# LHC Higgs Cross Section WG:

# Branching Ratios – MSSM

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1. Introduction
2. MSSM issues
3. What has been done (few)
4. What has to be done (a lot)
5. Discussion points / future plans

# 1. Introduction

**Supersymmetry (SUSY)** : Symmetry between

$$\text{Bosons} \leftrightarrow \text{Fermions}$$

$$Q\ |\text{Fermion}\rangle \rightarrow |\text{Boson}\rangle$$
$$Q\ |\text{Boson}\rangle \rightarrow |\text{Fermion}\rangle$$

Simplified examples:

$$Q\ |\text{top},\ t\rangle \rightarrow |\text{scalar top},\ \tilde{t}\rangle$$
$$Q\ |\text{gluon},\ g\rangle \rightarrow |\text{gluino},\ \tilde{g}\rangle$$

$\Rightarrow$ each SM multiplet is enlarged to its double size

Unbroken SUSY: All particles in a multiplet have the same mass

Reality: $m_e \neq m_{\tilde{e}} \Rightarrow$ SUSY is broken . . .

. . . via soft SUSY-breaking terms in the Lagrangian (added by hand)

SUSY particles are made heavy: $\boxed{M_{\text{SUSY}} = \mathcal{O}(1\ \text{TeV})}$

# The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_L \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_L \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^\pm, H^\pm} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \quad \tilde{\chi}^\pm_{1,2} \quad \tilde{\chi}^0_{1,2,3,4} \qquad \text{Spin } \frac{1}{2}$$

Enlarged Higgs sector: Two Higgs doublets $\Leftarrow$ focus here!

Problem in the MSSM: many scales

Problem in the MSSM: complex phases

## Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$
$$+ \underbrace{\frac{g'^2 + g^2}{8}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}} |H_1 \bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$

Goldstone bosons: $G^0, G^\pm$

Input parameters: (to be determined experimentally)

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2 (\tan\beta + \cot\beta)$$

## Enlarged Higgs sector: Two Higgs doublets with $\mathcal{CP}$ violation

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix} e^{i\xi}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}} |H_1 \bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$

2 $\mathcal{CP}$-violating phases: $\xi$, $\arg(m_{12})$ $\Rightarrow$ can be set/rotated to zero

Input parameters: (to be determined experimentally)

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_{H^\pm}^2$$

## $\tilde{t}/\tilde{b}$ sector of the MSSM: (scalar partner of the top/bottom quark)

Stop, sbottom mass matrices ($X_t = A_t - \mu^*/\tan\beta$, $X_b = A_b - \mu^* \tan\beta$):

$$\mathcal{M}^2_{\tilde{t}} = \begin{pmatrix} M^2_{\tilde{t}_L} + m_t^2 + DT_{t_1} & m_t X_t^* \\ m_t X_t & M^2_{\tilde{t}_R} + m_t^2 + DT_{t_2} \end{pmatrix} \xrightarrow{\theta_{\tilde{t}}} \begin{pmatrix} m^2_{\tilde{t}_1} & 0 \\ 0 & m^2_{\tilde{t}_2} \end{pmatrix}$$

$$\mathcal{M}^2_{\tilde{b}} = \begin{pmatrix} M^2_{\tilde{b}_L} + m_b^2 + DT_{b_1} & m_b X_b^* \\ m_b X_b & M^2_{\tilde{b}_R} + m_b^2 + DT_{b_2} \end{pmatrix} \xrightarrow{\theta_{\tilde{b}}} \begin{pmatrix} m^2_{\tilde{b}_1} & 0 \\ 0 & m^2_{\tilde{b}_2} \end{pmatrix}$$

mixing important in stop sector (also in sbottom sector for large $\tan\beta$)

soft SUSY-breaking parameters $A_t, A_b$ also appear in $\phi$-$\tilde{t}/\tilde{b}$ couplings

$SU(2)$ relation $\Rightarrow M_{\tilde{t}_L} = M_{\tilde{b}_L}$

$\Rightarrow$ relation between $m_{\tilde{t}_1}, m_{\tilde{t}_2}, \theta_{\tilde{t}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}, \theta_{\tilde{b}}$

## The BR subgroup:

contacts: Ansgar Denner, S.H., Ivica Puljak, Daniela Rebuzzi

other members/contributors: Michael Spira, Georg Weiglein

(and as ‘everywhere’: Chiara Mariotti, Reisaburo Tanaka)

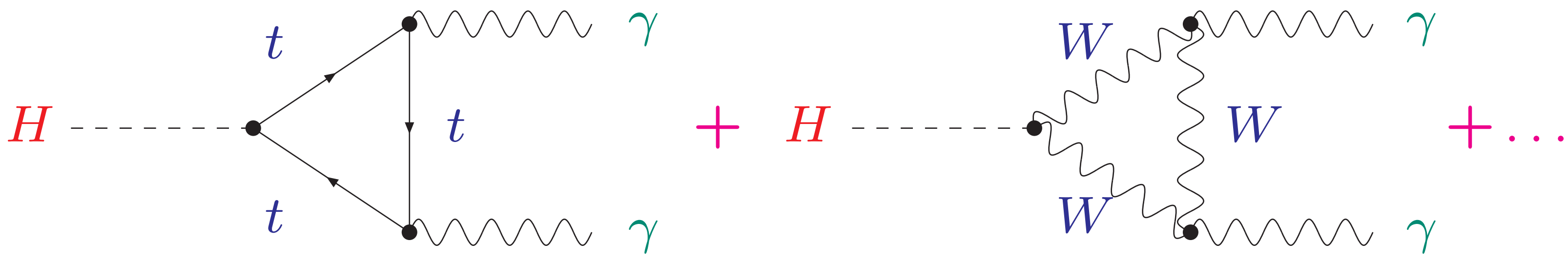
MSSM part: strong overlap with MSSM subgroup

$\Rightarrow$ more MSSM experimentalists needed!

