HiggsBounds: confronting arbitrary Higgs sectors with exclusion bounds from LEP & the Tevatron

Oliver Brein

Physikalisches Institut,
Universität Freiburg

e-mail: Oliver.Brein@physik.uni-freiburg.de

in collaboration with

P. Bechtle, S. Heinemeyer, G. Weiglein and K. Williams

[see arXiv:0811.4169 [hep-ph] and try it out at `www.ippp.dur.ac.uk/HiggsBounds/`]

outline :

- motivation
  - Higgs search
  - why HiggsBounds ?
- implementation
  - basic idea
  - LEP analyses
  - Tevatron analyses
- usage and applications
  - usage
  - applications

- motivation

– Higgs search

- The **search for Higgs bosons** is a major cornerstone in the effort to unravel the **nature of electroweak symmetry breaking**.

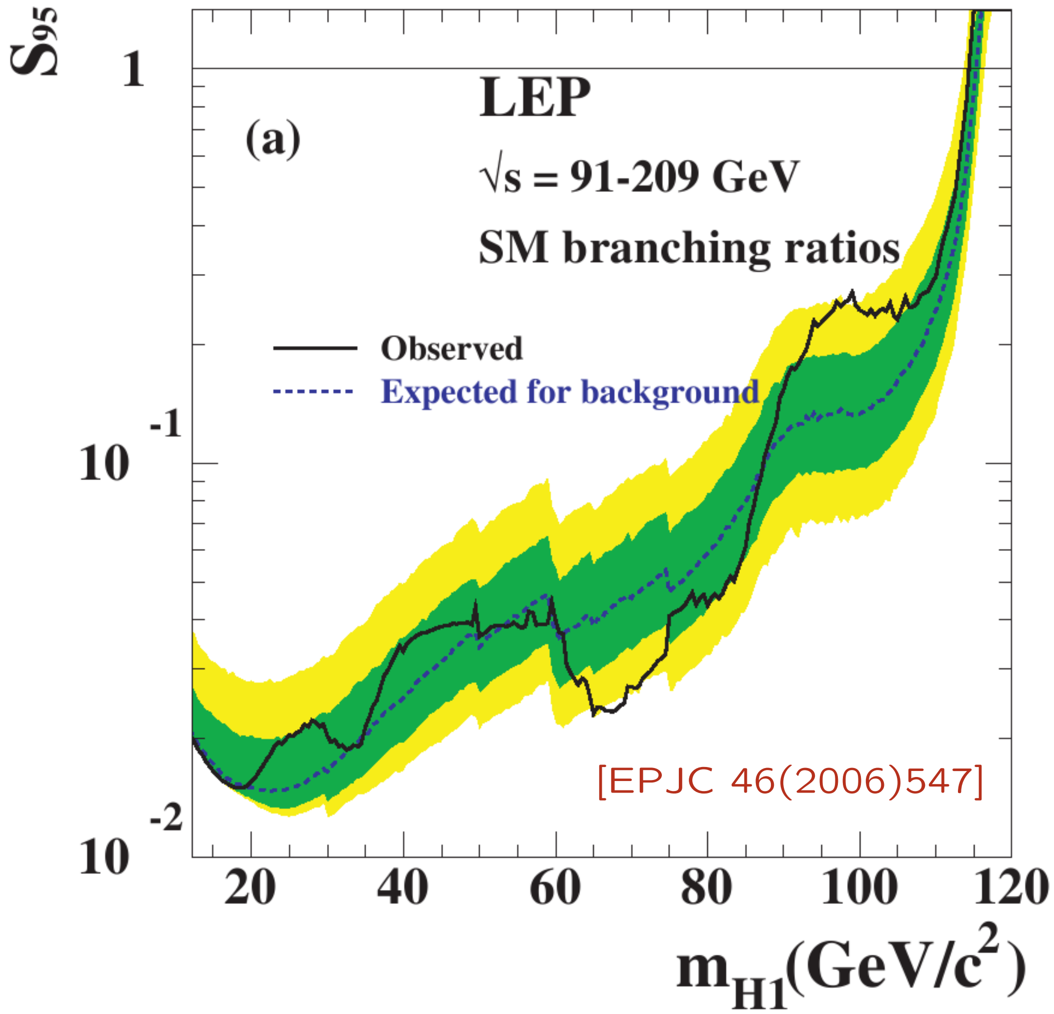
- So far: no Higgs signals.
  - LEP searched for them.
  - Tevatron is currently searching for them.

- Tevatron and LEP turn(ed) the non-observation of Higgs signals into 95% C.L. limits on rates/cross sections of ...

  a) ... individual signal topologies,
     e.g. $e^+e^- \to h_i Z \to b\bar{b}Z$, $p\bar{p} \to h_i \to W^+W^-$,

  b) ... combinations of signal topologies
     e.g. SM, MSSM combined limits.

example 1: LEP SM combined limit



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

where $\sigma_{\text{max}}(m_{H1})$ is the maximal Higgs production cross section compatible with the background-only hypothesis at 95% C.L.

A SM-like model with

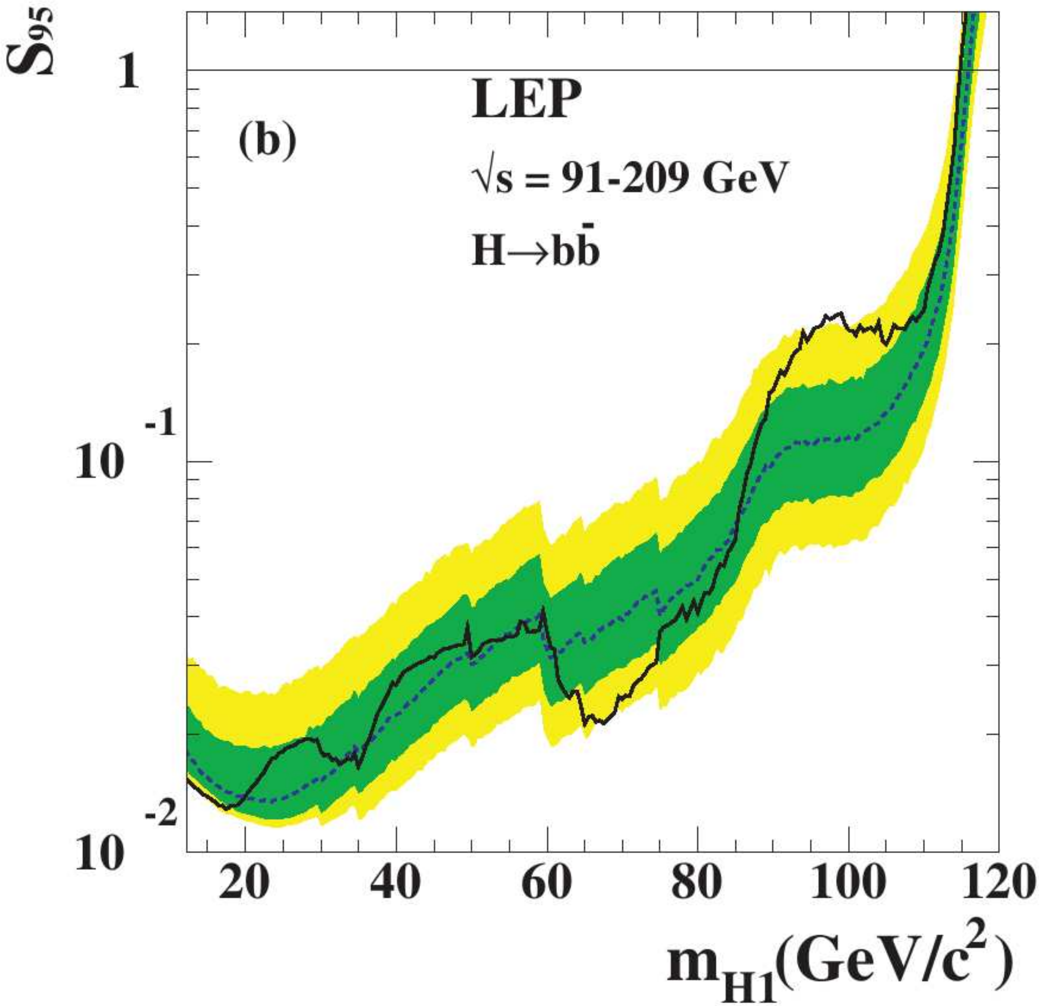
$$\sigma_{\text{model}}(m_{H1}) > \sigma_{\text{max}}(m_{H1})$$

