SUSY Higgs Searches: Tevatron 4 LHC ?

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based on collaboration with
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1. The ideas
2. Holes in the CPX scenario
3. Benchmarks for heavy Higgses
4. Conclusions

1. The ideas

How can the Tevatron help the LHC (SUSY, Higgs, . . .) ?

⇒ covering/excluding SUSY parameter space

Ideas:

1. Covering SUSY parameters that are complicated for the LHC
   → holes (uncovered by LEP) in the m_{h_1}–$\tan\beta$ plane
   for small values of m_{h_1}

2. Define benchmarks that include the Tevatron search channels
   ⇒ LHC can build on existing Tevatron searches and analyses

2. Holes in the CPX scenario

MSSM with complex phases:

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

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

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

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

gauge couplings, in contrast to SM

physical states (tree-level): $h^0, H^0, A^0, H^\pm$

$\mathcal{CP}$-even and $\mathcal{CP}$-odd fields can mix

$(A, H, h) \to (h_3, h_2, h_1)$ with $m_{h_3} > m_{h_2} > m_{h_1}$

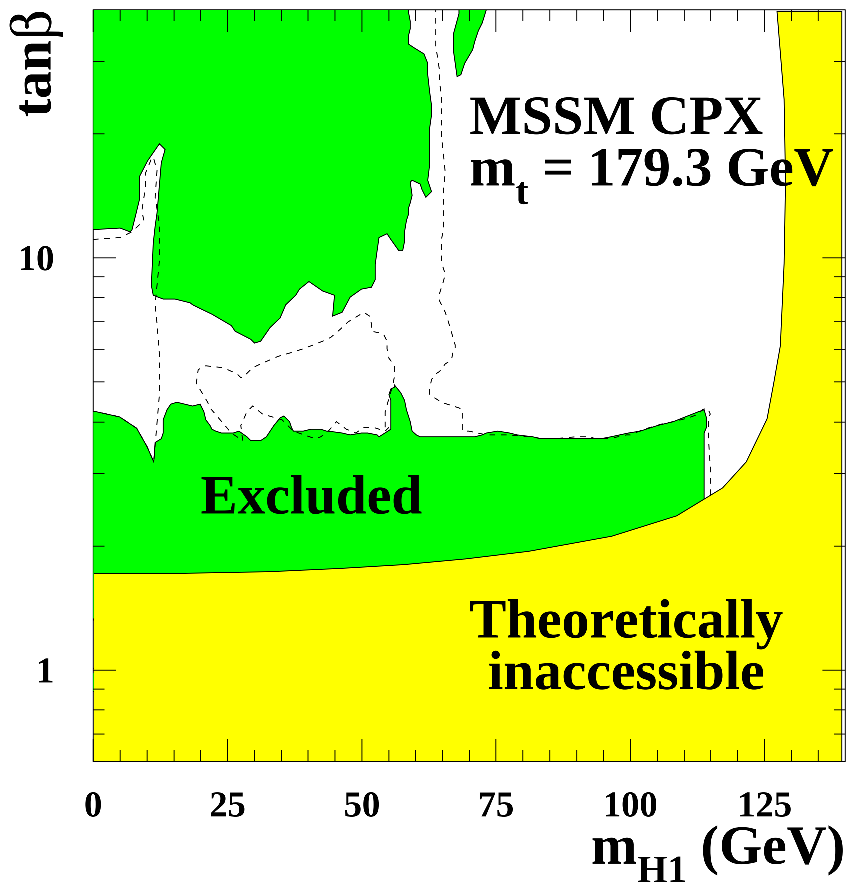
What is the problem?

CPX scenario:

→ emphasize "possible" large effects:

[M. Carena, J. Ellis, A. Pilaftsis, C. Wagner '01]

$M_{\text{SUSY}} = 500$ GeV, $|A_t| = 1$ TeV,
$A_b = A_\tau = A_t$,
$M_2 = 500$ GeV, $|m_{\tilde{g}}| = 1$ TeV,
$\mu = 2$ TeV
$\Phi = \Phi_{A_{t,b,\tau}} = \Phi_{m_{\tilde{g}}}$
$M_{H^\pm}$, $\tan\beta$ varied



LEP search left uncovered holes with low m_{h_1} ⇒ difficult for LHC

Q: Can the Tevatron cover these holes?

Possible channels:

- $V^* \to V h_1$

  $\Rightarrow$ no LEP discovery since VVh_1 coupling small

- $V^* \to V h_2$

  $\Rightarrow$ either VVh_2 small or m_{h_2} too large
  Tevatron can extend LEP reach to $m_{h_2} \lesssim$ 130 GeV

  Problem: BR($h_2 \to h_1 h_1$) large in CPX holes
  $\Rightarrow h_2 \to h_1 h_1 \to \tau^+\tau^- \, \tau^+\tau^-$ low rate!
  $\Rightarrow$ Tevatron Luminosity not high enough for this channel

  ($\to$ no analysis for $h_1 h_1 \to b\bar{b} \, \tau^+\tau^-$ yet)

- $Z^* \to h_2 h_1$

  $\Rightarrow$ too small rate in CPX holes (otherwise excluded by LEP)

Possible channels (cont.):

- $W^* \to H^{\pm} h_1$

  CPX holes $\Rightarrow$ relatively large $W^{\pm} H^{\mp} h_1$ coupling
  $\Rightarrow$ in principle interesting channel

  LHC analysis [*D. Ghosh, S. Moretti '04*]
  $\Rightarrow$ 15 events for 10 fb^{-1}
  $\Rightarrow$ not much hope for Tevatron

- $p\bar{p} \to t\bar{t}\,X \to W^+ b\ \ H^- \bar{b}\ \ X$

  coupling: $H^{\pm} tb\ \sim\ (m_t/\tan\beta + m_b \tan\beta)$
  $\Rightarrow$ coupling weakest at intermediate $\tan\beta$ values
  $\Rightarrow$ coupling weakest exactly where the CPX holes are

A: Tevatron cannot do much for the LHC

A': However, one more thing . . .