$\Rightarrow$ more MSSM theorists needed?

# 2. MSSM issues:

## Example: $h \to \gamma\gamma$:




## SM:

input:

– SM Higgs mass (free parameter)
– SM (fermion) masses
– SM couplings (at the appropriate scale)

output:

– SM amplitude, branching ratio

# Now for the MSSM:

Input parameters: $M_A$ and $\tan\beta$

$\Rightarrow$ all other masses and mixing angles are predicted!

Tree-level result for $m_h$, $m_H$:

$$m^2_{H,h} = \frac{1}{2}\left[M_A^2 + M_Z^2 \pm \sqrt{(M_A^2 + M_Z^2)^2 - 4M_Z^2 M_A^2 \cos^2 2\beta}\right]$$

$\Rightarrow m_h \leq M_Z$ at tree level

Huge higher-order corrections: *[G. Degrassi, S.H., W. Hollik, P. Slavich, G. Weiglein '02]*

$$\boxed{M_h \lesssim 135 \text{ GeV}}$$

$\Rightarrow$ (most) Higgs masses and couplings are not free parameters

Propagator/Mass matrix at tree-level:

$$\begin{pmatrix} q^2 - m_A^2 & 0 & 0 \\ 0 & q^2 - m_H^2 & 0 \\ 0 & 0 & q^2 - m_h^2 \end{pmatrix}$$

Propagator / mass matrix with higher-order corrections
($\rightarrow$ Feynman-diagrammatic approach):

$$M_{hHA}^2(q^2) = \begin{pmatrix} q^2 - m_A^2 + \hat{\Sigma}_{AA}(q^2) & \hat{\Sigma}_{AH}(q^2) & \hat{\Sigma}_{Ah}(q^2) \\ \hat{\Sigma}_{HA}(q^2) & q^2 - m_H^2 + \hat{\Sigma}_{HH}(q^2) & \hat{\Sigma}_{Hh}(q^2) \\ \hat{\Sigma}_{hA}(q^2) & \hat{\Sigma}_{hH}(q^2) & q^2 - m_h^2 + \hat{\Sigma}_{hh}(q^2) \end{pmatrix}$$

$\hat{\Sigma}_{ij}(q^2)$ $(i,j = h, H, A)$ : renormalized Higgs self-energies

$\hat{\Sigma}_{Ah}, \hat{\Sigma}_{AH} \neq 0 \Rightarrow \mathcal{CP}$V, $\mathcal{CP}$-even and $\mathcal{CP}$-odd fields can mix

complex roots of $\det(M_{hHA}^2(q^2))$: $\mathcal{M}_{h_i}^2 (i = 1, 2, 3)$: $\mathcal{M}^2 = M^2 - iM\Gamma$

## Higgs couplings, tree level:

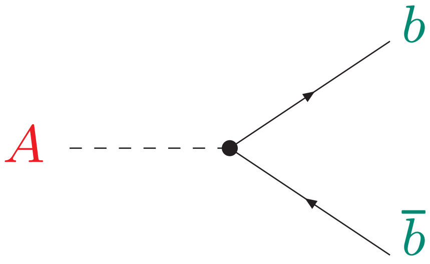
$$
\begin{aligned}
g_{hVV} &= \sin(\beta-\alpha)\, g^{\text{SM}}_{HVV}, \qquad V = W^{\pm}, Z \\
g_{HVV} &= \cos(\beta-\alpha)\, g^{\text{SM}}_{HVV} \\
g_{hAZ} &= \cos(\beta-\alpha)\, \frac{g'}{2\cos\theta_W} \\
g_{hb\bar{b}}, g_{h\tau^+\tau^-} &= -\frac{\sin\alpha}{\cos\beta}\, g^{\text{SM}}_{Hb\bar{b},H\tau^+\tau^-} \\
g_{ht\bar{t}} &= \frac{\cos\alpha}{\sin\beta}\, g^{\text{SM}}_{Ht\bar{t}} \\
g_{Ab\bar{b}}, g_{A\tau^+\tau^-} &= \gamma_5 \tan\beta\, g^{\text{SM}}_{Hb\bar{b}}
\end{aligned}
$$

$\Rightarrow$ $g_{hb\bar{b}}, g_{h\tau^+\tau^-}$: significant suppression or enhancement w.r.t. SM coupling possible

$\Rightarrow$ also here: large higher-order corrections!

