# FeynHiggs - the Swiss Army Knife for Higgs Physics


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# 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:**

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

- **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 $\xi$, $\arg(m_{12}^2)$.
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:**

- $\mu$ – 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.

## 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://www.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.**

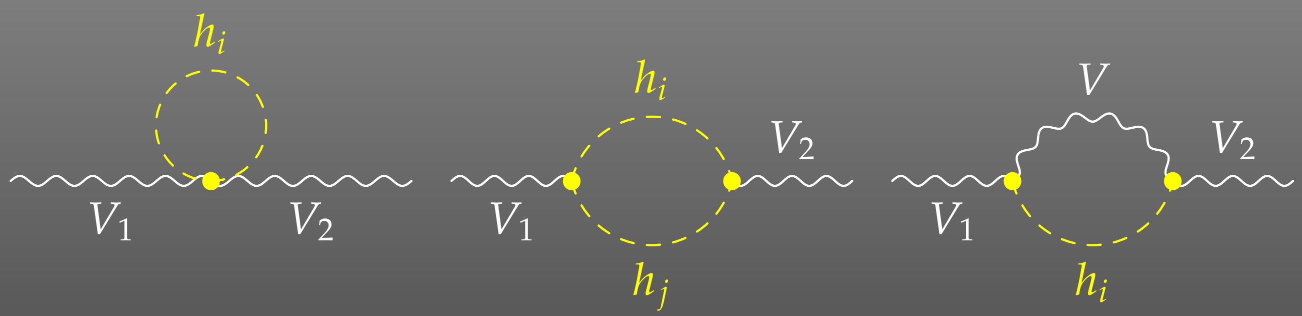
  Note: To obtain a unitary matrix, it is mathematically a necessity that $\mathcal{M}^2$ has no imaginary parts - making it Hermitian. This of course constrains the achievable quality of approximation.

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

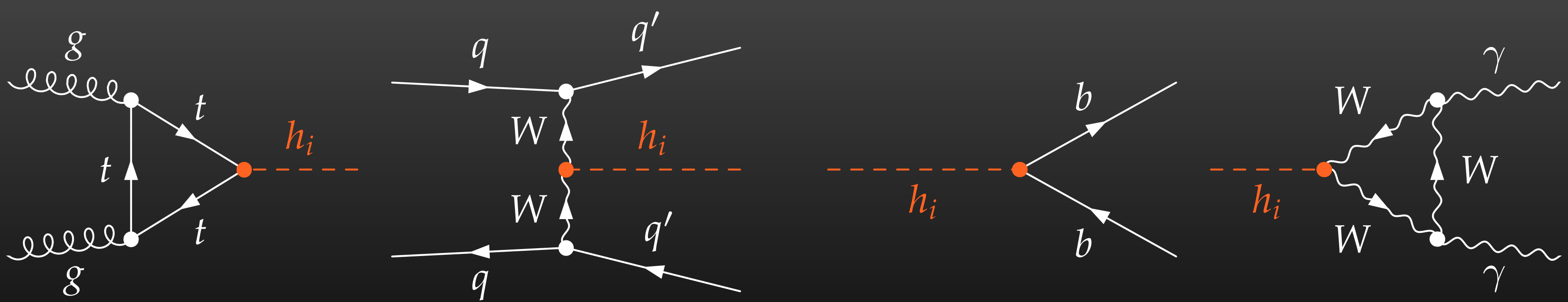
It is important to understand that `ZHiggs` and `UHiggs` are two objects with physically and mathematically distinct properties. Neither is universally 'better' than the other.

# 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 $\hat{\Sigma}_{ii}(q^2 = m_i^2)$,

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

- $q^2 = 0$

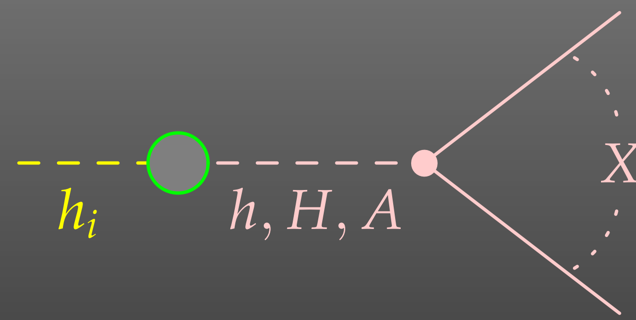
  In this limit, `UHiggs` corresponds to the effective potential approach and coincides with `ZHiggs`$(q^2 = 0)$.

