BSM Higgs Searches

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CERN, 07/2009

based on collaboration with
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1. Introduction

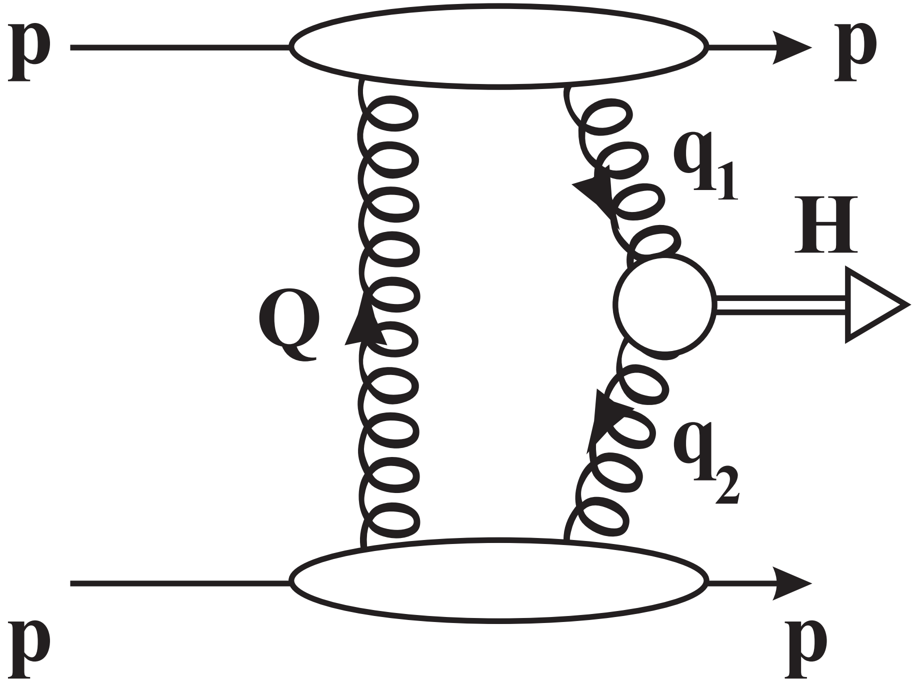
2. MSSM update

3. 4th generation model

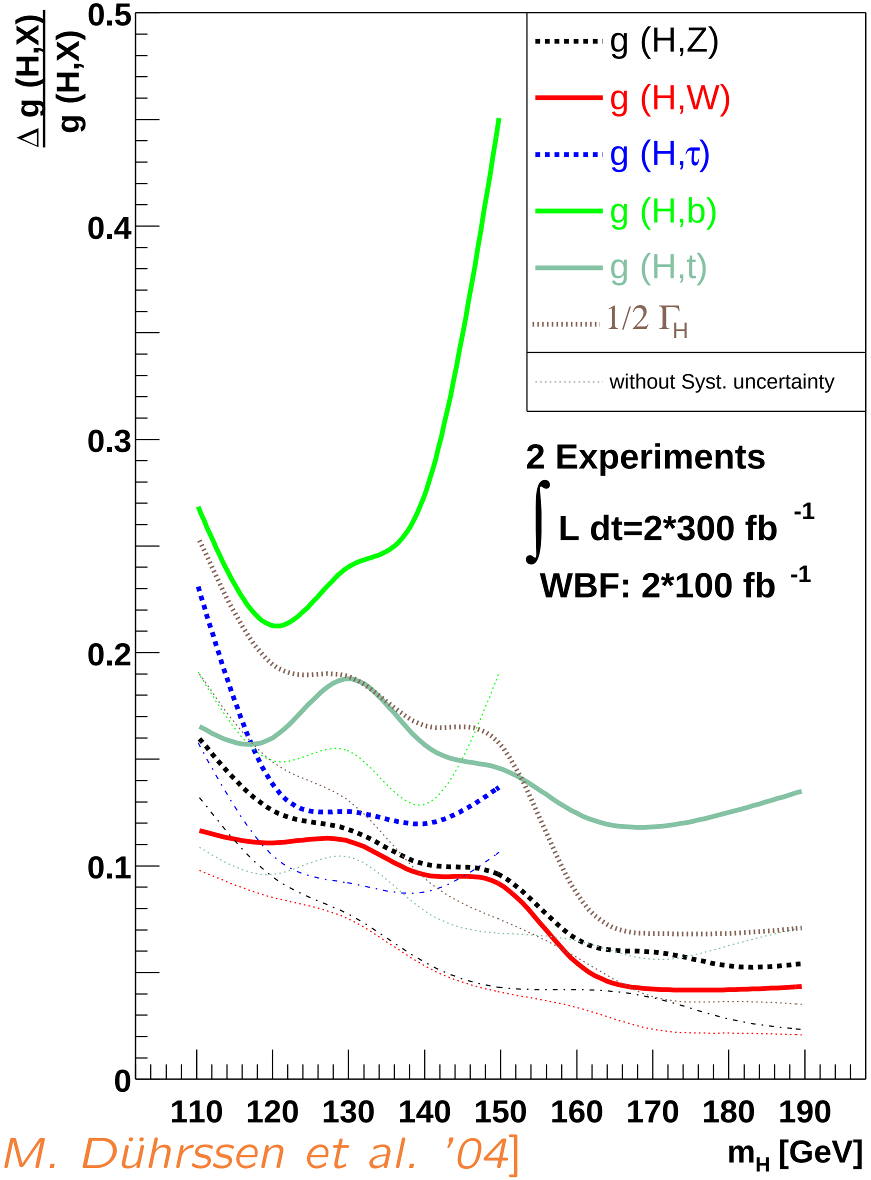
4. Conclusions

1. Introduction

$pp \;\longrightarrow\; p \oplus H \oplus p, \quad H \to b\bar{b}, \tau^+\tau^-, W^+W^-, \ldots$ (protons remain intact)



The LHC will find a SM-like Higgs and measure its characteristics:



[M. Dührssen et al. '04]

– mass: $\delta M_h \approx$ 200 MeV

– couplings: $(2 * 300 + 2 * 100)$ fb^{-1} :

typical accuracies of 20-30%

for $m_H \leq 150$ GeV

10% accuracies for HVV couplings

above WW threshold

Assumption:

– $g^2_{HVV} \leq g^2_{HVV,\mathrm{SM}} \times 1.05$

– SM rates for the Higgs

Problem:

$Hb\bar{b}$ only via $t\bar{t} \to H \to b\bar{b}$

signal shape ≈ background shape

⇒ reduced signal in new analyses

(for ATLAS and CMS)

⇒ other possibilities for $Hb\bar{b}$?

Some details ($\phi = h^{\text{MSSM}}, H^{\text{MSSM}}, H^{\text{4th gen}}$):

1. Proton detection: in Forward Proton Taggers at 220 m, 420 m
2. Higgs decay: (here only) $\phi \to b\bar{b}$
   two high p_T b jets, measured in ATLAS or CMS
3. Trigger to keep signal (2):
   "cocktail" of triggers: 220, high p_T jets, high p_T leptons, . . .
4. Identification of signal: (1) and (2) have to match in mass
5. Cross section calculation: $\sigma_{\text{SM}} \times \frac{\Gamma(gg\to\phi)_{\text{NP}}}{\Gamma(gg\to H)_{\text{SM}}}$
6. Decay calculation: $\text{BR}_{\text{NP}}(\phi \to b\bar{b})$ $\Rightarrow$ FeynHiggs (MSSM: incl. Δ_b dep.)
   advantage over SM: possibly enhanced decay rates
7. Backgrounds and pile-up:
   taken into account according to recent analyses/
   best available estimates

$\Rightarrow$ 5 σ discovery contours, 3 σ significance bounds

Four luminosity assumptions:

$60 \ \ \text{fb}^{-1}$:

$\mathcal{L} = 2 \times 30 \ \ \text{fb}^{-1}$: three years of low-luminosity running

$60 \ \ \text{fb}^{-1}$ eff $\times$ 2:

as "60", but assuming an improvement in signal efficiency etc.

effectively: signal rates doubled

$600 \ \ \text{fb}^{-1}$:

$\mathcal{L} = 2 \times 300 \ \ \text{fb}^{-1}$: three years of high-luminosity running

$600 \ \ \text{fb}^{-1}$ eff $\times$ 2:

as "600", but assuming an improvement in signal efficiency etc.

