Searches for additional heavy Higgs bosons at CMS

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on behalf of the CMS Collaboration

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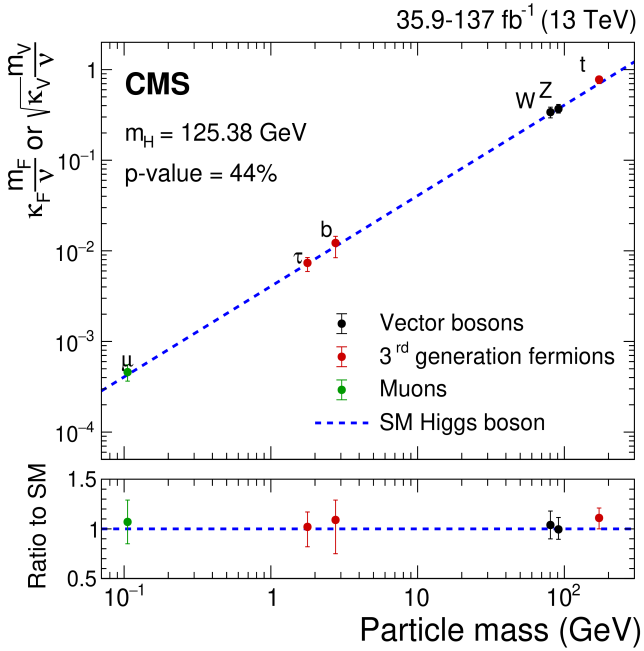
Introduction

- H(125) boson properties are consistent (at the current level of precision) with SM predictions



- Theories beyond SM motivated by observed phenomena (dark matter, neutrino masses, …) and theoretical arguments (hierarchy problem)

- New physics can manifest itself in the Higgs sector via

  deviation of the H(125) couplings to fermions and bosons from SM predictions

  exotic decays of H(125)

  existence of additional neutral and charged scalars

$$\begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \Rightarrow \mathrm{H_{SM}}$$

$$\begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix} + \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix} \Rightarrow \mathrm{h, H, A, H^{\pm}}$$

$$\begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix} + \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix} + \mathrm{s} \Rightarrow \mathrm{h_{(1,2,3)}, a_{(1,2)}, h^{\pm}}$$

