

Searches for additional Higgs bosons with the CMS detector

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On behalf of the CMS collaboration



125 GeV Higgs boson is (so far) consistent with **SM** predictions



However an extended Higgs sector is strongly motivated
(Hierarchy problem, baryon asymmetry, dark matter/energy...)

Many BSM theories require 2 Higgs doublets ϕ_1 and ϕ_2 (**2HDMs**)



2 important free parameters : α and $\tan \beta$
(mixing angle of h and H , and ratio of the VEVs of ϕ_1 and ϕ_2)

MSSM contains Type-2 2HDM
(up-type q couple to ϕ_2 , down-type q and ℓ^\pm couple to ϕ_1)

h usually identified as h(125)

2 additional neutral Higgs bosons : **H** (CP-even) and **A** (CP-odd)



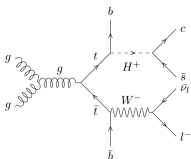
2 additional charged Higgs bosons : **H[±]**



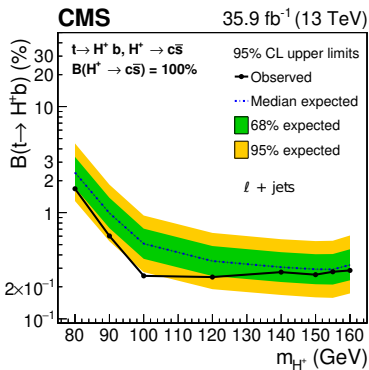
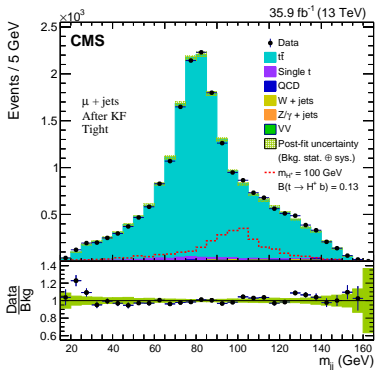
Will report on latest additional Higgs boson searches at CMS

Analyses reported here use 35.9 fb^{-1} of 2016 data

Low mass $H^\pm \rightarrow cs$

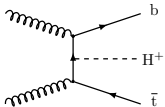


- Dominant H^\pm decay to cs at low $\tan \beta$ - Search in $t\bar{t}$ process
- Require ℓ , MET and ≥ 4 jets (≥ 2 b-tagged)
- Use kinematic fit with m_t constraints on reco objects
- Discriminant is m_{jj} of 2 non-b jets - Categorisation based on c-tagging of jj

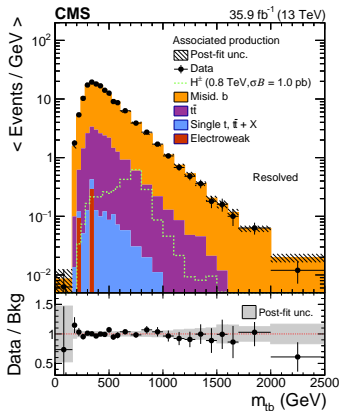
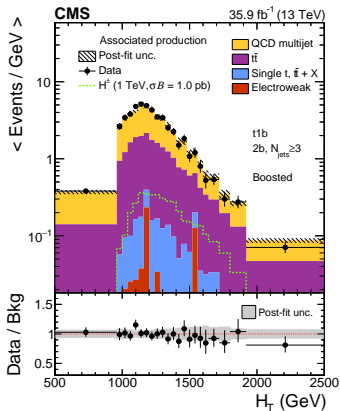


Heavy $H^\pm \rightarrow tb$ (All – Hadronic)

CMS-HIG-18-015
arXiv:2001.07763



- 2 production processes : s-channel and t+b associated production
- Target boosted and resolved topologies - Categorisation based on #Jets, boosted t/W and b tagging
- Discriminants are H_T (Boosted) and m_{tb} (Resolved)
- Data-driven estimate of QCD multijet Bkg using CRs