effectively: signal rates doubled

2. MSSM update

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

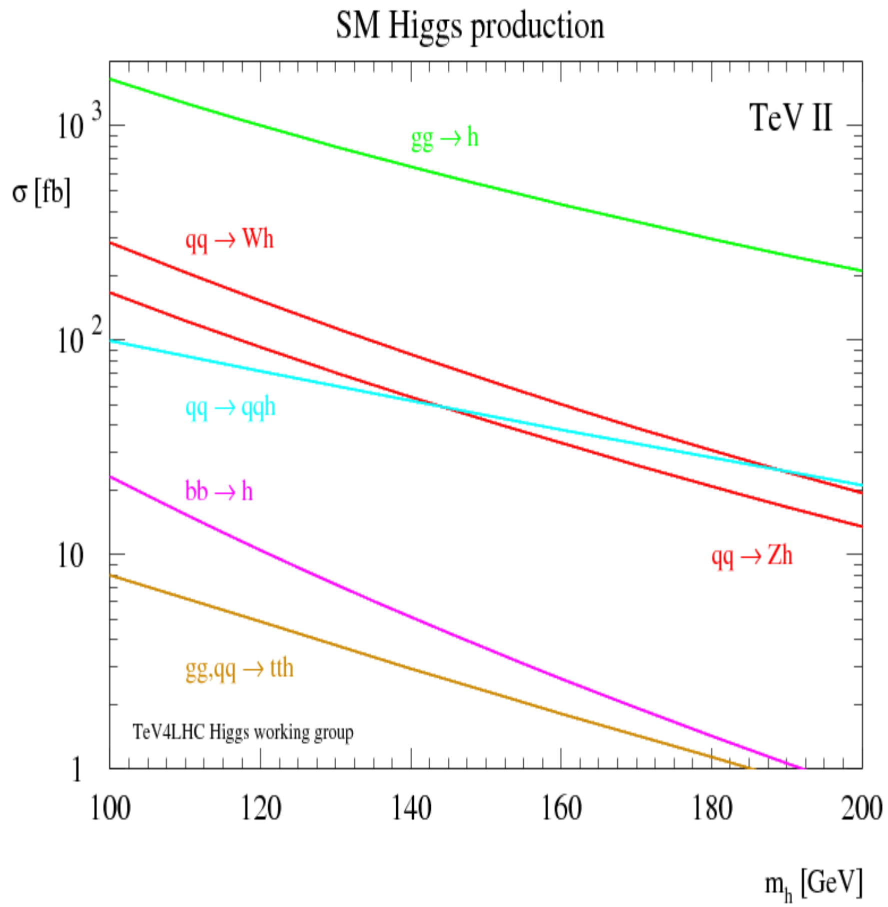
physical states: $h^0, H^0, A^0, H^\pm$ Goldstone bosons: $G^0, G^\pm$

Input parameters: (to be determined experimentally)

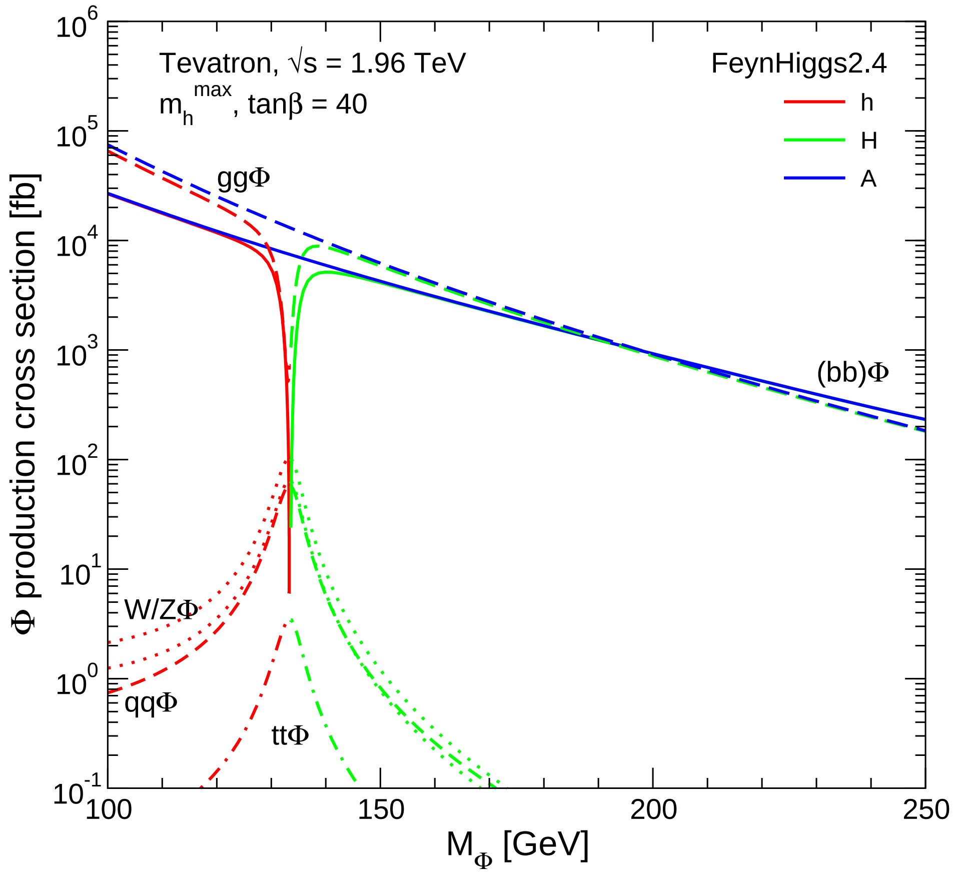
$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2(\tan\beta + \cot\beta)$$

Higgs production cross sections at the Tevatron:

SM



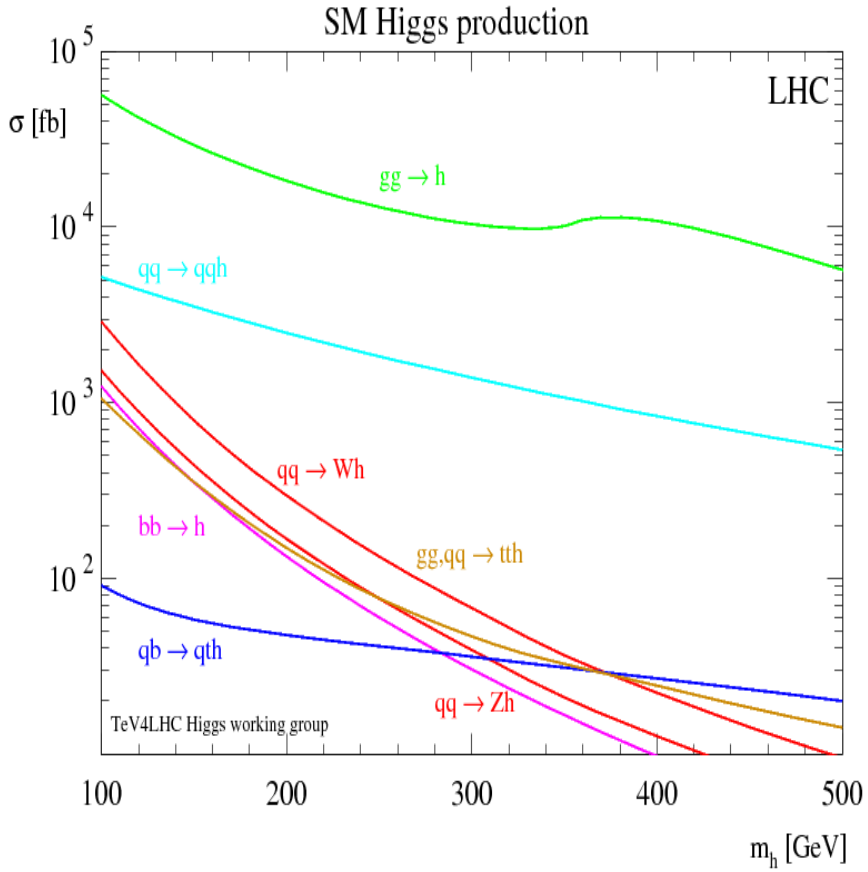
MSSM



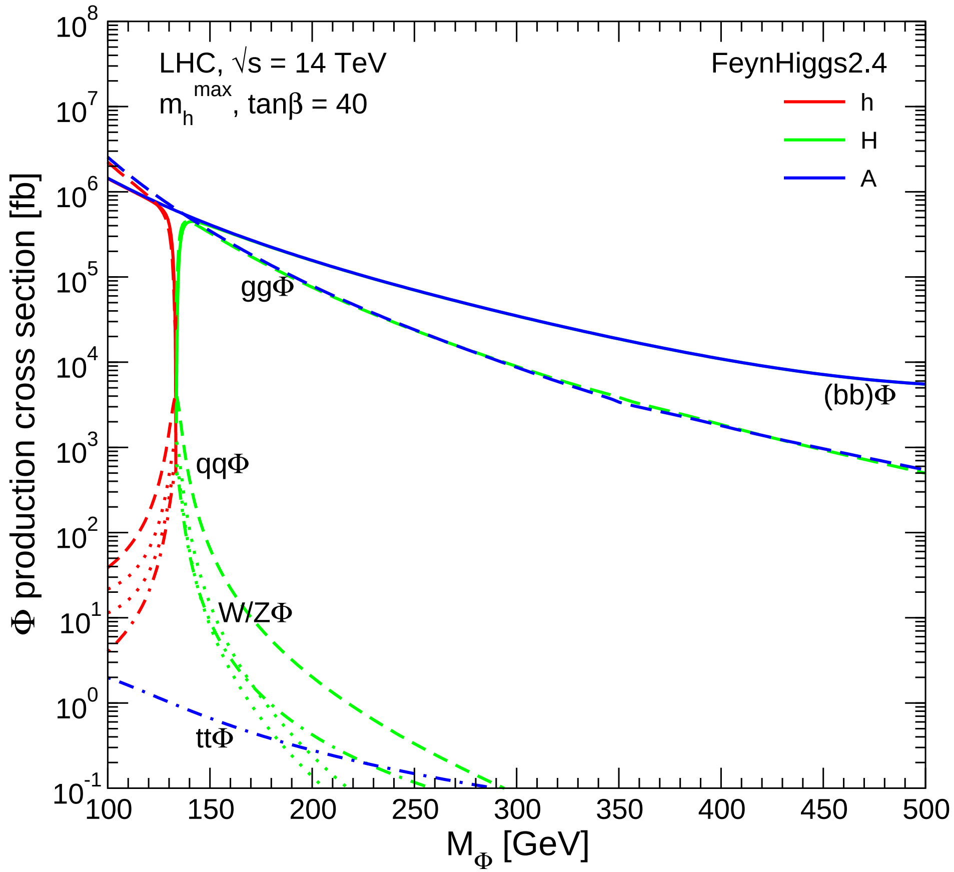
MSSM: possibly enhanced rates at high $\tan\beta$

Higgs production cross sections at the LHC:

SM



MSSM



MSSM: possibly enhanced rates at high tan β

Update with respect to 2007 analysis:

- Update of background estimates: NLO for $gg \to b\bar{b}$

- Update of LEP and Tevatron exclusion bounds

  $\Rightarrow$ `HiggsBounds` [*B. Bechtle, O. Brein, S.H., G. Weiglein, K. Williams '08*]

- Update of σ and BR calculation

  $\Rightarrow$ `FeynHiggs` [*T. Hahn, S.H., W. Hollik, H. Rzehak, G. Weiglein '98 - '09*]

  (small changes in Δ_b, $gg \to h$ improved)

MSSM scenarios:

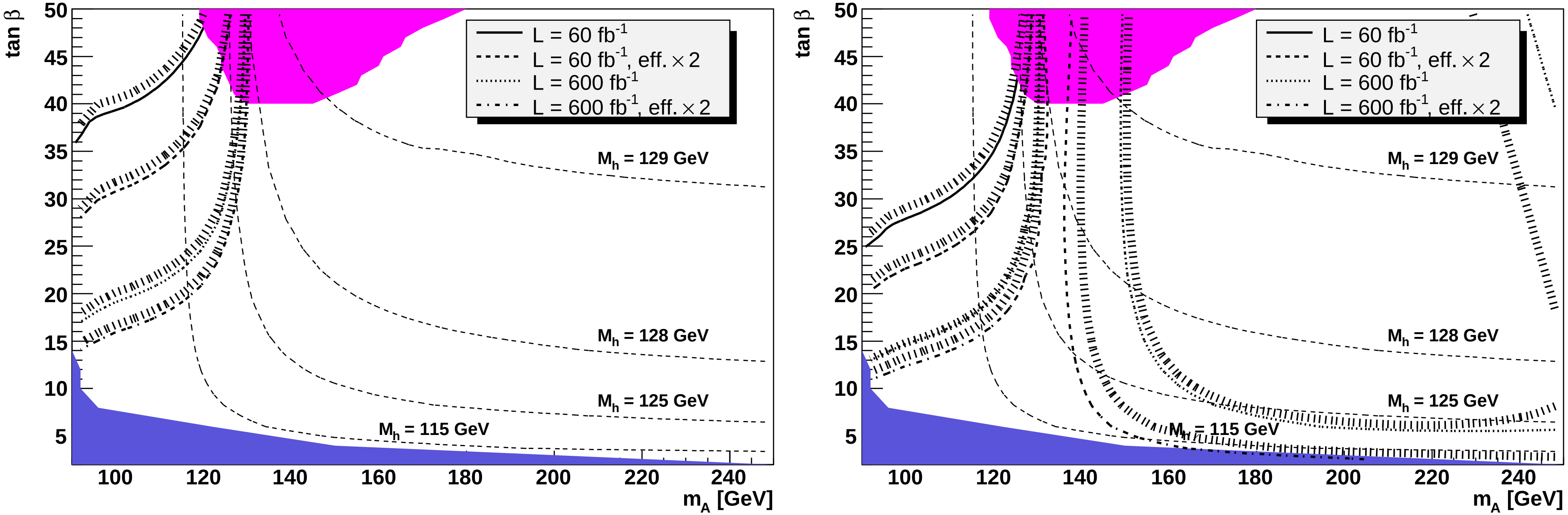
- "normal" benchmarks: $m_h^{\rm max}$, no-mixing ($\mu = +200$ GeV)

- CDM benchmarks: M_A-$\tan\beta$ planes in agreement with CDM

  [*J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07*] $\longrightarrow$backup

Results for h in the $m_h^{\rm max}$ scenario:

5 σ discovery | 3 σ evidence



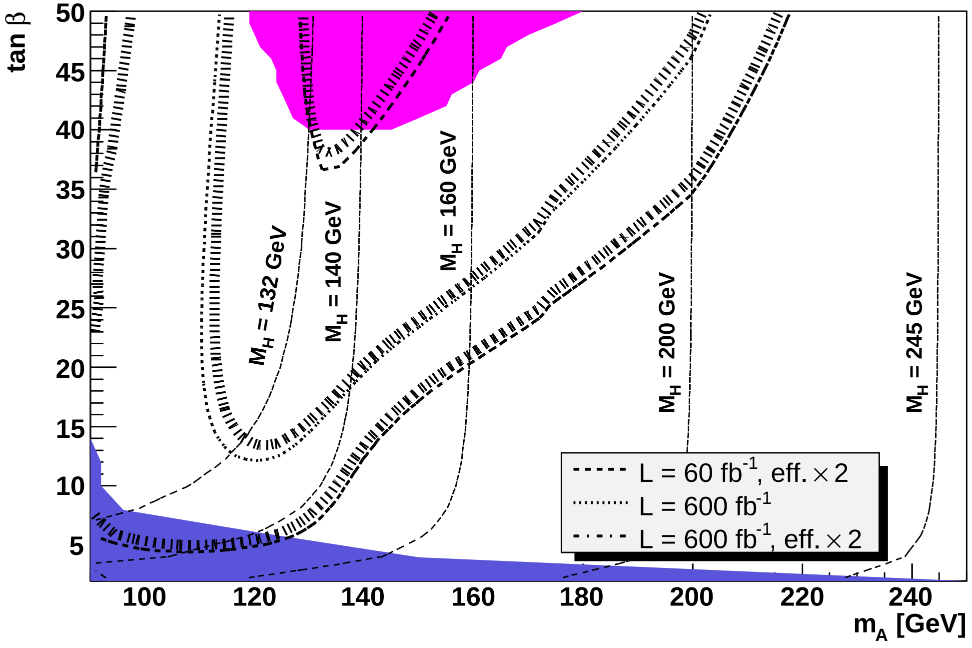
pink: Tevatron exclusion bounds

blue: LEP exclusion bounds

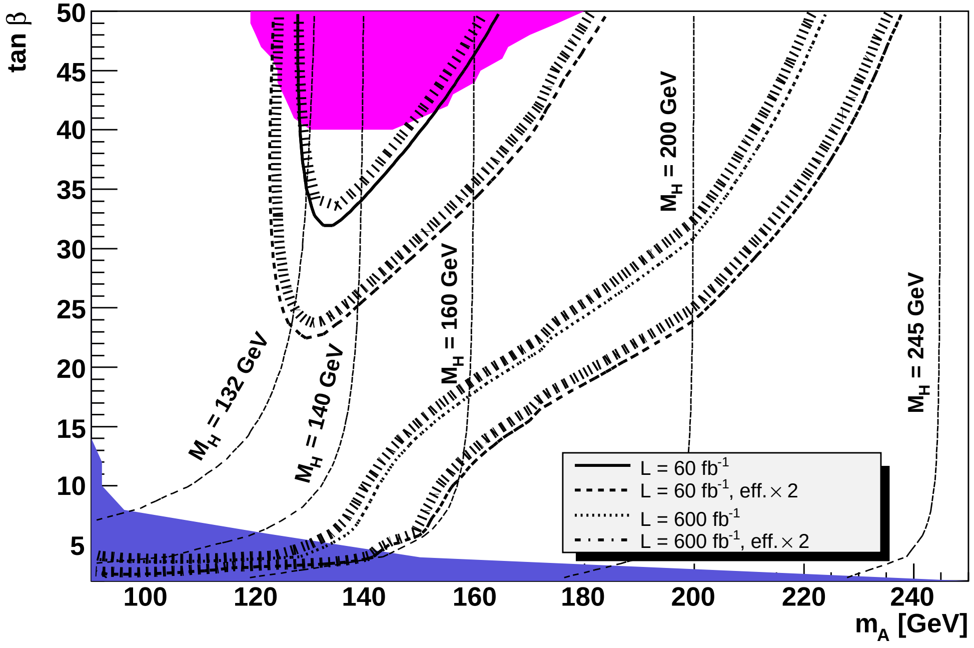
⇒ large parts can be covered at 3 σ!

Results for H in the $m_h^{\rm max}$ scenario:

5 σ discovery



3 σ evidence



pink: Tevatron exclusion bounds

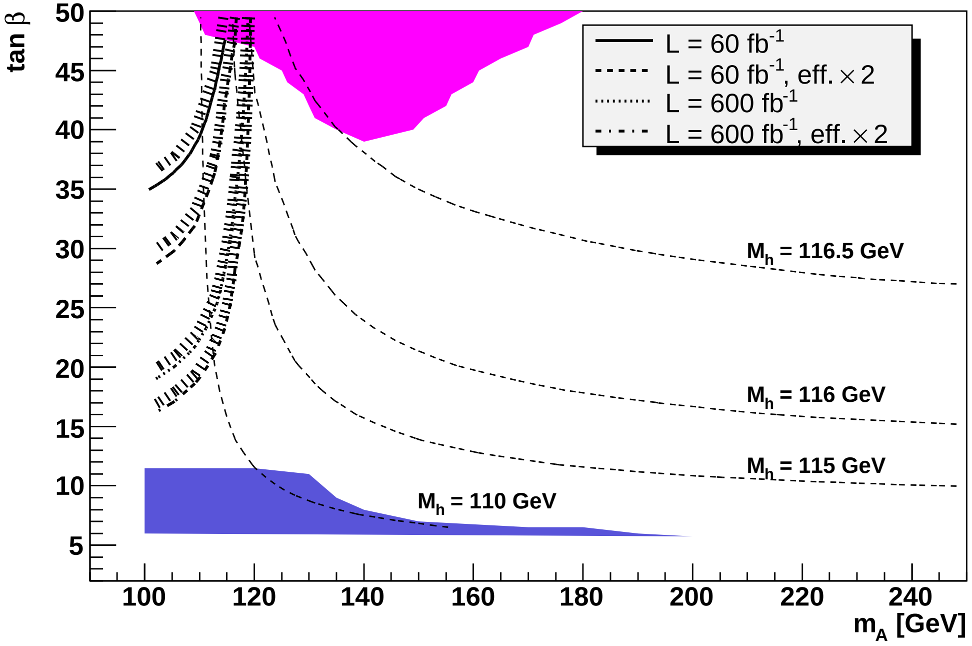
blue: LEP exclusion bounds

$\Rightarrow$ large discovery regions, but no "LHC wedge" coverage

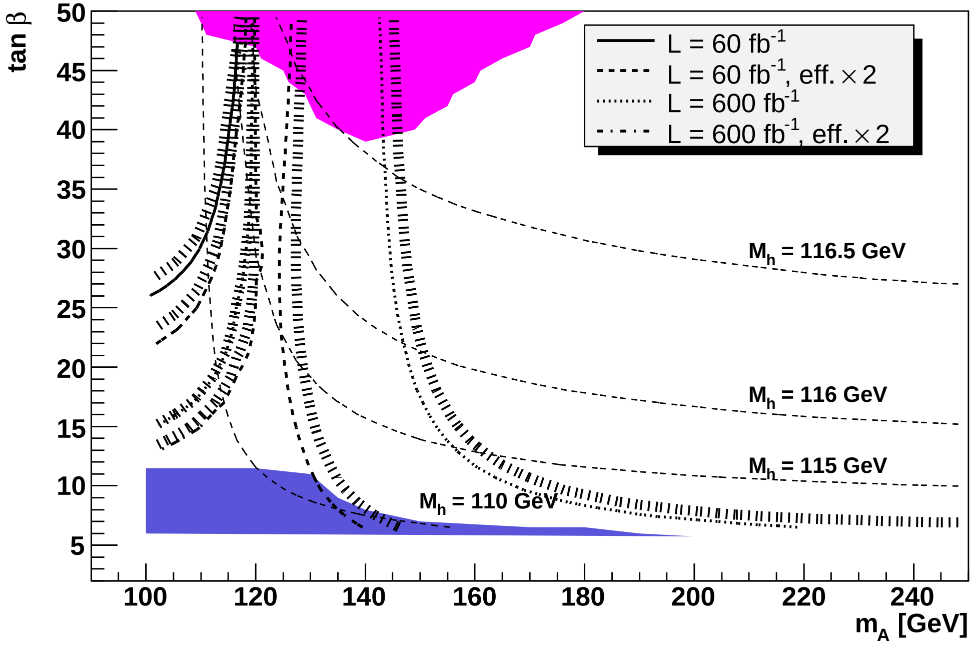
$\longrightarrow$backup

Results for h in the CDM scenario (#3):

