

Tutorial: Higgs mass in FlexibleSUSY

Thomas Kwasnitza

5th November 2020



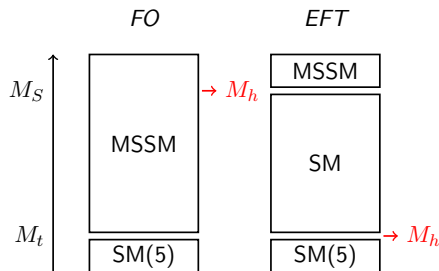
INSTITUTE OF
NUCLEAR AND
PARTICLE PHYSICS



Contents

- 1 Review of the existing codes in the MSSM
- 2 Building the spectrum generators
- 3 1D parameter scans

Approaches to predict M_h



- see review talk on M_h calculations by Milada Mühlleitner
- see slides of Wojciech Kotlarski for additional details on FlexibleSUSY

	low M_S $M_S \lesssim 1 \text{ TeV}$	high M_S $M_S \gtrsim 1 \text{ TeV}$
fixed-order (FO)	✓	✗
EFT	✗	✓
hybrid FlexibleEFTHiggs (FEFT)	✓	✓

Review of the existing codes in the MSSM

	low M_S $M_S \lesssim 1 \text{ TeV}$	high M_S $M_S \gtrsim 1 \text{ TeV}$
FO	✓	✗
EFT	✗	✓
FEFT	✓	✓

- **FO**: N³LO diagrammatic calculation M_h at $\mathcal{O}(1\ell + v^2(y_t^2 + y_b^2)^2 g_3^2 + v^2(y_t^2 + y_b^2 + y_\tau^2)^3 + v^2 y_t^4 g_3^4)$
[Harlander1708.05720],[Athron1710.03760]
- **EFT**: N³LL calculation of $\Delta\lambda$ at $\mathcal{O}(1\ell + (y_t^2 + y_b^2)^2 g_3^2 + (y_t^2 + y_b^2 + y_\tau^2)^3 + y_t^4 g_3^4)$
[Athron1710.03760],[Harlander1807.03509]
- **FEFT**: NLL + NLO hybrid calculation $\Delta\lambda$ at $\mathcal{O}(1\ell)$ and terms of $\mathcal{O}(v/M_S)$: [Athron1609.00371],[Athron1710.03760]
release coming soon: N³LL + N³LO [2003.04639], [20xx.xxxxx]

Fixed-order N³LO

- Pre-generated MSSM models:
 - ▶ **NUHMSSMNoFVHimalaya** (μ and $B\mu$ are fixed by EWSB)
 - ▶ **MSSMNoFVHimalaya** ($m_{H_u}^2$ and $m_{H_d}^2$ are fixed by EWSB)
 - ▶ **MSSMNoFVatMGUTHimalaya** (same as **MSSMNoFVHimalaya**, input scale is the input scale is the GUT scale)
- Requires Himalaya library ($v \geq 2.0.1$):
 - ▶ Can be downloaded as compressed package from <https://github.com/Himalaya-Library/Himalaya>
 - ▶ Building Himalaya library:

```
$ cd $HIMALAYA_PATH
$ mkdir build
$ cd build
$ cmake ..
$ make -j8
```

- Create the spectrum generator NUHMSSMNoFVHimalaya (with HIMALAYA v.4.0.0)

```
$ ./createmodel --name=NUHMSSMNoFVHimalaya -f
$ ./configure
--with-himalaya-incdir=$HIMALAYA_PATH/include/himalaya
--with-himalaya-libdir=$HIMALAYA_PATH/build
--with-models=NUHMSSMNoFVHimalaya
$ make -j8
```

- Pre-generated MSSM model with SM EFT below M_S : HSSUSY
- Required libraries
 - ▶ Himalaya library ($v \geq 2.0.1$)
 - ▶ tsil: <https://www.niu.edu/spmartin/tsil/>
- Building tsil:
 - ▶ `$ cd $TSIL_PATH`
open Makefile and edit line 22
 `TSIL_OPT = -O3 -funroll-loops`
 →`TSIL_OPT = -O3 -funroll-loops -fPIC`
 - ▶ `$ make -j8`

- Create the spectrum generator HSSUSY

```
$ ./createmodel --name=HSSUSY -f
```

```
$ ./configure
```

```
--with-himalaya-incdir=$HIMALAYA_PATH/include/himalaya
```

```
--with-himalaya-libdir=$HIMALAYA_PATH/build
```

```
--with-tsil-incdir=$TSIL_PATH
```

```
--with-tsil-libdir=$TSIL_PATH
```

```
--with-models=HSSUSY
```

```
$ make -j8
```


- Create the spectrum generator MSSMEFTHiggs (with HIMALAYA v.4.0.0 for upcoming calculation at $N^3\text{LO} + N^3\text{LO}$)

```
$ ./createmodel --name=MSSMEFTHiggs -f
$ ./configure --with-models=MSSMEFTHiggs
  --with-tsil-incdir=$TSIL_PATH
  --with-tsil-libdir=$TSIL_PATH
$ make -j8
```

Run the spectrum generator for a single parameter point

- The executable is in the directory
FSPATH/models/MODEL/run_MODEL.x
- The spectrum generator is evaluated at one parameter point as

```
$ ./models/HSSUSY/run_HSSUSY.x  
--slha-input-file=model_files/HSSUSY/LesHouches.in.HSSUSY  
--slha-output-file=LesHouches.out.HSSUSY
```

1D parameter scans

- Scan script is included in the FS Package
 - ▶ `FSPATH/utils/scan-slha.sh`
- can be used for a scan of a single entry in the LesHouches input file
- E.g. M_h scan for $t_\beta \in [1, 50]$ for the EFT calculation 30 with steps

```
$ ./utils/scan-slha.sh
--spectrum-generator=models/HSSUSY/run_HSSUSY.x
--slha-input-file=model_files/HSSUSY/LesHouches.in.HSSUSY
--scan-range=EXTPAR[25]=1~50:30
--output=EXTPAR[25],MASS[25] | tee Mh_scan_tb.dat
```

1D parameter scans

- M_{SUSY} -scan

copy `scan_ms.sh` and `plot_ms_scan.py` in the directory of FlexibleSUSY-2.5.0

```
$ sh scan_ms.sh | tee ms_scan_xt0_tb20.dat
```

```
$ python plot_ms_scan.py
```

- (if the output of the scan contains dashes only, try to install `gawk`)