

Searches for additional neutral Higgs bosons at CMS

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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)

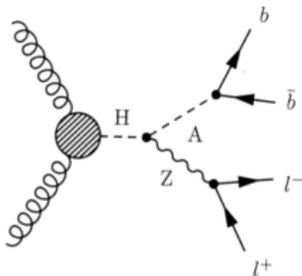
2 additional neutral Higgs bosons : **H** (CP-even) and **A** (CP-odd)



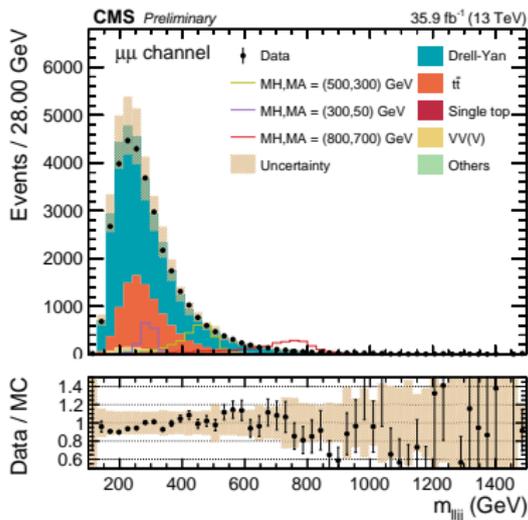
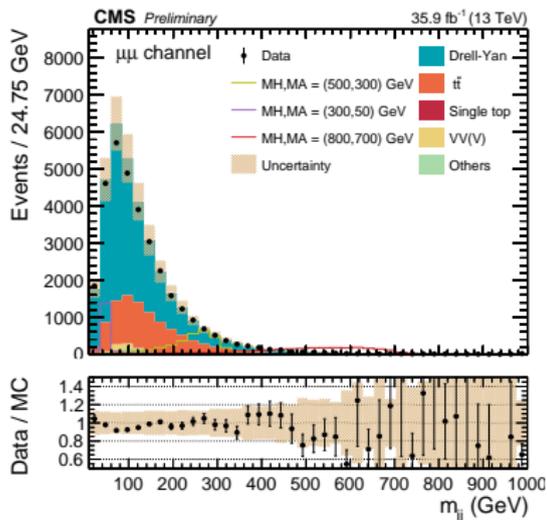
Will report on latest neutral Higgs boson searches at CMS

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

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



- Largest Br in 2HDM when $\cos(\beta - \alpha) \rightarrow 0$ (SM-like h)
- Main discriminants are m_{jj} (2 b-tagged jets) and $m_{\ell\ell jj}$
- Categorization by lepton flavour (ee and $\mu\mu$)
- Z+Jets (largest Bkg) estimated from simulation
- Data-driven estimate of $t\bar{t}$ with $e\mu$ CR



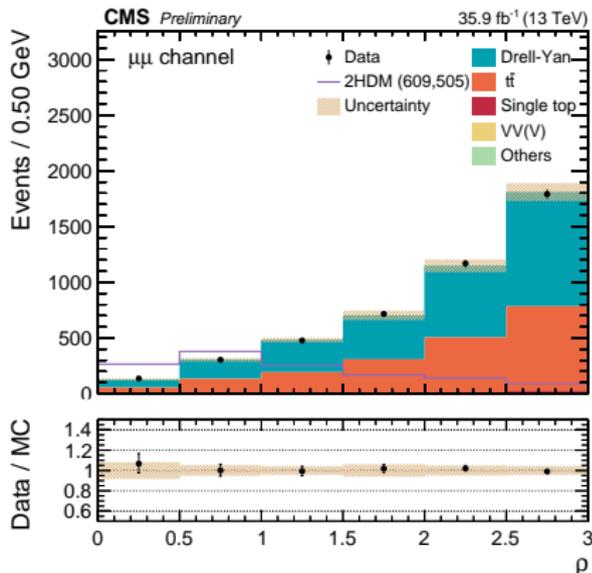
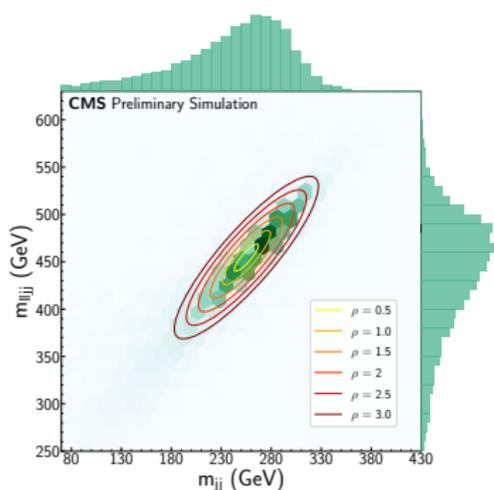
$H \rightarrow Z(\ell\ell)A(b\bar{b})$

