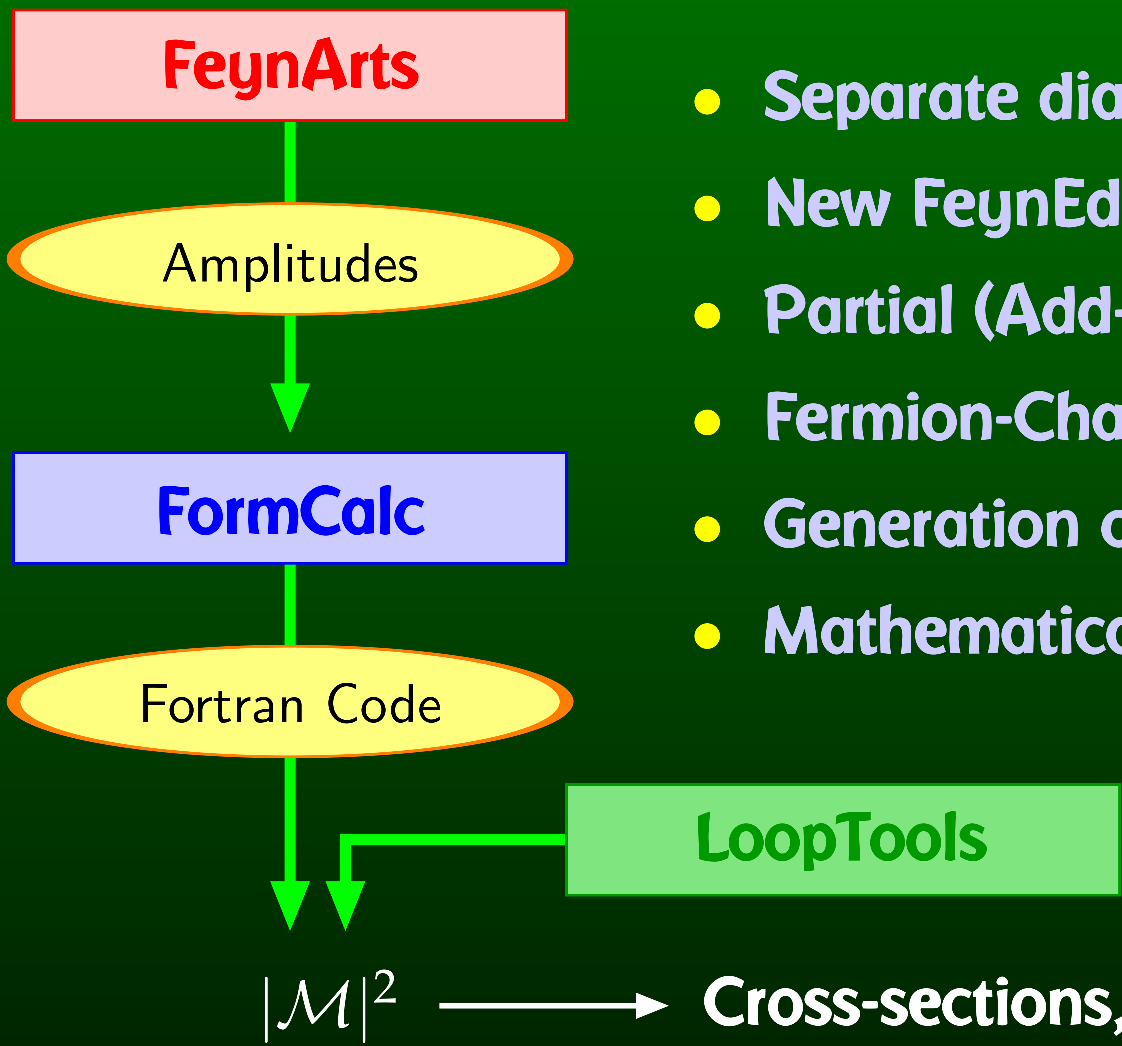
FeynHiggs – the Swiss Army Knife for Higgs Physics

T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. Weiglein

… and more



- Separate diagonalization package,
- New FeynEdit tool,
- Partial (Add-On) model files,
- Fermion-Chain rearrangement in 4D,
- Generation of if-statements,
- Mathematica interface.