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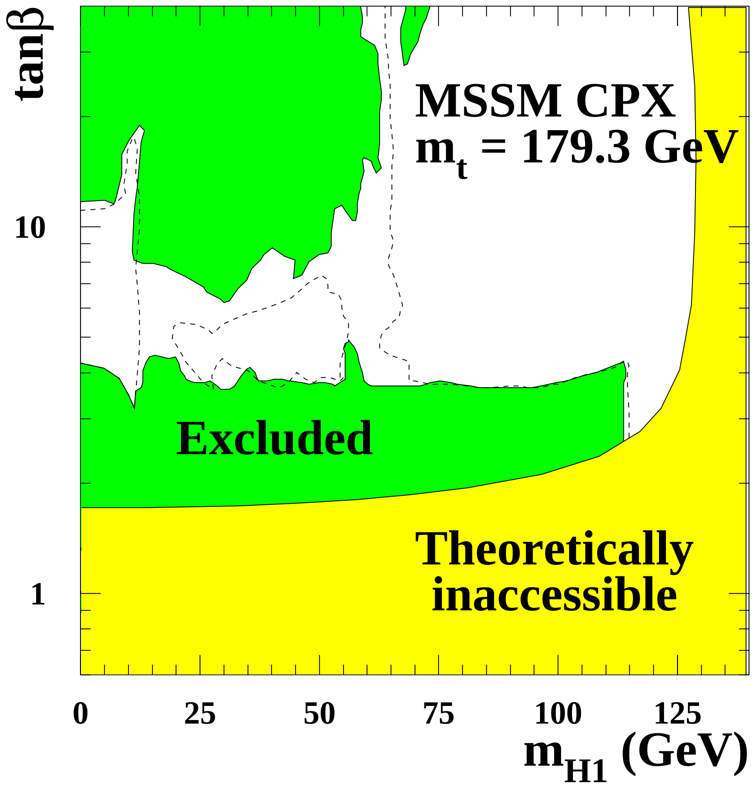
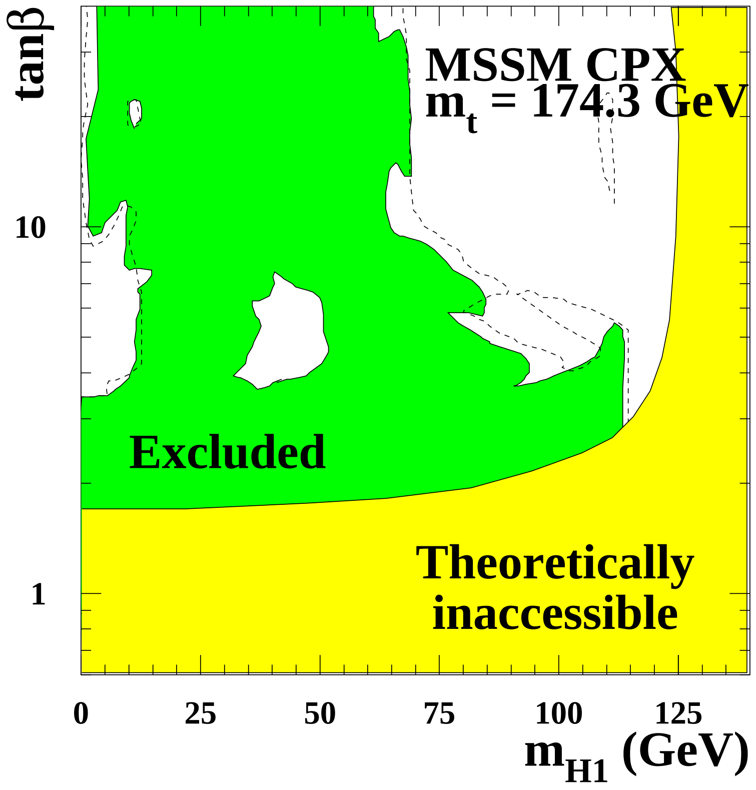
Compare m_t dependence:





What the Tevatron can possibly do:

⇒ measure a **small** and **accurate** m_t value

A": However, another thing . . .

LEP analysis:

Two codes: FeynHiggs2.0 and CPH

conservative approach (very good!):

CPX point not excluded

$\Leftrightarrow$

(point not excluded by FeynHiggs) or (point not excluded by CPH)

CPX holes "rely" heavily on large BR($h_2 \to h_1 h_1$)

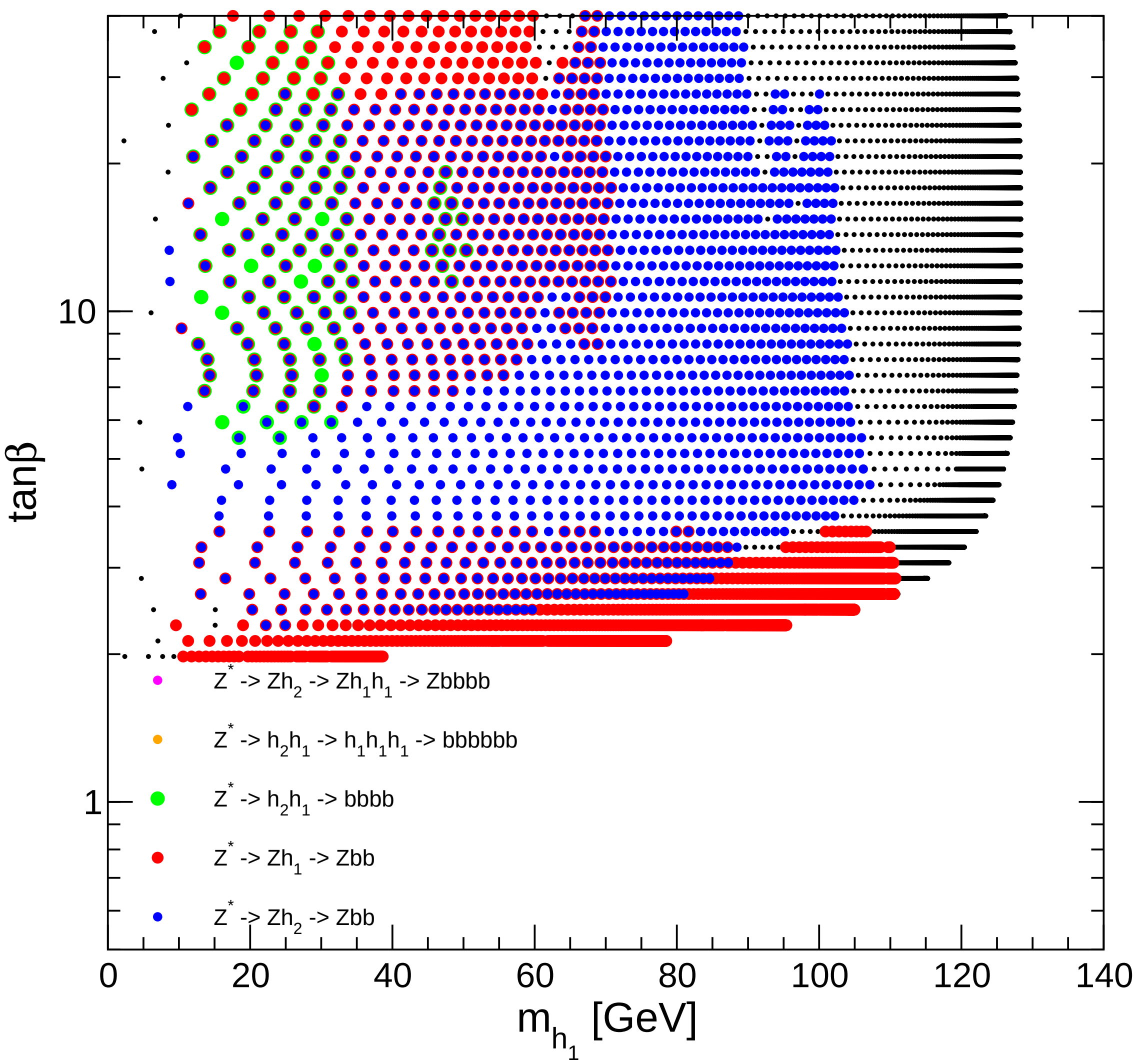
CPX holes: CPH has larger BR($h_2 \to h_1 h_1$) than FeynHiggs

$\Rightarrow$ reasons for differences under investigation

$\Rightarrow$ possibly higher-order effects that are not under control

($\Rightarrow$ LEP analysis is currently the best strategy!)

