FeynHiggs2.1 and CPsH: A Comparison

Sven Heinemeyer, CERN

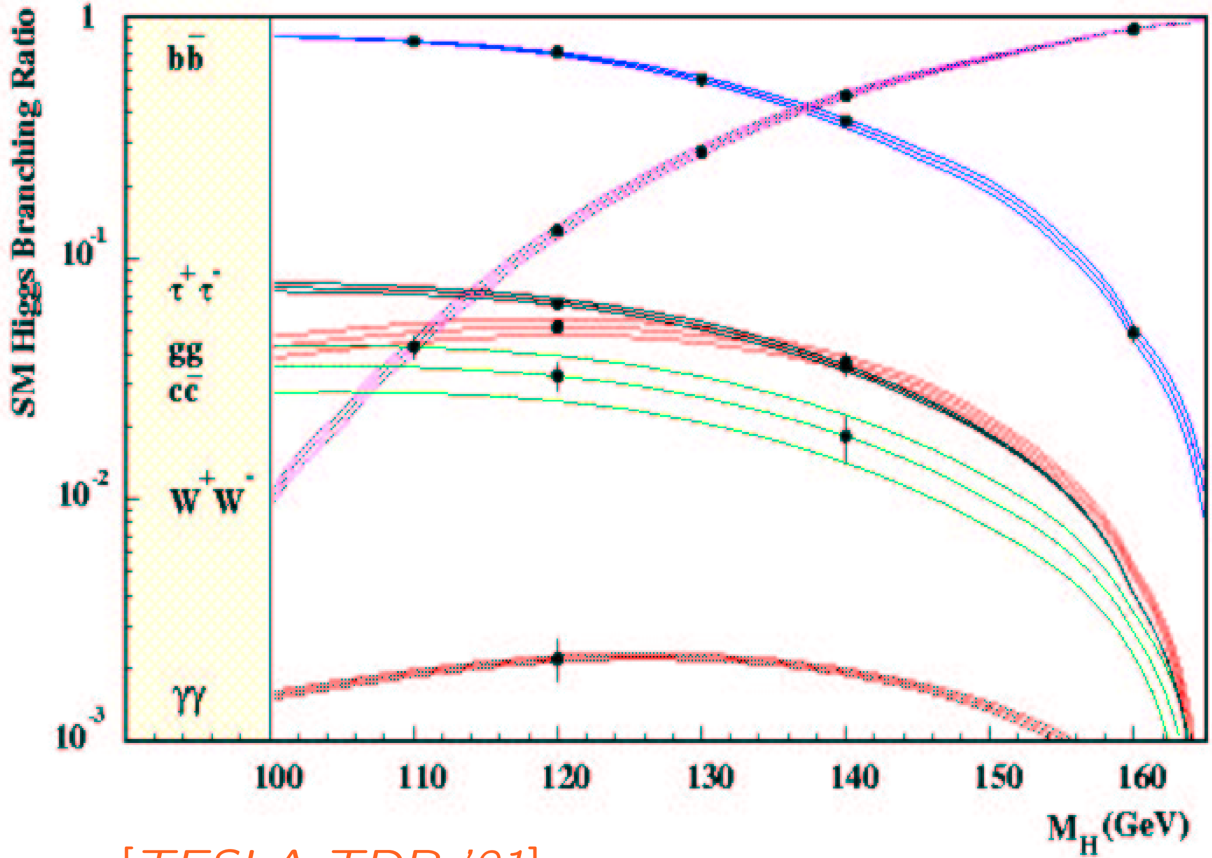
CERN, 05/2004

1. Introduction
2. Comparison I: usability
3. Comparison II: analytical
4. Comparison III: numerical
5. Conclusions

1. Introduction

SM Higgs @ LC:
Precise measurement of:

1. Higgs boson mass, $\delta M_H \approx 50$ MeV
2. Higgs boson width (direct/indirect)
3. Higgs boson couplings, $\mathcal{O}$ (few%) ⇒
4. Higgs boson quantum numbers: spin, . . .



[*TESLA TDR '01*]

MSSM: similar precision expected (possible problems from loop corrections)
⇒ need MSSM Higgs sector predictions at the % level

Two codes to be compared here:

FeynHiggs

[*T. Hahn, S.H., W. Hollik, G. Weiglein '03*]

CPsuperH

[*J. Lee, A. Pilaftsis, M. Carena, S. Choi, M. Drees, J. Ellis, C. Wagner '03*]

Both do more or less the same:

– input: low-energy parameters
– output: masses, BR's, couplings . . . (slight variations)

However: differences in

– usability: how to link, call, etc.
– analytical formulas: more/less corrections included
– numerical results: in the rMSSM/cMSSM
– non-Higgs output: $\Delta\rho$, $(g-2)_\mu$, . . . in *FeynHiggs2.1*

