H3m Reference Manual (v1.1)

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Contents

1 Overview

This document describes the usage of the program `H3.m`, a `Mathematica` package for evaluating the mass of the light Higgs Boson within the minimal supersymmetric extension of the Standard Model (*MSSM*) to three-loop accuracy.

For details on the calculation and phenomenological applications, see the paper [6] (which you should also cite in case you use this code for a publication).

The results presented in Ref. [6] are based on `FeynHiggs` 2.6.5 which contains a bug in the *SUSY* Les Houches interface. This results in a numerical change of M_H of the order of $1\,\mathrm{GeV}$ already at one-loop order. The bug has been fixed in version 2.7.x.[1]

2 Frontend

The package provides a handful of functions for interaction with the user. These fall into two categories: functions for setting up the parameters, and functions for evaluating the Higgs mass.

2.1 Functions that set up or retrieve parameters

The parameters for the calculation are set using the SUSY Les Houches Accord (SLHA) interface [9]. One can either prepare a spectrum file and call H3GetSLHA to read it, or use H3SetSLHA, which prepares an SLHA input file, passes it to a spectrum generator to prepare a spectrum file which is then read using H3GetSLHA.

For even more convenience, there are the functions `H3SetSPS1a/2/3(m12)`, `H3SetSPS2(m12)`, `H3SetSPS3(m12)`, `H3SetSPS4/5()` `H3SetSPS7/8(lambda)`, `H3SetSPS9(m32)`, which call `H3SetSLHA` using parameters according to a benchmark scenario from the Snowmass Points and Slopes.

In each case, the function H3ChooseHH is called automatically to decide which mass hierarchy will be chosen for the calculation of M_h at the three-loop level, and the spectrum file is given to `FeynHiggs` for the two-loop calculation. In addition (if not suppressed by setting the options `mt2l` or `decSUSY`, resp. to `False`), TSIL [8, 7] is used to get the value of the top mass in the $\overline{\mathrm{DR}}$ scheme at the two-loop level, and decSUSY is used to get a precise value of α_s.

To speed things up, the generated spectrum files (as well as the values for the top mass and strong coupling) are cached on disk and re-used, unless the option `recycle` is set to `False`.

It is also possible to change the value of particular parameters by manipulating the list H3`Private`parameters, although in this case the changes are not passed to `FeynHiggs`, and one would have to call TSIL and/or decSUSY manually, if desired.

2.1.1 H3GetSLHA

Parse an SLHA [9] spectrum file and set the parameters for the calculation accordingly. Then, pass the file to `FeynHiggs`. Additionally, the $\overline{\mathrm{DR}}$ top mass and α_s are calculated within `SUSY-QCD`.

- Options:

    mt2l If True, compute the $\overline{\mathrm{DR}}$ top mass to two-loop accuracy in SUSY-QCD, using the TSIL library [8, 7].

    decSUSY If True, use the package decSUSY to compute α_s in the full theory to three-loop accuracy.

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[1]Thanks to Thomas Hahn for confirmation.

recycle If True, use the cache for values of the $\overline{\mathrm{DR}}$ top mass and α_s.

savepath The path to a directory where the cache should be stored (if `recycle` is set to True).

Additional options control the behaviour of `FeynHiggs` and should not be altered.

The spectrum file should contain at least the following data:

Block	Required Entries
SMINPUTS	2, 3, 4, 5, 6
GAUGE	1, 2, 3
HMIX	1, 2, 3
MSOFT	3, 41 – 49
AU	(3, 3)
YU	(3, 3)
MASS	36, 1000021,
	1000001 – 1000006,
	2000001-2000006
STOPMIX	(1, 1)

2.1.2 `H3SetSLHA`

Prepare an input file for SoftSUSY and call that program to create a spectrum file. This file, in turn, is passed to H3GetSLHA.

- Options: All options that apply to H3GetSLHA are passed to that function. In addition, there are the following options:

  spectGen This option governs which spectrum generator to use. Possible choices are "softsusy", "spheno", and "suspect".

