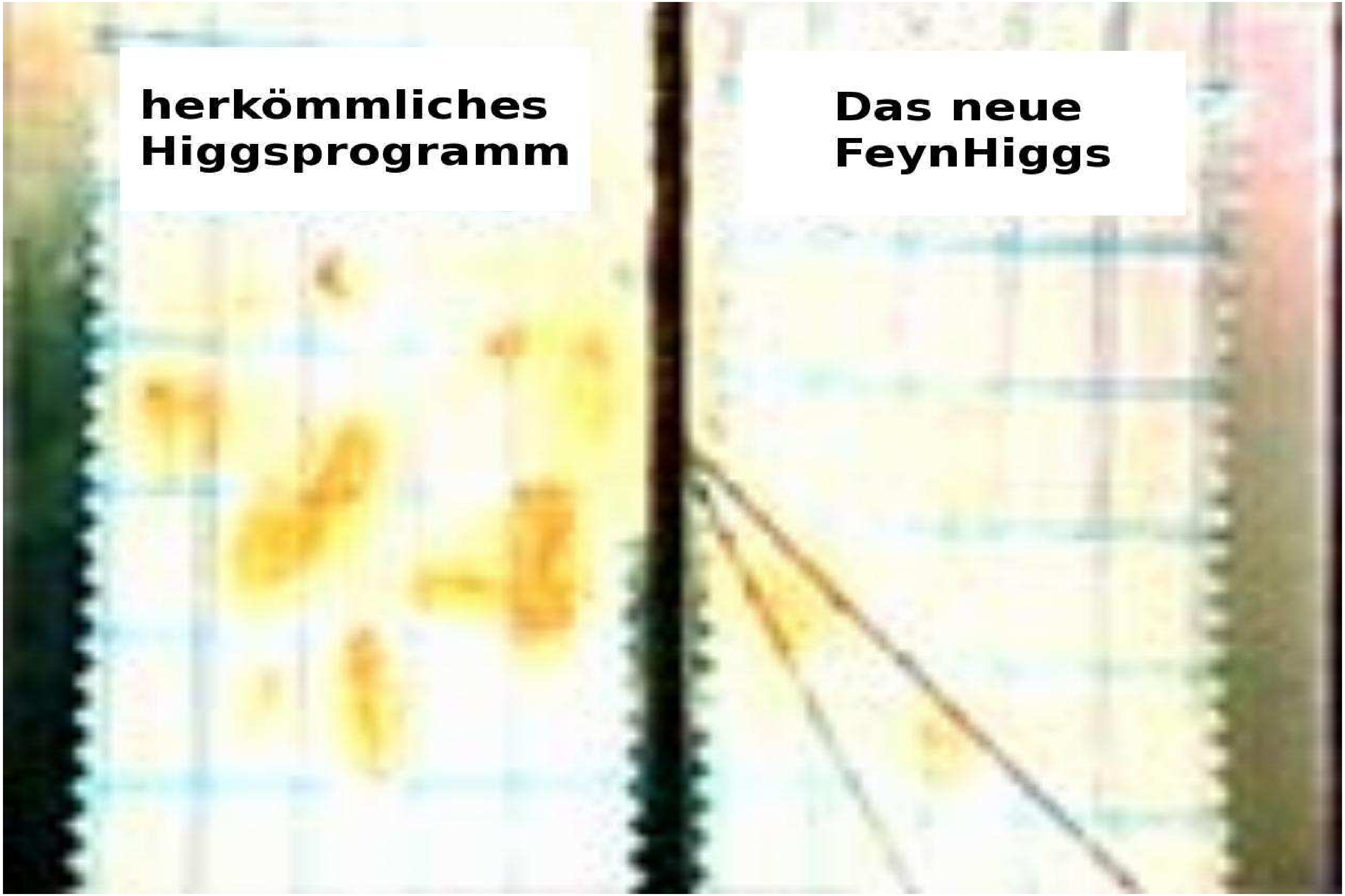
herkömmliches
Higgsprogramm
Das neue
FeynHiggs

Neutral Higgs Production - Status and Tools:

Sven Heinemeyer, IFCA (CSIC, Santander)

Wuppertal, 03/2010

1. My motivation and focus

2. MSSM issues

3. $gg \to \phi, \ \phi = h, H, A$

4. $b\bar{b} \to \phi, \ \phi = h, H, A$

Neutral Higgs Production - Status and Tools:

Sven's view (Michael's view later)

Sven Heinemeyer, IFCA (CSIC, Santander)

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1. My motivation and focus
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1. My motivation and focus

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:

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

⇒ each SM multiplet is enlarged to its double size

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

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

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

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

Supersymmetry: Motivation

The SM is in a pretty good shape.

Why MSSM? (Is it worth to double the particle spectrum?)

1.) Stability of the Higgs mass against higher-order corr.

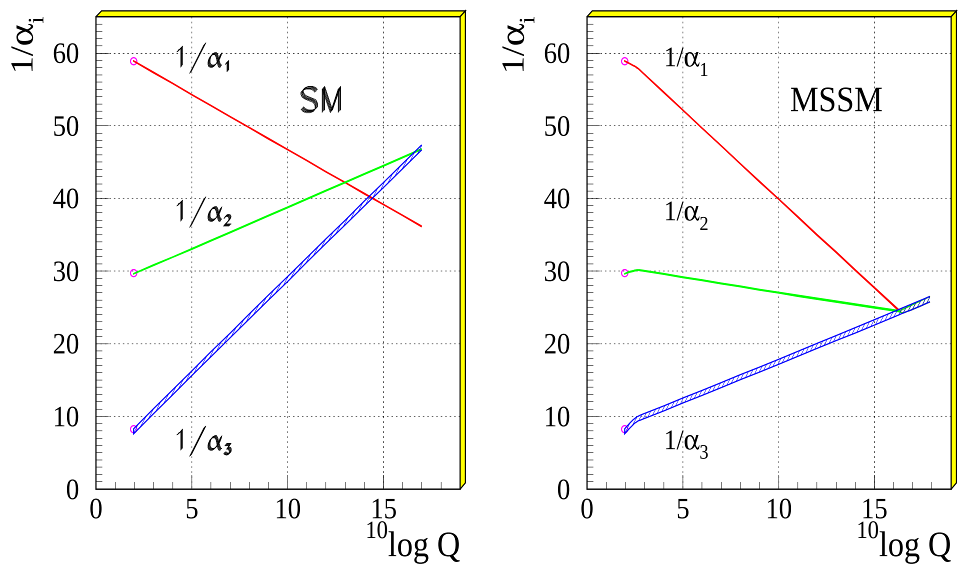
2.) Unification of gauge couplings: Not possible in the SM, but in the MSSM (although it was not designed for it.)