  In the absence of ~~CP~~ effects (i.e. $2 \times 2$ mixing only), this is identical to the $\alpha_{\text{eff}}$ description.

# ZHiggs

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

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




- $\Gamma_{h,H,A}$ **- 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 $q^2 = 0$.

# ZHiggs

The transition factors $Z_{ij}$ involve both the **tree-level mass** $m_i$ and the **loop-corrected mass** $M_i$ of each Higgs boson:

$$Z_{ij} = \frac{\hat{\Sigma}_{ik}(M_i^2)\,\hat{\Sigma}_{jk}(M_i^2) - \hat{\Sigma}_{ij}(M_i^2)\left[M_i^2 - m_j^2 + \hat{\Sigma}_j(M_i^2)\right]}{\left[M_i^2 - m_j^2 + \hat{\Sigma}_j(M_i^2)\right]\left[M_i^2 - m_k^2 + \hat{\Sigma}_k(M_i^2)\right] - \hat{\Sigma}_{jk}^2(M_i^2)}$$

To compute $Z_{ij}$ we thus have to make the connection between the 'loop' ($h_1$, $h_2$, $h_3$) and the 'tree' ($h$, $H$, $A$) states.

Neither the zero-search nor the diagonalization procedure allow to do this in an unambiguous way. For example, level crossings may occur when searching for the zeros of $\det \mathcal{M}^2$.

## ZHiggs

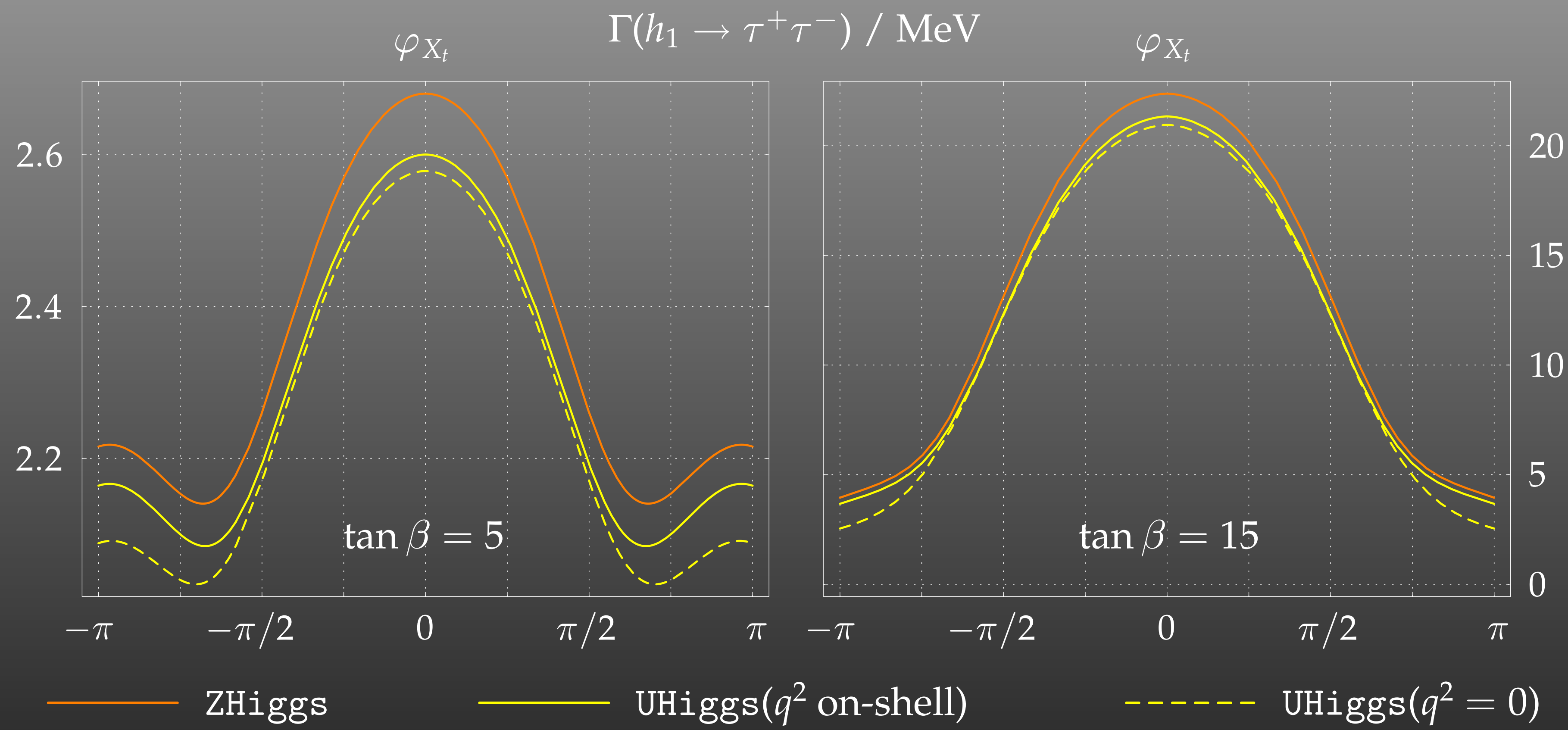
FeynHiggs computes `ZHiggs` and the associated masses $\tilde{M}_i$ for **all permutations $\pi$ of Higgs states** involved in the mixing and chooses the one which minimizes

