Randall-Sundrum scalar sector constrained by LEP & Tevatron results

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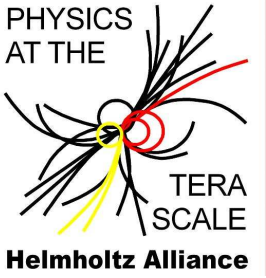


outline :

- Randall Sundrum model
- LEP & Tevatron constraints on RS scalar sector
- HiggsBounds 2.0.0

- Randall Sundrum model

– model

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 are $\mathcal{O}(M_{\rm Pl})$ with $kr_c \approx 12$.
  This "little hierarchy" can be generated & stabilized [Goldberger, Wise '00]

- 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!]

– 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_{ind}: 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

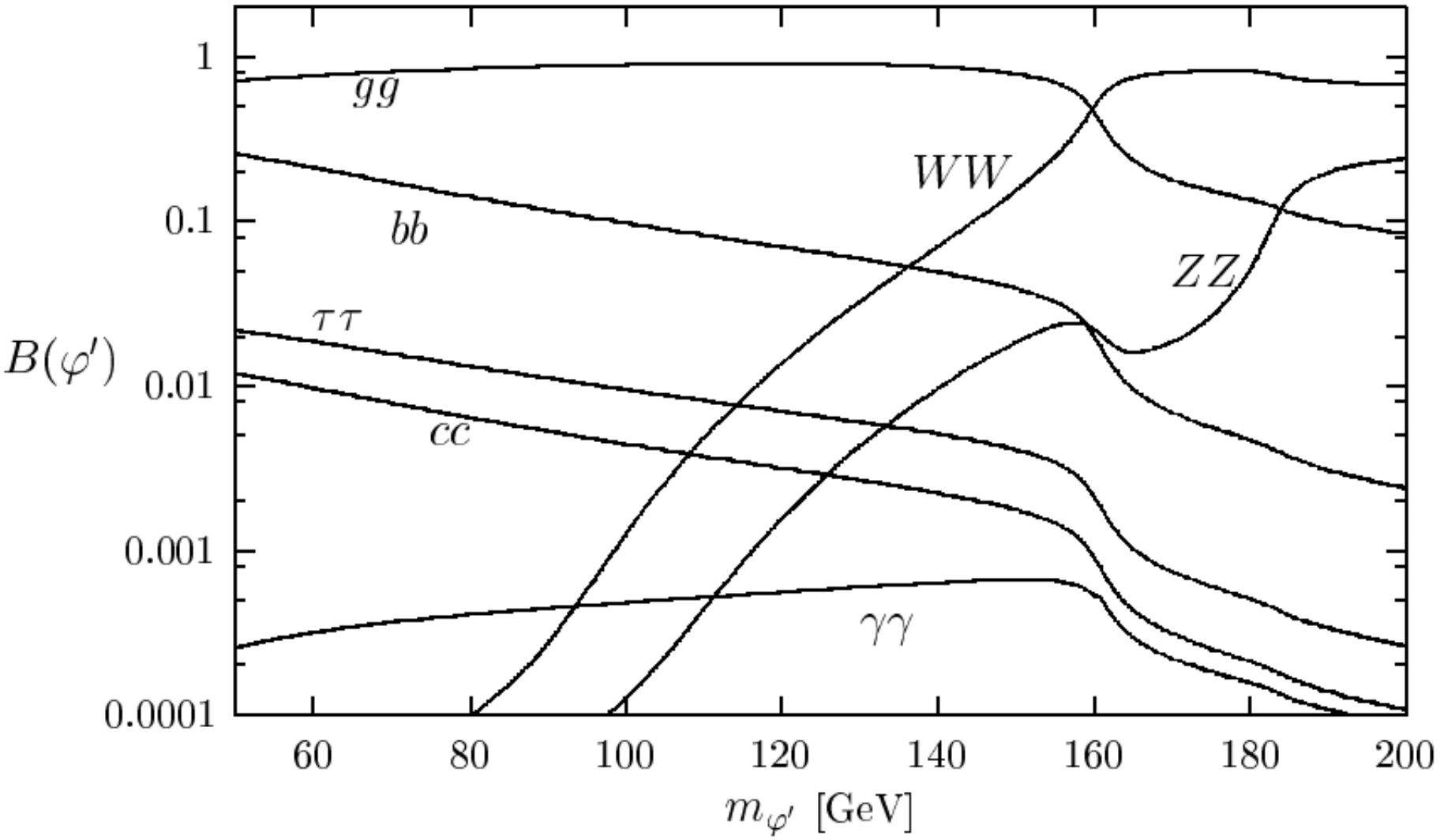
⋆ $\varphi\, \gamma\gamma$ coupling suppressed wrt SM Higgs

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

[Randall Sundrum model, scalar sector]

[Giudice, Rattazzi, Wells '00]

Radion branching ratios, no Higgs-mixing ($\xi = 0$), $\langle\varphi\rangle = 10$ TeV

