Two-Loop Corrections to Higgs Production and Decay in the MSSM

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Bastei, 04/00

1. Introduction
2. Radiative corrections at the two-loop level
3. Higgs production in e^+e^- colliders
4. Higgs decays
5. Conclusions

1. Introduction:

m_h calculable from MSSM parameters:

Stringent direct test of SUSY:

Light Higgs boson h required

Tree level: $m_h < M_Z$

Large radiative corrections: $\Rightarrow$ $m_h \lesssim$ 135 GeV

$\Rightarrow$ Precise prediction needed for Higgs search:
Discovery/exclusion potential of LEP2 and upgraded Tevatron and future colliders

- Higgs masses (m_h)

- Higgs production ($e^+e^- \to hZ,\ hA$)

- Higgs decay ($\Gamma(h \to f\bar{f}), BR(h \to f\bar{f})$)

Higgs sector of the MSSM:

MSSM: Enlarged Higgs sector:

Two Higgs doublets

$$
\begin{aligned}
H_1 &= \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix} \\
H_2 &= \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}
\end{aligned}
$$

Higgs potential:

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

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

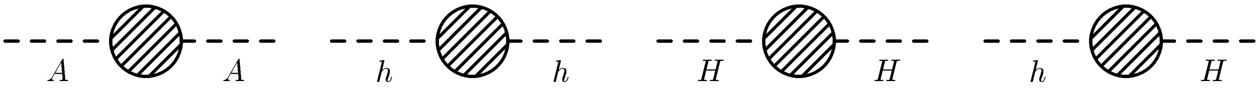
Input parameters:

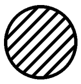
$$
\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2 (\tan\beta + \cot\beta)
$$

Dominant radiative corrections:

$\rightarrow \mathcal{O}(G_\mu\, m_t^4)$, $\mathcal{O}(G_\mu\, \alpha_s\, m_t^4)$

(via Higgs propagators)





: Complete MSSM in 1-loop order

[A. Dabelstein '95]

$+\ \mathcal{O}(\alpha\alpha_s)$ contributions from $t-\tilde{t}$-sector

(Yukawa contribution, $p^2 = 0$) $\rightarrow$ F

[S. H., W. Hollik, G. Weiglein '98]

$+\ G_\mu^2 m_t^6$ improvement terms

[M. Carena, J. Espinosa, M. Quirós, C. Wagner '95]

Full self-energy:

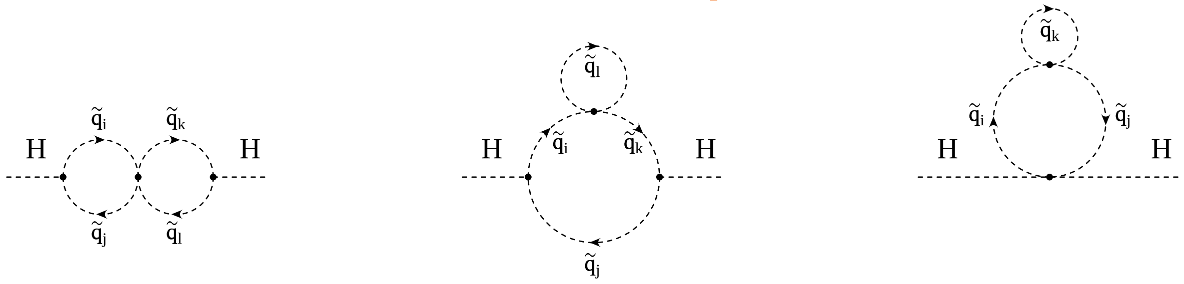
$$\hat{\Sigma}_s(q^2) = \hat{\Sigma}_s^{(1)}(q^2) + \hat{\Sigma}_s^{(2)}(0)$$

Approximation:

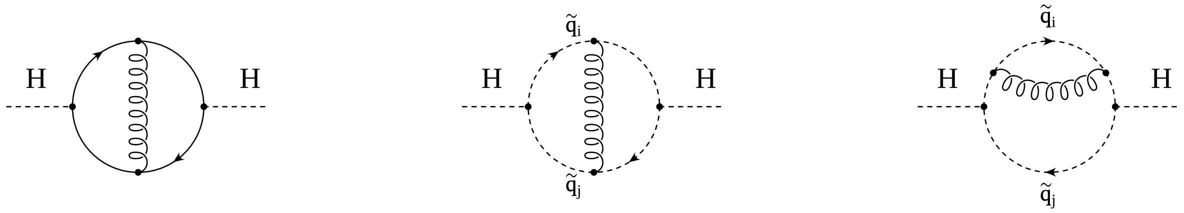
$$\hat{\Sigma}_s(q^2) \rightarrow \hat{\Sigma}_s^{(1)}(0) + \hat{\Sigma}_s^{(2)}(0)$$

Leading two-loop corrections :

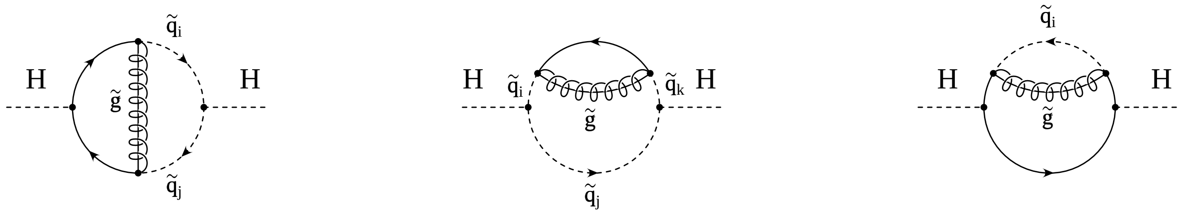
$\mathcal{O}(\alpha\alpha_s)$ contribution from $t-\tilde{t}$-sector
(Yukawa contribution, $p^2 = 0$)
[S. H., W. Hollik, G. Weiglein '98]



(a)



(b)



(c)

$\tilde{t}$ sector:

$$M^2_{\tilde{t}} = \begin{pmatrix} M_S^2 + DT_1 & m_t X_t \\ m_t X_t & M_S^2 + DT_2 \end{pmatrix}$$

$X_t = A_t - \mu \cot\beta$; large mixing possible

$\Rightarrow$ Physical parameters: $m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$, $\theta_{\tilde{t}}$

$X_t/M_{\mathrm{SUSY}} = 0$: no mixing
$X_t/M_{\mathrm{SUSY}} = \pm 2$: maximal mixing

Other approaches:

Other approaches mainly rely on
α_{eff} approximation :

Tree-level:

Mass matrix (in $\phi_1 - \phi_2$ basis):

$$M^{2,\text{tree}}_{\text{Higgs}} = \begin{pmatrix} m^2_{\phi_1} & m^2_{\phi_1\phi_2} \\ m^2_{\phi_1\phi_2} & m^2_{\phi_2} \end{pmatrix} =$$

$$\begin{pmatrix} M_A^2 \sin^2\beta + M_Z^2 \cos^2\beta & -(M_A^2 + M_Z^2)\sin\beta\cos\beta \\ -(M_A^2 + M_Z^2)\sin\beta\cos\beta & M_A^2\cos^2\beta + M_Z^2\sin^2\beta \end{pmatrix}$$

$$\Big\Downarrow \quad \leftarrow \ \text{Diagonalization} \ , \alpha$$

$$\begin{pmatrix} m_H^{2,\text{tree}} & 0 \\ 0 & m_h^{2,\text{tree}} \end{pmatrix}$$

$\Rightarrow$ m_h, m_H, mixing angle α at tree level

Higher orders:

Mass matrix: (in $\phi_1 - \phi_2$ basis):

$$M^2_{\rm Higgs} = \begin{pmatrix} m^2_{\phi_1} - \hat\Sigma_{\phi_1}(0) & m^2_{\phi_1\phi_2} - \hat\Sigma_{\phi_1\phi_2}(0) \\ m^2_{\phi_1\phi_2} - \hat\Sigma_{\phi_1\phi_2}(0) & m^2_{\phi_2} - \hat\Sigma_{\phi_2}(0) \end{pmatrix}$$

$$\Big\Downarrow \quad \leftarrow \text{ Diag. } \;, \alpha_{\rm eff}$$

$$\begin{pmatrix} M_H^2 & 0 \\ 0 & M_h^2 \end{pmatrix}$$

$\Rightarrow$ M_h, M_H, mixing angle $\alpha_{\rm eff}$ at higher order

$\hat\Sigma_s(0)$: renormalized Higgs self-energy
at zero external momentum

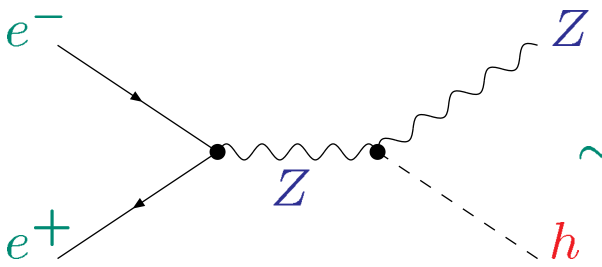
$\alpha_{\rm eff}$ contains dominant higher order corrections
$\rightarrow$ production
$\rightarrow$ decay

Within our calculation: agreement up to 2–3%

$\Rightarrow$ Deviations from other approaches:
different calculations of $\hat\Sigma_s(0)$

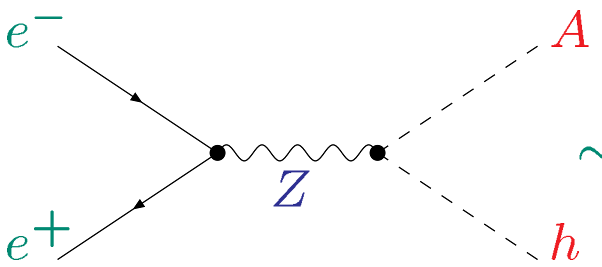
3. Higgs production in e^+e^-colliders

SM like: $e^+e^- \to Zh$



$\sim \sin(\beta - \alpha)$

Complementary: $e^+e^- \to hA$

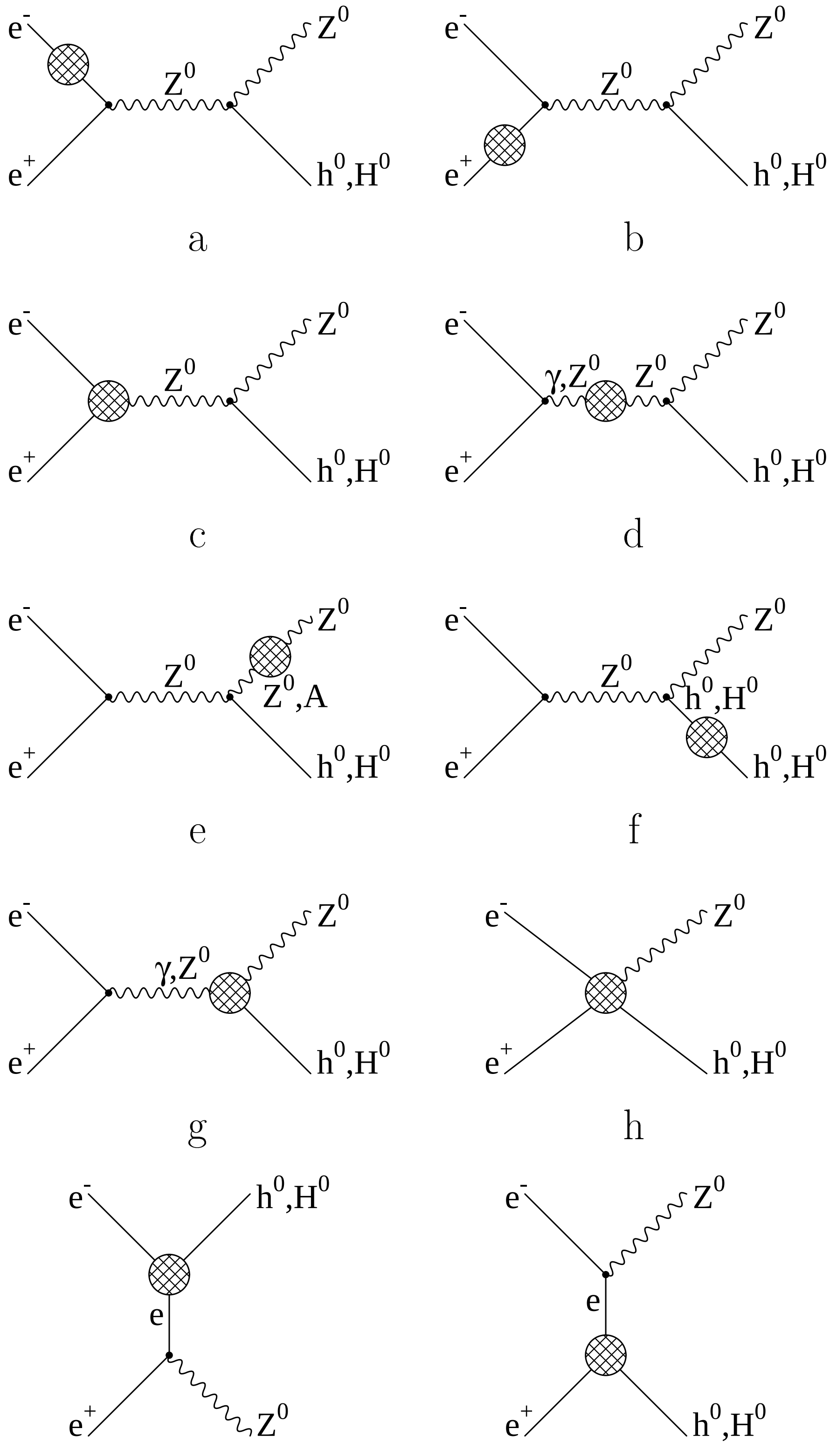


$\sim \cos(\beta - \alpha)$

– Complete diagrammatic one-loop result in on-shell scheme
full momentum dependence included
[V. Driesen, W. Hollik, J. Rosiek '95]

$\to$ F

– Dominant two-loop contributions $\mathcal{O}(G_\mu \, \alpha_s \, m_t^4)$
incorporation via propagator corrections
[S. H., W. Hollik, J. Rosiek, G. Weiglein '99]


e-
e+
Z0
h0,H0
γ,Z0
Z0,A
e
a
b
c
d
e
f
g
h
i
j

FD (1-loop, 2-loop) $\longleftrightarrow$ RG (2-loop):

[S. H., W. Hollik, J. Rosiek, G. Weiglein '00]

[preliminary]

M_A = 100 GeV (fixed)