2. Comparison I: usability

Download:

Go to www.feynhiggs.de or theory.ph.man.ac.uk/~jslee/CPsuperH.html
and download the latest version

Compilation:

CPsH: `./makelib`, `./compit` (f77)
$\Rightarrow$ `libcpsuperh.a`, `cpsuperh.exe`

FeynHiggs: `./configure`, `make` (f77, g77, pgf77, . . .)
$\Rightarrow$ `libFH.a`, `FeynHiggs`, `MFeynHiggs`

Running the code:

CPsH: file `run` contains the low energy parameters and flags
`./run` $\Rightarrow$ screen output of results

link of `libcpsuperh.a` to a Fortran code also possible
(by inspecting/including `call` and `common` from `cpsuperh.f`)

Running the code:

FeynHiggs: 3 possible ways

A) as a stand alone program

B) called from a Fortran/C++ code

C) called within Mathematica

processing of Les Houches Accord data possible

Detailed instructions and help are provided in the man pages

Example of application: *FeynHiggs* is used for

– final evaluations of LEP Higgs WG for $\mathcal{CP}$V scenario (together with CPH) [*P. Bechtle, K. Desch, priv. comm.*]

– ATLAS Higgs analyses [*M. Schumacher, priv. comm.*]

– CMS Higgs analyses [*A. Nikitenko, priv. comm.*]

A) Stand alone program

- Prepare input file:

```
MSusy          500
MHp            1000
TB             3 [ 50 20 l]
absAt          800
argAt          0.5
...
```

  [50 20 l] one- or two-dim. loops possible (here with 20 log steps)

- call *FeynHiggs*:

  `./FeynHiggs var.in 4003023110 [| table TB > out.dat]`

  `var.in` : input file (any name possible)
  `4003023110` : options (precision, r/cMSSM, ...)

- output to screen (human readable)

  output to file (machine readable) via `[| table TB > out.dat]`

B) Called from a Fortran/C++ code

Link *FeynHiggs* as a subroutine

`call FHSetFlags( ... )` :

$\longrightarrow$ specification of accuracy etc.

`call FHSetPara( ... )` :

$\longrightarrow$ specify input parameters

`call FHGetPara( ... )` :

$\longrightarrow$ obtain derived parameters

`call FHHiggsCorr( ... )` :

$\longrightarrow$ obtain Higgs boson masses and mixings

`call FHCouplings( ... )` :

$\longrightarrow$ obtain decay widths, BRs etc.

C) Called within Mathematica

- install the math link to *MFeynHiggs* , e.g.:

  `Install[''MFeynHiggs'']`

- `FHSetFlags[ ... ]` :
  → specification of accuracy etc.

  `FHSetPara[ ... ]` :
  → specify input parameters

  `FHGetPara[]` :
  → obtain derived parameters

  `FHHiggsCorr[]` :
  → obtain Higgs boson masses and mixings

  `FHCouplings[]` :
  → obtain decay widths, BRs etc.

3. Comparison II: analytical

Method of calculation:

CPsH:

– Renormalization group improved effective potential approach for masses and couplings (*)

– (mostly) effective coupling approximation for decays

FeynHiggs:

– Feynman-diagrammatic approach for masses and couplings (*)

– (mostly) effective coupling approximation for decays/production XS

(*) $\Rightarrow$ same "parameter names" can have different meaning:

example: $X_t \rightarrow$ maximum Higgs mass reached for

$$X_t^{\overline{\text{MS}}} \approx \sqrt{6} M_{\text{SUSY}} \quad \text{or} \quad X_t^{\text{OS}} \approx 2 M_{\text{SUSY}}$$

transition OS $\leftrightarrow$ $\overline{\text{MS}}$ possible

Corrections included:

CPsH:

– (leading) log approx. for one-loop
– approx. for momentum dependence (at one-loop)
– (leading) log approx. for $\mathcal{O}\left(\alpha_s\alpha_t, \alpha_t^2\right)$ including full complex phase dependence
– $\mathcal{O}(\alpha_s\alpha_b)$: $(\alpha_s \tan\beta)^n$ resummation including full complex phase dependence

FeynHiggs:

– full one-loop including full complex phase dependence
– full momentum dependence (at one-loop)
– full $\mathcal{O}\left(\alpha_s\alpha_t, \alpha_t^2\right)$, but with approx. for complex phase dependence
– $\mathcal{O}(\alpha_s\alpha_b)$: $(\alpha_s \tan\beta)^n$ resummation including full complex phase dependence + subleading terms (without phase dependence)

$\Rightarrow$ not trivial to disentangle where possible differences in the complex case come from

4. Comparison III: numerical

(thanks to S. Hesselbach, M. Velasco, M. Wood)

Strategy:

– Look at the real case first (masses, BR's, ...)
  $\Rightarrow$ differences will persist in the complex case