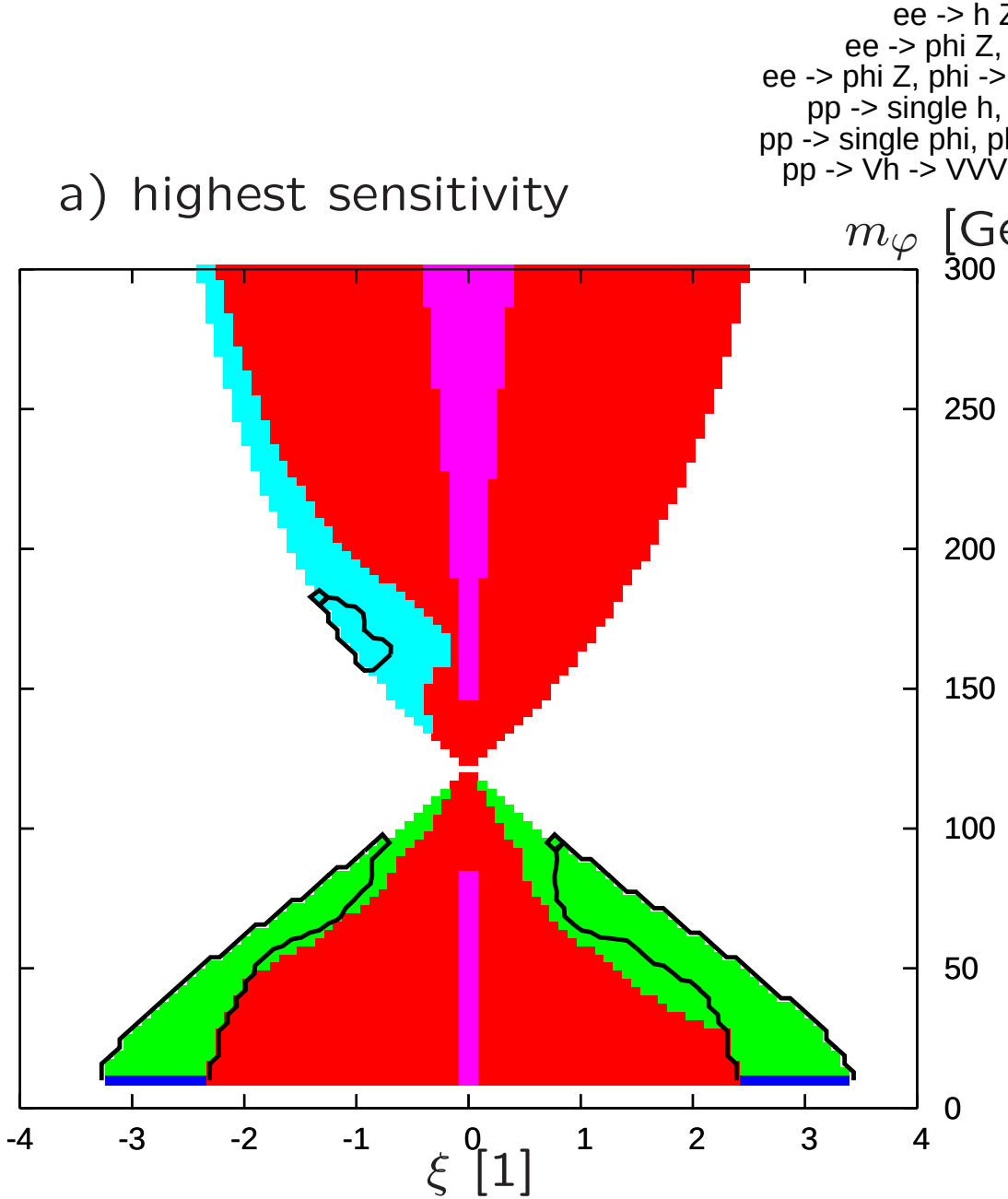


- LEP & Tevatron constraints on RS scalar sector

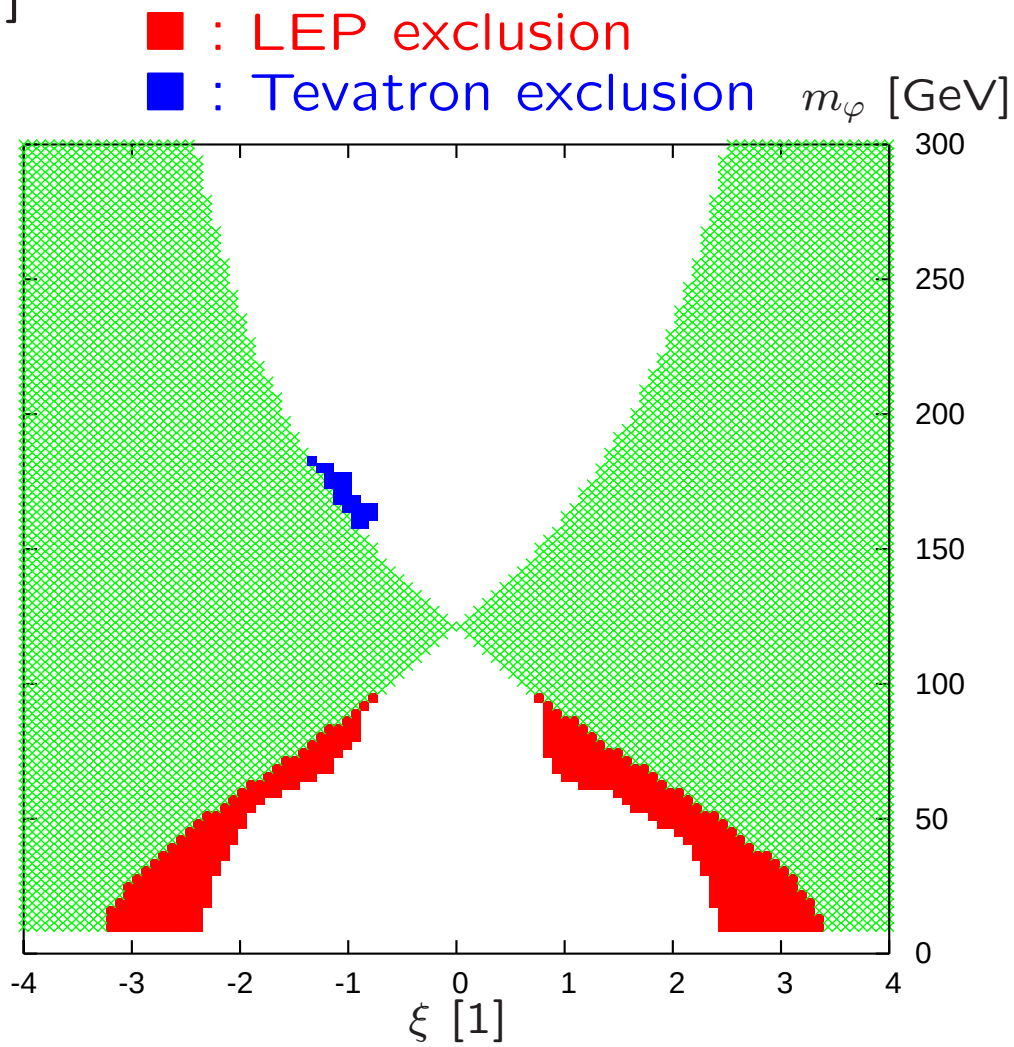
Exclusion range and sensitivity map: $\xi - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 5$ TeV
$m_h = 120$ GeV

a) highest sensitivity



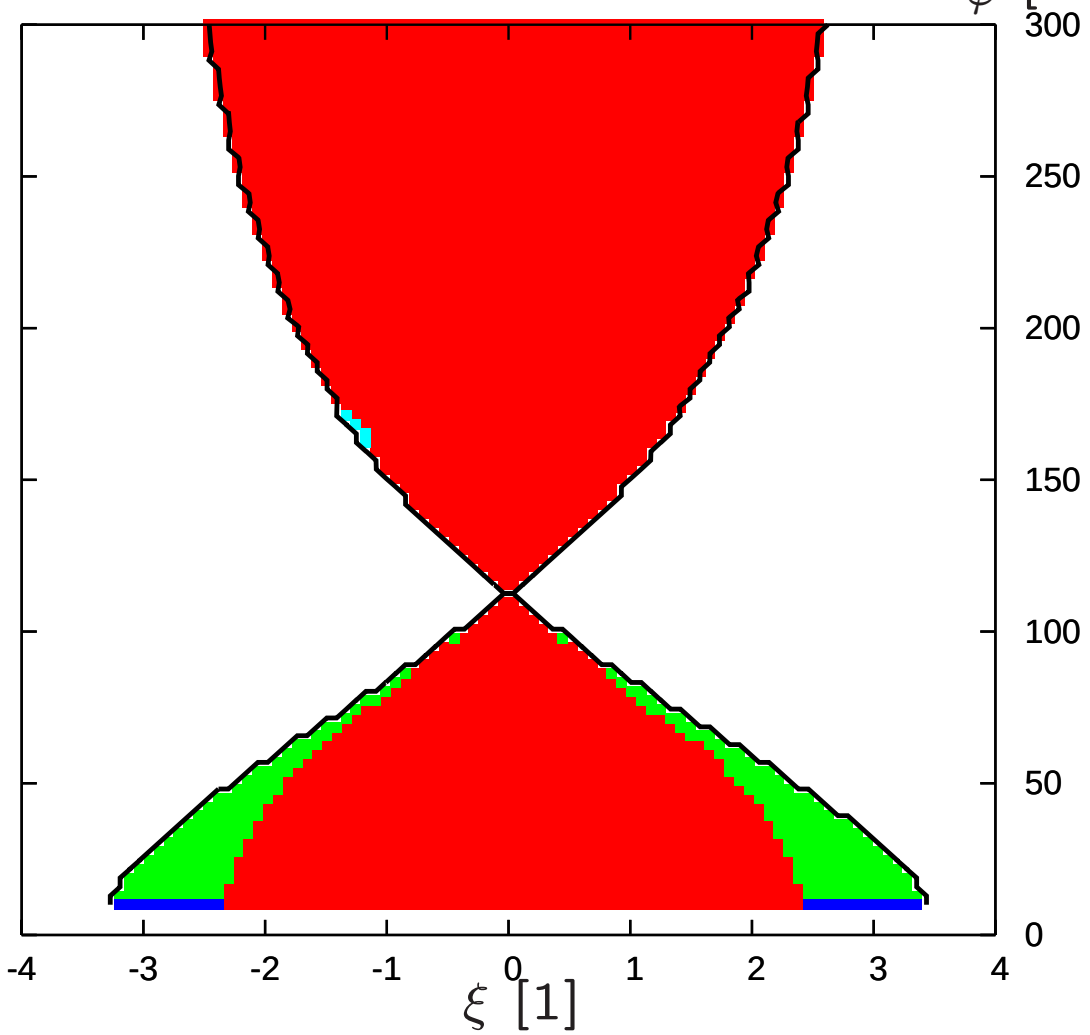
b) exclusion



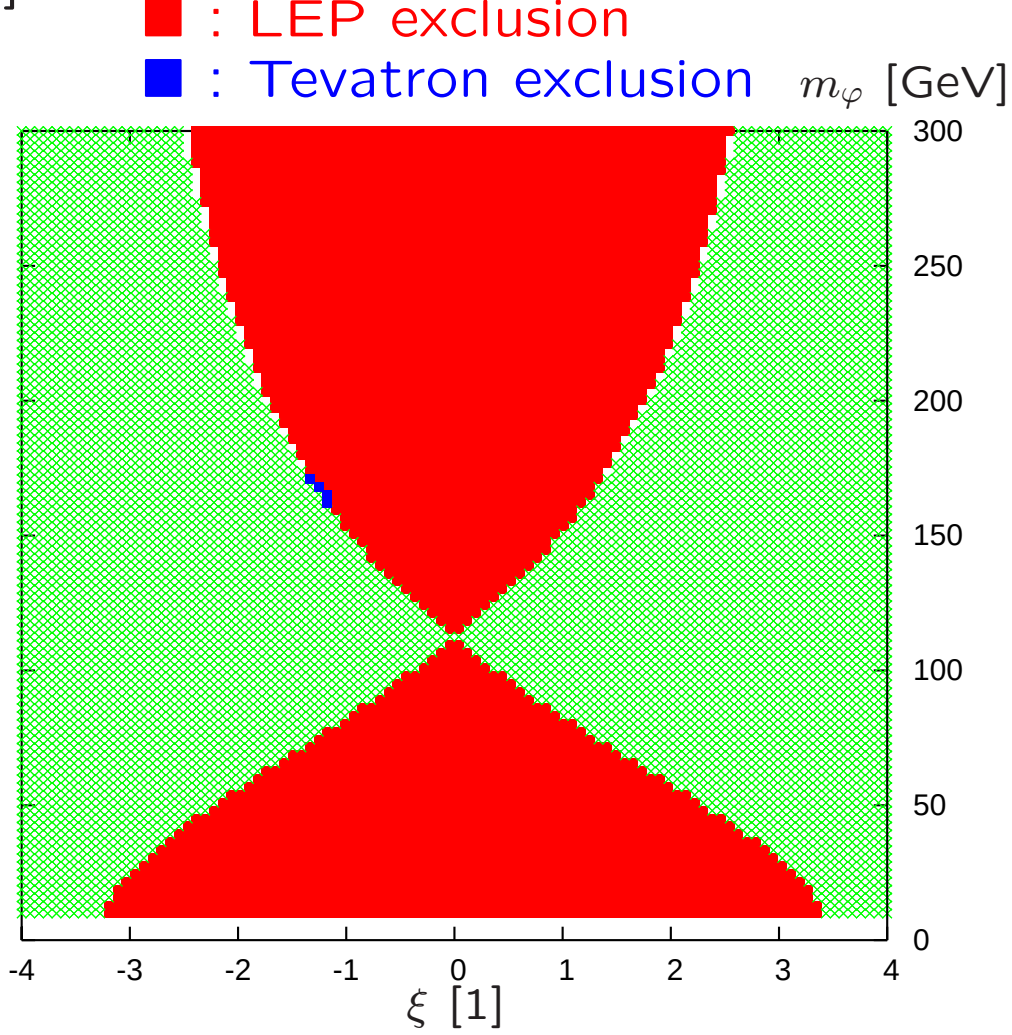
Exclusion range and sensitivity map: $\xi - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 5$ TeV
$m_h = 112$ GeV

