1 HiggsBounds with SLHA extension: using a SLHA file as input to HiggsBounds

This is a guide to using SLHA input with HiggsBounds. Note that this is an extension to HiggsBounds, which is still in the beta testing stage. Your feedback is very welcome and will help to shape this extension. This guide should be read in conjunction with the HiggsBounds 2.0.0 manual and will use the notation defined there.

1.1 What the SLHA file needs to contain

The option whichinput=SLHA involves extracting (at most) the following numbers from the SLHA file:

(1) masses for the neutral Higgs bosons h_k ($k = 1, n_{H^0}$) and singly charged Higgs bosons $H_j^\pm$ ($j = 1, n_{H^\pm}$),

$$m_{h_k}\,, m_{H_j^\pm},$$

(2) Higgs total decay widths,

$$\Gamma_{\rm tot}(h_k)\,, \Gamma_{\rm tot}(H_k^\pm),$$

(3) neutral Higgs branching ratios with SM equivalents (OP=ordinary particles i.e. particles which exist in the SM)

$$\mathrm{BR}_{\rm model}(h_k \to OP) \,\text{with}\, OP = s\bar{s}, c\bar{c}, b\bar{b}, \tau^+\tau^-, W^+W^-, ZZ, Z\gamma, \gamma\gamma, gg$$

(4) neutral Higgs branching ratios without SM equivalents

$$\mathrm{BR}_{\rm model}(h_k \to h_i h_i), \mathrm{BR}_{\rm model}(h_k \to \text{invisible}),$$

(5) charged Higgs branching ratios to SM particles

$$\mathrm{BR}(H_j^+ \to \mathrm{OP}) \,\text{with}\, OP = c\bar{s}, c\bar{b}, \tau^+\nu_\tau$$

(6) top quark branching ratios

$$\mathrm{BR}(t \to W^+ b), \mathrm{BR}(t \to H_j^+ b),$$

(7) normalised scalar and pseudoscalar effective couplings to fermions squared

$$\left(\frac{g^{\rm model}_{s,h_k(OP)}}{g^{\rm SM}_{H(OP)}}\right)^2, \left(\frac{g^{\rm model}_{p,h_k(OP)}}{g^{\rm SM}_{H(OP)}}\right)^2, OP = b\bar{b}, t\bar{t}, \tau^+\tau^-$$

(8) normalised effective couplings to bosons squared

$$\left(\frac{g^{\rm model}_{h_i h_j Z}}{g^{\rm ref}_{H'HZ}}\right)^2 , \left(\frac{g^{\rm model}_{h_k(OP)}}{g^{\rm SM}_{H(OP)}}\right)^2 , OP = W^+W^-, ZZ, gg$$

Any masses not specified in the SLHA file will be set to minus one. Any other parameters that are not specified in the SLHA file will be set to zero.

The normalised effective couplings squared are used to calculate the normalised Higgs production cross sections and the CP properties within `HiggsBounds`. Note that (unlike the option whichinput='effC') effective couplings are not used to calculate the branching ratios: branching ratios are taken directly from the decay blocks in the SLHA file (or set zero if they are not specified in these decay blocks).

`HiggsBounds` requires two extra ('SLHA'-inspired) blocks to specify the normalised effective couplings squared. The format of these blocks is shown in Fig. 1.

`HiggsBounds` is *unable* to use the SLHA file if

- the Block MODSEL indicates that there is R-parity violation
- `nHzero` is greater than 5
- `nHplus` is greater than 1

(recall that `nHzero` and `nHplus` are given as input, either as arguments to the subroutine `initialize_HiggsBounds` or on the command line).

Table 1 contains the sequence of PDG numbers which can be considered as neutral Higgs bosons. `nHzero` is used to specify how many of these PDG numbers are used, counting from the top of table 1 downwards. For example, if `nHzero=3`, the properties of particles with the PDG numbers 25,35,36 are read from the SLHA file. If `nHzero=5`, particles with the PDG numbers 25,35,36,45,46 are read in. Note that no CP properties are inferred from the PDG numbers of neutral Higgs.