CPX @ LEP with FeynHiggs only: ⇒ no holes



⇒ reasons for differences under investigation

⇒ possibly higher-order effects that are not under control

A'' ': However, yet another thing . . .

<u>LEP analysis:</u>

holes not excluded at the 95% C.L.

holes are excluded at the $\sim$ 75% C.L.

$\Rightarrow$ "combined" LEP/Tevatron analysis ??

3. Benchmarks for heavy Higgses

Idea:

Define benchmarks that include the Tevatron search channels
$\Rightarrow$ LHC can build on existing Tevatron searches and analyses

Benchmarks such that minimum/maximum region of SUSY parameter space is excluded
$\Rightarrow$ full potential of search channels investigated

Channels:

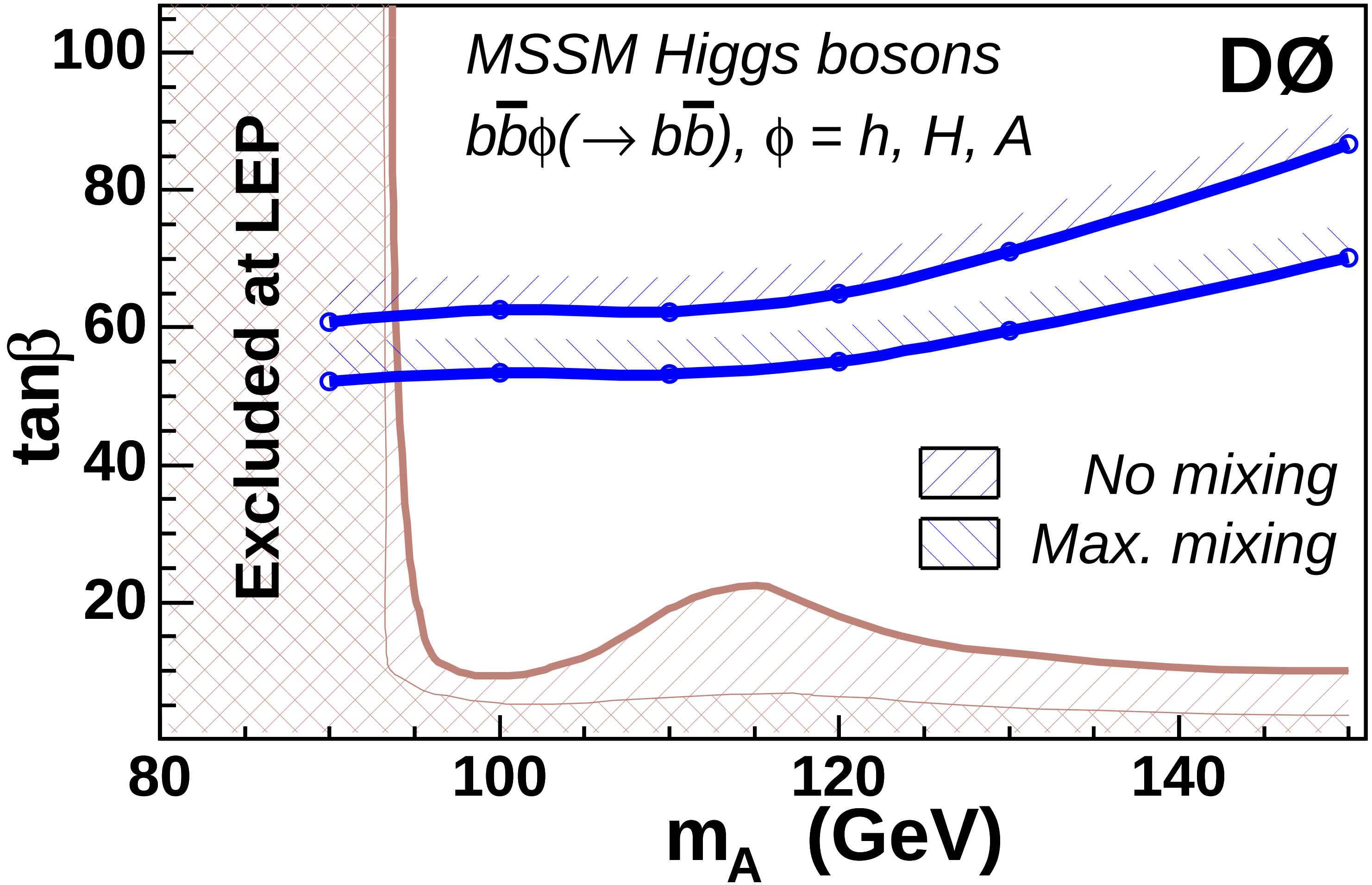
(A) $b\bar{b}\phi$, $\phi \to b\bar{b}/\tau^+\tau^-$, $\phi = h, H, A$

(B) $p\bar{p} \to t\bar{t}\,X \to W^+b\;\; H^-\bar{b}\;\; X$

(C) $gg \to h$?

3. (A): $b\bar{b}\phi$, $\phi \to b\bar{b}/\tau^+\tau^-$, $\phi = h, H, A$

Latest result from D0 [*hep-ex/0504018*]

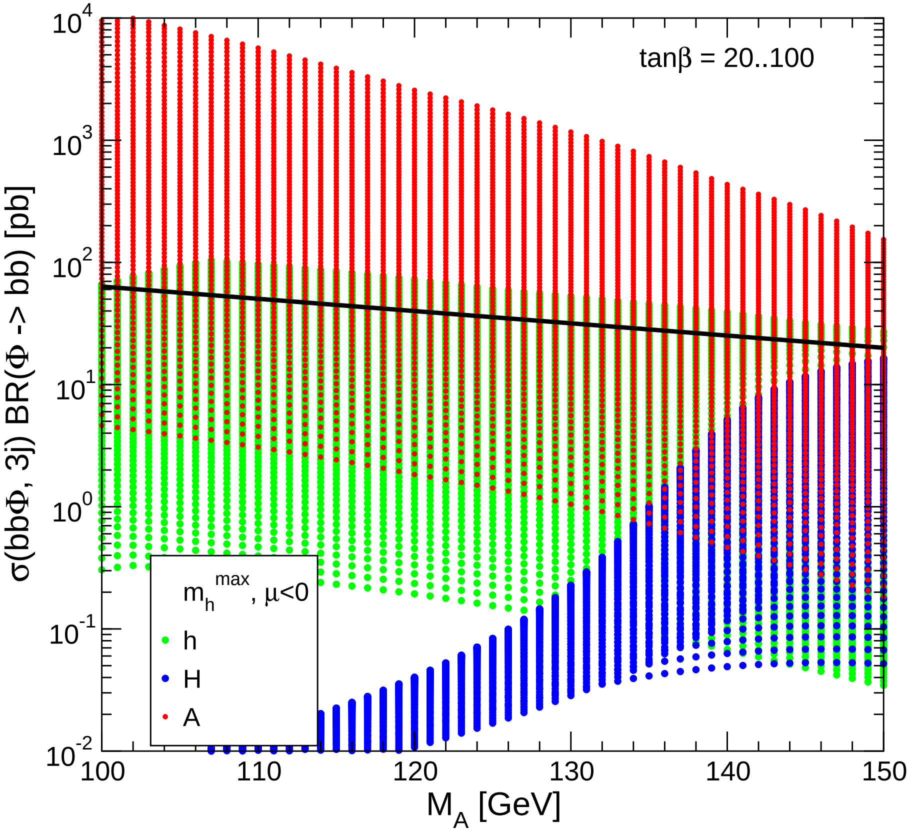


Where do the large differences in the "no mixing" and "max mixing" scenario come from?