a) highest sensitivity



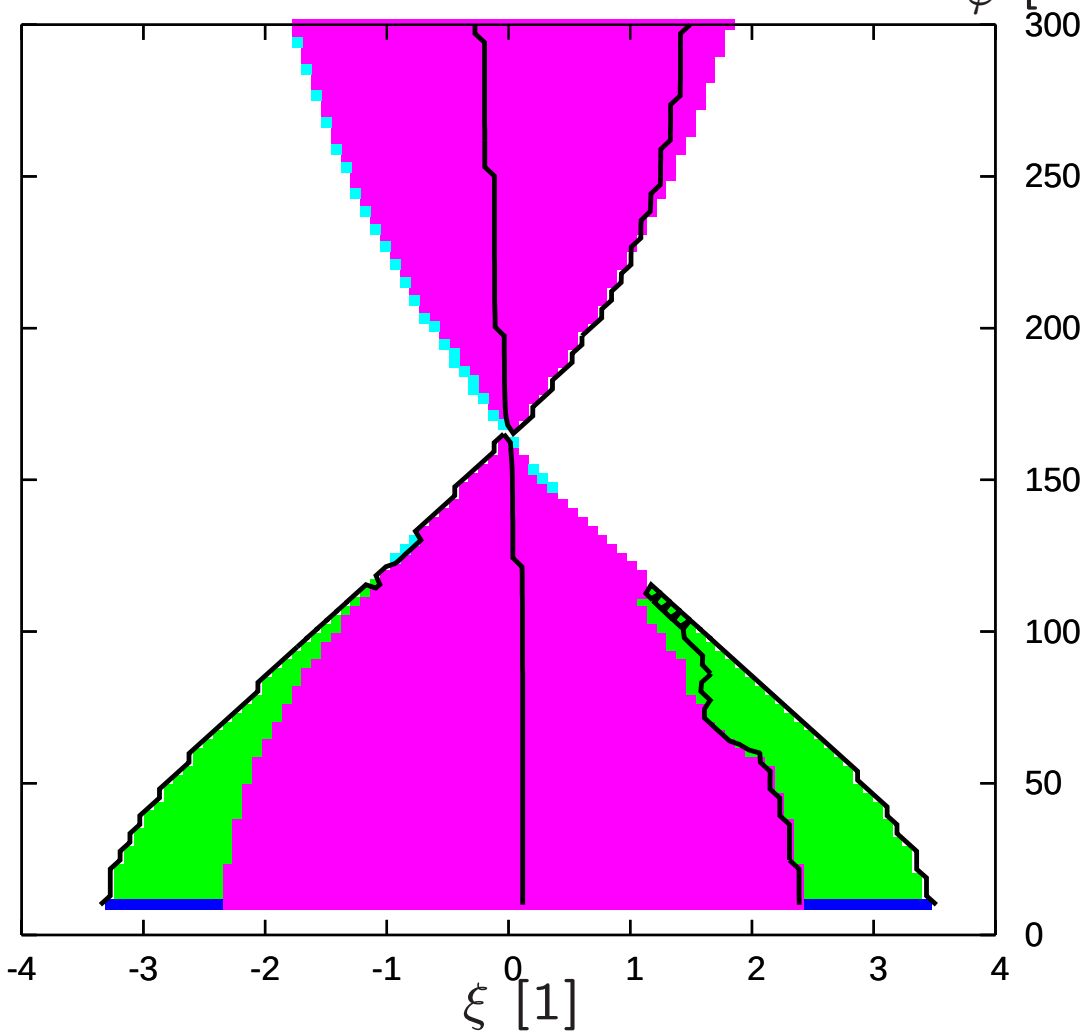
b) exclusion



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

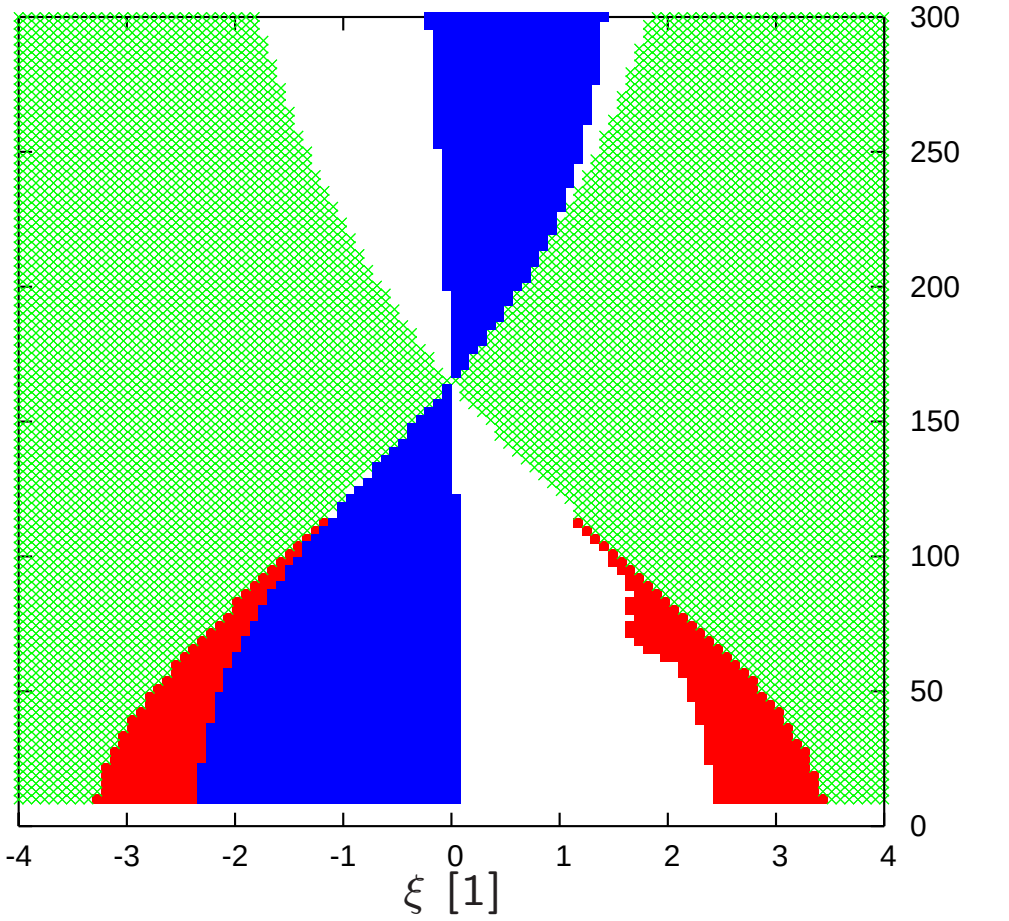
parameter:
$\Lambda_\varphi = 5$ TeV
$m_h = 165$ GeV

a) highest sensitivity



b) exclusion

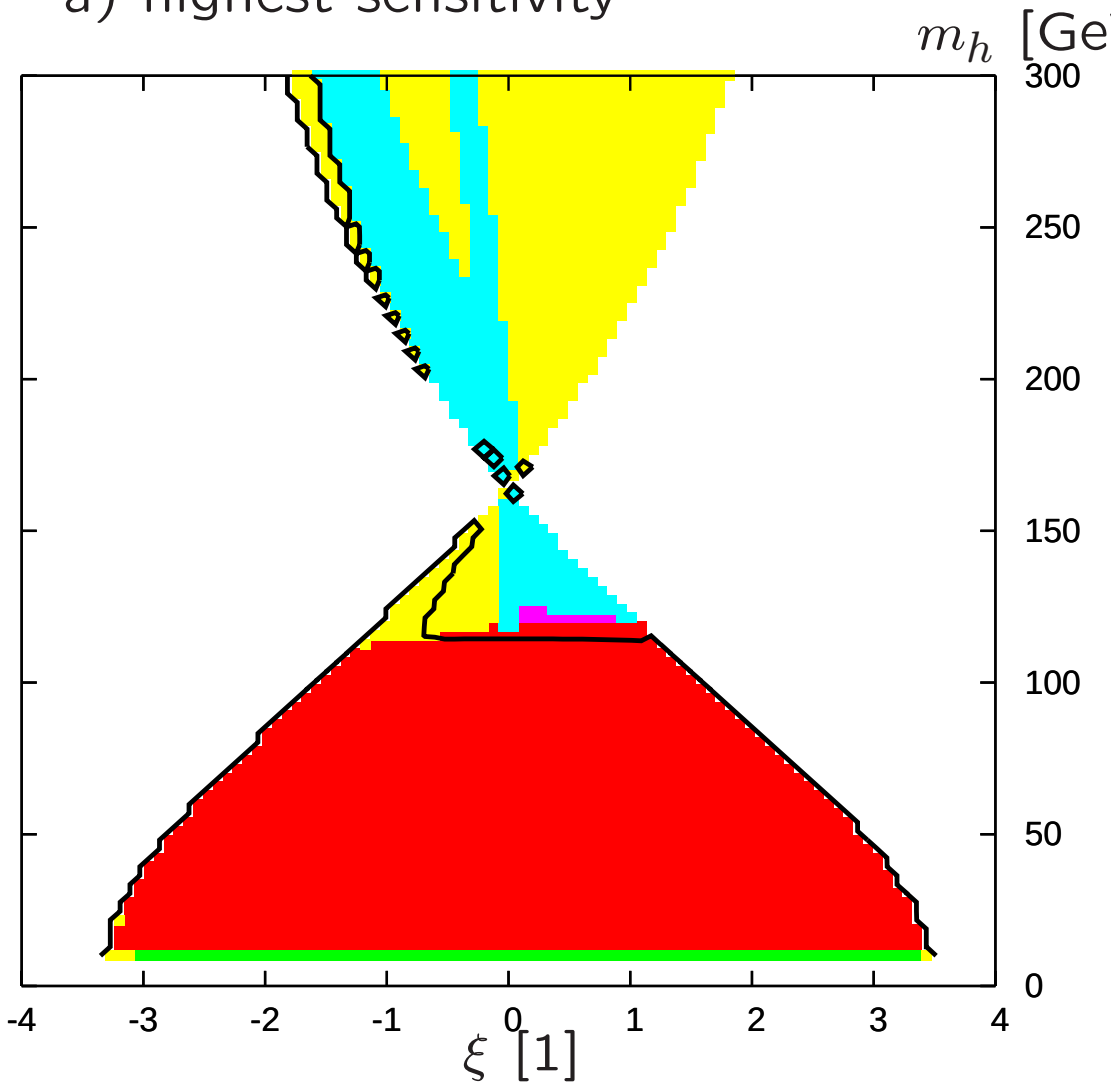
■ : LEP exclusion
■ : Tevatron exclusion