Heavy neutral Higgs bosons of MSSM

- Minimal Supersymmetric extension of the SM (MSSM) contains two Higgs doublets

  Φ_1 couples to $\ell^{\pm}$ and down-type q, Φ_2 couples to up-type q

- 5 physical states : h, H, A, $H^{\pm}$

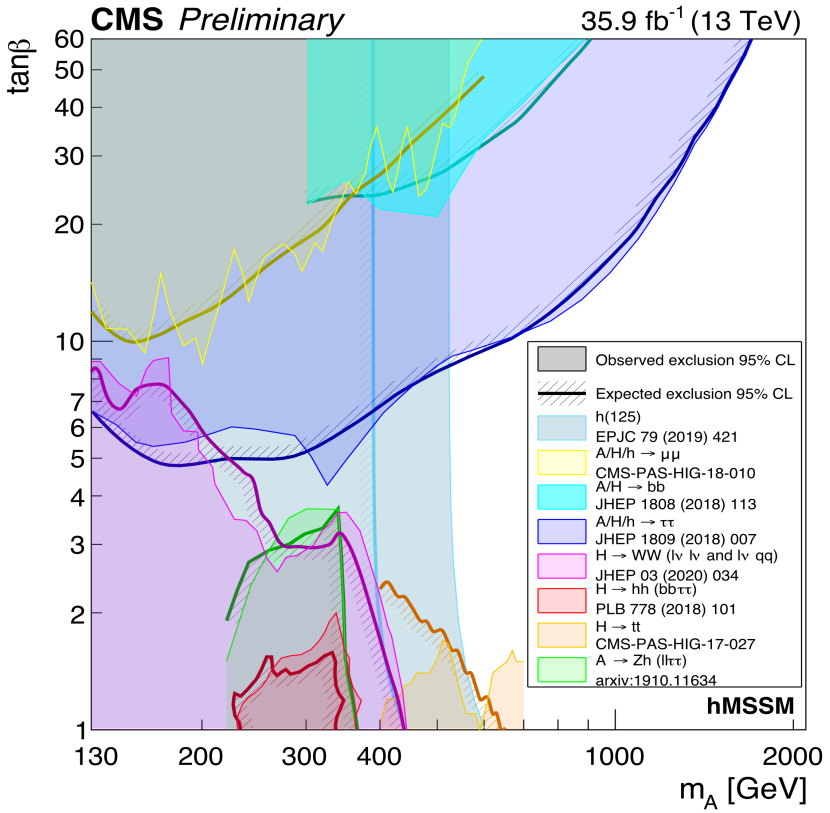
  h is identified with h_{125}

- described by two parameters

  $\tan\beta = \langle\Phi_2\rangle/\langle\Phi_1\rangle$ and m_A

- searches for H/A with 2016 dataset

	production		
decay	gg →H(A)	bbH(A)	qqH
H(A)→ττ	x	x	
H(A)→bb		x	
H(A)→μμ	x	x	
H(A)→tt	x		
A→Zh(ℓℓττ)	x		
H→hh(bbττ)	x		
H→WW(2ℓ2ν)	x		x

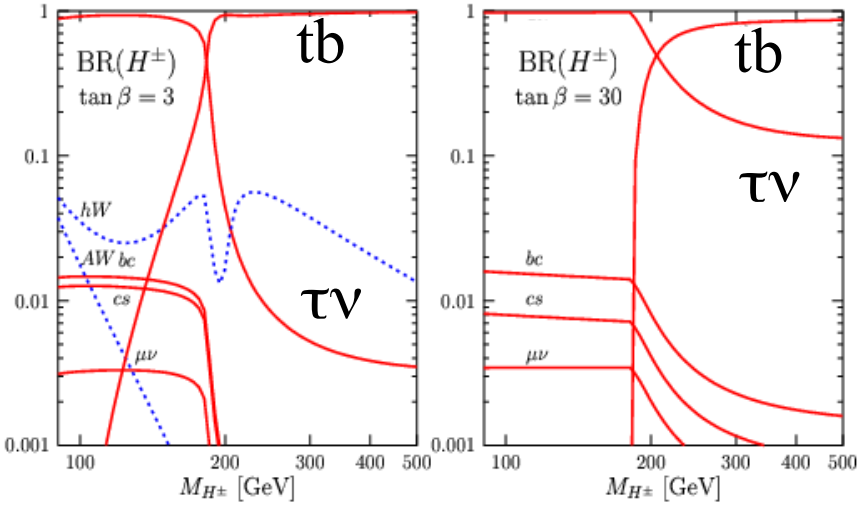


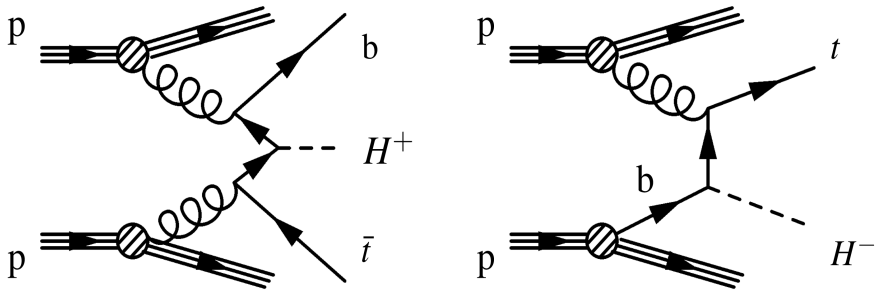
x - sensitivity at high tanβ

x - sensitivity at low tanβ

Heavy charged Higgs bosons of MSSM

$$g_{H^\pm tb} \sim m_t \cot\beta - m_b \tan\beta, \quad g_{H^\pm \tau\nu} \sim m_\tau \tan\beta$$