3.) Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs

4.) SUSY provides CDM candidate

5.) ...

Unification of the Coupling Constants in the SM and the minimal MSSM



[Amaldi, de Boer, Fürstenau '92]

Supersymmetry: Motivation

The SM is in a pretty good shape.

Why MSSM? (Is it worth to double the particle spectrum?)

1.) Stability of the Higgs mass against higher-order corr.

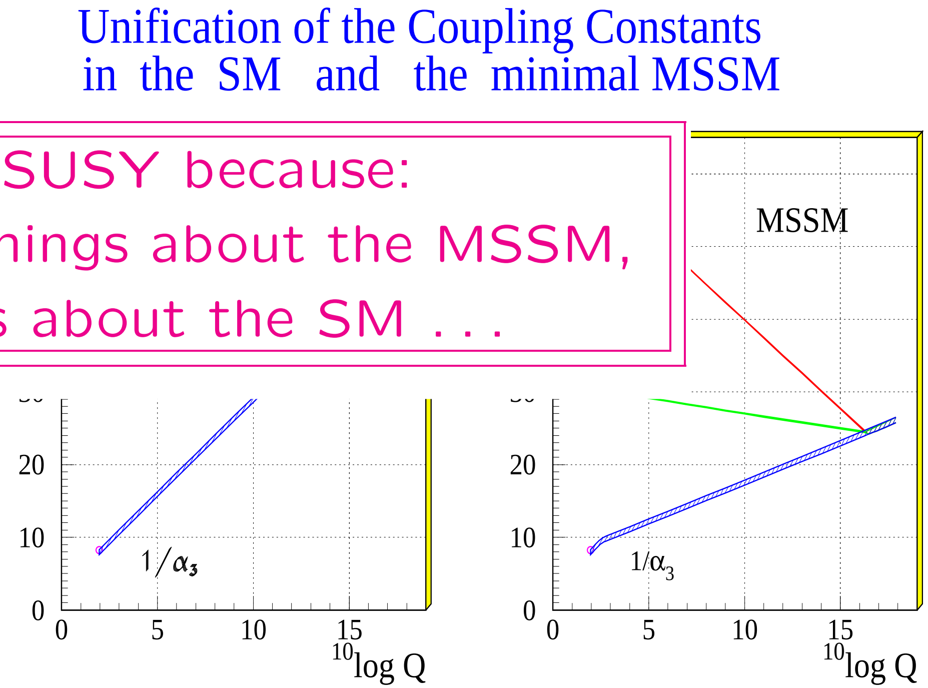
2.) Unification of gauge couplings:
Not possi
the MSSM
designed f

I will concentrate on SUSY because:
I might know a few things about the MSSM,
and I know much less about the SM . . .

3.) Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs

4.) SUSY provides CDM candidate

5.) . . .



[*Amaldi, de Boer, Fürstenau '92*]

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

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

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

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

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

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: ξ, $\arg(m_{12})$ $\Rightarrow$ 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 ϕ-$\tilde{t}/\tilde{b}$ couplings

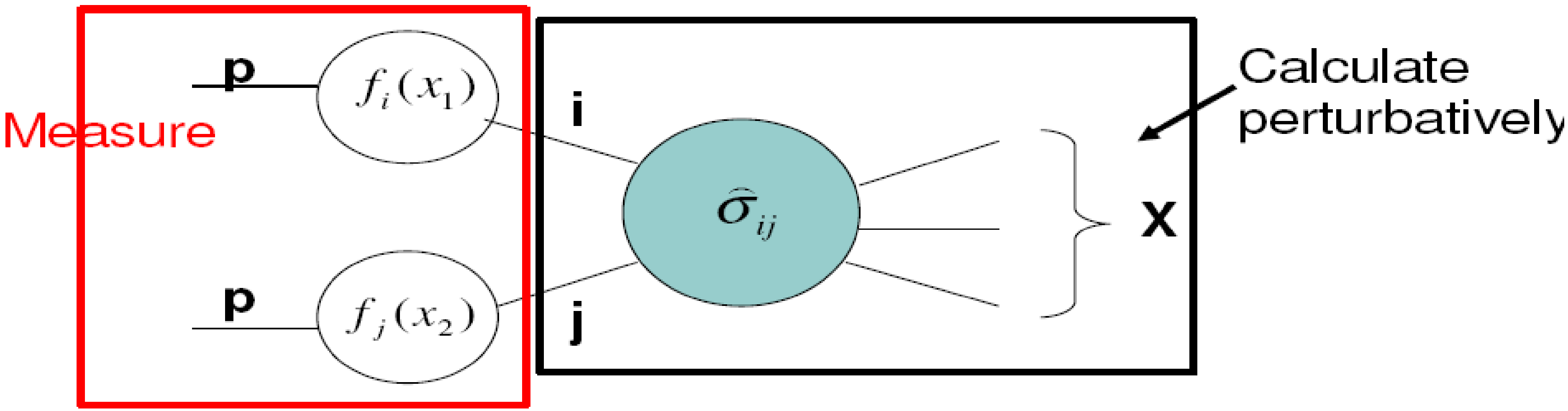
$$SU(2) \text{ relation} \Rightarrow M_{\tilde{t}_L} = M_{\tilde{b}_L}$$

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

2. MSSM issues:

(Higgs) cross section calculation at the LHC:

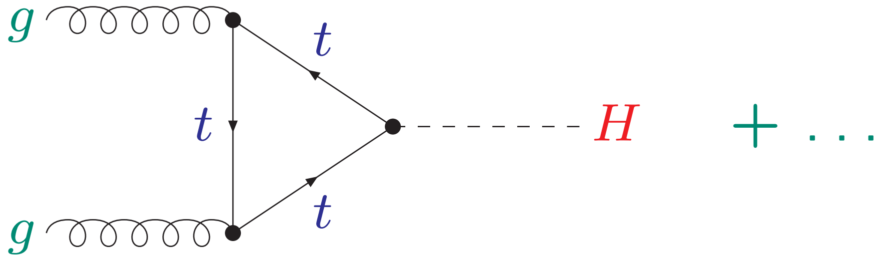
$$\sigma(pp \to X) = \sum_{ij} \int dx_1 dx_2\, f_i(x_1, \mu_f)\, f_j(x_2, \mu_f)\, \hat{\sigma}(ij \to X)$$