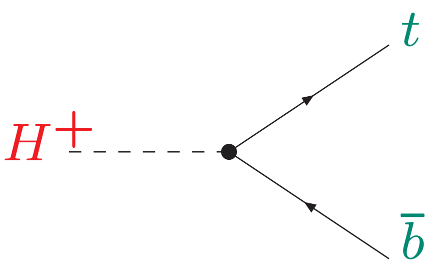
# Important higher-order corrections in the MSSM: $\Delta_b$

Additional enhancement factors compared to the SM case:




$$y_b \quad \longrightarrow \quad y_b \, \frac{\tan\beta}{1+\Delta_b}$$

At large $\tan\beta$: either $H \approx A$ or $h \approx A$



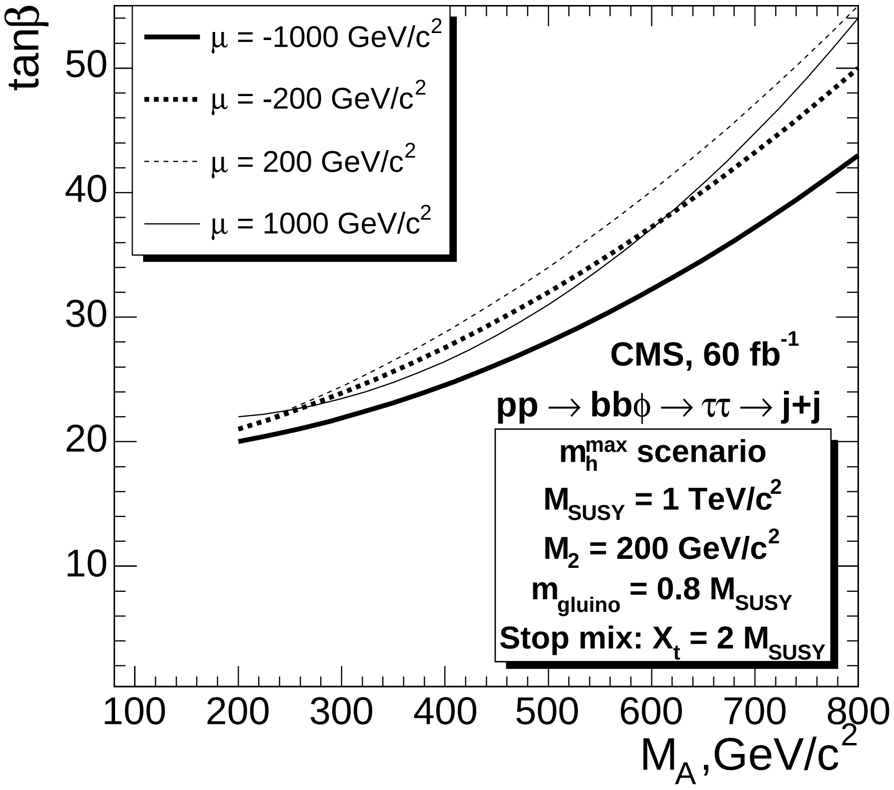

$$y_b \, \frac{\tan\beta}{1+\Delta_b}$$

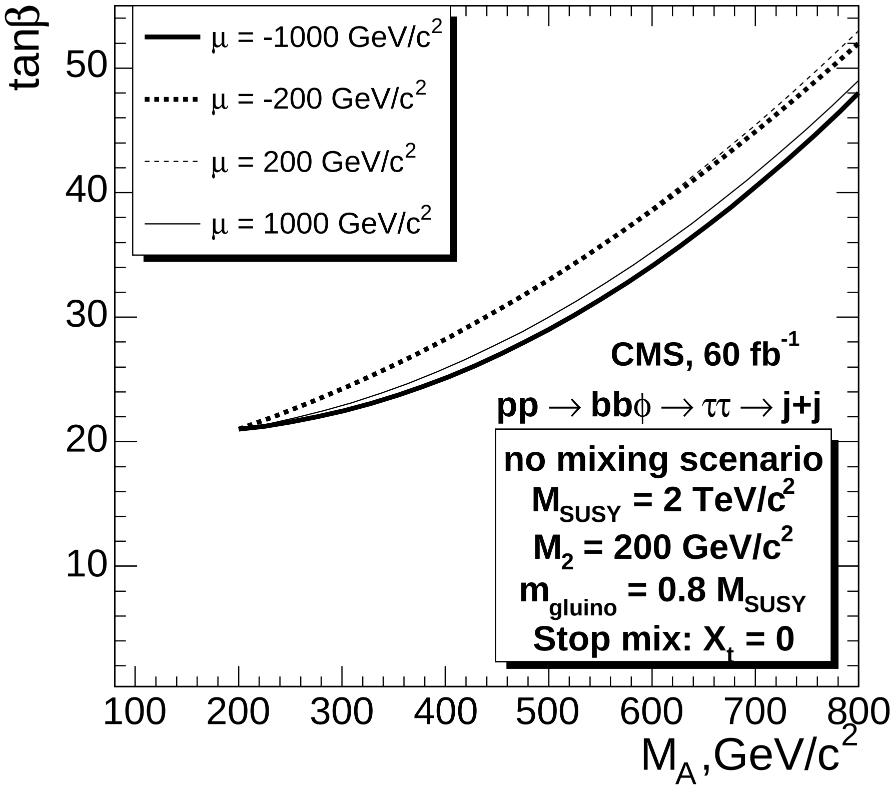
$$\Delta_b = \frac{2\alpha_s}{3\,\pi} m_{\tilde{g}}\, \mu \, \tan\beta \times I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) + \frac{\alpha_t}{4\,\pi} A_t\, \mu\, \tan\beta \times I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)$$

$\Rightarrow$ other parameters enter $\Rightarrow$ strong $\mu$ dependence

## Dependence of LHC wedge from $b\bar{b} \to H/A \to \tau^+\tau^- \to 2\,$jets on $\mu$:

[*S.H., A. Nikitenko, G. Weiglein et al. '06*]