or $\frac{\sigma_{\text{model}}(m_{H1})}{\sigma_{\text{max}}(m_{H1})} > 1$

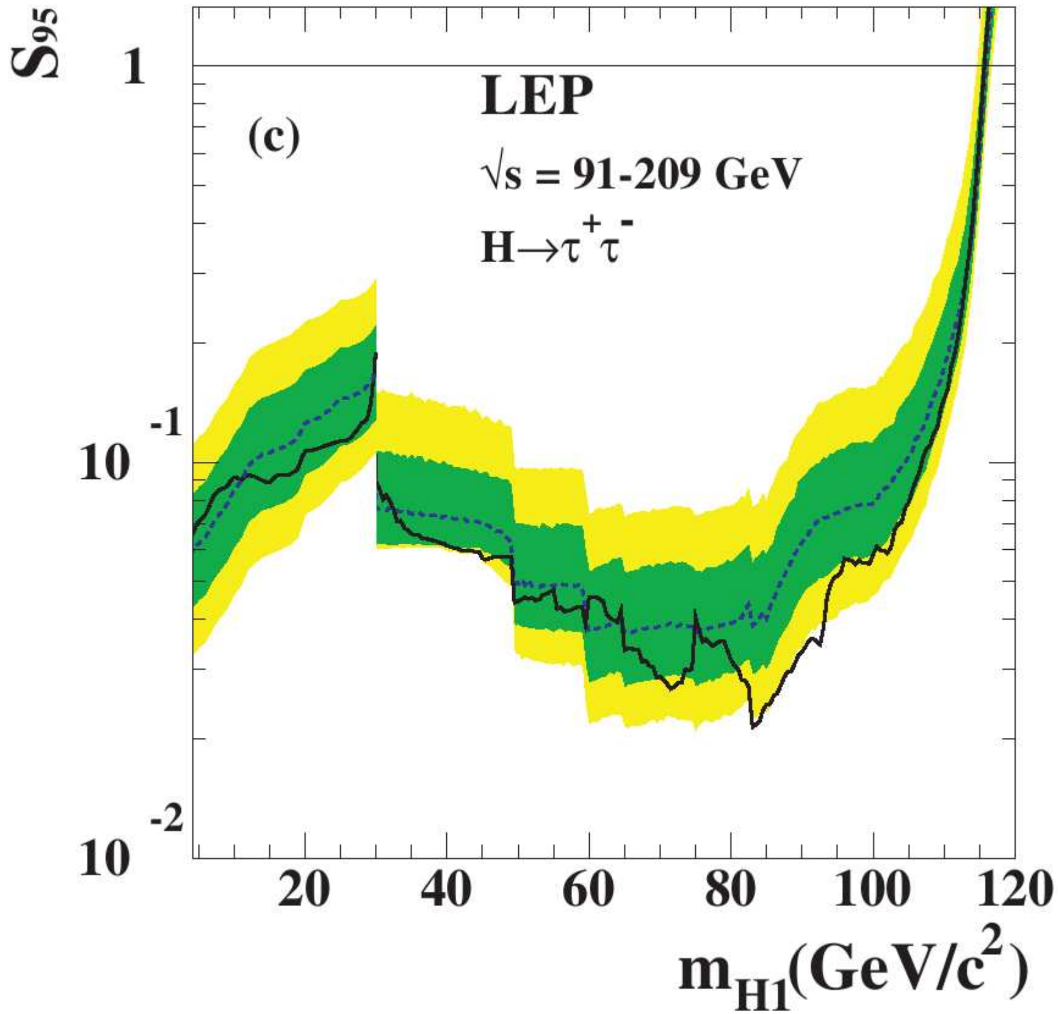
is said to be excluded at the 95% C.L.

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

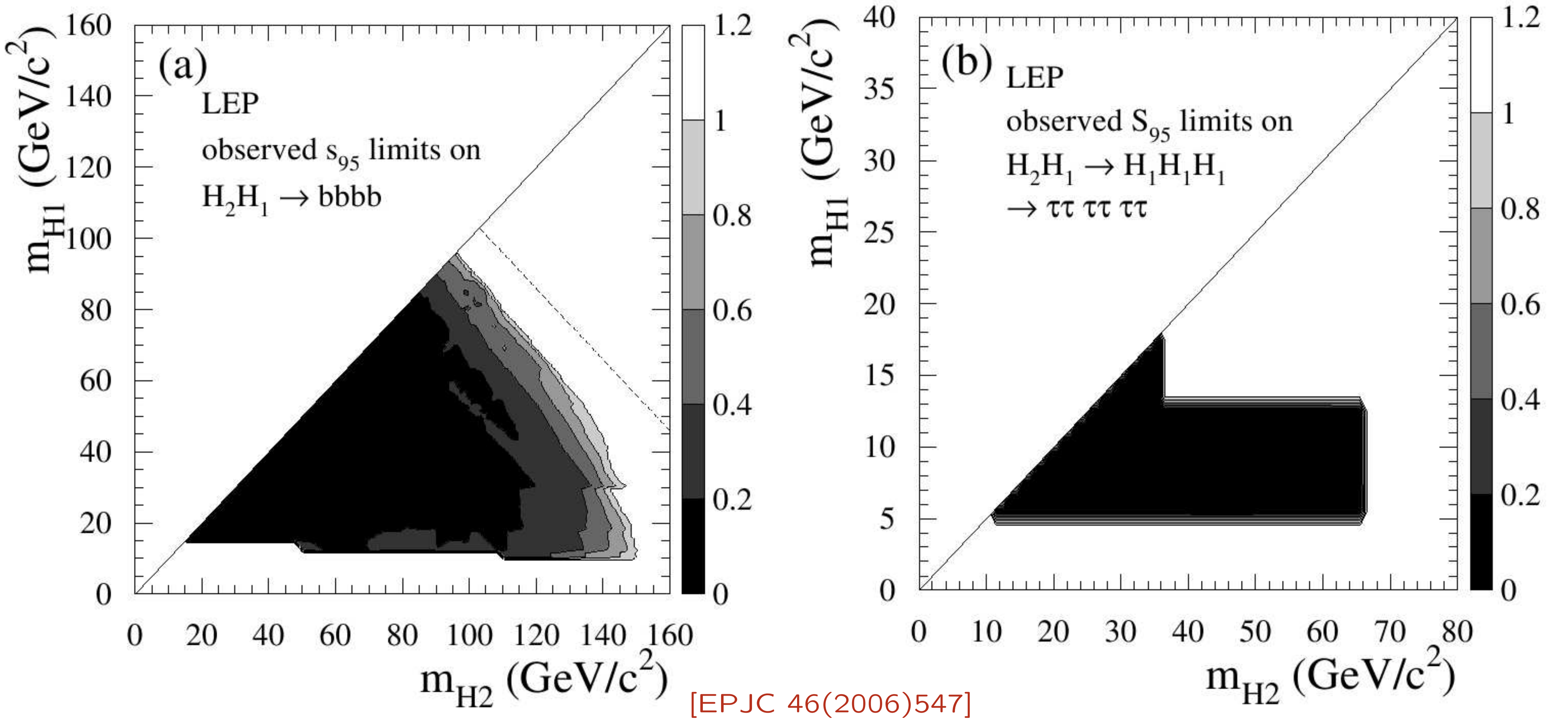


[EPJC 46(2006)547]

example 3: LEP single topology limits, assuming ...

a) ... H_2H_1 production and $\text{BR}(H_i \to b\bar{b}) = 1$

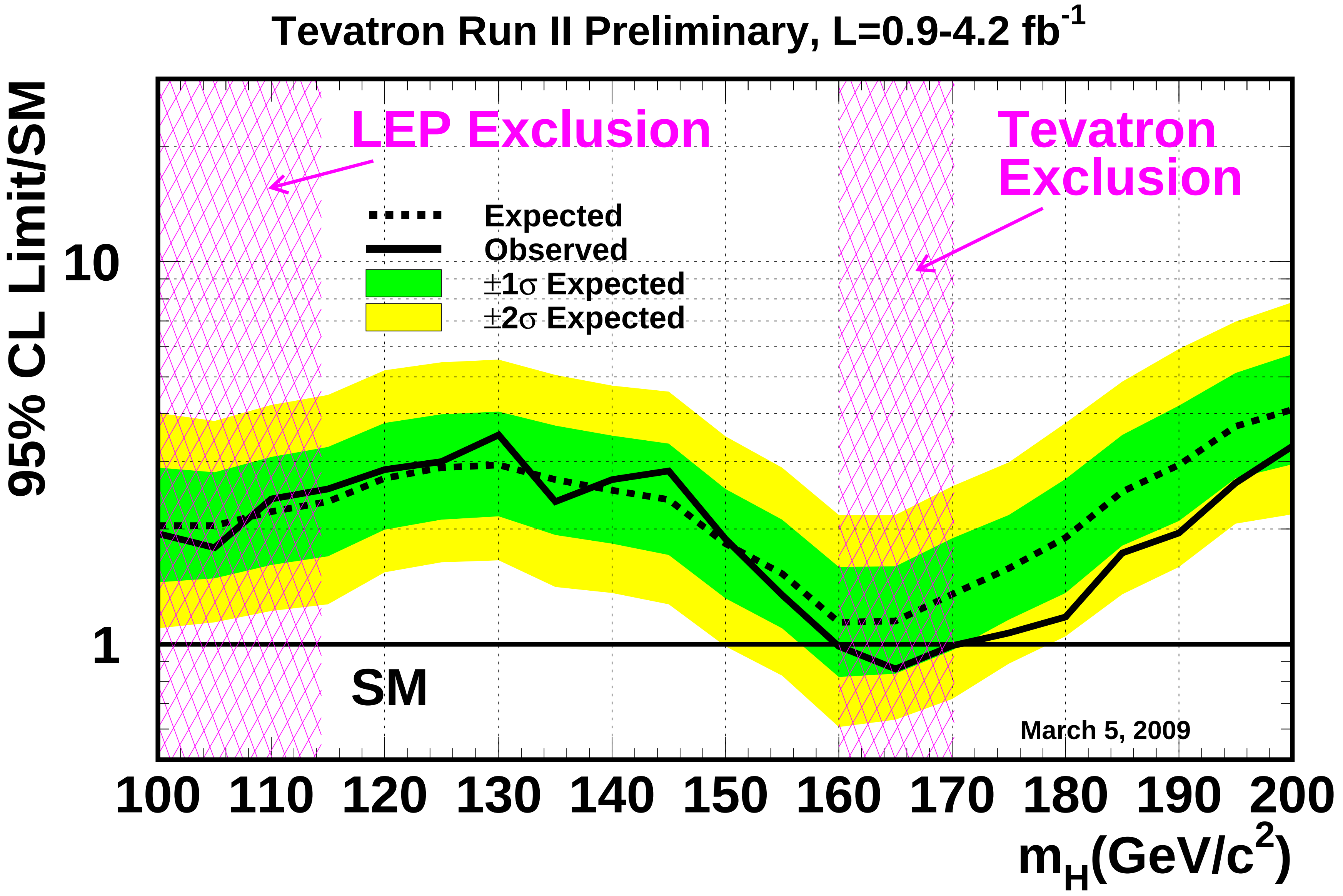
b) ... H_2H_1 production and $\text{BR}(H_i \to \tau^+\tau^-) = \text{BR}(H_2 \to H_1H_1) = 1$