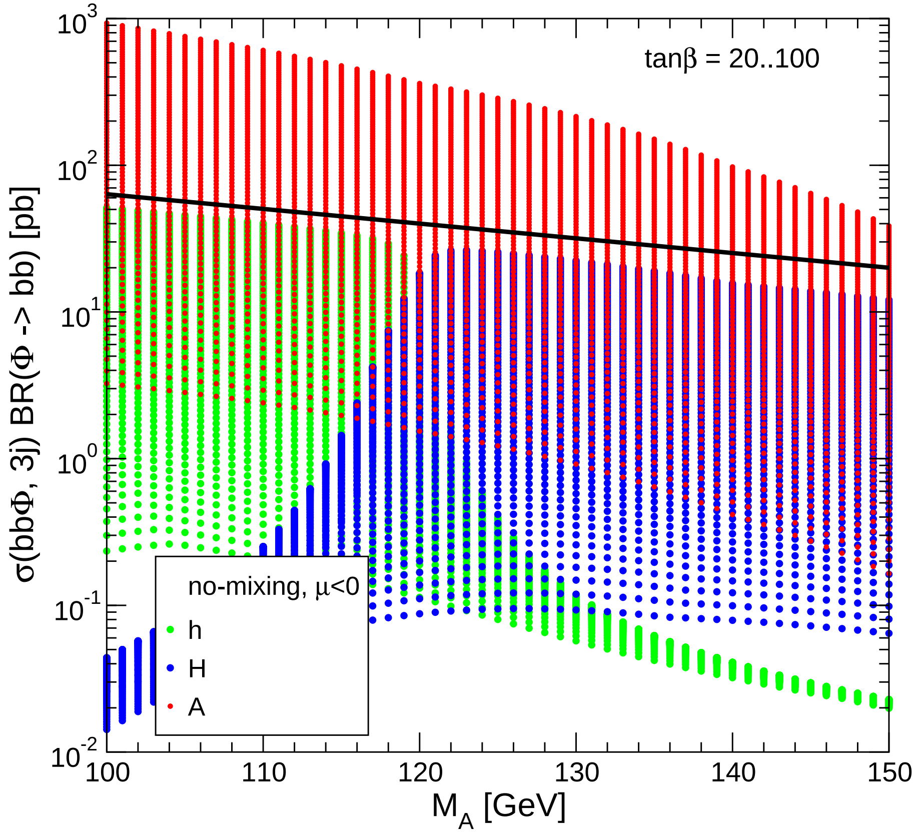
Compare $\sigma(bb\phi) \times \mathrm{BR}(\phi \to b\bar{b})$ in m_h^{max} and no-mix scenario:

[M. Carena, S.H., C. Wagner, G. Weiglein '99] *[+ thanks to Fabio Maltoni!]*

m_h^{max}



no-mix



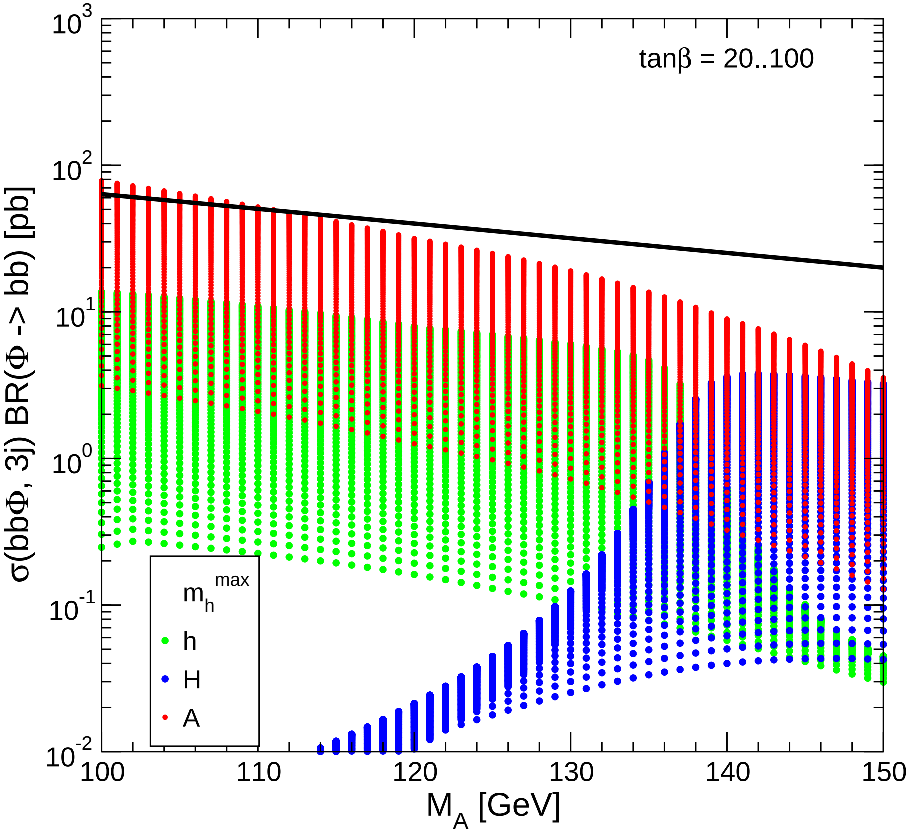
$\Rightarrow \sigma \times$ BR larger in m_h^{max} due to Δm_b effects

$$y_b \sim \frac{m_b}{1 + \Delta m_b}, \qquad \Delta m_b \sim \alpha_s \tan\beta\, \mu\, m_{\tilde{g}}\, I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$$