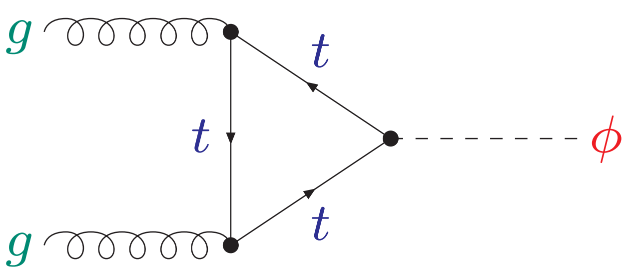

$\Rightarrow$ non-negligible variation with the sign and absolute value of $\mu$

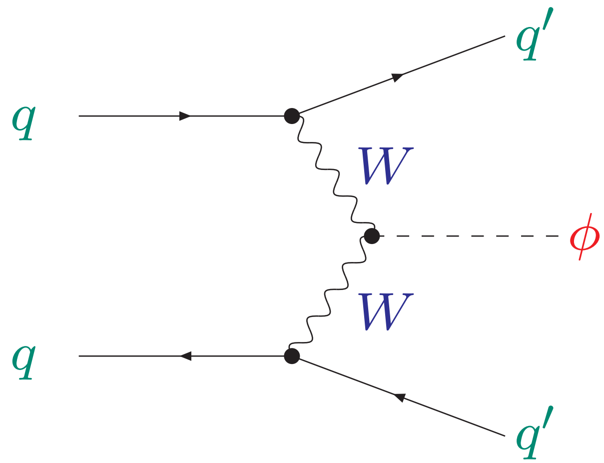
(despite numerical compensations in production and decay)

Another issue: external (on-shell) Higgs bosons

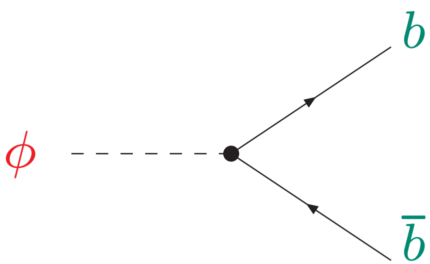
Examples for external (on-shell) Higgs bosons ($\phi = h_1, h_2, h_3$):

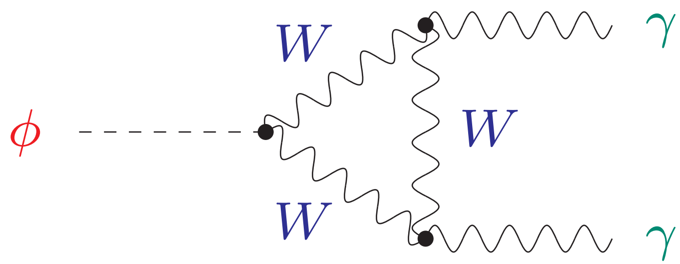
Higgs production:




Higgs decays:




$\Rightarrow$ important to ensure on-shell properties of external Higgs boson

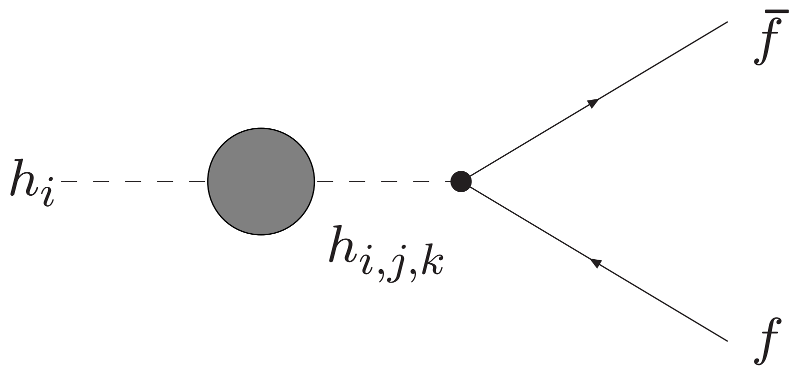
## Correct on-shell amplitude with external Higgs $h_i$ :

[M. Frank, T. Hahn, S.H., W. Hollik, H. Rzehak, G. Weiglein, K. Williams '06]

$$A(h_i) = \sqrt{Z_i}\left(\Gamma_{h_i} + Z_{ij}\Gamma_{h_j} + Z_{ik}\Gamma_{h_k}\right)$$

$\sqrt{Z_i}$ : ensures that the residuum of the external Higgs boson is set to 1

$Z_{ij}$ : describes the transition from $i \to j$




Written more compact with the $\mathbf{Z}$ matrix : $\mathbf{Z}_{ij} = \sqrt{Z_i}\, Z_{ij}$

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$$Z_i = \left[1 + \left(\hat{\Sigma}^{\rm eff}_{ii}\right)'(\mathcal{M}_i^2)\right]^{-1}, \qquad Z_{ij} = \left.\frac{\Delta_{ij}(p^2)}{\Delta_{ii}(p^2)}\right|_{p^2=\mathcal{M}_i^2}$$

$$\hat{\Sigma}^{\rm eff}_{ii}(p^2) = \hat{\Sigma}_{ii}(p^2) - i\frac{2\hat{\Gamma}_{ij}\hat{\Gamma}_{jk}\hat{\Gamma}_{ki} - \hat{\Gamma}^2_{ki}\hat{\Gamma}_{jj} - \hat{\Gamma}^2_{ij}\hat{\Gamma}_{kk}}{\hat{\Gamma}_{jj}\hat{\Gamma}_{kk} - \hat{\Gamma}^2_{jk}}$$

$$\hat{\Gamma}_{jk} \equiv \hat{\Gamma}_{jk}(p^2) = i(M^2_{hHA})_{jk}(p^2), \qquad \Delta(p^2) = \left(-\Gamma(p^2)\right)^{-1}$$