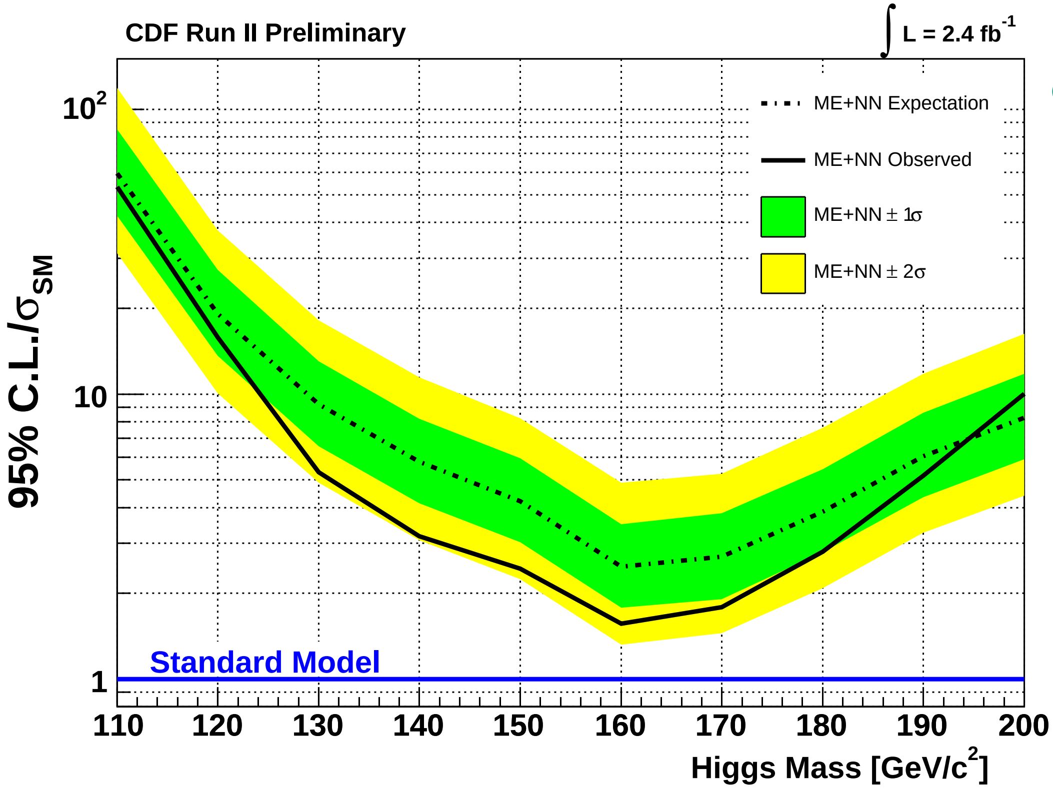
[EPJC 46(2006)547]

here: $S_{95}(m_{H1}, m_{H2}) := \frac{\sigma_{\text{max}}}{\sigma_{\text{ref}}}(m_{H1}, m_{H2})$ with a reference $\sigma_{\text{ref}}(m_{H1}, m_{H2})$

example 4: Tevatron SM combined limit [CDF note 9713, DØ note 5889]



example 5: Tevatron single topology limits

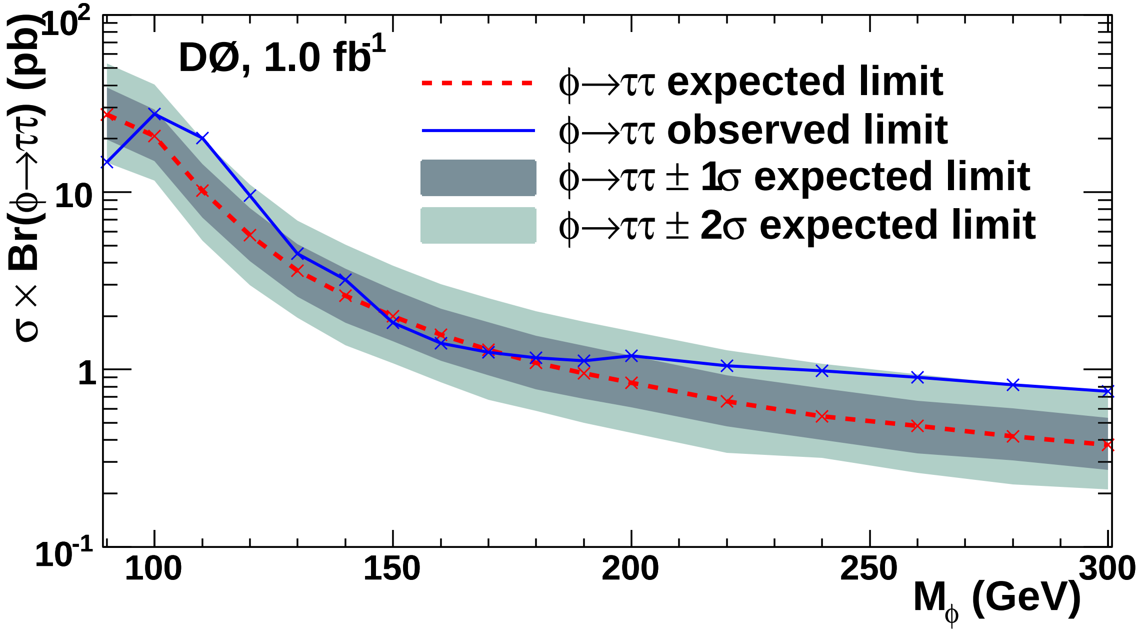


a) $p\bar{p} \to H \to WW^{\star}$ using 1.9 fb^{-1}
[CDF note 8958]

cross section ratio limit

b) $p\bar{p} \to H \to \tau^{+}\tau^{-}$ using 1 fb^{-1}
[DØ hep-ex/0805.2491]

absolute cross section limit



– why HiggsBounds ?

- Many limits on individual topologies (from LEP/Tevatron) and combined results available, more to be expected from the Tevatron and the LHC (hopefully not for too long).

- In general, BSM models contribute to individual Higgs signal topologies in different proportions than in the SM.
  $\rightarrow$ SM combined analyses cannot be used

- To test such models against LEP and Tevatron results:
  check model predictions for cross sections
  of individual search topologies
  against the experimental limits.

HiggsBounds:

Test theoretical predictions of models with arbitrary Higgs sectors against exclusion bounds obtained from Higgs searches at LEP and the Tevatron.

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

- Applicable to models with arbitrary Higgs sectors

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

- Combination of results from LEP and Tevatron possible

- Three ways to use HiggsBounds:
  command line, library of subroutines (Fortran 77/90), web interface

`www.ippp.dur.ac.uk/HiggsBounds`

- implementation

• implementation

– basic idea

- Evaluate model prediction Q_{model} for [cross section] $\times$ BR of all search topologies X for given Higgs masses and deviations from the SM and compare to experimental limit:

$$Q_{\text{model}}(X) = \frac{[\sigma \times \text{BR}]_{\text{model}}}{[\sigma \times \text{BR}]_{\text{ref}}} \quad \text{or} \quad [\sigma \times \text{BR}]_{\text{model}}.$$

- From the experimental results, read off the corresponding observed 95% C.L. limit: $Q_{\text{observed}}(X)$.

- If $\frac{Q_{\text{model}}(X)}{Q_{\text{observed}}(X)} > 1$ the model is excluded by this search topology at 95% C.L.

→ Problem : how to combine topologies 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 topology of highest statistical sensitivity.

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

- Determine for each search topology X the experimental expected limit $Q_{\text{expected}}(X)$.
- Determine the topology X_0 with the highest sensitivity for the signal, i.e. of all topologies X find the one X_0 where $\frac{Q_{\text{model}}(X)}{Q_{\text{expected}}(X)}$ is maximal.
- If for this topology $\frac{Q_{\text{model}}(X_0)}{Q_{\text{observed}}(X_0)} > 1$ the model is excluded at 95% C.L. by the corresponding experimental analysis for the search topology X_0.