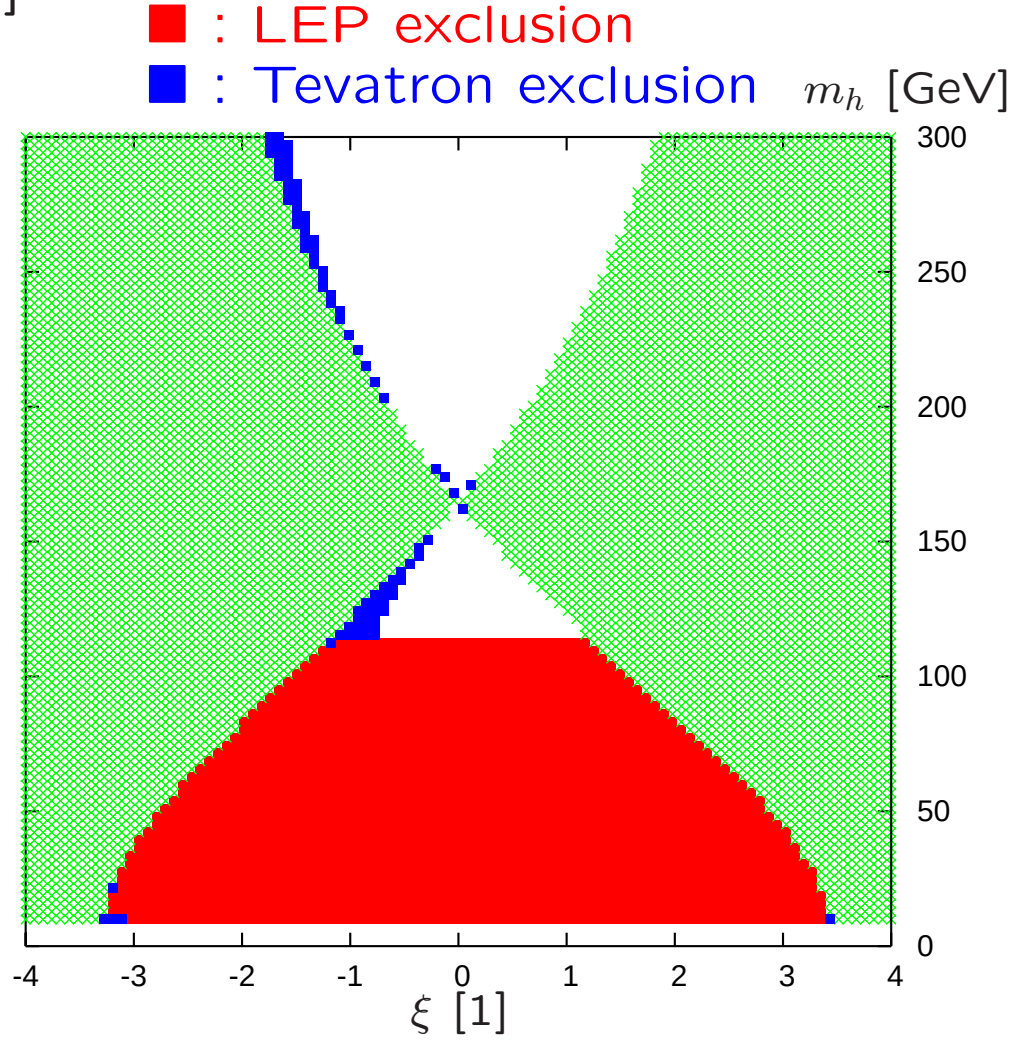
Exclusion range and sensitivity map: $\xi - m_h$ plane

parameter:
$\Lambda_\varphi = 5$ TeV
$m_\varphi = 165$ GeV

a) highest sensitivity



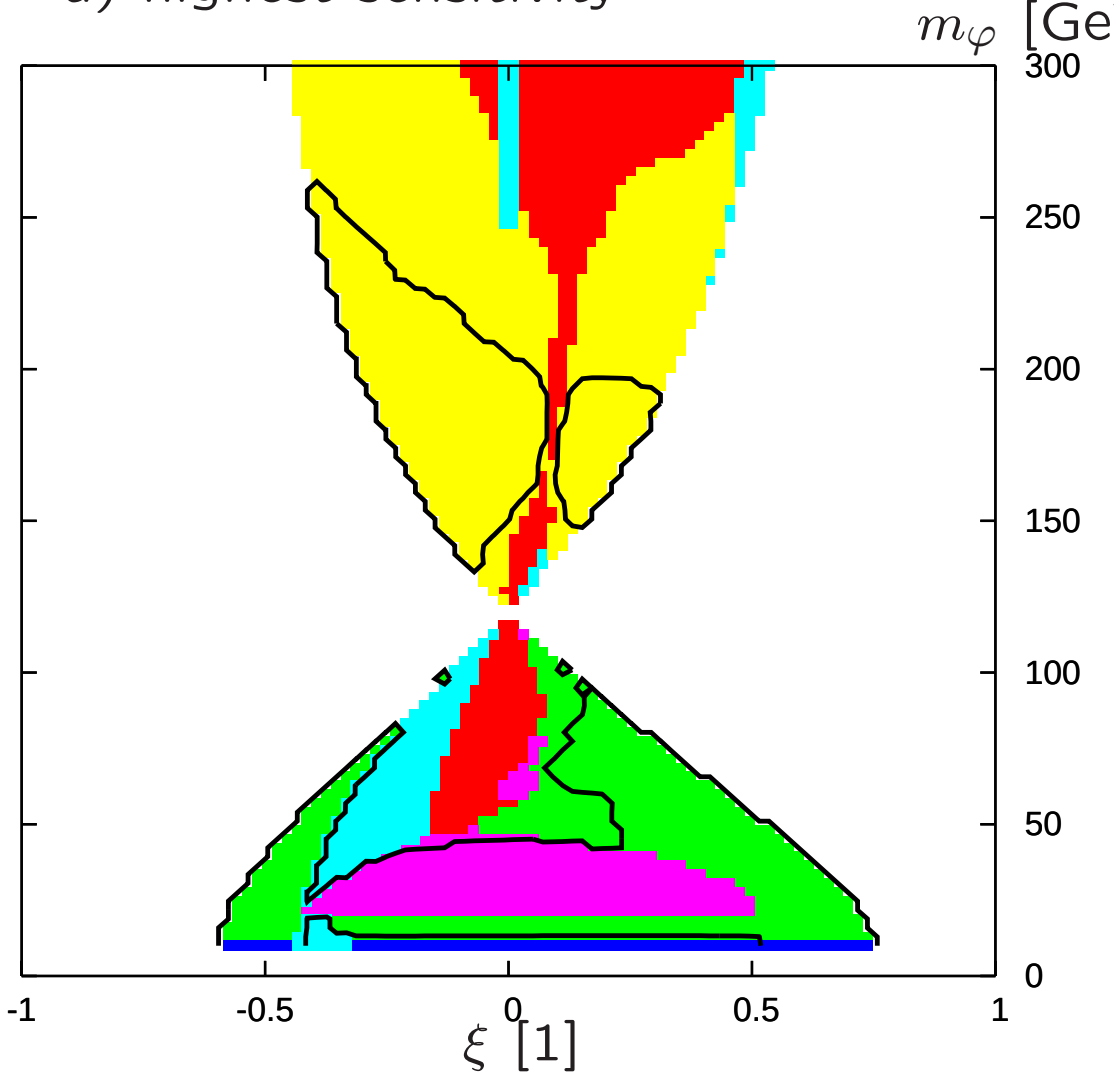
b) exclusion



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

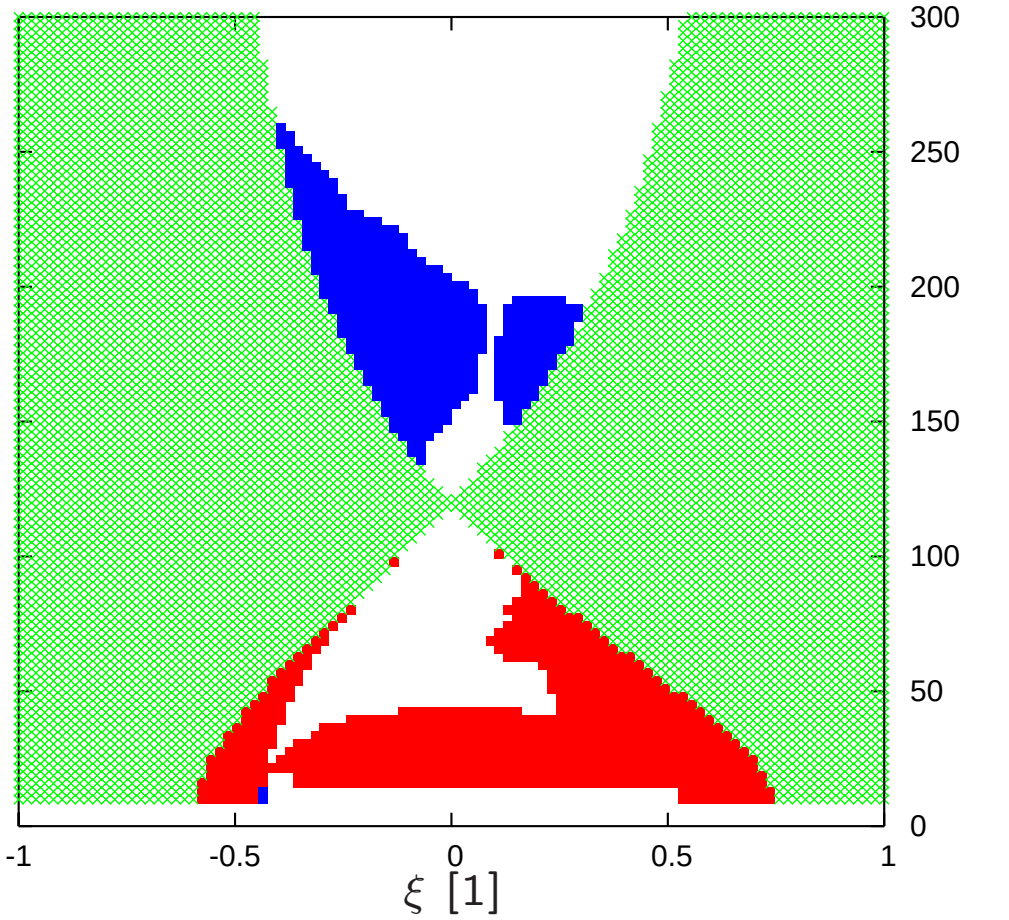
parameter:
$\Lambda_\varphi = 1$ TeV
$m_h = 120$ GeV

