How to use NMHDECAY_SLHA

NMHDECAY_SLHA.f is based on one single Fortran code that does not need to be linked with any other code. It needs data files in order to check against negative Higgs searches at LEP in the numerous channels discussed before. These data files are available in the directory LEPCON, that can be downloaded from the NMHDECAY home page. Note that the directory LEPCON has to be situated in the same directory that contains the executable NMHDECAY code.

NMHDECAY_SLHA uses an input file `slhainp.dat`, a version of which is downloaded automatically with the Fortran code. This sample file appears in Table 1 below. Several comments on its contents are in order:

a) "BLOCK MODSEL" contains the entry 3 (corresponding to the choice of the particle content) with switch 1, as attributed to the NMSSM in hep-ph/0311123.
b) "BLOCK SMINPUTS" contains important Standard Model parameters.

1. First, there is the inverse electromagnetic coupling constant at the scale 0, which is that required for the computations of the decay widths into two (on-shell) photons.

2. Second, various Higgs couplings are defined in terms of M_Z, $\alpha_s(M_Z)$, M_W and G_F, which means an on shell scheme is implicitly being used in order to define the electroweak parameters.

   M_Z, $\alpha_s(M_Z)$ and G_F are input as part of "BLOCK SMINPUTS", whereas the numerical value of $M_W = 80.42$ GeV is defined in the subroutine INPUT, that reads also the input file `slhainp.dat`. (Part of the corresponding code is copied from `pyslha.f`, with thanks to P. Skands.)

3. Third, as part of this block we input the running b quark mass $m_b(m_b)$, the top quark pole mass and m_τ.

4. In addition, NMHDECAY needs the (pole) quark masses m_s and m_c, as well as the CKM matrix elements V_{us}, V_{cb} and V_{ub}. The numerical values of these five parameters are defined in the subroutine INPUT. (For convenience, they are printed out in the output file `spectr.dat`, see below.)

c) "BLOCK MINPAR" contains only the switch 3 with the input value for $\tan\beta$ specified.
d) "BLOCK EXTPAR" contains inputs for the SUSY and soft-SUSY-breaking parameters. Needed generalizations of the SLHA conventions appear. The new entries are:

61	for λ
62	for κ
63	for A_λ
64	for A_κ

Note that the entry 23 (μ) is used for the effective μ parameter, $\mu_{\mathrm{eff}} = \lambda \langle S \rangle$, in the NMSSM. It should also be noted that neither the entry 3 (M_3), nor the slepton entries (all generations) nor the squark entries for the first and second generations are actually used; these are included for future use only.

The two output files of NMHDECAY_SLHA are `spectr.dat` and `decay.dat`. The contents of `spectr.dat` are as follows:
a) "BLOCK SPINFO" is followed by warnings (switch 3) if any of the constraints described in section 4 are violated. This segment of the output also displays error messages (switch 4) if any of the

Higgs, stop or sbottom states have a negative mass squared. No spectrum output is produced in this case.
b) "BLOCK SMINPUTS" is followed by a printout of the Standard Model input parameters. The numerical values for M_W, m_s, m_c, V_{us}, V_{cb} and V_{ub}, that have no SLHA numbers, appear in lines subsequent to "# SMINPUTS Beyond SLHA".
c) "BLOCK MINPAR" is followed by a printout of the value of $\tan\beta$ and "BLOCK EXTPAR" is followed by a printout of the important SUSY and soft-SUSY-breaking parameters.
d) The masses for the Higgs particles, the neutralinos and the charginos appear in the output following "BLOCK MASS". There, one finds several essential NMSSM generalizations of the SLHA conventions. The new entries, with proposed PDG codes, are

45	for the third CP-even Higgs boson,
37	for the second CP-odd Higgs boson,
1000045	for the fifth neutralino.

The Higgs mixings in the CP-even sector follow "BLOCK HIGMIX" and those in the CP-odd sector follow "BLOCK AMIX". Both segments of the output contain NMSSM generalizations of the SLHA conventions, that are required in order to parameterize the mixing in the enlarged Higgs sector. The meaning of the matrix elements S_{ij} (i, j = 1, 2, 3) and P'_{ij} (i, j = 1, 2) is as follows.