– investigate the complex case (masses, BR's, ...)

rMSSM benchmark scenarios:

[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

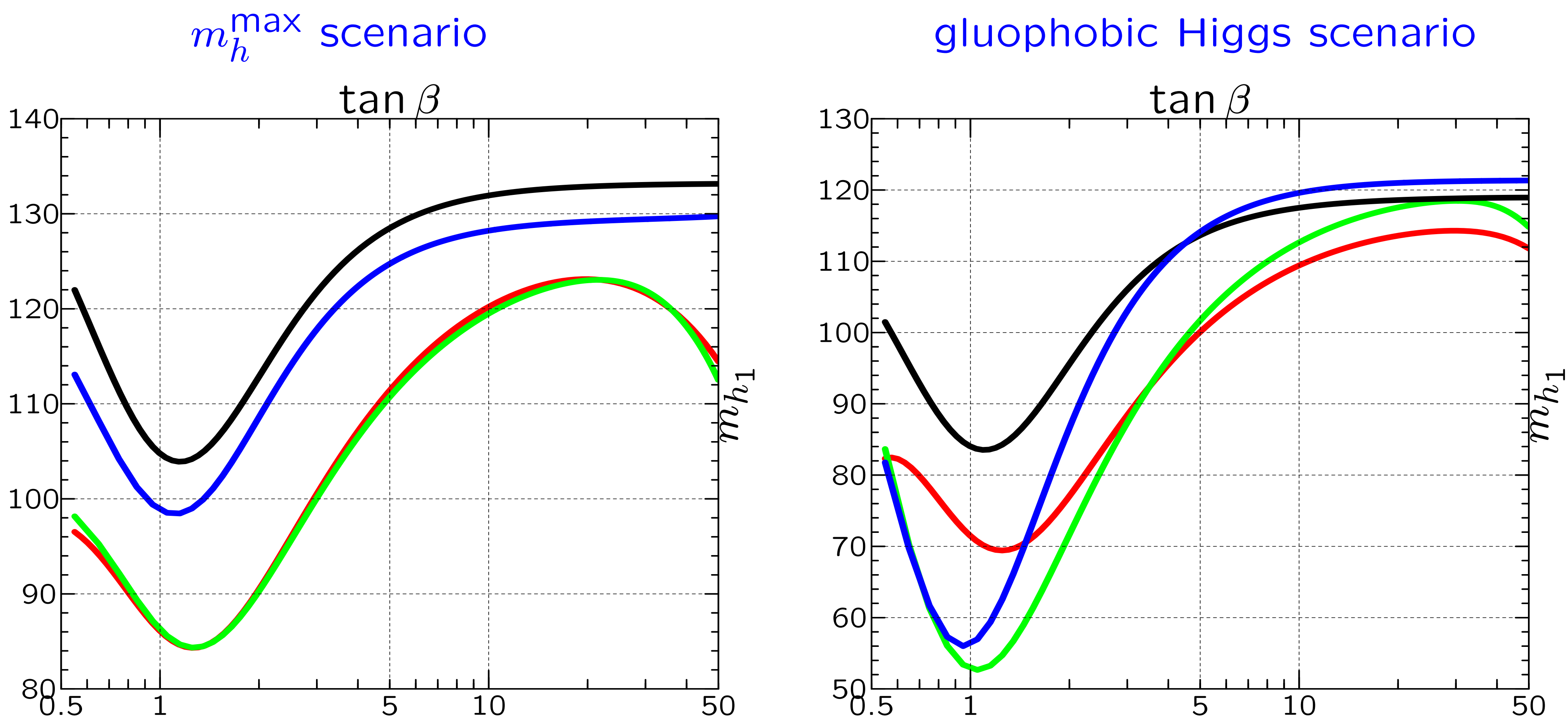
$m_h^{\rm max}$:

$$M_{\rm SUSY} = 1~{\rm TeV}, \quad X_t^{\rm OS} = 2M_{\rm SUSY}, \quad X_t^{\overline{\rm MS}} = \sqrt{6}M_{\rm SUSY},$$
$$\mu = M_2 = 200~{\rm GeV}, \quad m_{\tilde{g}} = 0.8M_{\rm SUSY}, \quad A_t = A_b$$

gluophobic Higgs:

$$M_{\rm SUSY} = 350~{\rm GeV}, \quad X_t^{\rm OS} = -750~{\rm GeV}, \quad X_t^{\overline{\rm MS}} = -770~{\rm GeV},$$
$$\mu = M_2 = 300~{\rm GeV}, \quad m_{\tilde{g}} = 500~{\rm GeV}, \quad A_t = A_b$$

