Constraining Higgs Sectors with LHC Searches using HiggsBounds 3.5.0

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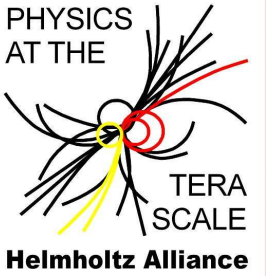

outline :

- HiggsBounds
  - overview of version 3.5.0 [beta]
  - some implementation details
  - status and outlook of the project
- Constraining Models
  - SM versus 4th generation model
  - SM+invisible model
  - Randall-Sundrum scalar sector
  - MSSM

- HiggsBounds

– overview of version 3.5.0 [beta]

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HiggsBounds : [Bechtle, OBr, Heinemeyer, Stefaniak, Weiglein, Williams '08-'11]

tests models with arbitrary Higgs sectors against
exclusion bounds from direct searches.

- easy access to all relevant Higgs exclusion limits
  including information not available in the publications.
  (e.g. expected 95% CL cross section limits)

- applicable to models with arbitrary Higgs sectors (narrow widths assumed)

  HiggsBounds Input: the predictions of the model for:
  # of neutral & charged Higgs bosons h_i , m_{h_i}, $\Gamma_{\rm tot}(h_i)$, BR($h_i \to \ldots$),
  production cross section ratios (wrt reference values)

- combination of results from LEP, Tevatron and LHC possible

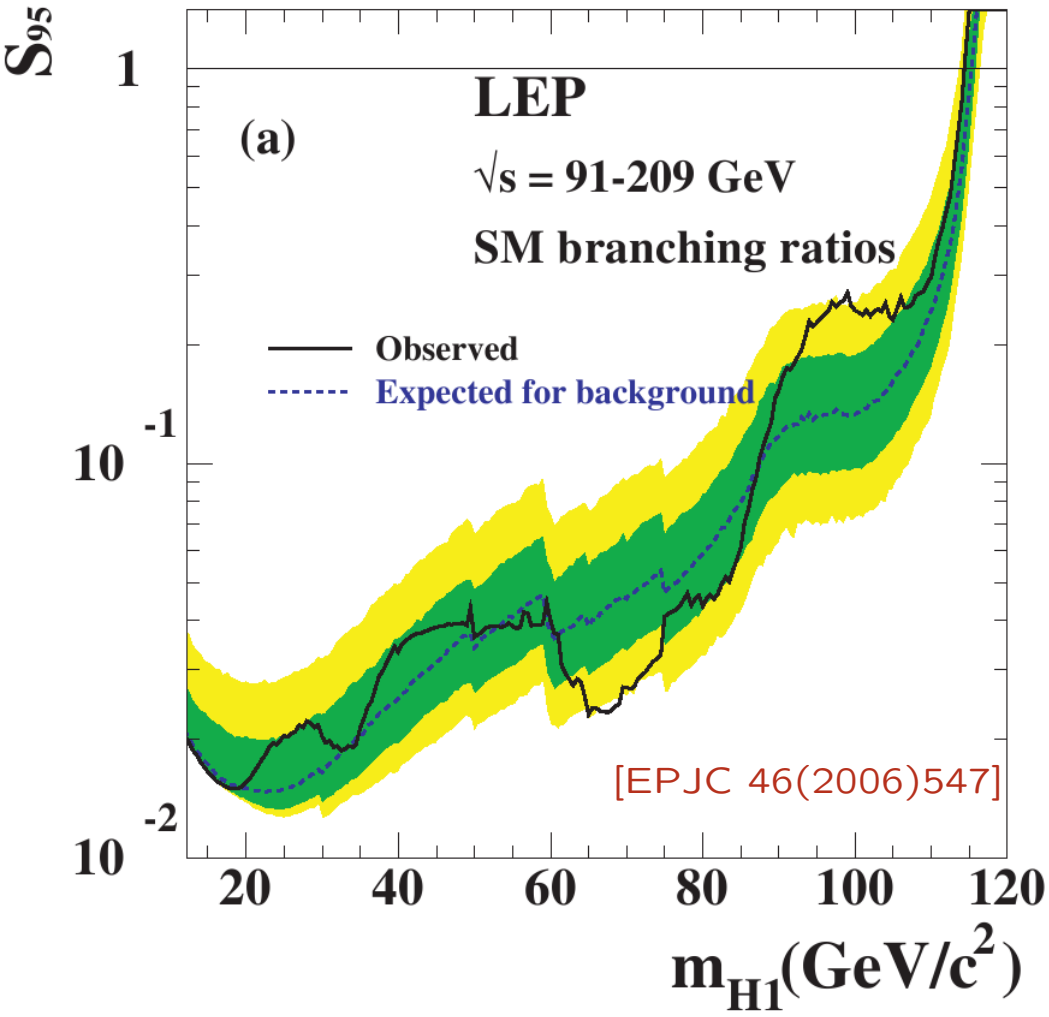
- three ways to use HiggsBounds:
  ☐ command line, ☐ subroutines (Fortran [77]/90), ☐ web interface:

  projects.hepforge.org/higgsbounds

– some implementation details

Higgs search results: example 1: LEP SM combined limit

exclusion = rejection of the Higgs hypothesis



$$S_{95}(m_{H1}) := \frac{\sigma_{\text{min}}}{\sigma_{\text{SM}}}(m_{H1})$$

where $\sigma_{\text{min}}(m_{H1})$ is the Higgs signal cross section where data and Higgs hypothesis are compatible with only 5% probability.

A SM-like model with

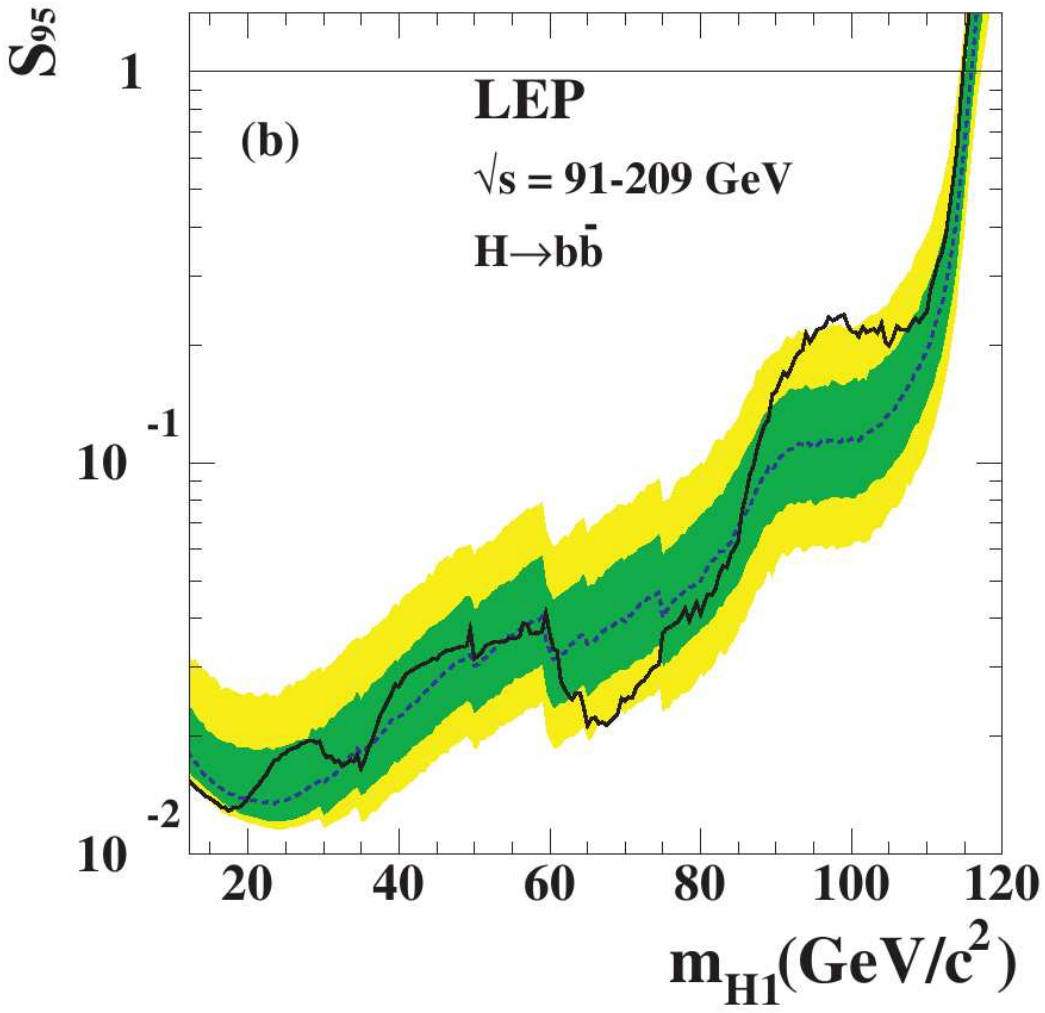
$$\sigma_{\text{model}}(m_{H1}) > \sigma_{\text{min}}(m_{H1})$$

or $\dfrac{\sigma_{\text{model}}(m_{H1})}{\sigma_{\text{min}}(m_{H1})} > 1$

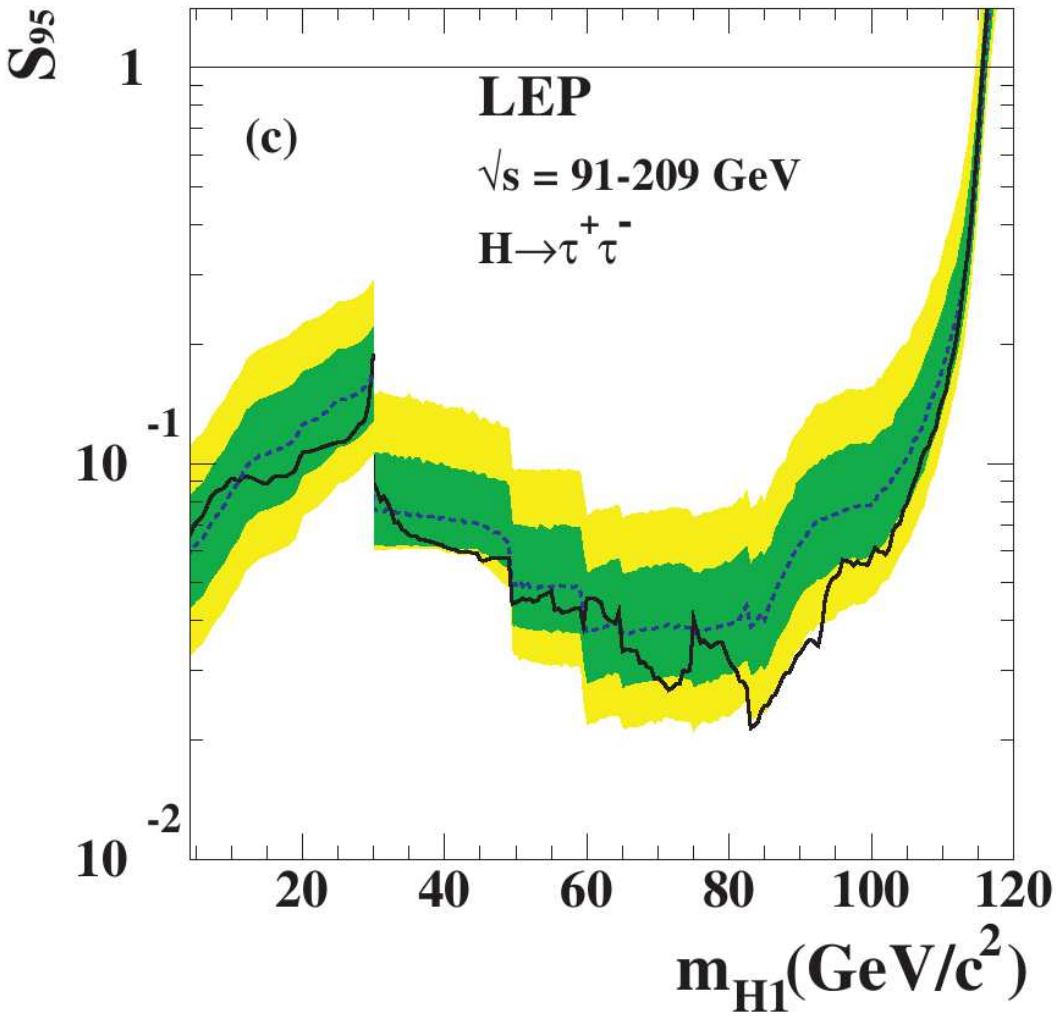
is said to be excluded at the 95% C.L.

example 2: LEP single topology limits, assuming HZ production and ...

