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The SUSY Les Houches Accord and PYTHIA 6.3

Interfacing SUSY Spectrum Calculators, Decay Packages, and Event Generators

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Updated writeup 27'th Aug '04:

v2: **hep-ph/0311123** & **JHEP 0407:036**

What is the SLHA?

SUSY model → **Spectrum Calculator** → **Event Gen./ XS Calc.**

SUSY model

- MSSM
- SUGRA
- GMSB
- AMSB
- RPV
- CPV
- NMSSM
- ...

Spectrum Calculator

- FEYNHIGGS
- ISASUSY
- (PYTHIA)
- SOFTSUSY
- SPHENO
- SUSPECT
- ...

Event Gen./ XS Calc.

- COMPHEP
- GRACE
- HERWIG
- ISAJET
- PROSPINO
- PYTHIA
- SHERPA
- SUSYGEN
- WHIZARD
- ...

CDM Package

- MICRΩS
- DARKSUSY
- NEUTDRIVER
- ...

Decay Package

- HDECAY
- NMHDECAY NEW!
- SDECAY
- ...

Ellwanger+Gunion+Hugonie
hep-ph/0406215
NMSSM Higgs sector

What is the SLHA?

SUSY model — SLHA Input → **Spectrum Calculator** — SLHA Input + Spectrum (+ Decay table) → **Event Gen./ XS Calc.**

SUSY model

- MSSM
- SUGRA
- GMSB
- AMSB
- RPV
- CPV
- NMSSM
- ...

Spectrum Calculator

- FeynHiggs
- IsaSusy
- (Pythia)
- SoftSusy
- SPheno
- SuSpect
- ...

Event Gen./ XS Calc.

- CompHEP
- Grace
- Herwig
- Isajet
- Prospino
- Pythia
- Sherpa
- SusyGen
- Whizard
- ...

Spectrum Calculator — SLHA Input + Spectrum → **CDM Package** and **Decay Package**

CDM Package

- MicrΩs
- DarkSusy
- NeutDriver
- ...

Decay Package

- HDecay
- NMHDecay
- SDecay
- ...

Decay Package — SLHA Input + Spectrum + Decay table → Event Gen./ XS Calc.

What is the SLHA?

SUSY model — SLHA Input → **Spectrum Calculator** — SLHA Input + Spectrum (+ Decay table) → **Event Gen./ XS Calc.**

SUSY model
MSSM✔
SUGRA✔
GMSB✔
AMSB✔
RPV
CPV
NMSSM(✔)
...

Spectrum Calculator
FEYNHIGGS✔
ISASUSY✔
(PYTHIA)✔
SOFTSUSY✔
SPHENO✔
SUSPECT(✔)
...

Event Gen./ XS Calc.
COMPHEP
GRACE
HERWIG
ISAJET
PROSPINO✔
PYTHIA✔
SHERPA
SUSYGEN
WHIZARD✔
...

SLHA Input + Spectrum ↙ **CDM Package**, ↘ **Decay Package**

CDM Package
MICRΩS✔
DARKSUSY
NEUTDRIVER
...

Decay Package
HDECAY
NMHDECAY✔
SDECAY✔
...

Decay Package — SLHA Input + Spectrum + Decay table → **Event Gen./ XS Calc.**

Starting Point

SLHA — Considerations:

- **Consistency**

  Define parameters consistently and unambiguously $\rightarrow$ specific conventions adopted (described in detail in writeup).

- **Flexible/Extendable**

  Structure should be general enough to *eventually* handle *any* model $\rightarrow$ files built of modular “data blocks”.

- **Usable**

  Easy to implement and to use $\rightarrow$ keep basic structure simple.

SLHA — Considerations:

- **Consistency**

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Conventions and Consistency

What is needed?

1. To specify experimental boundary conditions?
   (the measured “SM” couplings & masses).
2. To define the SUSY model?
   (W and the soft breaking terms, in a form suitable to spectrum calculation programs).
3. To communicate the resulting spectrum?
   (the mass and coupling spectrum at the EW scale, in a form suitable for cross section and width calculations).

($\rightarrow$ pretty much ‘theoretician’s definitions’, you start with assumptions about the high scale physics and work out the low scale consequences.)

Some Examples...