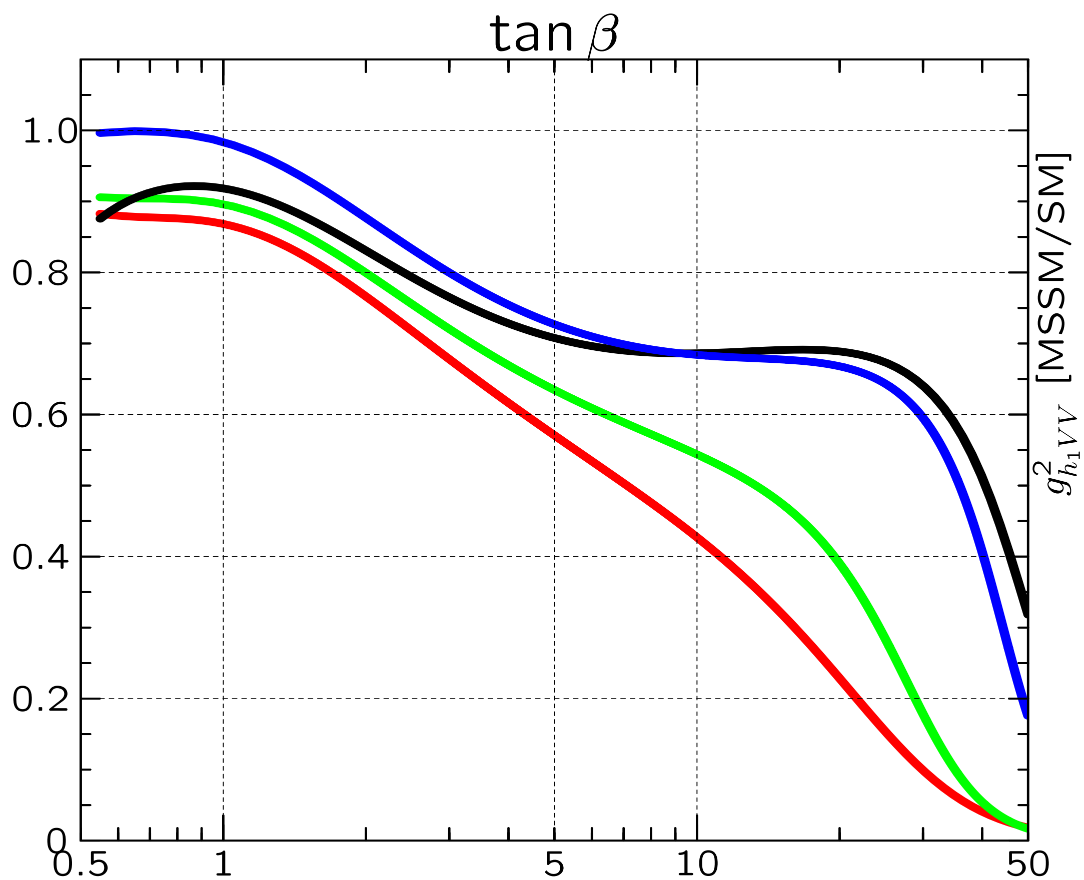
Compare m_{h_1} in the two scenarios:



FeynHiggs, $M_{H^\pm} = 150$ GeV ,   CPsH, $M_{H^\pm} = 150$ GeV
FeynHiggs, $M_{H^\pm} = 500$ GeV ,   CPsH, $M_{H^\pm} = 500$ GeV

$\Rightarrow$ large differences, but understood: $\mathcal{O}\left(\alpha_t^2\right)$ in *FeynHiggs2.1*

Compare $h_1 ZZ$ in the two scenarios for $M_{H^\pm} = 150$ GeV :



FeynHiggs, $m_h^{\rm max}$, CPsH, $m_h^{\rm max}$
FeynHiggs, gluophobic Higgs , CPsH, gluophobic Higgs

⇒ large differences, but understood: $\mathcal{O}\left(\alpha_t^2\right)$ in *FeynHiggs2.1*

Comparison of decay width in SPS1a:

$$\Gamma(h \to f\bar{f}) \propto \frac{1}{1+\Delta m_f} \times m_h \times \left(1 - \frac{4m_f^2}{m_h^2}\right)^{3/2} \times \left(\frac{\sin\alpha_{\rm eff}}{\cos\beta}\right)^2 \quad , \qquad f = b, \tau, \ldots$$

Different effects:

$$m_h \to m_h + \delta m_h \quad \Rightarrow \quad \Gamma(h \to f\bar{f}) \left\{ 1 + \frac{\delta m_h}{m_h} \left[1 + 12 \left(\frac{m_f^2}{m_h^2} \right) \right] \right\}$$

$\alpha_{\rm eff}$: dependence on radiative corrections

Δm_f irrelevant for SPS1a

	$\Gamma(h \to b\bar{b})[10^{-3}]$	$\Gamma(h \to \tau^+\tau^-)[10^{-3}]$	$(\sin\alpha_{\rm eff}/\cos\beta)$	m_h
CPsH	3.116	0.288	-1.1	112.6
HD(4)	2.800	0.284	-1.1	113.7
FH	2.942	0.293	-1.15	114.0

