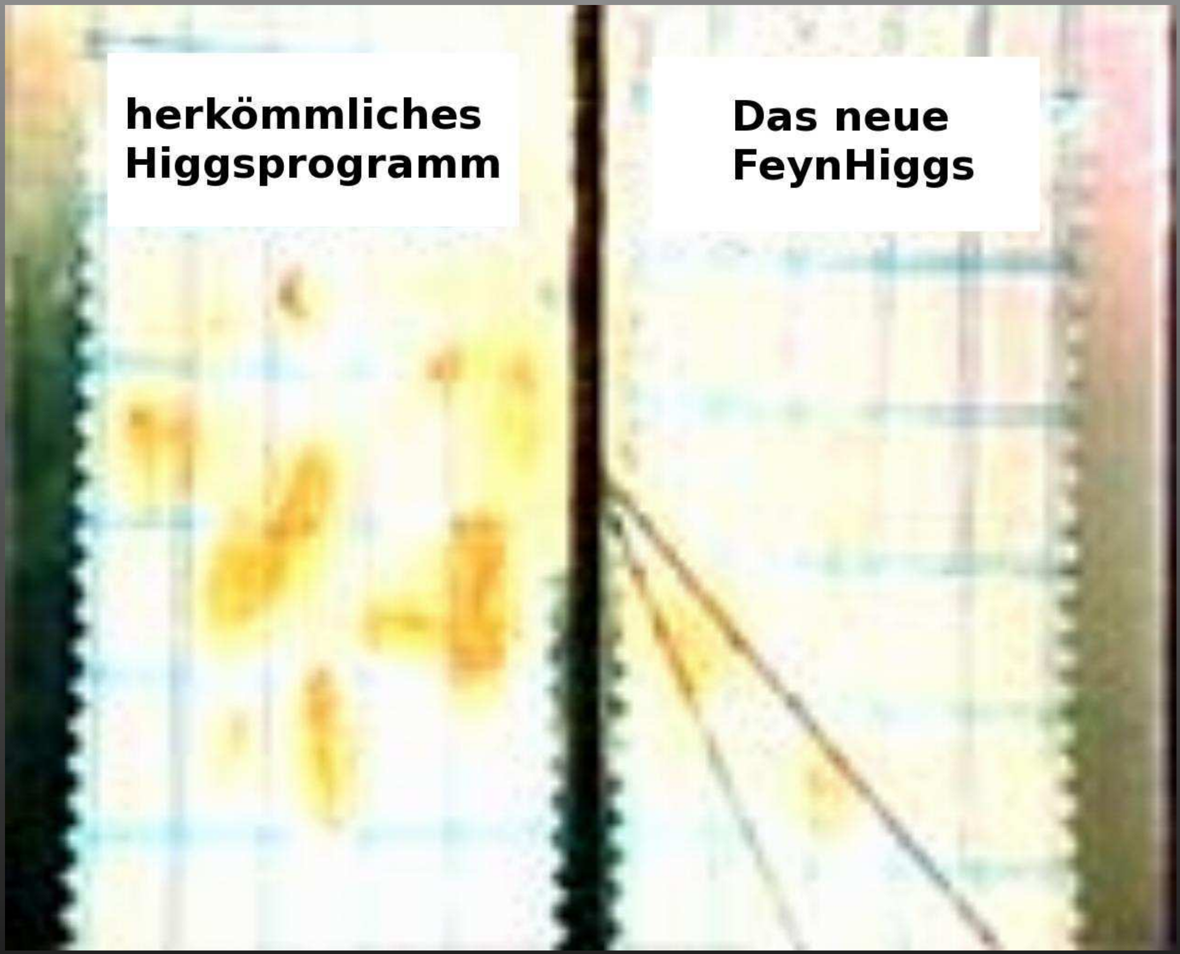
FeynHiggs 2.7



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Executive Summary

- $h_i \to f_j \bar{f}_k$ at one-loop precision.
- Improved treatment of NMFV corrections (sfermion section completely revamped).
- Better computation of Δ_b.
- Improved ggh production cross-section estimate.
- Inclusion of ΔM_s at one-loop level in NMFV.
- Many small additions and bug-fixes.

The MSSM Higgs Sector

$$H_1 = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(\phi_1 + \mathrm{i}\chi_1) \\ \phi_1^- \end{pmatrix}, \quad H_2 = \mathrm{e}^{\mathrm{i}\xi} \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}(\phi_2 + \mathrm{i}\chi_2) \end{pmatrix}$$

Higgs Potential:

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\varepsilon_{\alpha\beta} H_1^\alpha H_2^\beta + \text{h.c.}) + \frac{g_1^2 + g_2^2}{8} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \frac{g_2^2}{2} |H_1 \bar{H}_2|^2$$

- **Five physical states:** h, H, A, H^+, H^-.
- **Input parameters:** $\tan\beta = v_1/v_2$, M_A **or** $M_{H^\pm}$.
- **Unlike SM, MSSM predicts** M_h **(cf. Gauge Couplings).**
- $M_h < M_Z$ **at tree level, excluded by LEP searches.**

Complex Parameters

The Higgs potential contains two complex phases ξ, $\arg(m_{12}^2)$.
These can however be rotated away: **No $\not{CP}$ at tree level.**

$\not{CP}$ effects are induced by **complex parameters that enter via loop corrections:**

- μ - Higgsino mass parameter,
- $A_{t,b,\tau}$ - trilinear couplings,
- $M_{1,2,3}$ - gaugino mass parameters.

