

HiggsBounds and HiggsSignals

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Test scalar sectors against exclusion bounds from LEP, Tevatron, and the LHC.

- collects 95 % C.L. exclusion bounds from over 200 experimental analyses
- exclusion likelihoods that can be used for fitting or limit setting
- updated with new experimental results as they are released
- Fortran-95 code: <https://gitlab.com/higgsbounds/higgsbounds>
- New HiggsBounds-5 manual released in July [Bechtle et al. 2006.06007]

Scalar masses, total widths, mass uncertainties and all rates:

Hadronic input

- cross section (ratios) @ 7, 8 and 13 TeV LHC and Tevatron
 - $gg/bb \rightarrow h, Wh, gg/qq \rightarrow Zh, \text{VBF}, tth$ (s- and t-channel), $th, tWh, h_i h_j$
 - $tbH^\pm, t \rightarrow H^\pm b, \dots$
- cross section (ratios) @ LEP
 - $hZ, bbh, \tau\tau h, h_i h_j$
 - $H^\pm H^\mp$
- branching ratios
 - $f\bar{f}$ (2nd+3rd gen), $VV, \text{inv}, h_i h_j, h_i Z, H^\pm W, \ell\ell'$
 - $tb, cs, cb, \tau\nu, h_j W, WZ$

Effective coupling input

For neutral scalars:

- SM-normalized effective couplings κ
- BSM BRs

Parametrization of tbH^\pm cross section also available.

HiggsBounds-5.9.0 contains 273 exclusion limits at 95 % C.L. for different channels, colliders, energies, collaborations, and luminosities.

How to obtain a combined limit at $\sim 95\%$ C.L.?

1. Use the *expected limits* to rank the limits by sensitivity to each Higgs boson.
 2. Select the most sensitive limit for each Higgs boson.
 3. Test the model prediction against the *observed limit* for these selected limits.
- ⇒ The parameter point is allowed if it is not excluded by any of these selected limits.

This is a binary constraint, not something that can be fitted.

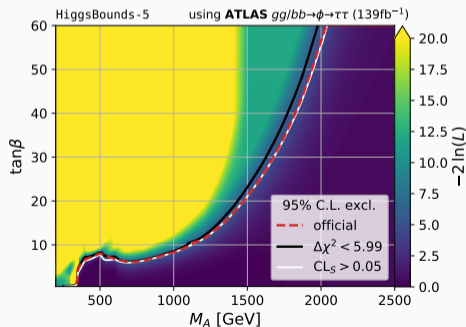
HiggsBounds — Exclusion Likelihoods

For some Higgs searches additional information is available in the form of simplified exclusion likelihood profiles.

- LEP Higgs Combination [ALEPH, DELPHI, L3, OPAL hep-ex/0602042]
- ATLAS and CMS $H \rightarrow \tau\tau$ searches [CMS:2015mca; ATLAS 1709.07242; CMS 1803.06553; ATLAS 2002.12223]

→ Construct CL_S limits in excellent agreement with official model interpretations.

→ Use as χ^2 /Likelihood contribution in a fit.



Compare scalar sectors to the latest measurements of the h_{125} .

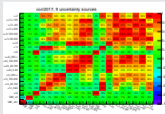
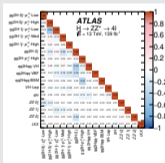
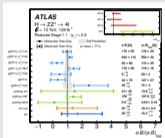
- observable sets of the latest LHC Higgs measurements:
 - 7+8 TeV measurements covered by the Run 1 combination [ATLAS, CMS 1606.02266]
 - newest available 13 TeV results, already including many with $\sim 130 \text{ fb}^{-1}$
- STXS results are used whenever available
- constructs a χ^2 from both rate and mass measurements
- Fortran-95 code: <https://gitlab.com/higgsbounds/higgssignals>
- Uses HiggsBounds to handle model predictions
- New HiggsSignals-2 manual before christmas.