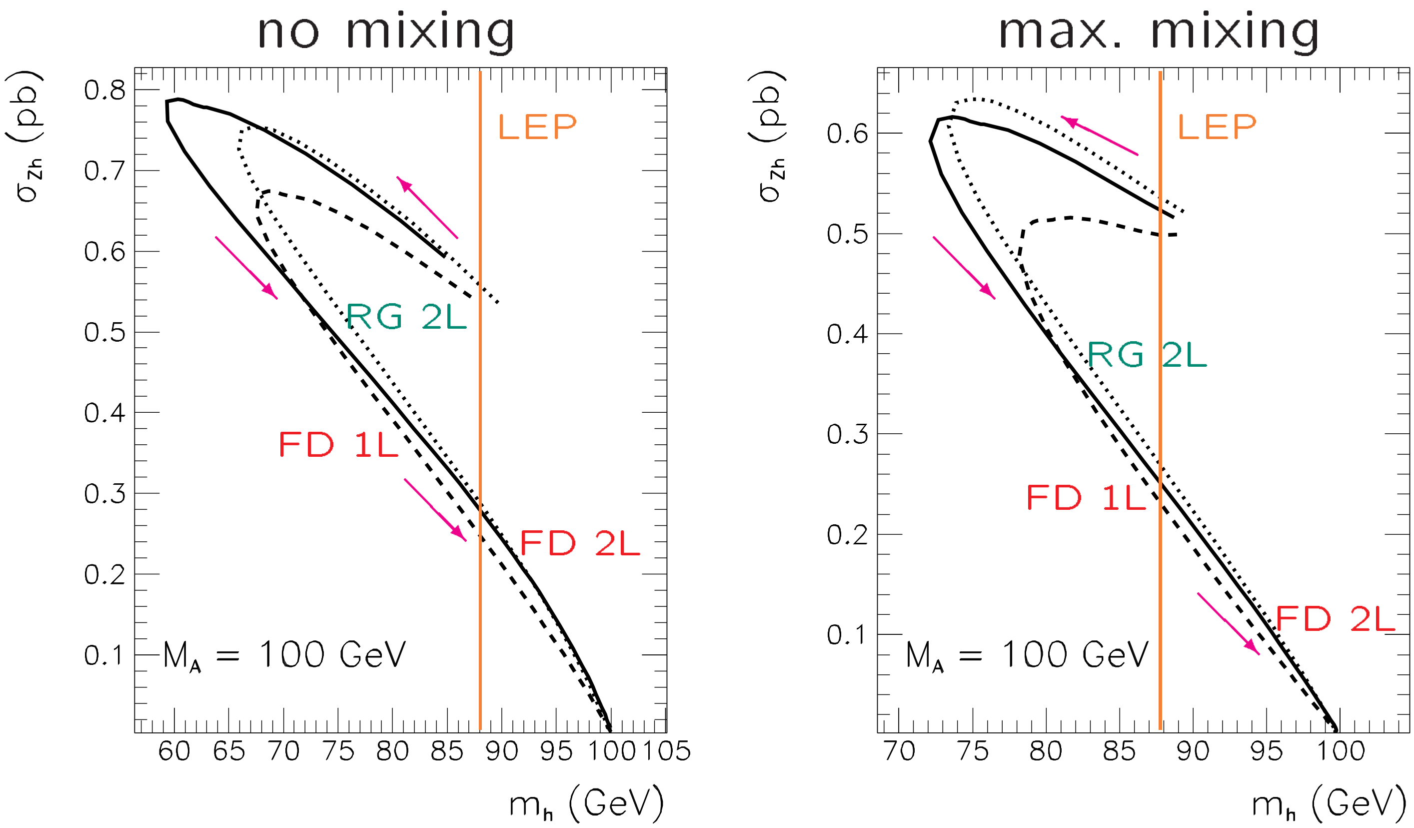
$\tan\beta$ = 0.5 .. 50 (varied) ($\to\to\to$)

$\to$ calculation of m_h

Other parameters:

$M_{\rm SUSY} = 1$ TeV, $M_2 = \mu = 200$ GeV

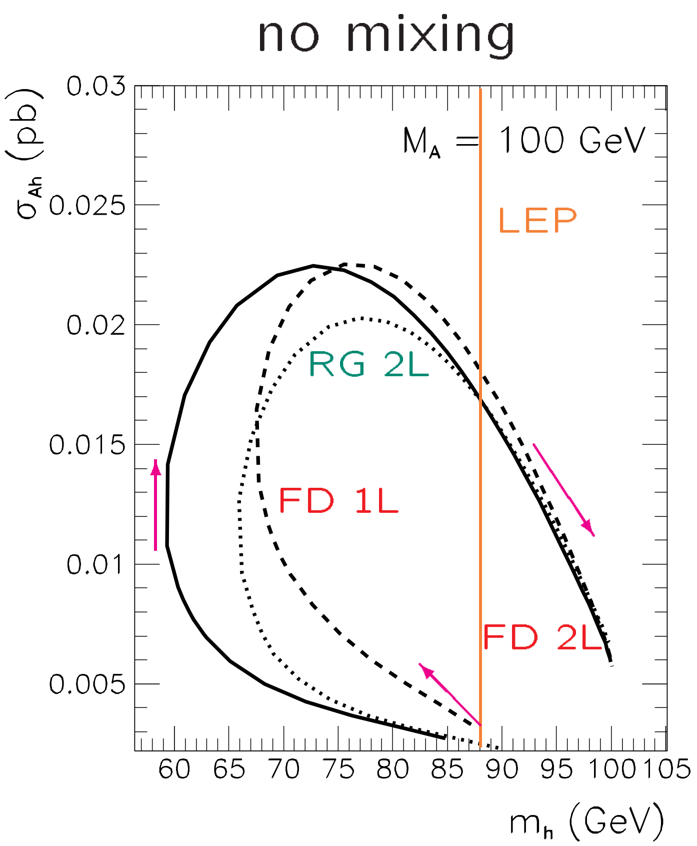
$\boxed{\sigma_{Zh} \,@\, \sqrt{s} = 206 \text{ GeV}}$



$\to$ two-loop up to 10% larger than one-loop

$\to$ FD up to 7% smaller than RG (max. mix.)

$\boxed{\sigma_{Ah} \text{ @ } \sqrt{s} = 206 \text{ GeV}}$



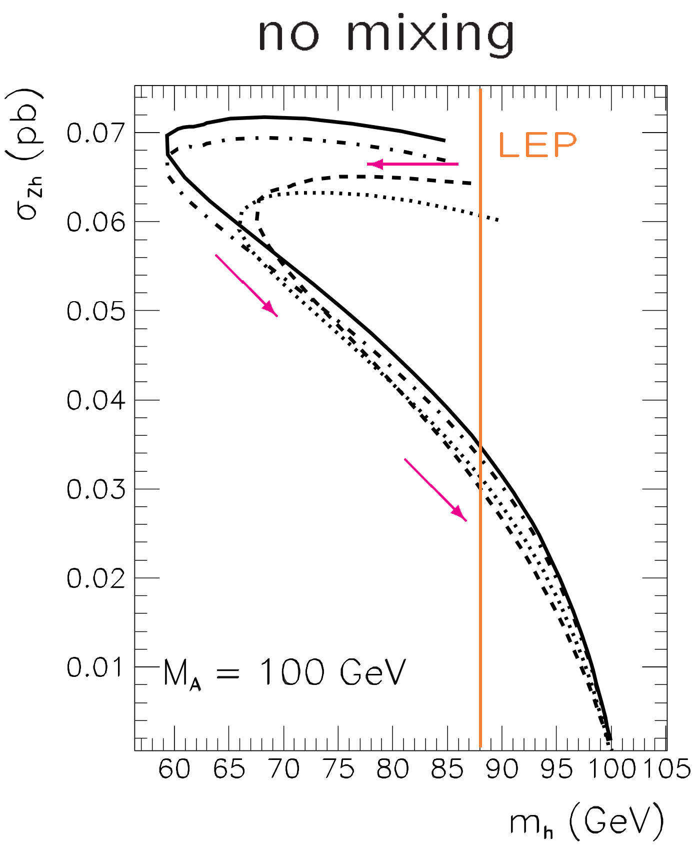
$\to$ two-loop up to 10% smaller than one-loop

