Bethe Center for Theoretical Physics

HiggsBounds: using results from the Higgs searches at LEP and the Tevatron to constrain extensions to the Standard Model

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

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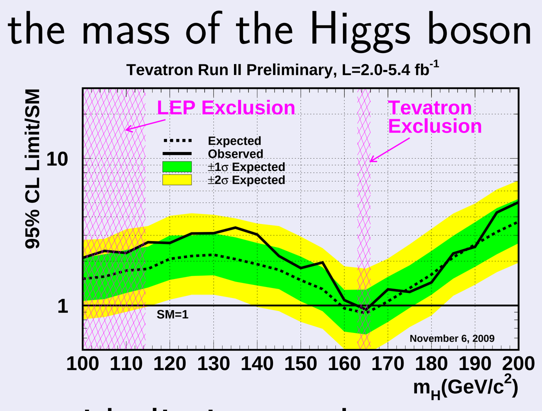
LEP (CERN, Geneva)

Higgs searches at LEP and the Tevatron have not yet found a Higgs boson and thus are able to restrict the mass of the Higgs boson in the Standard Model:



These experiments also provide limits on the cross sections of specific processes involving Higgs bosons. These can be used to constrain a wide variety of models.

Tevatron (Fermilab, Chicago)

HiggsBounds

HiggsBounds is a Fortran program designed to facilitate the comparison of Higgs sector predictions of new models against the existing constraints from LEP and the Tevatron. The user provides model information (e.g. Higgs masses, total decay widths, effective couplings) and HiggsBounds will determine whether this parameter point has been excluded at 95% CL.

About HiggsBounds

HiggsBounds [CPC 181(2010) 1387167] can be called from the command line, used as subroutines or via a form on the website:

http://www.ippp.dur.ac.uk/HiggsBounds

HiggsBounds uses the expected limits (based on simulations with no signal) to work out which channel has the highest statistical sensitivity. It then compares the model cross section prediction for this channel with the observed limit for this channel. Using only one observed limit for each parameter point in this way maintains the 95% CL.

HiggsBounds and other codes

Input to HiggsBounds can be provided as text files, subroutine arguments or using the form on the website. There are many public programs which can be used to calculate this input in the more common models e.g.

- FeynHiggs* for the MSSM (T. Hahn et al)
- CPsuperH* for the complex MSSM (J. S. Lee et al)
- 2HDMC† for Two-Higgs-Doublet Models (D. Eriksson et al)

∗ interface included in HiggsBounds packages
† interface included in 2HDMC package (vs. 1.0.2 and higher)

HiggsBounds is included in the DarkSUSY package. (P. Gondolo et al)

LEP and Tevatron analyses considered by HiggsBounds

HiggsBounds 1.2.0 currently includes cross-section limits for the following analyses involving neutral Higgs bosons:

- LEP Higgsstrahlung processes
  - $e^+e^- \to (h_k)Z \to (b\bar{b})Z$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k)Z \to (\tau^+\tau^-)Z$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to h_i h_i)Z \to (b\bar{b}b\bar{b})Z$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to h_i h_i)Z \to (\tau^+\tau^-\tau^+\tau^-)Z$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to h_i h_i)Z \to (b\bar{b})(\tau^+\tau^-)Z$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k)Z \to (...)Z$ Eur.Phys.J.C27:311-329,2003 (OPAL)]
  - $e^+e^- \to (h_k)Z \to (\gamma\gamma)Z$ [LHWG Note 2002-02]
- LEP pair production processes
  - $e^+e^- \to (h_k h_i) \to (b\bar{b}b\bar{b})$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k h_i) \to (\tau^+\tau^-\tau^+\tau^-)$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to h_i h_i)h_i \to (b\bar{b}b\bar{b})b\bar{b}$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to h_i h_i)h_i \to (\tau^+\tau^-\tau^+\tau^-)\tau^+\tau^-$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to b\bar{b})(h_i \to \tau^+\tau^-)$ [Eur.Phys.J.C47:547-587,2006]
  - $e^+e^- \to (h_k \to \tau^+\tau^-)(h_i \to b\bar{b})$ [Eur.Phys.J.C47:547-587,2006]
- Tevatron processes
  - $p\bar{p} \to Wh_i \to l\nu b\bar{b}$ [D0 Note 5972, CDF Note 9868, Phys.Rev.Lett.102:051803,2009 (D0), Phys.Rev.Lett.103:101802,2009 (CDF)]
  - $p\bar{p} \to Wh_i \to W^+W^-W^\pm$ [D0 Note 5873, CDF Note 7307]
  - $p\bar{p} \to Zh_i \to l^+l^-b\bar{b}$ [Phys.Rev.D80:071101,2009 (CDF), CDF Note 9889, D0 Note 5876]
  - $p\bar{p} \to Wh_i/Zh_i \to b\bar{b} + E_T^{\text{miss.}}$ (SM) [CDF Note 9891, D0 Note 5586, Phys.Rev.Lett.101:251802,2008 (D0), Phys.Rev.Lett.100:211801,2008 (CDF)]
  - $p\bar{p} \to h_i \to W^+W^- \to l^+l'^-\nu\nu$ [D0 Note 5757, Phys.Rev.Lett.102:021802,2009 (CDF)]
  - $p\bar{p} \to h_i/h_iW, h_i \to W^+W^-$ (SM) [CDF Note 9887, D0 Note 5871, arXiv:0903.4001 (TEVNPHWG) $M_H \geq 155$ GeV]
  - $p\bar{p} \to (b/\bar{b})h_i, h_i \to b\bar{b}$ [CDF Note 9284, D0 Note 5726, Phys.Rev.Lett.101:221802,2008 (D0)]
  - $p\bar{p} \to h_i \to \tau^+\tau^-$ [Phys.Rev.Lett.101:071804,2008 (D0), arXiv:0906.1014 (CDF), D0 Note 5740, D0 Note 5980, CDF Note 9888]
- Tevatron processes cont.
  - $p\bar{p} \to h_i/h_iW/h_iZ/h_i$ via VBF, $h_i \to \tau^+\tau^-$ (SM) [CDF Note 9248]
  - $p\bar{p} \to h_i/h_iW/h_iZ/h_i$ via VBF, $h_i \to \gamma\gamma$ [D0 Note 5858, Phys.Rev.Lett.102:231801,2009 (D0)]
  - $p\bar{p} \to (b/\bar{b})h_i, h_i \to \tau^+\tau^-$ [Phys.Rev.Lett.102:051804,2009 (D0), D0 Note 5985]
  - combined Higgs production and decay (SM) [arXiv:0712.2383v1 (TEVNPHWG), arXiv:0804.3423 (TEVNPHWG), CDF Note 9674, Phys.Lett.B663:26-36,2008 (D0), arXiv:0808.0534 (TEVNPHWG), CDF Note 9897]