5 σ discovery



3 σ evidence

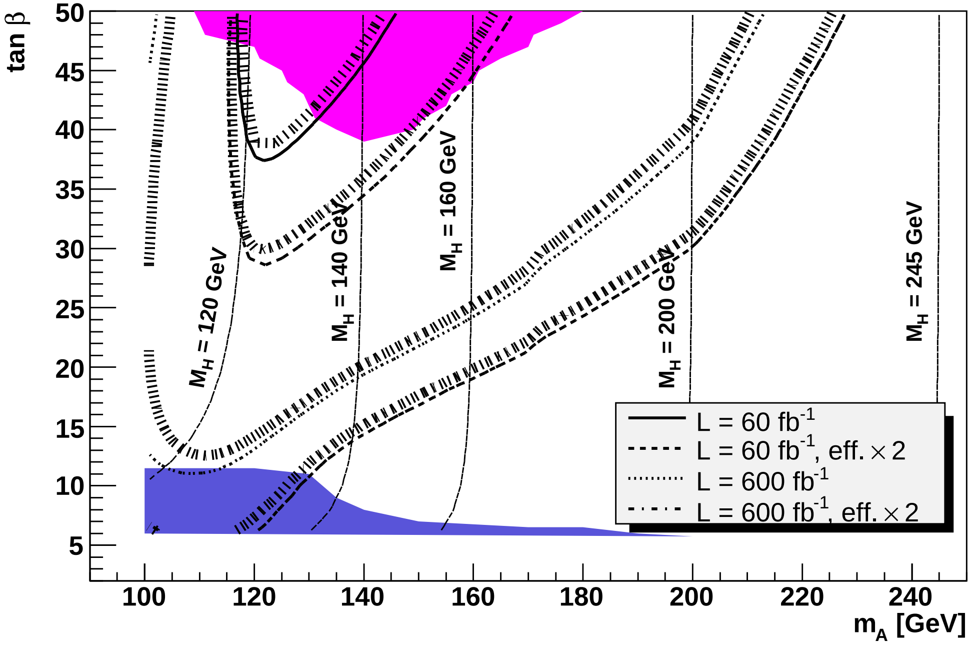


pink: Tevatron exclusion bounds
blue: LEP exclusion bounds

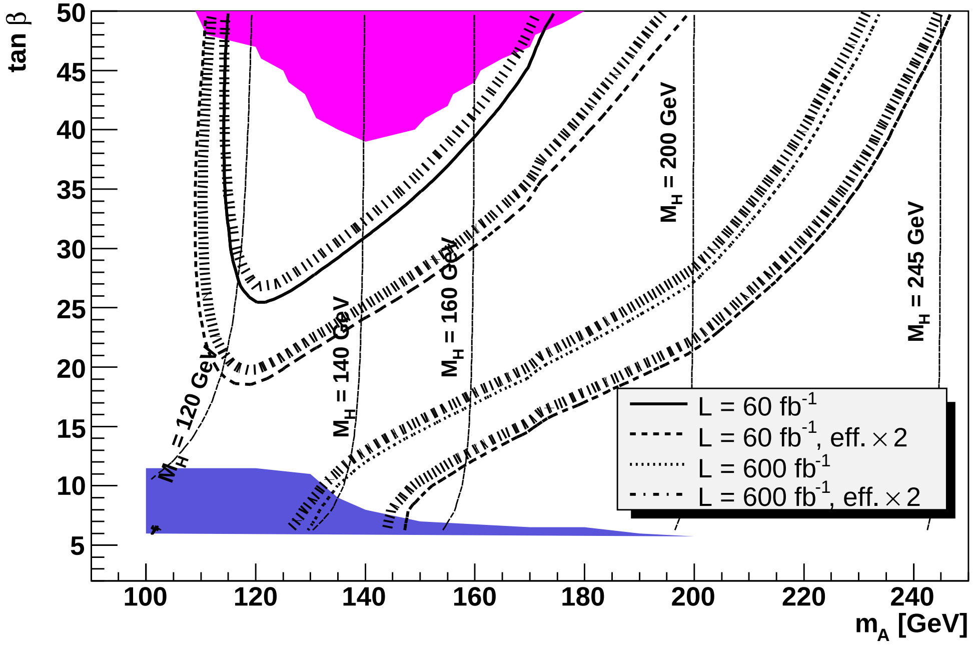
$\Rightarrow$ large parts allowed by CDM can be covered at 3 σ!
(5 σ slightly worse than in m_h^{max})

Results for H in the CDM scenario (#3):

5 σ discovery



3 σ evidence



pink: Tevatron exclusion bounds
blue: LEP exclusion bounds

$\Rightarrow$ large discovery regions, but no "LHC wedge" coverage
(slightly better than in $m_h^{\rm max}$)

Higgs coupling structure determination?

[T. Plehn, D. Rainwater, D. Zeppenfeld '01]
$\Rightarrow$ explore $HV_\mu V^\mu$ coupling ($V = W, Z$)
$\Rightarrow$ works well for $M_H = 160$ GeV (where $H \to WW$ is maximal)

Problem in MSSM:*

$$
\begin{aligned}
g_{hVV} &= g_{HVV}^{\text{SM}} \times \sin(\beta - \alpha) \\
g_{HVV} &= g_{HVV}^{\text{SM}} \times \cos(\beta - \alpha) \\
g_{AVV} &= 0 \qquad\qquad \text{at tree-level}
\end{aligned}
$$

$M_H \approx M_A \gtrsim 150$ GeV $\Rightarrow \beta - \alpha \to \pi/2$
$M_H \approx M_A \gtrsim 150$ GeV $\Rightarrow h$ has substantial VV coupling
$M_H \approx M_A \lesssim 130$ GeV $\Rightarrow H$ has substantial VV coupling

In the MSSM: $M_h \lesssim 130$ GeV

$\Rightarrow$ no heavy Higgs with substantial coupling to VV in the MSSM
$\Rightarrow$ method cannot be applied

* α diagonalizes the neutral $\mathcal{CP}$-even Higgs sector

Higgs coupling structure determination?

[*C. Ruwiedel, M. Schumacher, N. Wermes '07*]

$\Rightarrow$ explore $HW_\mu W^\mu$ coupling via $WW \to H \to \tau^+\tau^-$

$\Rightarrow$ $2\,\sigma$ effect for $M_H = 120$ GeV

Problem in MSSM:

$$g_{hVV} = g_{HVV}^{\text{SM}} \times \sin(\beta - \alpha)$$
$$g_{HVV} = g_{HVV}^{\text{SM}} \times \cos(\beta - \alpha)$$
$$g_{AVV} = 0 \qquad \text{at tree-level}$$

$M_H \approx M_A \gtrsim 150$ GeV $\Rightarrow$ h has substantial VV coupling
but no (sufficient) $h \to \tau^+\tau^-$ enhancement

$M_H \approx M_A \lesssim 130$ GeV $\Rightarrow$ H has substantial VV coupling
but no (sufficient) $H \to \tau^+\tau^-$ enhancement

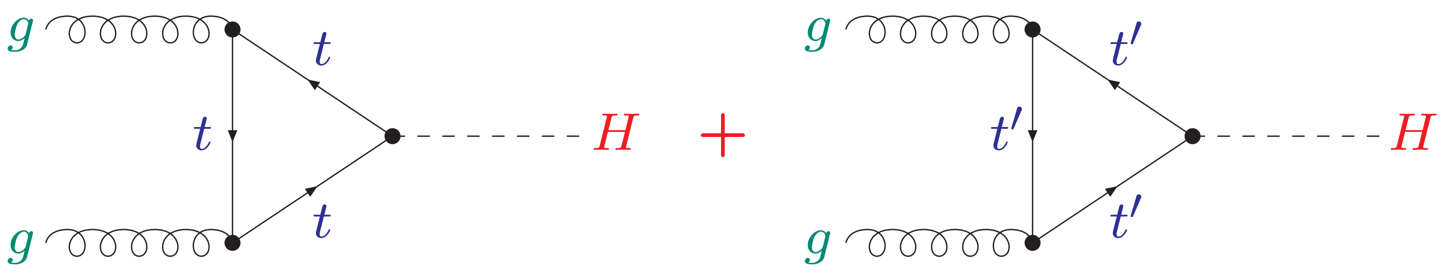
$\Rightarrow$ no improvement with respect to SM analysis

3. 4th generation model

Assume the SM with a 4th generation of heavy fermions

Relevant changes:

1. additional contribution to $gg \to H$:



   $\Rightarrow$ factor of ~ 9 in Higgs production cross section

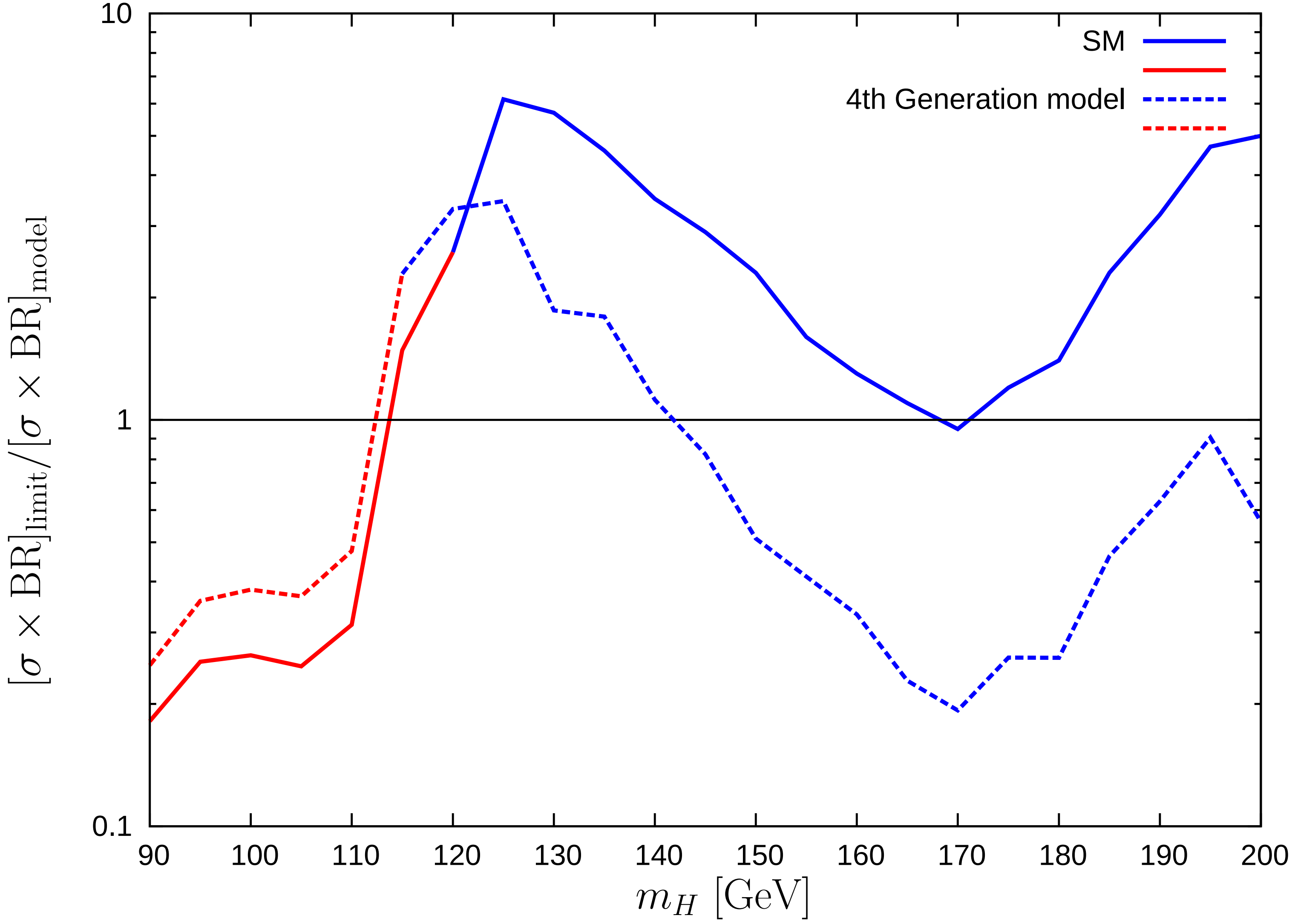
2. $\Rightarrow$ factor of ~ 9 in $\Gamma(H \to gg)$

   $\Rightarrow$ reduced $\text{BR}(H \to b\bar{b})$, $\text{BR}(H \to \tau^+\tau^-)$

Evaluation of SM quantities with `FeynHiggs`
subsequent application of reduction and enhancement factors

Tevatron limits for 4th generation model

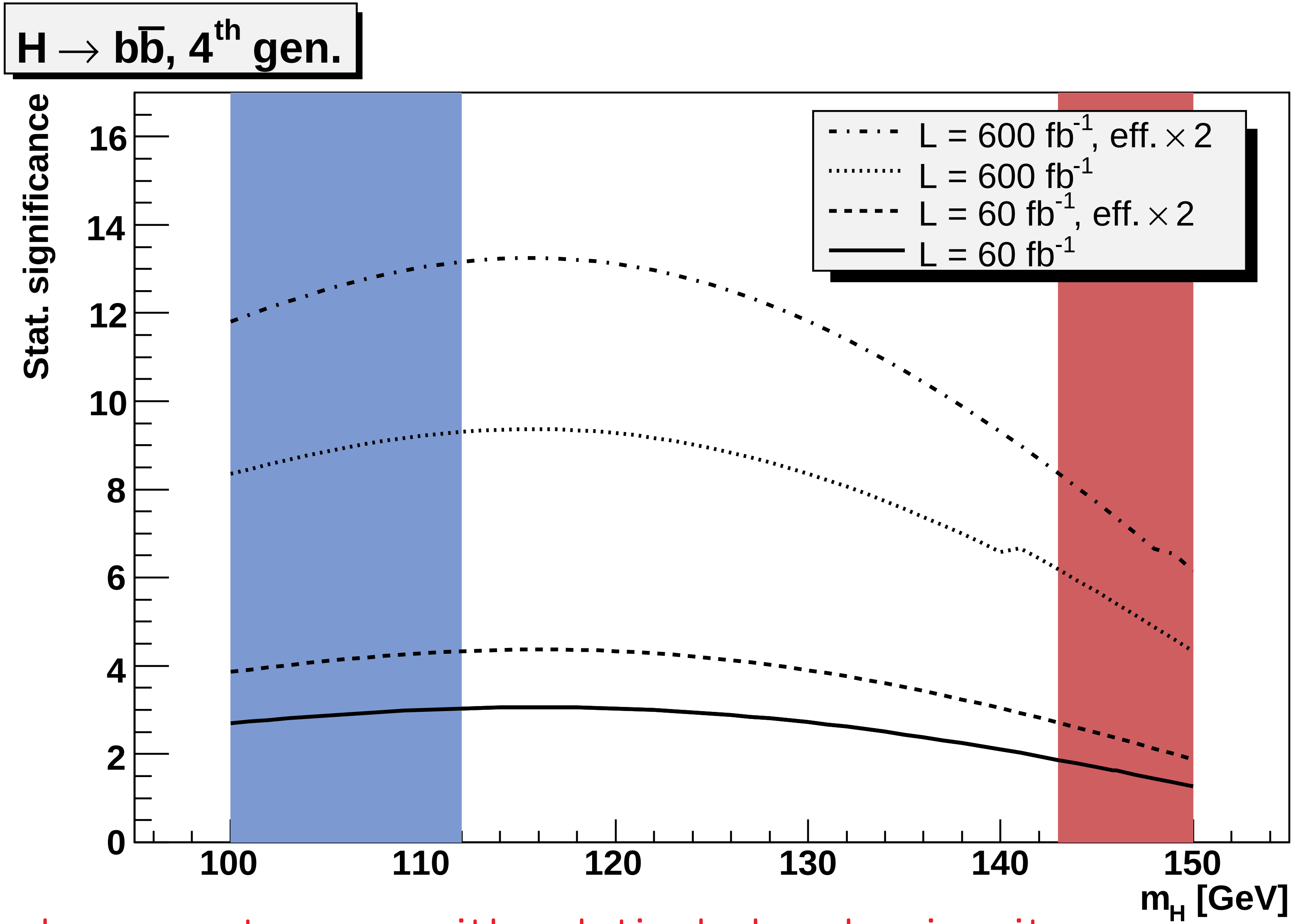
[*P. Bechtle, O. Brein, S.H., G. Weiglein, K. Williams '08*]



⇒ only 112 GeV $\lesssim M_H \lesssim$ 143 GeV, $M_H \gtrsim$ 220 GeV still allowed