a) ... BR($H \to b\bar{b}$)=1

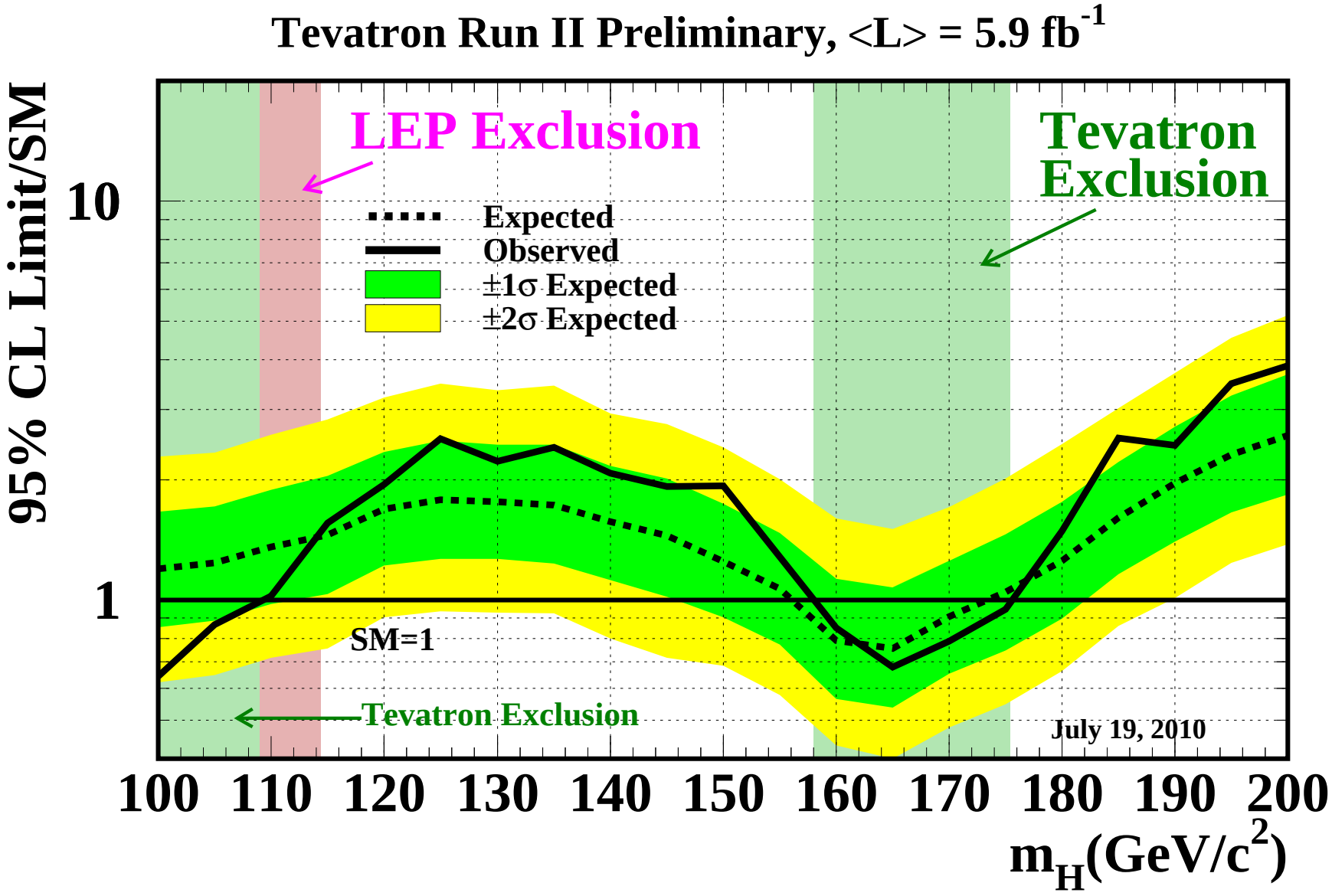


b) ... BR($H \to \tau^+\tau^-$)=1



[EPJC 46(2006)547]

example 3: Tevatron SM combined limit [CDF & DØ '10]



Considering many analyses for many Higgs bosons:

first a definition : **analysis application** X:

application of a certain analysis A_i
to a certain Higgs boson h_k (or a set)

that means: X corresponds to:

- ⋆ a signal topology (or a set),
- ⋆ the corresponding cross section prediction $\bar{\sigma}_{\text{model}}(X)$,
- ⋆ observed cross section limit $\bar{\sigma}_{\text{observed}}(X)$ of analysis A,
- ⋆ expected cross section limit $\bar{\sigma}_{\text{expected}}(X)$ of analysis A.

Basic idea:

for an analysis application X:

- evaluate model prediction

$$\bar{\sigma}_{\text{model}}(X) = \frac{[\sigma \times \text{BR}]_{\text{model}}}{[\sigma \times \text{BR}]_{\text{ref}}} \qquad \text{(reference: usually SM)}$$

  of the correponding search topology for given Higgs masses + deviations from the reference.

- read off the corresponding observed 95% C.L. limit: $\bar{\sigma}_{\text{observed}}(X)$.

- If $\bar{\sigma}_{\text{model}}(X) > \bar{\sigma}_{\text{observed}}(X)$ the model is excluded by this analysis application at 95% C.L.

$\rightarrow$ Problem : how to combine analysis applications without losing the 95% C.L. ?

Answer: We can't do that.

Only a dedicated experimental analysis can do that.

However: we can always use the analysis application of highest statistical sensitivity.

How to preserve the 95% C.L. limit:

- Obtain for each X the experimental expected limit $\bar{\sigma}_{\text{expected}}(X)$.

- Determine the analysis application X_0 with the highest sensitivity for the signal, i.e. of all X, find X_0 where $\dfrac{\bar{\sigma}_{\text{model}}(X)}{\bar{\sigma}_{\text{expected}}(X)}$ is maximal.

- If for this analysis application $\bar{\sigma}_{\text{model}}(X_0) > \bar{\sigma}_{\text{observed}}(X_0)$, the model is excluded at 95% C.L. by X_0.

– status and outlook of the project

HiggsBounds: status and outlook

- The code is publicly available since Feb. 2009 (current version: 3.5.0 beta)
  → projects.hepforge.org/higgsbounds
  - Tevatron & LHC results up to Lepton-Photon 2011 included
  - extended functionality ($H^{\pm}$ searches, `onlyP` analyses selection, ...)
  - HiggsBounds 3.5.0 beta available to download

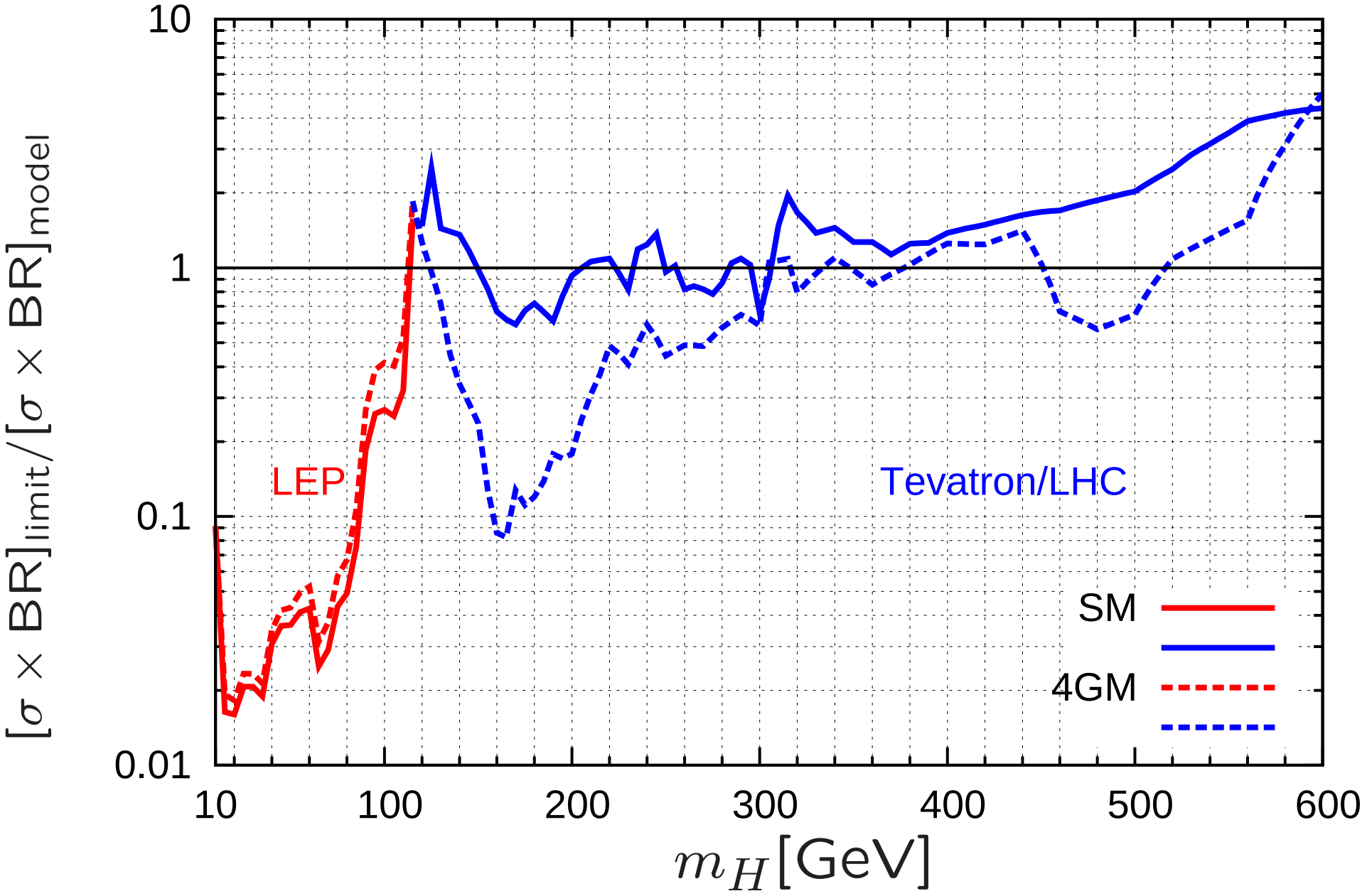
  → includes: SLHA input option, χ^2 fitting for LEP channels,

  optional addition: SusyBounds (Chargino, Neutralino bounds)
- Reception very good (>100 users). Code used in/by:
  FeynHiggs, CPsuperH, Fittino, MasterCode, 2HDMC, DarkSusy, SuperIso, etc.
- Current work/plans:
  - new LHC results after Lepton-Photon 2011
  - searches for fermiophobic models
  - doubly charged Higgs searches, LEP searches for $m_H < 10\,\text{GeV}$
  - inclusion of width-dependent limits