HiggsBounds 2.0.0 will be released shortly and will include

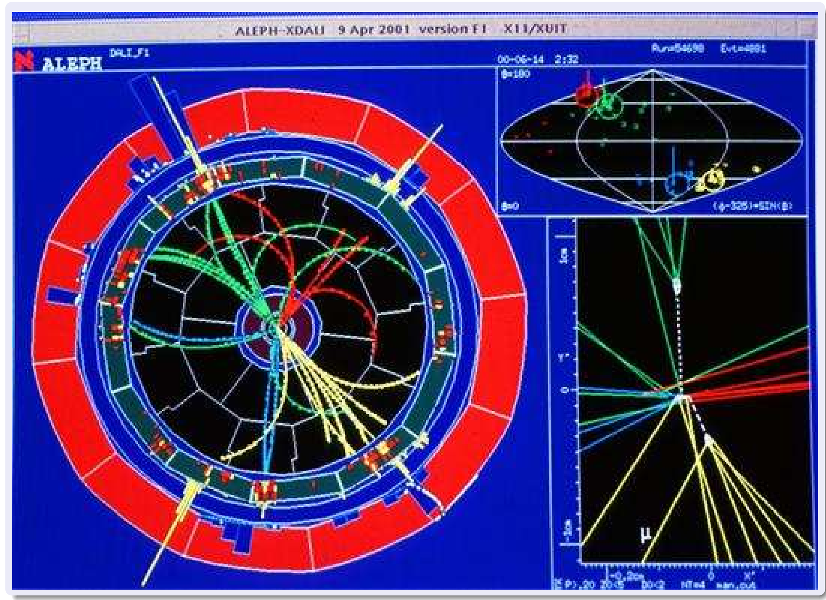
- more neutral Higgs searches at LEP e.g.
  - $e^+e^- \to (h_k)Z \to (\text{invisible})Z$ arXiv:0107032 (LEPHWG)
  - $e^+e^- \to (h_k)Z \to (\text{ 2 jets })Z$ LEPHWG (from Eur.Phys.J.C44:147-159,2005 (DELPHI),Phys.Lett.B544:25-34,2002 (ALEPH), Phys.Lett.B597:11-25,2004 (OPAL), Eur.Phys.J.C40:317-332,2005 (OPAL))
  - $e^+e^- \to b\bar{b}h_k \to b\bar{b}b\bar{b}$ (h_k is a CP-eigenstate) Eur.Phys.J.C38:1-28,2004 (DELPHI)
  - $e^+e^- \to b\bar{b}h_k \to b\bar{b}\tau^+\tau^-$ (h_k is a CP-eigenstate)Eur.Phys.J.C38:1-28,2004 (DELPHI)
  - $e^+e^- \to \tau^+\tau^-h_k \to \tau^+\tau^-\tau^+\tau^-$ (h_k is a CP-eigenstate)Eur.Phys.J.C38:1-28,2004 (DELPHI)
- more neutral Higgs searches at the Tevatron e.g.
  - $p\bar{p} \to t\bar{t}h \to t\bar{t}b\bar{b}$ (h_k is CP-even) D0 5739
  - $p\bar{p} \to (h_k) + ... \to (Z\gamma) + ...$ Phys.Lett.B671:349-355,2009 (D0) M_{h_k} <320 GeV)
- charged Higgs searches at LEP and the Tevatron e.g.
  - $e^+e^- \to H_k^+H_k^- \to \tau^+\nu\tau^-\nu$ arXiv:0812.0267 (OPAL)
  - $e^+e^- \to H_k^+H_k^- \to q_i\bar{q}_jq_l\bar{q}_m$ arXiv:0812.0267 (OPAL)
  - $e^+e^- \to H_k^+H_k^- \to q_i\bar{q}_j\tau^\pm\nu$ arXiv:0812.0267 (OPAL)
  - $t \to H_k^+b \to \tau^+\nu b$ arXiv:0908.1811 (D0)
  - $t \to H_k^+b \to q_i\bar{q}_jb$ arXiv:0908.1811 (D0)

SM results used within HiggsBounds

Internally, HiggsBounds uses

- SM Higgs branching ratios and total decay width from HDecay (A. Djouadi, J. Kalinowski and M. Spira)
- SM Higgs production cross sections at the Tevatron (S. Catani et al 2003, O. Brein et al 2003, M. L. Ciccolini et al 2003, R. Harlander et al 2003, J. M. Campbell et al 1999, U. Aglietti et al 2006, K.A.Assamagan et al 2004, W. Beenakker et al 2001, L. Reina et al 2001, S. Dawson et al 2002)
- The SM ratio $\sigma(p\bar{p} \to H \text{ via } WW \text{ fusion})/\sigma(p\bar{p} \to H \text{ via } ZZ \text{ fusion})$ using VBF@NLO (T.Figy et al 2003)
- ratios of SM hadronic cross sections $\sigma(p\bar{p} \to nm \to H + ...)/\sigma(p\bar{p} \to H + ...)$, where nm are particular partons O. Brein

to convert between different types of input and to ensure correct normalisation of experimental limits.



Case Study: The CPX scenario

Motivation

The CPX scenario is a benchmark scenario for the MSSM with complex phases (M.S.Carena, J.R.Ellis, A.Pilaftsis, C.E.M.Wagner 2000).