– LEP analyses

We include expected and observed S_{95} values for the following search topologies [EPJC 46(2006)547]

1. $e^+e^- \to (h_k)Z \to (b\bar{b})Z$,
2. $e^+e^- \to (h_k)Z \to (\tau^+\tau^-)Z$,
3. $e^+e^- \to (h_k \to h_i h_i)Z \to (b\bar{b}b\bar{b})Z$,
4. $e^+e^- \to (h_k \to h_i h_i)Z \to (\tau^+\tau^-\tau^+\tau^-)Z$,
5. $e^+e^- \to (h_k h_i) \to (b\bar{b}b\bar{b})$,
6. $e^+e^- \to (h_k h_i) \to (\tau^+\tau^-\tau^+\tau^-)$,
7. $e^+e^- \to (h_k \to h_i h_i)h_i \to (b\bar{b}b\bar{b})b\bar{b}$,
8. $e^+e^- \to (h_k \to h_i h_i)h_i \to (\tau^+\tau^-\tau^+\tau^-)\tau^+\tau^-$,
9. $e^+e^- \to (h_k \to h_i h_i)Z \to (b\bar{b})(\tau^+\tau^-)Z$,
10. $e^+e^- \to (h_k \to b\bar{b})(h_i \to \tau^+\tau^-)$,
11. $e^+e^- \to (h_k \to \tau^+\tau^-)(h_i \to b\bar{b})$,

Inclusion of additional topologies is work in progress
(e.g. $e^+e^- \to h_k Z, h_k \to$ invisible; $e^+e^- \to h_k Z, h_k \to$ anything, ...)

LEP input (Input Option `part/hadr`)

masses: m_{h_k},

branching ratios:

$$\mathrm{BR}_{\mathrm{model}}(h_i \to b\bar{b})\,, \qquad \mathrm{BR}_{\mathrm{model}}(h_i \to \tau^+\tau^-)\,, \qquad \mathrm{BR}_{\mathrm{model}}(h_k \to h_i h_i)\,,$$

ratios of cross sections:

$$\frac{\sigma_{\mathrm{model}}(e^+e^- \to h_k Z)}{\sigma_{\mathrm{ref}}(e^+e^- \to HZ)}\,, \qquad \frac{\sigma_{\mathrm{model}}(e^+e^- \to h_k h_i)}{\sigma_{\mathrm{ref}}(e^+e^- \to H'H)}\,,$$

with $m_{H'} = m_{h_k}$ and $m_H = m_{h_i}$ and for $k, i \in \{1, \ldots, n_{\mathrm{Higgs}}\}$.

With this input, we can evaluate Q_{model} to compare with S_{95} as e.g.

$$Q_{\mathrm{model}}\left[(h_1)Z \to (b\bar{b})Z\right] = \frac{\sigma_{\mathrm{model}}(h_1 Z)}{\sigma_{\mathrm{ref}}(HZ)}\mathrm{BR}_{\mathrm{model}}(h_1 \to b\bar{b})\,,$$

$$Q_{\mathrm{model}}\left[(h_2 \to h_1 h_1)Z \to (b\bar{b}b\bar{b})Z\right] = \frac{\sigma_{\mathrm{model}}(h_2 Z)}{\sigma_{\mathrm{ref}}(HZ)}\mathrm{BR}_{\mathrm{model}}(h_2 \to h_1 h_1)\mathrm{BR}_{\mathrm{model}}(h_1 \to b\bar{b})^2$$

– Tevatron analyses

At the moment, the following analyses of Higgs production signatures by CDF and DØ have been included in HiggsBounds:

single topology analyses

search topology X (analysis)	reference ($\star$=published)
$p\bar{p} \to ZH \to l^+l^-b\bar{b}$ (CDF with 1.0 fb^{-1})	CDF'08*
$p\bar{p} \to ZH \to l^+l^-b\bar{b}$ (CDF with 2.4 fb^{-1})	CDF note 9475
$p\bar{p} \to ZH \to l^+l^-b\bar{b}$ (DØ with 2.3 fb^{-1})	DØ note 5570
$p\bar{p} \to WH \to l\nu b\bar{b}$ (DØ with 1.7 fb^{-1})	DØ note 5472
$p\bar{p} \to WH \to l\nu b\bar{b}$ (CDF with 2.7 fb^{-1})	CDF note 9463
$p\bar{p} \to WH \to W^+W^-W^\pm$ (DØ with 1.0 fb^{-1})	DØ note 5485
$p\bar{p} \to WH \to W^+W^-W^\pm$ (CDF with 1.9 fb^{-1})	CDF note 7307
$p\bar{p} \to H \to W^+W^- \to l^+l'^-$ (DØ with 3.0 fb^{-1})	DØ note 5757
$p\bar{p} \to H \to W^+W^- \to l^+l'^-$ (CDF with 3.0 fb^{-1})	CDF'08*
$p\bar{p} \to H \to \gamma\gamma$ (DØ with 1.1 fb^{-1})	DØ '08*
$p\bar{p} \to H \to \gamma\gamma$ (DØ with 2.68 fb^{-1})	DØ note 5737
$p\bar{p} \to H \to \tau^+\tau^-$ (DØ with 1.0 fb^{-1})	DØ '08*
$p\bar{p} \to H \to \tau^+\tau^-$ (CDF with 1.8 fb^{-1})	CDF note 9071
$p\bar{p} \to bH, H \to b\bar{b}$ (CDF with 1.9 fb^{-1})	CDF note 9284
$p\bar{p} \to bH, H \to b\bar{b}$ (DØ with 1.0 fb^{-1})	DØ '08*
$p\bar{p} \to bH, H \to b\bar{b}$ (DØ with 2.6 fb^{-1})	DØ note 5726

– Tevatron analyses

At the moment, the following analyses of Higgs production signatures by CDF and DØ have been included in HiggsBounds:

analyses combining topologies

search topology X (analysis)	reference ($\star$=publ.)
$p\bar{p} \to WH/ZH \to b\bar{b} + E_T^{\text{miss.}}$ (CDF with 2.3 fb^{-1})	CDF note 9483
$p\bar{p} \to WH/ZH \to b\bar{b} + E_T^{\text{miss.}}$ (DØ with 2.1 fb^{-1})	D0 note 5586
$p\bar{p} \to H/HW/HZ/H$ via VBF, $H \to \tau^+\tau^-$ (CDF with 2.0 fb^{-1})	CDF note 9248
Combined SM analysis (CDF & DØ with 0.9 – 1.9 fb^{-1})	hep-ex/0712.2383
Combined SM analysis (CDF & DØ with 1.0 – 2.4 fb^{-1})	hep-ex/0804.3423
Combined SM analysis (CDF & DØ with 3.0 fb^{-1})	hep-ex/0808.0534

Inclusion of new results from Winter Conferences is work in progress.

Tevatron input (Input Option part)

Example: evaluation of the model cross section for the search topology $X = p\bar{p} \to H \to W^+W^- \to l^+l'^-$ normalised to the SM cross section:

$$Q_{\text{model}}(X) = \Bigg\{ \Bigg(\frac{\hat{\sigma}^{\text{model}}_{gg\to h_k}(\hat{s}_{\text{thr.}}, m_{h_k})}{\hat{\sigma}^{\text{SM}}_{gg\to h_k}(\hat{s}_{\text{thr.}}, m_H)} \frac{\sigma_{\text{SM}}(p\bar{p} \to gg \to H, m_H)}{\sigma_{\text{SM}}(p\bar{p} \to H, m_H)} + \frac{\hat{\sigma}^{\text{model}}_{b\bar{b}\to h_k}(\hat{s}_{\text{thr.}}, m_{h_k})}{\hat{\sigma}^{\text{SM}}_{b\bar{b}\to h_k}(\hat{s}_{\text{thr.}}, m_H)} \frac{\sigma_{\text{SM}}(p\bar{p} \to b\bar{b} \to H, m_H)}{\sigma_{\text{SM}}(p\bar{p} \to H, m_H)} \Bigg) \times \frac{\text{BR}^{\text{model}}_{h_k\to W^+W^-}(m_{h_k})}{\text{BR}^{\text{SM}}_{H\to W^+W^-}(m_H)} \Bigg\} \Bigg|_{m_H = m_{h_k}} .$$

(green: input, purple: provided functions)

For the SM normalisation, HiggsBounds provides also predicitons for SM branching ratios using HDECAY 3.303 [Djouadi et al.'98] and SM Higgs production processs using the compilation of the TEV4LHC Working Group [Aglietti et al.'06].

- usage and applications

– usage

Command-line version:

Command:

```
HiggsBounds <analyses to use> <input mode> <number of Higgses> [<fileprefix>]
```

with

<analyses to use>	:	LandT (LEP and Tevatron)
	:	onlyT (only Tevatron)
	:	onlyL (only LEP)
	:	singH (only analyses involving one Higgs)
<input mode>	:	part (partonic CS ratios)
	:	hadr (hadronic CS ratios)
	:	effC (effective couplings)
<number of Higgses>	:	1 to 9 (extendable)
<fileprefix>	:	prefix for input files (optional, can also be a subdirectory)

The command-line version works on a set of input files.
Which set depends on the selected analyses and input mode.