a) highest sensitivity



b) exclusion

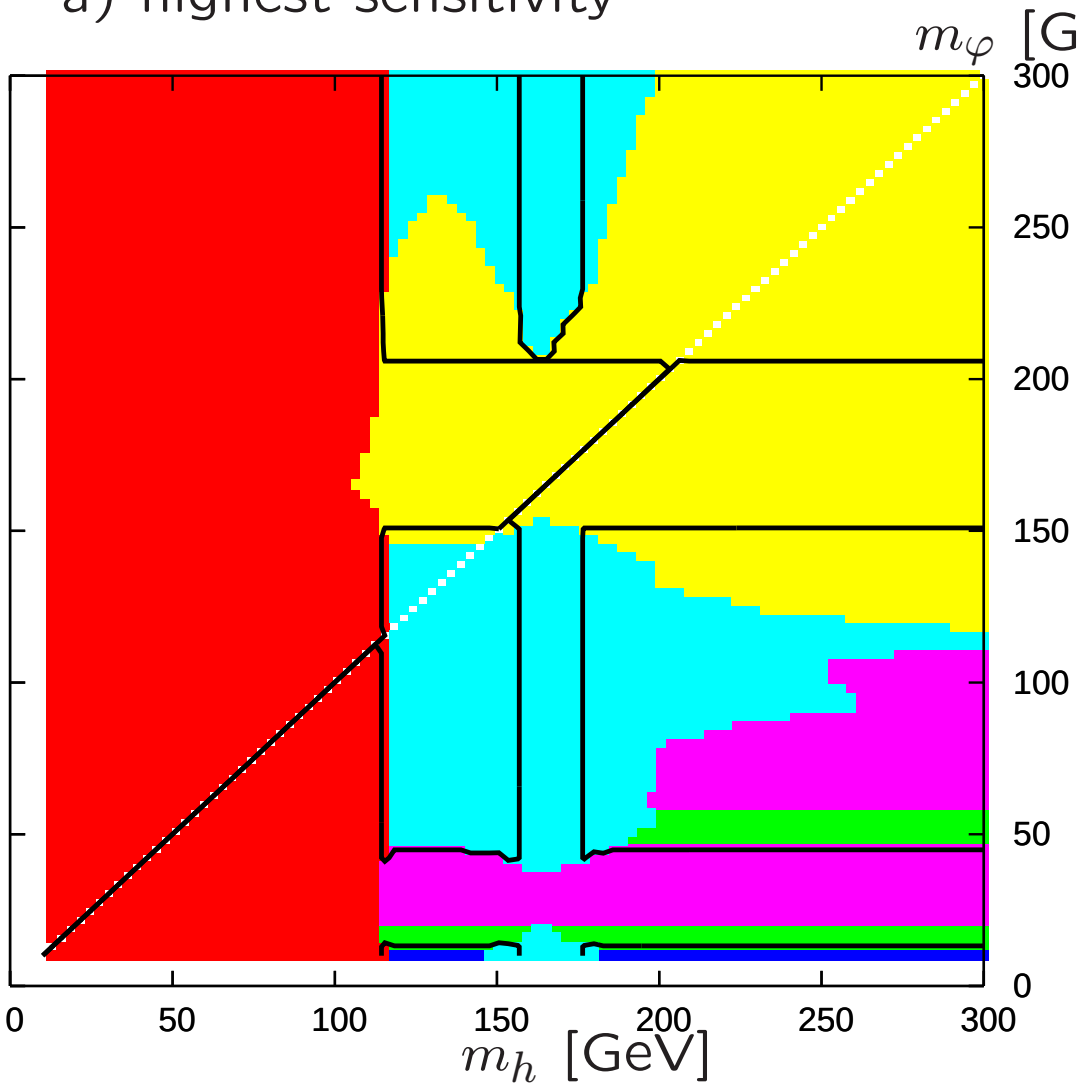
■ : LEP exclusion
■ : Tevatron exclusion



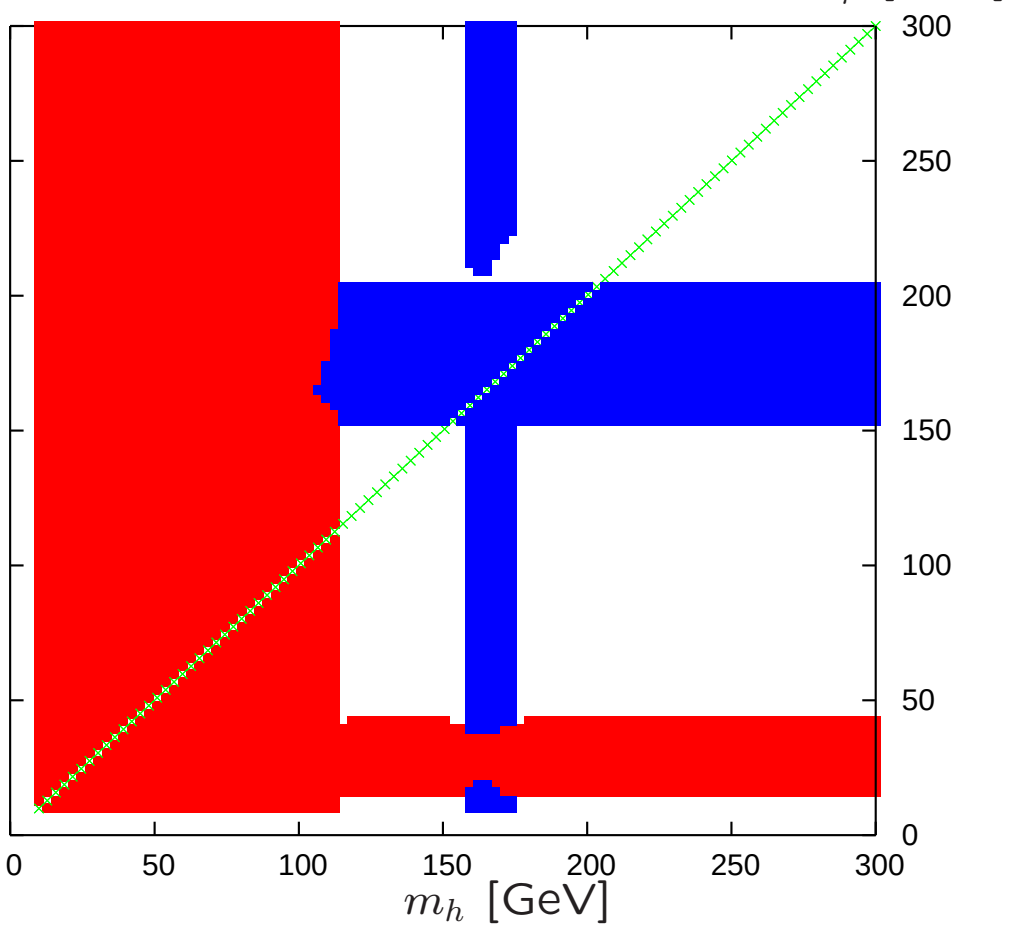
Exclusion range and sensitivity map: $m_h - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 1$ TeV
$\xi = 0$