$m_i$: tree-level masses $\qquad$ $M_i$: higher-order corrected masses

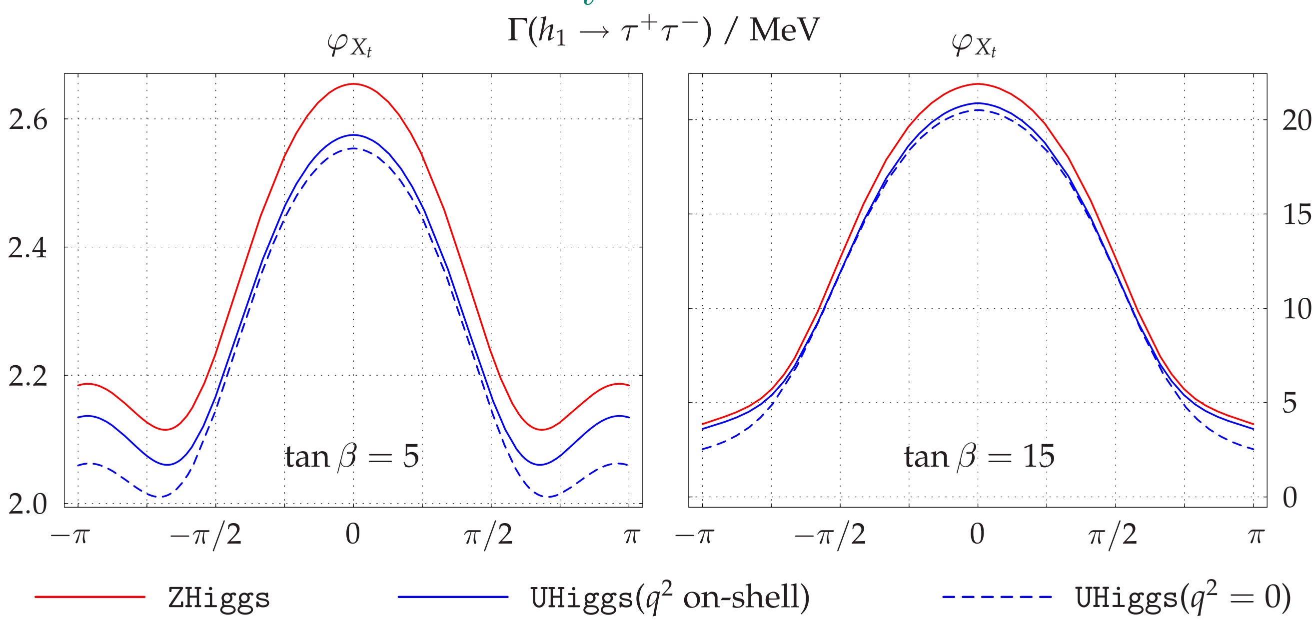
Written more compact with the $\mathbf{Z}$ matrix : $\mathbf{Z}_{ij} = \sqrt{Z_i}\, Z_{ij}$

## Numerical example for external Higgs bosons:

[*T. Hahn, S.H., W. Hollik, H. Rzehak, G. Weiglein '07*]

$M_{\text{SUSY}} = m_{\tilde{g}} = M_2 = 500$ GeV, $A_t = 1000$ GeV, $\mu = 1000$ GeV, $M_{H^\pm} = 150$ GeV

### $\Gamma(h_1 \to \tau^+\tau^-)$ as a function of $\phi_{X_t}$




full: red solid: **Z** , approximations: blue solid: **U** , blue dashed: **R**

$\Rightarrow$ deviations at the 5-10% level

## Needed:

### Output

### Input

```
MT          172.7
MB          4.7
MW          80.4
MZ          91.1
MSusy       975
MA0         200
Abs(M_2)    332
Abs(MUE)    980
TB          50
Abs(At)     -300
Abs(Ab)     1500
Abs(M_3)    975
```

Computercode →

```
------------------- HIGGS MASSES -------------------
| Mh0    =   116.022817
| MHH    =   199.943497
| MA0    =   200.000000
| MHp    =   216.973920
| SAeff  =  -0.02685112
| ZHiggs =   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
  ...
```

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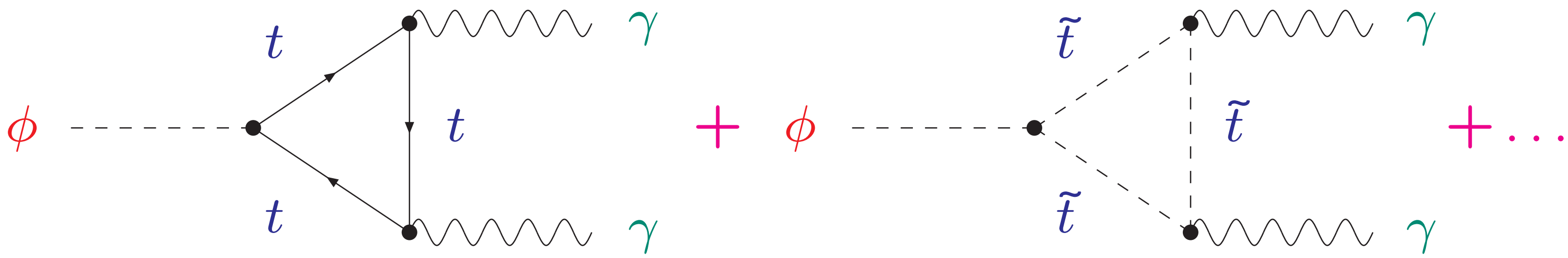
## Specialized codes on the market:

– FeynHiggs [*T. Hahn, S.H., W. Hollik, H. Rzehak, G. Weiglein*]
(www.feynhiggs.de)

– CPSuperH [*J.S. Lee, A. Pilaftsis et al.*]
(www.hep.man.ac.uk/u/jslee/CPsuperH.html)

## $\phi \to \gamma\gamma$ in the MSSM:

Additional contribution to $\phi \to \gamma\gamma$ :




input:
– SM (fermion) masses
– SM couplings (at the appropriate scale)
– MSSM parameters

output $\to$ new input (via FeynHiggs, CPSuperH, . . . ):
– MSSM Higgs masses
– MSSM couplings, $\mathbf{Z}$ matrix, . . .

output: (via FeynHiggs, CPSuperH, Hdecay, Prophecy4f, . . . )
– MSSM amplitude, decay width/branching ratio
How to re-use SM amplitudes? How to include MSSM corrections?

## Comparison?

→ see next section (and back-up)

## MSSM issues:

→ large (full?) overlap with MSSM subgroup

⇒ work together/coordinated!

## 3. What has been done (few)

### Which models should be considered?

(a) rMSSM (MSSM with real parameters)

(b) cMSSM (MSSM with complex parameters)

(c) GUT based models (i.e. simplified MSSM versions)

(d) extensions of the MSSM, e.g. NMSSM

Agreement so far: focus on (a)

– With more time/man power we continue with (b)
– (c) would require additional tools (SoftSUSY, Suspect, Spheno, ...) and this is probably not our task
– (d) will be considered (much?) later

often: MSSM $\equiv$ rMSSM

## Comparison of codes for calculation of ‘new input parameters’ ($M_h, \ldots$):

$\rightarrow$ comparison of
– FeynHiggs
– CPSuperH
– Hdecay (calculation based on extension of ‘old’ Carena/Wagner results)

Started: numerical comparison:

– grid of predictions from FeynHiggs in $M_A$–$\tan\beta$ plane
  in the $m_h^{\text{max}}$ and no-mixing scenario
– to be compared with CPSuperH
  $\rightarrow$ authors (Pilaftsis, Lee) contacted, will send data
– to be compared with Hdecay

Short (biased?) analytical comparison: $\longrightarrow$ back-up

rMSSM: FeynHiggs has more than CPSuperH

$\Rightarrow$ remaining differences should not be interpreted as theory uncertainties

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**Q:** how important is this? Can it be important for early data?

**A:** first measurements: low $M_A$, large $\tan\beta$
precise predictions (translation from input parameters to masses etc) can/will be relevant

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**Q:** on-line version important?
(testing of single points/'private' implementations)

**A:** theorists: opinions vary
experimentalists: would be helpful

# 4. What has to be done (a lot)

## Prediction of decay widths/branching ratios in the rMSSM:

Codes:

– FeynHiggs
– CPSuperH
– Hdecay
– Prophecy4F best(!) for $H \to VV^{(*)} \to 4f$ in the SM . . .

Short comparison between FH and CPsH: $\to$ back-up

Short comparison between FH and HD: $\to$ back-up

## Work to do:

– we have to find out how each decay width can be calculated best in the MSSM

⇒ possibly a mixture of codes

– can P4f be used?

P4f + effective couplings + Z-matrix for OS Higgses? IBA?

⇒ has to be investigated

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## Obvious strategy:

– evaluate above options for certain parameter choices (grid . . . )

– comparison!

  including general considerations/ideas how to evaluate the partial decay widths best

– decision: which option gives best result for one channel

  → take this result as default

– evaluate total width and BR (grid . . . ??)

# Prediction of BRs in the MSSM:

Not possible:

predictions in table format as in SM, due to the impact of SUSY parameters

Possible: 'test data' for certain scenarios (to check/validate)

MSSM-XS group is doing this for mhmax and no-mixing scenario;
$\Rightarrow$ use the same scenarios

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## Possible strategy:

– evaluate ‘best’ prediction for $m_h^{\text{max}}$- and no-mixing scenario
  $\Rightarrow$ provide tables tests/cross checks
– “combination of codes” to allow best and consistent calculations for any MSSM parameter point

**How?**

steering scripts, . . . ?
on-line version desirable?!

# 5. Discussion points / future plans

1. First data: low $M_A$, large $\tan\beta$

   First analyses: exclusion limits? benchmarks? XS $\times$ BR limits?

   SUSY parameter dependences ($\Delta_b$, $\mu$ dependence, ...)

   $\Rightarrow$ important for interpretation

2. Phenomenology in the MSSM can differ strongly from the SM

   Possible deviations:

   – $\phi \to$ SUSY

   – SUSY $\to \phi +$ SUSY

   – $\phi \to$ invisible, e.g. $\phi \to \tilde{\chi}^0_1 \tilde{\chi}^0_1$

   – several Higgses with similar masses

   – ... with relatively large width

   – very light Higgs bosons with $m_\phi < 114.4$. GeV

   – ...