Sample output file (written to <prefix>HiggsBounds_Results.dat)

```
# generated with HiggsBounds on 31.10.2008 at 11:18
# settings: LandT, effC
#
# column abbreviations
#   n          : line id of input
#   Mh(i)      : Higgs boson masses
#   HBresult   : scenario allowed flag (1: allowed, 0: excluded, -1: unphysical)
#   chan       : most sensitive channel (see below). chan=0 if no channel applies
#   obsratio   : ratio [sig x BR]_model/[sig x BR]_limit (<1: allowed, >1: excluded)
#   ncomb      : number of Higgs bosons combined in most sensitive channel
#   additional : optional additional data stored in <prefix>additional.dat (e.g. tan beta)
#
# channel numbers used in this file
#           3 : (ee)->(h3)Z->(b b)Z   (LEP table 14b)
#           4 : (ee)->(h1)Z->(tau tau)Z   (LEP table 14c)
#         124 : (pp)->W(h1)->l nu (b b)   (CDF Note 9463)
#         134 : (pp)->h2->tau tau   (arXiv:0805.2491)
#         157 : (pp)->h1+... where h1 is SM-like  (arXiv:0804.3423 [hep-ex])
# (for full list of processes, see Key.dat)
#
#cols: n    Mh(1)     Mh(2)     Mh(3)    HBresult  chan    obsratio     ncomb  additional(1)
#
       1   359.121   271.963   134.929         1   134    0.212206E-03     1    0.246862
       2   75.0123   92.8677   71.9716         1     4    0.306172E-01     1    0.714964
       3   136.293   345.483   330.026         1   124    0.640713E-01     1    0.434594
       4   111.377   220.765   51.7469         1     3    0.162811         1    0.727173
       5   186.131   355.002   146.448         0   157     15.2354         1    0.230522
```

Fortran subroutine version: e.g. for effective couplings input

```
call run_HiggsBounds_effC(nH,<analyses to use>,
&    Mh,GammaTotal,
&    g2hjbb,g2hjtautau,g2hjWW,g2hjZZ,
&    g2hjgaga,g2hjgg,g2hjhiZ,
&    BR_hjhihi,
&    HBresult,chan,
&    obsratio, ncombined )
```

WWW version:

options similar to command-line version, pointwise input only

see www.ippp.dur.ac.uk/HiggsBounds/

application 1: re-evaluation of SM exclusion with improved prediction

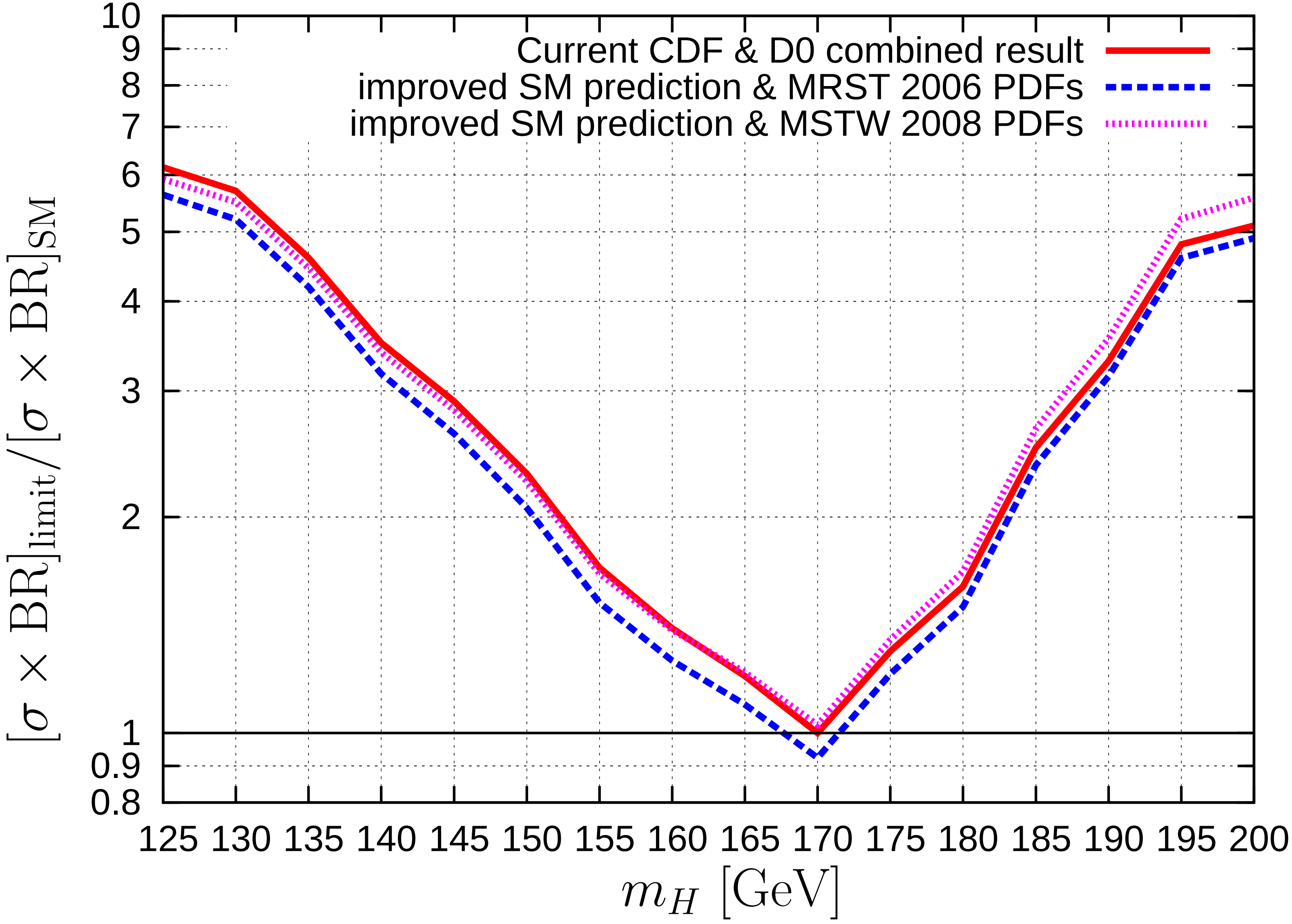
recent developments:

- Improved SM prediction for $\sigma(p\bar{p} \to gg \to H)$:
  mixed QCD-Electroweak corrections [Anastasiou, Boughezal, Petriello '08]
  $\to$ **"Our results motivate a reconsideration of the Tevatron exclusion limits."**

- Updated determination of PDFs: MSTW 2008 [Martin at al. '08]

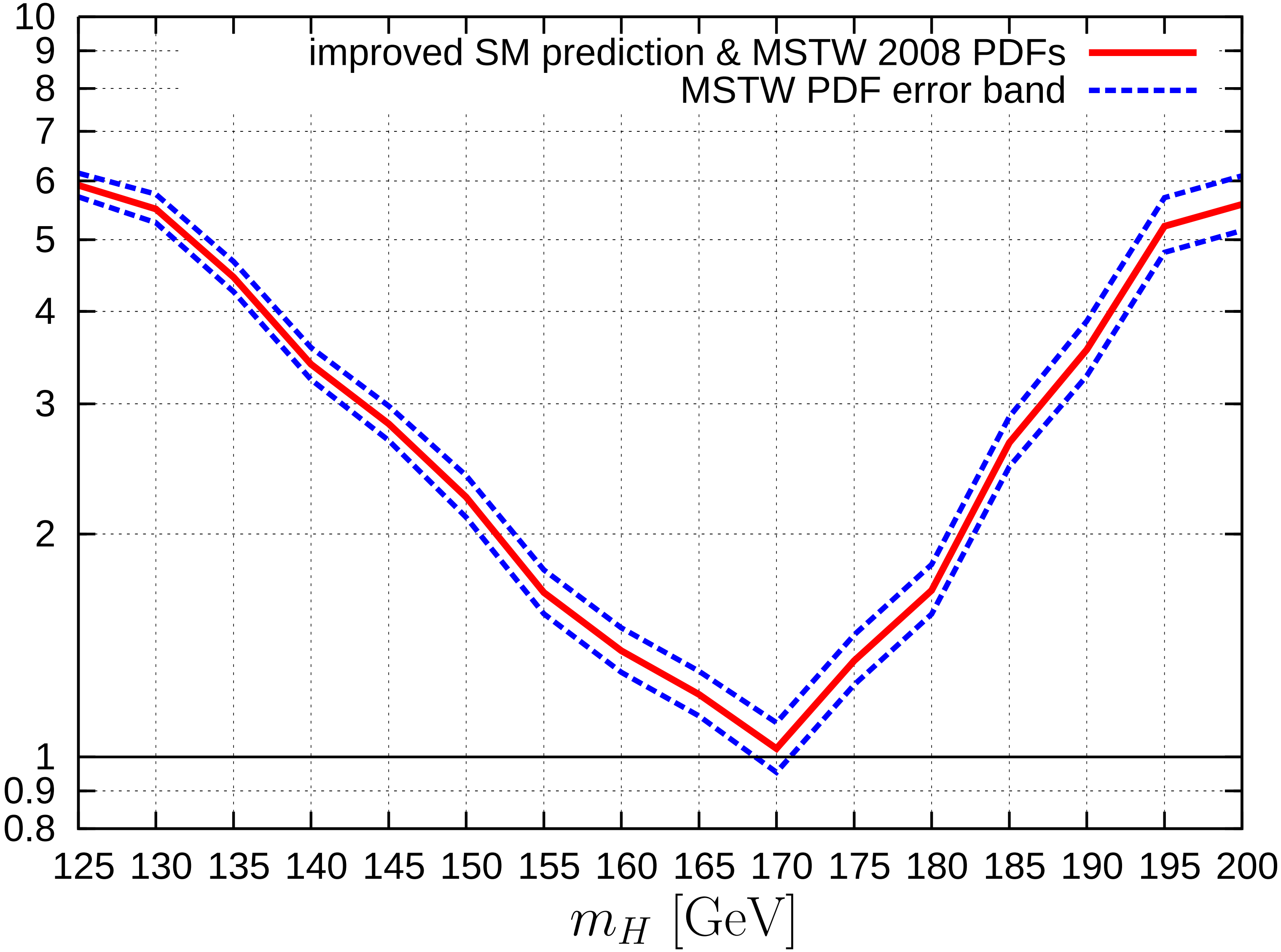
application 1: re-evaluation of SM exclusion with improved prediction

