MSSM Working Group Experimental Summary

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LHC Higgs Working Group Workshop

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U.S. DEPARTMENT OF ENERGY

Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

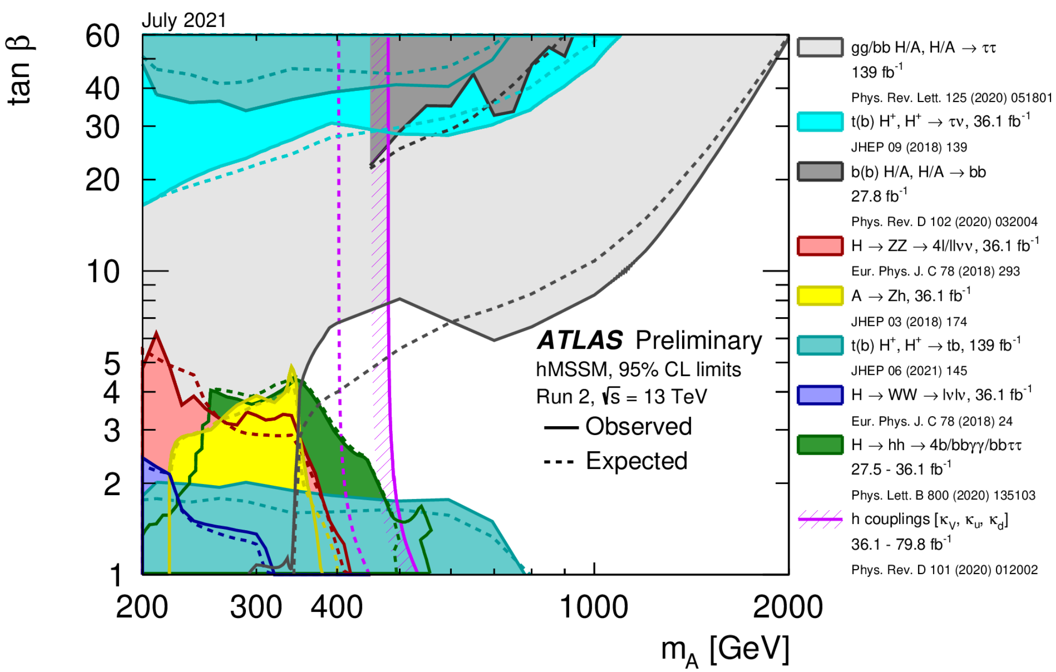
MSSM Higgs Analyses from ATLAS and CMS

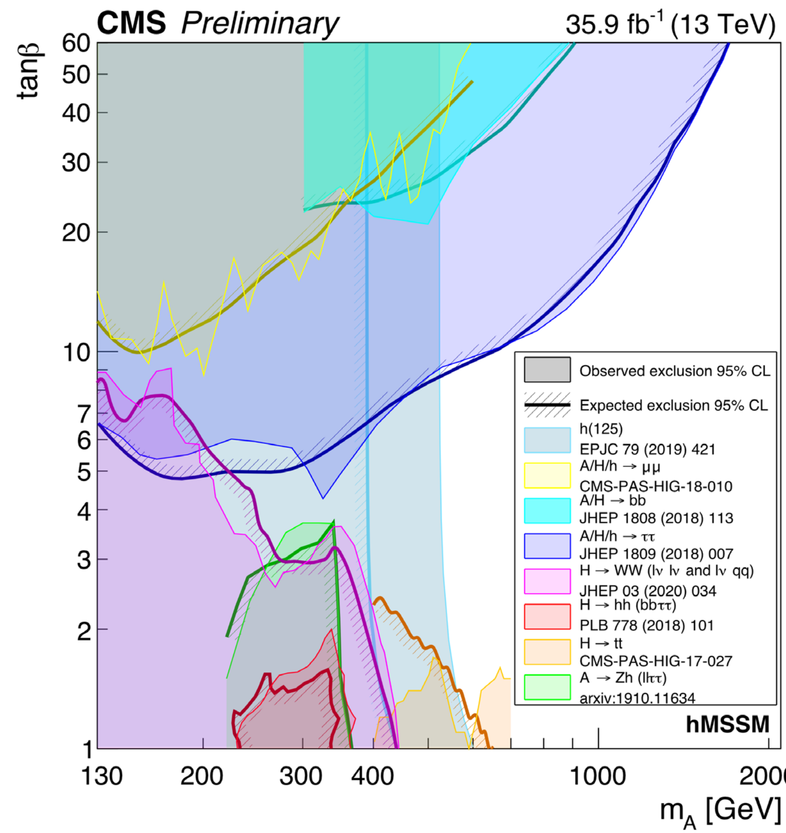
Channel	Mass (TeV)	ATLAS	CMS
$H/A \rightarrow \tau\tau$	0.09 – 3.2	139 fb^{-1} Phys. Rev. Lett. 125 (2020) 051801	36 fb^{-1} JHEP 09 (2018) 007
$H/A \rightarrow bb$	0.3 – 2.0	28 fb^{-1} Phys. Rev. D 102 (2020) 032004	36 fb^{-1} JHEP 08 (2018) 113
$H/A \rightarrow tt$	0.3 – 1.4	20 fb^{-1} Phys. Rev. Lett. 119 (2017) 191803	36 fb^{-1} JHEP 04 (2020) 171
$H/A \rightarrow \mu\mu$	0.13 – 1.0	36 fb^{-1} JHEP 07 (2019) 117	36 fb^{-1} Phys. Lett. B 798 (2019) 134992
$A \rightarrow Zh$	0.3 – 5.0	139 fb^{-1} ATLAS-CONF-2020-043	36 fb^{-1} JHEP03 (2020) 065
$A \rightarrow ZH$ $H \rightarrow ZA$	0.23 – 0.8 0.12 – 1.0	139 fb^{-1} Eur. Phys. J. C. 81 (2021) 396	36 fb^{-1} JHEP 03 (2020) 055