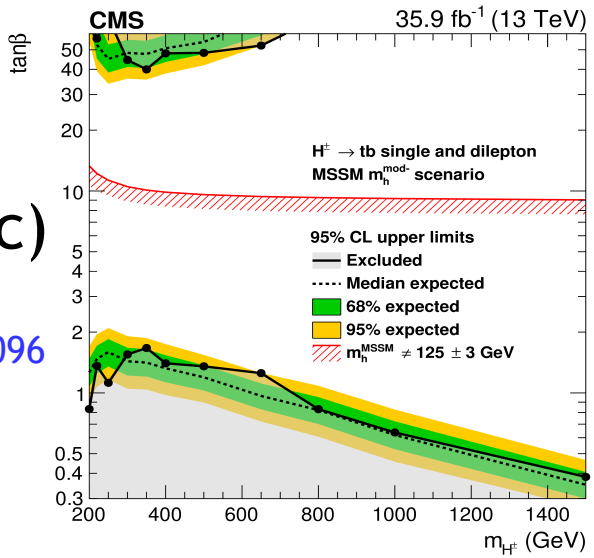




dominant production modes at high $m_{H^\pm}$

$H^\pm \to tb$ (leptonic)

JHEP 01 (2020) 096



$H^\pm \to \tau\nu$

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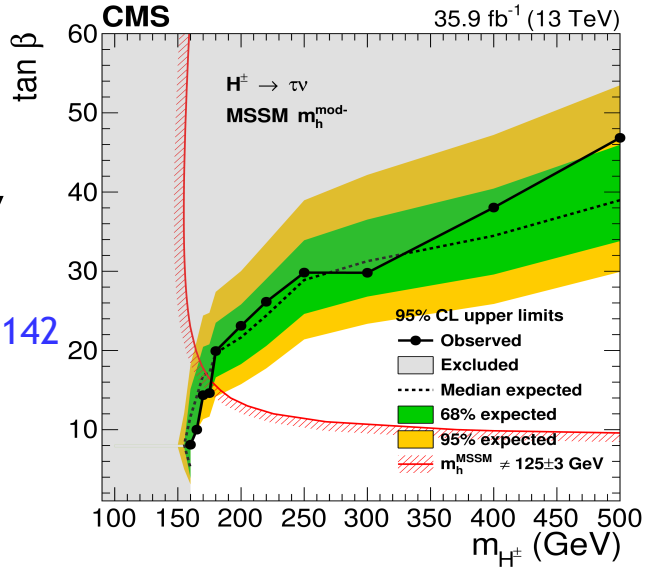


Search for $H \to h h_s \to (\tau\tau)(bb)$

- Next-to-MSSM contains 2 Higgs doublets + 1 singlet (2HD+1S)

  singlet interacts only with itself and Higgs doublets (doesn't couple to SM sector)

- 7 physical states: $h_{1,2,3}$ ($m_{h3} > m_{h2} > m_{h1}$), $a_{1,2}$ ($m_{a2} > m_{a1}$), $h^{\pm}$

- Peculiar scenario

  h_1 or h_2 is identified with h_{125} (denoted h)

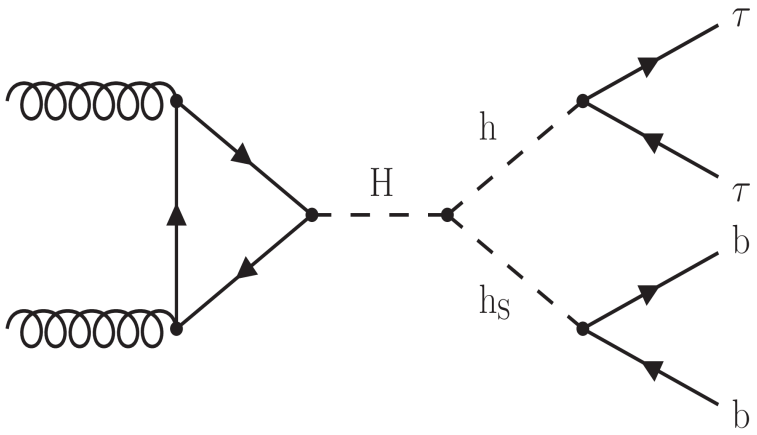
  h_2 or h_1 has large singlet admixture (h_s)