The invisible Higgs branching ratio is obtained from the branching ratio of the Higgs into a weakly-interacting LSP. Table 2 contains the particles which are considered as possible weakly-interacting LSP candidates. `HiggsBounds` finds the weakly-interacting candidate with the lowest mass and then confirms that this particle is indeed the LSP by comparing its mass against the masses of the charged leptons, lightest chargino and gluino. If it is not the LSP, the invisible Higgs branching ratio is set to zero.

Neutral Higgs bosons	
Common notation	PDG number
h^0 or h_1	25
H^0 or h_2	35
A^0 or h_3 or A_1^0	36
h_3	45
A_2^0	46

Table 1
PDG numbers which can represent neutral Higgs bosons. `nHzero` *of these will be considered by* `HiggsBounds`*, starting from the top row.*

Weakly-interacting LSP candidates	
Common notation	PDG number
χ_1^0	1000022
$\tilde{\nu}_e$ or $\tilde{\nu}_1$ or $\tilde{\nu}_{1S}$	1000012
$\tilde{\nu}_\mu$ or $\tilde{\nu}_2$ or $\tilde{\nu}_{2S}$	1000014
$\tilde{\nu}_\tau$ or $\tilde{\nu}_3$ or $\tilde{\nu}_{3S}$	1000016
$\tilde{\nu}_{1A}$	1000017
$\tilde{\nu}_{2A}$	1000018
$\tilde{\nu}_{3A}$	1000019

Table 2
PDG numbers which can represent a weakly-interacting LSP. `HiggsBounds` *will check whether one of these particles is indeed the LSP, and if it is, takes the branching ratio of neutral Higgs into this LSP as the invisible Higgs branching ratio.*

1.2 Installation

- Download `HiggsBounds` 2.0.0 package, available from `www.ippp.dur.ac.ukHiggsBounds`.
- Copy the files `extra_bits_for_SLHA.f90`, `string_manip.f90` `PDGnumbering.f90` and `SLHA_manip.f90` into the `HiggsBounds-f90` directory.
- In the `configure` script, uncomment the lines
  `USESLHAMODS = \$(SLHAMODS)`
  `ADDITIONALDEFINE = -DenableSLHA`
- Install the fortran90 version of `HiggsBounds` as normal.

1.3 Using SLHA input in the subroutine version of HiggsBounds

This is the same as for the other input modes, except that the subroutine

- HiggsBounds_input_SLHA

should be used rather the subroutines

- HiggsBounds_neutral_input_effC
- HiggsBounds_neutral_input_part
- HiggsBounds_neutral_input_hadr
- HiggsBounds_charged_input.

It is called as

```
call HiggsBounds_input_SLHA(SLHAfilename)
```

where SLHAfilename is a variable of type character(len=100) and contains the name of the SLHA file (including the path to this file if it is not in the current working directory.)

1.4 Using SLHA input in the command-line version of HiggsBounds

The command-line is of the form:

```
./HiggsBounds <whichanalyses> SLHA <nHzero> <nHplus> <prefix>
```

The variable <prefix> is the full name of the SLHA file (including the path to this file if it is not in the current working directory.).

The HiggsBounds results are added to the SLHA file in the form a new block: HiggsBoundsResults. An example is shown in 2. Strings are wrapped with '||'.

Note that using the command-line version of HiggsBounds with SLHA input is not currently efficient for large parameter scans, since the experimental tables must be read in again for each SLHA file. (If this is a concern for you, please contact us).