(Examples)

```
# SUSY Les Houches Accord 1.0
# Example input file - Snowmass point 1a
Block MODSEL    # Model selection
     1      1      # SUGRA model
Block SMINPUTS # SM parameters
     5      4.25   # mb(mb)
     6    174.3    # t pole mass
Block MINPAR    # Model Parameters
     1    100.     # m0
     2    250.     # m12
     3     10.     # tanbeta
     4      1.     # sgnmu
     5   -100.     # A0
```

(Examples)

```
# SUSY Les Houches Accord 1.0
# Example spectrum file - Snowmass point 1a
Block SPINFO          # Program information
     1   SOFTSUSY     # spectrum calculator
     2   1.8.4        # version number
Block MODSEL  # Select model
     1   1   # sugra
Block MINPAR  # Input parameters
     1   1.000000000e+02  # m0
     2   2.500000000e+02  # m12
     3   1.000000000e+01  # tanb
     4   1.000000000e+00  # sign(mu)
     5  -1.000000000e+02  # A0
Block SMINPUTS # SM parameters
     1   1.279340000e+02  # 1/alpha(MZ)[MSbar]
     2   1.166370000e-05  # Gmu [GeV**-2]
     3   1.172000000e-01  # alphas(MZ)[MSbar]
     4   9.118760000e+01  # Z pole mass
     5   4.250000000e+00  # mb(mb)[MSbar]
     6   1.743000000e+02  # t pole mass
     7   1.777000000e+00  # tau pole mas
Block MASS   # Mass spectrum (pole masses)
         24     8.024639840e+01   # W
         25     1.106368320e+02   # h0
         35     4.008746040e+02   # H0
         36     4.005062720e+02   # A0
         37     4.087847760e+02   # H+
    1000001     5.537379281e+02   # sd(L)
    1000002     5.480648005e+02   # su(L)
    1000003     5.536689385e+02   # ss(L)
    1000004     5.479950083e+02   # sc(L)
    1000005     4.990864878e+02   # sb(1)
    1000006     3.866681125e+02   # st(1)
    1000011     2.005077001e+02   # se(L)
    1000012     1.844822029e+02   # snue(L)
    1000013     2.005050044e+02   # smu(L)
    1000014     1.844792730e+02   # snumu(L)
    1000015     1.339969762e+02   # stau(1)
    1000016     1.836242253e+02   # snu(tau(L))
    1000021     5.934756712e+02   # gluino
    1000022     9.701573617e+01   # neutralino(1)
    1000023     1.788864799e+02   # neutralino(2)
    1000024     1.782649096e+02   # chargino(1)
```

```
    1000025    -3.536102287e+02   # neutralino(3)
    1000035     3.733417082e+02   # neutralino(4)
    1000037     3.736128390e+02   # chargino(2)
    2000001     5.269676664e+02   # sd(R)
    2000002     5.311251030e+02   # su(R)
    2000003     5.269652151e+02   # ss(R)
    2000004     5.309795680e+02   # sc(R)
    2000005     5.257115262e+02   # sb(2)
    2000006     5.704560875e+02   # st(2)
    2000011     1.430886701e+02   # se(R)
    2000013     1.430810123e+02   # smu(R)
    2000015     2.043832731e+02   # stau(2)
Block alpha # Effective Higgs mixing angle alpha
         -1.146864127e-01   # alpha
Block hmix Q= 4.520624648e+02   # DRbar Higgs mix
     1     3.439934743e+02   # mu
Block stopmix   # stop mixing matrix
  1  1     5.443784304e-01   # O(1,1)
  1  2     8.388397490e-01   # O(1,2)
  2  1     8.388397490e-01   # O(2,1)
  2  2    -5.443784304e-01   # O(2,2)
Block sbotmix   # sbottom mixing matrix
  1  1     9.355024721e-01   # O(1,1)
  1  2     3.533201449e-01   # O(1,2)
  2  1    -3.533201449e-01   # O(2,1)
  2  2     9.355024721e-01   # O(2,2)
Block staumix   # stau mixing matrix
  1  1     2.810947184e-01   # O(1,1)
  1  2     9.596800297e-01   # O(1,2)
  2  1     9.596800297e-01   # O(2,1)
  2  2    -2.810947184e-01   # O(2,2)
# Gaugino-higgsino mixing
Block nmix   # neutralino mixing matrix
  1  1     9.849417415e-01   # N(1,1)
  1  2    -5.795970738e-02   # N(1,2)
  1  3     1.526931274e-01   # N(1,3)
  1  4    -5.670314904e-02   # N(1,4)
  2  1     1.090115410e-01   # N(2,1)
  2  2     9.374300545e-01   # N(2,2)
  2  3    -2.852021039e-01   # N(2,3)
  2  4     1.673354023e-01   # N(2,4)
...
```