note! "current" = before March 2009



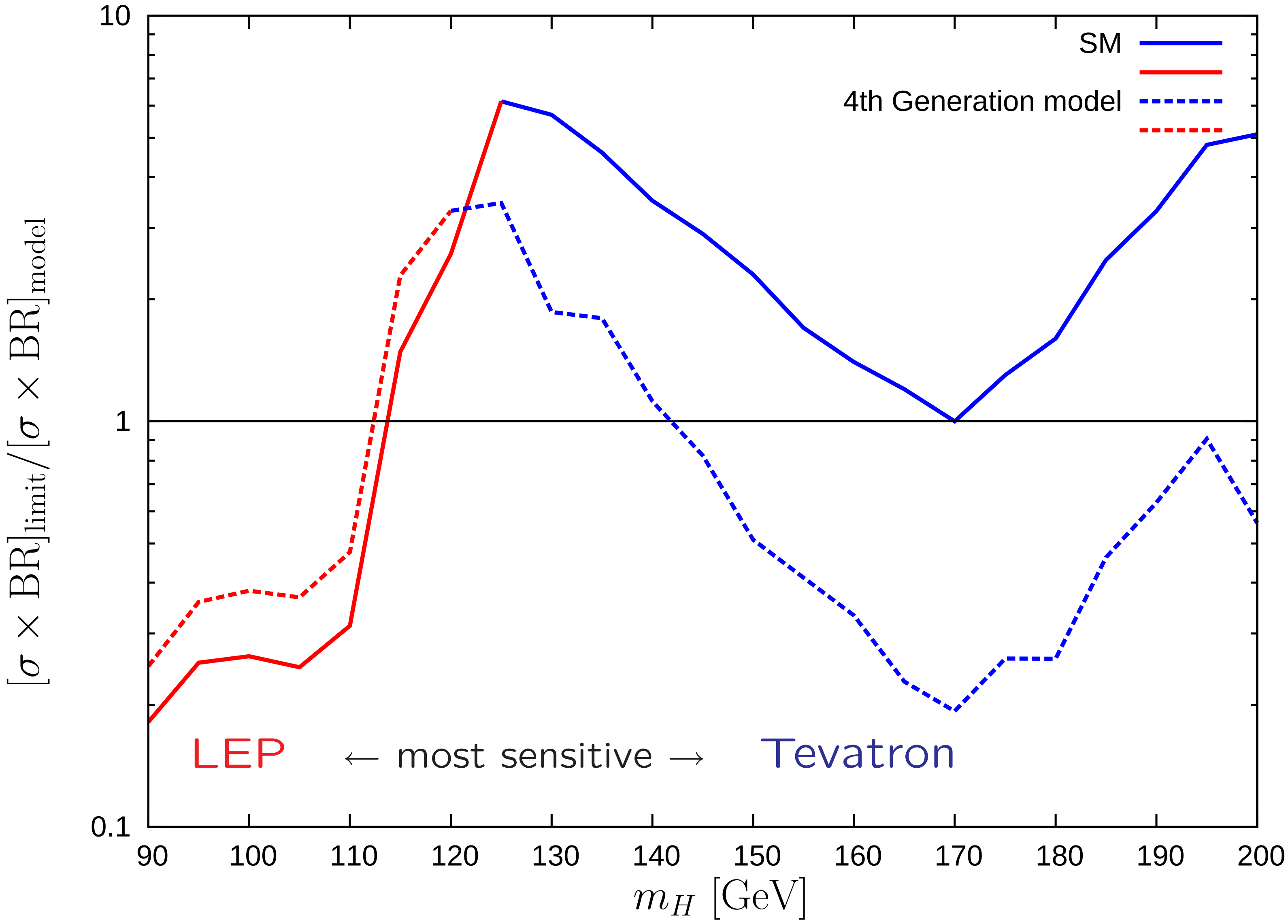
application 1: re-evaluation of SM exclusion with improved prediction

note! “current” = before March 2009



application 2: SM versus Fourth Generation Model exclusion

$$\Gamma(H \to gg)_{\text{model}} = 9 \times \Gamma(H \to gg)_{\text{SM}}$$

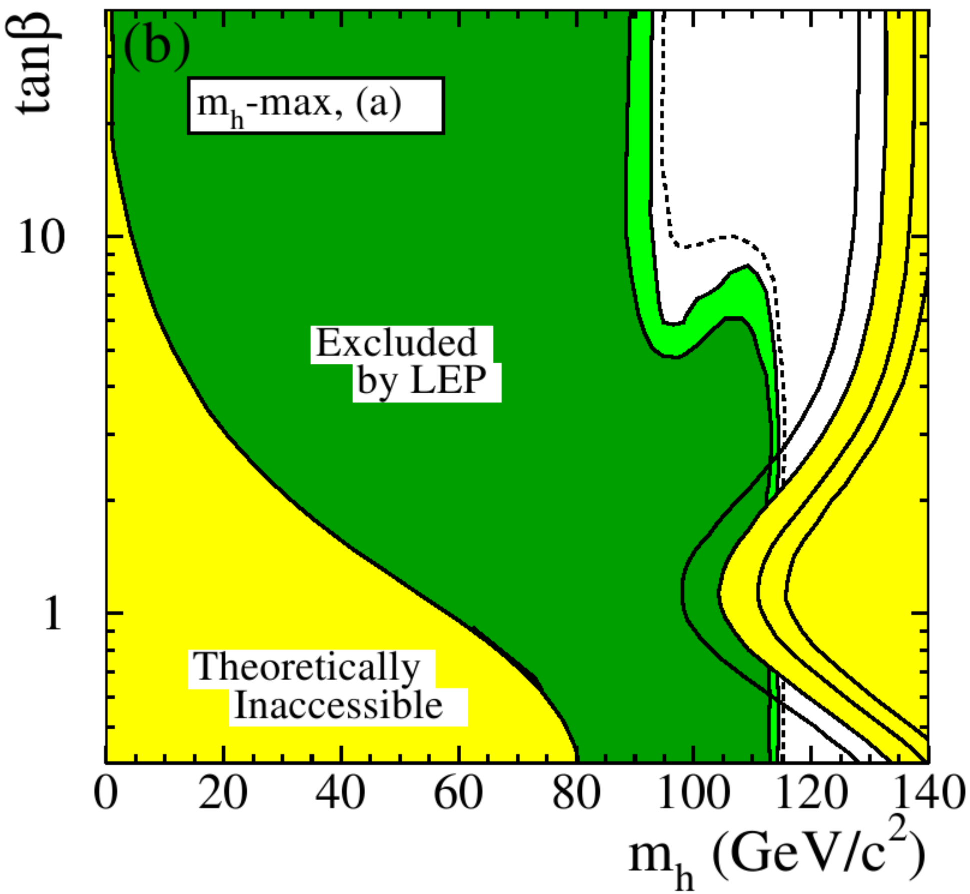


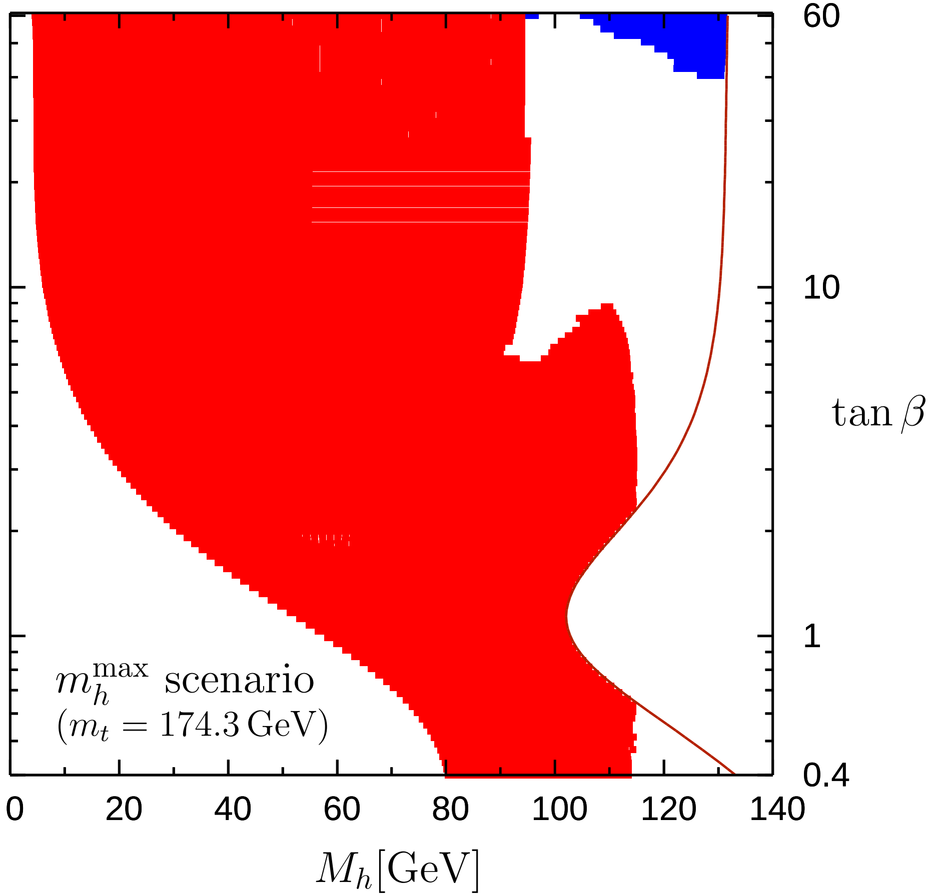
application 3: MSSM benchmark scenarios, exclusion update