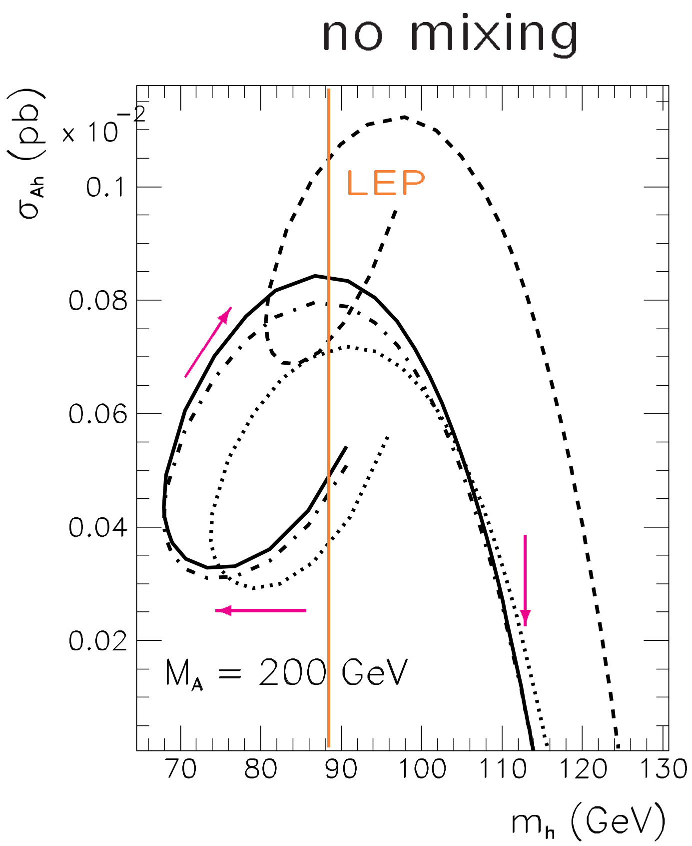
$\to$ FD up to 4% smaller than RG (max. mix.)

$e^+e^- \to hZ,\ hA$ at a Linear Collider:

σ_{Zh} @ $\sqrt{s} = 500$ GeV

σ_{Ah} @ $\sqrt{s} = 500$ GeV





solid: FD 2L (with box) [$M_{\rm SUSY} = 300$ GeV for sleptons]

dot-dashed: FD 2L (no box)

dashed: FD 1L

dotted: RG 2L

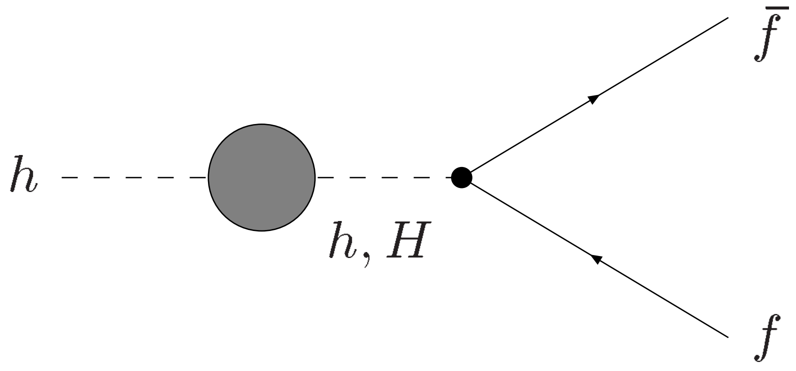
$\to$ large two-loop effect

$\to$ box effects up to 7%

$\to$ FD up to 10%/15% larger than RG

4. Higgs decays: $h \to f\bar{f}$

$\to$ leading Yukawa corrections: $\mathcal{O}(\alpha)$, $\mathcal{O}(\alpha\alpha_s)$



$$A(h \to f\bar{f}) = \sqrt{Z_h}\left(\Gamma_h - \frac{\hat{\Sigma}_{\mathrm{hH}}(M_h^2)}{M_h^2 - m_H^2 + \hat{\Sigma}_{\mathrm{HH}}(M_h^2)}\Gamma_H\right)$$

$$\begin{aligned} Z_h &= \mathrm{Res}_{M_h}\Delta_h \\ &= \frac{1}{1 + \hat{\Sigma}'_{\mathrm{hh}}(q^2) - \tilde{\Sigma}'_{\mathrm{hH}}}\,|_{q^2=M_h^2} \\ \tilde{\Sigma}_{\mathrm{hH}} &= \frac{\hat{\Sigma}^2_{\mathrm{hH}}(q^2)}{q^2 - m_H^2 + \hat{\Sigma}_{\mathrm{HH}}(q^2)} \end{aligned}$$

Mainly used so far: α_{eff} approximation :

$$\Rightarrow \; \hat{\Sigma}(q^2) \approx \hat{\Sigma}(0)$$

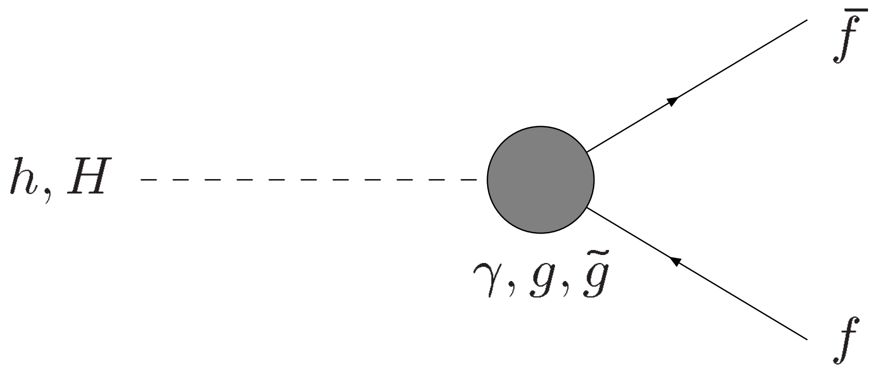
$\Rightarrow$ one-loop: keep momentum dependence

$+$ leading two-loop corrections

Decay rate:

$$\Gamma_{\rm ew}(h \to f\bar{f}) = \frac{M_h}{8\pi}\left(1 - 4\frac{m_f}{M_h}\right)^{\frac{3}{2}} N_f |A_{h\to f\bar{f}}|^2$$

Other contributions:
one-loop QED and QCD corrections:



[*A. Dabelstein '95*]

$$\Gamma(h \to f\bar{f}) \;=\; \Gamma_{\rm ew} + \Delta\Gamma_\gamma + \Delta\Gamma_g + \Delta\Gamma_{\tilde{g}}$$

(Gluino contribution not yet incorporated into other programs)

Branching ratio:

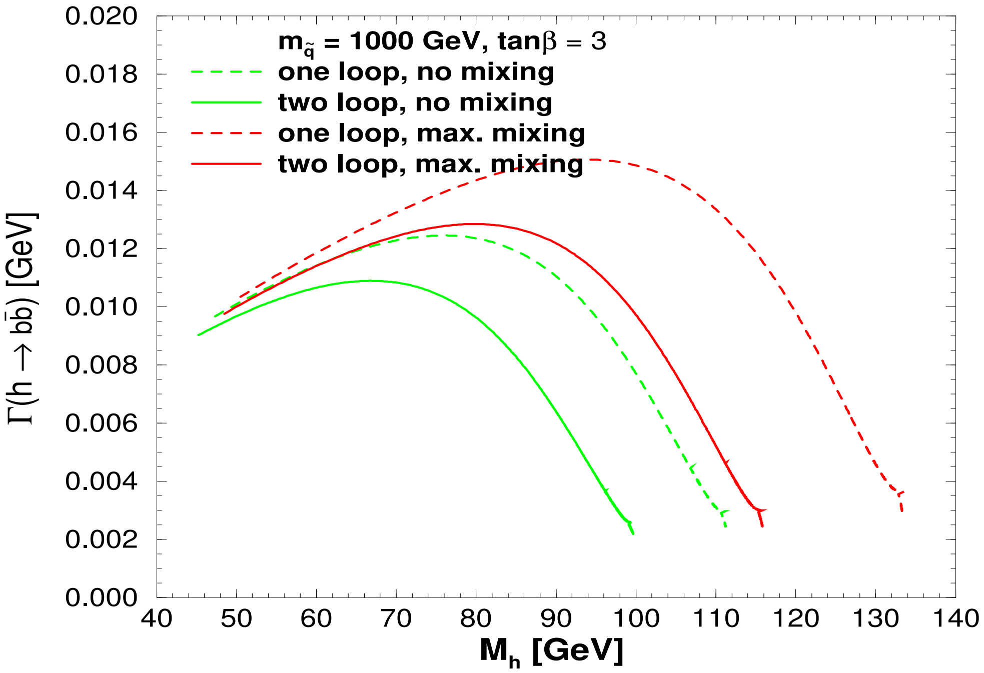
$$\Gamma_{\rm tot} \;\approx\; \sum_{f=b,c,\tau} \Gamma(h \to f\bar{f}) + \Gamma(h \to gg)$$