They make $\hat{\Sigma}_{hA}, \hat{\Sigma}_{HA} \neq 0$ and induce mixing between h, H, and A:

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \begin{pmatrix} U_{11} & U_{12} & U_{13} \\ U_{21} & U_{22} & U_{23} \\ U_{31} & U_{32} & U_{33} \end{pmatrix} \begin{pmatrix} h \\ H \\ A \end{pmatrix}$$

Higgs Mass Matrix

The Higgs mass matrix has the form

$$\mathcal{M}^2 = \begin{pmatrix} q^2 - M_h^2 + \hat{\Sigma}_{hh} & \hat{\Sigma}_{hH} & \hat{\Sigma}_{hA} \\ \hat{\Sigma}_{Hh} & q^2 - M_H^2 + \hat{\Sigma}_{HH} & \hat{\Sigma}_{HA} \\ \hat{\Sigma}_{Ah} & \hat{\Sigma}_{AH} & q^2 - M_A^2 + \hat{\Sigma}_{AA} \end{pmatrix}$$

The physical Higgs states h_1, h_2, h_3 diagonalize this matrix:

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = U \begin{pmatrix} h \\ H \\ A \end{pmatrix} \quad \textbf{where} \quad U\mathcal{M}^2 U^\dagger = \begin{pmatrix} M_{h_1}^2 & 0 & 0 \\ 0 & M_{h_2}^2 & 0 \\ 0 & 0 & M_{h_3}^2 \end{pmatrix}$$

Observe: $\mathcal{M}^2$ is symmetric but not Hermitian.

Corrections included in FeynHiggs 2.7

$$\begin{pmatrix} q^2 - M_h^2 + \hat{\Sigma}_{hh}^{\bullet\bullet\bullet} & \hat{\Sigma}_{hH}^{\bullet\bullet\bullet} & \hat{\Sigma}_{hA}^{\bullet\bullet} \\ \hat{\Sigma}_{Hh}^{\bullet\bullet\bullet} & q^2 - M_H^2 + \hat{\Sigma}_{HH}^{\bullet\bullet\bullet} & \hat{\Sigma}_{HA}^{\bullet\bullet} \\ \hat{\Sigma}_{Ah}^{\bullet\bullet} & \hat{\Sigma}_{AH}^{\bullet\bullet} & q^2 - M_A^2 + \hat{\Sigma}_{AA}^{\bullet\bullet} \end{pmatrix}, \quad \hat{\Sigma}_{H^+H^-}^{\bullet\bullet}$$

- **Leading $\mathcal{O}(\alpha_s\alpha_t)$ two-loop corrections in the cMSSM.**

  Heinemeyer, Hollik, Rzehak, Weiglein 2007

- **Leading $\mathcal{O}(\alpha_t^2)$ + subleading $\mathcal{O}(\alpha_s\alpha_b, \alpha_t\alpha_b, \alpha_b^2)$ two-loop corrections in the rMSSM (phases only partially included).**

  Degrassi, Slavich, Zwirner 2001
  Brignole, Degrassi, Slavich, Zwirner 2001, 02
  Dedes, Degrassi, Slavich 2003

- **Full one-loop evaluation (all phases, q^2 dependence).**

  Frank, Heinemeyer, Hollik, Weiglein 2002

Treatment of Phases

A flag controls the treatment of phases in the part of the two-loop corrections known only in the rMSSM so far:

- all corrections ($\alpha_s\alpha_t$, $\alpha_s\alpha_b$, $\alpha_t\alpha_t$, $\alpha_t\alpha_b$) in the rMSSM,
- only the cMSSM $\alpha_s\alpha_t$ corrections,
- the cMSSM $\alpha_s\alpha_t$ corrections combined with the remaining corrections in the rMSSM, truncated in the phases,
- the cMSSM $\alpha_s\alpha_t$ corrections combined with the remaining corrections in the rMSSM, interpolated in the phases [default].
  New in 2.7: choice of interpolation in A_t/X_t, A_b/X_b.

FeynHiggs thus not only has the most precise evaluation of the Higgs masses in the cMSSM available to date, but also a method to obtain a reasonably objective estimate of the uncertainties due to the rMSSM-only parts.

Masses

FeynHiggs performs a numerical search for the complex roots of $\det \mathcal{M}^2(q^2)$.

The Higgs masses are thus determined as the real parts of the complex poles of the propagator.

Complex contributions to the Higgs mass matrix ($\mathrm{Im}\,\hat\Sigma$) are taken into account.

The diagonalization routines are available as a stand-alone package: http://feynarts.de/diag

Hahn 2006

Mixings

FeynHiggs returns two different 'mixing' matrices.

- `UHiggs` is a 'true' mixing matrix in the sense of being unitary and hence preserving probabilities. This matrix must be used **for internal Higgs bosons.**

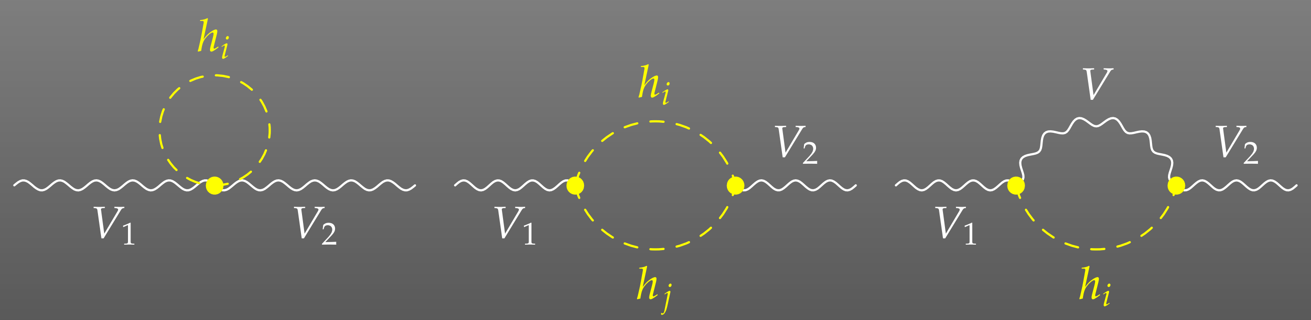
  Note: To obtain a unitary matrix, it is mathematically a necessity that $\mathcal{M}^2$ has no imaginary parts - making it Hermitian. This of course constrains the achievable quality of approximation.