- According to the SLHA conventions the Higgs states H_u, H_d are denoted by H_2, H_1, respectively. (Inside the Fortran code the Higgs states H_u, H_d are denoted by H_1, H_2, which is of no relevance for the SLHA output.) Hence, for the purpose of the SLHA output, the bare CP-even Higgs states are numbered by $S_i^{bare} = (H_{dR}, H_{uR}, S_R)$ (R refers to the real component of the field). If h_i are the mass eigenstates (ordered in mass), the convention is $h_i = S_{ij} S_j^{bare}$.

- In the CP-odd sector the bare Higgs fields are H_{uI}, H_{dI}, S_I (I for imaginary component). Again, for the purpose of the SLHA output, the bare CP-odd Higgs states are denoted by $H_{uI} = H_{2I}$, $H_{dI} = H_{1I}$. The mass eigenstates are a_i (ordered in mass, $i = 1, 2$) and the Goldstone mode $\tilde{G}$. Then the elements of P'_{ij} are defined as

$$\begin{aligned} H_{1I} &= \sin\beta(P'_{11}a_1 + P'_{21}a_2) + \cos\beta\tilde{G} \ , \\ H_{2I} &= \cos\beta(P'_{11}a_1 + P'_{21}a_2) - \sin\beta\tilde{G} \ , \\ S_I &= P'_{12}a_1 + P'_{22}a_2 \ . \end{aligned}$$

e) "BLOCK NMIX" is followed by a printout of the obvious generalization of the 4×4 MSSM neutralino mixing matrix to the 5×5 NMSSM neutralino mixing matrix (with real entries); "BLOCK UMIX" and "BLOCK VMIX" are followed by printouts of the U and V matrices as defined in the MSSM.

The output file `decay.dat` respects the SLHA conventions for the Decay file (at present we consider two particle final states only), using the above generalizations of the PDG codes both for the decaying particle and the final states.

```
#  INPUT FILE FOR NMHDECAY
#  BASED ON SUSY LES HOUCHES ACCORD, MODIFIED FOR THE NMSSM
#  IN EXTPAR: LINES 61-64: NMSSM YUKAWA COUPLINGS AND TRILIN. SOFT TERMS
BLOCK MODSEL
  3     1     # NMSSM PARTICLE CONTENT
BLOCK SMINPUTS
  1   137.036 # ALPHA_EM^-1(0)
  2   1.16639D-5   # GF
  3   0.12    # ALPHA_S(MZ)
  4   91.187  # MZ
  5     4.24  # MB(MB), RUNNING B QUARK MASS
  6   175.    # TOP QUARK POLE MASS
  7   1.7771  # MTAU
BLOCK MINPAR
  3    5.     # TANBETA
BLOCK EXTPAR
  1   5.D2    # M1
  2   1.D3    # M2
  3   3.D3    # M3
  11  1.5D3   # ATOP
  12  1.5D3   # ABOT
  13  1.5D3   # ATAU
  23  180.    # MU
  31  1.D3    # LEFT SELECTRON
  32  1.D3    # LEFT SMUON
  33  1.D3    # LEFT STAU
  34  1.D3    # RIGHT SELECTRON
  35  1.D3    # RIGHT SMUON
  36  1.D3    # RIGHT STAU
  41  1.D3    # LEFT 1ST GEN. SQUARKS
  42  1.D3    # LEFT 2ND GEN. SQUARKS
  43  1.D3    # LEFT 3RD GEN. SQUARKS
  44  1.D3    # RIGHT U-SQUARKS
  45  1.D3    # RIGHT C-SQUARKS
  46  1.D3    # RIGHT T-SQUARKS
  47  1.D3    # RIGHT D-SQUARKS
  48  1.D3    # RIGHT S-SQUARKS
  49  1.D3    # RIGHT B-SQUARKS
  61  .3D0    # LAMBDA
  62  .3D0    # KAPPA
  63  200.    # A_LAMBDA
  64  0.0     # A_KAPPA
```