$$BR(h \to f\bar{f}) \;=\; \frac{\Gamma(h \to f\bar{f})}{\Gamma_{\rm tot}}$$

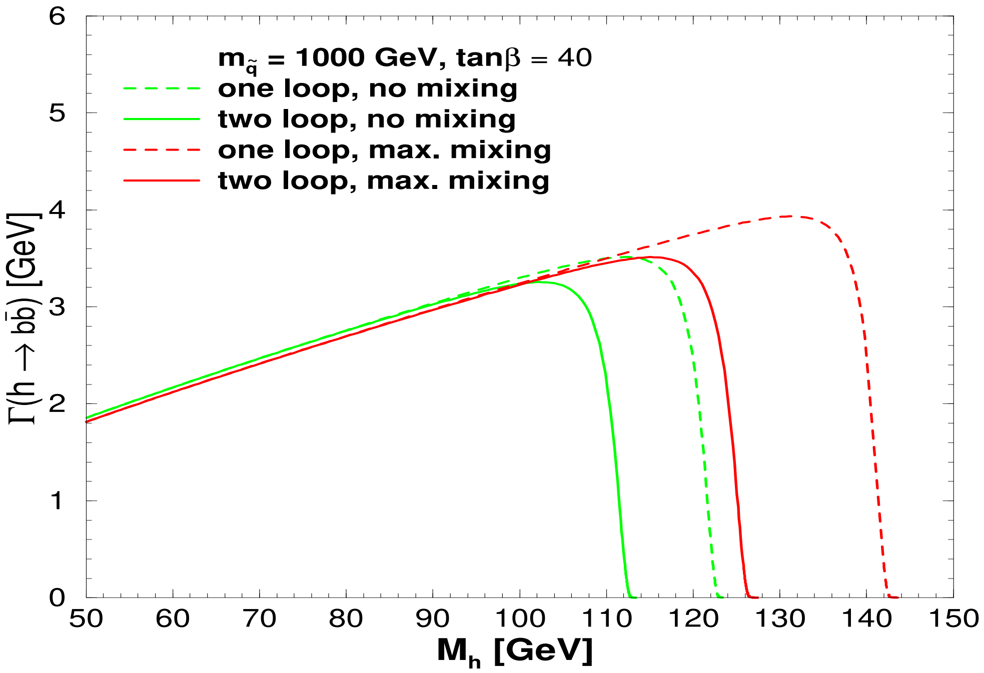
Decay rate: two-loop effects

[S. H., W. Hollik, G. Weiglein '00]

$h \to b\bar{b}$, $\tan\beta = 3$:



$h \to b\bar{b}$, $\tan\beta = 40$:



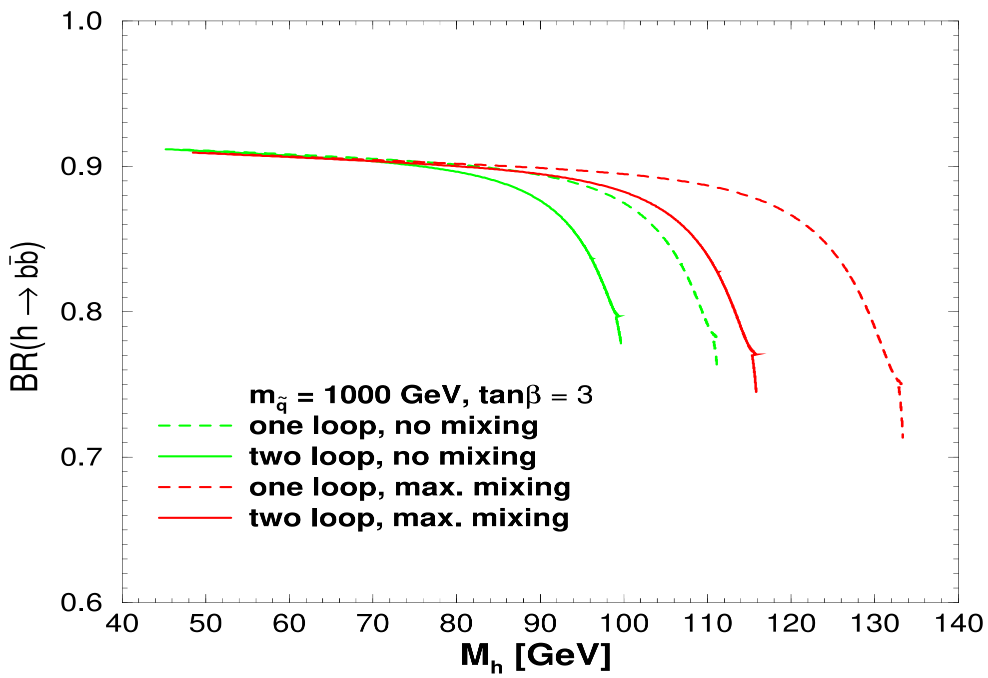
$\Rightarrow$ Large 2-loop corrections

$\Rightarrow$ large $\tan\beta$: mainly kinematical effect

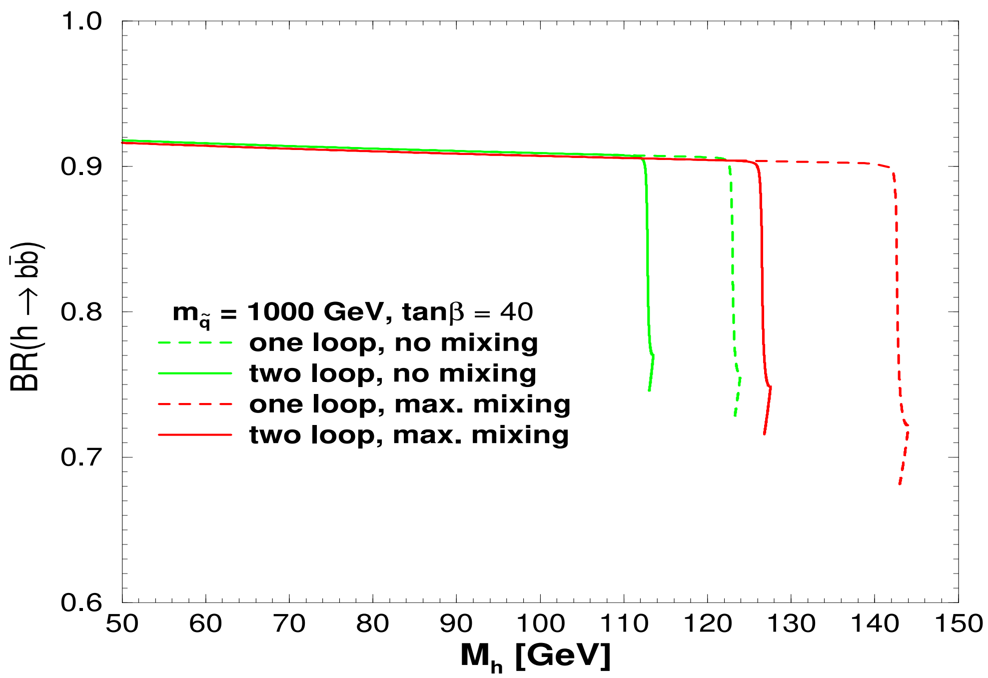
Branching ratio: two-loop effects

[*S. H., W. Hollik, G. Weiglein '00*]