- `ZHiggs` is a matrix of Z-factors. It guarantees on-shell properties **for external Higgs bosons.**

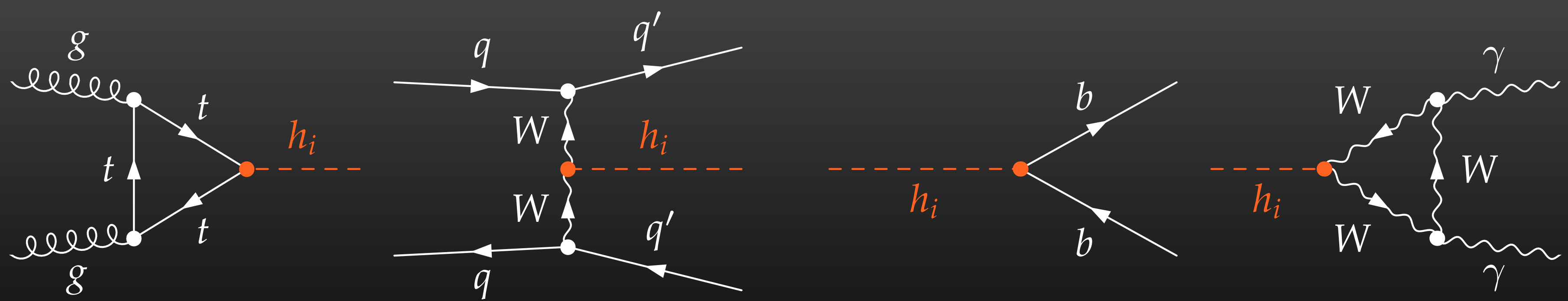
It is important to understand that `ZHiggs` and `UHiggs` are two objects with physically and mathematically distinct properties. Neither is universally 'better' than the other.

Examples of Internal and External Higgs Bosons

Internal Higgs bosons:



External Higgs bosons (production and decay):



UHiggs

FeynHiggs offers two approximations for `UHiggs`:

- q^2 **on-shell**

  meaning $\hat\Sigma_{ii}(q^2 = m_i^2)$,

  $\hat\Sigma_{ij}(q^2 = \frac{1}{2}(m_i^2 + m_j^2))$.

- $q^2 = 0$

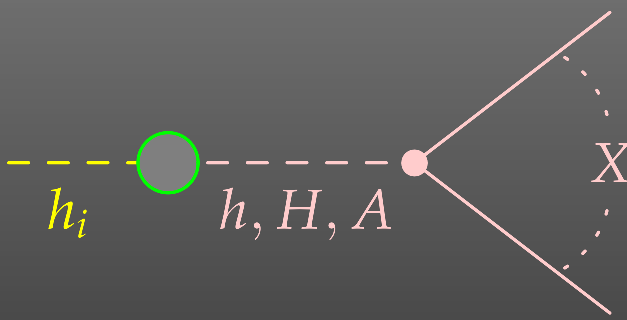
  In this limit, `UHiggs` corresponds to the effective potential approach and coincides with `ZHiggs`$(q^2 = 0)$.

  In the absence of ~~CP~~ effects (i.e. 2×2 mixing only), this is identical to the α_{eff} description.

ZHiggs

`ZHiggs` **is engineered to deliver the correct on-shell properties of an external Higgs boson, but is not necessarily unitary.**

$$\Gamma_{h_1} = \sqrt{Z_h}(\Gamma_h + Z_{hH}\Gamma_H + Z_{hA}\Gamma_A)$$
$$\Gamma_{h_2} = \sqrt{Z_H}(Z_{Hh}\Gamma_h + \Gamma_H + Z_{HA}\Gamma_A)$$
$$\Gamma_{h_3} = \sqrt{Z_A}(Z_{Ah}\Gamma_h + Z_{AH}\Gamma_H + \Gamma_A)$$



- $\Gamma_{h,H,A}$ **- amplitude for** $h, H, A \to X$**,**
- $\sqrt{Z_h}$ **- sets residuum of the external Higgs boson to 1,**
- Z_{hH}**,** Z_{hA} **- describe the transition** $h \to H, A$**.**