For each signal hypothesis define elliptical SR in $m_{jj} - m_{\ell\ell jj}$ plane (SR)

Dilation parameter ρ sets size of ellipse ($1\rho \sim 1\sigma$ of signal resolution)

6 elliptical bins defined from $\rho=0$ to $\rho=3$

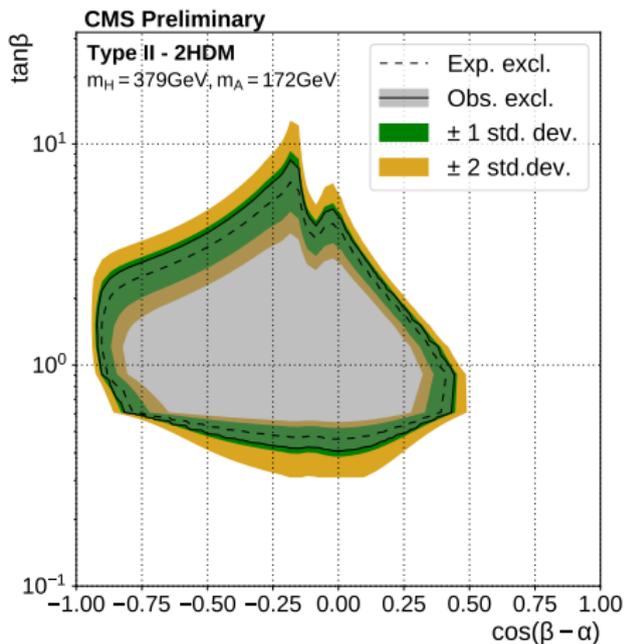
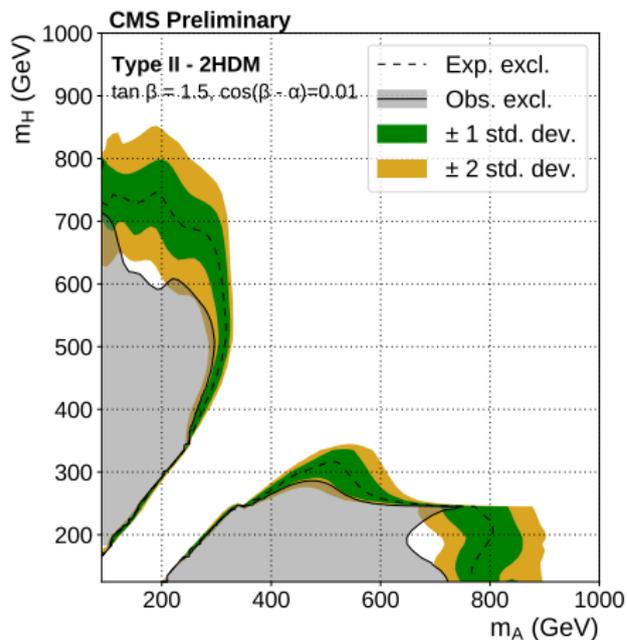
ρ templates used in final statistical analysis



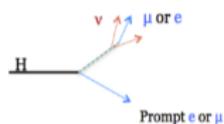
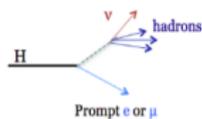
$H \rightarrow Z(\ell\ell)A(b\bar{b})$

Twisted (Classical) custodial symmetry : $m_H > m_A$ ($m_A > m_H$)