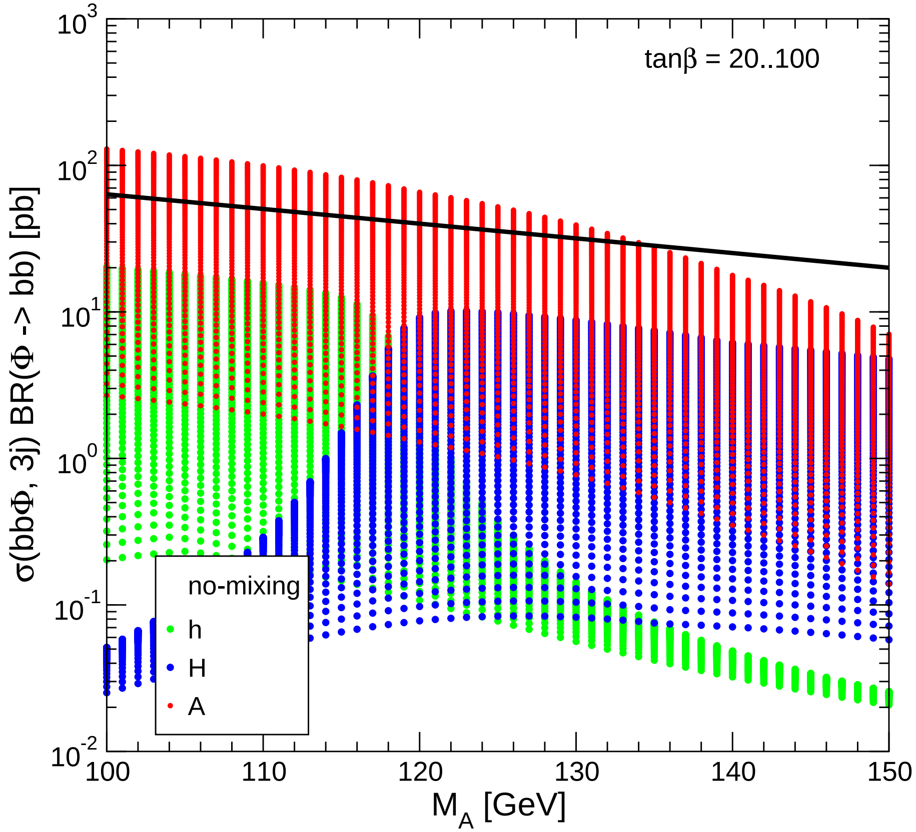
New benchmark definition with $\mu > 0$ (due to $(g-2)_\mu$):

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

$m_h^{\rm max}$



no-mix

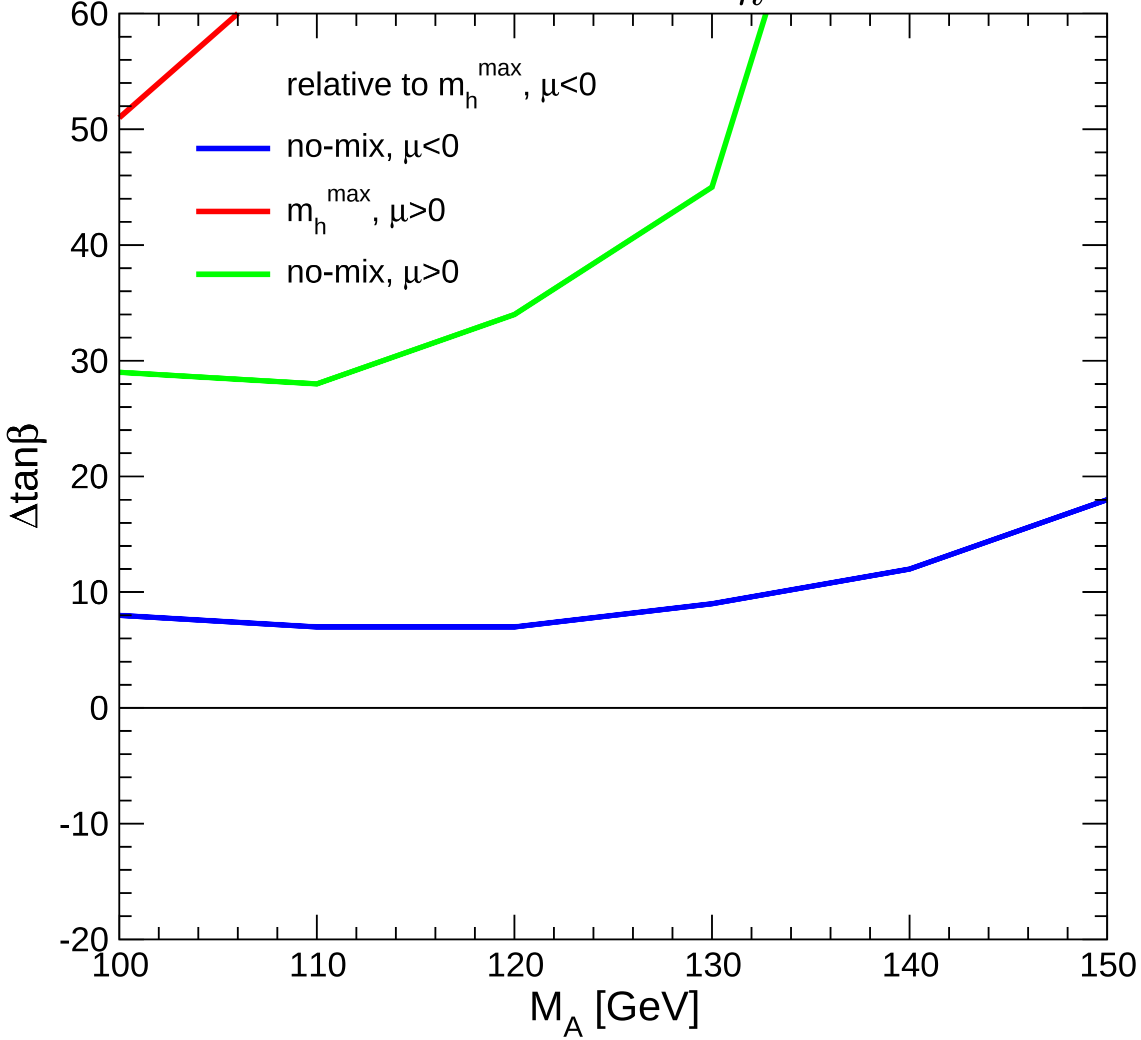


sign of μ reversed $\Rightarrow \Delta m_b > 0 \Rightarrow y_b$ smaller $\Rightarrow \sigma \times$ BR smaller

$\Rightarrow t/\tilde{t}$ sector plays a minor role

Effects on tan β exclusion region:

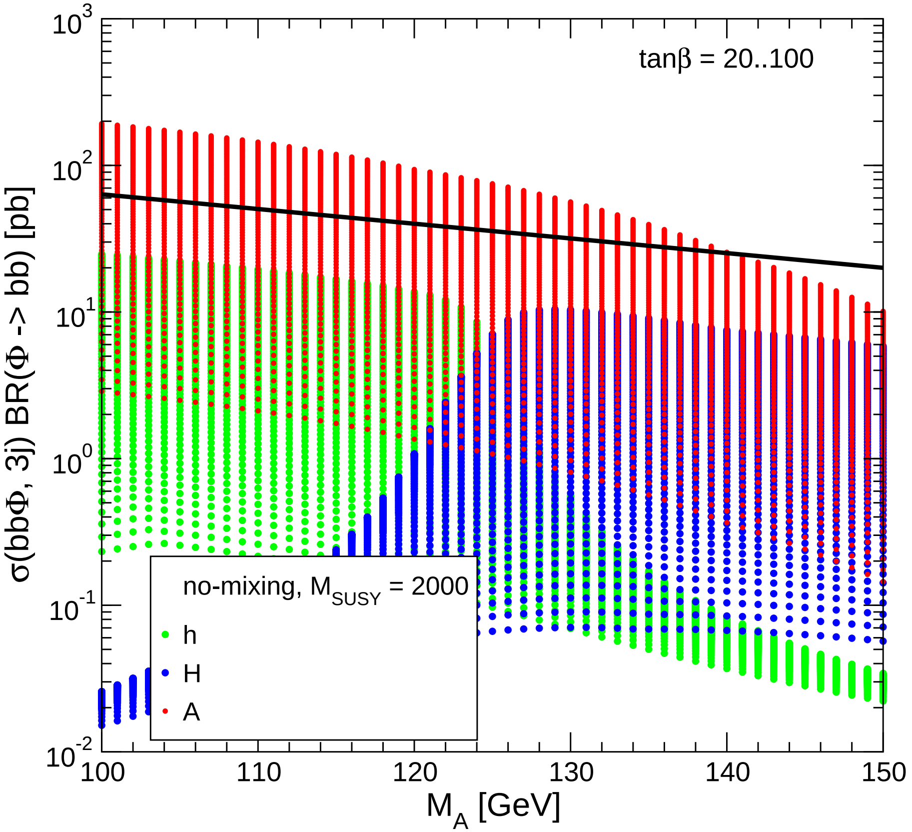
Show effects relative to "best" scenario: $m_h^{\rm max}$, $\mu < 0$