Table 1: Sample `slhainp.dat` file.

```
# NMHDECAY OUTPUT IN SLHA FORMAT
# Info about spectrum calculator
BLOCK SPINFO        # Program information
     1   NMHDECAY   # spectrum calculator
     2   1.0        # version number
# Input parameters
BLOCK MODSEL
    3     1         # NMSSM PARTICLE CONTENT
BLOCK SMINPUTS
     1     1.37036000E+02   # ALPHA_EM^-1
     2     1.16639000E-05   # GF
     3     1.20000000E-01   # ALPHA_S(MZ)
     4     9.11870000E+01   # MZ
     5     4.24000000E+00   # MB(MB)
     6     1.75000000E+02   # MTOP (POLE MASS)
     7     1.77710000E+00   # MTAU
# SMINPUTS Beyond SLHA:
# MW:     0.80419998E+02
# MS:     0.19000000E+00
# MC:     0.16100000E+01
# VUS:     0.22200000E+00
# VCB:     0.41000000E-01
# VUB:     0.36000000E-02
BLOCK MINPAR
     3     5.00000000E+00   # TANBETA
BLOCK EXTPAR
     1     5.00000000E+02   # M1
     2     1.00000000E+03   # M2
     3     3.00000000E+03   # M3
    11     1.50000000E+03   # ATOP
    12     1.50000000E+03   # ABOTTOM
    13     1.50000000E+03   # ATAU
    23     1.80000000E+02   # MU
    33     1.00000000E+03   # LEFT STAU
    36     1.00000000E+03   # RIGHT STAU
    43     1.00000000E+03   # LEFT 3RD GEN. SQUARKS
    46     1.00000000E+03   # RIGHT T-SQUARKS
    49     1.00000000E+03   # RIGHT B-SQUARKS
    61     3.00000000E-01   # LAMBDA
    62     3.00000000E-01   # KAPPA
    63     2.00000000E+02   # A_LAMBDA
    64     0.00000000E+00   # A_KAPPA
#
BLOCK MASS   # Mass spectrum
#  PDG Code     mass             particle
        25     1.16846074E+02   # lightest neutral scalar
        35     3.56992549E+02   # second neutral scalar
        45     5.91262232E+02   # third neutral scalar
        36     4.90592939E+01   # lightest pseudoscalar
        46     5.87728592E+02   # second pseudoscalar
        37     5.90689358E+02   # charged Higgs
   1000022     1.66456703E+02   # neutralino(1)
   1000023    -1.85971845E+02   # neutralino(2)
   1000025     3.67762262E+02   # neutralino(3)
   1000035     5.04634098E+02   # neutralino(4)
   1000045     1.00711878E+03   # neutralino(5)
   1000024     1.76259627E+02   # chargino(1)
   1000037     1.00710838E+03   # chargino(2)
```

Table 2: Sample `spectr.dat` file (page 1)

```
# 3*3 Higgs mixing
BLOCK HIGMIX
  1  1    -1.27439162E-01   # S_(1,1)
  1  2    -3.16459888E-02   # S_(1,2)
  1  3    -9.91341410E-01   # S_(1,3)
  2  1    -2.01786540E-01   # S_(2,1)
  2  2    -9.77760593E-01   # S_(2,2)
  2  3     5.71525690E-02   # S_(2,3)
  3  1     9.71103214E-01   # S_(3,1)
  3  2    -2.07322828E-01   # S_(3,2)
  3  3    -1.18219256E-01   # S_(3,3)
# 2*2 Pseudoscalar Higgs mixing
BLOCK AMIX
  1  1    -2.37324844E-02   # P'_(1,1)
  1  2    -9.99718345E-01   # P'_(1,2)
  2  1     9.99718345E-01   # P'_(2,1)
  2  2    -2.37324844E-02   # P'_(2,2)
# Gaugino-Higgsino mixing
BLOCK NMIX  # 5*5 Neutralino Mixing Matrix
  1  1     1.05202671E-01   # N_(1,1)
  1  2    -7.87589631E-02   # N_(1,2)
  1  3     6.92565025E-01   # N_(1,3)
  1  4    -6.93980327E-01   # N_(1,4)
  1  5     1.46541512E-01   # N_(1,5)
  2  1    -3.48143940E-02   # N_(2,1)
  2  2     3.76738427E-02   # N_(2,2)
  2  3     7.01102969E-01   # N_(2,3)
  2  4     7.06807991E-01   # N_(2,4)
  2  5     7.90299289E-02   # N_(2,5)
  3  1     9.93510538E-01   # N_(3,1)
  3  2     1.73884449E-02   # N_(3,2)
  3  3    -5.24484443E-02   # N_(3,3)
  3  4     9.87396900E-02   # N_(3,4)
  3  5     1.15796113E-02   # N_(3,5)
  4  1    -2.45218320E-02   # N_(4,1)
  4  2     9.59570918E-03   # N_(4,2)
  4  3    -1.58479313E-01   # N_(4,3)
  4  4     4.52366830E-02   # N_(4,4)
  4  5     9.85973910E-01   # N_(4,5)
  5  1    -7.47306864E-03   # N_(5,1)
  5  2     9.95983570E-01   # N_(5,2)
  5  3     3.06884365E-02   # N_(5,3)
  5  4    -8.37728195E-02   # N_(5,4)
  5  5    -1.10280322E-03   # N_(5,5)
BLOCK UMIX  # Chargino U Mixing Matrix
  1  1     4.31428408E-02   # U_(1,1)
  1  2    -9.99068914E-01   # U_(1,2)
  2  1     9.99068914E-01   # U_(2,1)
  2  2     4.31428408E-02   # U_(2,2)
BLOCK VMIX  # Chargino V Mixing Matrix
  1  1     1.18343118E-01   # V_(1,1)
  1  2    -9.92972762E-01   # V_(1,2)
  2  1     9.92972762E-01   # V_(2,1)
  2  2     1.18343118E-01   # V_(2,2)
```