$H \rightarrow hh$	0.25 – 1.3	36 fb^{-1} Phys. Lett. B 800 (2019) 135103	36 fb^{-1} Phys. Lett. B 778 (2018) 101
$H^+ \rightarrow \tau\nu$	0.09 – 2.0	36 fb^{-1} JHEP 09 (2018) 139	36 fb^{-1} JHEP 07 (2019) 142
$H^+ \rightarrow tb$	0.2 – 2.0	139 fb^{-1} JHEP 06 (2021) 145	36 fb^{-1} JHEP 01 (2020) 096

No change from Nov 2020 except some conf notes are now published papers

Most analyses with <= 36 fb^{-1} are being updated to full Run2 139 fb^{-1} - results in 2022

hMSSM summary plots from ATLAS and CMS





ATL-PHYS-PUB-2021-030

CMS public Higgs PAG Summary Plots

Limits in the M_h^{125} scenarios are slow in coming, but we have the root files

Baseline scenarios

Subsequently you find ROOT histograms for the MSSM benchmark scenarios defined in:
"MSSM Higgs Boson Searches at the LHC: Benchmark Scenarios for Run 2 and Beyond"
Emanuele Bagnaschi, Henning Bahl, Elina Fuchs, Thomas Hahn, Sven Heinemeyer, Stefan Liebler, Shruti Patel, Pietro Slavich, Tim Stefaniak, Carlos E.M. Wagner, Georg Weiglein
arXiv:1808.07542
inSPIRE texkey: \cite{Bahl:2018zmf}

Most scans in the m_A-tanβ-plane have been made between m_A=70 GeV and m_A=2600 GeV and between tanβ=0.5 and 60.