ZHiggs

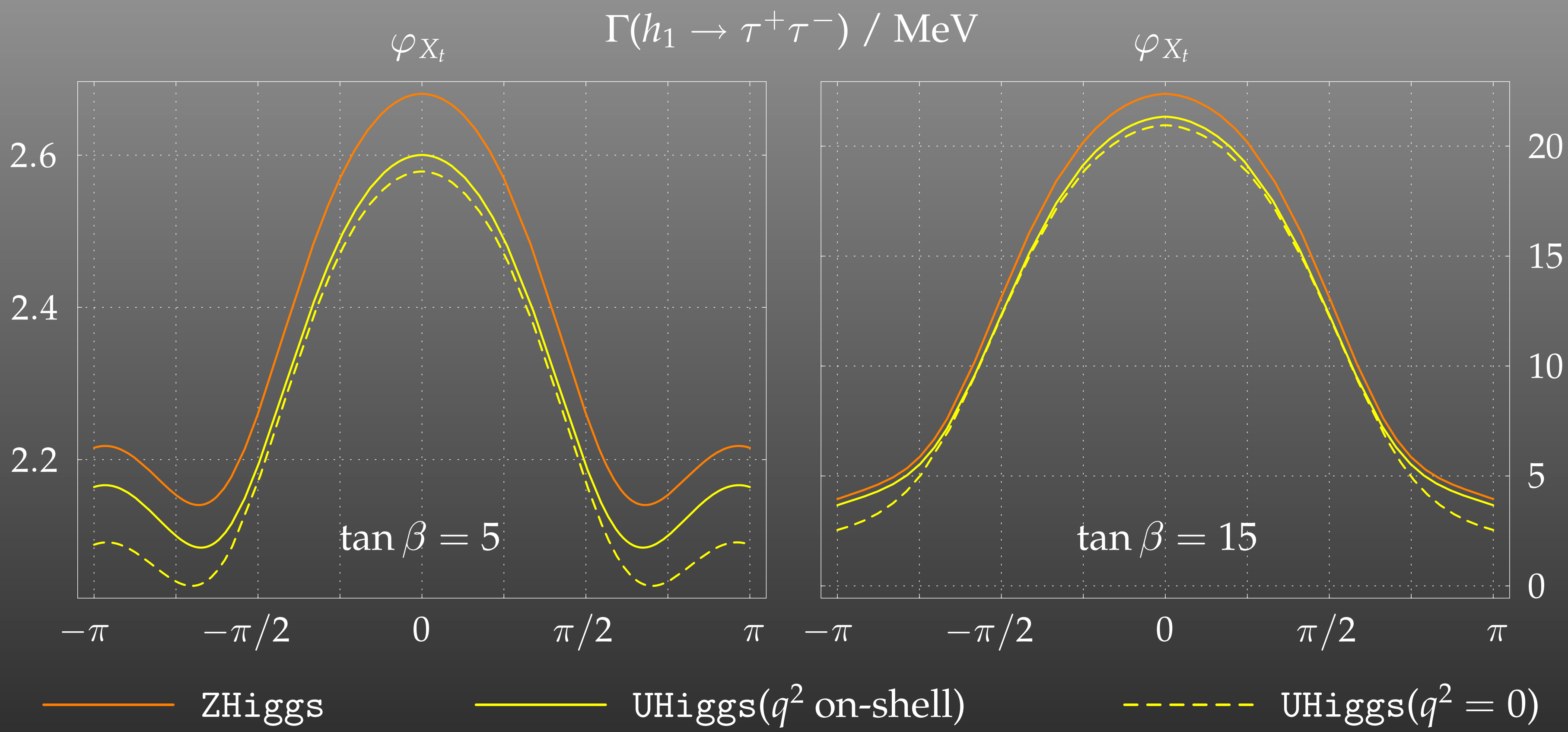
For convenience, the Z factors can be arranged in matrix form:

$$\texttt{ZHiggs} = \begin{pmatrix} \sqrt{Z_h} & \sqrt{Z_h}\, Z_{hH} & \sqrt{Z_h}\, Z_{hA} \\ \sqrt{Z_H}\, Z_{Hh} & \sqrt{Z_H} & \sqrt{Z_H}\, Z_{HA} \\ \sqrt{Z_A}\, Z_{Ah} & \sqrt{Z_A}\, Z_{AH} & \sqrt{Z_A} \end{pmatrix}$$

In this guise, `ZHiggs` can be used very much like `UHiggs`, even though its theoretical origin is quite different.

Reassuringly, `ZHiggs` and `UHiggs` coincide in the limit $q^2 = 0$.

Phenomenological Effects



[$M_{\text{SUSY}} = M_3 = M_2 = 500$ GeV, $\mu = 1000$ GeV, $M_{H^+} = 150$ GeV, $X_t = 700\, e^{i\varphi_{X_t}}$ GeV]

UHiggs(q^2 on-shell) **gives results closer to the full result than** UHiggs($q^2 = 0$) **with deviations at the few-percent level.**

Mixing Matrix Overview

- **Internal** Higgs boson: use `UHiggs`.
  Two approximations:
  - q^2 on-shell,
  - $q^2 = 0$ = effective potential approximation.
- **External** Higgs boson: use `ZHiggs`.

Choice of mixing matrices in all Higgs production and decay channels through `FHSelectUZ` (default: `ZHiggs`).

Non-Minimal Flavour Violation

In NMFV, the sfermion flavours are allowed to mix with each other, i.e. the mixing is 6×6 rather than 2×2:

NMFV	MFV	NMFV	MFV
$\tilde u_i = R^{\rm u}_{ij} \begin{pmatrix} \tilde u_L \\ \tilde c_L \\ \tilde t_L \\ \tilde u_R \\ \tilde c_R \\ \tilde t_R \end{pmatrix}_j$	$\tilde u_i = U^{\rm u}_{ij} \begin{pmatrix} \tilde u_L \\ \tilde u_R \end{pmatrix}_j$ $\tilde c_i = U^{\rm c}_{ij} \begin{pmatrix} \tilde c_L \\ \tilde c_R \end{pmatrix}_j$ $\tilde t_i = U^{\rm t}_{ij} \begin{pmatrix} \tilde t_L \\ \tilde t_R \end{pmatrix}_j$	$\tilde d_i = R^{\rm d}_{ij} \begin{pmatrix} \tilde d_L \\ \tilde s_L \\ \tilde b_L \\ \tilde d_R \\ \tilde s_R \\ \tilde b_R \end{pmatrix}_j$	$\tilde d_i = U^{\rm d}_{ij} \begin{pmatrix} \tilde d_L \\ \tilde d_R \end{pmatrix}_j$ $\tilde s_i = U^{\rm s}_{ij} \begin{pmatrix} \tilde s_L \\ \tilde s_R \end{pmatrix}_j$ $\tilde b_i = U^{\rm b}_{ij} \begin{pmatrix} \tilde b_L \\ \tilde b_R \end{pmatrix}_j$

Technical remark: FeynHiggs 2.7 keeps the MFV arrays U exactly ‘on top’ of the NMFV R ones.