  $\rightarrow$ h_s has reduced couplings to SM particles

  suppressed rates of conventional production modes ($gg \to h_s$, bbh_s etc)

  but still decays into SM particles (e.g $h_s \to bb$)

arXiv:2106.10361
submitted to JHEP



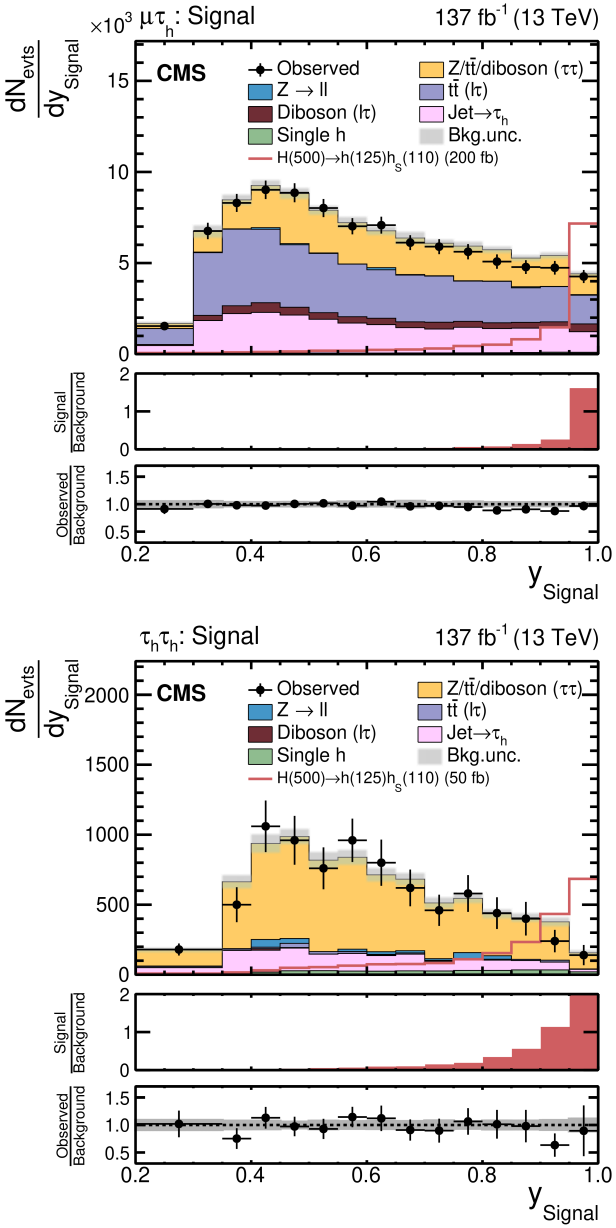
h_3 contains large doublet admixture $\rightarrow$ has properties of MSSM H boson

in this scenario h_s is accessible via $H \to h h_s$ decay

search targets $gg \to H$ production and exploits $h h_s \to (\tau\tau)(bb)$ decays

Search for $H \to hh_s \to (\tau\tau)(bb)$

- Search strategy
  - categorization of τ decays: $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_h\tau_h$
  - identification of b-jets and τ_h with Deep Neural Network (DNN)
  - dedicated DNN classifies events into signal and control regions
  - DNN score distributions are used to extract signal
- Background estimation
  - genuine τ pairs: embedding simulated τ decays in $\mu^+\mu^-$ events (selected in data)
  - $j \to \tau_h$: applying misId probability to events in sideband region
  - prompt e/μ : MC simulation