⇒ will be tested very soon by the Tevatron

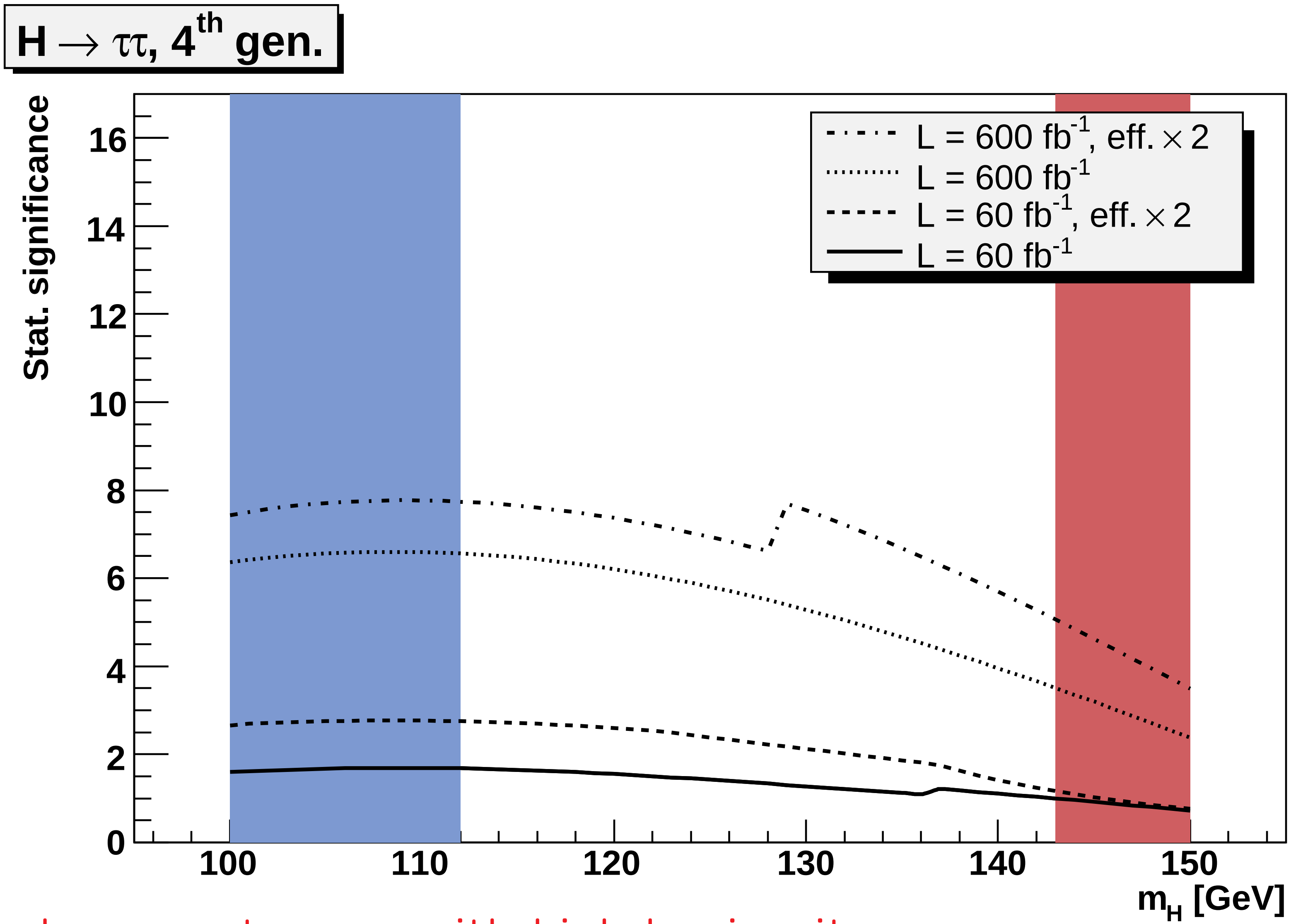
CED Higgs production in 4th generation model



⇒ good prospects even with relatively low luminosity

$M_H \gtrsim 200$ GeV ⇒ BR($H \to b\bar{b}$) too small

CED Higgs production in 4th generation model



⇒ good prospects even with high luminosity

$M_H \gtrsim 200$ GeV ⇒ BR($H \to \tau^+\tau^-$) too small

4. Conclusions

- CED Higgs production

  $pp \rightarrow p \oplus \Phi \oplus p, \quad \Phi \rightarrow b\bar{b}, \tau^+\tau^-, W^+W^-$

  – extended discovery reach (in BSM models)?

  – new handle for bottom Yukawa coupling: y_b

- CED production of MSSM Higgs bosons:

  update of 2007 analysis:

  – background: NLO for $gg \rightarrow b\bar{b}$

  – LEP/Tevatron exclusion bounds (`HiggsBounds`)

  – theory calculation (`FeynHiggs`)

  – new CDM benchmark planes

  $\Rightarrow$ at very high luminosity: good chances for $hb\bar{b}$ coupling

  $\Rightarrow$ additional channel for H (but not reducing the LHC wedge)

- CED production of 4th generation Higgs boson:

  LEP/Tevatron searches: 112 GeV $\lesssim M_H \lesssim$ 143 GeV allowed

  $\Rightarrow$ good chances for $H \rightarrow b\bar{b}$ at low luminosity

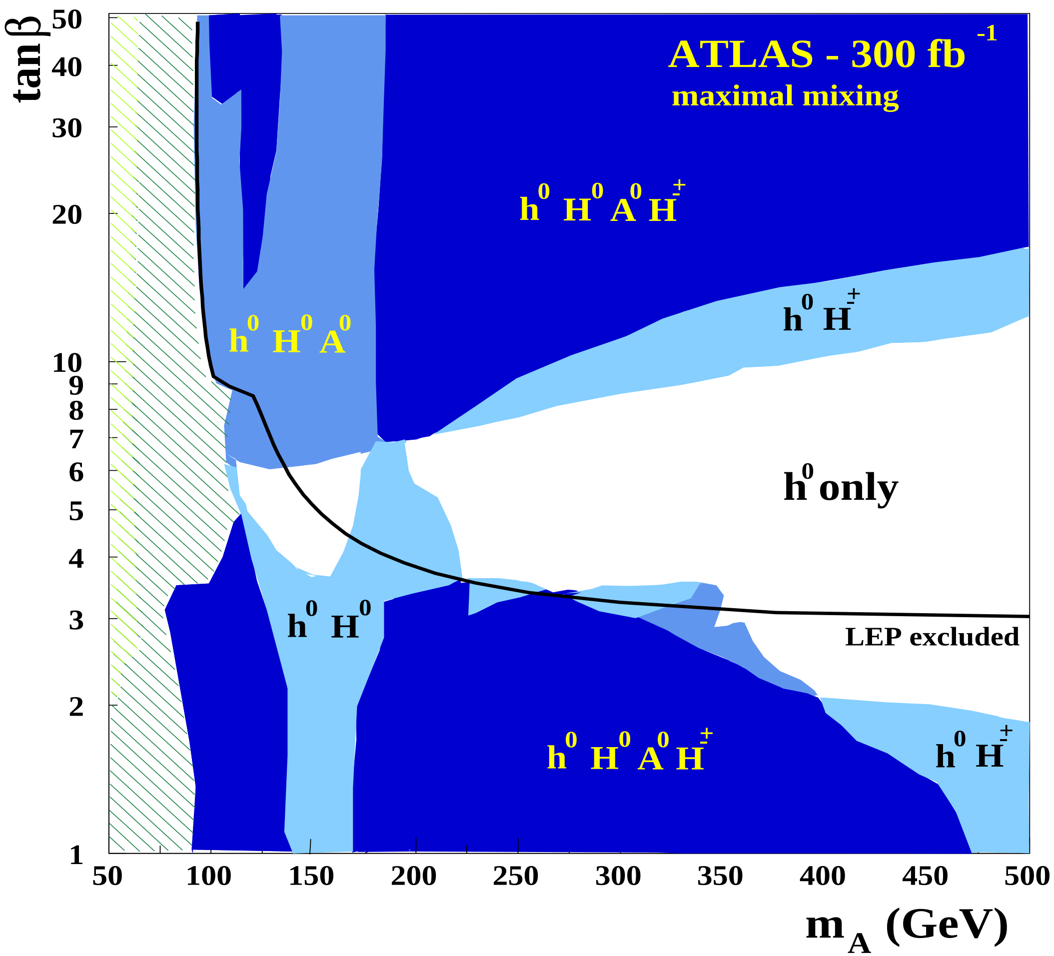
  $\Rightarrow$ good chances for $H \rightarrow \tau^+\tau^-$ at high luminosity