Non-Minimal Flavour Violation

The mixing matrices R diagonalize the mass matrices

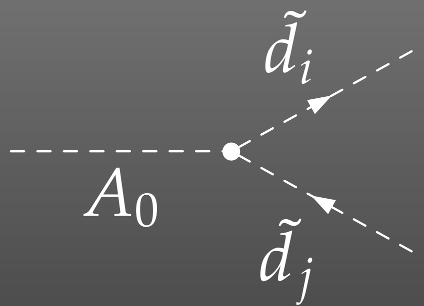
$$M^2_{u,d} = \left(\begin{array}{ccc|ccc} M^2_{\tilde L,i} & 0 & 0 & m_i X_i^* & 0 & 0 \\ 0 & M^2_{\tilde L,j} & 0 & 0 & m_j X_j^* & 0 \\ 0 & 0 & M^2_{\tilde L,k} & 0 & 0 & m_k X_k^* \\ \hline m_i X_i & 0 & 0 & M^2_{\tilde R,i} & 0 & 0 \\ 0 & m_j X_j & 0 & 0 & M^2_{\tilde R,j} & 0 \\ 0 & 0 & m_k X_k & 0 & 0 & M^2_{\tilde R,k} \end{array}\right) + \Delta_{u,d}$$

$$M^2_{\tilde L,q} = M^2_{\tilde Q,q} + m_q^2 + \cos 2\beta\,(T_3^q - Q_q s_W^2) m_Z^2 \qquad X_q = A_q - \mu^* \tan^{-2T_3^q}\beta$$

$$M^2_{\tilde R,q} = M^2_{\tilde U/\tilde D,q} + m_q^2 + \cos 2\beta\, Q_q s_W^2 m_Z^2$$

NMFV Effects

The most immediately notable effect comes from the LR(RL) sector, as the A^f_{ij} enter the couplings directly, e.g.



$$\propto \sum_{g,g'} \Big[m_{d_{g'}} R^{d*}_{i,g+3} R^{d}_{j,g'} (\delta_{gg'} \mu + A^{d*}_{g'g} \tan\beta) - m_{d_g} R^{d*}_{i,g} R^{d}_{j,g'+3} (\delta_{gg'} \mu^* + A^{d}_{gg'} \tan\beta) \Big]$$

This enters the Higgs masses through the A_0 self-energy and can lead to sizable effects.

Main constraints from low-energy observables.
Currently included in FeynHiggs are $b \to s\gamma$ and ΔM_s, both at one-loop including NMFV effects, with more to follow.

$gg \to h$ Production Cross-Section

SM estimate: NNLL prediction

de Florian, Grazzini 2009 · Anastasiou, Boughezal, Petriello 2009

MSSM estimate in effective-coupling approximation, i.e. multiply parts of the amplitude with correction factors:

$$\mathcal{A}^{\text{MSSM}} = c_t^{\text{NLO}} c_t^{\text{NNLO}} \mathcal{A}_t^{\text{MSSM,LO}} + c_{b,r} \operatorname{Re} \mathcal{A}_b^{\text{MSSM,LO}} + c_{b,i} \operatorname{Im} \mathcal{A}_b^{\text{MSSM,LO}} + c_{\tilde f} \mathcal{A}_{\tilde f}^{\text{MSSM,LO}} + \mathcal{A}_{\text{rest}}^{\text{MSSM,LO}},$$

$$\mathcal{A}^{\text{SM}} = c_t^{\text{NLO}} \mathcal{A}_t^{\text{SM,LO}} + c_{b,r} \operatorname{Re} \mathcal{A}_b^{\text{SM,LO}} + c_{b,i} \operatorname{Im} \mathcal{A}_b^{\text{SM,LO}} + \mathcal{A}_{\text{rest}}^{\text{SM,LO}},$$

$$\sigma^{\text{MSSM}} = \frac{|\mathcal{A}^{\text{MSSM}}|^2}{|\mathcal{A}^{\text{SM}}|^2} \sigma^{\text{SM,NLO}}.$$

Bonciani, Degrassi, Vicini 2007 · Aglietti, Bonciani, Degrassi, Vicini 2007

Dedes, Slavich 2003 · Dedes, Degrassi, Slavich 2003

Higgs Decays

The Higgs decays to fermions, $h_i \to f_j \bar{f}_k$ **are now available at one-loop precision.**

Weiglein, Williams 2007

The real gluon (photon) which cancels the IR pole is treated fully inclusive.

Braaten, Leveille 1980

The (phenomenologically important) resummed Δ_b corrections are still taken into account, with the corresponding one-loop contribution subtracted to prevent double counting.

Benchmark Scenarios

FeynHiggs has long included Benchmark Scenarios which are useful in the search for the MSSM Higgs bosons:

- Vary only M_A and $\tan\beta$,
- Keep all other SUSY parameters fixed.

