FeynHiggs 2.9

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Executive Summary

- $h_i \to h_j\, h_k$ at one-loop precision included.
- $h_i \to f_j\, \bar{f}_k$ now exactly as in arXiv:1103.1335.
- Overhaul of effective masses used internally.
- Improved/added routines for output and retrieval of parameters, to make FeynHiggs frontend for other programs, e.g. `model_fh.F` of FormCalc.
- FeynHiggs can now create SLHA Files, i.e. can be the first element in an SLHA chain.
- Many small additions and bug-fixes.

The MSSM Higgs Sector

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

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 ~~CP~~ at tree level.**

~~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:

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

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

Corrections included in FeynHiggs 2.9

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

- **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].
  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.**

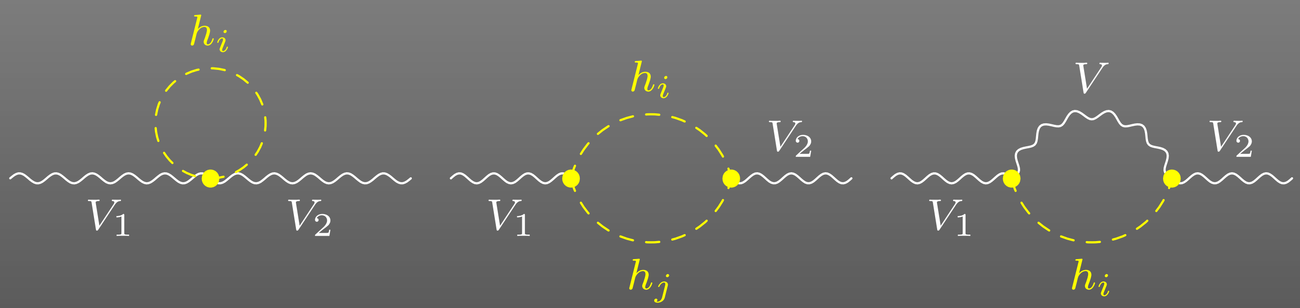
  Note: To obtain a unitary matrix, it is mathematically a necessity that $\mathcal{M}^2$ has no imaginary parts - making it Hermitian. This of course constrains the achievable quality of approximation.

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

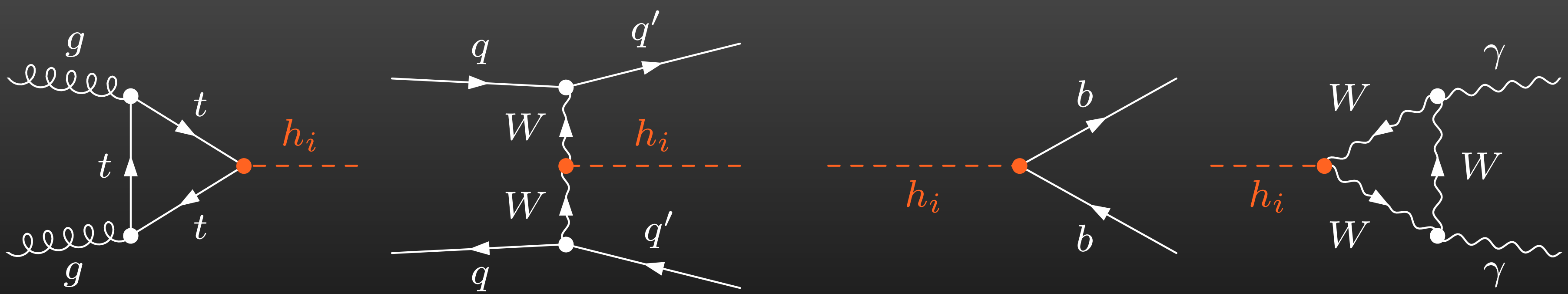
It is important to understand that `ZHiggs` and `UHiggs` are two objects with physically and mathematically distinct properties. Neither is universally 'better' than the other.

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 $\hat{\Sigma}_{ii}(q^2 = m_i^2)$,
  $\hat{\Sigma}_{ij}(q^2 = \frac{1}{2}(m_i^2 + m_j^2))$.