PDFs ($x_{1,2}$:) momentum fraction carried by the incoming quarks, gluons
$\Rightarrow$ universal for SM and MSSM

$\hat{\sigma}$: partonic cross section, calculated perturbatively
$\Rightarrow$ different in SM and MSSM

Gluon-Fusion:



SM:

input:

– SM Higgs mass (free parameter)
– SM (fermion) masses
– SM couplings (at the appropriate scale)
  $\rightarrow$ more in "Michael's view"?

output:

– SM amplitude, cross section

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:

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

$\Rightarrow m_h \le M_Z$ 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
($\to$ Feynman-diagrammatic approach):

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

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

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

Higgs couplings, tree level:

$$g_{hVV} = \sin(\beta - \alpha)\, g_{HVV}^{\text{SM}}, \qquad V = W^{\pm}, Z$$

$$g_{HVV} = \cos(\beta - \alpha)\, g_{HVV}^{\text{SM}}$$

$$g_{hAZ} = \cos(\beta - \alpha)\, \frac{g'}{2\cos\theta_W}$$

$$g_{hb\bar{b}}, g_{h\tau^+\tau^-} = -\frac{\sin\alpha}{\cos\beta}\, g_{Hb\bar{b},H\tau^+\tau^-}^{\text{SM}}$$

$$g_{ht\bar{t}} = \frac{\cos\alpha}{\sin\beta}\, g_{Ht\bar{t}}^{\text{SM}}$$

$$g_{Ab\bar{b}}, g_{A\tau^+\tau^-} = \gamma_5 \tan\beta\, g_{Hb\bar{b}}^{\text{SM}}$$

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

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

Example for large higher-order corrections in the MSSM:

$$gg \to h \to \gamma\gamma$$

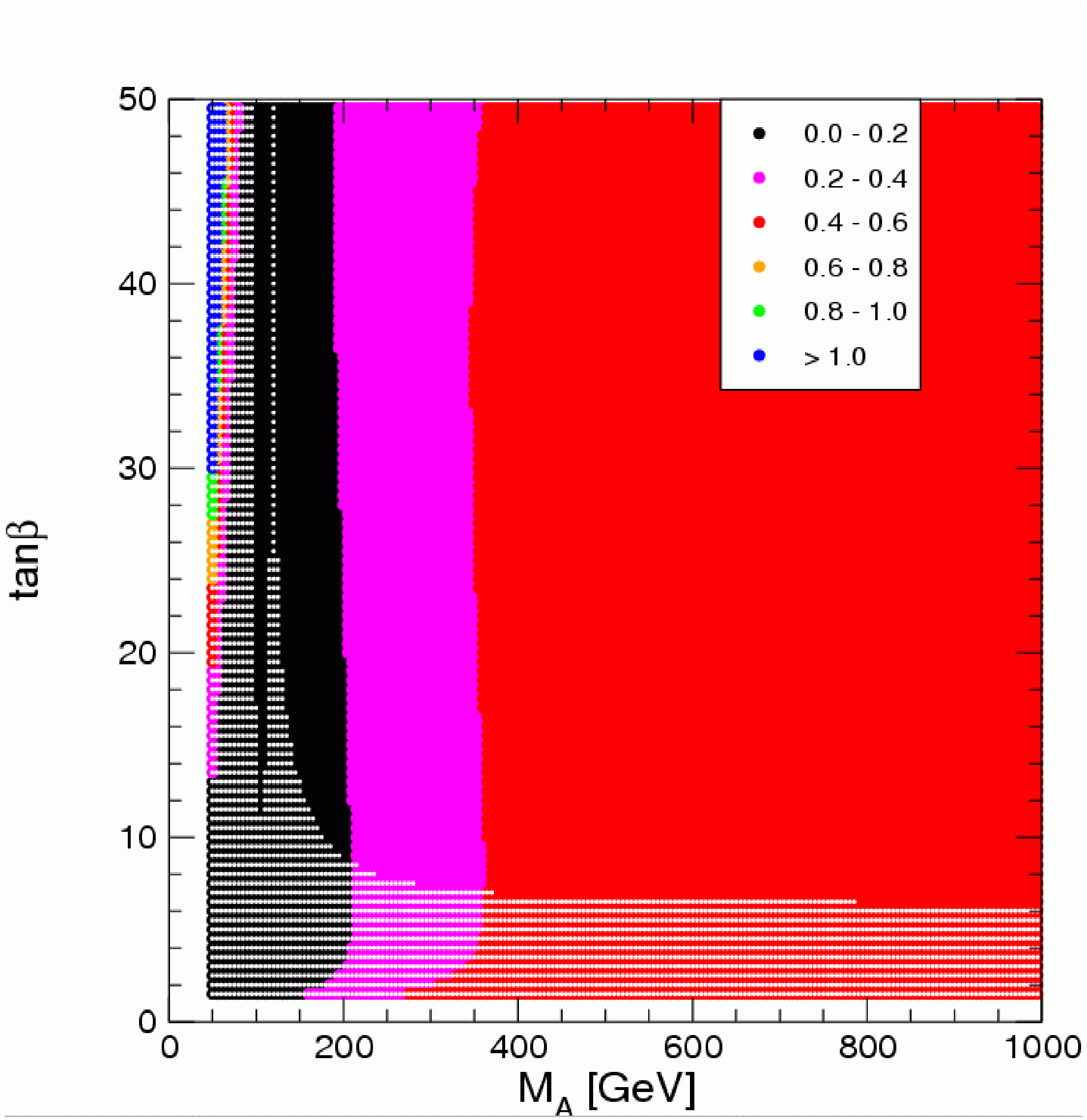
can be strongly suppressed

$\to$ "gluophobic Higgs scenario"

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

$\Rightarrow$ Strong suppression of $gg \to h \to \gamma\gamma$ possible over the whole parameter space

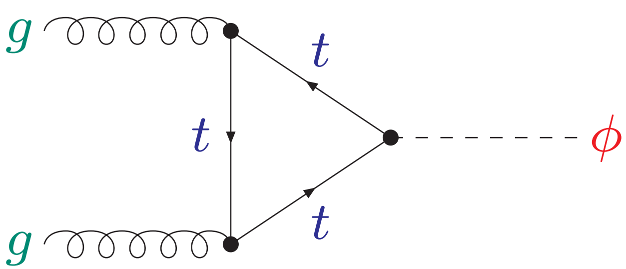
(not realized in mSUGRA/CMSSM, GMSB, AMSB, . . .)