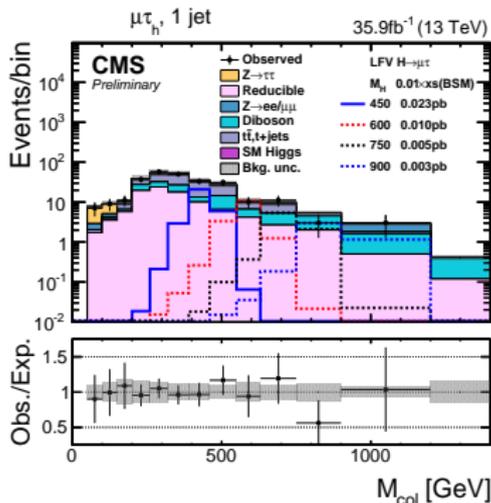
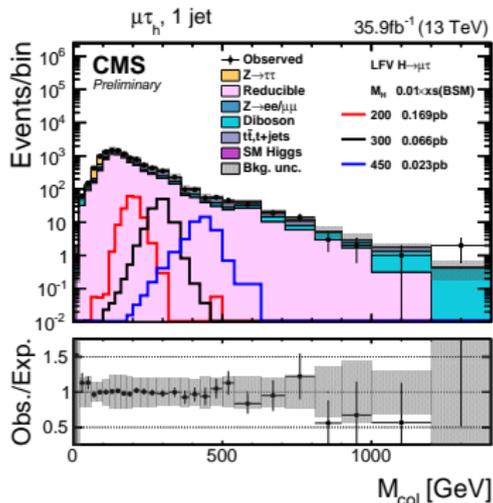
Also sensitive to $A \rightarrow Z(\ell\ell)H(b\bar{b})$



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

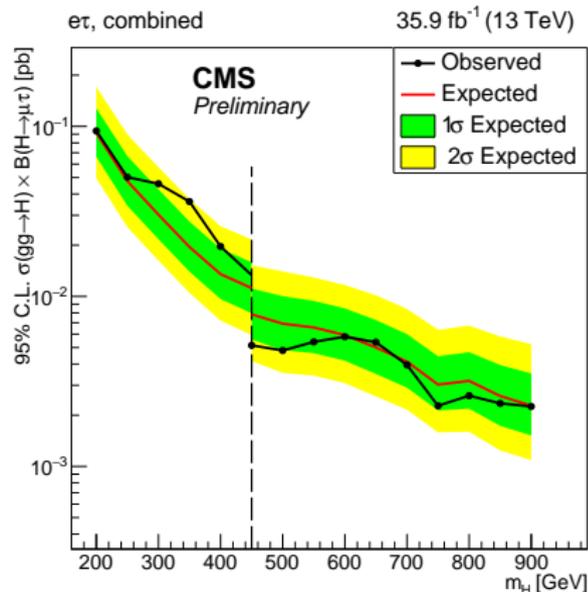
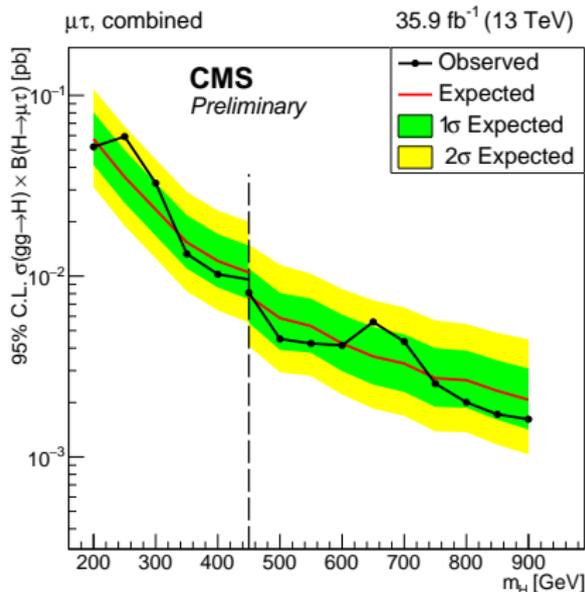


- Lepton flavour violating decays of Higgs allowed in some BSM theories - 4 decay channels considered : $\mu\tau_e$, $\mu\tau_h$, $e\tau_\mu$, $e\tau_h$
- Discriminant is collinear mass $M_{Col} = M_{Vis}/\sqrt{x_\tau^{vis}}$ (x_τ^{vis} estimated assuming ν are collinear with visible τ decay)
- Categorization by jet multiplicity (0 and 1 jet)
- 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