- M_h^{125}
  - This scenario is characterized by relatively heavy superparticles, so the Higgs phenomenology at the LHC resembles that of a THDM with MSSM-inspired Higgs couplings.
  - mh125_8.root: 8 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_13.root: 13 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_14.root: 14 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
- $M_h^{125}(\tilde \chi)$
  - This scenario is characterized by all charginos and neutralinos being relatively light, with significant higgsino-gaugino mixing. This affects the decays of the heavier Higgs bosons, weakening the exclusion bounds from H/A->tau tau searches, as well as the decay of the SM-like Higgs boson to photons. On the other hand, the possibility to look for additional Higgs bosons through their decays to charginos and neutralinos opens up.
  - mh125_lc_8.root: 8 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_lc_13.root: 13 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_lc_14.root: 14 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
- $M_h^{125}(\tilde\tau)$
  - This scenario is characterized by light staus and light gaugino-like charginos and neutralinos. The effect of the light staus on the decays of the heavier Higgs bosons, as well as on the decay of the SM-like Higgs boson to photons, is most relevant at large tanβ. Compared with the previous scenario, a larger mass for the higgsinos implies that the decays of the heavier Higgs bosons to charginos and neutralinos become relevant at larger values of mA.
  - mh125_ls_8.root: 8 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_ls_13.root: 13 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_ls_14.root: 14 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
- M_h^{125}(alignment)
  - This scenario is characterized by the phenomenon of "alignment without decoupling", in which, for a given value of tanβ, one of the two neutral CP-even scalars has SM-like couplings independently of the mass spectrum of the remaining Higgs bosons. In particular, for tanβ around 7 the properties of the lighter scalar h are in agreement with those of the observed Higgs boson also for relatively low values of mA.
  - [NOTE: In contrast to the definition in arXiv:1808.07542, the ROOT files start only at mA > 120 GeV due to a theoretically inaccessible region at low mA < 120 GeV and tanβ>10].
  - mh125_align_8.root: 8 TeV, tanβ= 1-20, mA = 120-1000 GeV
  - mh125_align_13.root: 13 TeV, tanβ= 1-20, mA = 120-1000 GeV
  - mh125_align_14.root: 14 TeV, tanβ= 1-20, mA = 120-1000 GeV
- M_H^{125}(alignment)
  - This scenario is characterized by the phenomenon of "alignment without decoupling", in which, for a given value of tanβ, one of the two neutral CP-even scalars has SM-like couplings independently of the mass spectrum of the remaining Higgs bosons. In particular, for this scenario the properties of the heavier scalar H are tuned to be agreement with those of the observed Higgs boson, for part of the parameter plane.
  - [NOTE: ROOT files temporarily generated using FeynHiggs only!].
  - mHH125_8.root: 8 TeV, tanβ= 5-6, mHp = 150-200 GeV
  - mHH125_13.root: 13 TeV, tanβ= 5-6, mHp = 150-200 GeV
  - mHH125_14.root: 14 TeV, tanβ= 5-6, mHp = 150-200 GeV
- $M_{h_1}^{125}$(CPV)
  - This scenario incorporates CP violation in the Higgs sector and gives rise to a strong admixture of the two heavier neutral states, leading to significant interference effects in their production and decay which weaken the exclusion bounds from tau tau searches.
  - [NOTE: the scenario contains three neutral Higgs bosons H1, H2 and H3 rather than h, H and A. H1 is understood as the SM-like Higgs boson with a mass at 125 GeV in large parts of the parameter space. The input parameters are tanβ and the charged Higgs mass mHp rather than mA. Please consider mssm_xs_tools.h for new access functions for the cross sections, masses and branching ratios. In contrast to the CP conserving scenarios we do not provide relative Yukawa couplings as those do have a real and imaginary contribution to both the vector and axial-vector component. On the other hand, we do provide interference factors eta(bb->H2/H3->bb/tau tau) as in such channels large destructive interferences between H2 and H3 appear. When interpreting a search in those final states, do not forget to multiply sigma(bb->H2/H3)*BR(H2/H3->bb/tautau) with the corresponding (1+eta) factor! This scenario needs access tool version 2.3 or higher.]
  - mh1125_CPV_8.root: 8 TeV, tanβ= 1-20, mHp = 130-1500 GeV
  - mh1125_CPV_13.root: 13 TeV, tanβ= 1-20, mHp = 130-1500 GeV
  - mh1125_CPV_14.root: 14 TeV, tanβ= 1-20, mHp = 130-1500 GeV