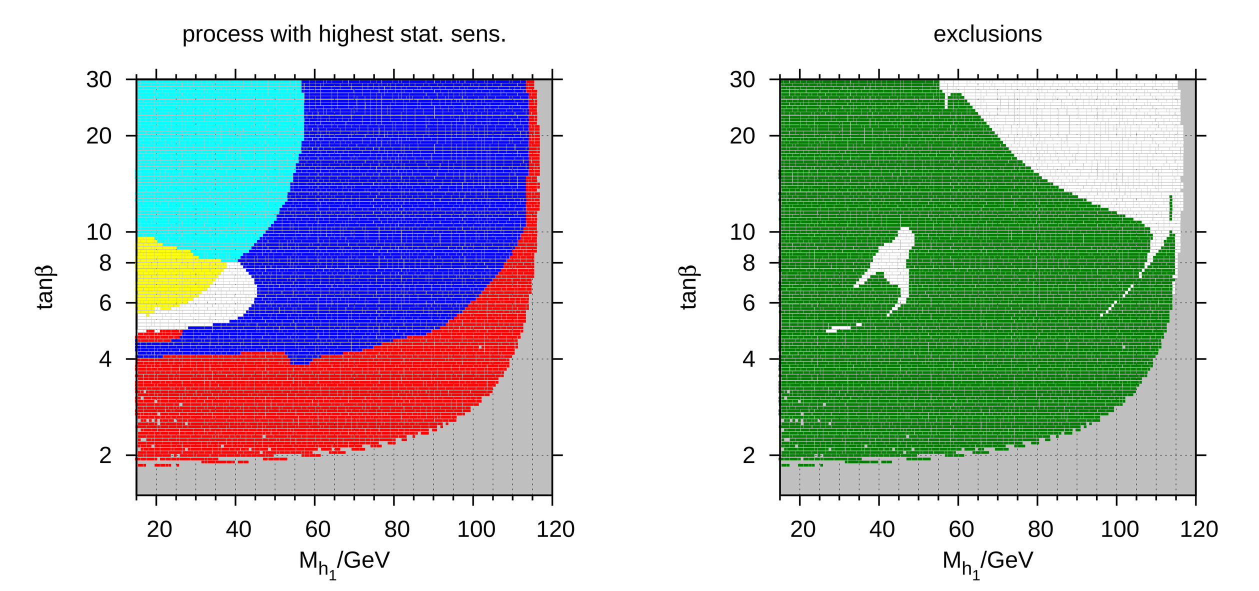
The LEP Higgs Working Group and LEP Collaborations did a dedicated analysis for this scenario [EP JC 46(2006)547] and found an unexcluded region at $M_{h_1} \sim 45$ GeV, $\tan\beta \sim 8$.

Since this analysis, new results have been obtained in the Feynman-diagrammatic approach, in particular:

- $\mathcal{O}(\alpha_s\alpha_t)$ corrections to the Higgs self-energies (S.Heinemeyer, W.Hollik, H.Rzehak, G.Weiglein 2007)
- 1-loop corrections to the Higgs decay $h_2 \to h_1h_1$, effective triple Higgs vertices (K.W., G.Weiglein 2008, KW, G. Weiglein in prep)
- Improved treatment of the Higgs propagator corrections (T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. Weiglein, KW, 2006)
- Higgs decays to fermions (K.W., G.Weiglein 2008, KW, G. Weiglein in prep)
- Leading non-propagator corrections to Higgsstrahlung and Higgs pair production at e^+e^- colliders (KW, G. Weiglein in prep)

We can use HiggsBounds to look at the effect of these new corrections.

Results



■ $= e^-e^+ \to h_1Z \to b\bar{b}Z$
■ $= e^-e^+ \to h_2Z \to b\bar{b}Z$
□ $= e^-e^+ \to h_2Z \to h_1h_1Z \to b\bar{b}b\bar{b}Z$
■ $= e^-e^+ \to h_2h_1 \to b\bar{b}b\bar{b}$
■ $= e^-e^+ \to h_2h_1 \to h_1h_1h_1 \to b\bar{b}b\bar{b}b\bar{b}$

green = excluded at 95 % CL
white = unexcluded

(CPX scenario as defined in KW, G.Weiglein 2008, except $m_t = 173.1$ GeV)

We can see that, even with the new corrections, there remains an unexcluded region at $M_{h_1} \sim 45$ GeV, $\tan\beta \sim 8$. Furthermore, using the information about the which process has the highest statistical sensitivity at each point, we can see that, e.g., the $h_2 \to h_1h_1$ branching ratio is very important near to this unexcluded region.

Future plans for HiggsBounds

We are currently in the process of incorporating tables of CL_{s+b} from LEP Higgs searches. This information will then be used by the programs

- Fittino P. Bechtle, K. Desch, P. Wienemann
- MasterCode O. Buchmller, R. Cavanaugh, A. de Roeck, J. Ellis, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. Weiglein,

which extract SUSY Langrangian parameters from experimental data.

- We are currently extending the program to cover SUSY searches
- We are investigating the possibility of including predicted limits for the LHC

Acknowledgements

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