3. Can we always achieve decoupling to the SM limit?
Example for the problem: some SM corrections that are know can possibly not be implemented into the SUSY calculation. Then decoupling to the SM limit cannot be reached

4. For which part of the MSSM parameter space should the code be reliable/optimized?
SM-limit?
Or where one expects large differences between SM and MSSM?

5. . . .

Back-up

## Short (biased?) comparison for calculation of 'new input':

### Higgs self-energy correction in the rMSSM:

CPsH:

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

FeynHiggs:

– full one-loop including full complex phase dependence
– full momentum dependence (at one-loop)
– full $\mathcal{O}\left(\alpha_s\alpha_t, \alpha_t^2\right)$
– $\mathcal{O}(\alpha_s\alpha_b)$: $(\alpha_s \tan\beta)^n$ resummation + subleading terms of $\mathcal{O}\left(\alpha_t\alpha_b, \alpha_b^2\right)$
– $\mathrm{Im}\,\hat{\Sigma}$ included consistently in mass and coupling evaluation

## Short (biased?) comparison between FH and CPsH: (to be extended!)

1) Calculation of $h \to f\bar{f}$

$\to$ full one-loop corrections in FH

effects: possibly visible, depending on the parameter choices

2) OS properties for external Higgs bosons:

$\to$ only FeynHiggs has the $\mathbf{Z}$ matrix

effects: possibly relevant, depending on the parameters

## Short (biased?) comparison between FH and HD: (to be extended!)

1) Calculation of ‘new input parameters’ ($M_h, \ldots$)

→ HD does everything on its own or uses SLHA
(additionally induced uncertainties??)

2) $h \to q\bar{q}$:

→ HD has some 3L corrections in $h \to q\bar{q}$
effects: small, but equally important: reduced theory uncertainty

3) $h \to VV^{(*)}$:

→ HD has more corrections in $h \to VV^{(*)}$
effects: visible in the SM, less visible in the MSSM
problem here: the SM-EW corrections cannot simply be applied in the MSSM (see SM part)

4) $h \to f\bar{f}$

→ full one-loop corrections in FH
effects: possibly visible, depending on the parameter choices

5) OS properties for external Higgs bosons:

→ only FH has the $\mathbf{Z}$ matrix
effects: possibly relevant, depending on the parameters

## FeynHiggs and CPsuperH: Comparison

Input:

| on-shell squark parameters | $\overline{\text{DR}}$ squark parameters |
|---|---|
| FeynHiggs | CPsuperH |

Transformation from one scheme to another necessary:

Use relation:

$$X^{\overline{\text{DR}}} + \delta X^{\overline{\text{DR}}} = X^{\text{OS}} + \delta X^{\text{OS}}$$

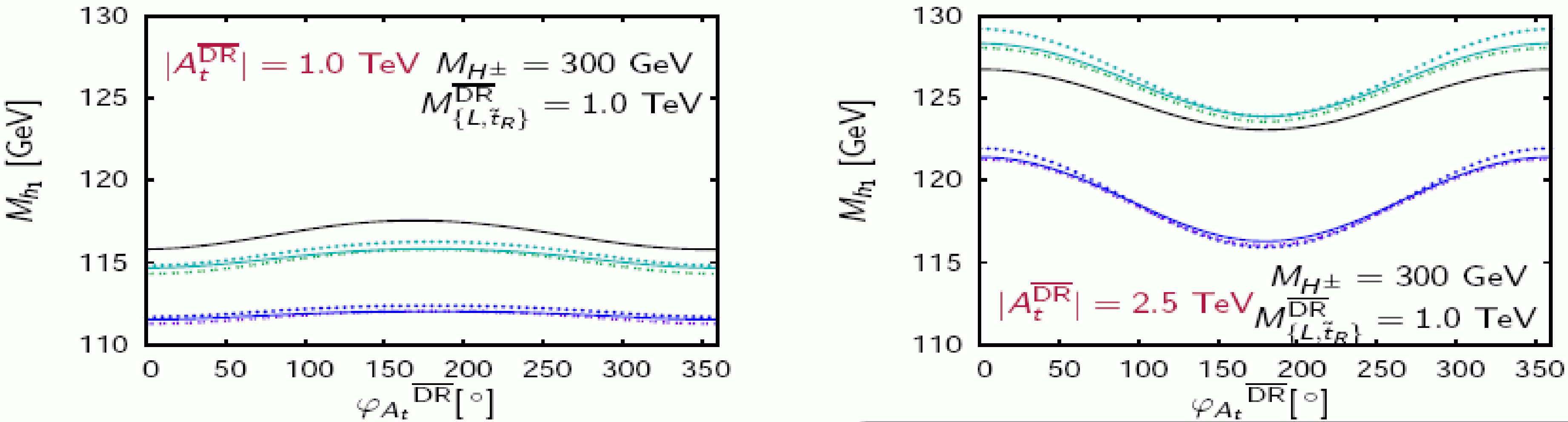
with $X = \{A_t, M_L, M_{\tilde{t}_R}\}$: squark soft breaking parameter

$\delta X^{\text{OS}}$ is then determined by the on-shell counterterms:

$$\delta X^{\text{OS}} = \delta X^{\text{OS}}(\delta m_{\tilde{t}_1}^{\text{OS}}, \delta m_{\tilde{t}_2}^{\text{OS}}, \delta m_t^{\text{OS}}, \delta \theta_{\tilde{t}}^{\text{OS}}, \delta \varphi_{\tilde{t}}^{\text{OS}})$$