- $q^2 = 0$

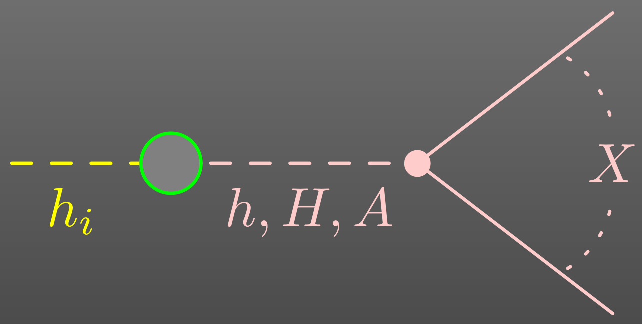
  In this limit, `UHiggs` corresponds to the effective potential approach and coincides with `ZHiggs`$(q^2 = 0)$.

  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

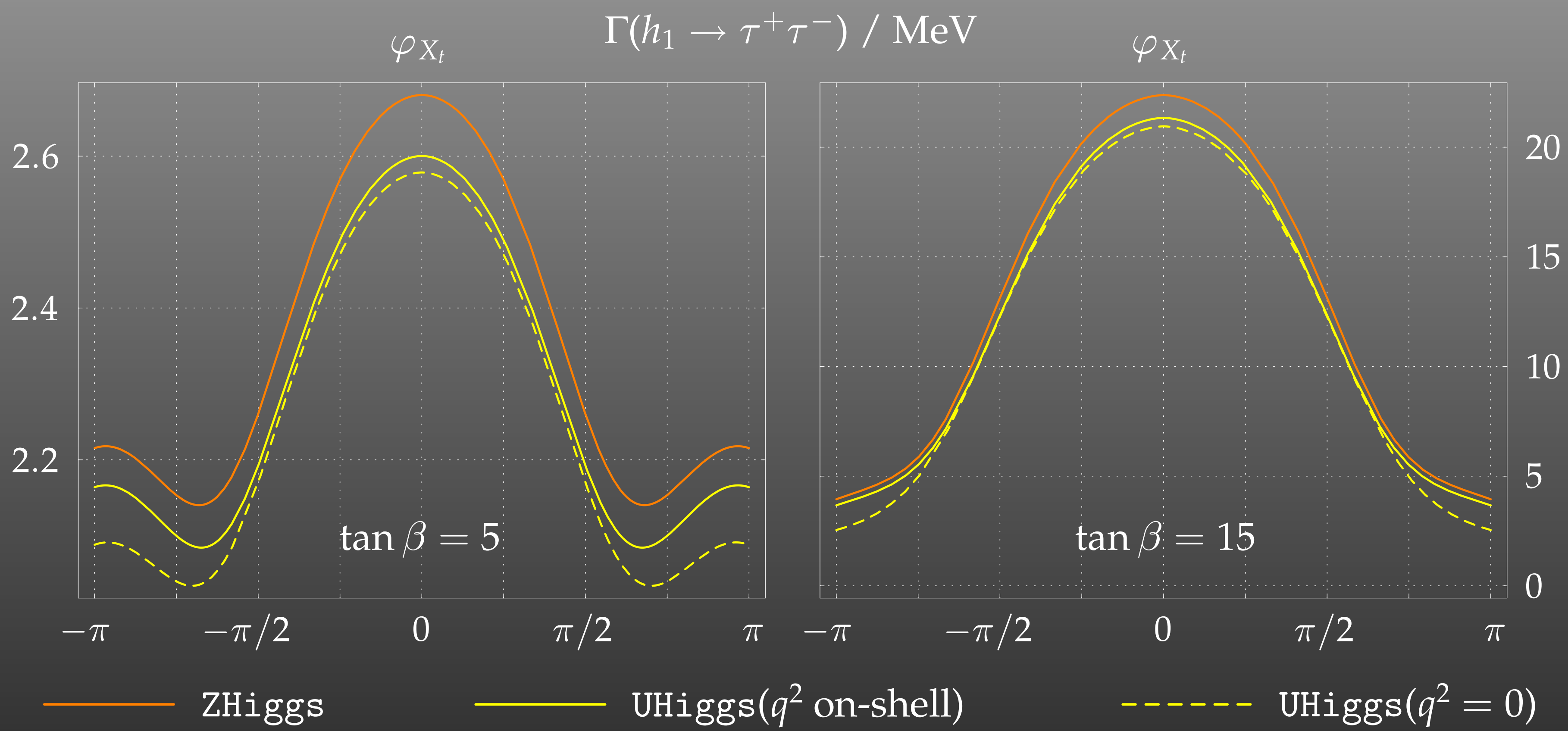
For convenience, the Z factors can be arranged in matrix form:

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

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.**

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

Non-Minimal Flavour Violation

The mixing matrices R diagonalize the mass matrices

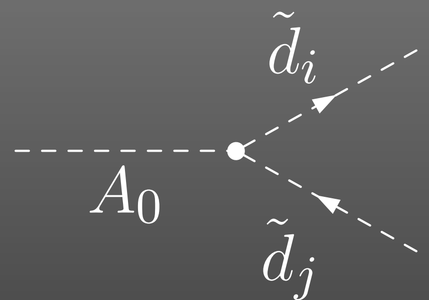
$$M^2_{u,d} = \left(\begin{array}{ccc|ccc} M^2_{\tilde L,i} & 0 & 0 & m_i X_i^* & 0 & 0 \\ 0 & M^2_{\tilde L,j} & 0 & 0 & m_j X_j^* & 0 \\ 0 & 0 & M^2_{\tilde L,k} & 0 & 0 & m_k X_k^* \\ \hline m_i X_i & 0 & 0 & M^2_{\tilde R,i} & 0 & 0 \\ 0 & m_j X_j & 0 & 0 & M^2_{\tilde R,j} & 0 \\ 0 & 0 & m_k X_k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

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

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

NMFV Effects

Essentially all one-loop pieces in FH are ‘NMFV-ready.’
The most immediately notable effect comes from the LR(RL) sector, as the A^q_{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.

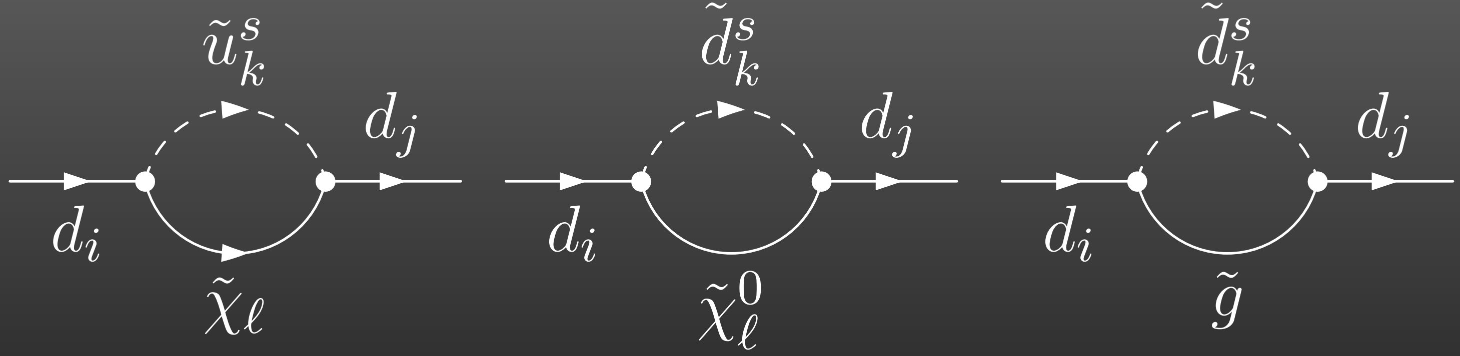
Main constraints from low-energy observables.
Currently included in FeynHiggs are $b \to s\gamma$, ΔM_s, and $B_s \to \mu^+\mu^-$ both at LO including NMFV effects and Δ_b.