a) highest sensitivity



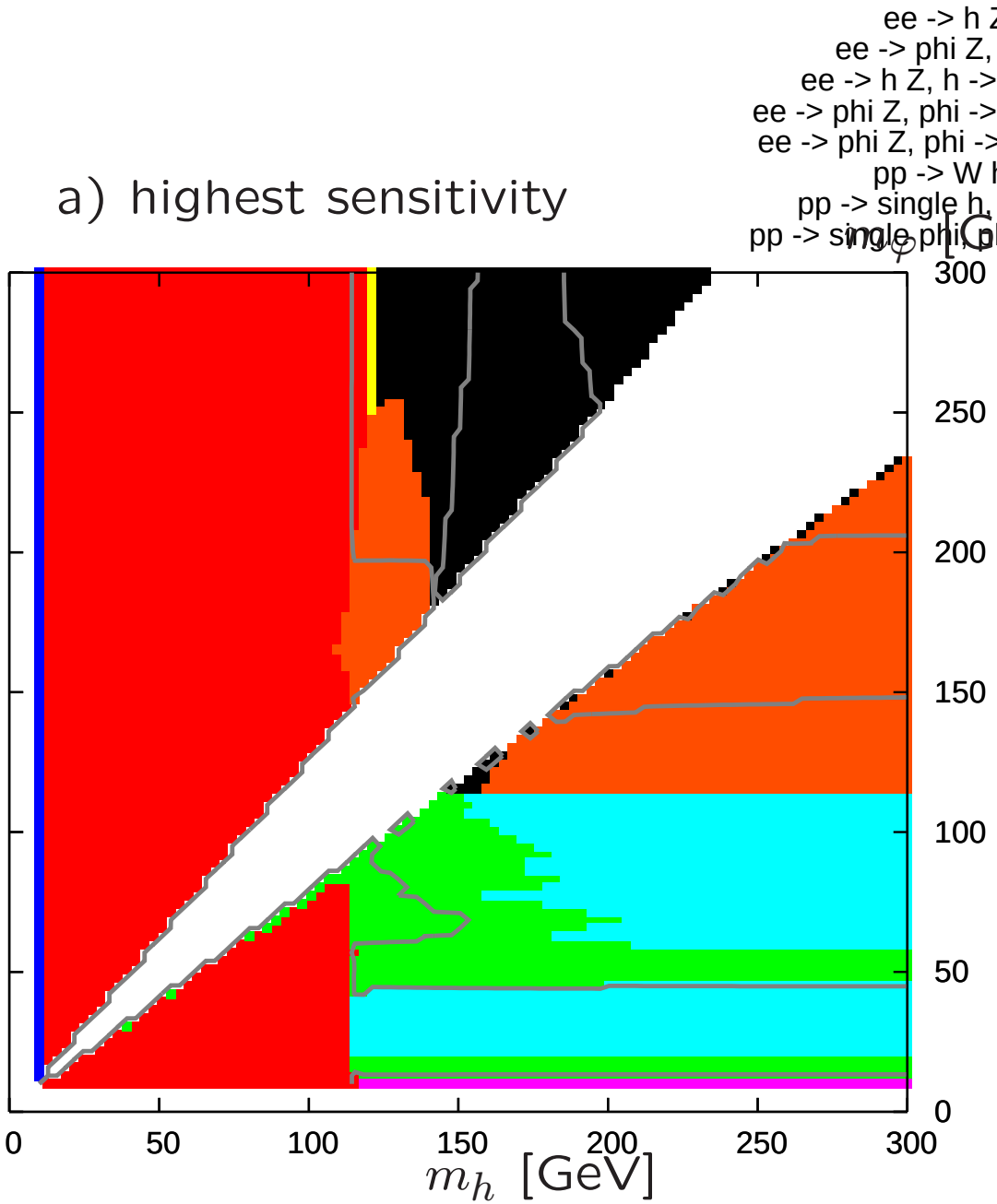
b) exclusion



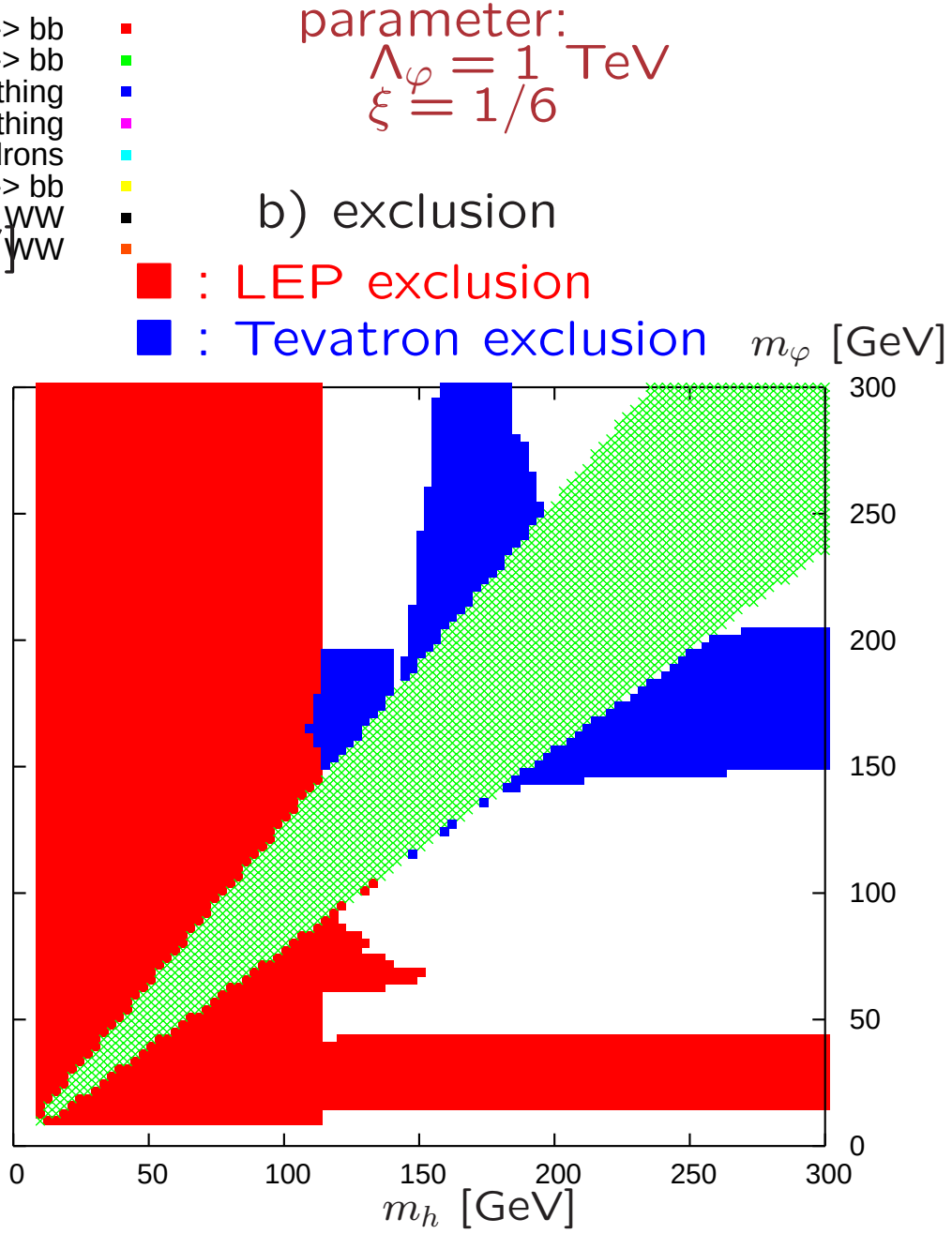
Exclusion range and sensitivity map: $m_h - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 1$ TeV
$\xi = 1/6$