(Examples)

```
# SUSY Les Houches Accord 1.0
# Example decay file - Gluino decays
Block DCINFO      # Program information
     1     SDECAY    # Decay package
     2     1.0       # version number
#          PDG            Width
DECAY    1000021    1.01752300e+00   # gluino decays
#           BR             NDA      ID1       ID2
     4.18313300E-02     2      1000001        -1   # BR(sg -> sd(L) dbar)
     1.55587600E-02     2      2000001        -1   # BR(sg -> sd(R) dbar)
     3.91391000E-02     2      1000002        -2   # BR(sg -> su(L) ubar)
     1.74358200E-02     2      2000002        -2   # BR(sg -> su(R) ubar)
     4.18313300E-02     2      1000003        -3   # BR(sg -> ss(L) sbar)
     1.55587600E-02     2      2000003        -3   # BR(sg -> ss(R) sbar)
     3.91391000E-02     2      1000004        -4   # BR(sg -> sc(L) cbar)
     1.74358200E-02     2      2000004        -4   # BR(sg -> sc(R) cbar)
     1.13021900E-01     2      1000005        -5   # BR(sg -> sb(1) bbar)
     6.30339800E-02     2      2000005        -5   # BR(sg -> sb(2) bbar)
     9.60140900E-02     2      1000006        -6   # BR(sg -> st(1) tbar)
     0.00000000E+00     2      2000006        -6   # BR(sg -> st(2) tbar)
     4.18313300E-02     2     -1000001         1   # BR(sg -> sdbar(L) d)
     1.55587600E-02     2     -2000001         1   # BR(sg -> sdbar(R) d)
     3.91391000E-02     2     -1000002         2   # BR(sg -> subar(L) u)
     1.74358200E-02     2     -2000002         2   # BR(sg -> subar(R) u)
     4.18313300E-02     2     -1000003         3   # BR(sg -> ssbar(L) s)
     1.55587600E-02     2     -2000003         3   # BR(sg -> ssbar(R) s)
     3.91391000E-02     2     -1000004         4   # BR(sg -> scbar(L) c)
     1.74358200E-02     2     -2000004         4   # BR(sg -> scbar(R) c)
     1.13021900E-01     2     -1000005         5   # BR(sg -> sbbar(1) b)
     6.30339800E-02     2     -2000005         5   # BR(sg -> sbbar(2) b)
     9.60140900E-02     2     -1000006         6   # BR(sg -> stbar(1) t)
     0.00000000E+00     2     -2000006         6   # BR(sg -> stbar(2) t)
```

News and Updates...

News

- NMHDecay: [U. Ellwanger et al., hep-ph/0406215]
  - NMSSM Higgs sector: masses + couplings.
  - NMSSM Higgs decays.
- SDecay: [M. Mühlleitner et al., hep-ph/0311167]
  - 3-body sbottom decays.
  - QCD corrections for gaugino $\to \tilde{q}q'$ and $\tilde{q} \to \tilde{q}'V$.
  - SLHA spectrum read-in. (SLHA output already there.)
- SLHAlib-1.0 [T. Hahn, hep-ph/0408283]
  - F77 SLHA Read-Write libraries.

Using the SLHA with PYTHIA 6.3

Using the SLHA with PYTHIA 6.3

1. Run a spectrum calculator of your choice, and get an SLHA output file with the spectrum.
   (Optional: also run a decay package, with the SLHA file as input, to add a list of decay modes and partial widths to the spectrum.)

2. In your event generation code, before initializing PYTHIA, open the SLHA file on some unit number, for instance unit 42.
   ```
   OPEN(42,file='SPheno.spc',status='old')
   ```

3. Tell PYTHIA 1) to use this file and 2) where it is.
   ```
   CALL PYGIVE('IMSS(1)=11;IMSS(21)=42')
   ```

4. (To also read in the decay table, add:
   `CALL PYGIVE('IMSS(22)=42')`)

Where to find more info:

- The SUSY Les Houches Accord:
  PS et al., JHEP 0407:036 (hep-ph/0311123)
- SLHA Latest News, codes, examples, workshops, ...:
  `http://www.thep.lu.se/~zeiler/slha/`
- The PYTHIA 6.3 Manual:
  TS, SM, PS, L. Lönnblad, hep-ph/0308153
- The PYTHIA 6.3 Update Notes (running):
  `http://www.thep.lu.se/~torbjorn/Pythia.html`,
  click on `Preview` to get to the PYTHIA 6.3 homepage
- If <u>all else fails</u>, skands@fnal.gov

EXTRA MATERIAL

Conventions and Consistency

1. Experimental Boundary Conditions

$\alpha_{\mathrm{em}}(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}$	$\frac{\alpha}{1-\Delta\alpha(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}}$
G_F	The Fermi constant determined from μ decay
m_{Z}	The Z boson pole mass
$\alpha_s(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}$	The 5–flavour $\overline{\mathrm{MS}}$ strong coupling at m_{Z}
$m_{\mathrm{b}}(m_{\mathrm{b}})^{\overline{\mathrm{MS}}}$	The $\overline{\mathrm{MS}}$ b quark running mass at m_{b}
m_{t}	Top pole mass
m_{τ}	Tau pole mass

Note: no SUSY corrections here!