a) [EPJC 46(2006)547]

b) **HiggsBounds**

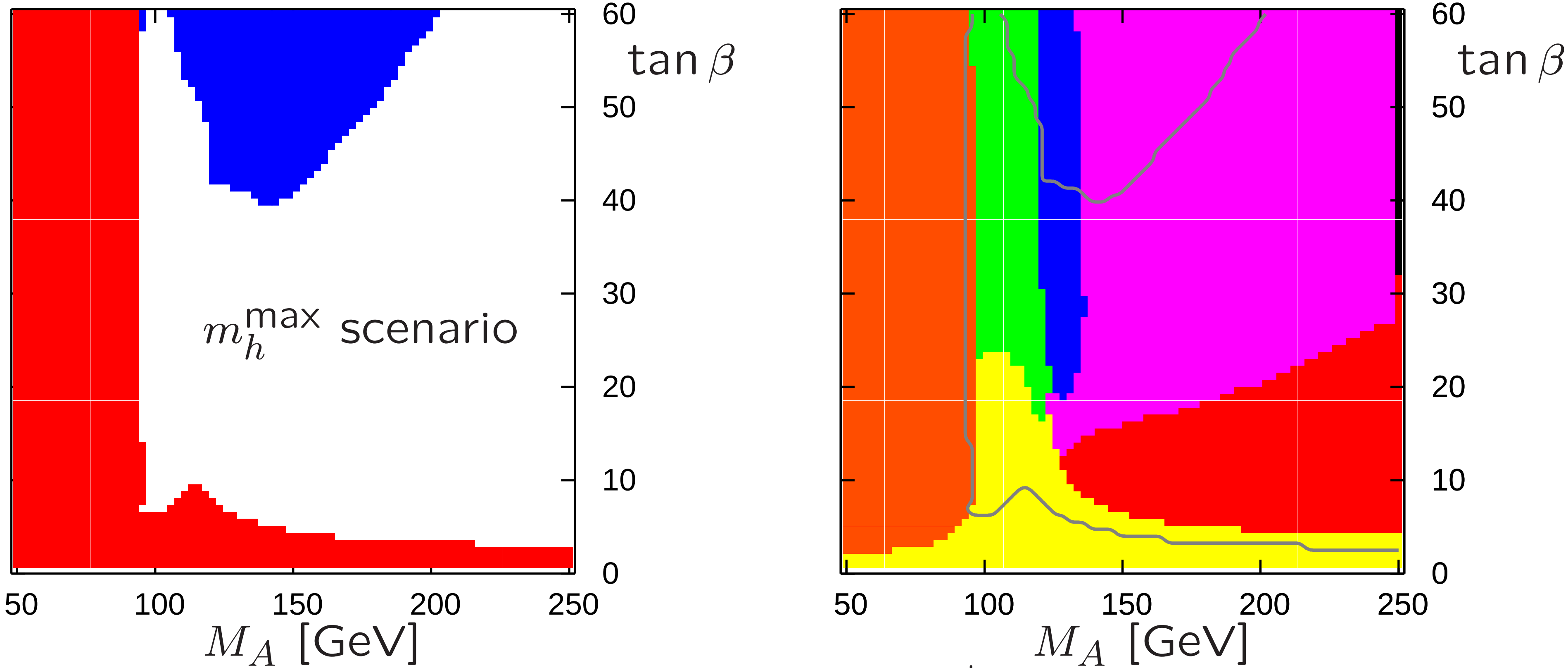
with: new m_t,
impoved m_h prediction,
Tevatron data included





application 3: MSSM benchmark scenarios, exclusion update

a) LEP and Tevatron exclusion b) highest sensitivity



■ : LEP exclusion
■ : Tevatron exclusion

■ : $e^+e^- \to hZ, h \to b\bar{b}$
■ : $e^+e^- \to hA \to b\bar{b}b\bar{b}$
■ : $p\bar{p} \to h/A \to \tau^+\tau^-$ [CDF note 9071]
■ : $p\bar{p} \to h/H/A \to \tau^+\tau^-$ [CDF note 9071]
■ : $p\bar{p} \to H/A \to \tau^+\tau^-$ [CDF note 9071]
■ : $p\bar{p} \to hW \to b\bar{b}l\nu$ [CDF note 9463]
■ : $p\bar{p} \to H/A \to \tau^+\tau^-$ [DØ'08]

summary

- The Higgs search at Tevatron and LEP turn(ed) out many limits on cross sections of individual and combined signal topologies.

- Those limits are published as figures and tables in many individual papers which don't allow for making use of all of them in a convenient way.

- HiggsBounds offers easy access to a wealth of published limits in 3 ways: command line, subroutines, web interface.

- HiggsBounds is a model-independent tool which offers a flexible range of input formats for the necessary model predictions (including the number of neutral Higgs bosons).

The code is publicly available (current verison: 1.0.3).

Please visit the web page `www.ippp.dur.ac.uk/HiggsBounds/` for downloading the package or using the web interface.

backup

LEP input (Input Option `effC`)

masses: m_{h_k} ,

total widths: $\Gamma_{\text{tot}}(h_k)$,

normalised squared effective couplings:

$$\left(\frac{g^{\text{model}}_{h_k ZZ}}{g^{\text{SM}}_{HZZ}}\right)^2 , \qquad \left(\frac{g^{\text{model}}_{h_k h_i Z}}{g^{\text{ref}}_{H'HZ}}\right)^2 , \qquad \left(\frac{g^{\text{model}}_{h_k f\bar{f},\text{eff}}}{g^{\text{SM}}_{Hf\bar{f}}}\right)^2 ,$$

branching ratios: $\text{BR}_{\text{model}}(h_k \to h_i h_i)$,

for $k, i \in \{1, \ldots, n_{\text{Higgs}}\}$ and $f \in \{b, \tau\}$.

Relation to Input Option `part/hadr` quantities:

$$\frac{\sigma_{\text{model}}(e^+e^- \to h_k Z)}{\sigma_{\text{ref}}(e^+e^- \to HZ)} = \left(\frac{g^{\text{model}}_{h_k ZZ}}{g^{\text{SM}}_{HZZ}}\right)^2 , \quad \frac{\sigma_{\text{model}}(e^+e^- \to h_k h_i)}{\sigma_{\text{ref}}(e^+e^- \to h_k h_i)} = \left(\frac{g^{\text{model}}_{H'HZ}}{g^{\text{ref}}_{H'HZ}}\right)^2 ,$$

$$\text{BR}_{\text{model}}(h_k \to f\bar{f}) = \text{BR}_{\text{SM}}(H \to f\bar{f})(m_H) \left.\frac{\Gamma^{\text{SM}}_{\text{tot}}(m_H)}{\Gamma_{\text{tot}}(h_k)}\right|_{m_H = m_{h_k}} \left(\frac{g^{\text{model}}_{h_k f\bar{f},\text{eff}}}{g^{\text{SM}}_{Hf\bar{f}}}\right)^2 .$$

Evaluation of model predictions Q_{model}: similar to LEP case.

However, for the cross section input of each search channel X, ratios of hadronic cross sections are needed (Input Option `hadr`):

$$Q_{\text{model}}(X, m_H) = \frac{\sigma_{\text{model}}(X, m_H)}{\sigma_{\text{SM}}(X, m_H)} = \left(\frac{\sigma_{\text{model}}(P)}{\sigma_{\text{SM}}(P)}\right)\left(\frac{\text{BR}_{\text{model}}(H \to F)}{\text{BR}_{\text{SM}}(H \to F)}\right)$$

However, it can be rather inconvenient for the user.

The user input can also be ratios of partonic cross sections and the ratios of hadronic cross sections are calculated from it (Input Option `part`).