Comparison in the CPX scenario:

CPX: [*M. Carena, J. Ellis, A. Pilaftsis, C. Wagner '00*]

$$M_{\text{SUSY}} = 500 \text{ GeV}, \quad |A_f| = 2M_{\text{SUSY}}, \quad , |\mu| = 4M_{\text{SUSY}}$$
$$|M_1| = 50 \text{ GeV}, \quad |M_2| = 100 \text{ GeV}, \quad |M_3| = 1000 \text{ GeV}$$
$$M_{H^\pm} = 300 \text{ GeV}, \quad \tan\beta = 5$$

For the plots: $\phi = \phi_{A_f} = \phi_{m_{\tilde{g}}}$

→ extreme scenario, "small" analytical differences can lead to large(r) numerical differences

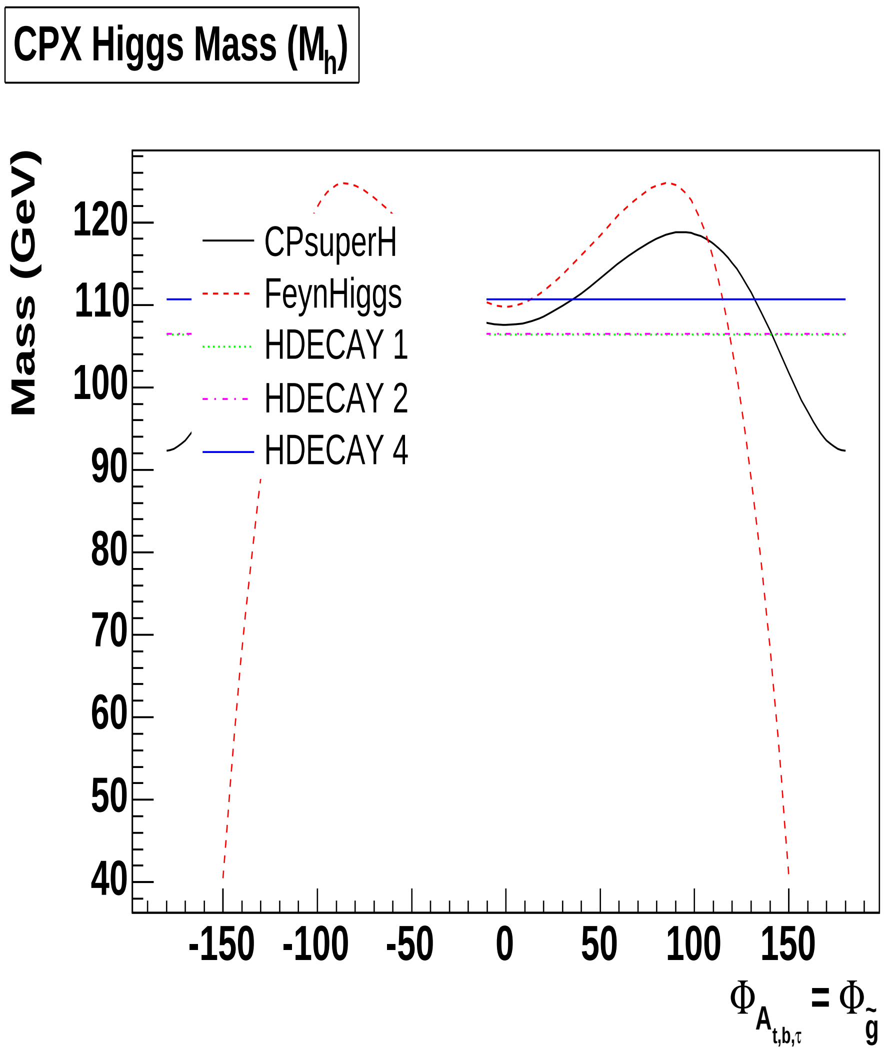
→ Δm_b very important

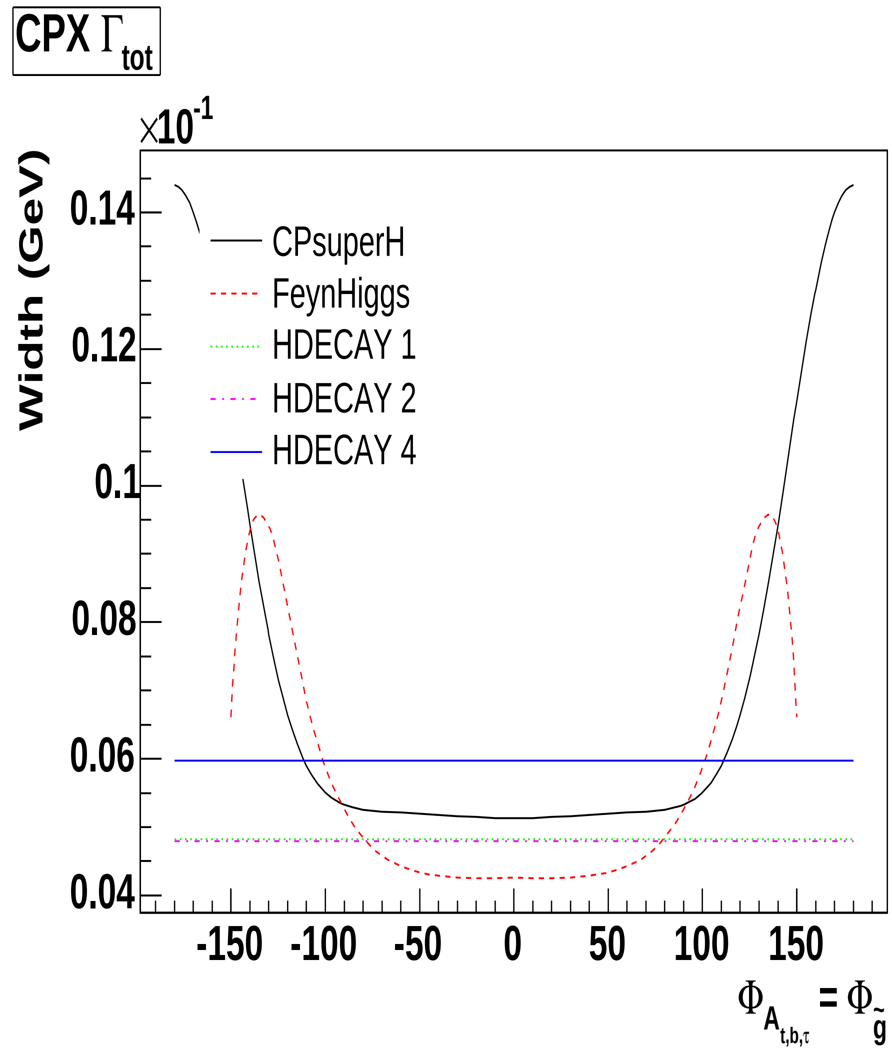
1) compare masses

2) compare decay widths (not latest *FeynHiggs2.1* version used)

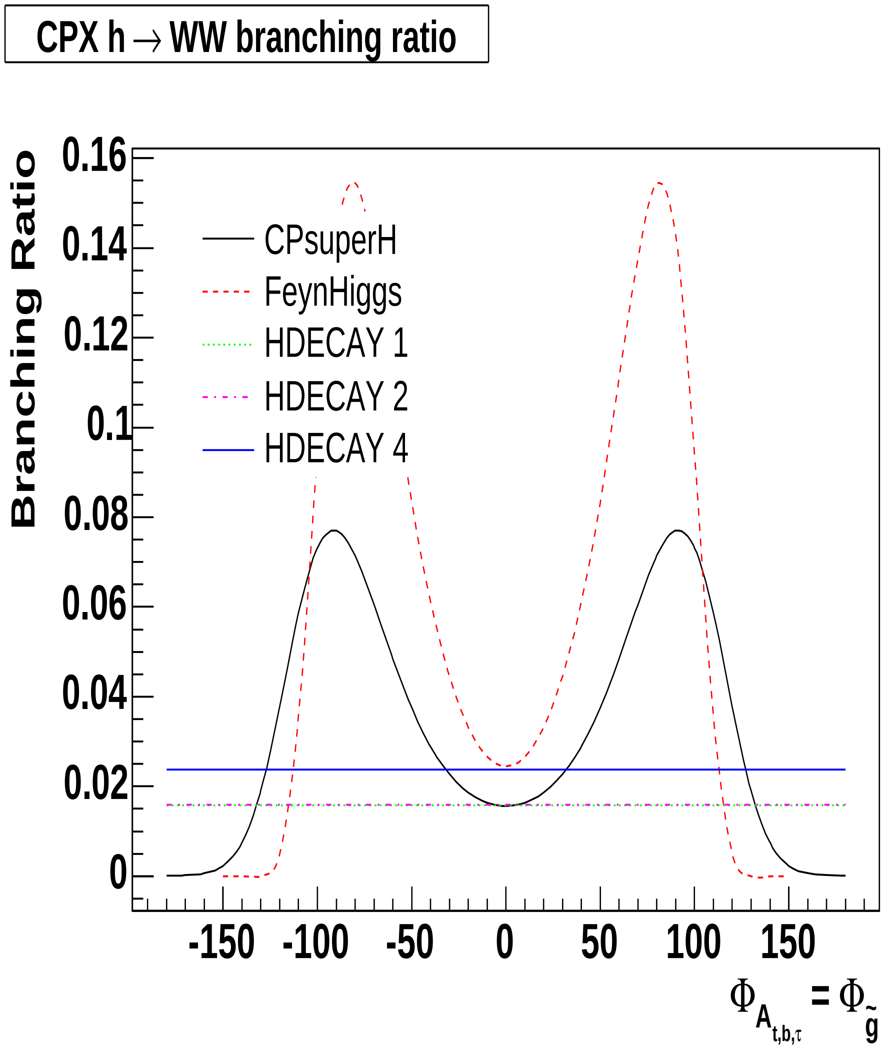
work in progress ...