$h \to b\bar{b}$, $\tan\beta = 3$:



$h \to b\bar{b}$, $\tan\beta = 40$:



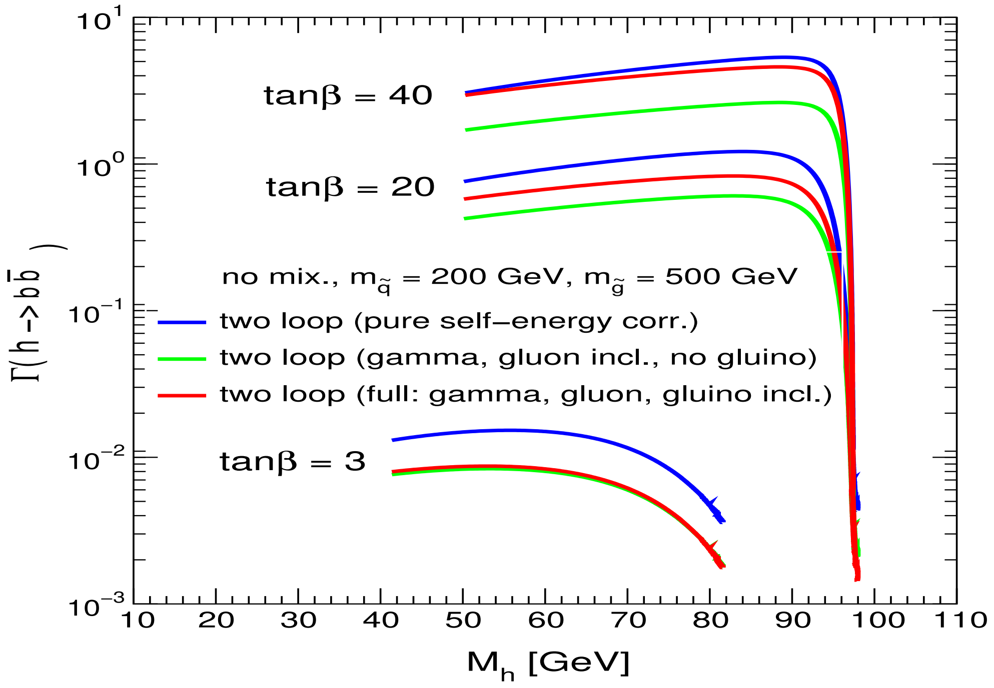
$\Rightarrow$ Large 2-loop corrections

$\Rightarrow$ large $\tan\beta$: mainly kinematical effect

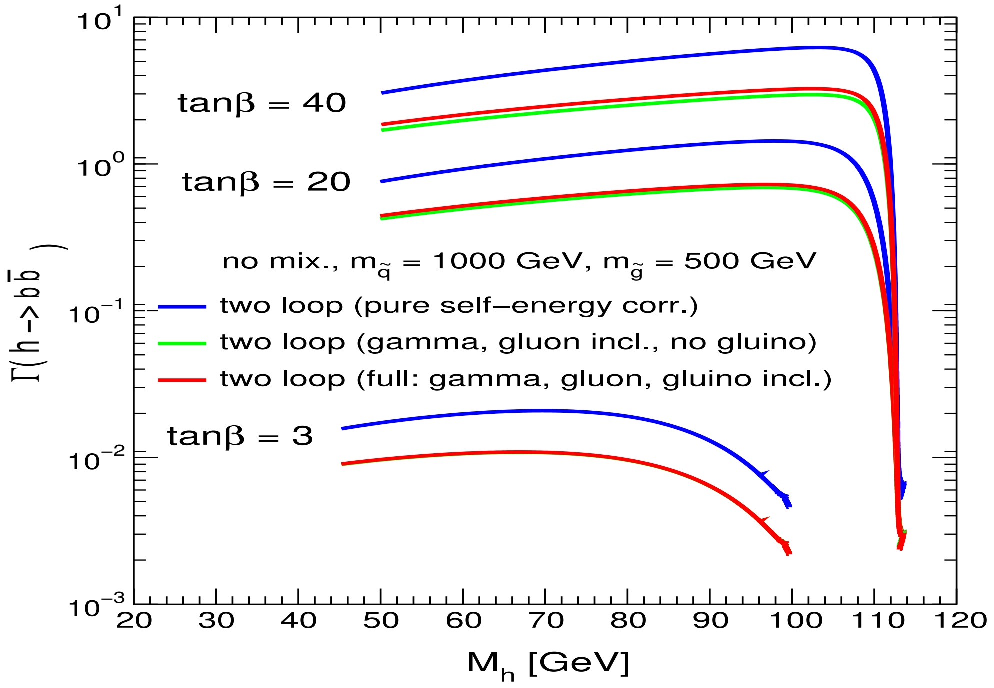
Decay rate: gluino effects (one-loop vertex)

[*S. H., W. Hollik, G. Weiglein '00*]

$h \to b\bar{b}$, various $\tan\beta$, low $m_{\tilde{q}}$:



$h \to b\bar{b}$, various $\tan\beta$, high $m_{\tilde{q}}$:



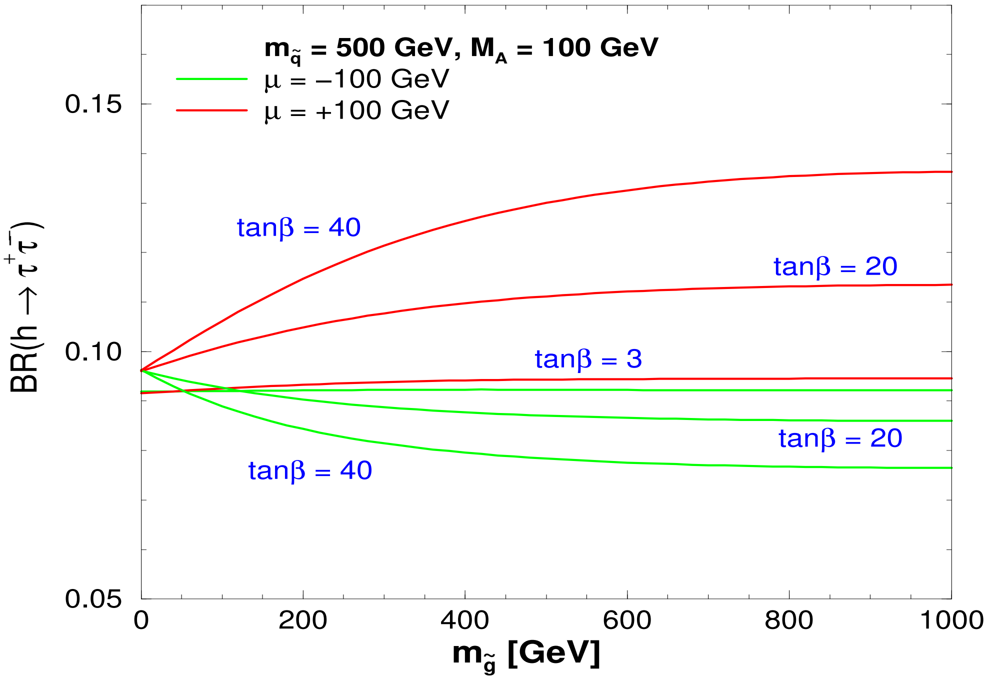
$\Rightarrow$ Large gluino corrections possible