$|\mathcal{M}|^2 \longrightarrow$ **Cross-sections, Decay rates, …**

The MSSM Higgs Sector

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

Higgs Potential:

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

- **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 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.

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

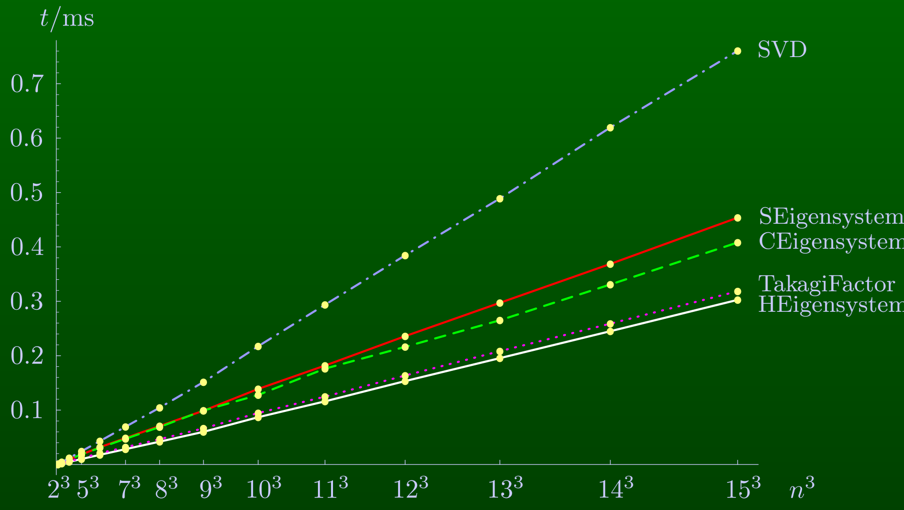
Diag Package

The Diag routines are based on the **Jacobi algorithm.**

This is conceptually simple but scales less favourably than e.g. the QR method.

Applicability range is thus **small to medium-size matrices.**

Timings on an AMD X2-5000:



- rather **compact code** ($\sim$ 3 kBytes each), therefore easy to adapt to own conventions,
- implemented in **Fortran 77**, but C/C++ and Mathematica interface included,
- **LGPL license.**

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.

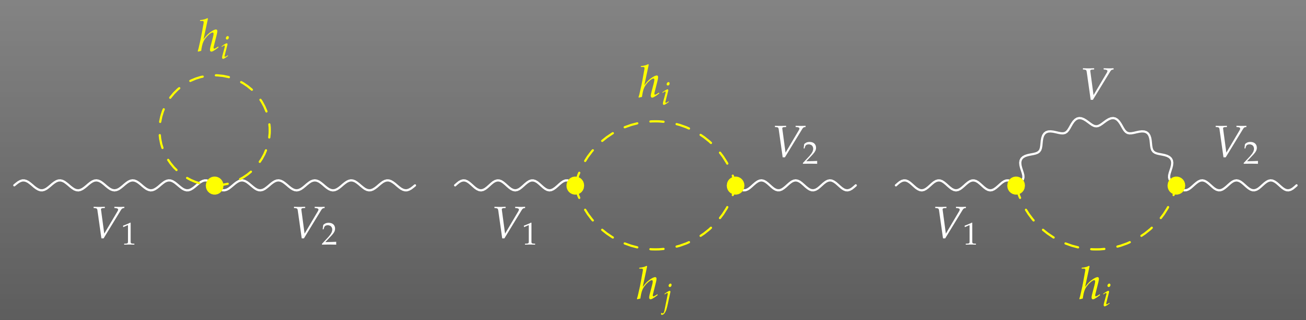
  Note: To obtain a unitary matrix, it is mathematically a necessity that $\mathcal{M}^2$ has no imaginary parts - making it Hermitian. This of course constrains the achievable quality of approximation.