$$\sum_i |M_i - \tilde{M}_{\pi(i)}| + \sum_{i,j} |C_{ij} - \mathtt{ZHiggs}_{\pi(i)j}|$$

where $C$ is the mixing matrix that comes out of the diagonalization of $\mathcal{M}^2$, i.e. a by-product of the zero-search.

This is an **empirical recipe,** so don't be confused by the different dimensions of $M$ and $Z$. The permutation is decided in 99+% of all cases by the mass pattern. The $|C - Z|$ term becomes relevant only for (almost) degenerate masses where it can tell e.g. the symmetric from the antisymmetric state.

# Phenomenological Effects




[ $M_{SUSY} = M_3 = M_2 = 500$ 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`.

There exists a version of the MSSM Model File for FeynArts (HMix.mod) with

- $\texttt{S[0,}\{h\}\texttt{]} = \sum_{i=1}^{3} \texttt{UHiggs[}h\texttt{,}\, i\texttt{]}\ \texttt{S[}i\texttt{]}$,
- $\texttt{S[10,}\{h\}\texttt{]} = \sum_{i=1}^{3} \texttt{ZHiggs[}h\texttt{,}\, i\texttt{]}\ \texttt{S[}i\texttt{]}$,
  inserted only on external lines.

# 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 $\alpha_{\text{eff}}$ 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

Candidate models:

- CMSSM (or mSUGRA)
  characterized by $m_0$, $m_{1/2}$, $A_0$, $\tan\beta$, $\mathrm{sign}\,\mu$.
  But: Too restricted.
- NUHM (Non-universal Higgs mass model)
  Assumption: no unification of scalar fermion and scalar Higgs parameters at the GUT scale.
  additional parameters: $M_A$, $\mu$.

The NUHM introduces non-trivial relations between parameters, which thus cannot be scanned naively by independent loops.

FeynHiggs 2.6 offers the new format of Parameter Tables to deal with such cases.

# 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 **www.feynhiggs.de.**

Definition of new planes by the user is possible.

The Table concept is actually embedded into the new **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.

# Corrections included in FeynHiggs 2.6

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

- **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 new 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].

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.