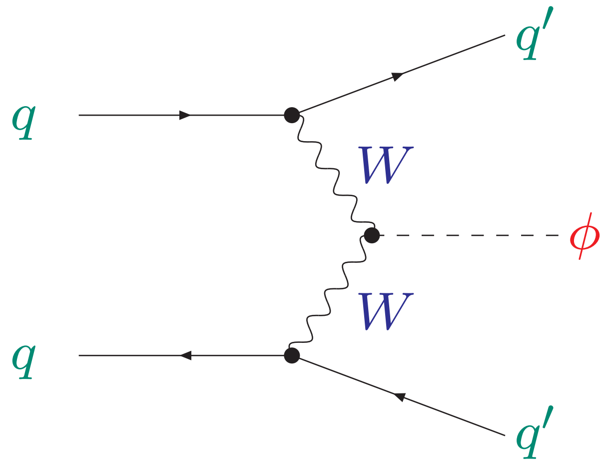


Another issue: external (on-shell) Higgs bosons

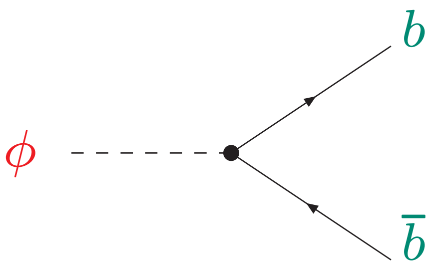
Examples for external (on-shell) Higgs bosons ($\phi = h_1, h_2, h_3$):

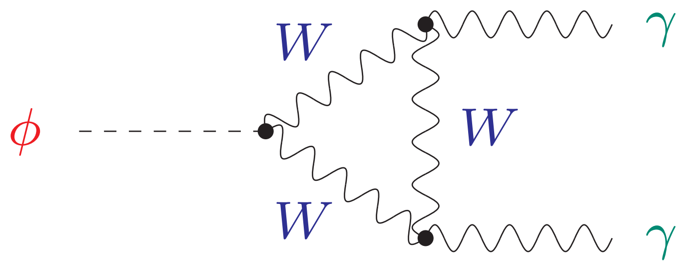
Higgs production:





Higgs decays:





⇒ 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 $i \to j$

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

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

$$\hat{\Gamma}(p^2) = iM^2_{hHA}(p^2) \qquad \Delta(p^2) = \left(-\Gamma(p^2)\right)^{-1}$$

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

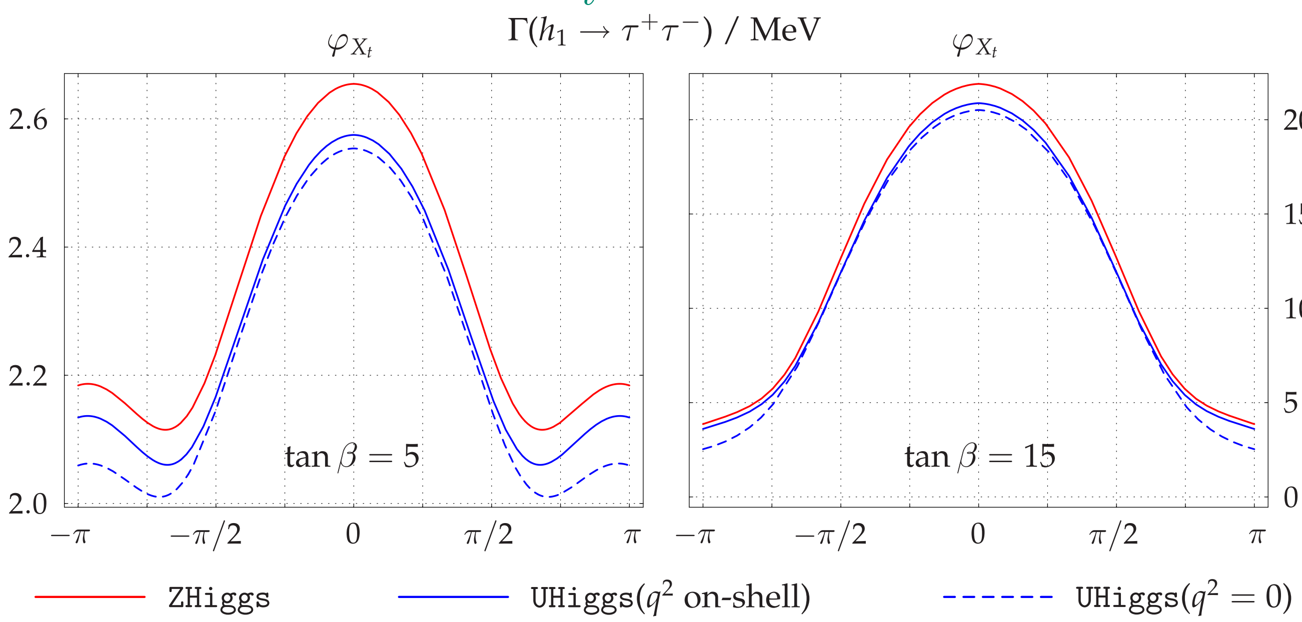
Written more compact with the $\mathbf{Z}$ matrix : $\mathbf{Z}_{ij} = \sqrt{Z_i}\, Z_{ij}$

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 ϕ_{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 $\longrightarrow$

```
------------------- 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
  ...
```

Needed:

Input

```
MT          172.7
MB          4.7
MW          80.4
MZ          91.1
MSusy       975
MA0         200
Abs(M_2)    332
Abs(MUE)    980
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```

Computercode →

Output

```
------------------- HIGGS MASSES -------------------
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|            0.00000000   0.00000000   1.00000000