HiggsSignals — Rate Measurements

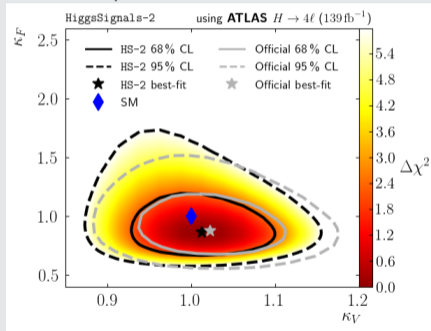
Example: ATLAS $H \rightarrow 4\ell$ [ATLAS 2004.03447]

HiggsSignals implementation

- measurements (12-bin STXS)
- experimental correlations
- theory correlations [2017 Scheme]



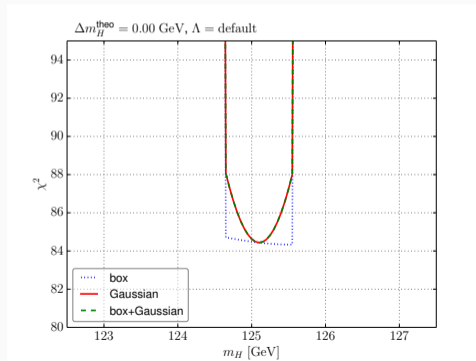
Performance of HiggsSignals compared to official κ -fit.



HiggsSignals — Mass Measurements

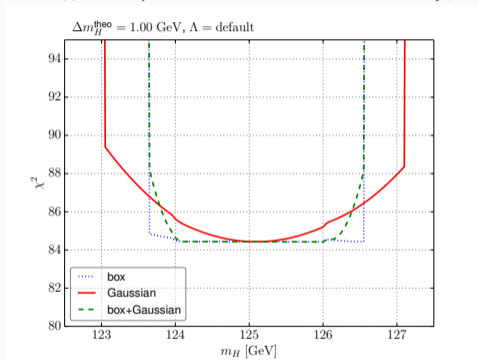
Mass measurement from Run 1 combination: 125.09 ± 0.24 GeV [ATLAS, CMS 1503.07589].

- If Higgs masses are input parameters \rightarrow set one mass to 125.09 GeV.
 - Not possible if Higgs masses are predictions of the theory.
- > **assignment**: m_H consistent with the mass assumption/measurement of a rate measurement
- > $\chi_{m_H}^2$: explicit contribution from mass measurements
- > **pdf**: treat the ± 0.24 GeV as a box or a gaussian error



Theoretical Mass Uncertainties

If m_H is a prediction of the theory, it usually has an important mass uncertainty.

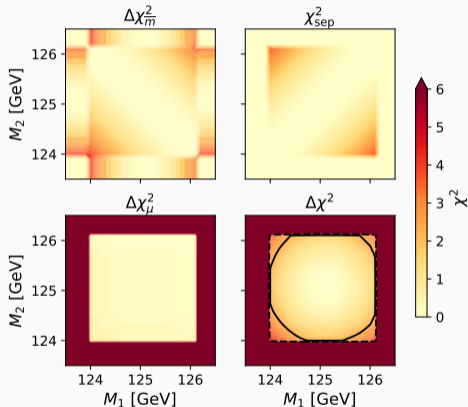


- **assignment** within the mass uncertainty (if it lowers the total χ^2)
- the $\chi_{m_H}^2$ contribution is broadened by Δm_H^{theo}
- **pdf**: treat Δm_H^{theo} as a box or a gaussian error

In HiggsBounds the mass uncertainty is used to always set a conservative limit.

Combining Multiple Higgs Bosons

What if $H_{1,2}$ with $\Delta m_{H_{1,2}}^{\text{theo}} = 0.5 \text{ GeV}$ and $\mu_{1,2} = 0.5$ are unresolved near 125 GeV?



Using gaussian pdf.

- $\Delta\chi_m^2$: mass χ^2 for the rate-weighted average mass
- χ_{sep}^2 : separation χ^2 to approximate a partially resolved signal
- $\Delta\chi_\mu^2$: ~ 0 for these μ if both scalars are assigned, large otherwise

HiggsBounds also combines scalars within the mass resolution of a search.

Summary — HiggsBounds and HiggsSignals in BSM Model Fits

HiggsSignals χ^2 from Higgs measurements

- covers all measured channels with the latest available measurements
- handles theoretical mass uncertainties and contributions from several scalars

HiggsBounds χ^2 from exclusion likelihoods

- allows easy inclusion of the important $H \rightarrow \tau\tau$ searches and LEP results

HiggsBounds limits

- binary constraint that can be applied after a fit
- automatically chooses the most sensitive limits, no manual selection needed