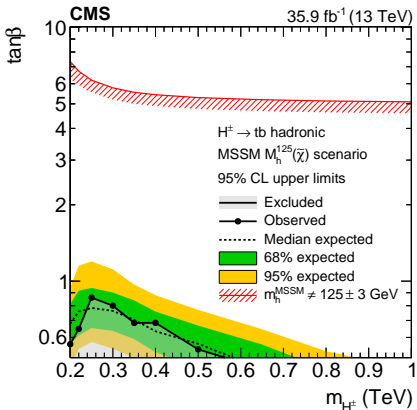
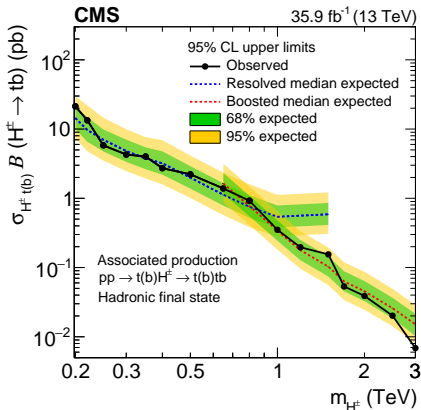


Heavy $H^\pm \rightarrow tb$ (All – Hadronic)

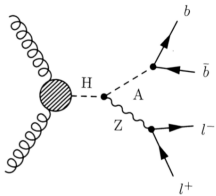
Limits set on $\sigma_{H^\pm \rightarrow tb}$

Resolved/Boosted crossover at 0.9 TeV

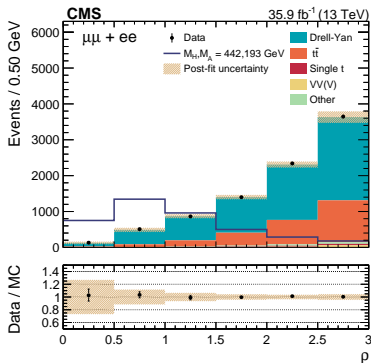
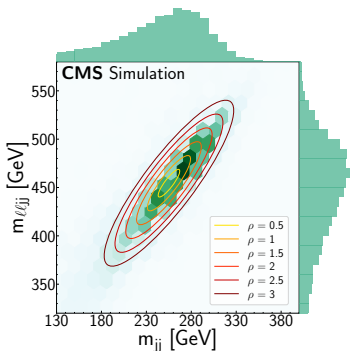
Limits set in MSSM benchmark scenarios



Heavy $H \rightarrow Z(\ell\ell)A(b\bar{b})$

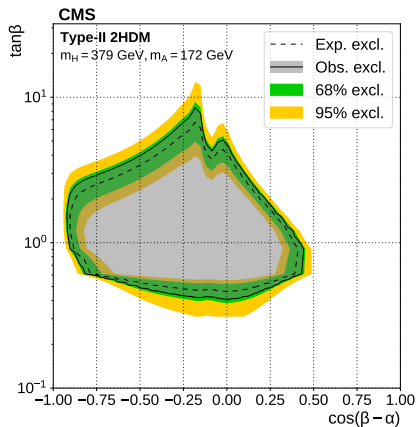
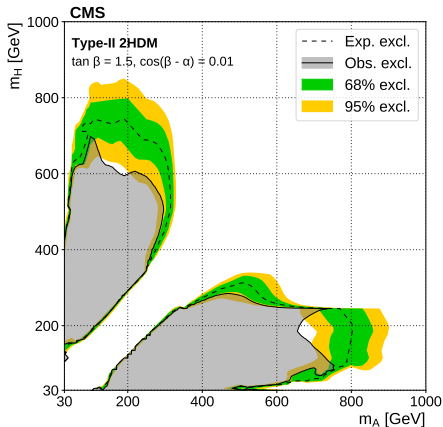