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

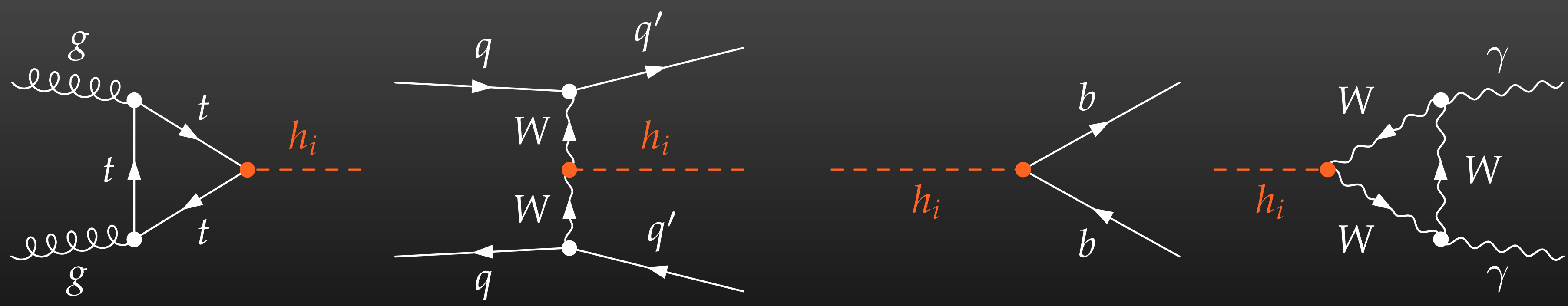
It is important to understand that `ZHiggs` and `UHiggs` are two objects with physically and mathematically distinct properties. Neither is universally 'better' than the other.

Examples of Internal and External Higgs Bosons

Internal Higgs bosons:



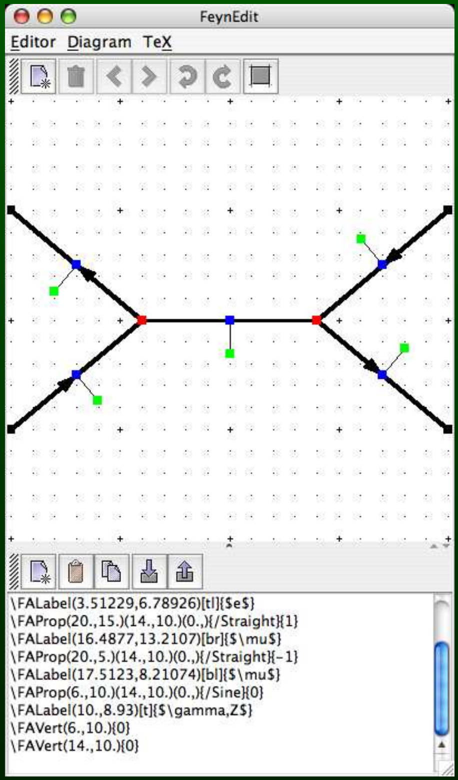
External Higgs bosons (production and decay):



Editing Feynman Diagrams

In FeynArts' LaTeX format, the elements of the diagram are easy to recognize and it is easy to make changes e.g. to the label text, but not so easy to move vertices and propagators.

```
\FAProp(0.,15.)(6.,10.)(0.,){/Straight}{-1}
\FALabel(2.48771,11.7893)[tr]{$e$}
\FAProp(0.,5.)(6.,10.)(0.,){/Straight}{1}
\FALabel(3.51229,6.78926)[tl]{$e$}
\FAProp(20.,15.)(14.,10.)(0.,){/Straight}{1}
\FALabel(16.4877,13.2107)[br]{$\mu$}
\FAProp(20.,5.)(14.,10.)(0.,){/Straight}{-1}
\FALabel(17.5123,8.21074)[bl]{$\mu$}
\FAProp(6.,10.)(14.,10.)(0.,){/Sine}{0}
\FALabel(10.,8.93)[t]{$\gamma$}
\FAVert(6.,10.){0}
\FAVert(14.,10.){0}
```



The new tool FeynEdit lets the user:

- copy & paste the LaTeX code into the lower panel,
- modify the diagram using the mouse, and
- copy & paste it back.