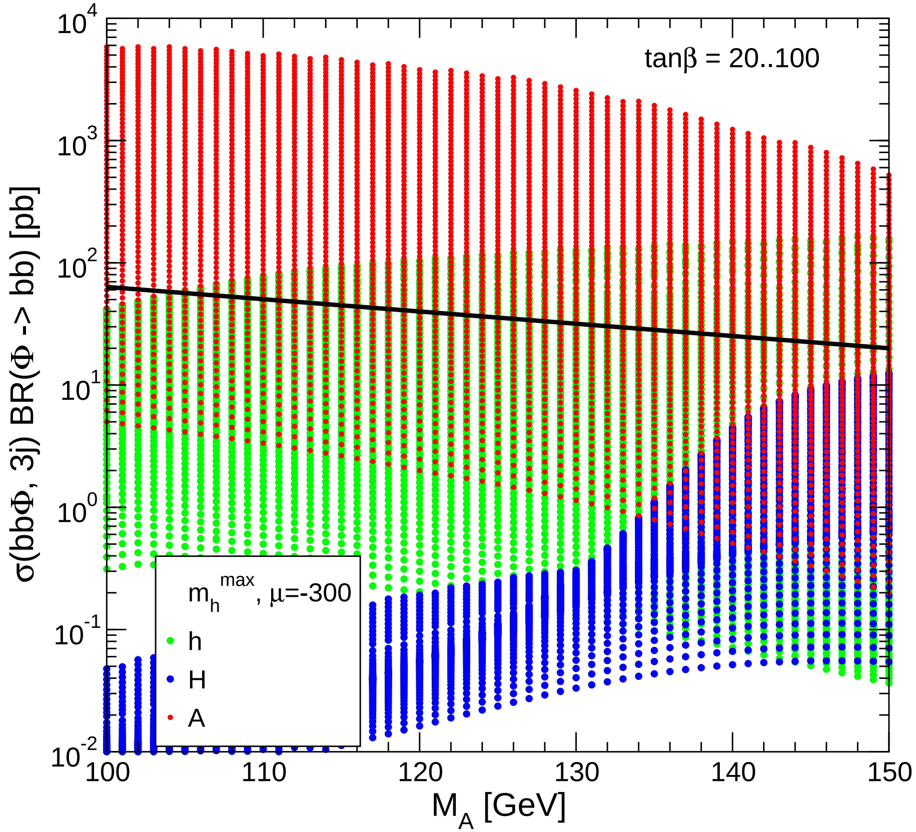
$\Rightarrow$ large freedom to tune best/worst scenario

Two other "random" scenarios:

no-mix, $M_{\text{SUSY}} = 2$ TeV



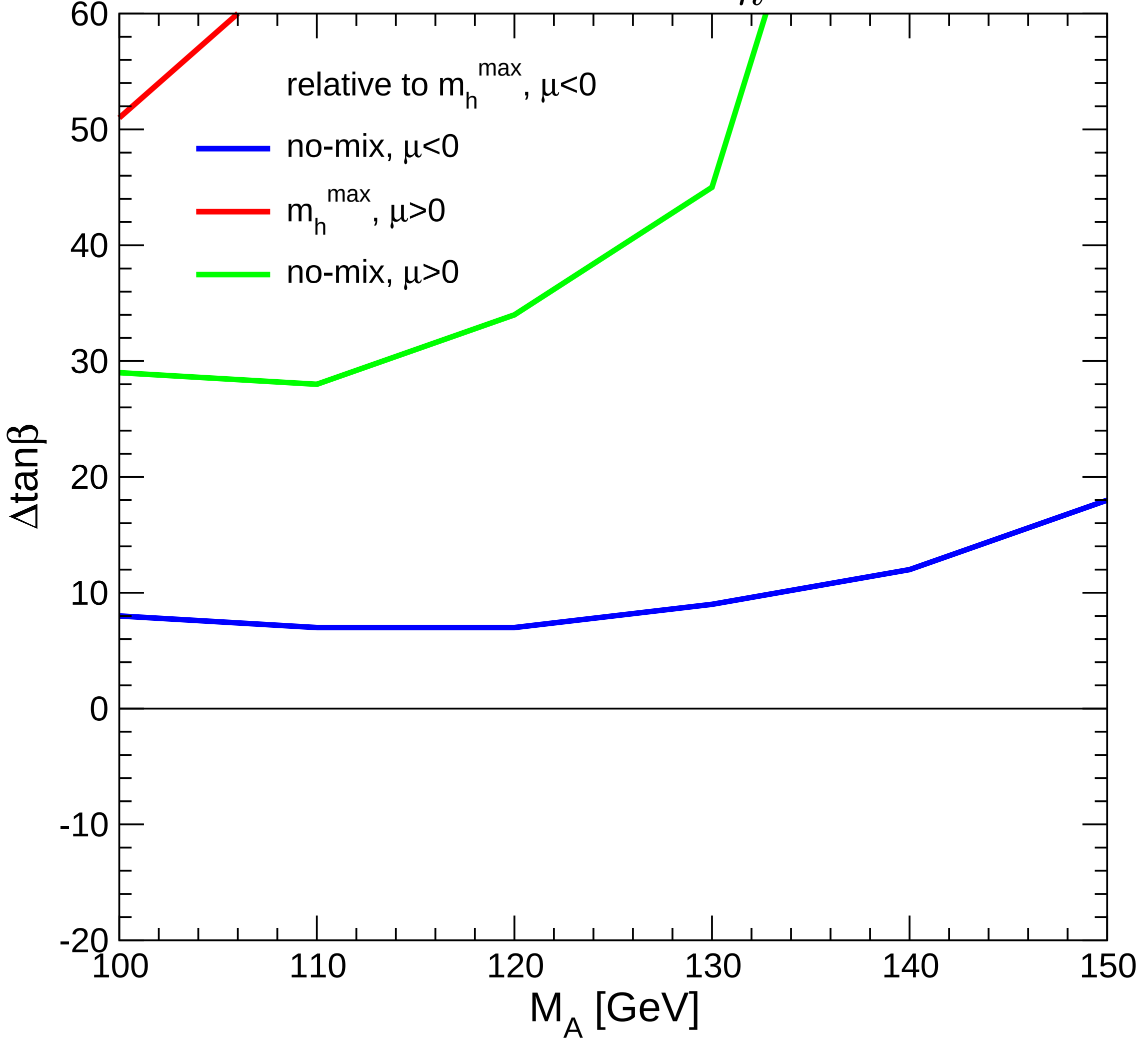
m_h^{max}, $\mu = -300$ GeV



$\Rightarrow$ large effects via $\Delta m_b \Rightarrow t/\tilde{t}$ sector plays a minor role