- Largest Br in 2HDM when $\cos(\beta - \alpha) \rightarrow 0$ (SM-like h)
- Main discriminants are m_{jj} (2 b-tagged jets) and $m_{\ell\ell jj}$
- Define elliptical SR in $m_{jj} - m_{\ell\ell jj}$ plane
- 6 elliptical bins defined in ρ ($\sim 1\sigma$ of signal resolution)
- Data-driven estimate of $t\bar{t}$ with $e\mu$ CR



Heavy $H \rightarrow Z(\ell\ell)A(b\bar{b})$

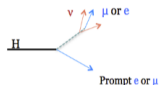
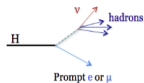
Twisted (Classical) custodial symmetry : $m_H > m_A$ ($m_A > m_H$)
 Also sensitive to $A \rightarrow Z(\ell\ell)H(b\bar{b})$



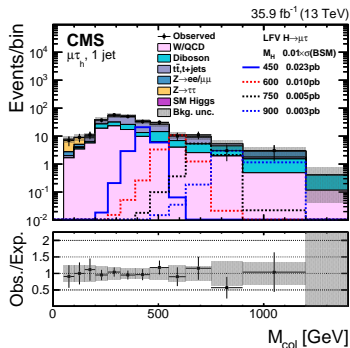
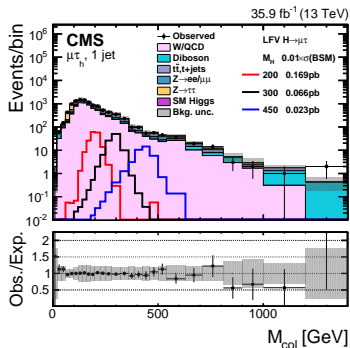
+ New spin-1 $X \rightarrow Z(\ell\ell, \nu\nu)h(b\bar{b})$ search

*See talk by Dennis

Heavy $H \rightarrow \mu\tau$ and $e\tau$

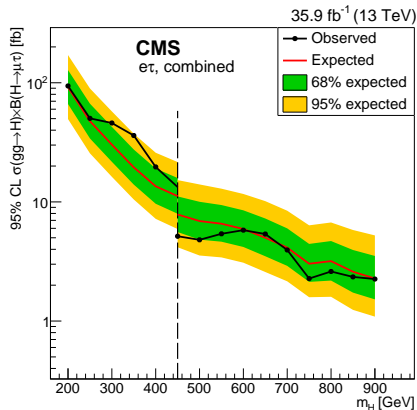
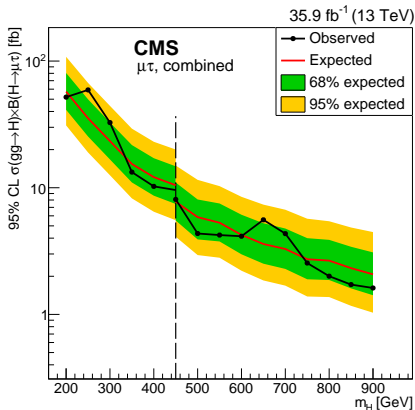


- Lepton flavour violating decays of Higgs allowed in some BSM theories - 4 decay channels considered : $\mu\tau_e, \mu\tau_h, e\tau_\mu, e\tau_h$
- Discriminant is collinear mass $M_{Col} = M_{Vis} / \sqrt{\chi_{\tau}^{vis}}$
- Low ($m_H < 450$ GeV) and high mass ($m_H \geq 450$ GeV) selection
- Reducible bkg (Fake ℓ) estimation from Z+Jets and $\ell^{\pm}\tau^{\pm}$ data