UHiggs

FeynHiggs offers two approximations for `UHiggs`:

- **q^2 on-shell**

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

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

- **$q^2 = 0$**

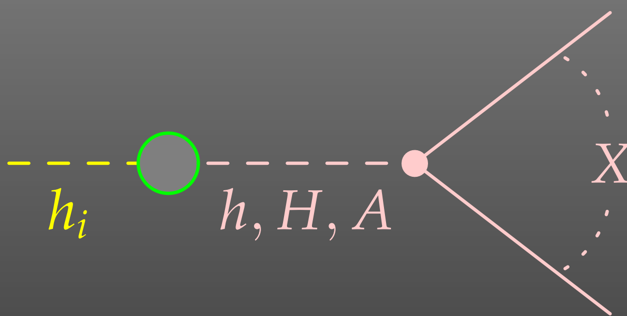
  In this limit, `UHiggs` corresponds to the effective potential approach and coincides with `ZHiggs`$(q^2 = 0)$.

  In the absence of $\not{C}\!\!P$ 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.**

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



- $\Gamma_{h,H,A}$ **- 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

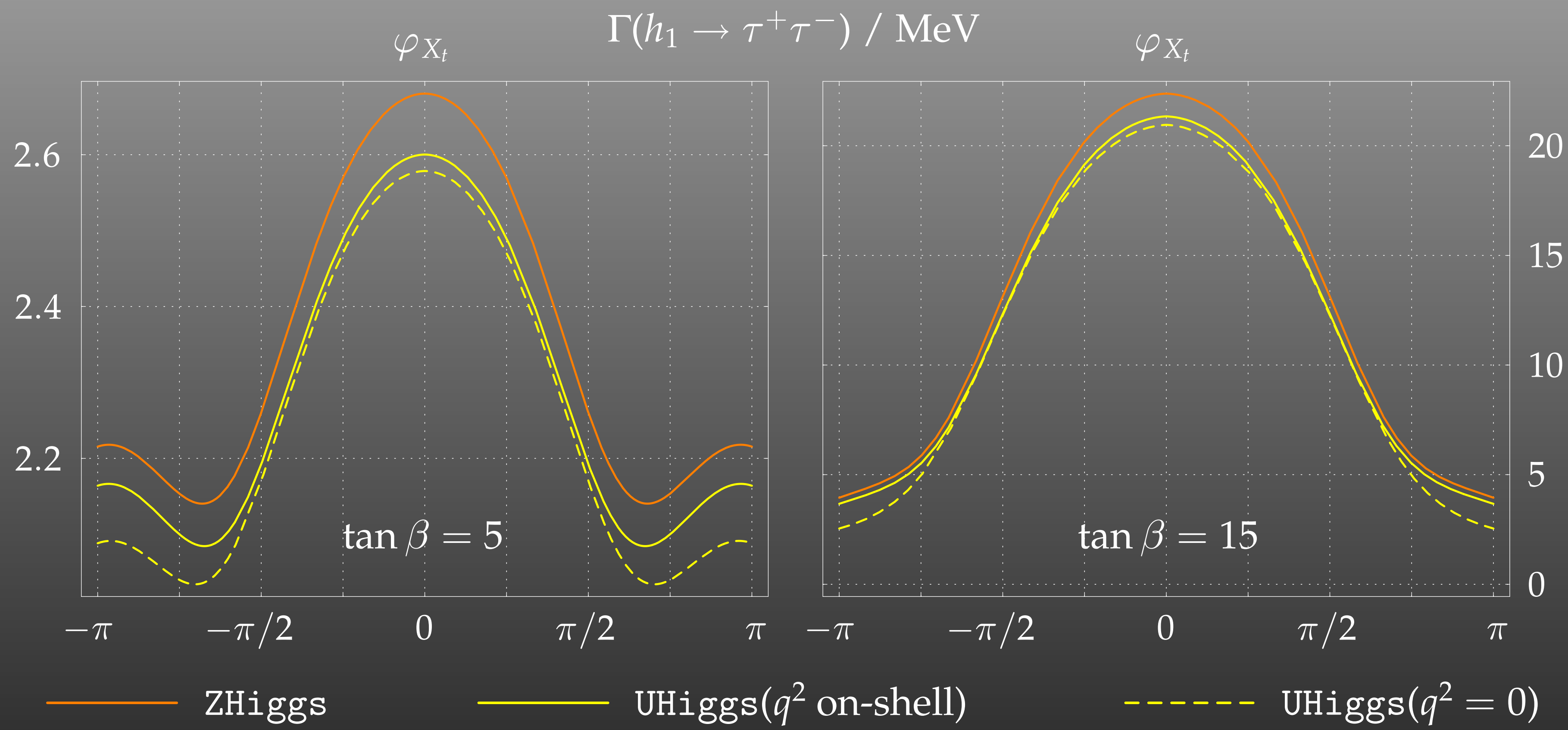
FeynHiggs computes `ZHiggs` and the associated masses $\tilde{M}_i$ for **all permutations π of Higgs states** involved in the mixing and chooses the one which minimizes