$m_h^{\max}$ scenario
Yields conservative $\tan\beta$ exclusion bounds ($X_t = 2\,M_{\text{SUSY}}$).

gluophobic Higgs scenario
Looks at a small hgg coupling, such that a main LHC production mode vanishes.

no-mixing scenario
No mixing in the scalar top sector ($X_t = 0$).

small α_{eff} scenario
Explores $\alpha_{\text{eff}} \to 0$ where the $hb\bar b$ coupling $\sim \sin\alpha_{\text{eff}}/\cos\beta$ and thus a main decay mode and important search channel vanishes.

Carena, Heinemeyer, Wagner, Weiglein 2002

But: constraints such as CDM so far ignored.
Wanted: M_A-$\tan\beta$ planes in agreement with CDM.

Parameter Planes

Moreover, models like the NUHM* introduce **non-trivial relations between parameters,** which thus cannot be scanned naively by independent loops.

FeynHiggs offers the **Parameter Table** format to deal with such cases.

*Non-universal Higgs mass model:
assumes no unification of sfermion and Higgs parameters at the GUT scale.

Parameter Tables

Input parameters can either be given in an input file (as before) or interpolated from a table, in almost any mixture.

The table format is pretty straightforward:

```
MT      MSusy  MA0    TB    At      MUE ...
171.4   500    200    5     1000    761
171.4   500    210    5     1000    753
...
171.4   500    200    6     1000    742
171.4   500    210    6     1000    735
```

For **two given inputs** (typically M_A and $\tan\beta$) the four **neighbouring grid points** are searched in the table and the other parameters are **interpolated** from those points.
An error is returned if the inputs fall outside of the table boundaries (i.e. no extrapolation).

Tables and Records

Four predefined **NUHM M_A-$\tan\beta$ planes** can be downloaded from **feynhiggs.de.**

Definition of new planes by the user is possible.

The Table is actually embedded in the concept of the **FeynHiggs Record.** This is a data type which captures the entire content of a FeynHiggs parameter file.

Using a Record, the programmer can process FeynHiggs parameter files independently of the frontend.

Output of FeynHiggs 2.7

- `FHHiggsCorr` - **All Higgs-boson masses and mixings:** M_{h_1}, M_{h_2}, M_{h_3}, $M_{H^\pm}$, $\alpha_{\rm eff}$, `UHiggs`, `ZHiggs`, ...
- `FHUncertainties` - **Uncertainties of masses and mixings.**
- `FHCouplings`
  - **Couplings and Branching Ratios for the channels**

    $$h_{1,2,3} \to f\bar{f}', \gamma\gamma, ZZ^*, WW^*, gg \qquad H^\pm \to f\bar{f}' \qquad t \to W^+ b$$
    $$h_i Z^*, h_i h_j, H^+H^- \qquad h_i W^{\pm *} \qquad H^+ b$$
    $$\tilde{f}_i \tilde{f}_j, \qquad \tilde{f}_i \tilde{f}'_j,$$
    $$\tilde{\chi}_i^\pm \tilde{\chi}_j^\pm, \tilde{\chi}_i^0 \tilde{\chi}_j^0 \qquad \tilde{\chi}_i^0 \tilde{\chi}_j^\pm$$
  - **Branching Ratios of an SM Higgs with mass M_{h_i}:**

    $$h^{\rm SM}_{1,2,3} \to f\bar{f}, \gamma\gamma, ZZ^*, WW^*, gg$$

Output of FeynHiggs 2.7

- `FHHiggsProd` - **Higgs production-channel cross-sections:** **(SM: most up-to-date, MSSM: effective coupling approximation)**
  - $gg \to h_i$ - gluon fusion.
  - $WW \to h_i$, $ZZ \to h_i$ - gauge-boson fusion.
  - $W \to Wh_i$, $Z \to Zh_i$ - Higgs-strahlung.
  - $b\bar{b} \to b\bar{b}h_i$ - Yukawa process.
  - $b\bar{b} \to b\bar{b}h_i,\, h_i \to b\bar{b}$, one b tagged.
  - $t\bar{t} \to t\bar{t}h_i$ - Yukawa process.

Note: Not all are available for $\sqrt{s} \neq$ 2, 14 TeV at present.

Output of FeynHiggs 2.7

- FHConstraints - **Electroweak precision observables:**
  - $\Delta\rho$
    at $\mathcal{O}(\alpha, \alpha\alpha_s)$ including NMFV effects.
  - M_W, s_w^{eff}
    via SM formula + $\Delta\rho$.
  - $(g_\mu - 2)_{\text{SUSY}}$
    full one-, leading/subleading two-loop SUSY corrections.
    Heinemeyer, Stöckinger, Weiglein 2004
  - **EDMs of electron (Th), neutron, Hg.**
- FHFlavour - **Flavour observables:**
  - $\text{BR}(b \to s\gamma)$
    Hahn, Hollik, Illana, Peñaranda 2006
  - ΔM_s
    Hahn, Illana 2009

Download and Build

- Get the FeynHiggs tar file from feynhiggs.de.
- Unpack and configure:

```
tar xfz FeynHiggs-2.7.2.tar.gz
cd FeynHiggs-2.7.2
./configure
```

- Type make to build the Fortran/C++ part only.
  Type make all to build also the Mathematica part.
  Build takes about 75 sec on a Macbook Air.
- Type make install to install the package.
- Type make clean to remove unnecessary files.

Build tested on Linux, Tru64 Unix, Mac OS, Windows (Cygwin).