a) highest sensitivity



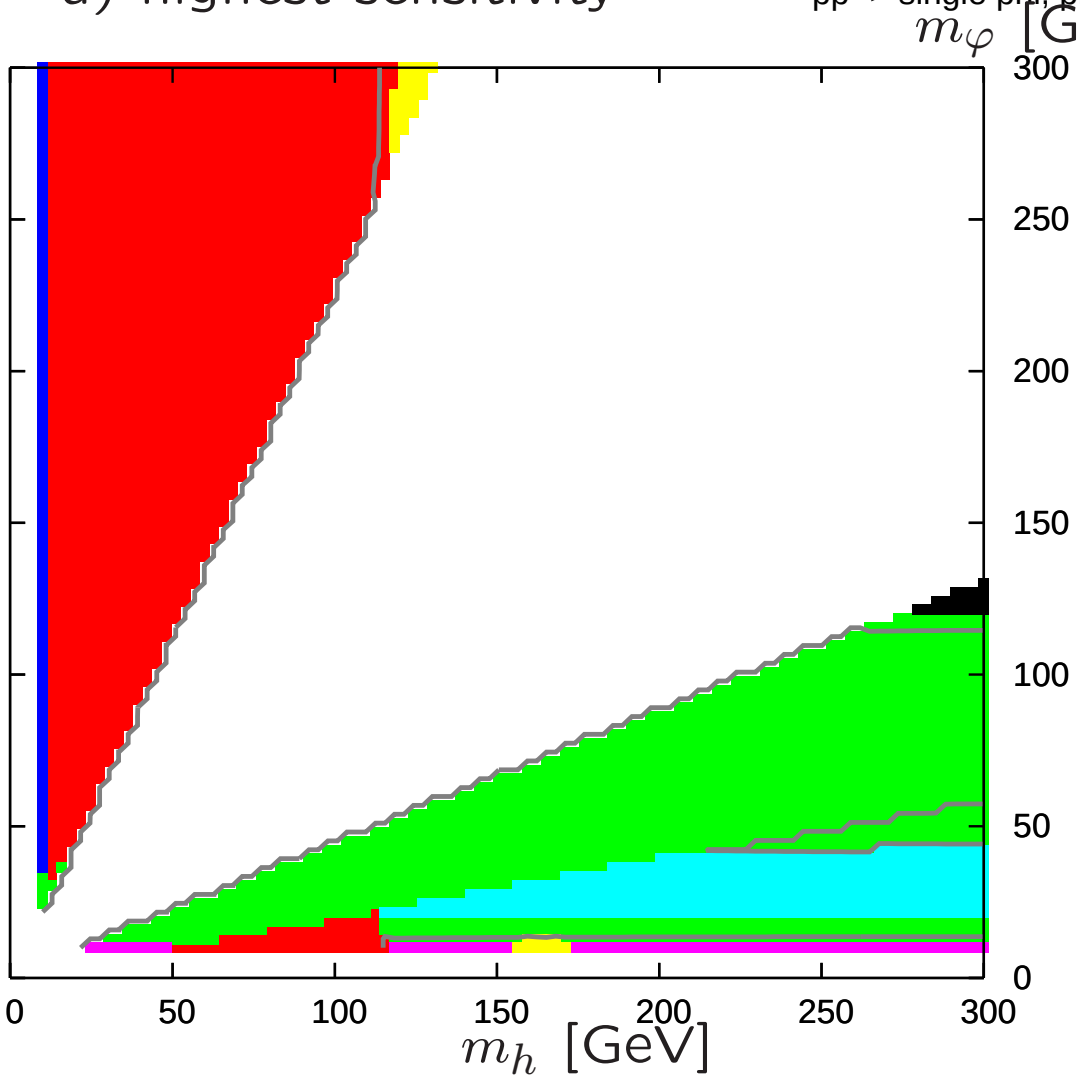
b) exclusion



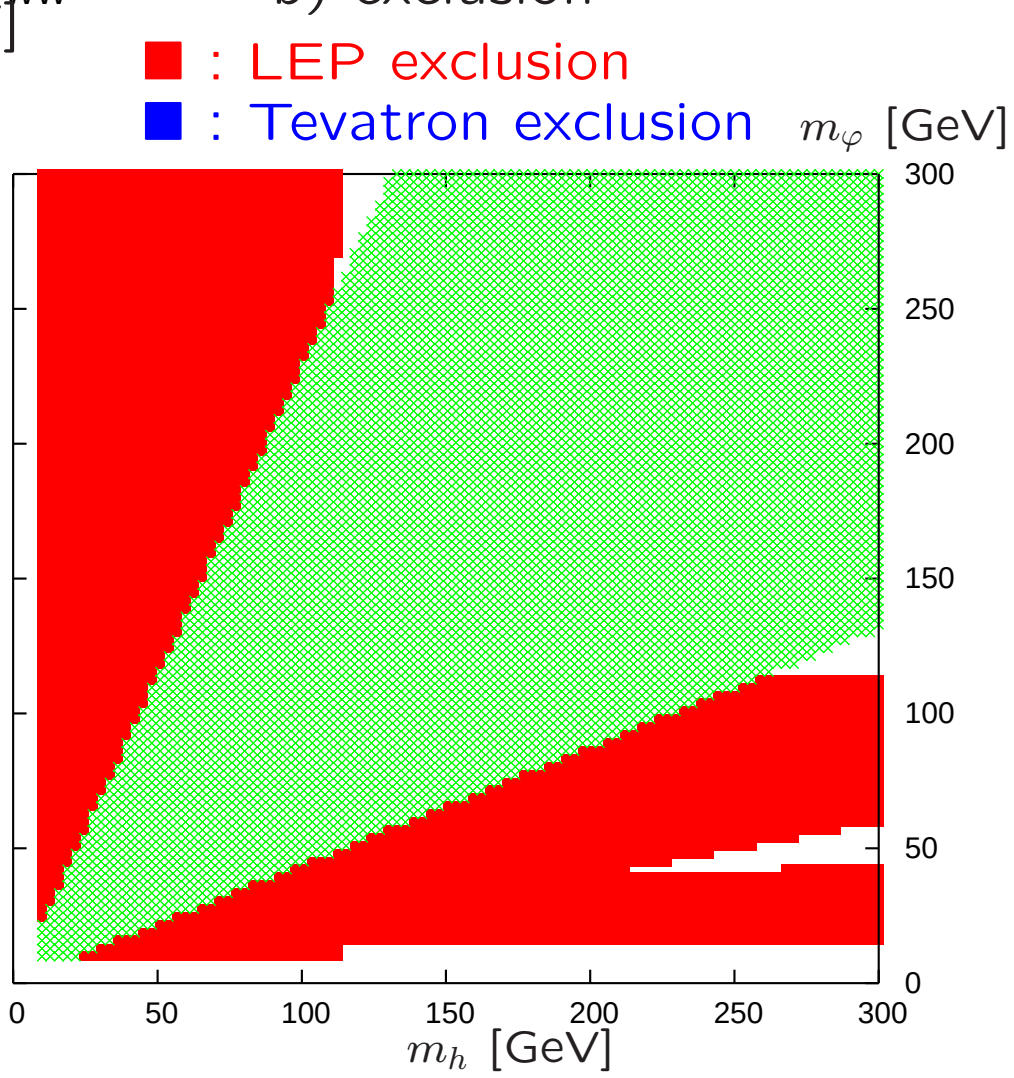
Exclusion range and sensitivity map: $m_h - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 1$ TeV
$\xi = 1/2$

a) highest sensitivity



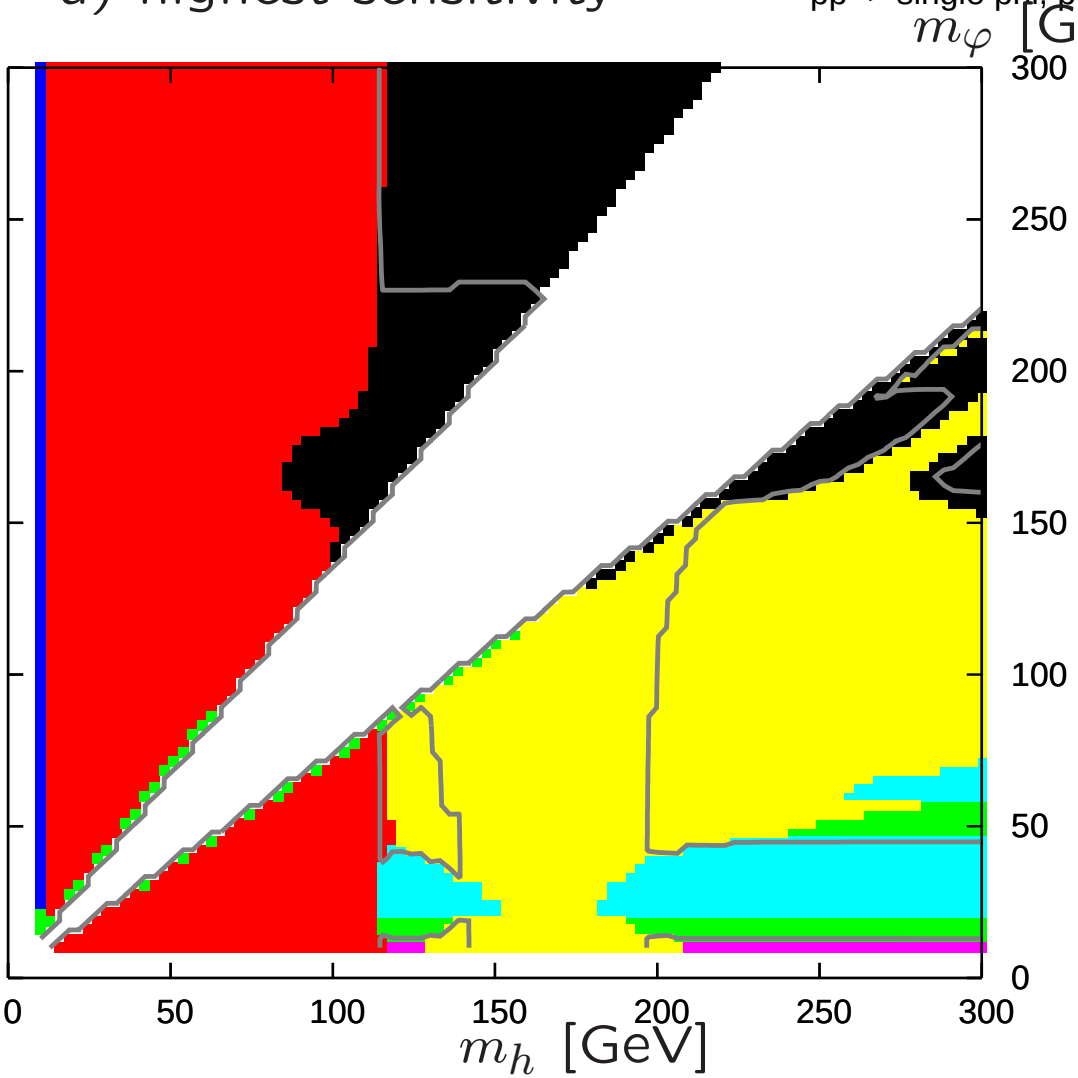
b) exclusion



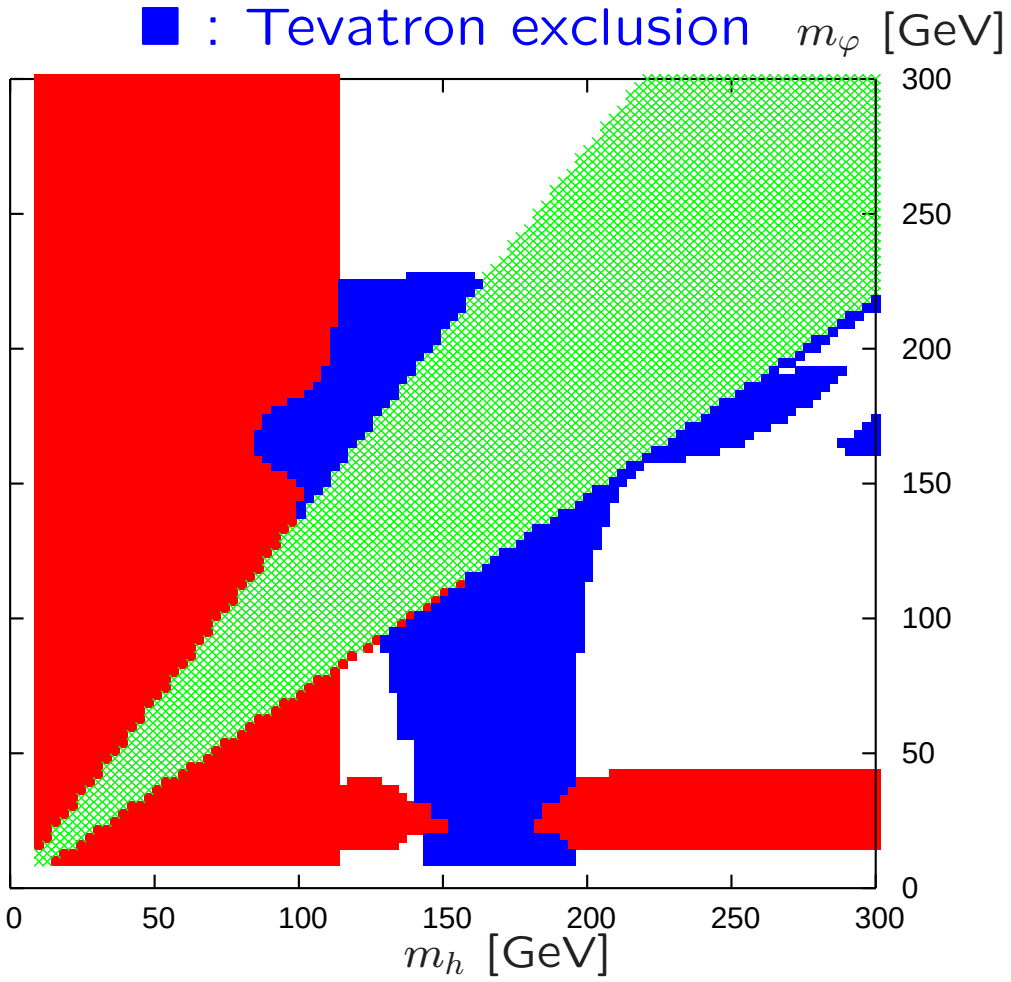
Exclusion range and sensitivity map: $m_h - m_\varphi$ plane

parameter:
$\Lambda_\varphi = 1$ TeV
$\xi = -0.2$

a) highest sensitivity



b) exclusion



- HiggsBounds 2.0.0

– the program

[Bechtle, OBr, Heinemeyer, Weiglein, Williams '08]

HiggsBounds : tests models with arbitrary Higgs sectors against exclusion bounds from LEP/Tevatron Higgs searches.