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

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



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

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.

Partial (Add-On) Model Files

FeynArts distinguishes

- **Basic Model Files** and
- **Partial (Add-On) Model Files.**

Basic Model Files, e.g. `SM.mod`, `MSSM.mod`, can be modified by Add-On Model Files, for example,

```
InsertFields[..., Model -> {"MSSMQCD", "FV", "HMix"}]
```

This loads the Basic Model File `MSSMQCD.mod` and modifies it through the Add-Ons `FV.mod` (non-minimal flavour violation) and `HMix.mod` (3×3 neutral Higgs mixing).

Model files can thus be built up from several parts.

The 'old' `FVMSSM.mod` exists for compatibility and just has

```
LoadModel[{"MSSMQCD", "FV"}]
```

Corrections included in FeynHiggs 2.6.3

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

- **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 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.

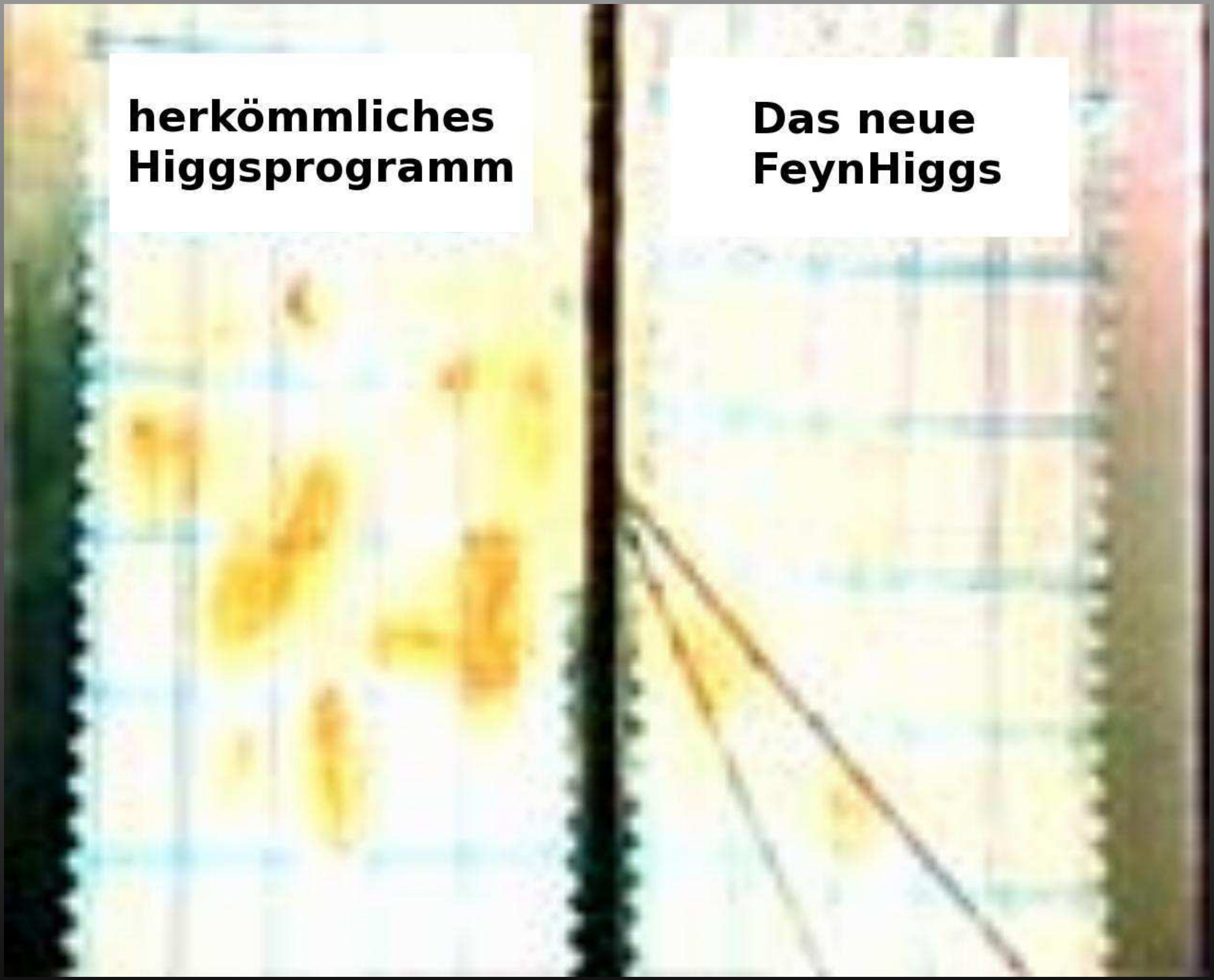
Size matters

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 2.6.3

- `FHHiggsCorr` - **All Higgs-boson masses and mixings:**
  M_{h_1}, M_{h_2}, M_{h_3}, $M_{H^\pm}$, α_{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}:**

$$h_{1,2,3}^{\text{SM}} \to f\bar{f}, \gamma\gamma, ZZ^*, WW^*, gg$$

Output of FeynHiggs 2.6.3

- `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 2.6.3

- `FHConstraints` – **Electroweak precision observables:**
  - $\Delta\rho$
    at $\mathcal{O}(\alpha, \alpha\alpha_s)$ including NMFV effects.
  - M_W, s_w^{eff}
    via SM formula + $\Delta\rho$.
  - $\text{BR}(b \to s\gamma)$
    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.