Effects on tan β exclusion region:

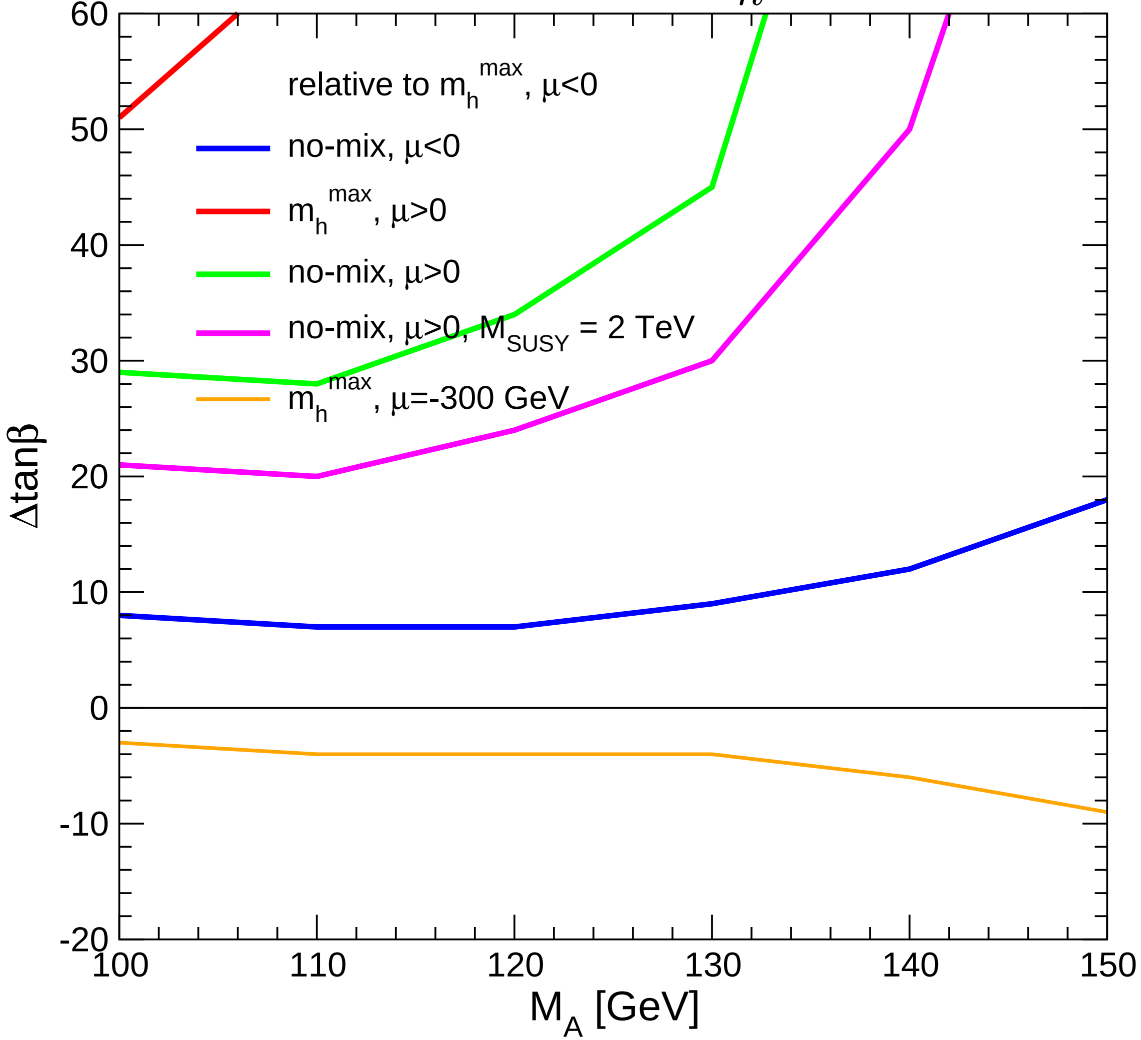
Show effects relative to "best" scenario: m_h^{max}, $\mu < 0$



$\Rightarrow$ large freedom to tune best/worst scenario

Effects on $\tan\beta$ exclusion region:

Show effects relative to "best" scenario: $m_h^{\rm max}$, $\mu < 0$



$\Rightarrow$ large freedom to tune best/worst scenario

⇒ large freedom to tune best/worst scenario

The question is: what are you willing to accept?

- large disagreement with $(g-2)_\mu$?
- (nearly) non-perturbative parameters: $\Delta m_b \approx -1$
- sfermion masses (very) close to experimental limit?
  (or possibly beyond experimental limits in the future?)
- ...

3. (B) $p\bar{p} \to t\bar{t}\,X \to W^{+}b \;\; H^{-}\bar{b} \;\; X$

$H^{\pm}tb$ coupling: $\sim y_t/\tan\beta + y_b\tan\beta$

$$y_b \sim \frac{m_b}{1+\Delta m_b}, \qquad \Delta m_b \sim \alpha_s \tan\beta\, \mu\, m_{\tilde{g}}\; I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$$