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| DeltaMh0  =  1.591957
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  ...
```

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)

Short (biased?) comparison:

1) 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

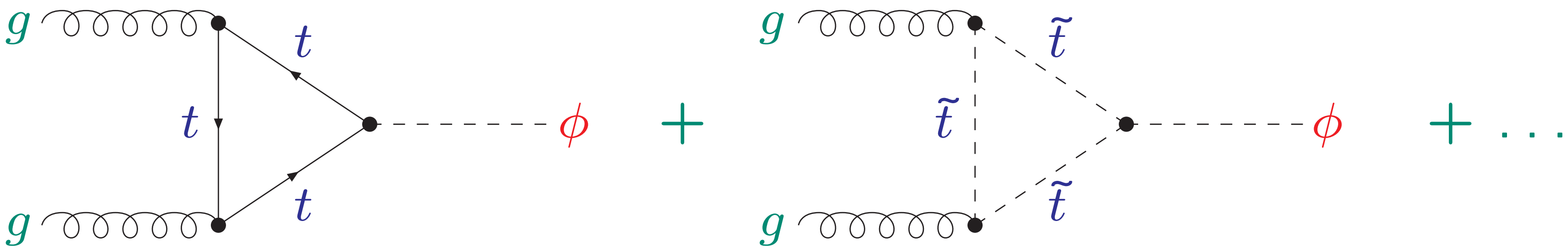
2) Higgs self-energy corrections in the cMSSM: see back-up

3) OS properties for external Higgs bosons:

Only FeynHiggs has the $\mathbf{Z}$ matrix

Gluon-Fusion in the MSSM:

Additional contribution to $gg \to \phi$:



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

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

output:
– MSSM amplitude, cross section
How to re-use SM amplitudes? How to include MSSM corrections?

3. $gg \to \phi, \ \phi = h, H, A$

Q: How to obtain the best MSSM prediction?

- What can be used from the SM?
- How to include new MSSM corrections
- ...

A: Several methods possible:

0) Full calculation
1) FeynHiggs (old)
2) FeynHiggs (new)
3) Michael's proposal
4) ...

0) Full calculation

[*C. Anastasiou, S. Beerli, A. Daleo '08*]

[*M. Mühlleitner, H. Rzehak, M. Spira '10*] (?)

$\rightarrow$ NLO QCD calculation(s)

– How to include more SM results (NNLO top, NLO EW)?

– How to include "MSSM issues"?
(so far unsolved?)

$\rightarrow$ Michael's view ?

1) FeynHiggs (old):

$$\mathcal{A}_{\text{MSSM}} = \text{top}^{\text{MSSM}} \times k_t^{\text{NLO}} \times k_t^{\text{NNLO}}$$
$$+ \text{Re}\,\text{bot}^{\text{MSSM}} \times k_{b,r} + \text{Im}\,\text{bot}^{\text{MSSM}} \times k_{b,i}$$