## FeynHiggs and CPsuperH: Comparison

$\varphi_{A_t}{}^{\overline{\rm DR}}$-dependence for different $|A_t^{\overline{\rm DR}}|$: Preliminary $\tan\beta = 10$




CPsuperH

FeynHiggs (up to $\mathcal{O}(\alpha_t\alpha_s)$)

FeynHiggs with Interpolation

Parameter transformation: $\mathcal{O}(\alpha_s)$ $\mathcal{O}(\alpha_s + \alpha_t)$

also $\mu$ transformed

Differences:

CPsuperH:

(leading) log $\mathcal{O}(\alpha_t^2)$ terms

FeynHiggs: non-log $\mathcal{O}(\alpha_t\alpha_s)$ terms

FeynHiggs: non-log $\mathcal{O}(\alpha_t\alpha_s)$ terms

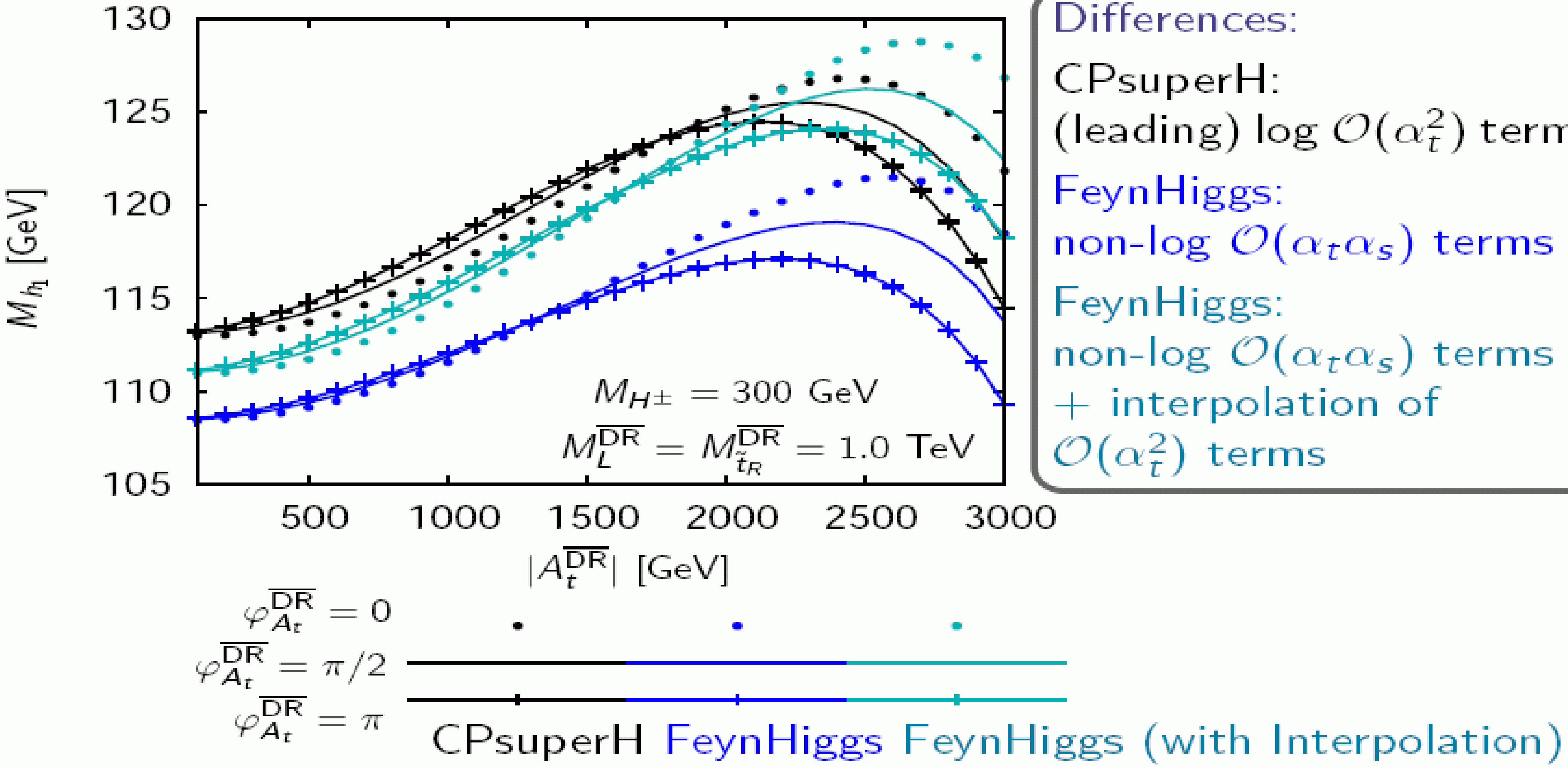
+ interpolation of $\mathcal{O}(\alpha_t^2)$ terms

MSSM Higgs Physics Tools: FeynHiggs in Comparison with CPsuperH Heidi Rzehak

## FeynHiggs and CPsuperH: Comparison

$A_t^{\overline{DR}}$-dependence: Preliminary

$\tan\beta = 10$




Differences:

CPsuperH:
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FeynHiggs:
non-log $\mathcal{O}(\alpha_t\alpha_s)$ terms
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