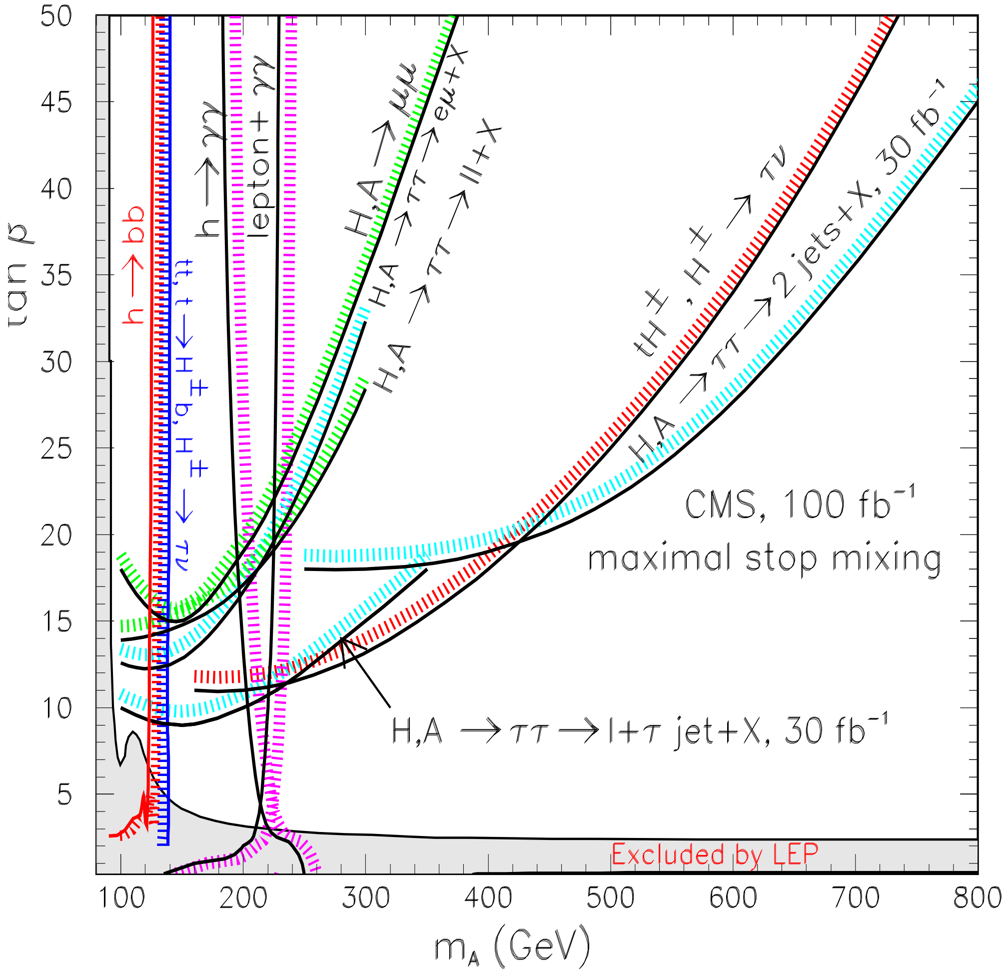

Higgs Days at Santander 2009
Theory meets Experiment
14.-18. September
contact: Sven.Heinemeyer@cern.ch
http://www.ifca.es/HDays09
IFCA
Instituto de Física de Cantabria
CSIC
UC
UNIVERSIDAD DE CANTABRIA
HEPTOOLS
Foto: R. Harlander (HDays 2008)

Back-up

"Heavy" MSSM Higgs searches:

MSSM Higgs discovery contours in M_A–$\tan\beta$ plane
($m_h^{\rm max}$ benchmark scenario): [*ATLAS '99*] [*CMS '03*]





Where can the heavy Higgses be observed? With which precision?

The Charged MSSM Higgs boson and CDM benchmarks

[*J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07*]

NUHM: (Non-universal Higgs mass model)

> $\Rightarrow$ besides the CMSSM parameters (m_0, $m_{1/2}$, A_0, $\tan\beta$)
>
> M_A and μ

Assumption:

no unification of scalar fermion and scalar Higgs parameters
at the GUT scale

$\Rightarrow$ effectively M_A and μ free parameters at the EW scale

$\Rightarrow$ particle spectra from renormalization group running to weak scale

Lightest SUSY particle (LSP) is the lightest neutralino

$\Rightarrow$ possible: M_A–$\tan\beta$ planes in agreement with CDM :-)

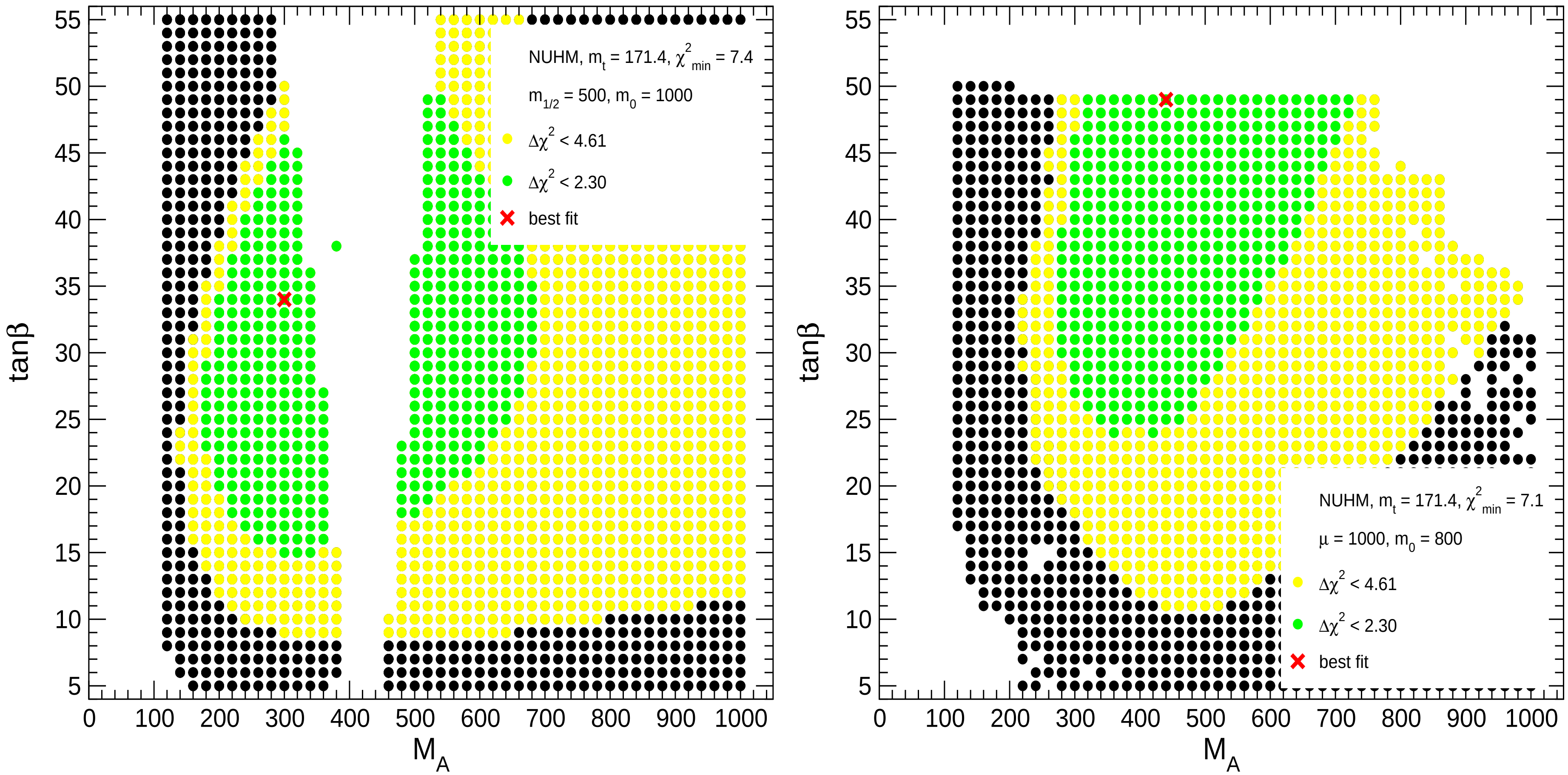
$\Rightarrow M_A$–$\tan\beta$ planes in agreement with CDM possible!

Also in agreement with other constraints from
electroweak precision observables and B physics observables:

$\Rightarrow \chi^2$ test with:

1. W boson mass M_W
2. effective leptonic weak mixing angle $\sin^2\theta_{\mathrm{eff}}$
3. total Z boson width Γ_Z
4. lightest Higgs boson mass M_h
5. anomalous magnetic moment of the muon $(g-2)_\mu$
6. b decay $\mathrm{BR}(b \to s\gamma)$
7. b decay $\mathrm{BR}(B_s \to \mu^+\mu^-)$
8. b decay $\mathrm{BR}(B_u \to \tau\nu_\tau)$
9. B_s mixing ΔM_{B_s}

Example: NUHM planes 2,3



$\Rightarrow$ good χ^2 (M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, M_h, $(g-2)_\mu$, BR($b \to s\gamma$) and other BPO)
$\Rightarrow$ larger regions o.k.