$$+ \text{SM}^{\text{MSSM}}\,\text{rest} + \text{SUSY} \times k_{\text{SUSY}}$$

$$\mathcal{A}_{\text{SM}}^{\text{NNLO}} = \text{top} \times k_t^{\text{NLO}} \times k_t^{\text{NNLO}} + \text{Re}\,\text{bot} \times k_{b,r} + \text{Im}\,\text{bot} \times k_{b,i}$$
$$+ \text{SM rest}$$

$$\mathcal{M}_{\text{MSSM}} = |\mathcal{A}_{\text{MSSM}}|^2$$

$$\mathcal{M}_{\text{SM}}^{\text{NNLO}} = |\mathcal{A}_{\text{SM}}^{\text{NNLO}}|^2$$

$$\sigma_{\text{MSSM}} = \frac{\mathcal{M}_{\text{MSSM}}}{\mathcal{M}_{\text{SM}}^{\text{NNLO}}} \times \sigma_{\text{SM}}^{\text{NNLO}}$$

$k_t, k_{b,r}, k_{b,i}$ from $\sigma_{\text{SM}}^{\text{LO}}, \sigma_{\text{SM}}^{\text{NLO}}$ (top, bottom , top + bottom)

2) FeynHiggs (new):

$$\mathcal{A}_{\text{MSSM}} = \text{top}^{\text{MSSM}} \times k_t^{\text{NLO}} \times k_t^{\text{NNLO}}$$
$$+ \,\text{Re}\,\text{bot}^{\text{MSSM}} \times k_{b,r} + \text{Im}\,\text{bot}^{\text{MSSM}} \times k_{b,i}$$
$$+ \,\text{SM}^{\text{MSSM}}\,\text{rest} + \text{SUSY} \times k_{\text{SUSY}}$$

$$\mathcal{A}_{\text{SM}}^{\text{NLO}} = \text{top} \times k_t^{\text{NLO}} + \text{Re}\,\text{bot} \times k_{b,r} + \text{Im}\,\text{bot} \times k_{b,i}$$
$$+ \,\text{SM}\,\text{rest}$$

$$\mathcal{M}_{\text{MSSM}} = |\mathcal{A}_{\text{MSSM}}|^2$$

$$\mathcal{M}_{\text{SM}}^{\text{NLO}} = |\mathcal{A}_{\text{SM}}^{\text{NLO}}|^2$$

$$\sigma_{\text{MSSM}} = \frac{\mathcal{M}_{\text{MSSM}}}{\mathcal{M}_{\text{SM}}^{\text{NLO}}} \times \sigma_{\text{SM}}^{\text{NLO}}$$