  Model Select the model of SUSY breaking. So far, "msugra", "mgmsb", and "mamsb" are implemented. In addition, the benchmark scenarios from [3] are implemented and can be accessed by setting Model to "mhmax", "nomix", "gluophob" and "smallalpha".

  softsusytwoloop Either 1 (default) or 0. If 1, SoftSUSY uses full 2-loop running in the RGEs.

  mu The renormalisation scale at which the $\overline{\mathrm{DR}}$ parameters are evaluated.

  invalpha, GF, asmz, MZ, mb, Mt, mtau Standard Model input values.

- Options specific to `msugra`

  m0, m12, tanb, signmu, A0 Specify a point in the `msugra` parameter space. See [1, 2] for details.

- Options specific to `mgmsb`

  lambda, mmess, tanb, signmu, nmess Specify a point in the `mgmsb` parameter space. See [1, 2] for details.

- Options specific to `mamsb`

  m0, m32, tanb, signmu Specify a point in the `mamsb` parameter space. See [1, 2] for details.

- Options specific to the benchmark scenarios from [3]

  tanb, MA Set tan(beta) and the mass of the pseudoscalar Higgs.

2.1.3 `H3ChooseHH`

Automatically choose a mass hierarchy suitable for the current parameters. The hierarchies from which to choose are given in the list `H3'Private'H3HHList`. Hierarchies that do not fit the mass spectrum are discarded. For each of the remaining hierarchies, the Higgs mass is evaluated at the two-loop level, and the result is compared with the exact result. The hierarchy with the smallest deviation is chosen. This function is automatically called when parameters are being set using the SLHA interface.

2.1.4 `H3'Private'H3SetPar`

This routine is used internally to give values to specific parameters. It is possible for the user to use it directly, although care has to be taken to maintain a consistent spectrum. In particular, it will not be a good idea to use the routine H3m after modifying individual parameters, since H3m combines corrections parametrised by $\overline{\text{DR}}$ parameters with corrections given in terms on on-shell parameters, and the conversion between the two schemes will be spoiled.

The variable `H3'Private'parameters` contains a list of all parameters that are used by `H3.m`.

2.1.5 `H3GetSpectrum`

This function returns the values of the parameters that are relevant to the calculation of the Higgs mass. Most of the parameters are given in the $\overline{\text{DR}}$ scheme. Names containing "OS" indicate that the corresponding parameter is given in the on-shell scheme. The suffix "mod" is given to parameters in the modified $\overline{\text{DR}}$ scheme as described in [6]. All other parameters are given in the $\overline{\text{DR}}$ scheme.

2.2 Functions for calculating the Higgs mass

The calculation of the Higgs mass is performed by the function H3m, which can be called after the parameters have been set using the SLHA interface described above. Without giving any options, it just returns the value of mh using the mass hierarchy that has been chosen to minimise the error at two loops.

2.2.1 `H3m`

This routine performs the calculation of the Higgs mass. `FeynHiggs` is queried for the neutral Higgs mass matrix including corrections up to two loop order, using on-shell input parameters (masses of the top and the SUSY particles). Subsequently, the $\mathrm{O}(\alpha_t)$ and $\mathrm{O}(\alpha_t\,\alpha_s)$ contributions

are subtracted, to be added again expressed through parameters in the modified $\overline{\text{DR}}$ scheme described in [6]. This is neccessary in order to treat the corrections from the top/stop sector consistently, since the three-loop corrections are handled in the modified $\overline{\text{DR}}$ scheme.

The function returns a replacement rule that, when applied, assigns the Higgs mass to the symbol mh. By setting the option `tests`, one can increase the verbosity.

- Options

    HH Governs the choice of the mass hierarchy according to which the three-loop terms are expanded. If set to "auto", the optimal choice as determined by H3ChooseHH is used. Alternatively, one can choose the name of a specific hierarchy to force evaluation according to this hierarchy.

    upcut A list of lists of the form {DELTA, NN}. In the evaluation of the three-loop corrections, terms of Order > DELTA^{NN} are neglected. This is useful to get a feeling for the convergence in the expansion in the mass hierarchies (as in Figure 9 and Table 3 of [6]).

    tests List of strings, where every string present causes the output to be more verbose.