Table 3: Sample `spectr.dat` file (page 2)

```
# HIGGS BRANCHING RATIOS IN SLHA FORMAT
# Info about decay package
BLOCK DCINFO        # Program information
     1   NMHDECAY   # Decay package
     2   1.0        # Version number
#           PDG          Width
DECAY        25     2.30614187E-02   # Lightest neutral Higgs scalar
     8.68293526E-03    2          21        21   # BR(H_1 -> gluon gluon)
     3.93016339E-05    2          13       -13   # BR(H_1 -> muon muon)
     1.11026200E-02    2          15       -15   # BR(H_1 -> tau tau)
     7.00339694E-05    2           3        -3   # BR(H_1 -> s sbar)
     6.02581831E-03    2           4        -4   # BR(H_1 -> c cbar)
     1.21190255E-01    2           5        -5   # BR(H_1 -> b bbar)
     0.00000000E+00    2           6        -6   # BR(H_1 -> t tbar)
     1.23849483E-02    2          24       -24   # BR(H_1 -> W+ W-)
     9.95108414E-04    2          23        23   # BR(H_1 -> Z Z)
     3.09060615E-04    2          22        22   # BR(H_1 -> gamma gamma)
     1.18608507E-04    2          23        22   # BR(H_1 -> Z gamma)
     8.39081310E-01    2          36        36   # BR(H_1 -> A_1 A_1)
     0.00000000E+00    2          36        46   # BR(H_1 -> A_1 A_2)
     0.00000000E+00    2          46        46   # BR(H_1 -> A_2 A_2)
     0.00000000E+00    2          23        36   # BR(H_1 -> A_1 Z)
     0.00000000E+00    2     1000022   1000022   # BR(H_1 -> neu_1 neu_1)
     0.00000000E+00    2     1000022   1000023   # BR(H_1 -> neu_1 neu_2)
     0.00000000E+00    2     1000022   1000025   # BR(H_1 -> neu_1 neu_3)
     0.00000000E+00    2     1000022   1000035   # BR(H_1 -> neu_1 neu_4)
     0.00000000E+00    2     1000022   1000045   # BR(H_1 -> neu_1 neu_5)
     0.00000000E+00    2     1000023   1000023   # BR(H_1 -> neu_2 neu_2)
     0.00000000E+00    2     1000023   1000025   # BR(H_1 -> neu_2 neu_3)
     0.00000000E+00    2     1000023   1000035   # BR(H_1 -> neu_2 neu_4)
     0.00000000E+00    2     1000023   1000045   # BR(H_1 -> neu_2 neu_5)
     0.00000000E+00    2     1000025   1000025   # BR(H_1 -> neu_3 neu_3)
     0.00000000E+00    2     1000025   1000035   # BR(H_1 -> neu_3 neu_4)
     0.00000000E+00    2     1000025   1000045   # BR(H_1 -> neu_3 neu_5)
     0.00000000E+00    2     1000035   1000035   # BR(H_1 -> neu_4 neu_4)
     0.00000000E+00    2     1000035   1000045   # BR(H_1 -> neu_4 neu_5)
     0.00000000E+00    2     1000045   1000045   # BR(H_1 -> neu_5 neu_5)
     0.00000000E+00    2     1000024  -1000024   # BR(H_1 -> cha_1 cha_1)
     0.00000000E+00    2     1000024  -1000037   # BR(H_1 -> cha_1 cha_2)
     0.00000000E+00    2     1000037  -1000037   # BR(H_1 -> cha_2 cha_2)
```

Table 4: Sample `decay.dat` file (page 1)