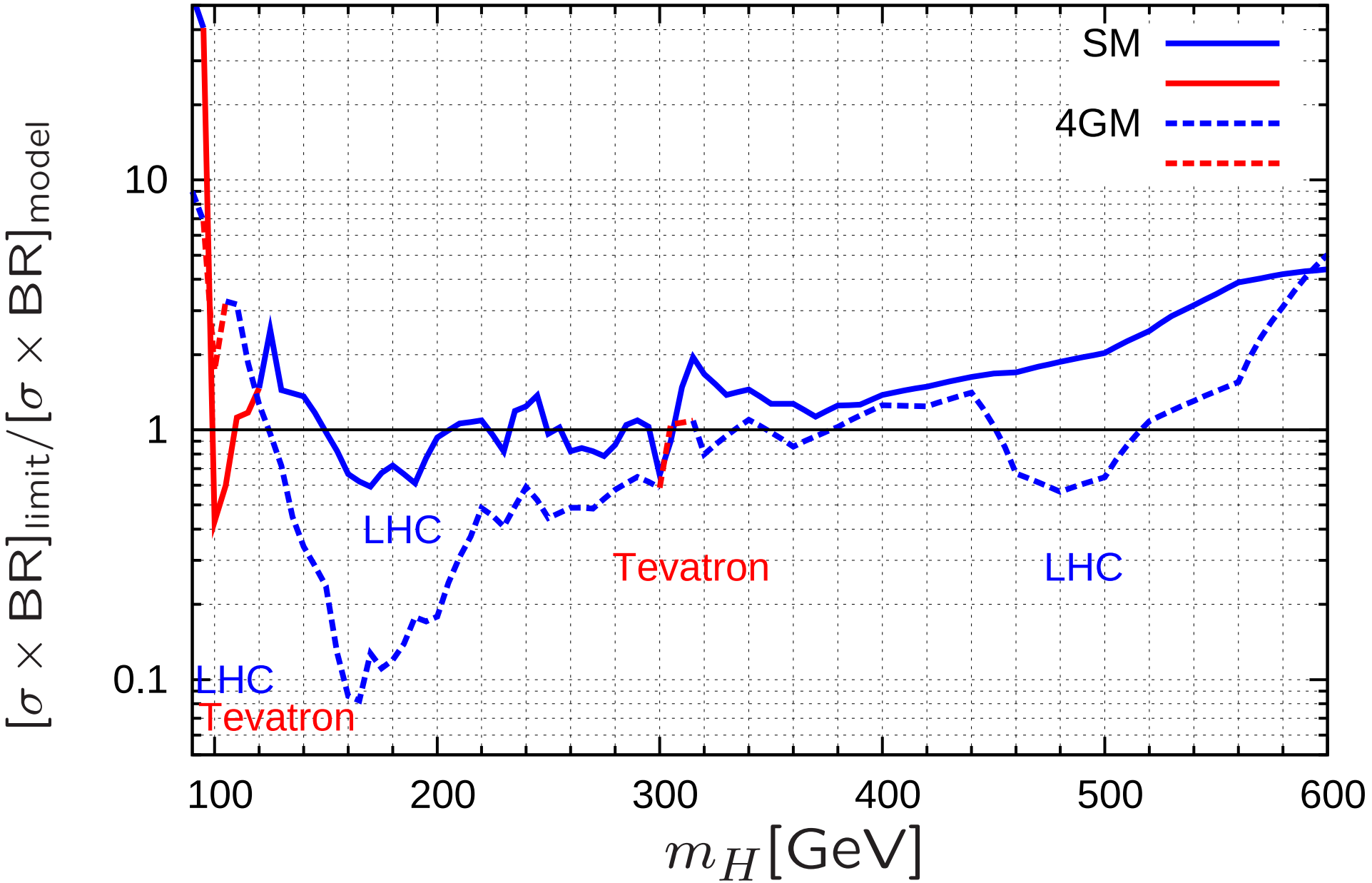
- Constraining Models

– SM versus 4th generation model

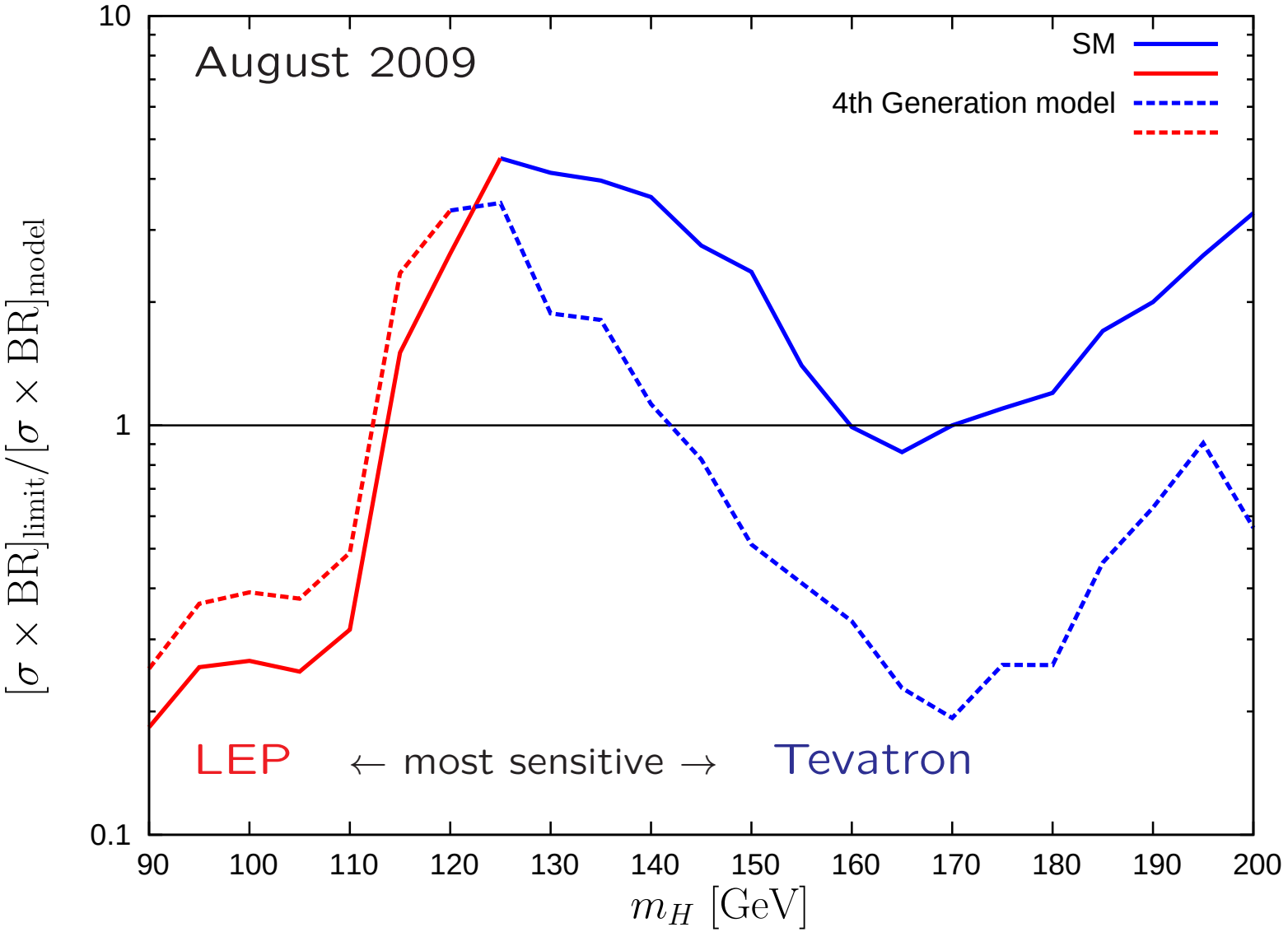
– SM versus 4th generation model [using $\Gamma(H \to gg)_{\text{model}} = 9 \times \Gamma(H \to gg)_{\text{SM}}$]



– SM versus 4th generation model only hadron collider searches

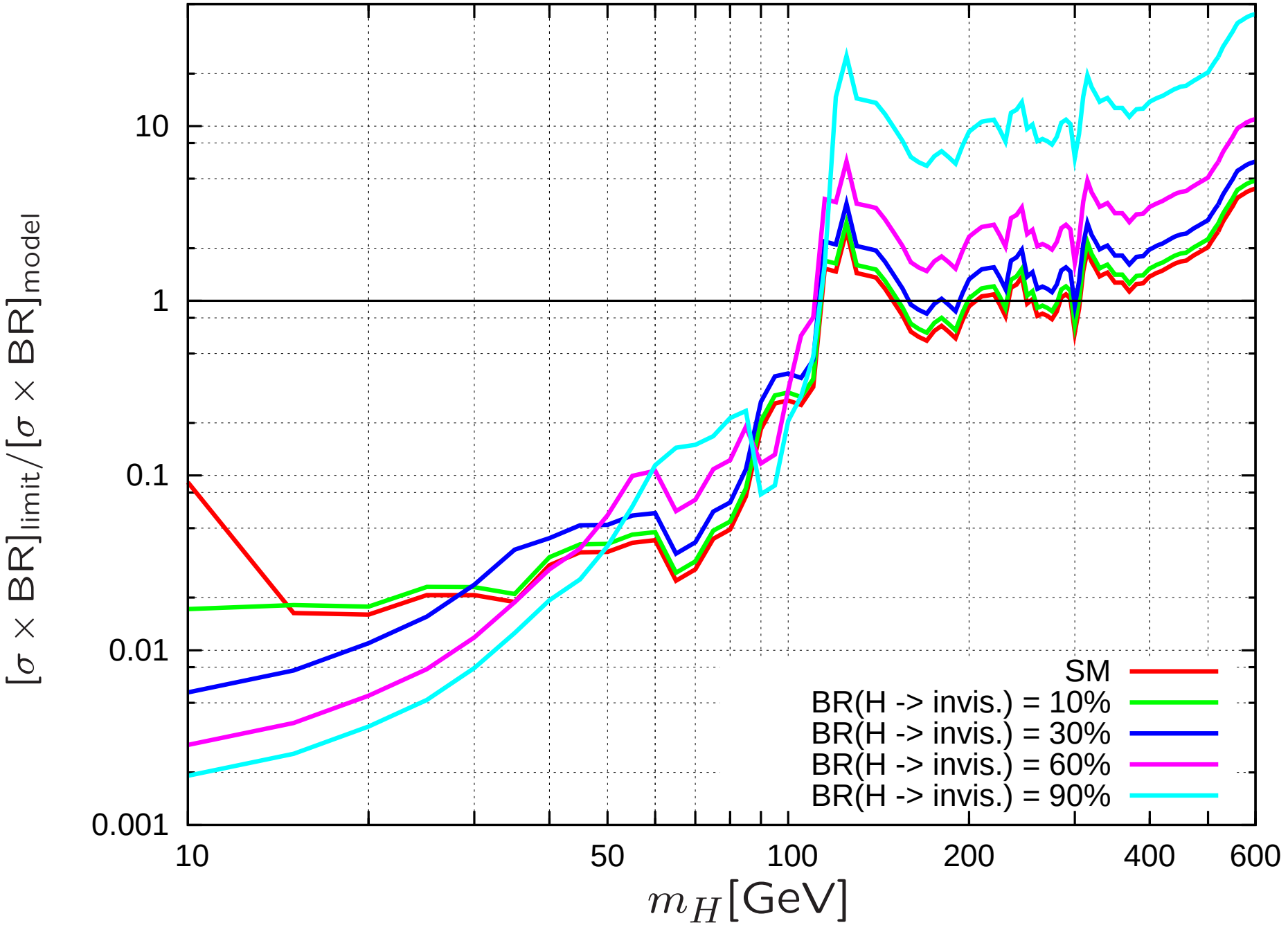


for comparion: status in August 2009 (without LHC results)



– SM+invisible model

– SM+invisible model: SM + one extra decay mode $H \rightarrow$invisible



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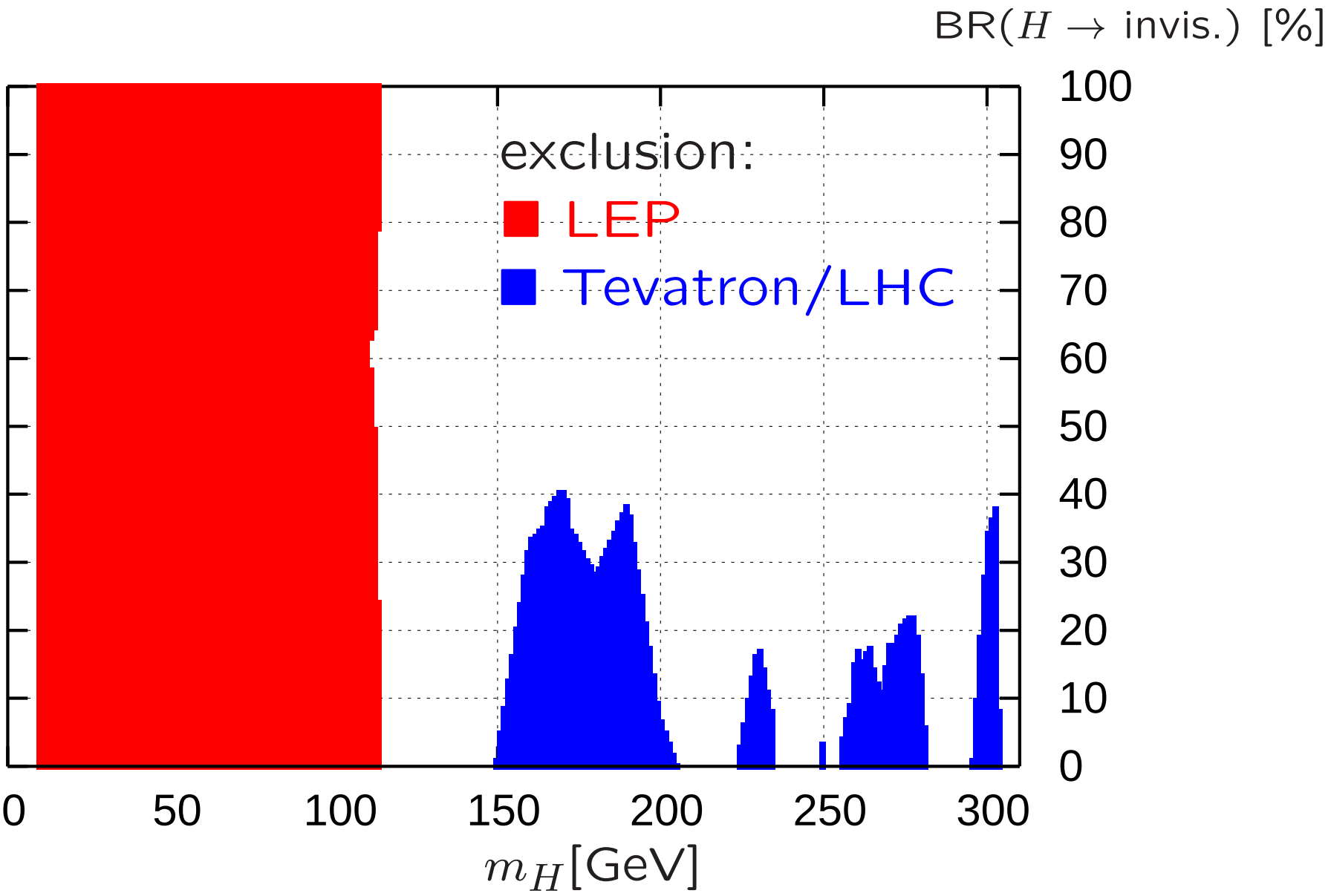

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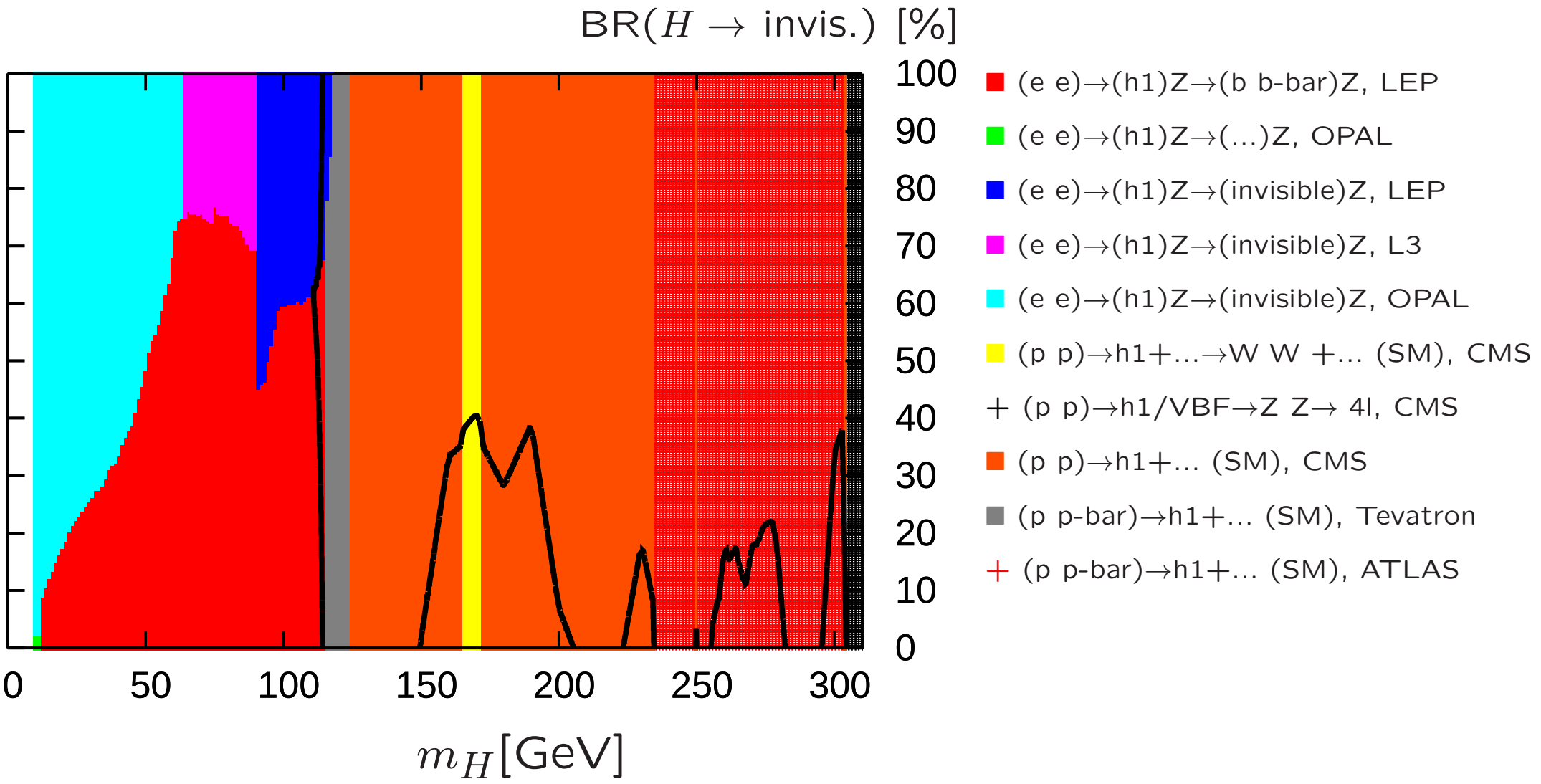

– Randall-Sundrum scalar sector

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■ Randall Sundrum model basics: [Randall, Sundrum '99]

- space has $D = 3 + 1$ dimensions, metric:

$$ds^2 = e^{-2kr_c\phi}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2\,, \quad \phi \in [0, \pi]\,.$$

  Spacetime is a slice of 5d anti-de-Sitter space:
  two boundaries: $\phi = \pi$: IR brane (our 3-space)
  $\phi = 0$: UV brane

- k, r_c^{-1} are $\mathcal{O}(M_{\rm Pl})$ with $kr_c \approx 12$.
  This "little hierarchy" can be generated & stabilized [Goldberger, Wise '00]
  $\Rightarrow$ fluctuations of r_c: scalar d.o.f φ, gets a VEV Λ_ϕ

- resolution of the hierarchy problem: Why is the EW scale $<<$ $M_{\rm Pl}$?:
  mass parameters in the fundamental 5d model m_0 appear in our visible space as:

$$m = m_0 e^{-kr_c\pi} \approx m_0 10^{-16}\,.$$

- propagating in extra dimension:
  originally: only gravity,
  nowadays: gauge bosons, fermions [EW & flavour observables!]

