into \(t + \tilde{\chi}_i^0, t + \tilde{G}, b + \tilde{\chi}_i^\pm, \tilde{b}_{1,2} + H^\pm, \tilde{b}_{1,2} + W^\pm;\)
- \(\tilde{t}_2\) 2-body decays into \(\tilde{t}_1 + H_i, \tilde{t}_1 + A_i, \tilde{t}_1 + Z;\)
- Loop-induced \(\tilde{t}_1\) decay into a charm quark + \(\tilde{\chi}_i^0;\)
- \(\tilde{t}_{1,2}\) 3-body decays into \(b + \ell + \tilde{\ell}', \tilde{b}_{1,2} + q + q', \tilde{b}_{1,2} + \ell + \tilde{\ell}';\)
- \(\tilde{t}_2\) 3-body decays into \(\tilde{t}_1 + q + \tilde{q}, \tilde{t}_1 + \ell + \tilde{\ell}\).
NS_gluino.f:

\[ \tilde{G} \] 2-body decays into \( q + \tilde{q}_{L,R} \) (all 3 generations);

Loop-induced \( \tilde{G} \) decays into \( g + \tilde{\chi}^0_i \);

\[ \tilde{G} \] 3-body decays into \( \tilde{\chi}^0_i + q + \tilde{q}, \tilde{\chi}^\pm_i + q + \tilde{q}' \), \( \tilde{\tau}_{1,2} + b + H^\pm, \tilde{\tau}_{1,2} + b + W^\pm \).

NS_slepton.f:

\[ \ell_{L,R} (\tilde{\nu}_{L}) \] 2-body decays (first two generations) into \( \ell (\nu) + \tilde{\chi}^0_i, \nu (\ell) + \tilde{\chi}^\pm_i \);

\[ \tilde{\tau}_{1,2} \] 2-body decays into \( \tau + \chi^0_i, \nu + \tilde{\chi}^\pm_i, \tilde{\nu}_i + H^\pm, \tilde{\nu}_i + W^\pm \);

\[ \tilde{\nu}_i \] 2-body decays into \( \nu + \chi^0_i, \tau + \tilde{\chi}^\pm_i, \tilde{\tau}_{1,2} + H^\pm, \tilde{\tau}_{1,2} + W^\pm \);

\[ \tilde{\tau}_{1} \] 2-body decays into \( \tilde{\tau}_1 + H_i, \tilde{\tau}_1 + A_i, \tilde{\tau}_1 + Z \);

\[ \ell_{L,R} (\tilde{\nu}_{L}) \] 3-body decays (first two generations) into \( \tilde{\tau}_1 + \tau + \ell (\nu), \tilde{\tau}_1 + \nu + \nu (\ell) \);

\[ \tilde{\nu}_i \] 3-body decays into \( \tilde{\tau}_1 + \tau + \nu_i \).

NS_neutralino.f:

\[ \tilde{\chi}^0_i \] 2-body decays into \( \tilde{\chi}^0_j + H_i, \tilde{\chi}^0_j + A_i, \tilde{\chi}^0_j + Z, \tilde{\chi}^\pm_i + W^\pm, \tilde{\chi}^\pm_i + H^\pm, \ell + \tilde{\ell}, \nu + \tilde{\nu}, q + \tilde{q} \);

Loop-induced \( \tilde{\chi}^0_i \) decays into \( \tilde{\chi}^0_j + \gamma \);

\[ \tilde{\chi}^0_i \] 3-body decays into \( \tilde{\chi}^0_j + q + \tilde{q}, \tilde{\chi}^0_j + \ell + \tilde{\ell}, \tilde{\chi}^0_j + \nu + \tilde{\nu}, \tilde{\chi}^\pm_i + q + \tilde{q}', \tilde{\chi}^\pm_i + \ell + \tilde{\ell}', \tilde{\chi}^\pm_i + \ell + \tilde{\ell}, \tilde{\chi}^\pm_i + \ell + \tilde{\ell}'.