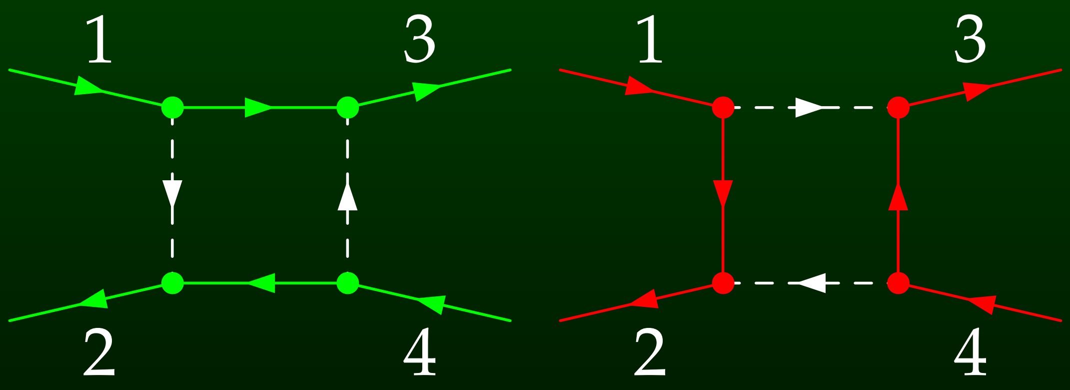
Fermion-Chain Rearrangement in 4D

Two new functions/options help in selecting and identifying given fermion structures. This is most obviously useful for the extraction of Wilson coefficients from an amplitude.

The new FeynArts function FermionRouting can be used to select diagrams according to their fermion structure, e.g.

```
DiagramSelect[...,
    FermionRouting[##] === {1,3, 2,4} & ]
```

selects only diagrams where external legs 1-3 and 2-4 are connected through fermion lines.



Fermion-Chain Rearrangement in 4D

FormCalc's CalcFeynAmp has the new FermionOrder option with which a given ordering of the external spinors can be enforced on spinor chains. For example,

```
CalcFeynAmp[..., FermionOrder -> {2,1, 3,4}]
```

brings the spinor chains into the order $\langle 2|\, X \,|1\rangle\, \langle 3|\, Y \,|4\rangle$ using Fierz and charge-conjugation identities.

New functions to group diagrams:

```
DiagramGrouping[ins, foo]
```

groups the diagrams `ins` for all different values of `foo`.
Special Case:

```
ColourGrouping[ins]
```

groups diagrams according to their colour structure.

Generation of if-Statements

Obstacle to generic code for e.g. fermion decays ($h \to f_i f_j$ for arbitrary i and j): objects like

$$\delta Z_{ij} = \begin{cases} \delta Z_{ii} \\ \delta Z_{i\neq j} \propto (m_i^2 - m_j^2)^{-1} \end{cases}$$

This cannot be solved by `IndexDelta` constructions, such as are supplied by the model file.

New functions:

- `IndexIf` **is written out as true if-statement in Fortran,**
- `ToIndexIf` **turns** `IndexDelta` **into** `IndexIf` **instances.**