  But: Higgs needs to be localized on/near IR brane [hierarchy problem!]

Randall Sundrum scalar sector:

– There is one graviscalar in 5d: the radion φ
(typically the lightest new particle to appear)

– Higgs – radion mixing via the interaction

$$\mathcal{L} = -\xi\sqrt{-g_{\text{ind}}}\, R(g_{\text{ind}})\, \Phi^\dagger\Phi$$

with $g_{\text{ind}}(\varphi(x), \ldots)$: induced 4d metric on IR brane, R: Ricci scalar.

$\rightarrow$ Radion φ and physical Higgs h mix to form two mass eigenstates

– φ coupling to massive fermions and gauge bosons $\propto$ mass, but

⋆ $\varphi\, b\bar{b}$ coupling suppressed wrt SM Higgs

⋆ $\varphi\, gg$ coupling enhanced wrt SM Higgs

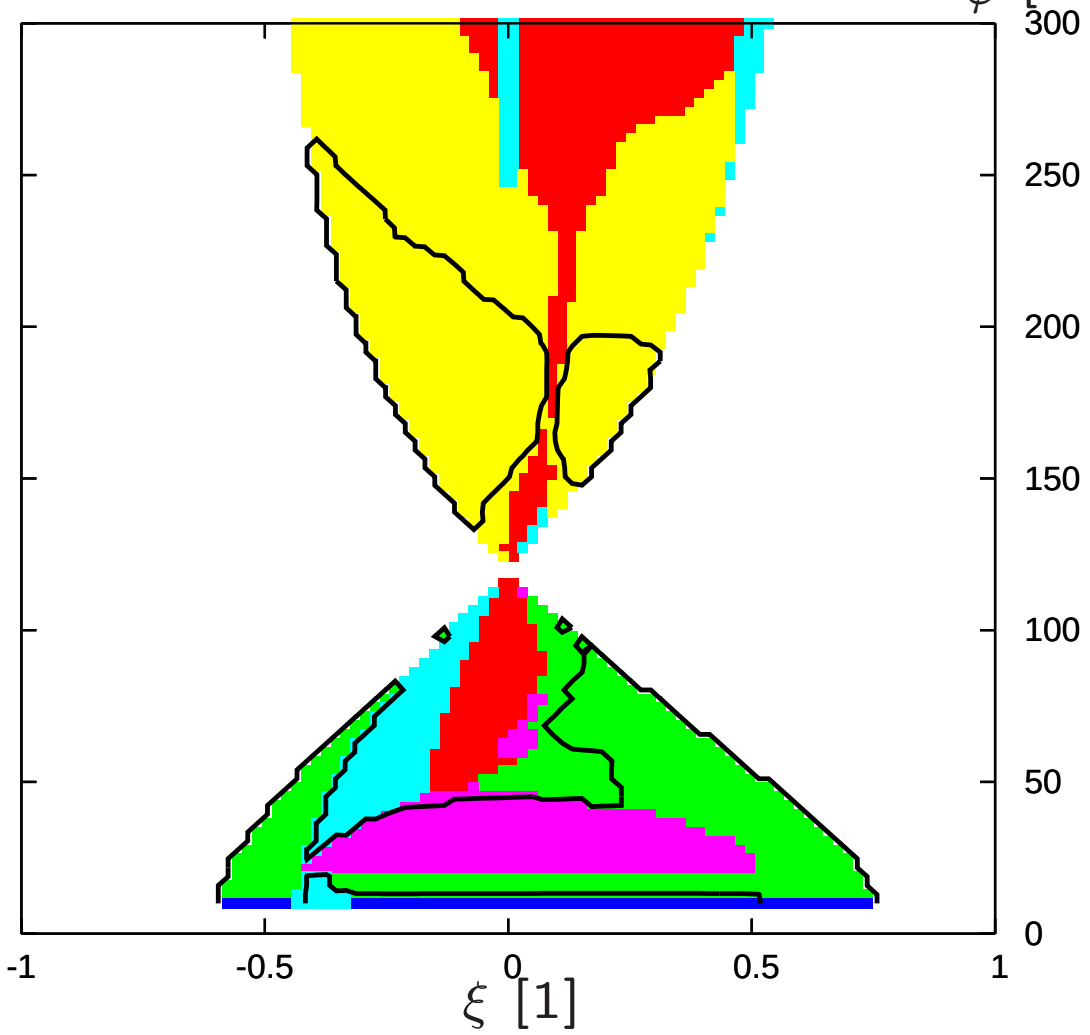
⋆ $\varphi\, \gamma\gamma$ coupling suppressed wrt SM Higgs

$\rightarrow$ two scalars in the spectrum with modified couplings
compared to the SM Higgs boson

Exclusion range and sensitivity map: $\xi - m_\varphi$ plane w/o LHC data (12/2010)

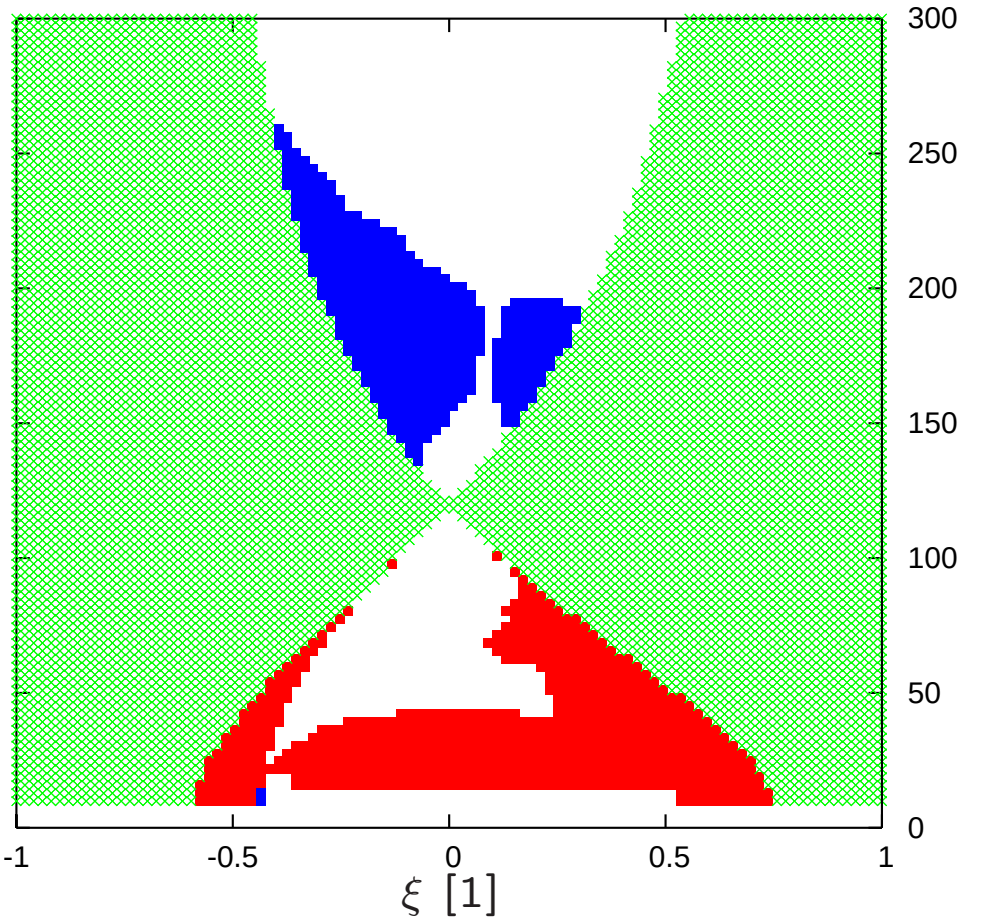
parameter:
$\Lambda_\varphi = 1$ TeV
$m_h = 120$ GeV

a) highest sensitivity



b) exclusion

■ : LEP exclusion
■ : Tevatron exclusion



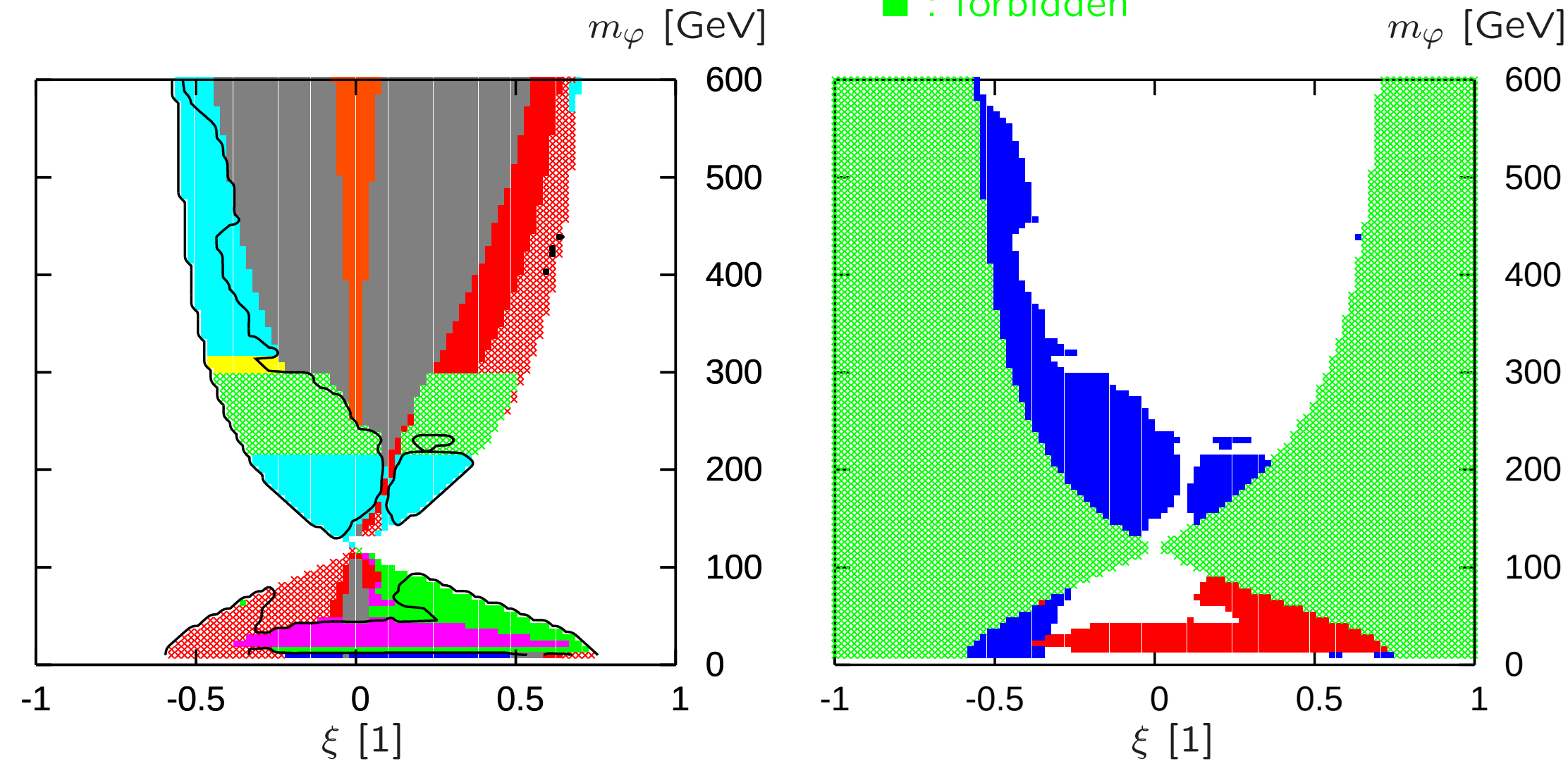
Exclusion range and sensitivity map: $\xi - m_\varphi$ plane with LHC data