Negative mu scenarios

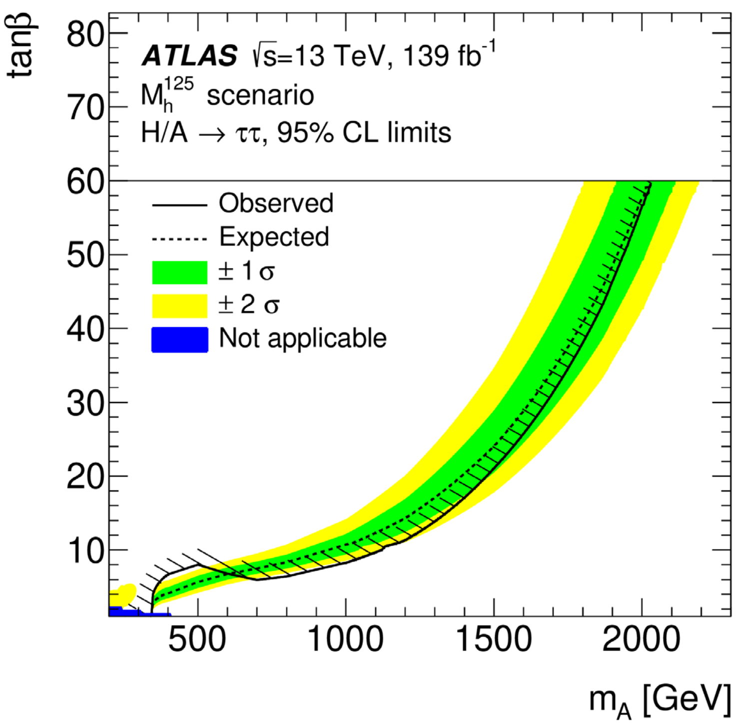
A set of scenarios corresponding to the M_h^{125} one but with negative values of $\mu = -1, -2, -3$ TeV have been defined in
"HL-LHC and ILC sensitivities in the hunt for heavy Higgs bosons"
H. Bahl, P. Bechtle, S. Heinemeyer, S. Liebler, T. Stefaniak, G. Weiglein
arXiv:2005.14536
inSPIRE texkey: \cite{Bahl:2020kwe}

These scenarios are characterized by larger Δ_b effects, which reduce the allowed parameter space.

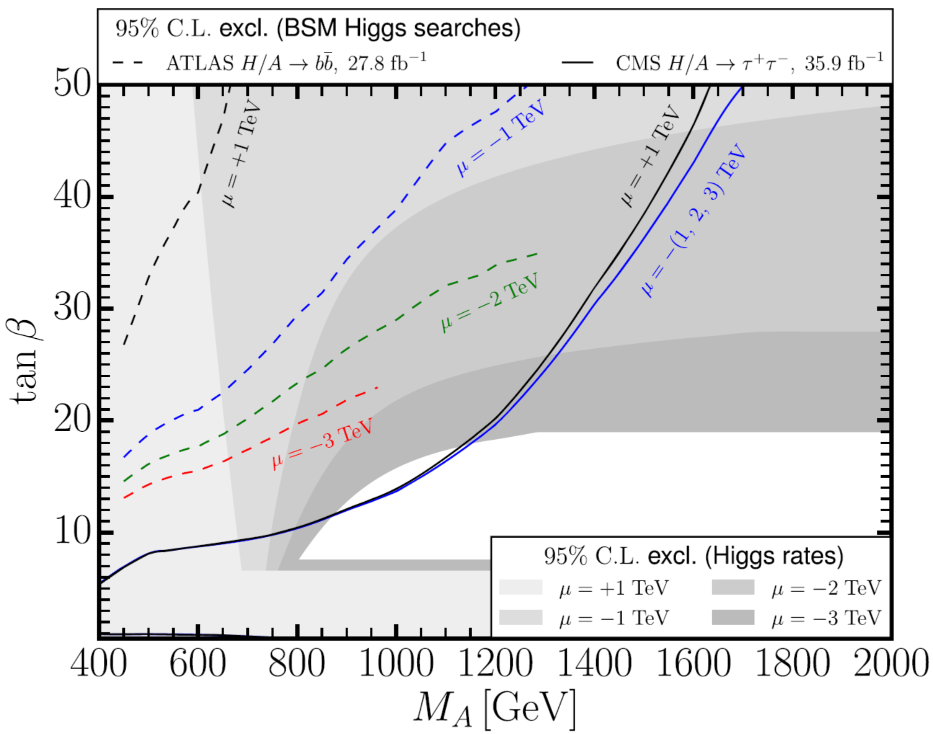
- M_h^{125} ($\mu = -1$ TeV)
  - mh125_muneg_1_8.root: 8 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_muneg_1_13.root: 13 TeV, tanβ= 0.5-60, mA = 70-2600 GeV
  - mh125_muneg_1_14.root: 14 TeV, tanβ= 0.5-60, mA = 70-2600 GeV