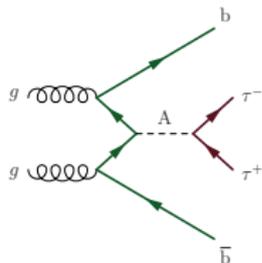


$H \rightarrow \mu\tau$ and $e\tau$

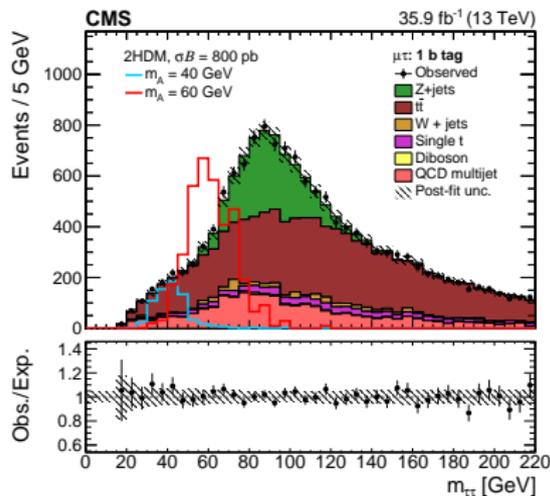
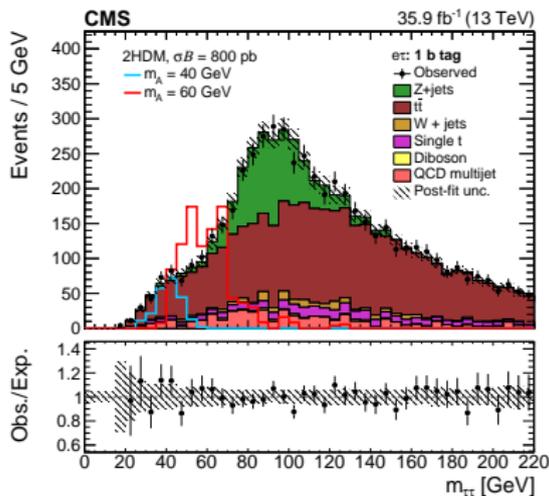
Limits set on $\sigma(gg \rightarrow H) \times Br(H \rightarrow \mu\tau)$ and $\sigma(gg \rightarrow H) \times Br(H \rightarrow e\tau)$



$bbA(\text{low mass } A \rightarrow \tau\tau)$



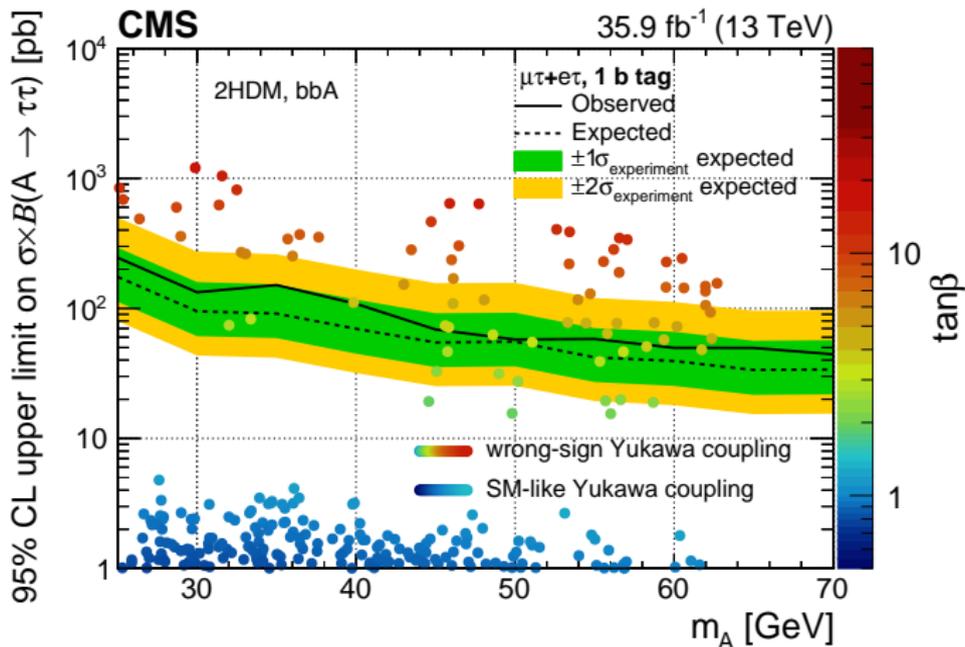
- Enhanced when Yukawa coupling of A to down-type fermions is negative - Search for $e\tau_h$ or $\mu\tau_h$ and a b-tag jet
- Cut on D_ζ which quantifies alignment of visible decay products with missing neutrinos
- Discriminant is $m_{\tau\tau}$ from SV_{FIT} algorithm
- $t\bar{t}$ and W +Jets predictions verified in data CRs while Multijet bkg estimated with $\ell^\pm\tau^\pm$ CR