parameter: $\Lambda_\varphi = 1$ TeV, $m_h = 120$ GeV

a) highest sensitivity

b) exclusion

■ : LEP exclusion
■ : LHC/Tevatron exclusion
■ : forbidden



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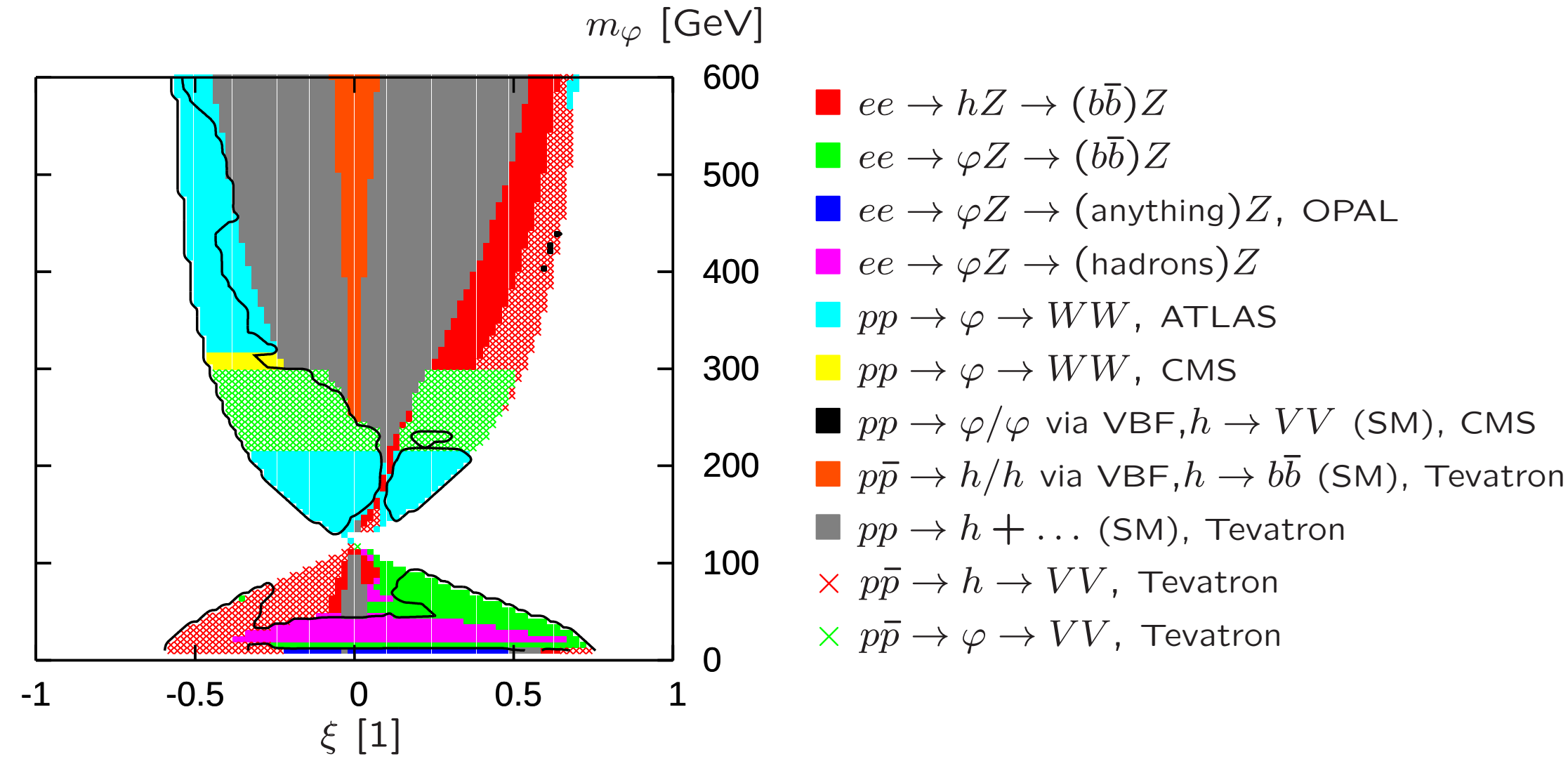
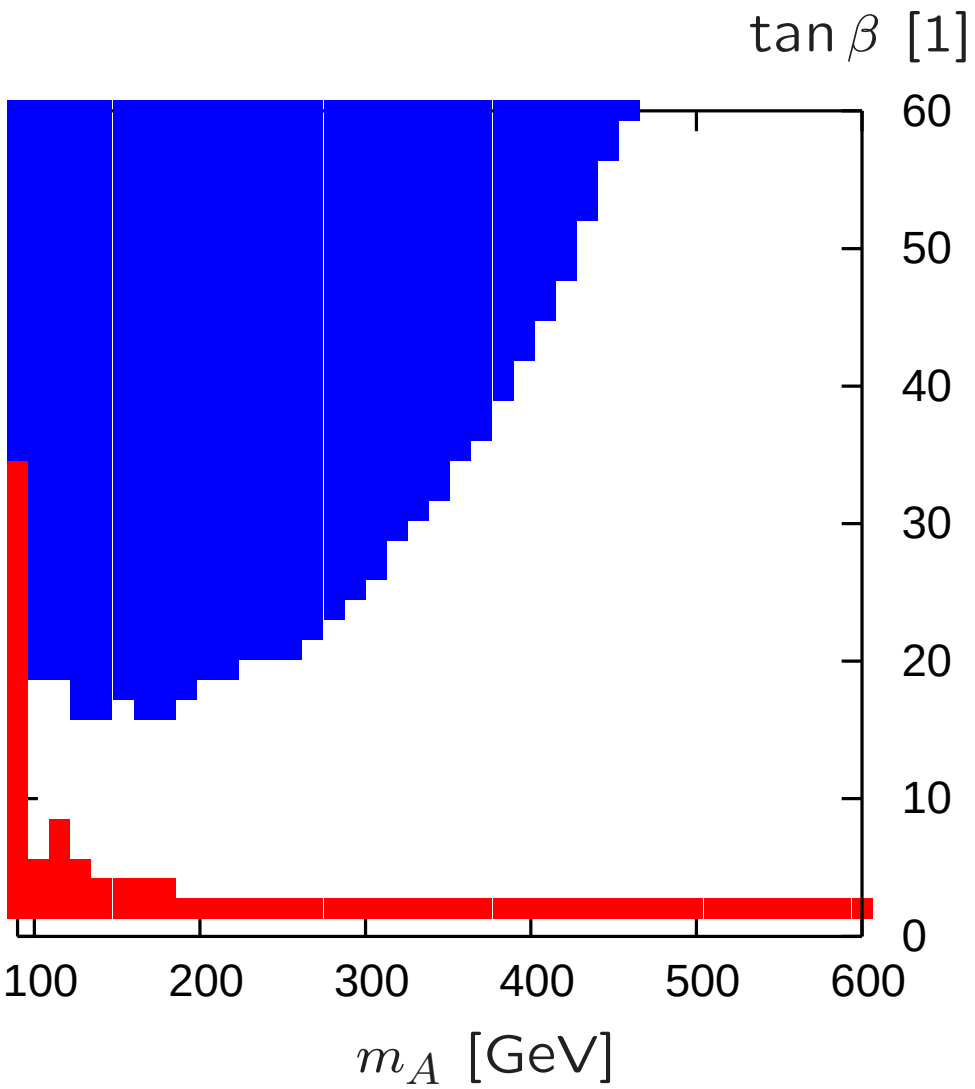


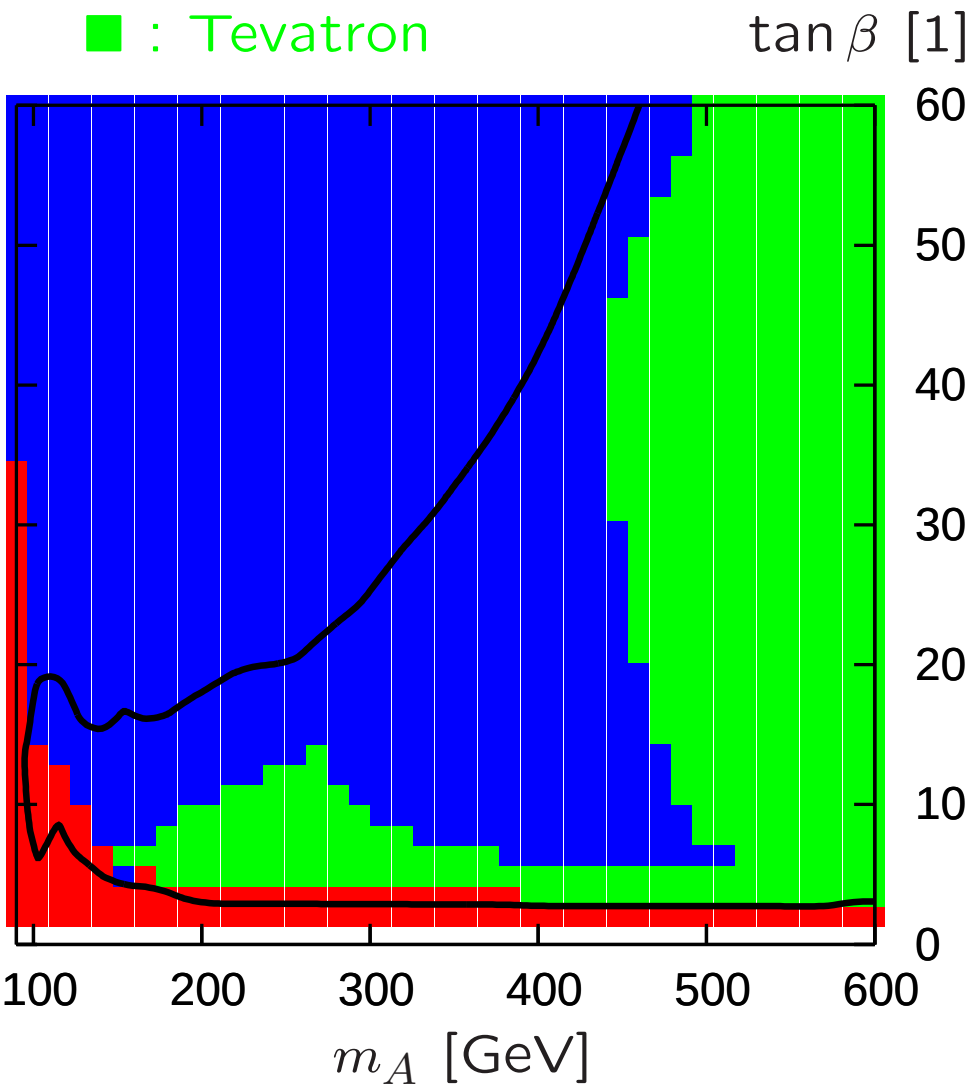
– MSSM

Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : $m_h^{\max}+$ scenario

a) exclusion

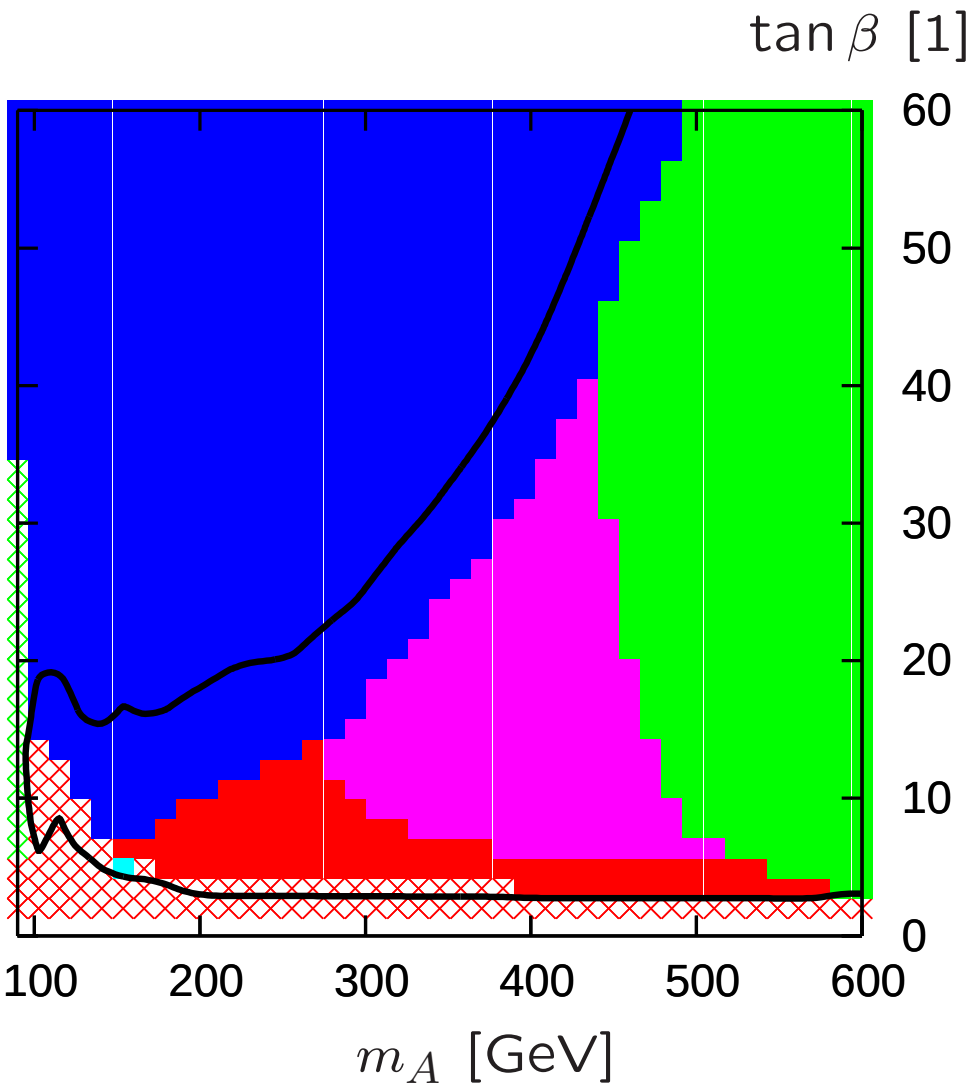


b) highest sensitivity experiment



Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : $m_h^{\text{max}}+$ scenario