$k_t, k_{b,r}, k_{b,i}$ from $\sigma_{\text{SM}}^{\text{LO}}, \sigma_{\text{SM}}^{\text{NLO}}$ (top, bottom , top + bottom)

3) Michael's proposal

$\longrightarrow$ Michael's view :-)

3) Michael's proposal

$\rightarrow$ Michael's view :-)

$$\sigma_{\text{MSSM}} = \sigma_{\text{SM,top}}^{\text{NLO+NNLO?}} \times \left(\frac{g_t^{\text{MSSM}}}{g_t^{\text{SM}}}\right)^2$$

$$+ \sigma_{\text{SM,bot}} \times \left(\frac{g_b^{\text{MSSM}}}{g_b^{\text{SM}}}\right)^2$$

$$+ \sigma_{\text{SM,top-bot}} \times \frac{g_t^{\text{MSSM}} g_b^{\text{MSSM}}}{g_t^{\text{SM}} g_b^{\text{SM}}}$$

$$+ \text{SUSY?}$$

Pros and cons:

By construction:

All three versions get the top-bottom (interference) contribution right

To be discussed:

- inclusion of NNLO SM corrections?
- inclusion of SUSY corrections?
- interference between SUSY and SM?
- inclusion of Δ_b corrections in $b\bar{b}\phi$ vertex?
- ...

4. $b\bar{b} \to \phi$, $\phi = h, H, A$

4FS vs. 5FS

$\to$ calculations and investigations in the SM

$\Rightarrow$ more discussions later!?

Relevance for MSSM:

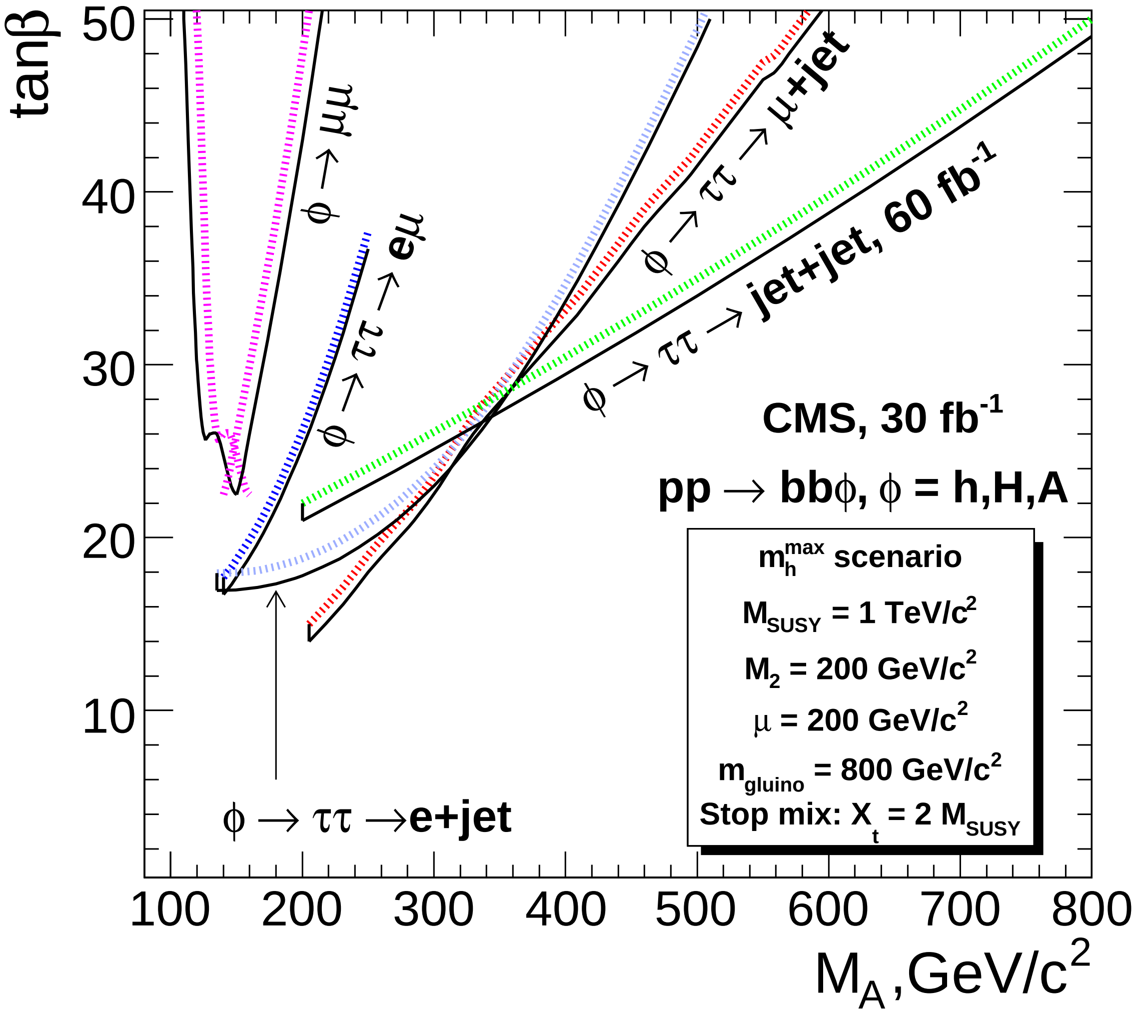
$b\bar{b}\phi$ coupling can grow with $\tan\beta$

Heavy Higgs bosons can be detected via

$$b\bar{b} \to H/A \to \tau^+\tau^- \to \ldots$$

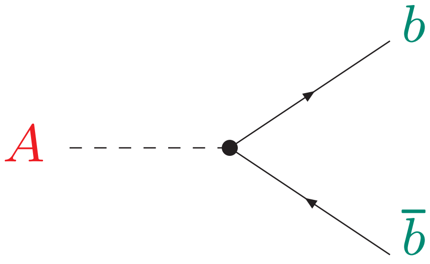
Results for neutral heavy Higgs bosons:

MSSM Higgs discovery contours in M_A–$\tan\beta$ plane ($\Phi = H, A$) (m_h^{max} benchmark scenario): [*CMS PTDR '06*]



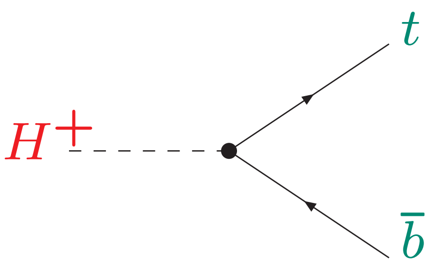
Differences compared to the SM Higgs:

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 μ dependence