Conventions and Consistency

2. Defining the SUSY Model

$\mathrm{sgn}(\mu)$	$W_\mu = \epsilon_{ab}\left[-\mu H_1^a H_2^b\right]$, $(\epsilon_{12} = 1)$
$\tan\beta(m_\mathrm{Z})^{\overline{\mathrm{DR}}}$	v_2/v_1 (can also be given at $Q \neq m_Z$)
$V_3(M_\mathrm{input})$	$\epsilon_{ab}\sum_{ij}\left[(T_E)_{ij} H_1^a \tilde{L}^b_{i_L}\tilde{e}^*_{j_R} + (T_D)_{ij} H_1^a \tilde{Q}^b_{i_L}\tilde{d}^*_{j_R} + (T_U)_{ij} H_2^b \tilde{Q}^a_{i_L}\tilde{u}^*_{j_R}\right] + \mathrm{h.c.},\quad A_{ij} = T_{ij}/Y_{ij}$
$V_2(M_\mathrm{input})$	$m^2_{H_j} H^*_{j\,a} H^a_j + \tilde{Q}^*_{i_L a}(m^2_{\tilde{Q}})_{ij}\tilde{Q}^a_{j_L} + \tilde{L}^*_{i_L a}(m^2_{\tilde{L}})_{ij}\tilde{L}^a_{j_L} + \tilde{q}_{i_R}(m^2_{\tilde{q}})_{ij}\tilde{q}^*_{j_R} + \tilde{e}_{i_R}(m^2_{\tilde{e}})_{ij}\tilde{e}^*_{j_R} - (m_3^2\epsilon_{ab}H_1^a H_2^b + \mathrm{h.c.})$
	∘ Either $(m^2_{H_1}, m^2_{H_2})$ or $(\mu, m_A^2 = \frac{m_3^2}{\sin\beta\cos\beta})$
$\mathcal{L}_G(M_\mathrm{input})$	$\frac{1}{2}\left(M_1\tilde{b}\tilde{b} + M_2\tilde{w}^A\tilde{w}^A + M_3\tilde{g}^X\tilde{g}^X\right) + \mathrm{h.c.}$

Conventions and Consistency

3. Communicating the Spectrum: $\overline{\mathrm{DR}}$ parameters

$W(Q_i)^{\overline{\mathrm{DR}}}$	$\epsilon_{ab}\left[(Y_E)_{ij}H_1^aL_i^b\bar{E}_j + (Y_D)_{ij}H_1^aQ_i^b\bar{D}_j + (Y_U)_{ij}H_2^bQ_i^a\bar{U}_j - \mu H_1^aH_2^b\right]$
$\tan\beta(Q_i)^{\overline{\mathrm{DR}}}$	v_2/v_1
$g_j(Q_i)^{\overline{\mathrm{DR}}}$	g', g, and g_3: gauge couplings
$A_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking trilinear couplings
$v_j(Q_i)^{\overline{\mathrm{DR}}}$	$\sqrt{2}\langle H_j^0\rangle$, so $v^2 = (v_1^2 + v_2^2) = (246\ \text{GeV})^2$
$M_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking gaugino masses
$m_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking sfermion masses
$m_A(Q_i)^{\overline{\mathrm{DR}}}$	Running A mass.

In v1 writeup / In v2 writeup (& JHEP)

Conventions and Consistency

3. Communicating the Spectrum: mixing matrices

- mixing angles avoided, matrix elements given instead.

$$T = \xcancel{\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}$$

- No consensus on best ‘scheme’ $\rightarrow$
  Effective ‘best choice’ definitions, at the discretion of each spectrum calculator.

E.g. α: Diagonalizes loop–corrected mass matrices, but not a $\overline{\mathrm{DR}}$ or $\overline{\mathrm{MS}}$ parameter. Still, not scale independent. On–shell scheme has scale fixed by renormalization conditions, and external propagators still carry some momentum, which momentum?