Treatment of Δ_b

We use Δ_f to resum $\tan\beta$-enhanced corrections.
Note: This includes Δ_b but also $\Delta_{s,d}$.

Hofer, Nierste, Scherer 2009

Δ_f includes the following contributions:



- **We take into account only the $\tan\beta$-enhanced terms, thus no NMFV effects.**

$gg \to h$ 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

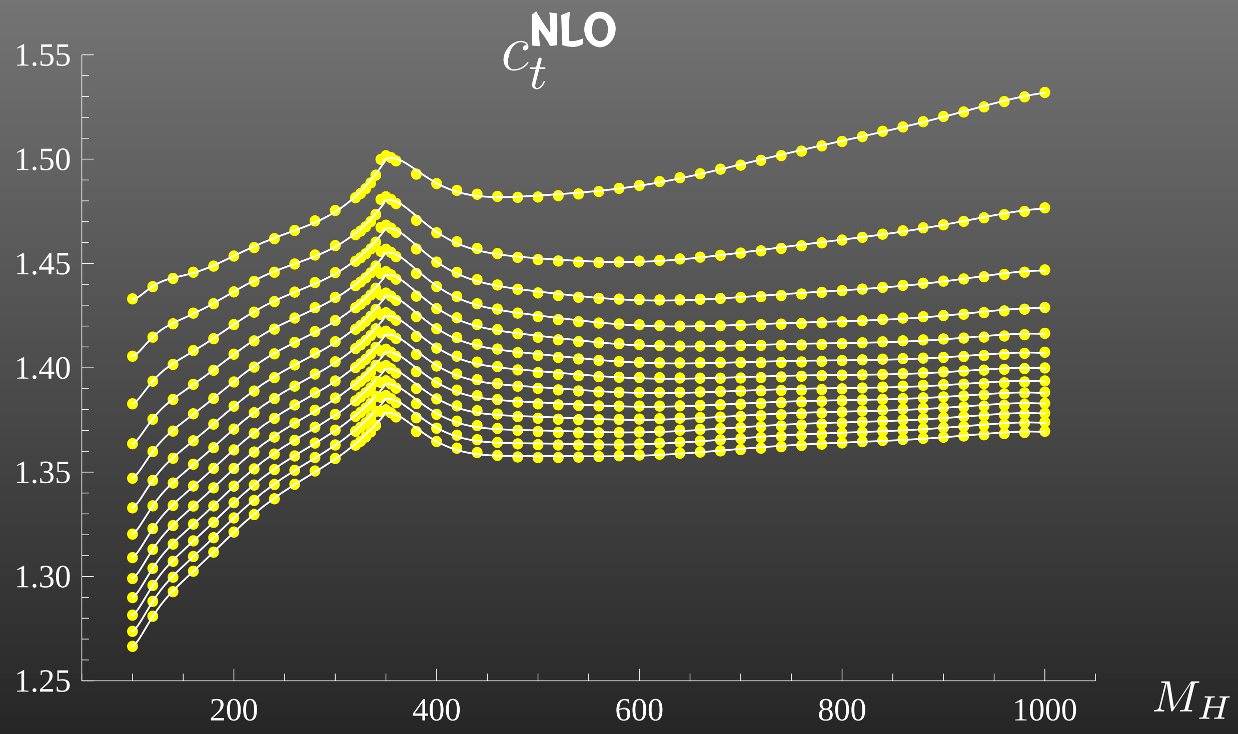
$gg \to h$ Production Cross-Section

Alternative approximation with true k-factors:

$$\mathcal{M}^{\text{MSSM}} = |\mathcal{A}_t^{\text{MSSM,LO}} + \mathcal{A}_b^{\text{MSSM,LO}} + \mathcal{A}_{\tilde{f}}^{\text{MSSM,LO}} + \mathcal{A}_{\text{rest}}^{\text{MSSM,LO}}|^2 +$$
$$(k_t^{\text{NLO}} k_t^{\text{NNLO}} - 1)\,|\mathcal{A}_t^{\text{MSSM,LO}}|^2 +$$
$$(k_b^{\text{NLO}} - 1)\,|\mathcal{A}_b^{\text{MSSM,LO}}|^2 +$$
$$(k_{tb}^{\text{NLO}} - 1)\,2\,\text{Re}\,\mathcal{A}_t^{\text{MSSM,LO}*}\,\mathcal{A}_b^{\text{MSSM,LO}}$$