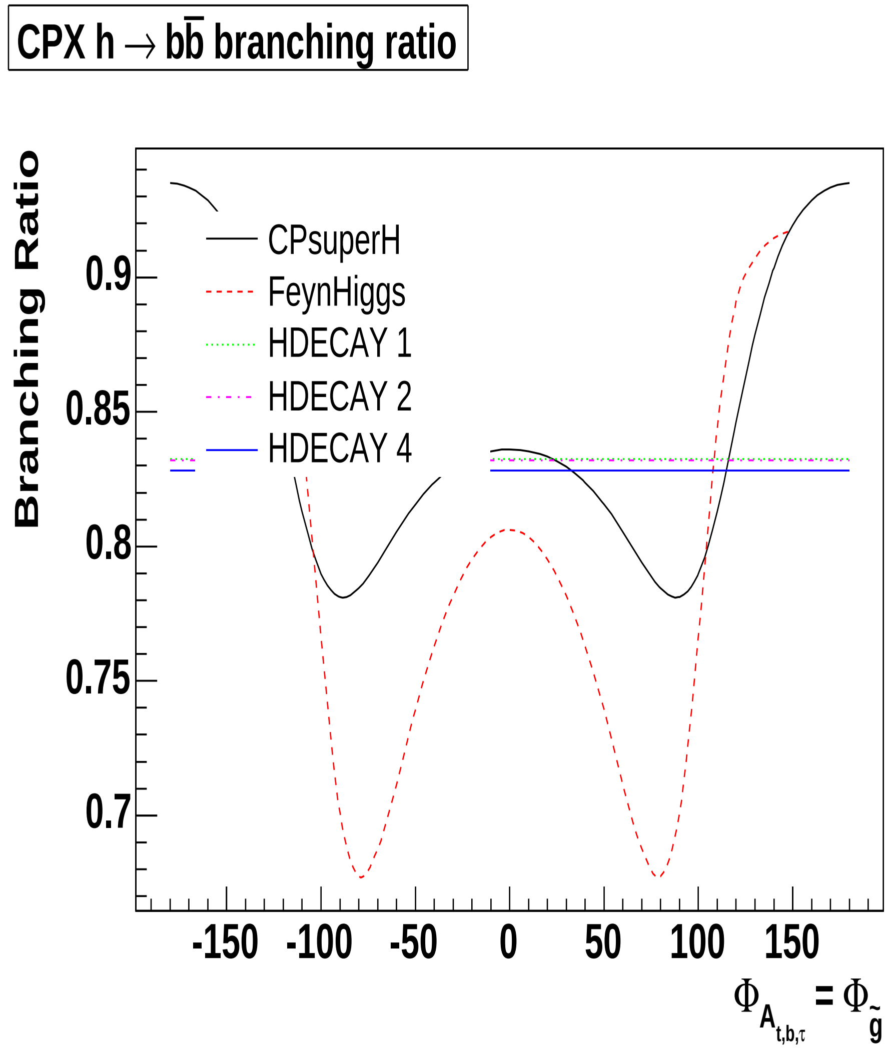
m_{h_1} and total width:





BR($h \to WW^*$), BR($h \to b\bar{b}$)