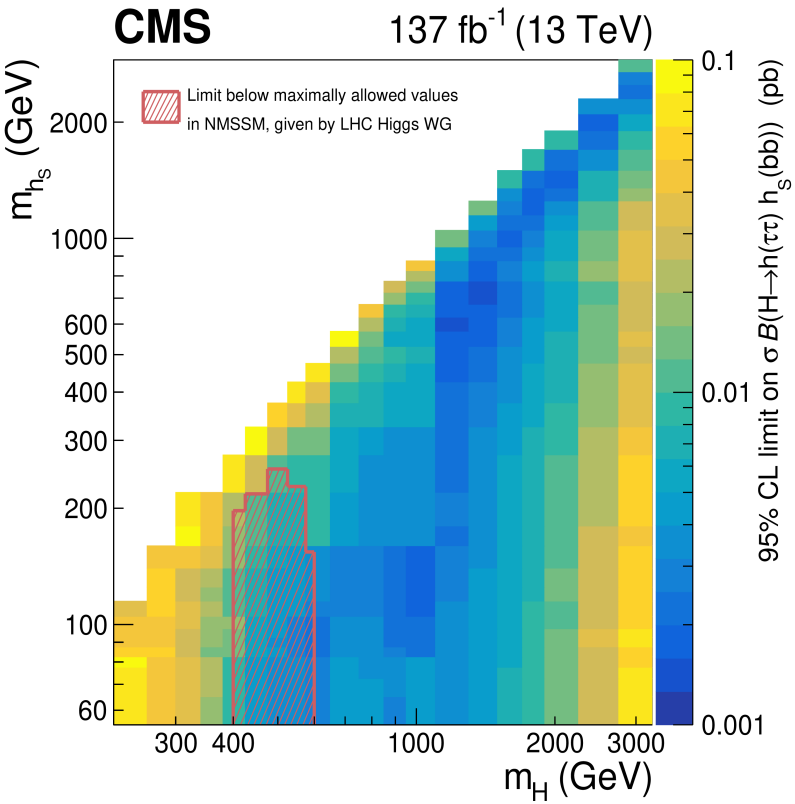
Search for $H \to h h_s \to (\tau\tau)(bb)$

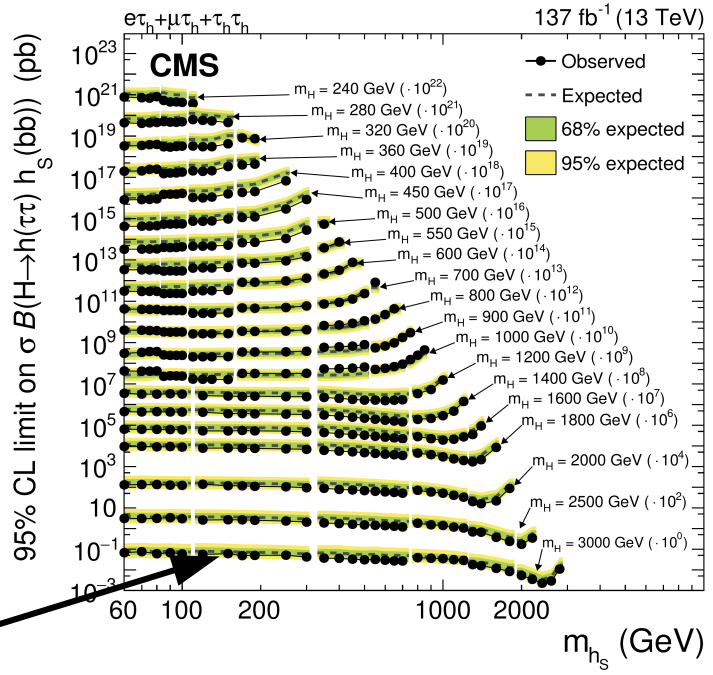
- no signal found

→ upper 95% CL limits on σ×BR

240 GeV < m_H < 3000 GeV, 60 GeV < m_{hs} < 2800 GeV

limits range from 125 fb (m_H = 240 GeV, m_{hs} = 85 GeV) to 2.7 fb (m_H = 1000 GeV, m_{hs} = 350 GeV)