Example limits in the M_h^{125} scenarios

M_h^{125}



M_h^{125} $\mu < 0$



Likelihood Scans

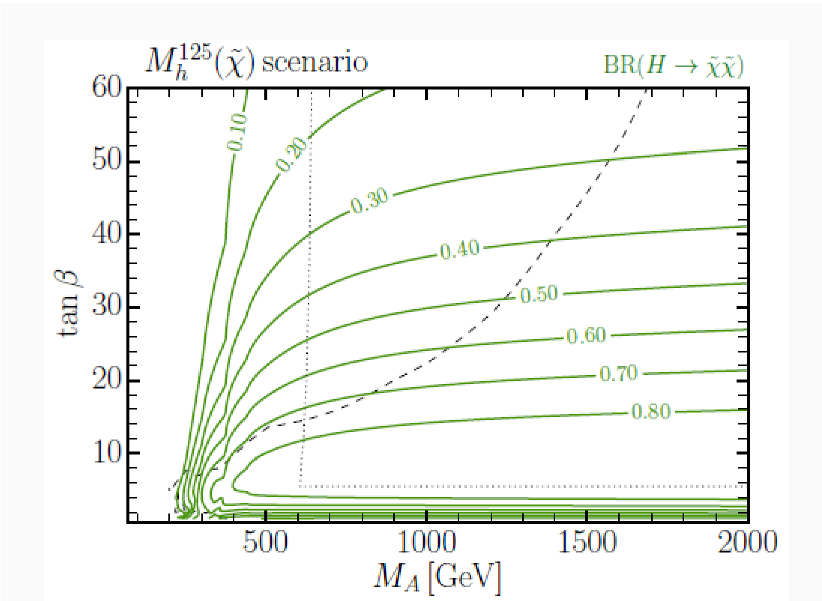
Table of parameters of interest for model-independent (profiled) $\Delta(-ln\mathcal{L})$ scans

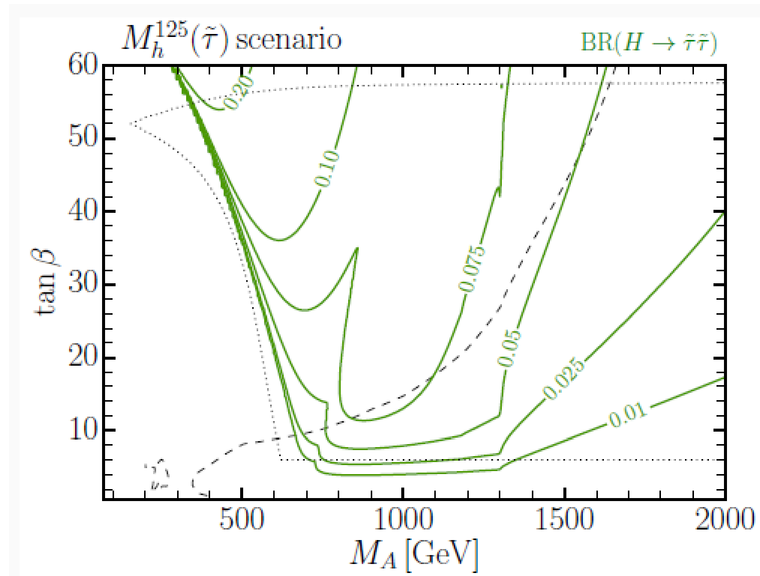
In the following, a table of parameters is given, for which (profiled) Δ(-lnL) scans are desired to be provided by direct, model-independent searches of experimental collaborations for re-interpretation by theory community. These parameters of interest depend on the particular production and decay channels of considered BSM Higgs bosons.

Channel	Discrete Parameters	Continious Parameters
$pp \to \phi + X \to \tau\tau + X$	m_ϕ	$\sigma(gg\phi) \cdot BR$, $\sigma(bb\phi) \cdot BR$
$pp \to b(b)\phi + X \to b(b)bb + X$	m_ϕ	$\sigma(b(b)\phi) \cdot BR$
$pp \to \phi + X \to tt + X$	m_ϕ, Γ_ϕ / m_ϕ	$g_{\phi \leftrightarrow tt}$
$pp \to \phi + X \to \mu\mu + X$	m_ϕ, Γ_ϕ / m_ϕ	$\sigma(gg\phi) \cdot BR$, $\sigma(bb\phi) \cdot BR$
$pp \to tbH^\pm + X \to tb\{tb, \tau\nu\} + X$	$m_{H^\pm}$	$\sigma(tbH^\pm) \cdot BR$
$pp \to t + X \to bH^\pm + X \to b\{tb, \tau\nu\} + X$	$m_{H^\pm}$	$BR(t \to bH^\pm) \cdot BR$

ATLAS and CMS have generally agreed to provide these likelihood scans as part of their final Run2 139 fb^{-1} results.

A/H → SUSY states





Not aware of ongoing analyses by ATLAS or CMS

Heavy Higgs decays to light gauginos and sleptons should be given consideration.