NS_chargino.f:

\[ \tilde{\chi}^\pm_i \] 2-body decays into \( \tilde{\chi}^\pm_i + W^\pm, \tilde{\chi}^\pm_i + H^\pm, \ell + \tilde{\ell}, q + \tilde{q}'_{L,R} \);

\[ \tilde{\chi}^\pm_i \] 2-body decays into \( \tilde{\chi}^\pm_i + H_i, \tilde{\chi}^\pm_i + A_i, \tilde{\chi}^\pm_i + Z \);

\[ \tilde{\chi}^\pm_i \] 3-body decays into \( \tilde{\chi}^\pm_i + q + \tilde{q}', \tilde{\chi}^\pm_i + \ell + \tilde{\ell}', \tilde{\chi}^\pm_i + \ell + \tilde{\ell}', \tilde{\chi}^\pm_i + \ell + \tilde{\ell}. \)

We recall that as a consequence of the extended Higgs and neutralino sectors of the NMSSM, in the above decays one now has \( \tilde{\chi}^0_i \) (\( i = 1, ..., 5 \)), \( H_i \) (\( i = 1, ..., 3 \)) and \( A_i \) (\( i = 1, 2 \)).

For every sparticle decay computed in NS_sparticle.f, the various widths, 2-body and 3-body branching ratios are collected in COMMON statements COMMON/SPARTICLE_WIDTH, COMMON/SPARTICLE_BR_2BD and COMMON/SPARTICLE_BR_3BD, respectively. These COMMON statements are used in the file NS_output.f, which writes the total widths and partial branching ratios into the user-defined output file #decay# using the SUSY Les Houches Accord 2 format [34] (see above).

Additional auxiliary subroutines are contained in the file NS_auxfunc.f, notably routines from SDECAY concerning QCD corrections.

Working in the so-called NMSSM decoupling regime (\( \lambda, \kappa \to 0 \)), we have verified that all partial widths and branching ratios of processes not involving NMSSM specific neutralino or Higgs states coincide with the results of SDECAY for the corresponding MSSM parameters.

NMSSM specific results of NMSDECAY (partial widths and branching ratios) have also been compared to results previously obtained in the literature, whenever details of spectrum and decays were available. In particular, we confronted our results for the following processes: \( \tilde{\chi}^0_2 \to \tilde{\chi}^0_1 + A_i \) to [25]; \( \tilde{\chi}^0_2 \to \tilde{\chi}^0_1 + \ell^+ + \ell^- \) to [26]; \( \tilde{\chi}^0_0, \tilde{\chi}^\pm_i, \tilde{\ell}_{L,R} (\tilde{\nu}_L) \) decays into many leptons to [27]; in all cases we found reasonable agreement. Furthermore we compared several widths with the results of SPheno [7,8], finding a fair consistency in most of the cases.
To conclude, the routines in NMSDECAY will make it easy to compute all sparticle decay widths and branching ratios in the NMSSM, once the sparticle and Higgs spectra are computed by one of the spectrum calculators in NMSSMTools; it suffices to switch on a corresponding flag in the input file. Various applications will be published in a separate paper.

Since NMSDECAY is based on SDECAY, any publication using NMSDECAY should also refer explicitly to SDECAY [5].

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Appendix

Here we list the variables which are transferred to NMSDECAY from other routines in NMSSMTools. The COMMON statements appear both in NMSDECAY_INTERFACE and, occasionally, in the other subroutines.

Parameters PAR(l), l=1...25, in the argument of NMSDECAY_INTERFACE(PAR): the NMSSM-specific couplings $\lambda$, $\kappa$, $\tan(\beta)$, $\mu_{\text{eff}}$, and all soft SUSY breaking parameters as specified at the beginning of nmhdecay.f (i.e. without the Higgs mass terms). All parameters are assumed to be defined at the SUSY scale $Q^2$, with the exception of $\tan(\beta)$ (which is defined at $M_Z$).

COMMON/RENSCALE/: the SUSY scale $Q^2$ where the couplings and soft SUSY breaking terms are defined

COMMON/SUSYMH/: soft SUSY breaking Higgs mass terms at the SUSY scale $Q^2$

COMMON/GAUGE/: gauge couplings and $\sin^2(\theta_W)$ at the scale $M_Z$

COMMON/SUSYCOUP/: gauge and Yukawa couplings at the SUSY scale $Q^2$

COMMON/SMSPEC/: SM quark, lepton and electroweak gauge boson pole masses

COMMON/HIGGSPEC/: NMSSM Higgs pole masses and mixing angles

COMMON/SUSYSPEC/: gluino, chargino and neutralino pole masses and mixing angles

COMMON/SFSPEC/: squark and slepton pole masses and mixing angles

COMMON/QHIGGS/: Higgs vevs and $\tan(\beta)$ at the scale QSTSB (the scale of stop/sbottom masses, close to $Q^2$ in general)
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