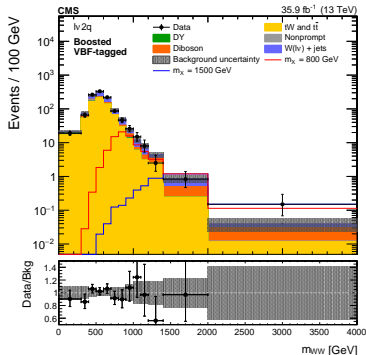
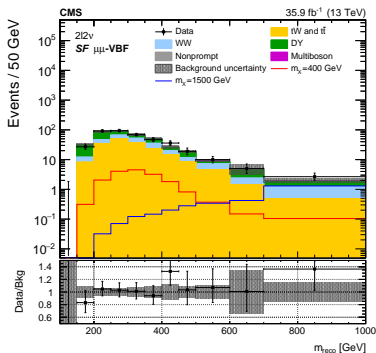
Heavy $H \rightarrow \mu\tau$ and $e\tau$

Limits set on $\sigma(gg \rightarrow H) \times Br(H \rightarrow \mu\tau)$ and $\sigma(gg \rightarrow H) \times Br(H \rightarrow e\tau)$



Heavy $H \rightarrow WW$

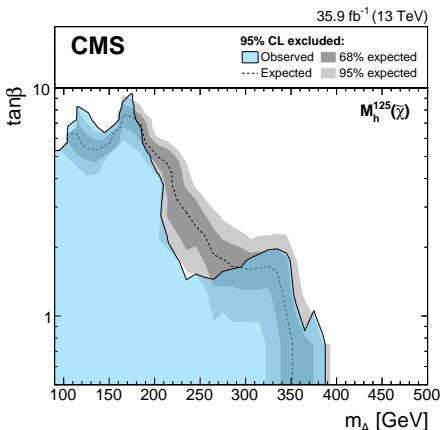
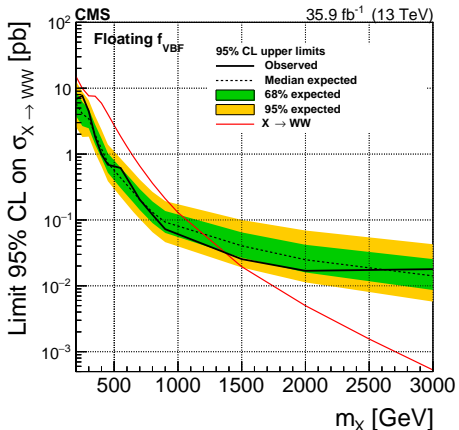
- ggF and VBF H with SM width (interference effects considered)
- $2l2\nu$ (SF & DF ll) and $l\nu q\bar{q}$ (Resolved & Boosted W_{Had}) channels
- Discriminants are reconstructable mass m_{reco} and H invariant mass m_{WW}
- Categorisation of ggF and VBF-like events



Heavy $H \rightarrow WW$

Limits set on $\sigma_{H \rightarrow WW}$ for different f_{VBF}
 f_{VBF} = fraction of σ_H due to VBF

Limits set in MSSM benchmark scenarios



And many more final states investigated!!

- $H \rightarrow t\bar{t}$
JHEP 04 (2020) 171
- $A \rightarrow Z(\ell^+\ell^-)h(b\bar{b})$
JHEP 06 (2019) 143
- $H \rightarrow \mu^+\mu^-$
PLB 798 (2019) 134992
- $A \rightarrow Z(\ell^+\ell^-)h(\tau^+\tau^-)$
JHEP 03 (2020) 065
- $A \rightarrow \tau\tau$
JHEP 05 (2019) 210
- $H^\pm \rightarrow tb$ (Leptonic)
JHEP 01 (2020) 096
- $H^\pm \rightarrow W^\pm A$
PRL 123 (2019) 131802
- $H^\pm \rightarrow \tau^\pm\nu$
JHEP 07 (2019) 142

+ Many $H \rightarrow 2a$ searches - Extensions of 2HDM/MSSM with additional scalars

*See talk by Fengwangdong

+ Many resonant HH searches

*See talk by Alessia

Summary

- Latest results using 2016 dataset on searches for additional Higgs bosons at CMS presented
- No evidence for BSM physics observed
- Large areas of parameter space of 2HDMs excluded
- Many new results to come with full Run 2 dataset