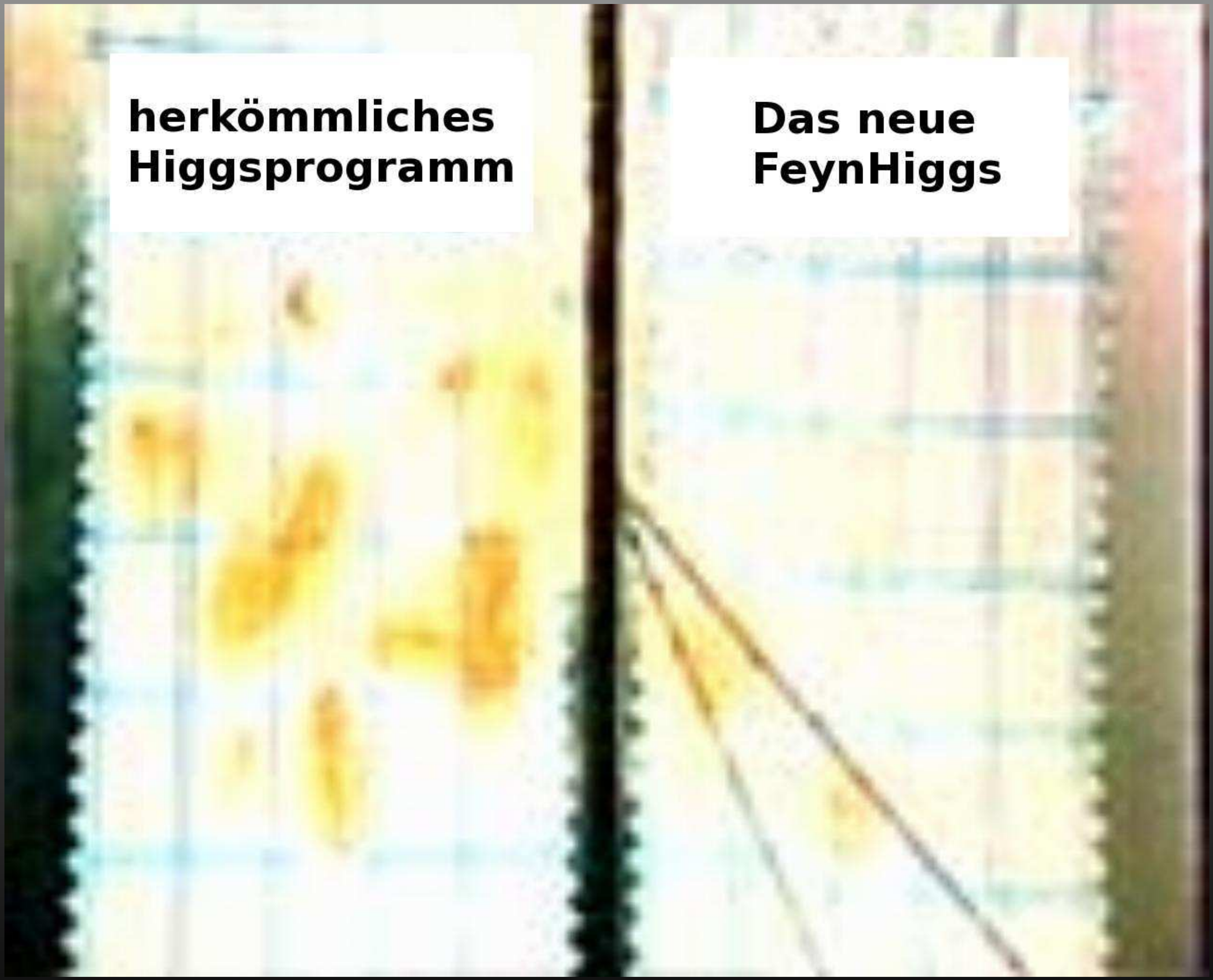
## Size matters

Implementing the $\alpha_s\alpha_t$ cMSSM corrections in FeynHiggs was a major piece of work. The amplitudes could be shrunk from 38 MB to less than 1.5 MB, mainly by abbreviationing techniques and exploiting the unitarity of the sfermion mixing matrices.

- Compile time is about 3 min (up from 45 sec in FeynHiggs 2.5).
- Run time is 28 msec per parameter point (up from 27 msec in FeynHiggs 2.5).

These figures show that the full cMSSM evaluation is actually usable in everyday life.