- Interpretation within NMSSM

→ exclusion of (m_{hs},m_H) region based on maximally allowed σ×BR

$m_H \simeq$ 400 – 600 GeV

$m_{hs} \simeq$ 60 – 200 GeV

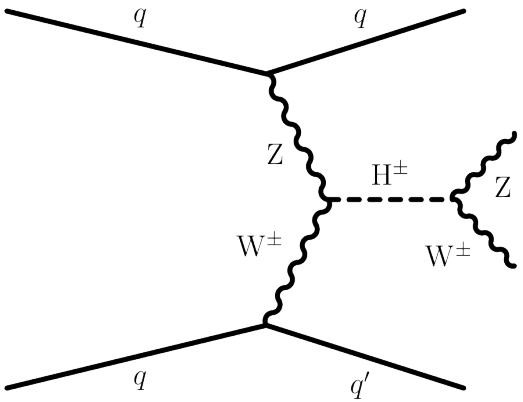
$H^{\pm}\rightarrow W^{\pm}Z$ and $H^{\pm\pm}\rightarrow W^{\pm}W^{\pm}$ decays

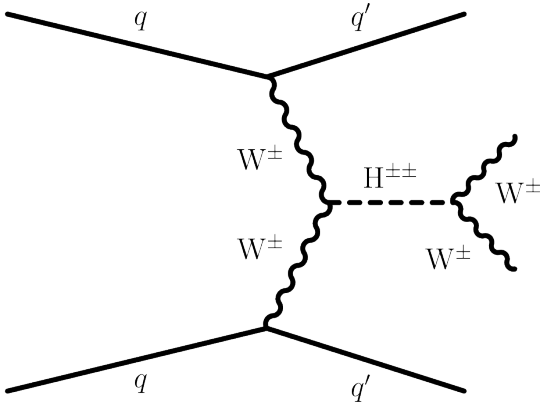
- Georgi-Machacek model : SM doublet + 2 triplets (real and complex)
  - preserves custodial SU(2) symmetry
  - physical spectrum contains quintet of fermiophobic states $(\mathrm{H}_5^{--}, \mathrm{H}_5^{-}, \mathrm{H}_5^{0}, \mathrm{H}_5^{+}, \mathrm{H}_5^{++})$ degenerate in mass (m_{H_5})
  - accessible via VBF/VH production and decays to weak bosons

$$g_{H_5VV} \sim s_{\mathrm{H}} = 2\sqrt{2}\frac{v_\chi}{v}, \quad v^2 = v_\phi^2 + 8v_\chi^2, \quad v = 246\ \mathrm{GeV}$$

v_ϕ - v.e.v. of doublet, v_χ - v.e.v. of triplets

- presented analysis searches for singly and doubly charged Higgs bosons





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arXiv:2104.04762

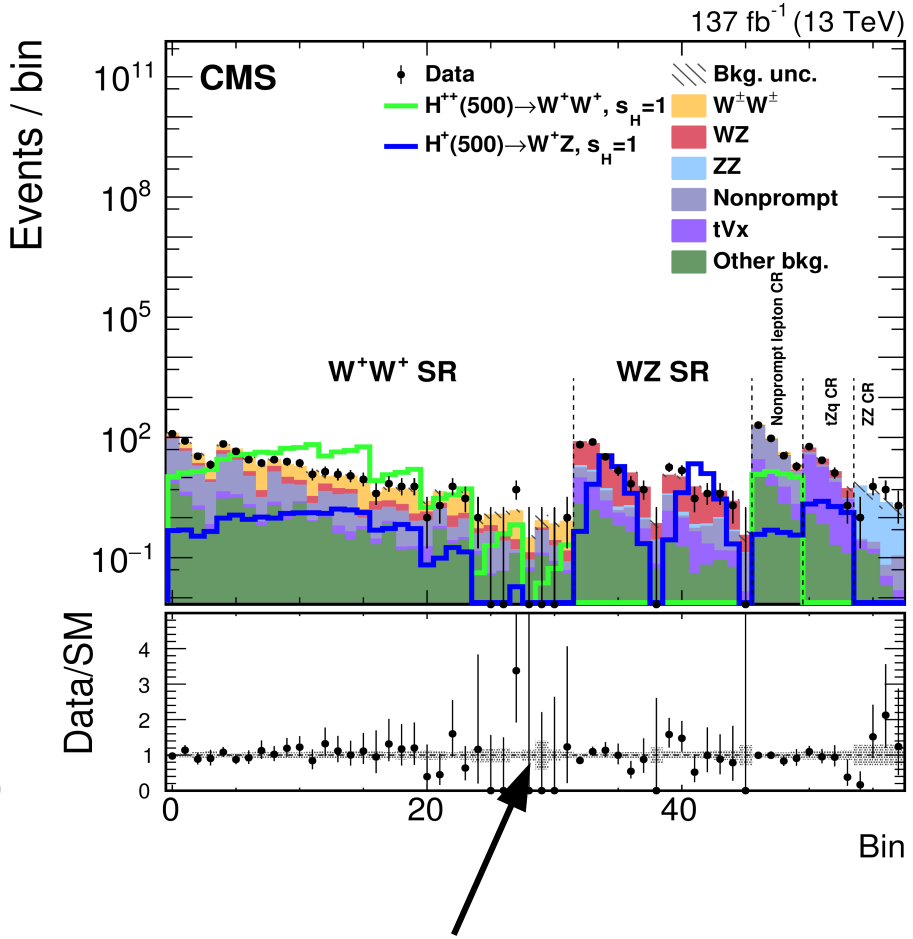
$H^{\pm}\to W^{\pm}Z$ and $H^{\pm\pm}\to W^{\pm}W^{\pm}$ decays