$\Rightarrow$ especially important for low $m_{\tilde{q}}$

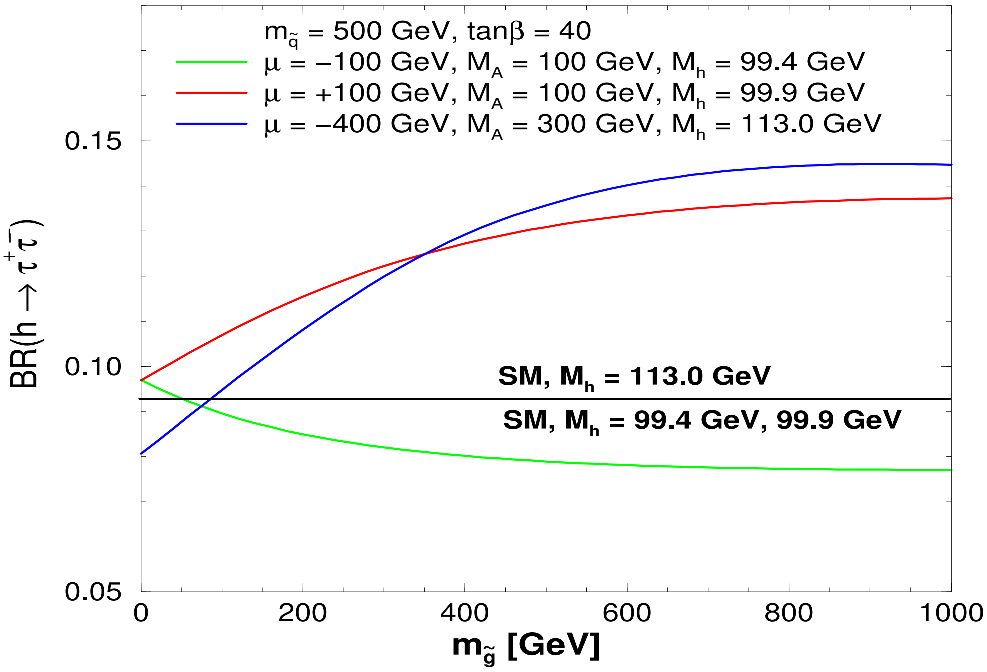
Branching ratio: gluino effects on $BR(h \to \tau^+\tau^-)$

[*S. H., W. Hollik, G. Weiglein '00*]

various $\tan\beta$, $M_A = 100$ GeV, $\mu = \pm 100$ GeV:



$\tan\beta = 40$, $M_A = 100, 300$ GeV,
$\mu = \pm 100, 400$ GeV :

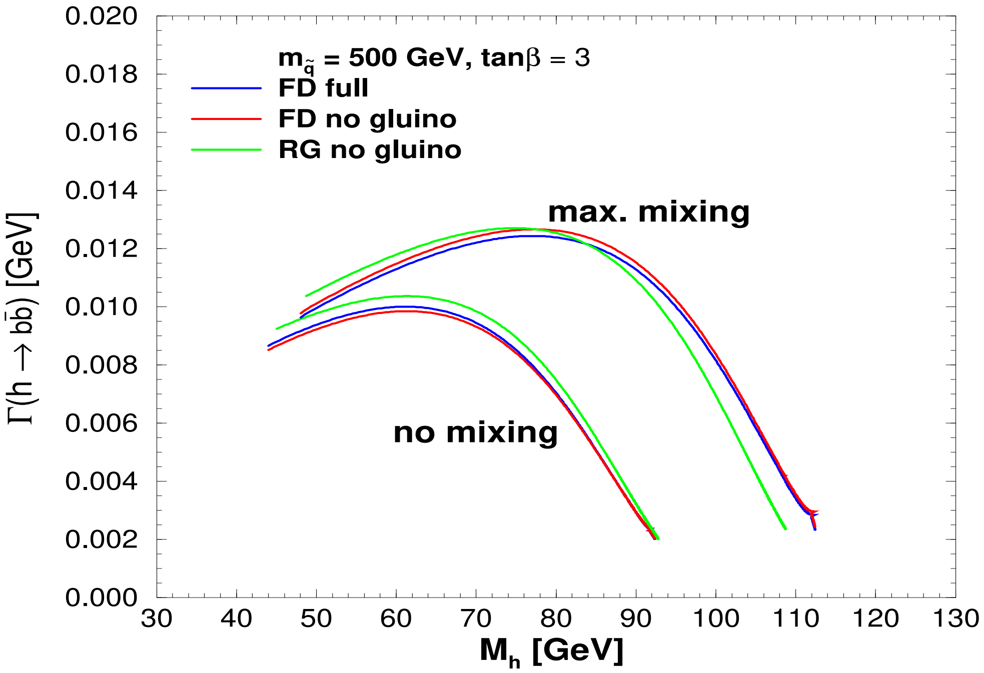


$\Rightarrow$ Large effect possible
even for large M_A and large $m_{\tilde{g}}$

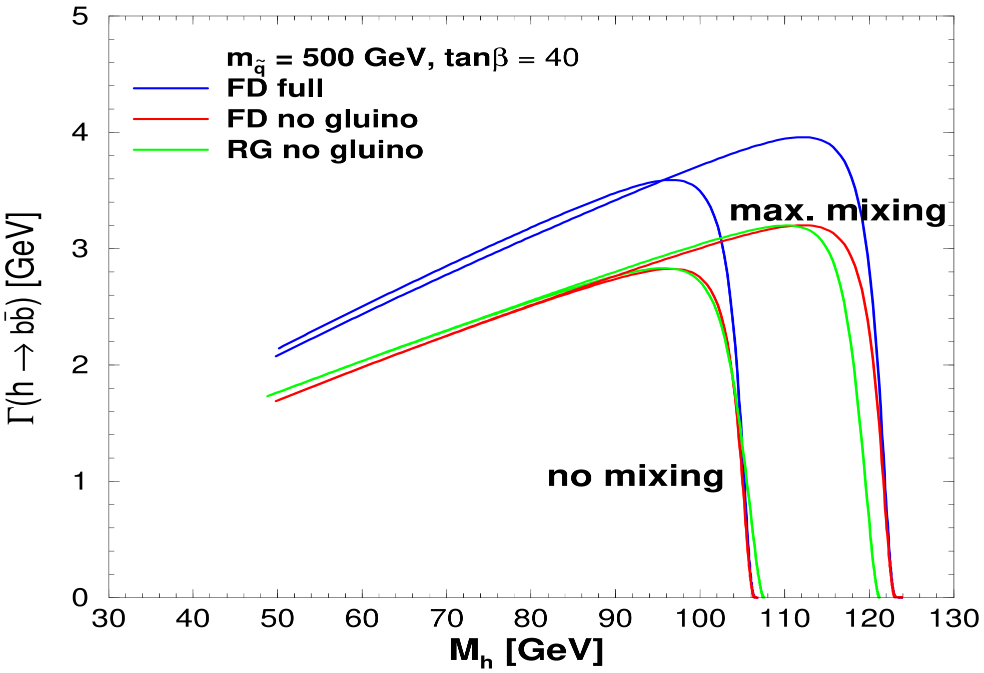
Comparison with RG calculations (HDECAY)

[*S. H., W. Hollik, G. Weiglein '00*]

$h \to b\bar{b}$, $\tan\beta = 3$:



$h \to b\bar{b}$, $\tan\beta = 40$:



$\Rightarrow$ Deviations up to $10 - 15\%$ ($\alpha_{\rm eff}$ effect)