$bbA(\text{low mass } A \rightarrow \tau\tau)$

Limits set on $\sigma(bbA) \times Br(A \rightarrow \tau\tau)$

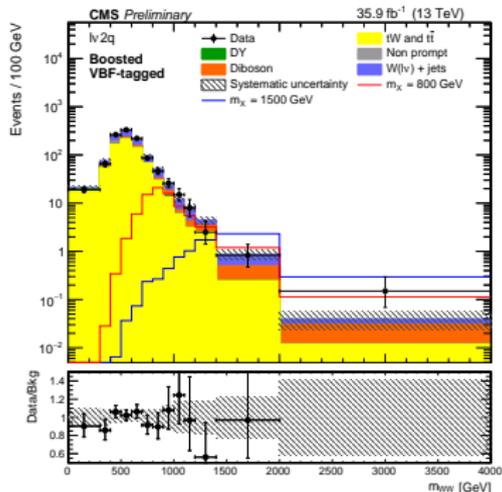
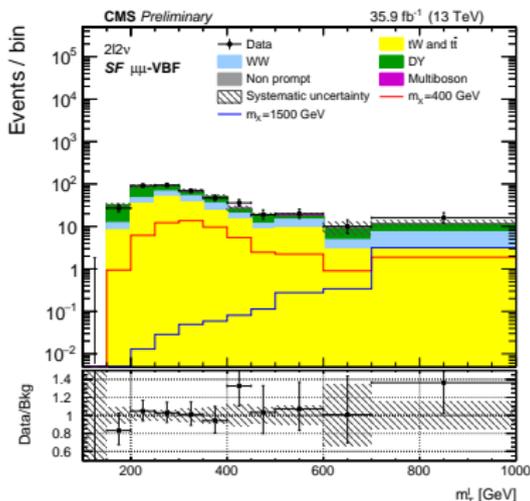
Representative 2HDMs shown for 2 types of Yukawa couplings (SM-like and wrong-sign)



$H \rightarrow WW$

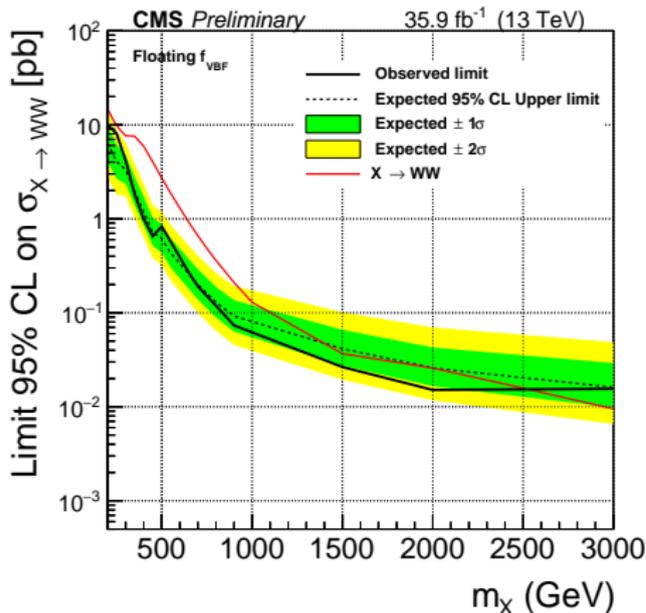
ggF and VBF H with SM width (interference effects considered)

Channel	$2l2\nu$	$l\nu q\bar{q}$
Discriminant	Higgs Visible mass m_T^l	Higgs mass m_{WW}
Channels	DF & SF ll	l , Resolved & Boosted W_{Had}
Categorization	based on #jets and tagging of VBF-like events	based on MELA and tagging of VBF-like events
Major bkg s :	WW, DY and $t\bar{t}$ from data-driven estimates	W+Jets and $t\bar{t}$ from data-driven estimates