Usage

Four operation modes:

- **Library Mode:** Invoke the FeynHiggs routines from a Fortran or C/C++ program linked with `libFH.a`.
- **Command-line Mode:** Process parameter files in FeynHiggs or SLHA format at the shell prompt or in scripts with the standalone executable `FeynHiggs`.
- **Web Mode:** Interactively choose the parameters at the FeynHiggs User Control Center (FHUCC) and obtain the results on-line.
- **Mathematica Mode:** Access the FeynHiggs routines in Mathematica via MathLink with `MFeynHiggs`.

All programs and subroutines are documented in man pages.

Library Mode

- Static Fortran 77 library `libFH.a`.
- All global symbols prefixed to prevent symbol collision.
- Uses only subroutines (no functions):
  No include files needed (except for couplings).
  C/C++ users include `CFeynHiggs.h` for prototypes.
- Detailed debugging output can be turned on at run time.
- Main routines:
  `FHSetFlags` - set the flags of the calculation,
  `FHSetPara` - set the MSSM input parameters,
  `FHHiggsCorr` - compute Higgs masses and mixings,
  `FHUncertainties` - estimate their uncertainties,
  `FHCouplings` - compute the Higgs couplings and BRs,
  `FHHiggsProd` - estimate Higgs production cross-sections,
  `FHConstraints` - evaluate additional constraints.

Command-line Mode

Input File

```
MT          178
MB          4.7
MW          80.450
MZ          91.1875
MSusy       975
MA0         200
Abs(M_2)    332
Abs(MUE)    980
TB          50
Abs(At)     -300
Abs(Ab)     1500
Abs(M_3)    975
```

Command

FeynHiggs *file [flags]* →

Screen Output

```
------------------- HIGGS MASSES -------------------
| Mh0     =   116.022817
| MHH     =   199.943497
| MA0     =   200.000000
| MHp     =   216.973920
| SAeff   =  -0.02685112
| UHiggs =    0.99999346   -0.00361740    0.00000000 \
|             0.00361740    0.99999346    0.00000000 \
|             0.00000000    0.00000000    1.00000000

-------------- ESTIMATED UNCERTAINTIES -------------
| DeltaMh0   =   1.591957
| DeltaMHH   =   0.004428
| DeltaMA0   =   0.000000
| DeltaMHp   =   0.152519
  ...
```

- **Mask off details with**
  FeynHiggs *file [flags]* | grep -v %
- table **utility converts to machine-readable format, e.g.**
  FeynHiggs *file [flags]* | table TB Mh0 > outfile

Access to Tables

Input File "normal"

```
MT          170.9
MB          4.7
MW          80.392
MZ          91.1875
MSusy       975
MA0         200
Abs(M_2)    332
Abs(MUE)    980
TB          50
Abs(At)     -300
Abs(Ab)     1500
Abs(M_3)    975
```

"table"

```
MT          170.9
MB          4.7
MW          80.392
MZ          91.1875
MA0         200
TB          50
table file.dat MA0 TB
```

"inline table"

```
MT          170.9
MB          4.7
MW          80.392
MZ          91.1875
MA0         200
TB          50
table - MA0 TB
MA0   TB   At     MUE ...
200   5    1000   761
210   5    1000   753
...
```

Loops over parameter values possible (parameter scans).

- `MA0 200 400 50` - linear: 200, 250, 300, 350, 400,
- `TB 5 40 *2` - logarithmic: 5, 10, 20, 40,
- `TB 5 50 /6` - # of steps: 5, 14, 23, 32, 41, 50.

Command-Line Mode Scripted

```
#! /bin/sh

make || exit 1

FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT             173.1
MSusy          3000
MA0            1000
Abs(M_2)       2500
Abs(MUE)       2000
TB             5
Abs(Xt)        1000
Abs(M_3)       2000
_EOF_
```

Command-Line Mode Scripted

Shell "Magic"

```
#! /bin/sh

make || exit 1

FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT              173.1
MSusy           3000
MA0             1000
Abs(M_2)        2500
Abs(MUE)        2000
TB              5
Abs(Xt)         1000
Abs(M_3)        2000
_EOF_
```

Command-Line Mode Scripted

```
#! /bin/sh

make || exit 1
```



```
FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT              173.1
MSusy           3000
MA0             1000
Abs(M_2)        2500
Abs(MUE)        2000
TB              5
Abs(Xt)         1000
Abs(M_3)        2000
_EOF_
```

Command-Line Mode Scripted

```
#! /bin/sh

make || exit 1

FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT              173.1
MSusy           3000
MA0             1000
Abs(M_2)        2500
Abs(MUE)        2000
TB              5
Abs(Xt)         1000
Abs(M_3)        2000
_EOF_
```

env. variable

Command-Line Mode Scripted

```
#! /bin/sh

make || exit 1

FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT             173.1
MSusy          3000
MA0            1000
Abs(M_2)       2500
Abs(MUE)       2000
TB             5
Abs(Xt)        1000
Abs(M_3)       2000
_EOF_
```

default flags
(if arg #1 not given)

Command-Line Mode Scripted

```
#! /bin/sh

make || exit 1

FHDEBUG=2 ./build/FeynHiggs - ${1:-400202113} << _EOF_
MT              173.1
MSusy           3000
MA0             1000
Abs(M_2)        2500
Abs(MUE)        2000
TB              5
Abs(Xt)         1000
Abs(M_3)        2000
_EOF_
```

stdin ↓

begin “here” document

end “here” document

SUSY Les Houches Accord Format

Input File

```
BLOCK MODSEL
    1    1
BLOCK MINPAR
    1   0.100000000E+03  # m0
    2   0.250000000E+03  # m12
    3   0.100000000E+02  # tanb
    4   0.100000000E+01  # Sign(mu)
    5  -0.100000000E+03  # A
BLOCK SMINPUTS
    4   0.911870000E+02  # MZ
    5   0.425000000E+01  # mb(mb)
    6   0.175000000E+03  # t
  ...
```