$\Rightarrow$ gluino contributions important

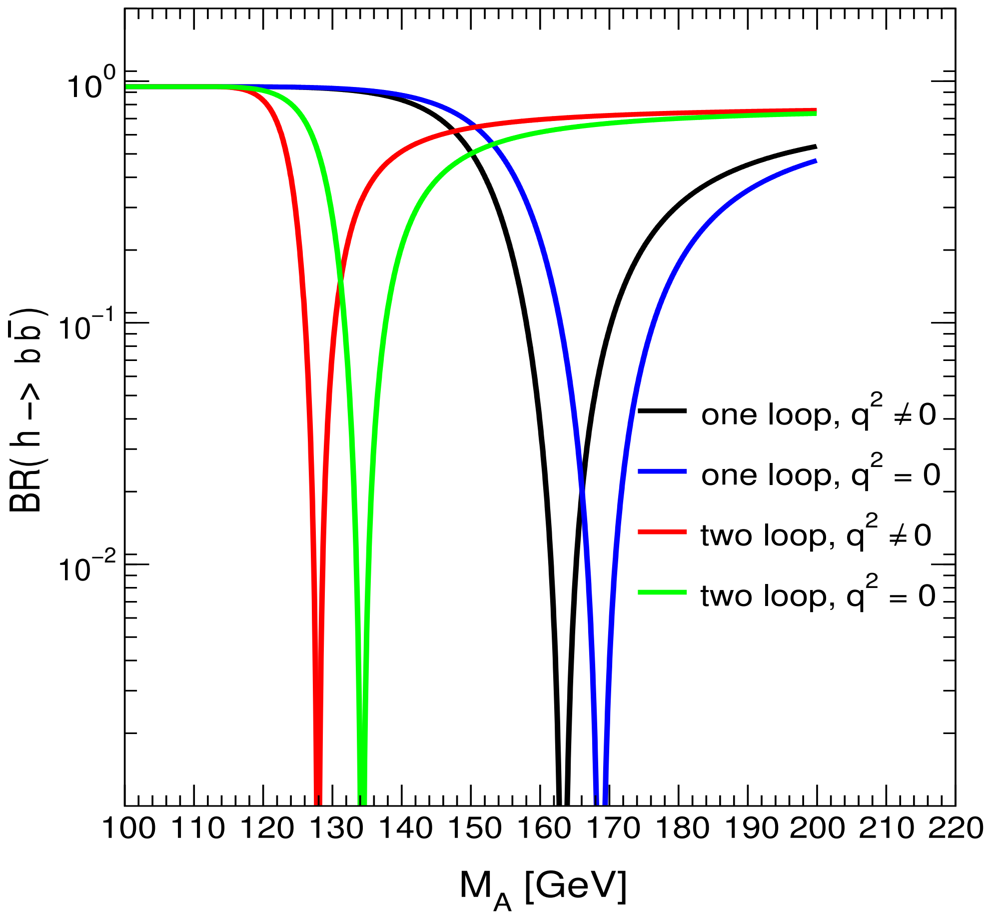
Possible problem for Higgs searches:

Higgs search relies on b search

Amplitude:

$$A(h \to f\bar{f}) = \sqrt{Z_h}\left(\Gamma_h - \frac{\hat{\Sigma}_{\mathrm{hH}}(M_h^2)}{M_h^2 - m_H^2 + \hat{\Sigma}_{\mathrm{HH}}(M_h^2)}\Gamma_H\right)$$

$\to$ can go to zero for large $\hat{\Sigma}_{\mathrm{hH}}(M_h^2)$



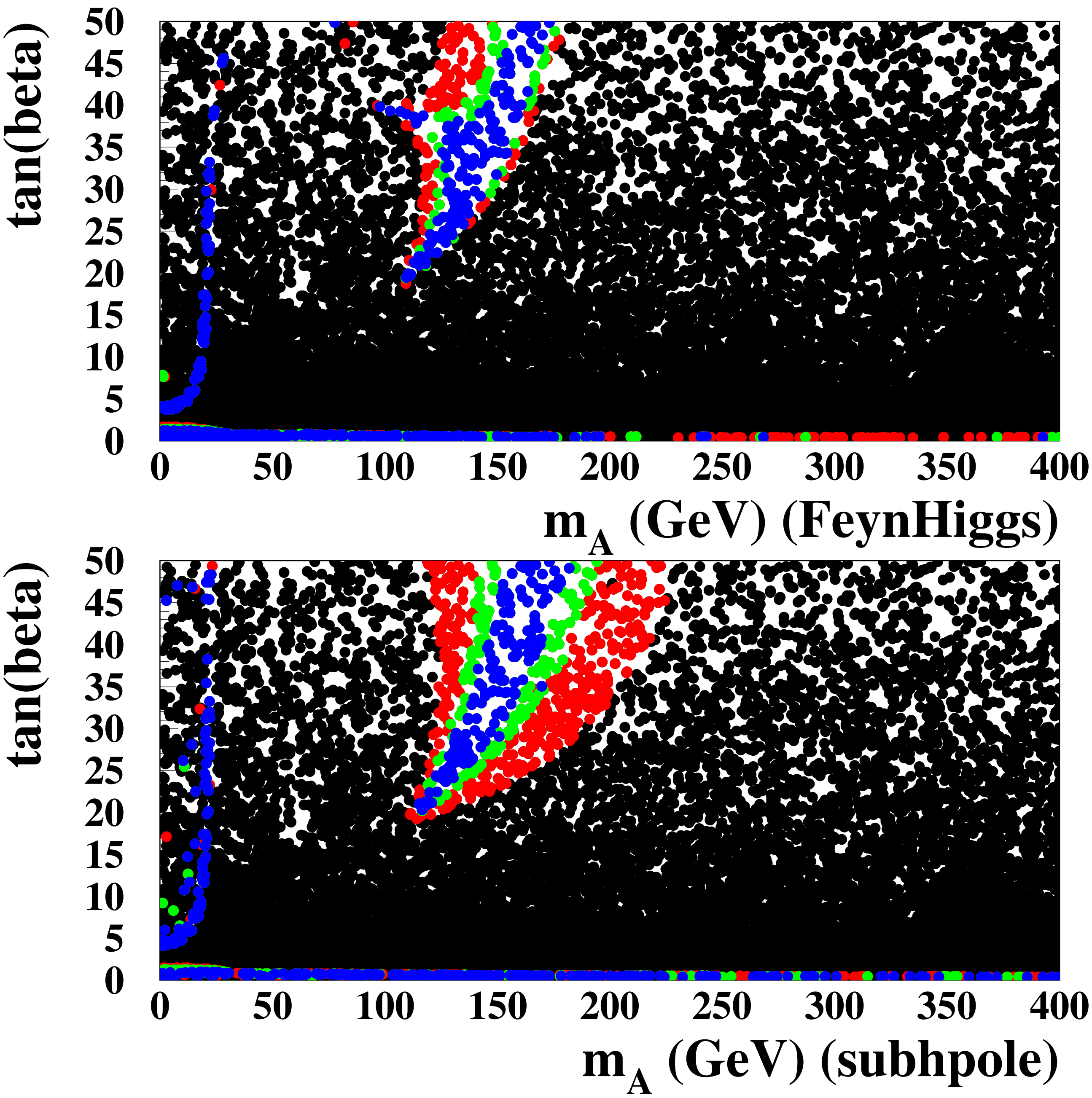
$\to$ large two-loop effect
$\to$ non-negligible effect from $q^2 \neq 0$

$BR(h \to b\bar{b}) \to 0$

via gluino corrections possible:

$\to$ "Pathological points"

[large μ scenario]



[S.H., A. Quadt, G. Weiglein '00]

5. Conclusinos

- Dominant corrections in MSSM Higgs sector $\mathcal{O}(G_\mu m_t^4)$, $\mathcal{O}(G_\mu \alpha_s m_t^4)$ via Higgs propagators corrections

  $\to$ Leading two-loop result combined with complete one-loop on-shell result

  further one-loop corrections included (QED, QCD vertices, boxes)

- Corrections implemented in predictions for
  - Higgs masses (m_h)
  - Higgs production ($e^+e^- \to hZ, hA$)
  - Higgs decay ($\Gamma(h \to f\bar{f}), BR(h \to f\bar{f})$)

- Sizable correction for $e^+e^- \to hZ, hA$

- Large corrections for $\Gamma(h \to f\bar{f})$
  - Sizable two-loop contributions
  - Large gluino effects
  - Effect on $BR(h \to \tau^+\tau^-)$, even for large M_A, $m_{\tilde{g}}$

- Comparison with RG results: ($\to \alpha_{\text{eff}}$) deviations up to 10-15 %