As before, a key to the numbering scheme used to identify the channels and experimental analyses can be found in the `Key.dat` file.

```
Block HiggsBoundsInputHiggsCouplingsFermions
# For exact definitions of NormEffCoupSq see HiggsBounds manual
# ScalarNormEffCoupSq PseudoSNormEffCoupSq    NP    IP1      IP2      IP3 # Scalar, Pseudoscalar Normalised Effective Coupling Squared
     1.0000001E+00        1.0000101E+00        3     25        5        5 # h0-b-b eff. coupling^2, normalised to SM
     1.0000002E+00        1.0000102E+00        3     35        5        5 # HH-b-b eff. coupling^2, normalised to SM
     1.0000003E+00        1.0000103E+00        3     36        5        5 # A0-b-b eff. coupling^2, normalised to SM
#
     1.0000004E+00        1.0000104E+00        3     25        6        6 # h0-top-top eff. coupling^2, normalised to SM
     1.0000005E+00        1.0000105E+00        3     35        6        6 # HH-top-top eff. coupling^2, normalised to SM
     1.0000006E+00        1.0000106E+00        3     36        6        6 # A0-top-top eff. coupling^2, normalised to SM
#
     1.0000007E+00        1.0000107E+00        3     25       15       15 # h0-tau-tau eff. coupling^2, normalised to SM
     1.0000008E+00        1.0000108E+00        3     35       15       15 # HH-tau-tau eff. coupling^2, normalised to SM
     1.0000009E+00        1.0000109E+00        3     36       15       15 # A0-tau-tau eff. coupling^2, normalised to SM
#
Block HiggsBoundsInputHiggsCouplingsBosons
# For exact definitions of NormEffCoupSq see HiggsBounds manual
     1.0000010E+00     3     25       24       24 # h0-W-W effective coupling^2, normalised to SM
     1.0000011E+00     3     35       24       24 # HH-W-W effective coupling^2, normalised to SM
     1.0000012E+00     3     36       24       24 # A0-W-W effective coupling^2, normalised to SM
#
     1.0000013E+00     3     25       23       23 # h0-Z-Z effective coupling^2, normalised to SM
     1.0000014E+00     3     35       23       23 # HH-Z-Z effective coupling^2, normalised to SM
     1.0000015E+00     3     36       23       23 # A0-Z-Z effective coupling^2, normalised to SM
#
     1.0000016E+00     3     25       21       21 # h0-gluon-gluon effective coupling^2, normalised to SM
     1.0000017E+00     3     35       21       21 # HH-gluon-gluon effective coupling^2, normalised to SM
     1.0000018E+00     3     36       21       21 # A0-gluon-gluon effective coupling^2, normalised to SM
#
     1.0000019E+00     3     25       25       23 # h0-h0-Z effective coupling^2, normalised
     1.0000020E+00     3     25       35       23 # h0-HH-Z effective coupling^2, normalised
     1.0000021E+00     3     25       36       23 # h0-A0-Z effective coupling^2, normalised
     1.0000022E+00     3     35       35       23 # HH-HH-Z effective coupling^2, normalised
     1.0000023E+00     3     35       36       23 # HH-A0-Z effective coupling^2, normalised
     1.0000024E+00     3     36       36       23 # A0-A0-Z effective coupling^2, normalised
```

Fig. 1. *Examples of the Block HiggsBoundsInputHiggsCouplingsFermions and Block HiggsBoundsInputHiggsCouplingsBosons, which are required by HiggsBounds if using the SLHA input option.*

```
Block HiggsBoundsResults      # results from HiggsBounds http://www.ippp.dur.ac.uk/HiggsBounds
# HBresult   : scenario allowed flag (1: allowed, 0: excluded, -1: unphysical)
# chan id number: most sensitive channel (see below). chan=0 if no channel applies
# obsratio   : ratio [sig x BR]_model/[sig x BR]_limit (<1: allowed, >1: excluded)
# ncomb      : number of Higgs bosons combined in most sensitive channel
# Note that the HB channel id number varies depending on the HB version and setting "whichanalyses"
#
    0    2.0.0     ||LandT||            # version of HB used to produce these results,the HB setting "whichanalyses"
#
#CHANNELTYPE 1: channel with the highest statistical sensitivity
    1           1           1                  # channel id number
    1           2           0                  # HBresult
    1           3   23.531085611946065         # obsratio
    1           4           1                  # ncombined
    1           5 ||(ee)->(h1)Z->(b b-bar)Z   (hep-ex/0602042, table 14b (LEP))|| # text description of channel
```

Fig. 2. *Example of the Block HiggsBoundsResults.*