$gg \to h$ Production Cross-Section

Details like the top threshold are obviously taken into account, for example:



Higgs Decays

The decays $h_i \to h_j\, h_k$ are now available at one-loop precision.
The decays $h_i \to f_j\, \bar{f}_k$ have been modified to exactly reproduce arXiv:1103.1335.

Weiglein, Williams 2007 · Williams, Rzehak, Weiglein 2011

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

Braaten, Leveille 1980

Of the (phenomenologically important) resummed Δ_b corrections the one-loop contribution is subtracted, to prevent double counting.

Parameter Planes

Scanning over parameters independently (as in the Benchmark Scenarios) is not sufficient if models introduce **non-trivial relations between parameters.** (Example: NUHM.) Moreover, independent scanning does not take into account **constraints** e.g. from CDM.

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

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

Definition of new planes by the user is possible.

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).

Output of FeynHiggs 2.9

- 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** $h_{1,2,3} \to$

$f\bar{f}', \gamma\gamma, ZZ^*, WW^*, gg$	$H^\pm \to f\bar{f}'$	$t \to W^+ b$
$h_i Z^*, h_i h_j, H^+ H^-$	$h_i W^{\pm *}$	$H^+ b$
$\tilde{f}_i \tilde{f}_j,$	$\tilde{f}_i \tilde{f}'_j,$	
$\tilde{\chi}^\pm_i \tilde{\chi}^\pm_j, \tilde{\chi}^0_i \tilde{\chi}^0_j$	$\tilde{\chi}^0_i \tilde{\chi}^\pm_j$	

  - **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 2.9

- `FHHiggsProd` - **Higgs production-channel cross-sections:**
  (SM: most up-to-date, MSSM: effective coupling approximation)
  - $gg \to h_i$ - gluon fusion. — all energies
  - $WW \to h_i$, $ZZ \to h_i$ - gauge-boson fusion. — 2, 7, 8, 14 TeV
  - $W \to Wh_i$, $Z \to Zh_i$ - Higgs-strahlung. — 2, 7, 8, 14 TeV
  - $b\bar{b} \to b\bar{b}h_i$ - Yukawa process. — all energies
  - $b\bar{b} \to b\bar{b}h_i,\ h_i \to b\bar{b}$, **one b tagged.** — 2, 14 TeV
  - $t\bar{t} \to t\bar{t}h_i$ - Yukawa process. — 2, 7, 8, 14 TeV

Output of FeynHiggs 2.9

- `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
  - $B_s \to \mu^+\mu^-$
    Hahn, Illana 2012

Download and Build

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

```
tar xfz FeynHiggs-2.9.0.tar.gz
cd FeynHiggs-2.9.0
./configure
```

- Type make to build.
- 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.

FeynHiggs as a SUSY Frontend

On the technical level, FeynHiggs provides an interface for SUSY parameters with

- several input methods (direct, file, SLHA, Mathematica),
- parameter-scan capable.

Easy I/O with `SLHARead`, `SLHAWrite`, `FHReadRecord`, etc.
Routines to extract parameters from FeynHiggs:

- `FHGetPara`, retrieve computed parameters (masses etc.),
- `FHRetrievePara`, `FHRetrieveSMPara`, ... retrieve input parameters. The `FHRetrieveXY` functions have the same invocation as `FHSetXY`.

Even more comprehensive, the programmer can process FeynHiggs parameter files independently of the frontend through the FeynHiggs Record.