- Signature : 2 same-sign ($\ell^{\pm}\ell^{\pm}$) or 3 ($\ell^{\pm}\ell^{\pm}\ell^{\mp}$) leptons + 2 VBF jets
- 2 signal regions (SR)
  - I. WW : $\ell^{\pm}\ell^{\pm}$ + 3rd lepton veto
  - II. WZ : $\ell^{\pm}\ell^{\pm}\ell^{\mp}$
- control regions (CR) to constrain backgrounds:

  j→ℓ fakes, ZZ, qZt
- signal extracted from combined fit in SRs and CRs

SRs : 2D distributions: $(m_{\mathrm{T}}^{VV}, m_{jj})$

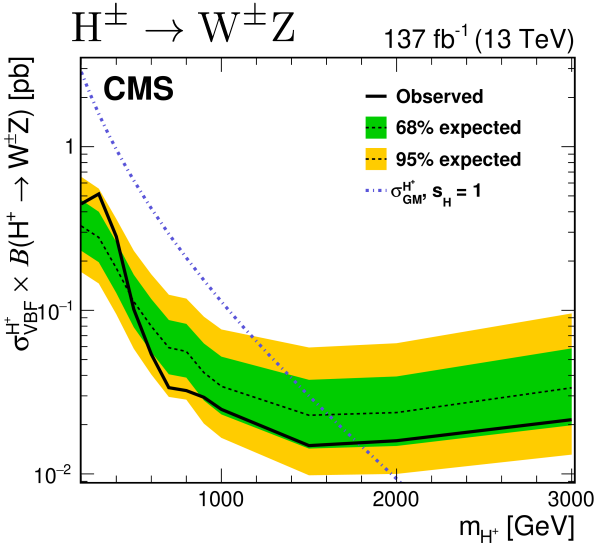
CRs : 1D distributions: m_{jj}

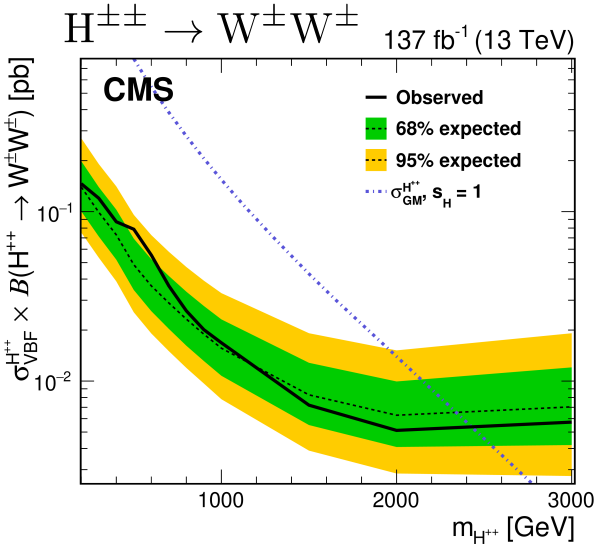


Set of analysis bins used in fit (unrolled 2D distributions in SRs + 1D distributions in CRs)