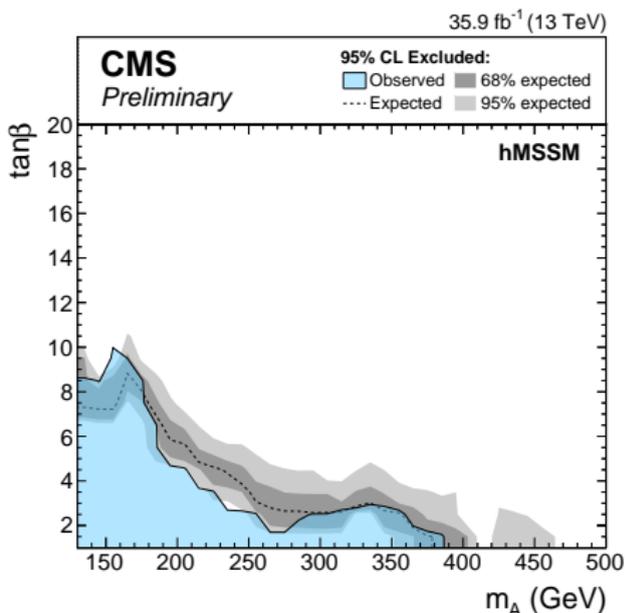


$H \rightarrow WW$

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



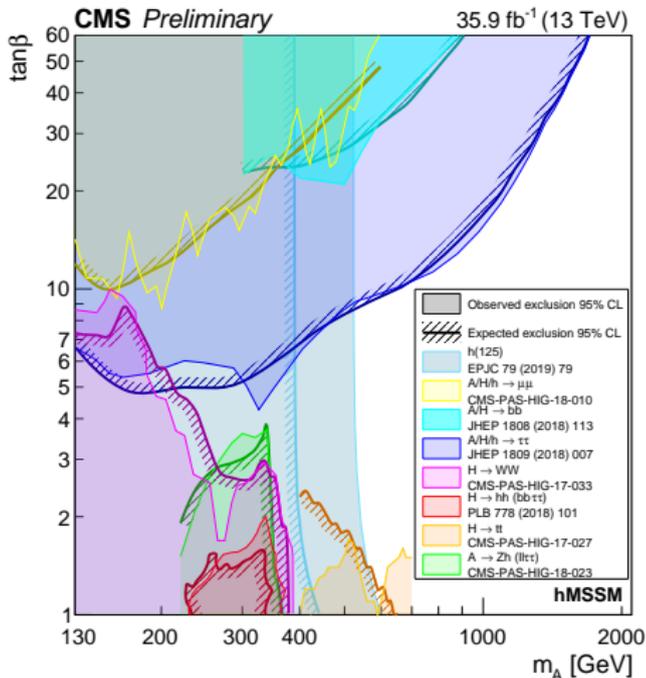
Limits set in MSSM benchmark scenarios
 Free parameters set so wide range of
 $m_A - \tan\beta$ is compatible with h(125)



*See talk by Dennis Roy yesterday in Searches for New Physics

And many more final states have been investigated!!

- $H \rightarrow t\bar{t}$
CMS-PAS-HIG-17-027
- $A \rightarrow Z(\ell^+\ell^-)h(b\bar{b})$
CMS-PAS-HIG-18-005
- $H \rightarrow \mu^+\mu^-$
CMS-PAS-HIG-18-010
arXiv:1907.03152
- $A \rightarrow Z(\ell^+\ell^-)h(\tau^+\tau^-)$
CMS-PAS-HIG-18-023
- Many $H \rightarrow 2a$ searches
- Extensions of
2HDM/MSSM with
additional scalars
*See talk by Fengwangdong
yesterday



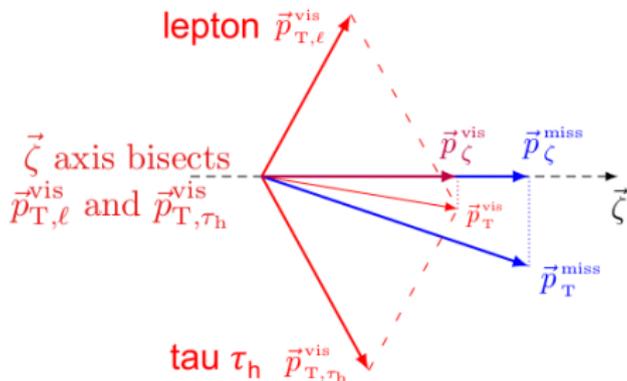
Summary

- Latest results using 2016 dataset on searches for additional neutral 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
→ Almost factor 4 increase in statistics!

Backup

D_ζ Discriminant

p_ζ^{miss} = component of p_T^{miss} along bisector ζ
 p_ζ^{vis} = sum of parallel components of ℓ and τ p_T



$$D_\zeta = p_\zeta^{\text{miss}} - 0.85 p_\zeta^{\text{vis}}$$

Remove $t\bar{t}$ and $W+\text{Jets}$ with $D_\zeta > -40$ GeV