$\Rightarrow$ larger variations possible via Δm_b for large $\tan\beta$

$\longrightarrow$ look at same scenarios as before

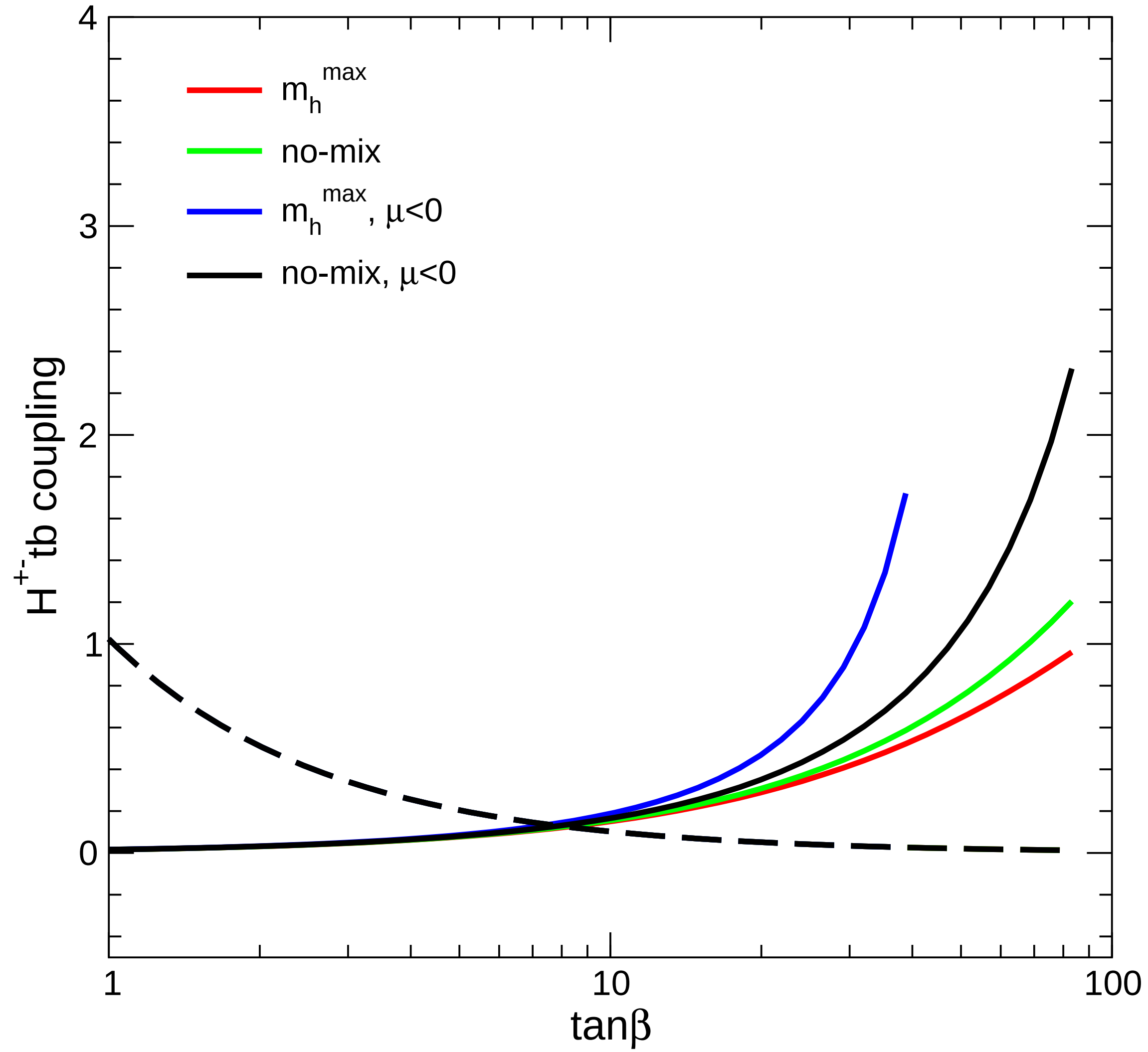
$H^{\pm}tb$ coupling:

$\Gamma(t \to H^{+}b) \sim (H^{\pm}tb)^2$

$\Rightarrow$ variation at large $\tan\beta$

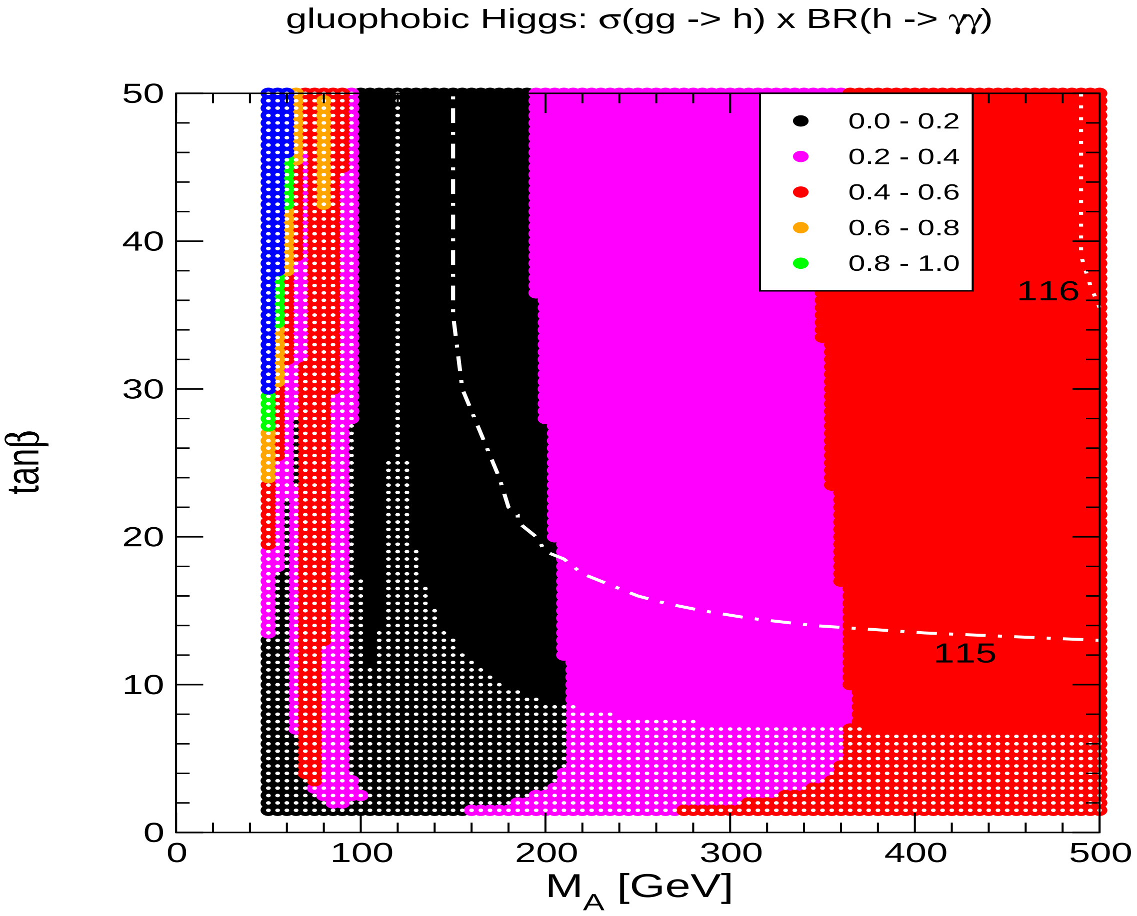
$\Rightarrow$ variation in $\tan\beta$ exclusion

What are you willing to accept?



3. (C) $gg \to h$?

→ gluophobic scenario



→ gluophil scenario?

4. Conclusinos

- Idea I: Tevatron can cover "complicated" MSSM parameters

  $\rightarrow$ holes in CPX scenario with very light Higgs

  $\Rightarrow$ very difficult for the Tevatron . . . $W^* \rightarrow H^{\pm} h_1$??

  (other issues: m_t dependence, higher-order uncertainties, LEP/Tevatron analysis . . .)

- Idea II: Define benchmarks $\Rightarrow$ continuous Tevatron/LHC search

  $\rightarrow$ "optimistic" /" pessimistic" scenarios to show possible variation in exclusion bounds

  $\rightarrow$ focus on Tevatron search channels

  $\Rightarrow$ largest variation via $\Delta m_b \sim \alpha_s \, \mu \tan \beta$

  $\Rightarrow$ large variation in exclusion bounds

  $\rightarrow$ $b\bar{b}\phi \rightarrow b\bar{b}\, b\bar{b}$ (also: $t \rightarrow H^+ b$, $gg \rightarrow h$, . . .)