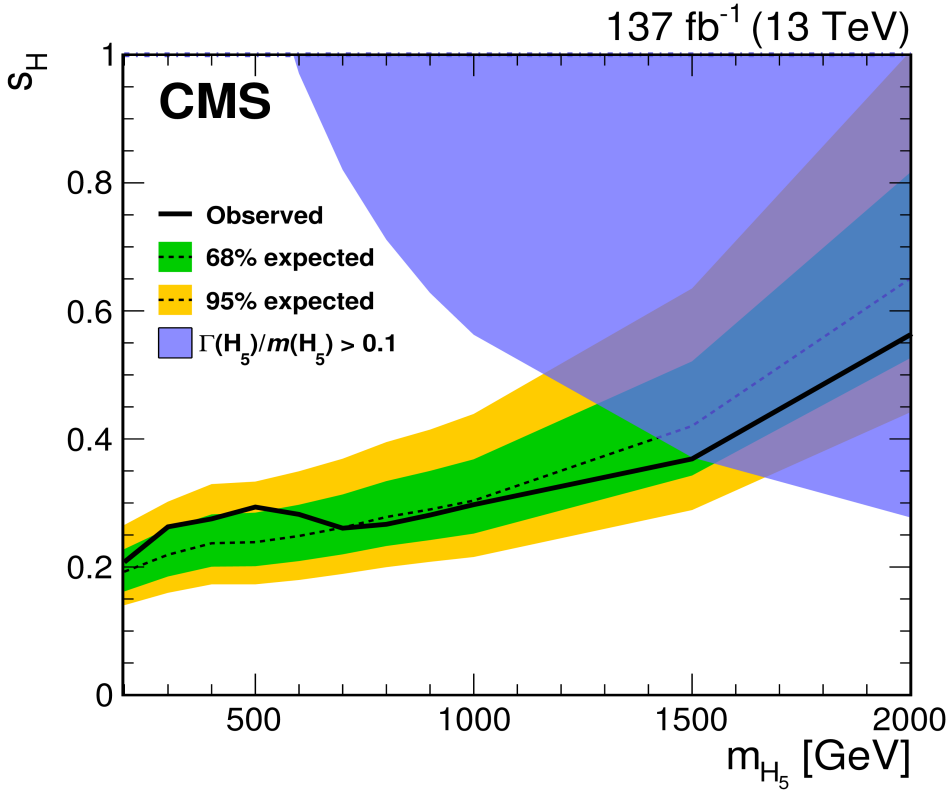
$H^{\pm} \to W^{\pm}Z$ and $H^{\pm\pm} \to W^{\pm}W^{\pm}$ decays

- no signal found → upper 95% CL limits on σ×BR





assumption: $\Gamma_{H^{\pm}(\pm)} \leq 0.1 \cdot m_{H^{\pm}(\pm)}$



- Interpretation within Georgi-Machacek model

→ limits on s_H as a function of m_{H_5}

Summary

- Theories with extended Higgs sector are proposed to overcome shortcomings of the SM
  - predict deviations of the H(125) properties from the SM expectations
  - postulate existence of additional Higgs bosons
- Searches for additional Higgs bosons of 2HDM (MSSM) and beyond are performed at CMS with partial or full LHC Run 2 dataset
  - large variety of channels studied
  - broad mass range probed
- Advanced analysis techniques are developed to boost sensitivity of searches beyond increase in luminosity
  - e.g. deep learning to identify physics objects (b-jets, τ, …) and discriminate signal against background
- No signal found (so far) $\rightarrow$ large set of models excluded
- Many new results with full Run 2 and eventually Run 3 datasets are expected.