# FeynHiggs



## Output of FeynHiggs 2.6

- 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**

$$h_{1,2,3} \to f\bar{f}, \gamma\gamma, ZZ^*, WW^*, gg, \; h_i Z^*, h_i h_j, H^+H^-, \; \tilde{f}_i \tilde{f}_j, \; \tilde{\chi}_i^\pm \tilde{\chi}_j^\pm, \tilde{\chi}_i^0 \tilde{\chi}_j^0$$

$$H^\pm \to f\bar{f}', \; h_i W^{\pm *}, \; \tilde{f}_i \tilde{f}'_j, \; \tilde{\chi}_i^0 \tilde{\chi}_j^\pm$$

$$t \to W^+ b, \; H^+ b$$

  - **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 2.6

- `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.**

# Output of FeynHiggs 2.6

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

## Download and Build

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

```
tar xfz FeynHiggs-2.6.1.tar.gz
cd FeynHiggs-2.6.1
./configure
```

- Type make to build the Fortran/C++ part only.
  Type make all to build also the Mathematica part.
  Takes about 3 min to build on a Pentium IV.
- 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.

# 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 and the SLHA Library.**

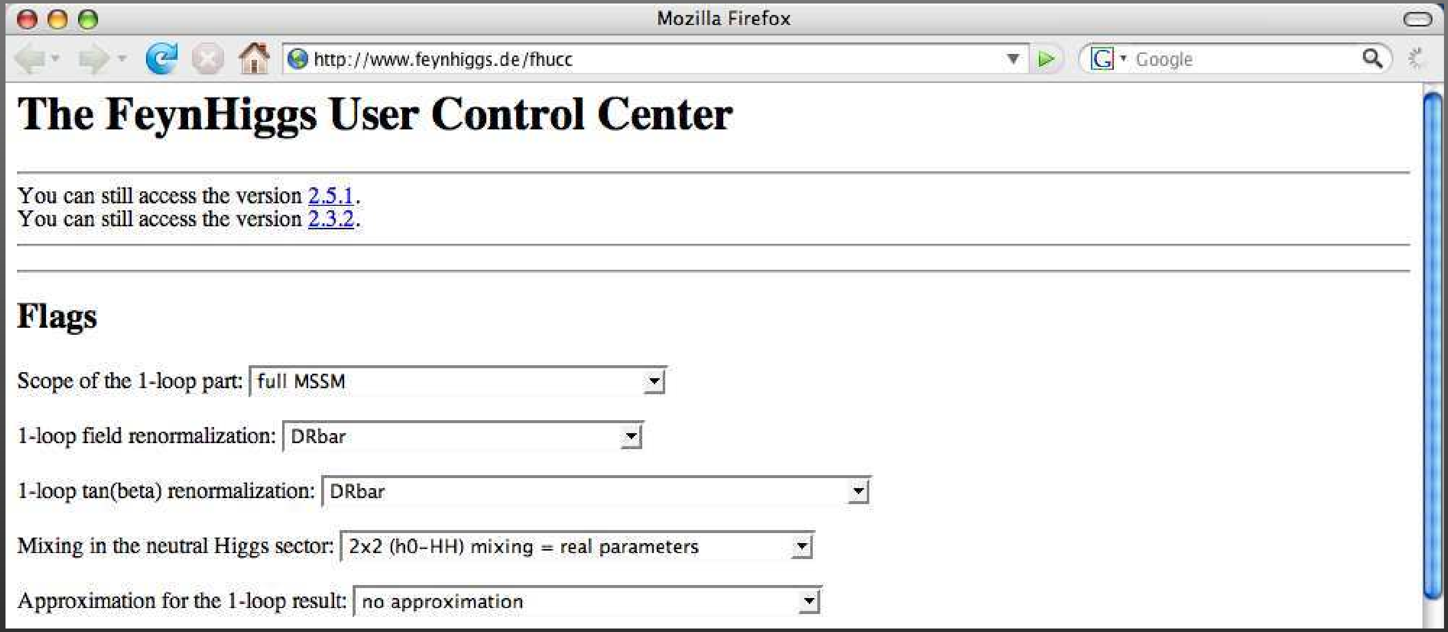
  Hahn 2004, 06

- **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://www.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: Main New Features

- Higgs masses are the real part of the complex pole.
- Two kinds of 'mixing' matrices (`UHiggs`, `ZHiggs`).
  Choice of mixing matrices in all Higgs production and decay channels (default: `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.
  Availability of $M_A$-$\tan\beta$ planes in agreement with CDM constraints.
- Estimates of Higgs production cross-sections.
- EDMs of electron (Th), neutron, Hg.