- 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 (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 and Tevatron possible

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

  www.ippp.dur.ac.uk/HiggsBounds

– implemented analyses

⋆ neutral Higgs, LEP [HiggsBounds 2.0.0]

$e^+e^- \to h_k Z, h_k \to bb$ or $h_k \to \tau\tau$ [LEP, EPJC46(2006)547)]

$e^+e^- \to h_k Z, h_k \to$ anything [OPAL, EPJC 27(2003)311]

$e^+e^- \to h_k Z, h_k \to$ invisible [hep-ex/0107032], DELPHI [hep-ex/0401022]
L3 [hep-ex/0501033], OPAL [hep-ex/0707.0373]

$e^+e^- \to h_k Z, h_k \to \gamma\gamma$ [LEP, LHWG note 2002-02]

$e^+e^- \to h_k Z, h_k \to$ hadrons [LEP combined limit]

$e^+e^- \to b\bar{b}h_k \to b\bar{b}b\bar{b}$, h_k CP even or odd, DELPHI [hep-ex/0410017]

$e^+e^- \to b\bar{b}h_k \to b\bar{b}\tau\tau$, h_k CP even or odd, DELPHI [hep-ex/0410017], OPAL [hep-ex/0111010]

$e^+e^- \to \tau\tau h_k \to \tau\tau\tau\tau$, h_k CP even or odd, DELPHI [hep-ex/0410017]

$e^+e^- \to h_k Z, h_k \to h_i h_i, h_i \to bb$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k Z, h_k \to h_i h_i, h_i \to \tau\tau$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k h_i, h_k, h_i \to bb$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k h_i, h_k, h_i \to \tau\tau$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k h_i, h_k \to h_i h_i, h_i \to bb$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k h_i, h_k \to h_i h_i, h_i \to \tau\tau$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k Z, h_k \to h_i h_i, h_i \to bb, \tau\tau$ [LEP, EPJC 46(2006)547]

$e^+e^- \to h_k h_i, h_k \to bb, h_i \to \tau\tau$ [LEP, EPJC 46(2006)547]

⋆ neutral Higgs, Tevatron, single topology [HiggsBounds 2.0.0]

$p\bar{p} \to Zh_k \to llb\bar{b}$, CDF with 5.7 fb^{-1} [CDF note 10235] and with 2.7 fb^{-1} [hep-ex/0908.3534]

$p\bar{p} \to Zh_k \to llb\bar{b}$, D0 with 6.2 fb^{-1} [D0 note 6089]

$p\bar{p} \to Wh_k \to l\nu b\bar{b}$, D0 with 5.3 fb^{-1} [D0 note 6092] and with 1.1 fb^{-1} [hep-ex/0808.1970],
CDF with 5.6 fb^{-1} [CDF note 10217] and with 2.7 fb^{-1} [hep-ex/0906.5613]

$p\bar{p} \to bh_k \to 3b$ jets, CDF with 2.5 fb^{-1} [CDF note 10105],
D0 with 2.6 fb^{-1} [D0 note 5726] and with 1 fb^{-1}[hep-ex/0805.3556]

$p\bar{p} \to$ single $h_k \to WW$,
CDF with 3.0 fb^{-1} [hep-ex/0809.3930], CDF & D0 with 4.8/5.4 fb^{-1} [hep-ex/1005.3216]

$p\bar{p} \to h_k \to \tau\tau$ absolute limits,
D0 with 1 fb^{-1} [hep-ex/0805.2491] and with 2.2 fb^{-1} [D0 note 5740],
CDF with 1.8 fb^{-1} [hep-ex/0906.1014],
CDF & D0 with up to 2.2 fb^{-1} [hep-ex/1003.3363]

$p\bar{p} \to Wh_k \to 3W$, D0 with 3.6 fb^{-1} [D0 note 5873], CDF with 2.7 fb^{-1} [CDF note 7307v3]

$p\bar{p} \to bh_k \to b\tau\tau$,
D0 with 2.7 fb^{-1} [hep-ex/0912.0968, D0 note 5985] and with 4.3 fb^{-1} [D0 note 6083]

$p\bar{p} \to t\bar{t}h_k \to t\bar{t}b\bar{b}$, D0 with 2.1 fb^{-1} [D0 note 5739]

$p\bar{p} \to h_k \to Z\gamma$, D0 with 1.0 fb^{-1} absolute limits [hep-ex/0806.0611]

⋆ neutral Higgs, Tevatron, combined topologies I [HiggsBounds 2.0.0]

$p\bar{p} \to V h_k \to b\bar{b}$+miss. $E_T(V = W, Z)$ SM combined,

CDF with 5.7 fb^{-1} [CDF note 10212] and with 2.1 fb^{-1} [hep-ex/0911.3935],

D0 with 6.4 fb^{-1} [D0 note 6087] and with 5.2 fb^{-1} [hep-ex/0912.5285]

$p\bar{p} \to h_k + X \to WW + X$ SM combined,

CDF with 5.3 fb^{-1} [CDF note 10102] and with 4.8 fb^{-1} [hep-ex/1001.4468],

D0 with 4.2 fb^{-1} [D0 note 5871] and with 6.7 fb^{-1} [D0 note 6082],

D0 with 5.4 fb^{-1} [hep-ex/1001.4481], CDF & D0 with 4.8-5.4 fb^{-1} [hep-ex/1001.4162]

$p\bar{p} \to h_k \to WW \to ll$, D0 with 3.0 fb^{-1} SM combined [D0 note 5757]

$p\bar{p} \to h_k + X$, CDF & D0 SM combined with 2-4.8 fb $^{-1}$ [hep-ex/0712.2383]

$p\bar{p} \to h_k + X \to \tau\tau$ SM combined,

CDF with 2.0 fb^{-1} [CDF note 9248],

D0 with 4.9 fb^{-1} [D0 note 5845] and with 1.0 fb^{-1} [hep-ex/0903.4800]

$p\bar{p} \to h_k + X$ SM combined, CDF & D0 with 1-2.4 fb^{-1} [hep-ex/0804.3423]

CDF & D0 with 3 fb^{-1} [hep-ex/0808.0534], D0 with 0.44 fb^{-1} [hep-ex/0712.0598]

CDF with 2.0-4.8 fb^{-1} [CDF note 9999], D0 with 2.1-5.4 fb^{-1} [D0 note 6008],

CDF & D0 with 2.1-5.4 fb^{-1} [hep-ex/0911.3930],

CDF & D0 SM with up to 6.7 fb^{-1} [hep-ex/1007.4587]

⋆ neutral Higgs, Tevatron, combined topologies II [HiggsBounds 2.0.0]

$p\bar{p} \to h_k + X \to bb + X$, CDF with 4 fb^{-1} SM combined [CDF note 10010]

$p\bar{p} \to V h_k \to VVV \to$ same sign di-lepton(e,mu) (V=W,Z),

D0 with 6.4 fb^{-1} SM combined [D0 note 6091]

$p\bar{p} \to h_k \to \gamma\gamma$ SM combined,

D0 with 4.2 fb^{-1} [D0 note 5858] and with 2.7 fb^{-1} [hep-ex/0901.1887],

CDF with 5.4 fb^{-1} [CDF note 10065]

⋆ charged Higgs, LEP [HiggsBounds 2.0.0]

$e^+e^- \to H^+H^- \to$ 4 jets [LEP, hep-ex/0107031],

$e^+e^- \to H^+H^- \to$ 4 jets [DELPHI, hep-ex/0404012],

$e^+e^- \to H^+H^- \to \tau\nu\tau\nu$ [DELPHI, hep-ex/0404012].

⋆ charged Higgs, Tevatron [HiggsBounds 2.0.0]

$p\bar{p} \to tt, t \to H + b$(& c.c.), $H^+ \to cs$, D0 with 1.0 fb^{-1} [hep-ex/0908.1811],

CDF with 2.2 fb^{-1} [hep-ex/0907.1269]

$p\bar{p} \to tt, t \to H + b$(& c.c.), $H^+ \to \tau\nu$, D0 with 1.0 fb^{-1} published [hep-ex/0908.1811]

implemented in total: 82 analyses (29 LEP, 53 Tevatron)

– status and outlook

- The code is publicly available (current verison: 2.0.0 released July 2010)
  - all accessible results presented at ICHEP'10 included
  - extended functionality ($H^{\pm}$ searches, `onlyP` analyses selection, ...)
  - new manual available

    → www.ippp.dur.ac.uk/HiggsBounds/

- Reception very good. Code used in or by:

  FeynHiggs, CPsuperH, Fittino, MasterCode,
  2HDMC, DarkSusy, SuperIso, etc.
  S. Kraml et al., M. Carena et al., W. Bernreuther et al., etc.

- Current work/plans:
  - providing CL_{s+b} for given m_H and $\sigma \times$ BR (→ useful for model fitting)
  - inclusion of width-dependent limits
  - ...

summary

- The Randall Sundrum model is an appealing resolution of the hierarchy problem. Variants of the original model are in agreement with present observations and e.g. allow for a natural explanation of flavour.

- Among these variations, the Higgs-radion sector comprises a robust prediction of the model upon which LEP and current Tevatron search results place interesting constraints.

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

The code is publicly available (current verison: 2.0.0).

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