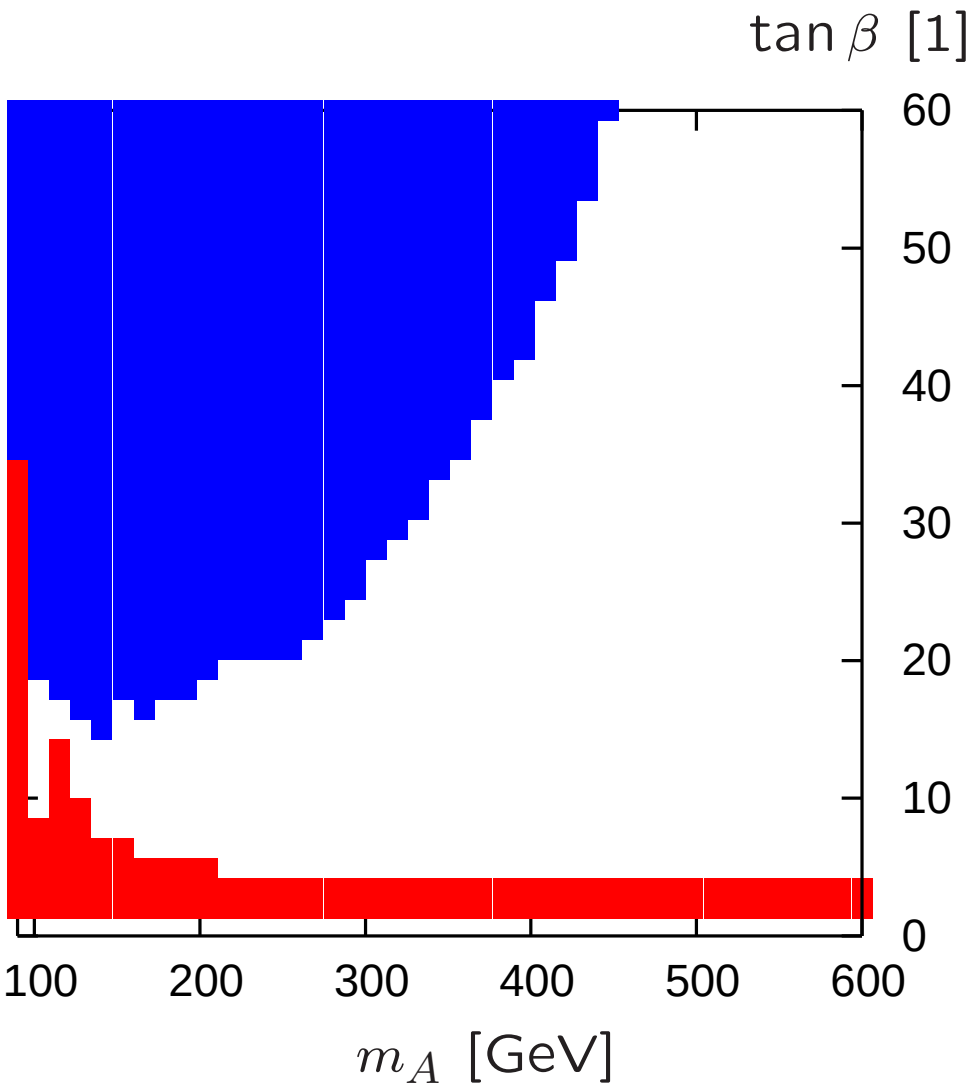
c) highest sensitivity analysis



Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : m_h^{max}+(400) scenario

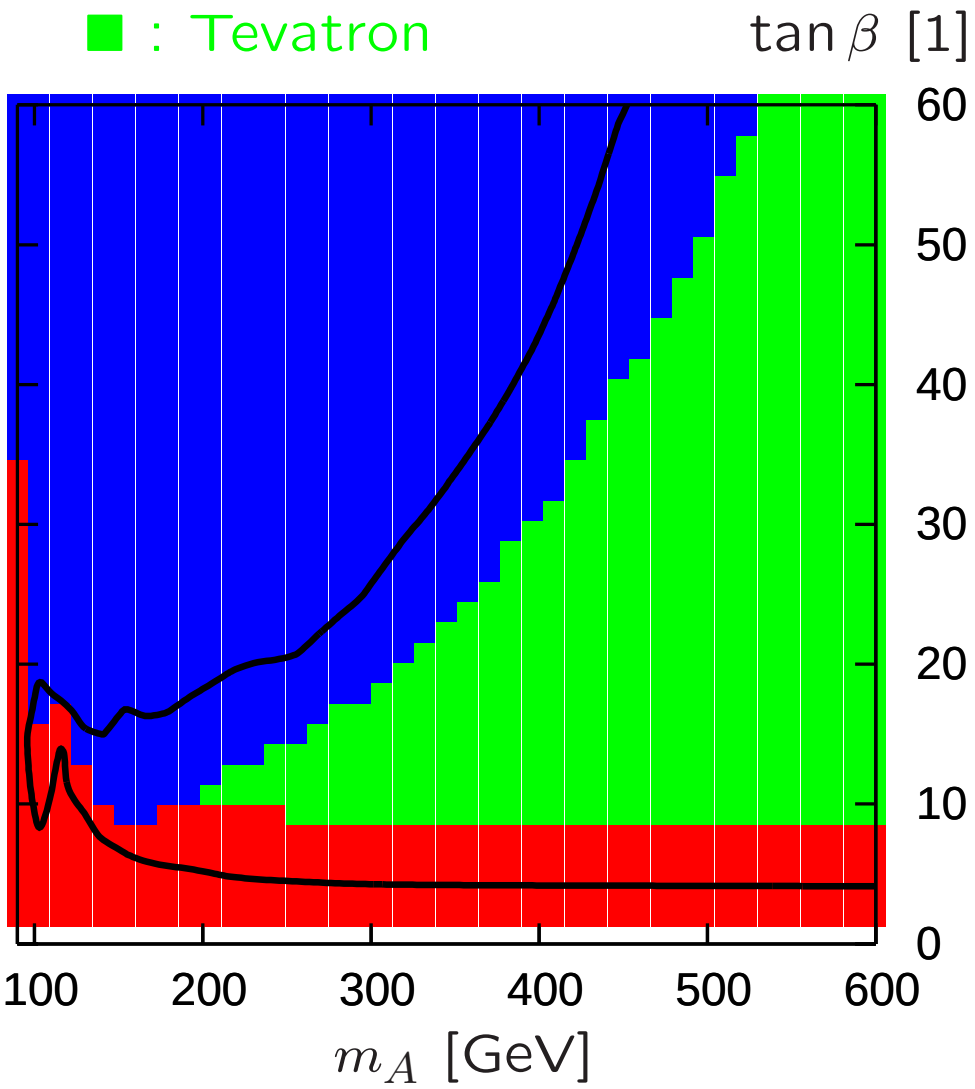
$[M_{\text{SUSY}} = 400$ GeV$]$

a) exclusion



b) highest sensitivity experiment

■ : LEP
■ : LHC
■ : Tevatron



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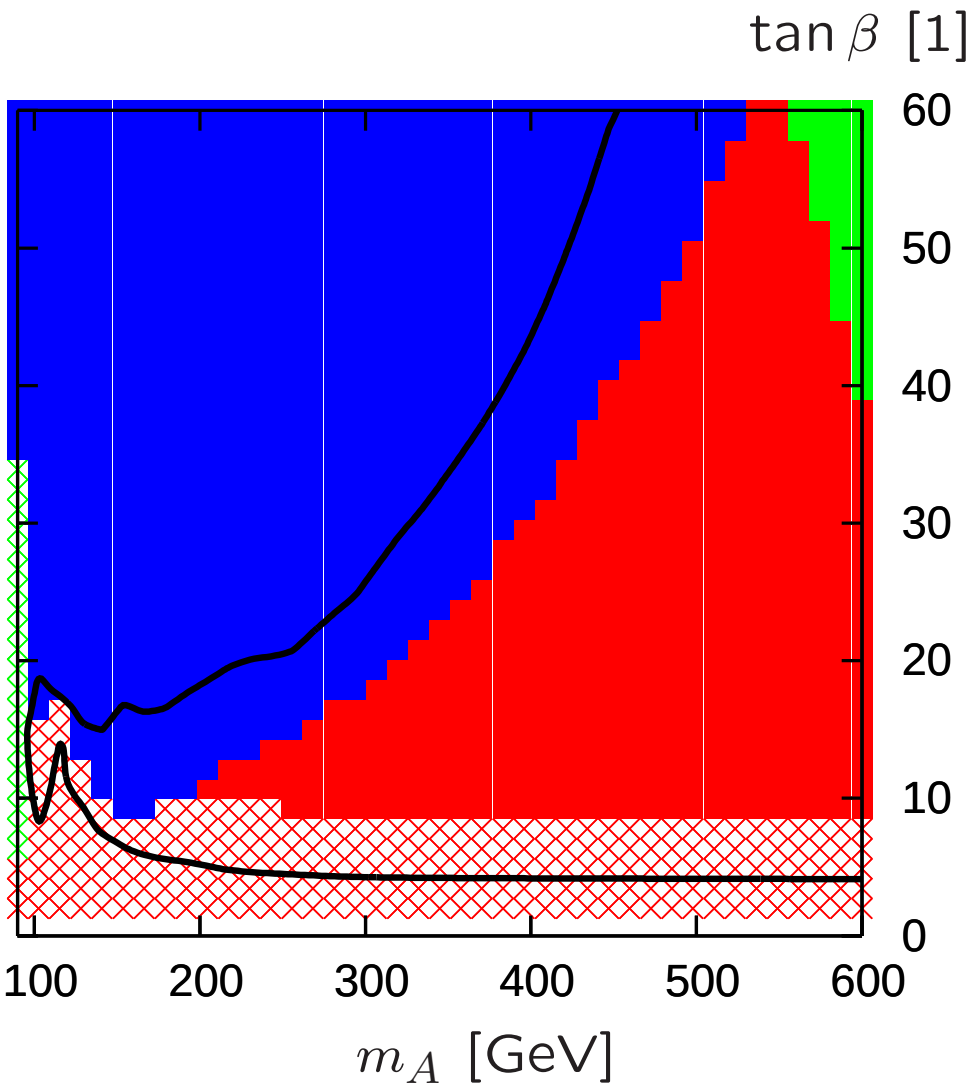
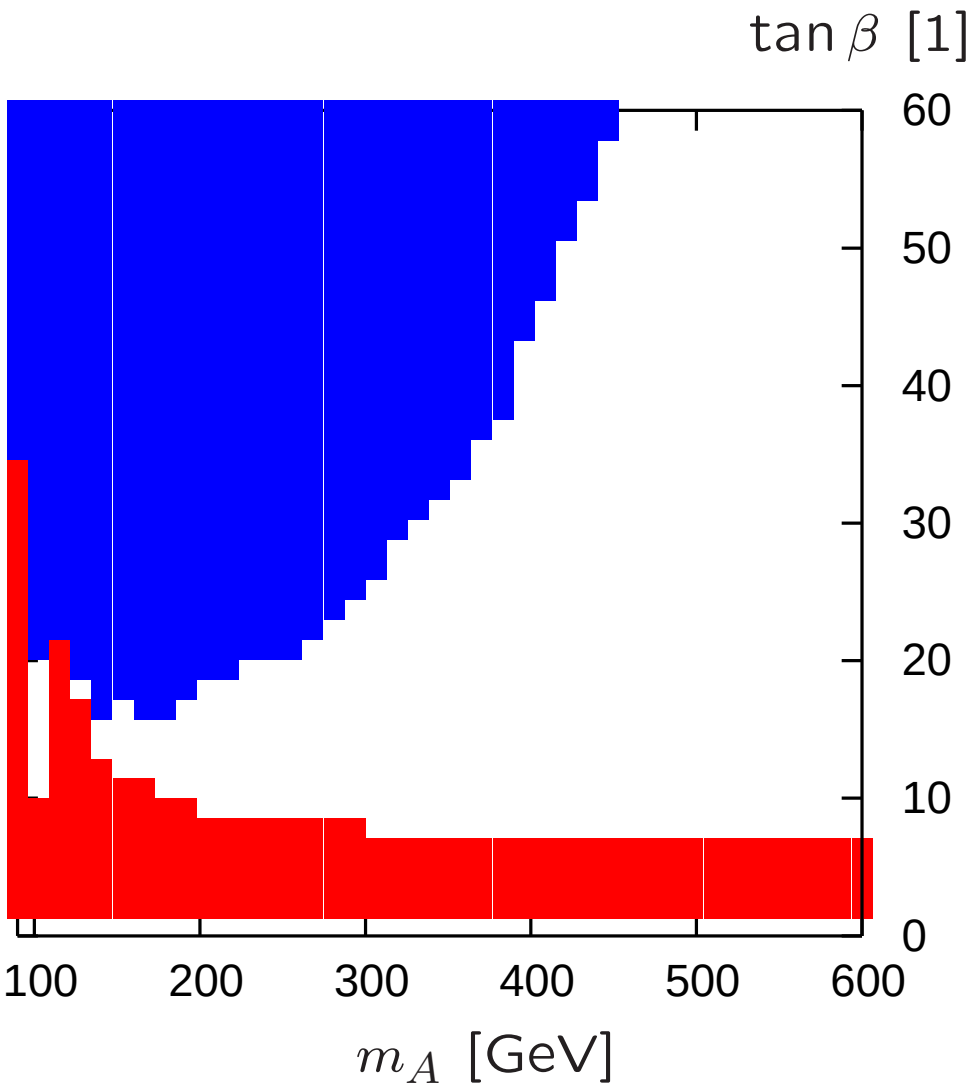