FormCalc Model Initialization through FeynHiggs

- `model_fh.F` uses **FeynHiggs as Frontend for FormCalc-generated code:**

```
run :fhparameterfile :fhflags uuuu 0,1000
```

- FeynHiggs initializes MSSM (SM) parameters and passes them to FormCalc code.
- No duplication of initialization code.
- Much more versatile way of specifying parameters.
- Includes NMFV parameters.
- Parameters consistent between Higgs-mass computation and cross-section calculation.
- Needs FeynHiggs 2.8.1 or above.

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`

Command-Line Mode Scripted

Use "–" file name to embed FeynHiggs in shell scripts:

```
#! /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_
```

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

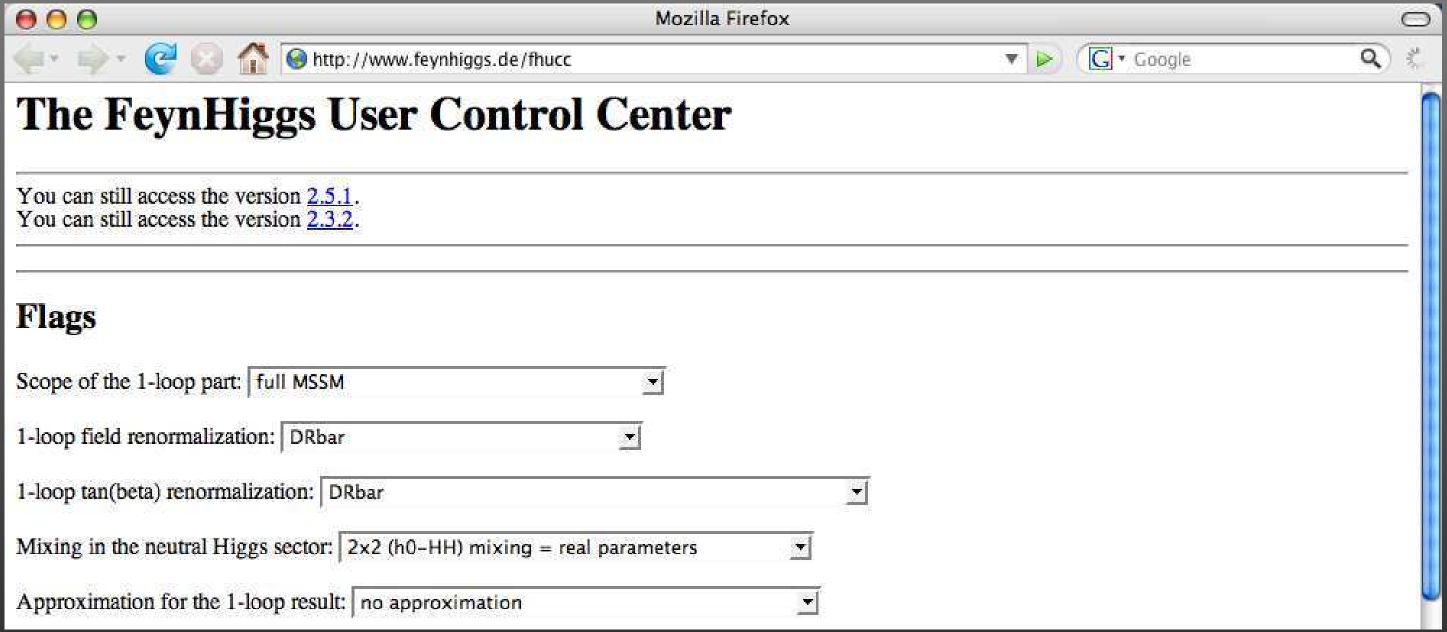
```
BLOCK MASS
   25    1.12697840E+02    # Mh0
   35    4.00145460E+02    # MHH
   36    3.99769788E+02    # MA0
   37    4.08050556E+02    # MHp
  ...
BLOCK ALPHA
        -1.10658125E-01    # Alpha
  ...
```

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

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 at 1L: $h_i \to h_j \bar{h}_k$, Improved: $h_i \to f_j \bar{f}_k$.
- Estimates of Higgs production cross-sections.
- Flexible interface, can also be used as frontend, as in FormCalc's `model_fh.F`.