MSSM NLO calculation (5FS):

[*S. Dittmaier, M. Krämer, A. Mück, T. Schlüter '08*]

$\Rightarrow$ Δ_b gives a very good approximation for the SUSY corrections

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⇒ Δ_b gives a very good approximation for the SUSY corrections

FeynHiggs approach:

1. use bbh@nnlo [*R. Harlander, W. Kilgore '03*]
   so far: grid in M_H and $\sqrt{s}$
   planned: link bbh@nnlo directly to FeynHiggs

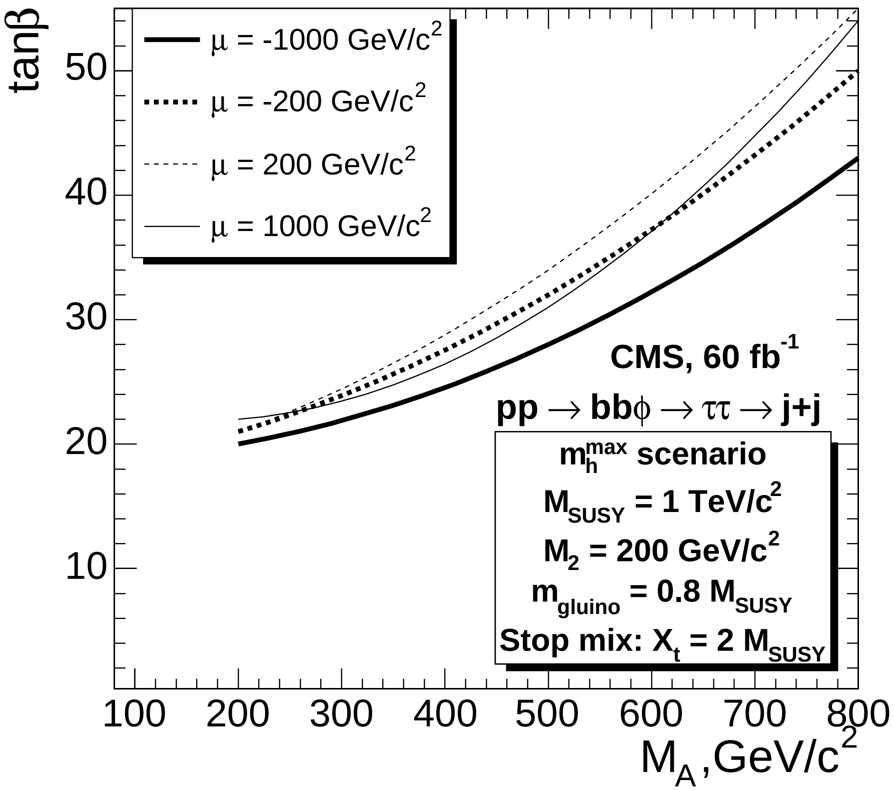
2. include Δ_b corrections ("effective coupling approximation")

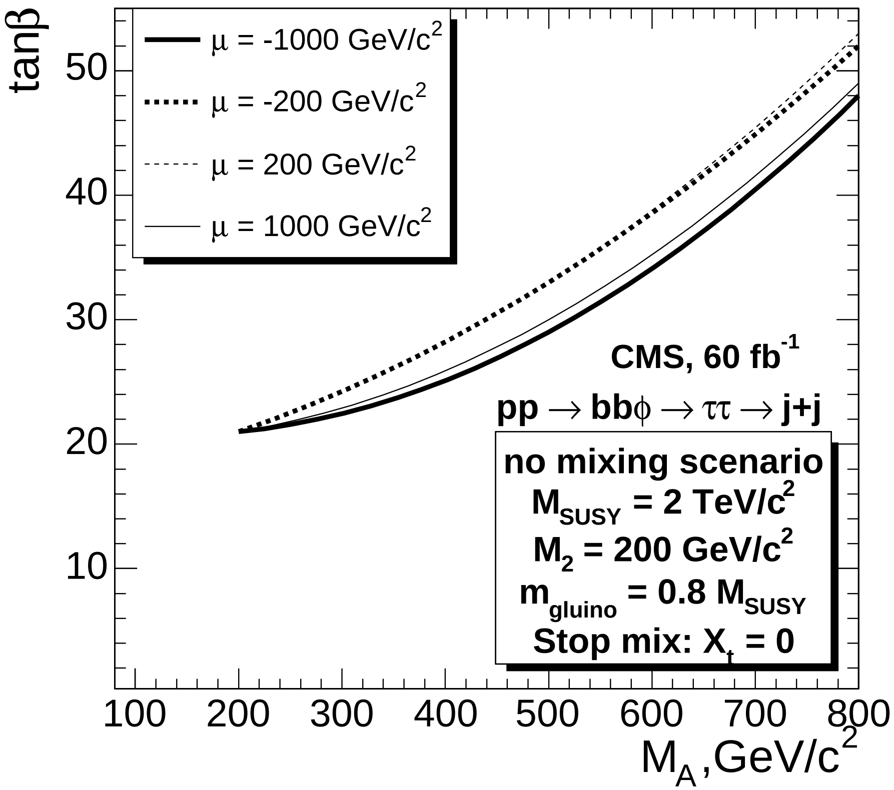
3. include "MSSM issues"

⇒ best MSSM prediction?

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

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





$\Rightarrow$ based on full CMS simulation

$\Rightarrow$ non-negligible variation with the sign and absolute value of μ
(→ numerical compensations in production and decay)

Back-up

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:

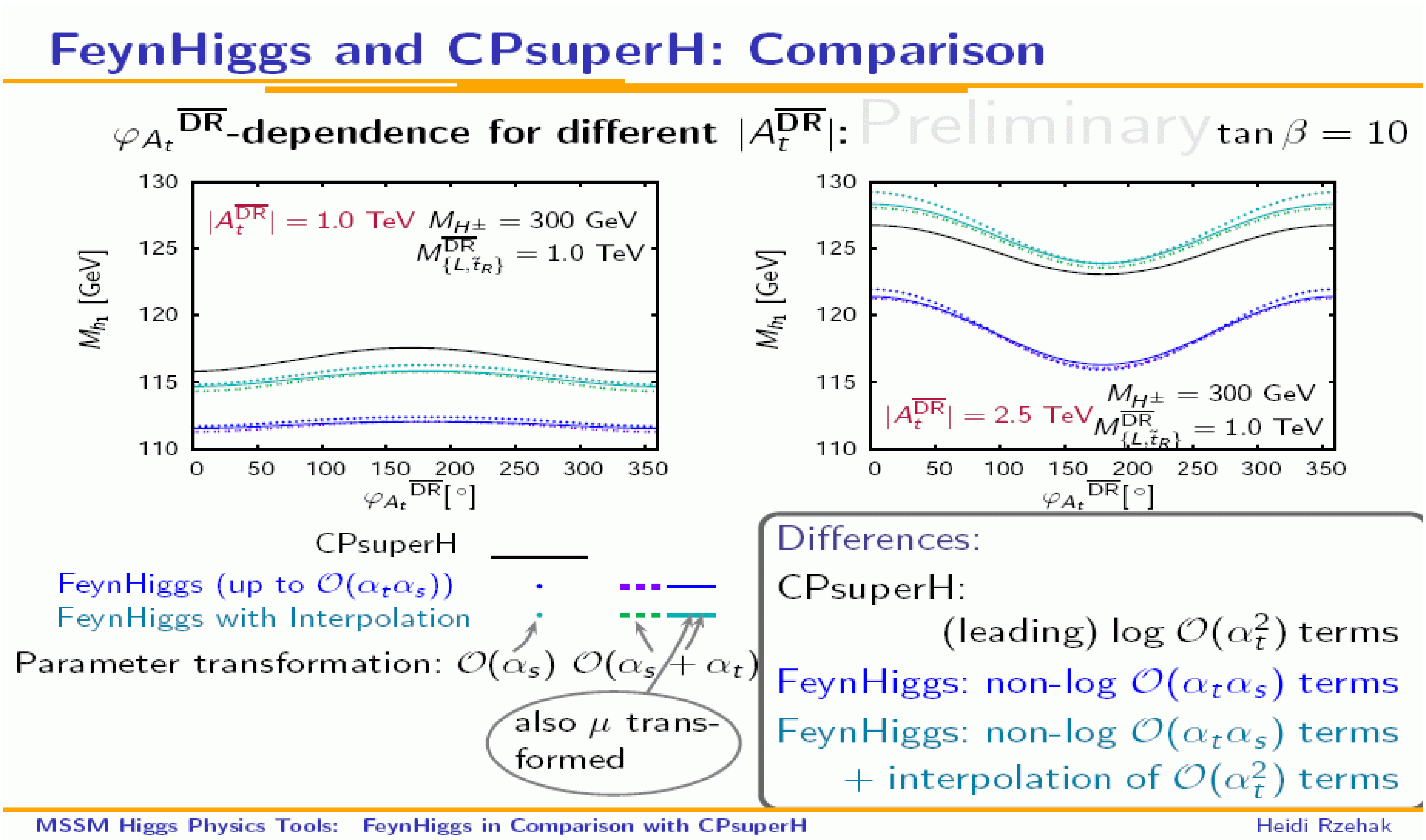
$$X^{\overline{\text{DR}}} + \delta X^{\overline{\text{DR}}} = X^{\text{OS}} + \delta X^{\text{OS}}$$

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

δX^{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 vs. CPsH in the cMSSM (II):

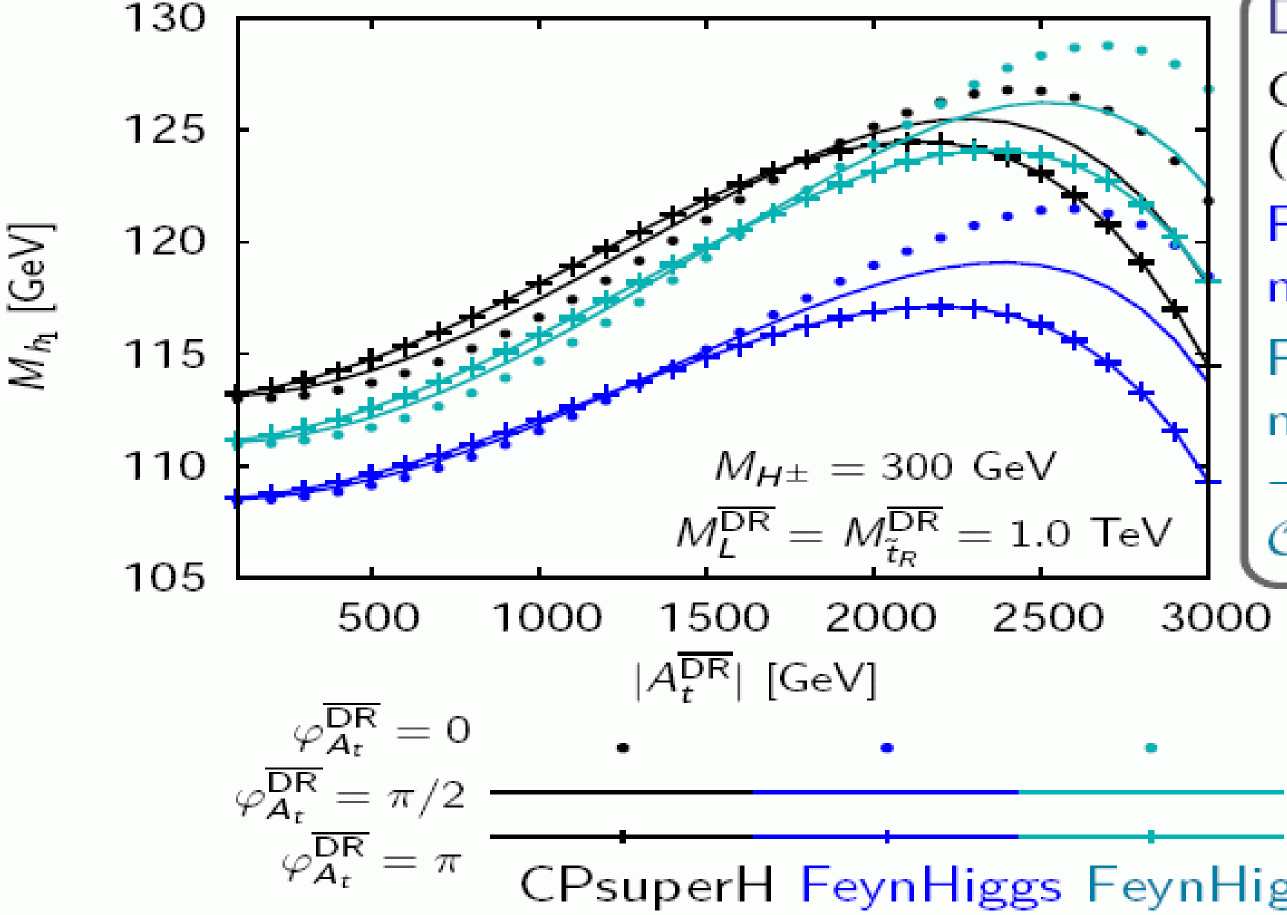


FeynHiggs vs. CPsH in the cMSSM (III):

FeynHiggs and CPsuperH: Comparison

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

$\tan\beta = 10$



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