Download and Build

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

```
tar xfz FeynHiggs-2.6.3.tar.gz
cd FeynHiggs-2.6.3
./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`

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 (latest version) 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.**

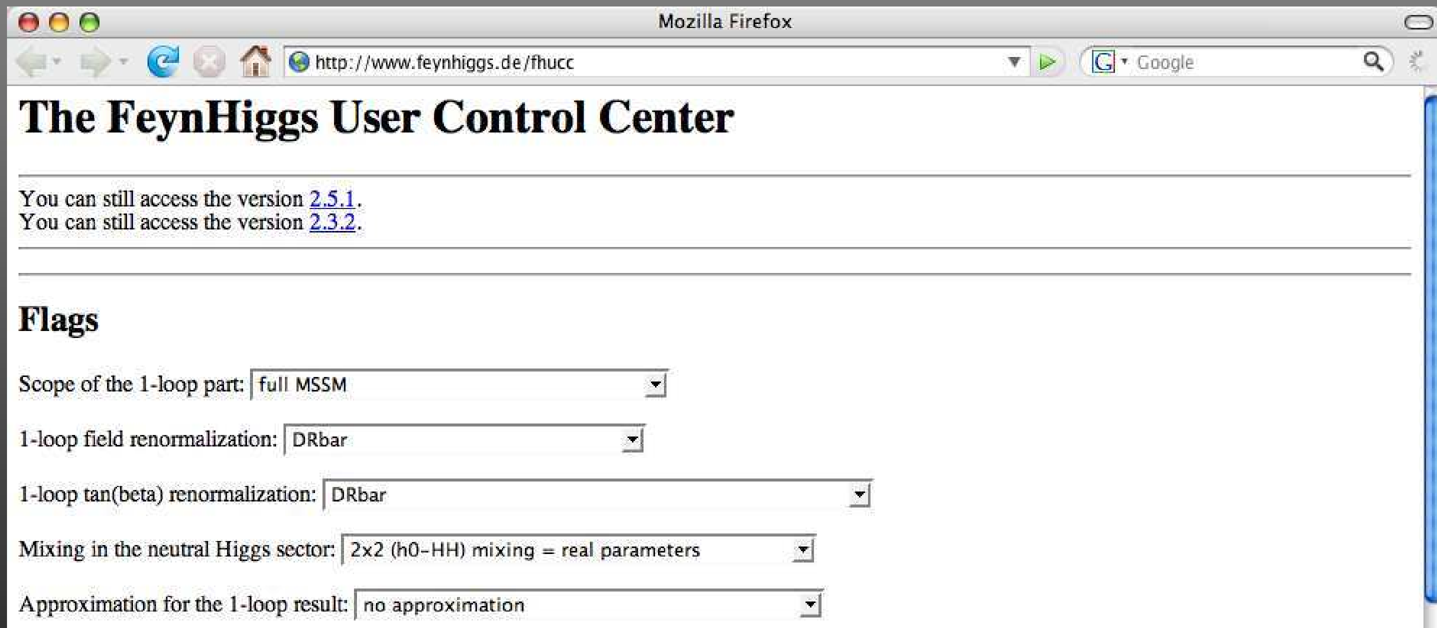
SLHA I/O Library

- The SUSY Les Houches Accord defines a common interface for SUSY tools.
- Reading/writing SLHA files not entirely straightforward.
- The SLHA I/O Library fills this gap:
  - Implemented as native Fortran 77 Library.
  - All data transferred in one double-complex array.
  - This array is indexed by preprocessor macros, e.g. `MinPar_TB` instead of `slhadata(20)`.
  - Main functions: `SLHARead`, `SLHAWrite`.
  - Implements the Latest version (now final) of the SLHA2.
- Freely available at http://www.feynarts.de/slha.

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.**

Mathematica Interface

FormCalc's new Mathematica Interface turns the generated stand-alone Fortran code into a Mathematica function for evaluating the cross-section or decay rate as a function of user-selected model parameters.

The benefits of such a function are obvious, as the whole instrumentarium of Mathematica commands can be applied to them. Just think of

```
FindMinimum[sigma[TB, MA0], {{TB, 15}, {MA0, 350}}]
ContourPlot[sigma[TB, MA0], {{TB, 5, 50}, {MA0, 250, 500}}]
...
```

Mathematica Interface

The changes to the code are minimal.

Example line in `run.F` for Stand-alone Fortran code:

```
#define LOOP1 do 1 TB = 5, 50, 5
```

Change for the Mathematica Interface:

```
#define LOOP1 call MmaGetReal(TB)
```

The variable `TB` is ‘imported’ from Mathematica now, i.e. the cross-section function in Mathematica becomes a function of `TB` hereby.

The user has full control over which variables are ‘imported’ from Mathematica and which are set in Fortran and similar for ‘exported’ variables.

Compile as usual (`./configure`, `make`).

FeynHiggs Summary

- 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.

… and more Summary

- The current FeynArts and FormCalc versions have the new features
  - Partial (Add-On) model files,
  - Fermion-Chain rearrangement in 4D,
  - Generation of if-statements,
  - Mathematica interface.

  and are available from http://www.feynarts.de.
- The drawing tool FeynEdit is available from http://www.feynarts.de.
- The diagonalization package is available from http://www.feynarts.de/diag.
- The SLHA Library is available from http://www.feynarts.de/slha.