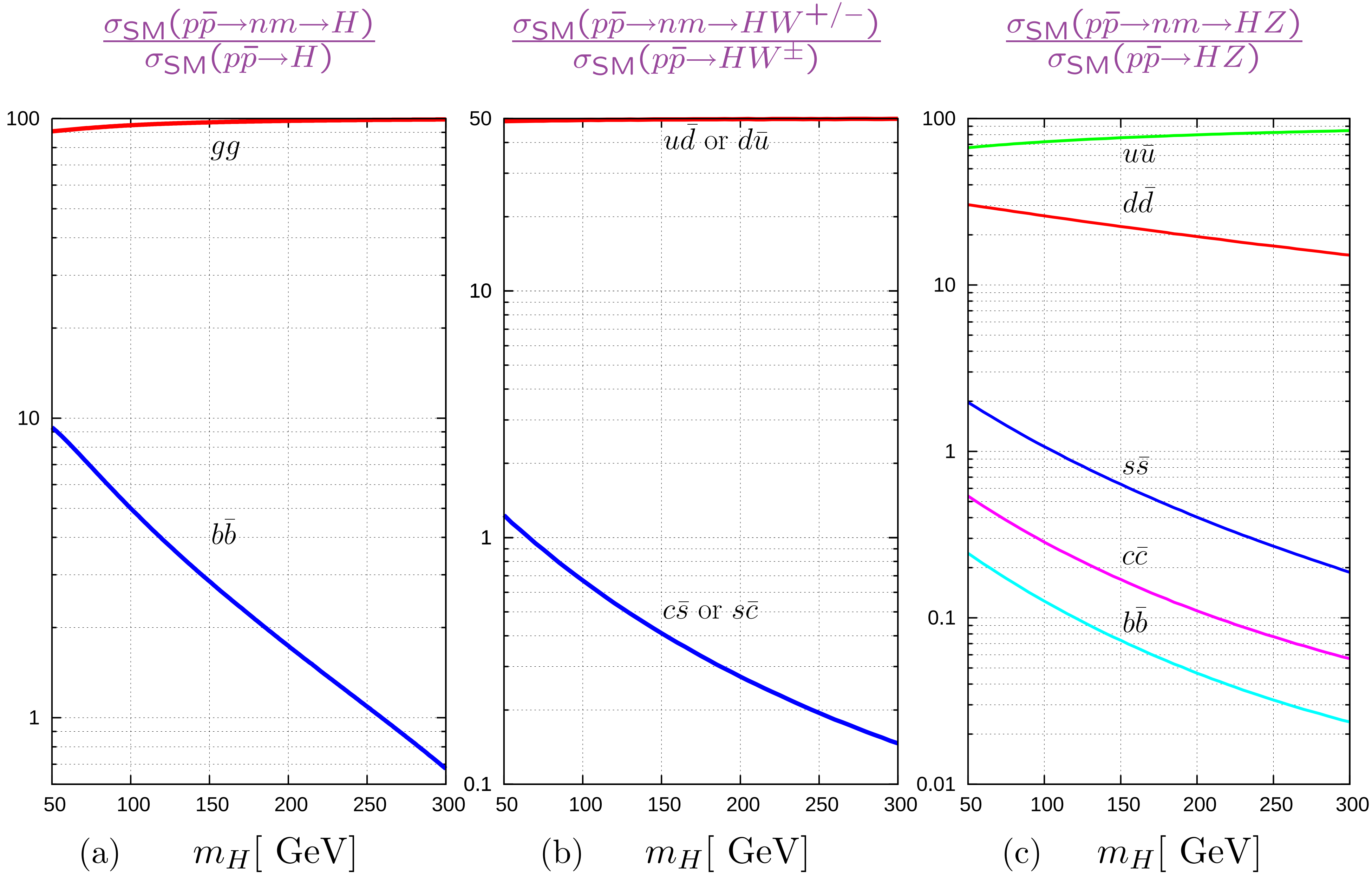
$$\left(\frac{\sigma_{\text{model}}(P)}{\sigma_{\text{SM}}(P)}\right) \approx \sum_{\{n,m\}} R_{nm}^{H+y}(\hat{s}_{\text{thr.}}, m_H) \frac{\sigma_{\text{SM}}(p\bar{p} \to nm \to H+y, m_H)}{\sigma_{\text{SM}}(p\bar{p} \to H+y, m_H)},$$

with

$$R_{nm}^{H+y}(\hat{s}, m_H) := \frac{\hat{\sigma}_{nm \to H+y}^{\text{model}}(\hat{s}, m_H)}{\hat{\sigma}_{nm \to H+y}^{\text{SM}}(\hat{s}, m_H)}.$$

These ratios can usually be expressed in terms of ratios of effective Higgs couplings (Input Option `effC`).

SM cross section fractions in % (using MRST 2006 NNLO PFDs)



Tevatron input (Input Option `hadr`)

masses: m_{h_k} ,

branching ratios:

$$\mathrm{BR}_{\mathrm{model}}(h_k \to b\bar{b}), \qquad \mathrm{BR}_{\mathrm{model}}(h_k \to \tau^+\tau^-),$$
$$\mathrm{BR}_{\mathrm{model}}(h_k \to W^+W^-), \qquad \mathrm{BR}_{\mathrm{model}}(h_k \to \gamma\gamma),$$

ratios of the hadronic cross sections:

$$\frac{\sigma_{\mathrm{model}}(p\bar{p} \to h_k Z)}{\sigma_{\mathrm{SM}}(p\bar{p} \to HZ)}, \quad \frac{\sigma_{\mathrm{model}}(p\bar{p} \to h_k W^{\pm})}{\sigma_{\mathrm{SM}}(p\bar{p} \to HW^{\pm})}, \quad \frac{\sigma_{\mathrm{model}}(p\bar{p} \to h_k \text{ via VBF})}{\sigma_{\mathrm{SM}}(p\bar{p} \to H \text{ via VBF})},$$
$$\frac{\sigma_{\mathrm{model}}(p\bar{p} \to h_k)}{\sigma_{\mathrm{SM}}(p\bar{p} \to H)}, \quad \frac{\sigma_{\mathrm{model}}(p\bar{p} \to h_k b)}{\sigma_{\mathrm{SM}}(p\bar{p} \to Hb)},$$

for $k \in \{1, \ldots, n_{\mathrm{Higgs}}\}$.

Tevatron input (Input Option `part`)

masses: m_{h_k} ,

branching ratios:

$$\text{BR}_{\text{model}}(h_k \to b\bar{b})\,, \qquad \text{BR}_{\text{model}}(h_k \to \tau^+\tau^-)\,,$$
$$\text{BR}_{\text{model}}(h_k \to W^+W^-)\,, \qquad \text{BR}_{\text{model}}(h_k \to \gamma\gamma)\,,$$

ratios of partonic cross sections ($\hat{s} = \hat{s}_{\text{threshold}}$):

$$\frac{\hat{\sigma}_{\text{model}}(gg \to h_k)}{\hat{\sigma}_{\text{SM}}(gg \to H)}\,, \qquad \frac{\hat{\sigma}_{\text{model}}(b\bar{b} \to h_k)}{\hat{\sigma}_{\text{SM}}(b\bar{b} \to H)}\,, \qquad \frac{\hat{\sigma}_{\text{model}}(bg \to h_k b)}{\hat{\sigma}_{\text{SM}}(bg \to Hb)}\,,$$
$$\frac{\hat{\sigma}_{\text{model}}(q\bar{q}' \to h_k W^+)}{\hat{\sigma}_{\text{SM}}(q\bar{q}' \to HW^+)}\,, \qquad \frac{\hat{\sigma}_{\text{model}}(q'\bar{q} \to h_k W^-)}{\hat{\sigma}_{\text{SM}}(q'\bar{q} \to HW^-)}\,, \qquad (q,q') \in \{(u,d),(c,s)\}\,,$$
$$\frac{\hat{\sigma}_{\text{model}}(q\bar{q} \to h_k Z)}{\hat{\sigma}_{\text{SM}}(q\bar{q} \to HZ)}\,, \qquad q \in \{u,d,c,s,b\}\,,$$

and the hadronic cross section ratio:

$$\frac{\sigma_{\text{model}}(p\bar{p} \to h_k \text{ via VBF})}{\sigma_{\text{SM}}(p\bar{p} \to H \text{ via VBF})}\,,$$

for $k \in \{1,\ldots,n_{\text{Higgs}}\}$.

Tevatron input (Input Option `effC`)

masses: m_{h_k} ,

total widths: $\Gamma_{\text{tot}}(h_k)$,

normalised squared effective couplings:

$$\left(\frac{g^{\text{model}}_{h_k ZZ}}{g^{\text{SM}}_{HZZ}}\right)^2, \qquad \left(\frac{g^{\text{model}}_{h_k h_i Z}}{g^{\text{ref}}_{H'HZ}}\right)^2, \qquad \left(\frac{g^{\text{model}}_{h_k f\bar{f},\text{eff}}}{g^{\text{SM}}_{Hf\bar{f}}}\right)^2,$$

$$\left(\frac{g^{\text{model}}_{h_k gg}}{g^{\text{SM}}_{Hgg}}\right)^2, \qquad \left(\frac{g^{\text{model}}_{h_k \gamma\gamma}}{g^{\text{ref}}_{H\gamma\gamma}}\right)^2, \qquad \left(\frac{g^{\text{model}}_{h_k W^+W^-}}{g^{\text{SM}}_{HW^+W^-}}\right)^2,$$

for $k \in \{1, \ldots, n_{\text{Higgs}}\}$ and $f \in \{b, \tau\}$.

From this input, all quantities required in Input Option `part` can be calculated in the effective coupling approximation.