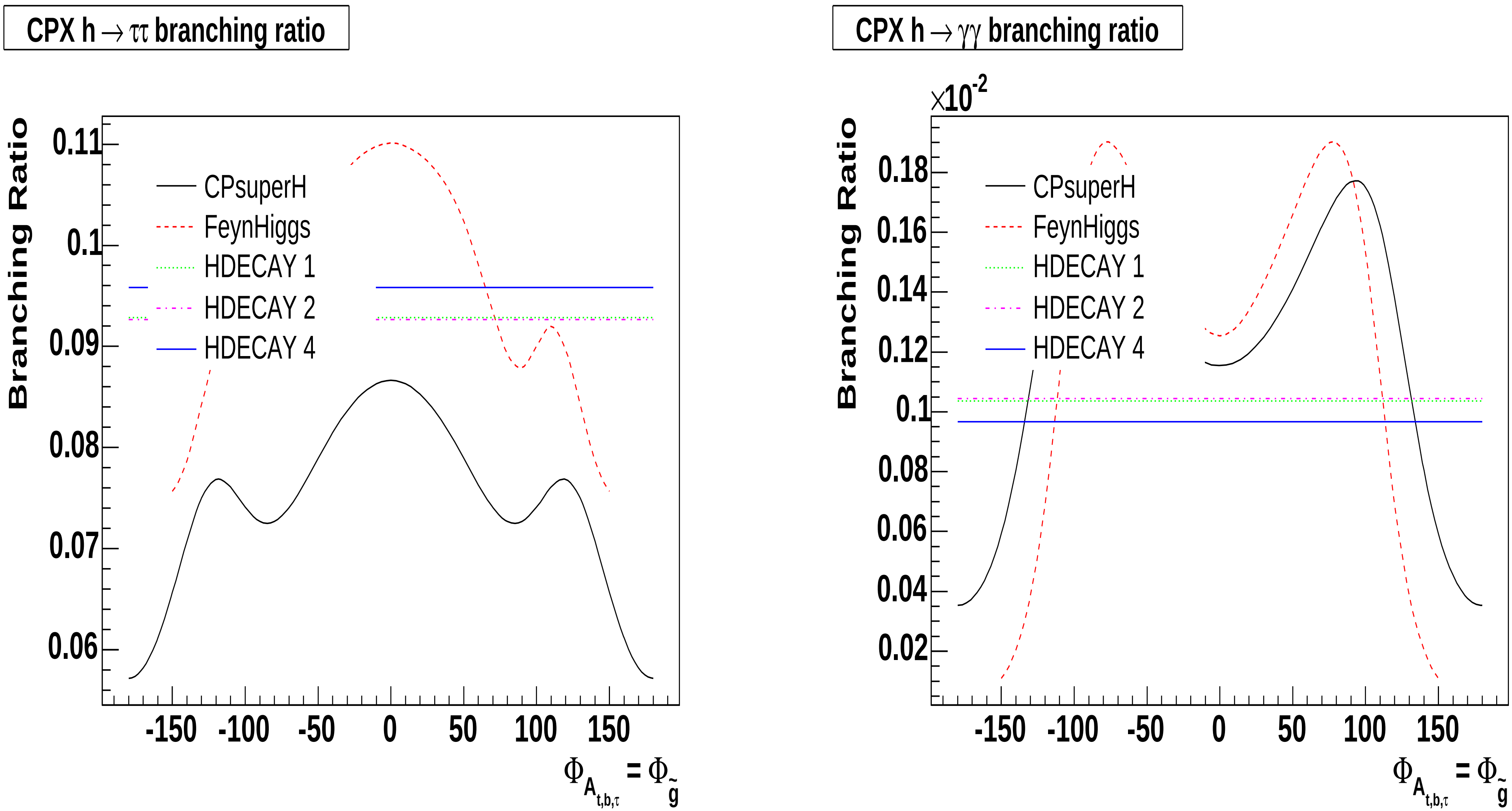




→ large effect for BR($h \to WW^*$)

→ latest *FeynHiggs2.1*: $\Gamma(h \to b\bar{b})$ enhanced (long story . . .)

BR($h \to \tau^+\tau^-$), BR($h \to \gamma\gamma$)



⇒ agreement for qualitative behavior

$\Rightarrow$ agreement for qualitative behavior

$\rightarrow$ latest *FeynHiggs2.1*: $\Gamma(h \to b\bar{b})$ enhanced

Effects on BR$(h \to \ldots)$ depend strongly on $m_h \to \Gamma(h \to WW^*) \to \Gamma_{\text{tot}}$

$\Rightarrow$ need full comparison of $\Gamma(h \to \ldots)$ (w.i.p.)

$\rightarrow$ keep in mind that CPX is an extreme scenario!

parameter ranges with extreme behavior often excluded
$\Rightarrow$ take constraints into account

5. Conclusinos

- High experimental precision and large radiative corrections in the cMSSM Higgs sector make reliable codes mandatory

- Two codes compared here: **FeynHiggs** and **CPsuperH**

- Some differences in usability and non-Higgs evaluations

- Analytical differences:
  - different approach for masses and couplings
  - some parts more/less complete in both codes

- Numerical differences:
  - rMSSM: differences in masses couplings mostly due to full one-loop and complete $\mathcal{O}\left(\alpha_t^2\right)$ in *FeynHiggs2.1*
  - rMSSM: Γ/BR comparison of CPsH/Hdecay/FeynHiggs
  - cMSSM: comparison in (extreme) CPX scenario:
    agreement in qualitative behavior
    effects from $m_h \to \Gamma(h \to WW^*) \to \Gamma_{\text{tot}}$
    $\Rightarrow$ need full comparison of $\Gamma(h \to \ldots)$ (w.i.p.)