Command

`FeynHiggs` *file [flags]* →

file`.fh`

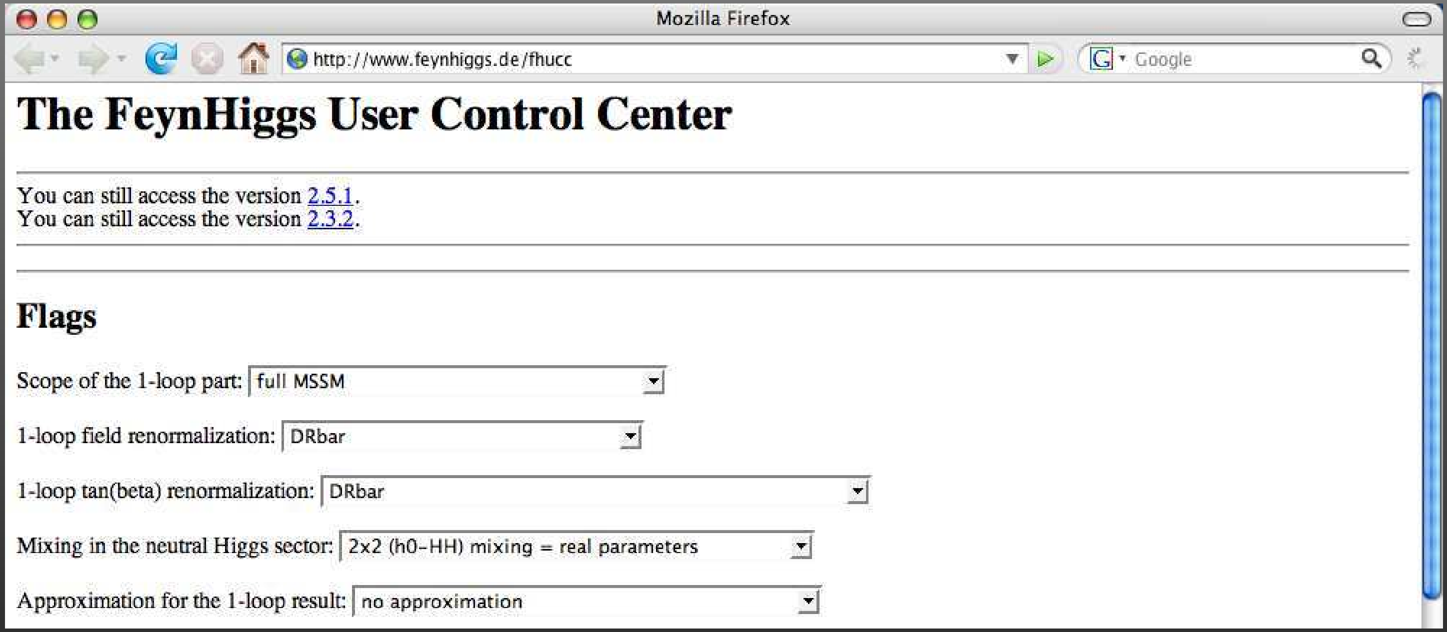
```
BLOCK MASS
   25    1.12697840E+02    # Mh0
   35    4.00145460E+02    # MHH
   36    3.99769788E+02    # MA0
   37    4.08050556E+02    # MHp
  ...
BLOCK ALPHA
        -1.10658125E-01    # Alpha
  ...
```

- **Uses the SLHA 2.**
- **SLHA can also be used in Library Mode with `FHSetSLHA`.**
- **FeynHiggs tries to read each file in SLHA format first. If that fails, fallback to native format.**

Web Mode

The FeynHiggs User Control Center (FHUCC) is on-line at

http://feynhiggs.de/fhucc



FHUCC is a Web interface for the Command-line Frontend. The user gets the results together with the input file for the Command-line Frontend.

Mathematica Mode

Provides the FeynHiggs functions in Mathematica, e.g.

```
In[1]:= Install["MFeynHiggs"];

In[2]:= FHSetFlags[...];

In[3]:= FHSetPara[...];

In[4]:= FHHiggsCorr[]

Out[4]= {MHiggs -> {117.184, 194.268, 200., 212.67},
>         SAeff -> -0.37575,
>         UHiggs -> {{0.994782, 0.102021, 0},
>                    {-0.102021, 0.994782, 0},
>                    {0, 0, 1.}}}
```

- **Can use all Mathematica functions on the results (e.g.** `ContourPlot`, `FindMinimum`**).**
- **Convenient interactive mode for FeynHiggs.**

Summary

- Higgs masses are the **real part of the complex pole.**
- **Two kinds of 'mixing' matrices** (`UHiggs`, `ZHiggs`).
- Inclusion of the **full cMSSM two-loop $\alpha_s \alpha_t$ corrections** in highly optimized form.
- Inclusion of **full one-loop NMFV effects.**
- Possibility to **interpolate parameters from data tables.** M_A-$\tan\beta$ **planes** in agreement with CDM constraints.
- All important **Higgs decay channels.** New: $h_i \to f_j \bar{f}_k$ **at one-loop.**
- Estimates of Higgs **production cross-sections.**
- Precision **EW and flavour observables** as constraints.