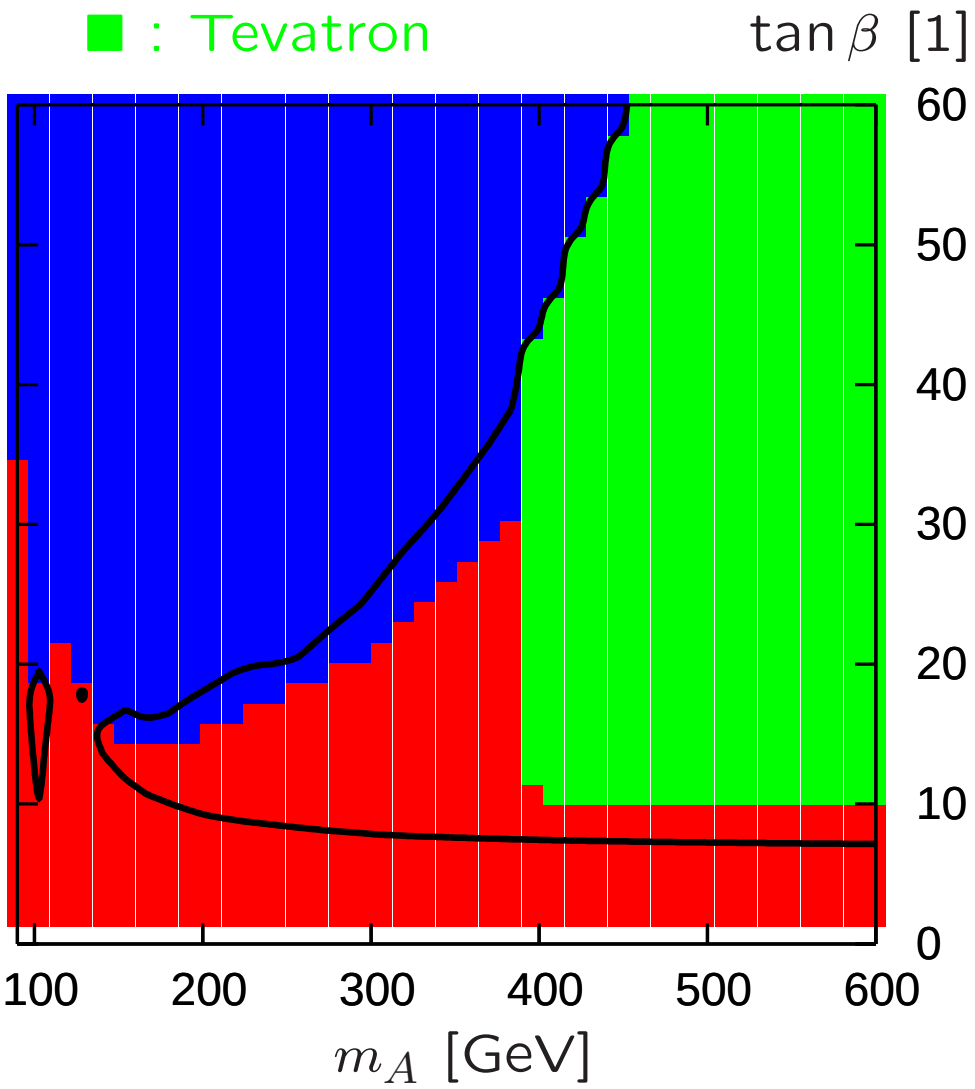
- × $ee \to hZ \to (b\bar{b})Z$
- × $ee \to Ah \to bbbb$
- $p\bar{p} \to Vh, h \to b\bar{b}$ (SM), CDF
- $p\bar{p} \to Vh/h$ via VBF, $h \to b\bar{b}$ (SM), CDF&D0
- $p\bar{p} \to h/H/A \to \tau\tau$, ATLAS

Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : nomix+ scenario

a) exclusion



b) highest sensitivity experiment



Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : nomix+ scenario

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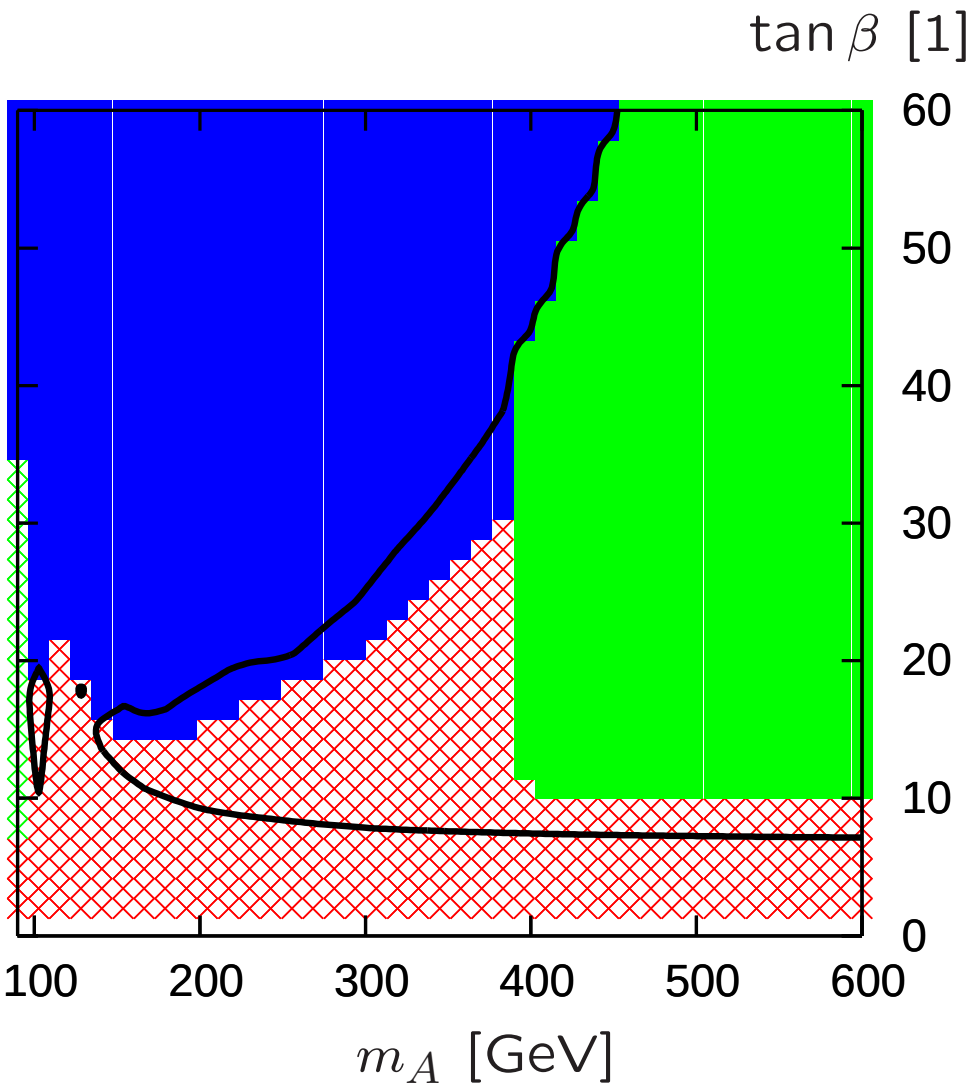

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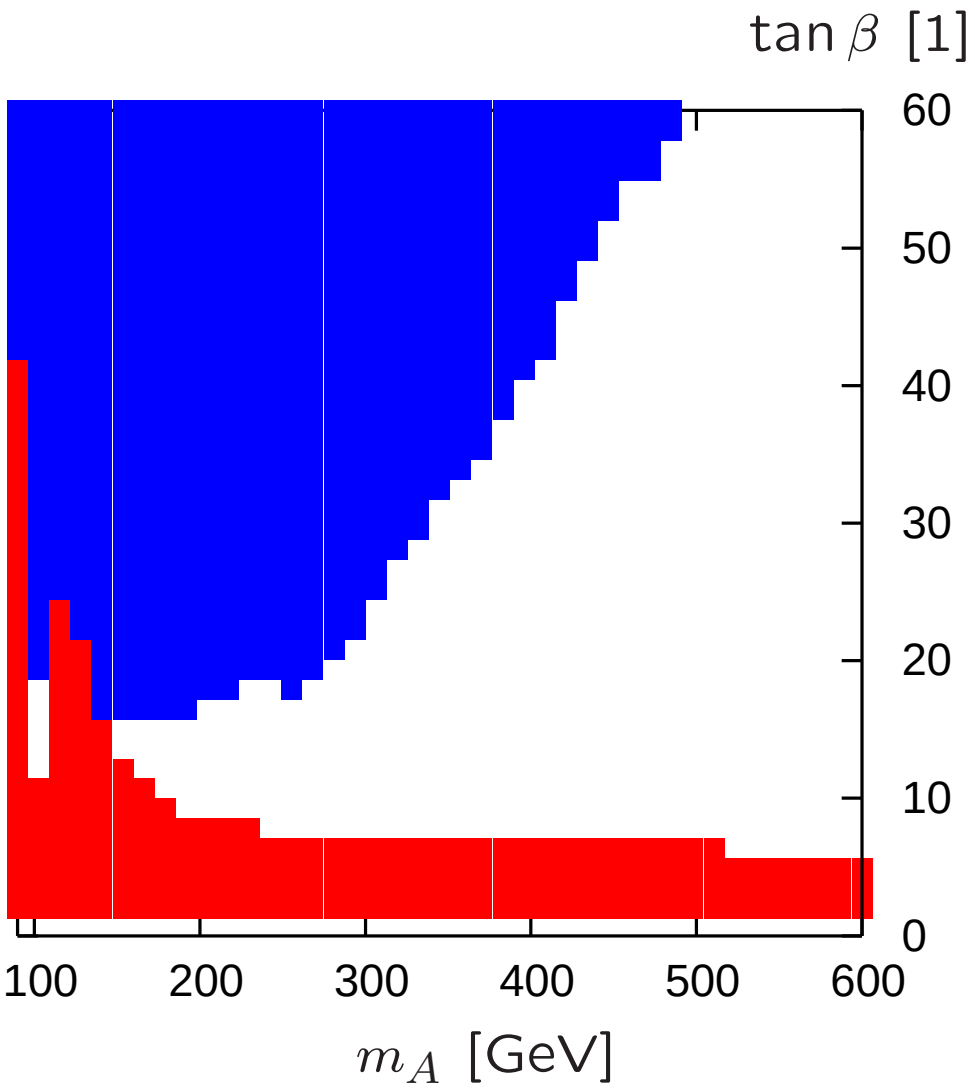
Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : gluophobic scenario

a) exclusion



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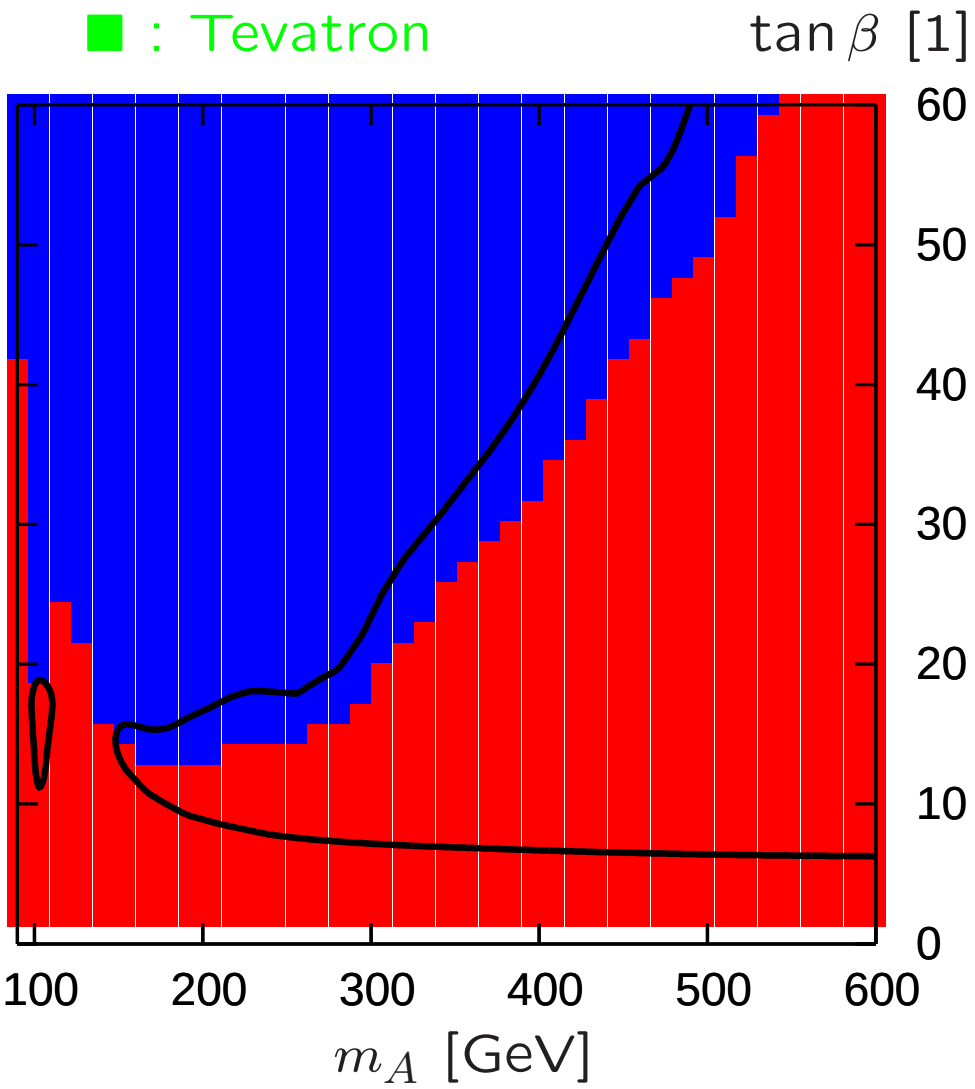

Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : gluophobic scenario

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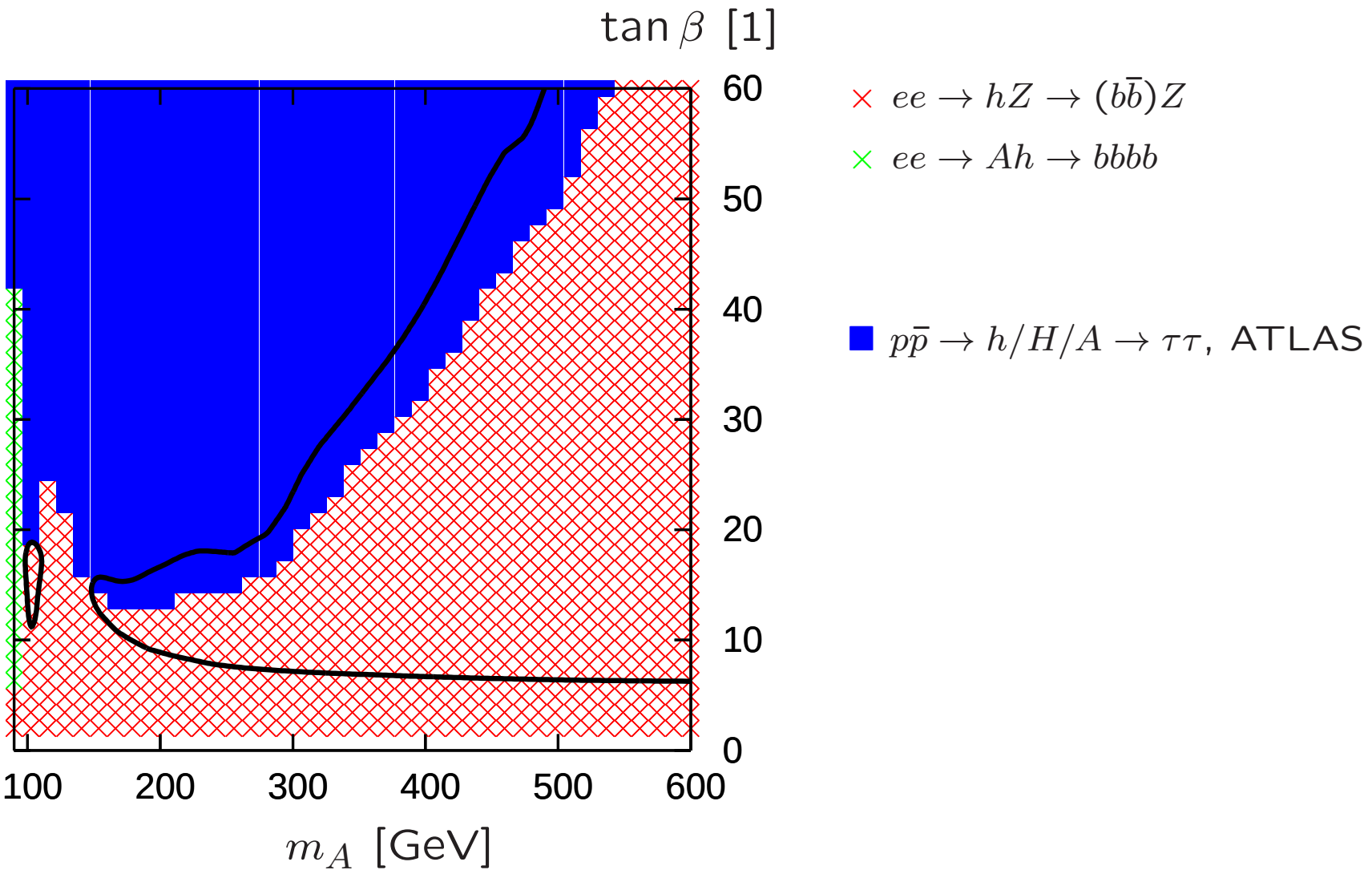
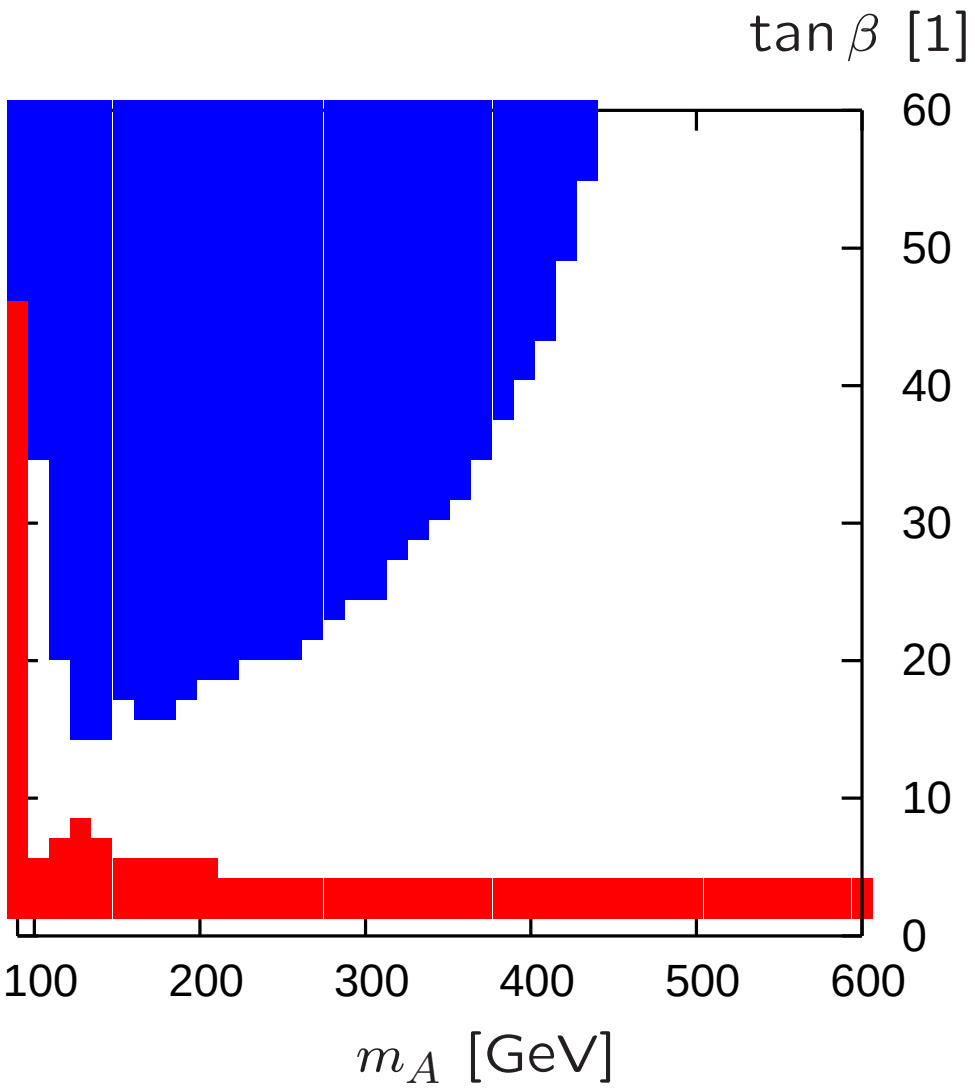
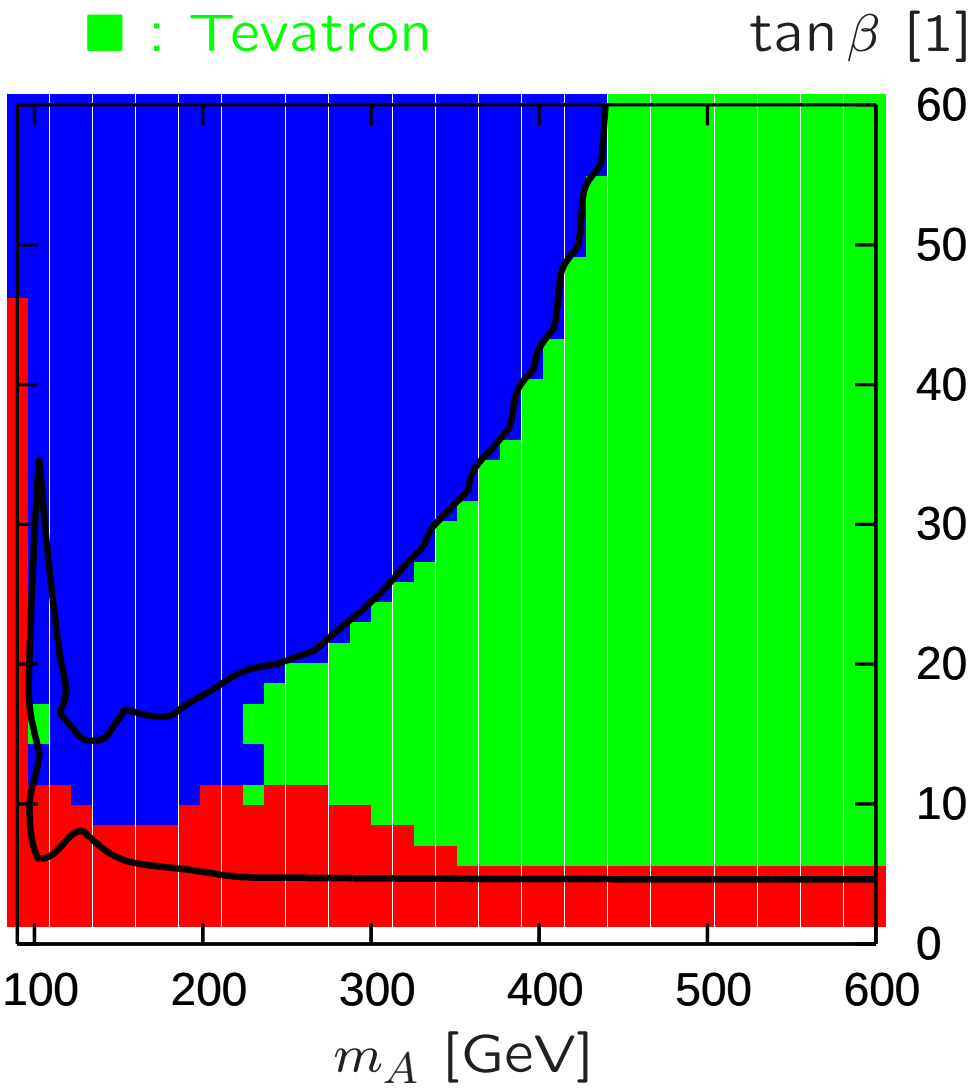


Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : small α_{eff} scenario

a) exclusion

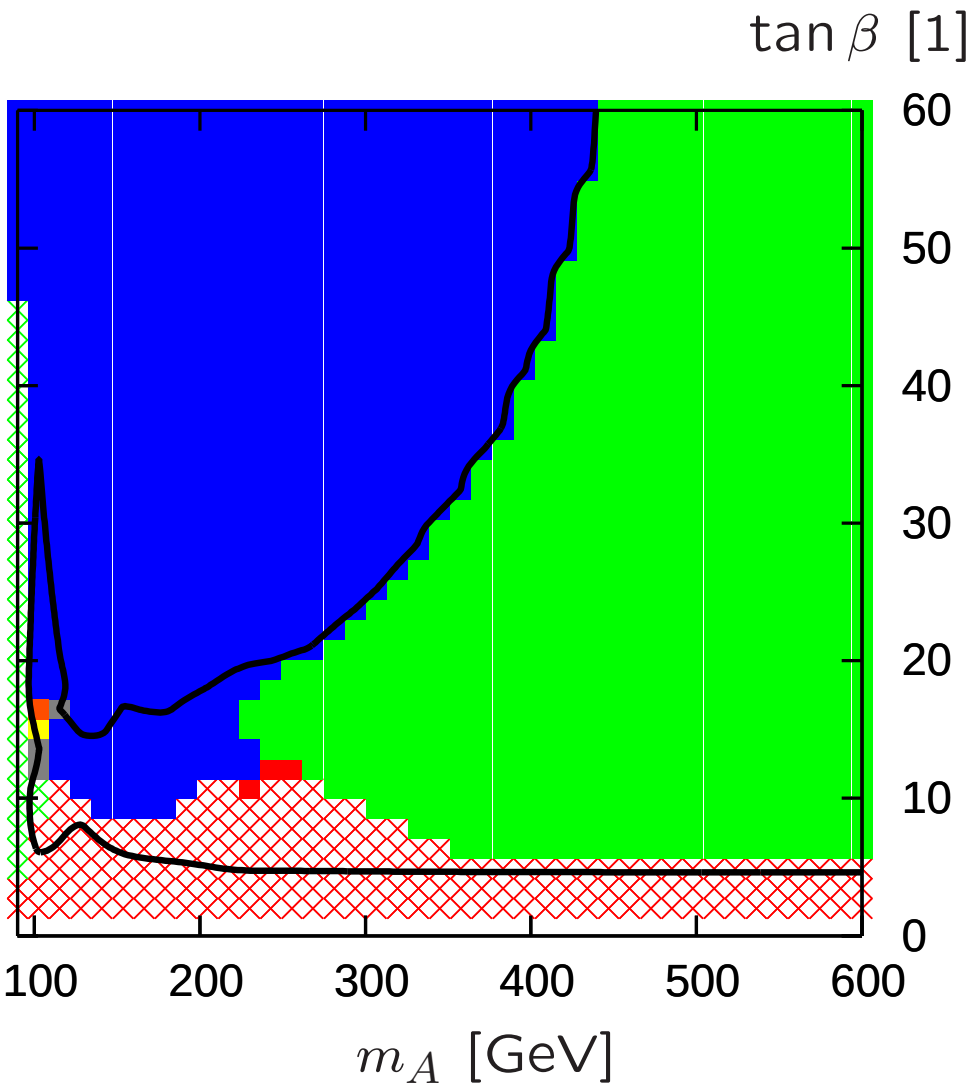


b) highest sensitivity experiment



Exclusion range and sensitivity map: $\tan\beta - m_A$ plane : small α_{eff} scenario

c) highest sensitivity analysis



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- $p\bar{p} \to H \to WW$ (SM), CDF
- $p\bar{p} \to H \to WW$ (SM), CMS
- $p\bar{p} \to H \to VV$ (SM), CDF&D0

summary

- HiggsBounds: powerful tool for constraining Higgs sectors of new physics models systematically.

- Tevatron has only few places left where it keeps the highest sensitvity in Higgs search. LHC takes over!

- ... that's also true for the MSSM benchmark scenarios

- Current LHC (& Tevatron) results rule out additional parts of the Randall-Sundrum model's parameter space (compared to LEP results).