        – Possible strings are

            "FH2l" Give the `FeynHiggs` result, without any subtractions or additions. This will be called `mhFL1l` in the output.

            "2lCompareWithDSZ" Make a comparison at the two-loop level between the exact calculation of [4] and the expansion in the ratios of masses. Output will feature `mh2lDSZ`, `mh2lHH` and `relerr2l`, the last of which is the relative error (in %) due to the expansion at two loops.

            "1lCompareWithDSZ" as above, but with every 2 replaced by a 1.

            "expandAll" Instead of using the exact 1- and 2-loop results, use the expansion in 1 through 3 loops. This check returns `mhHH`.

            "showSpectrum" Give the value of the masses of the superpartners, the top mass, α_s, etc. in the output.

            "all" Do all of the above checks.

2.2.2 H3mhmt4

Calculates Higgs mass taking into account only the mt^4 corrections.

Since `FeynHiggs` is not needed for this, this function does not rely on the conversion of on-shell and $\overline{\text{DR}}$ corrections. This allows the user to modify specific parameters in the $\overline{\text{DR}}$ scheme (via H3SetPar) without worrying about the corresponding values in the on-shell scheme. This feature has been used, for example, to produce figs. 2, 3 and 11 in [6].

2.2.3 `H3SchemeCompare`

This routine compares the predictions for the Higgs mass using $\overline{\text{DR}}$ and on-shell input parameters. Since the on-shell result from [5] assumes a degenerate *SUSY* mass spectrum, in this function a degenerate spectrum is assumed also in the $\overline{\text{DR}}$ calculation.

2.2.4 `H3ExpansionError`

This function gives an estimate on the stability of the expansion in mass ratios at the three-loop level. It does so by comparing the Higgs mass calculated using all available terms with the value that results if the highest terms in the expansion are dropped. See fig. 9 in [6] for an example.

3 Setup

3.1 Prerequisites

`H3.m` is a `Mathematica` package and thus needs `Mathematica`. It has been tested with versions 7 and 8. The one- and two-loop corrections from other sectors of the *MSSM* are evaluated using the `Mathematica` version of `FeynHiggs`, `MFeynHiggs`. Please note that version 2.8.4 or later of `FeynHiggs` is required.

To use the function H3SetSLHA (or any of the `H3SetSPS` functions), you will need a spectrum generator. Currently, `softsusy`, `SPheno` ans `SuSpect` are supported by H3SetSLHA. Of course, you do not have to use this interface and could rely, instead, on H3GetSLHA to read in spectrum files prepared by any other means.

3.2 Installation procedure

H3m comes with an `autoconf` generated `configure` script, which searches for the required programs and compilers. Make sure that the executable files

```
MFeynHiggs (version 2.7.x)
```

```
softpoint.x  OR
SPheno       OR
suspect2
```

```
math
```

are in a directory that is in your `$PATH` variable. Then, unpack the file `H3.tar.gz` via

```
tar xzvf H3.tar.gz
```

which will create a directory H3. Go to this directory and execute `configure` and `make`:

```
cd H3
./configure
make
make install
```

To install to some custom directory, you might want to use the `-prefix` option of `configure`:

```
./configure --prefix=/path/you/want/to/install/to
make && make install
```

3.2.1 Installation on 32bit architecture

The makefile assumes a 64bit architecture. To install on 32bit machines, you have to modify the file mh2l/makefile. Change the line

```
   $(CC) -o $@ -I$(INCDIR) -L$(INCDIR) -lML64i3 -lm -lpthread -lrt
-lstdc++ $(libs) -lm -shared-libgcc $^ -Wl,-rpath,$(INCDIR)
```

to

```
   $(CC) -o $@ -I$(INCDIR) -L$(INCDIR) -lML32i3 -lm -lpthread -lrt
-lstdc++ $(libs) -lm -shared-libgcc $^ -Wl,-rpath,$(INCDIR)
```

3.3 Changes

- v1.1: adapted to the new FeynHiggs version 2.8.4.

3.4 Acknowledgements

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