Searches for BSM Higgs at CMS

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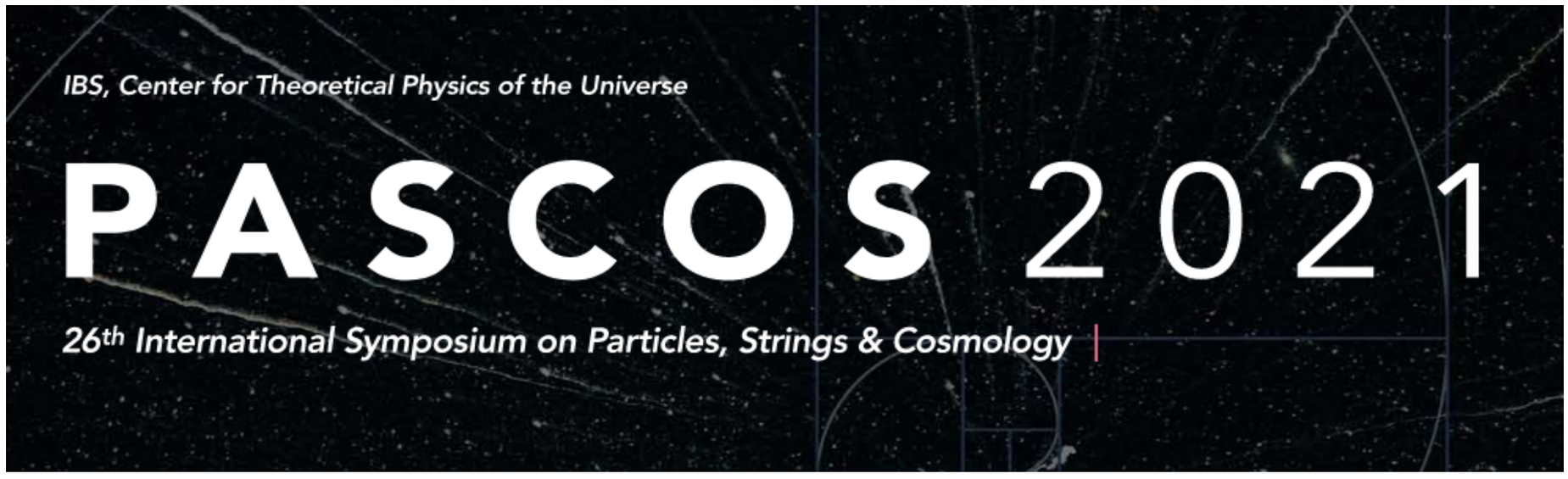


Motivation: BSM Higgs searches

Observed Standard model Higgs boson at a mass of 125 GeV may not be the only one in nature.

Extended Higgs sector is strongly motivated (Hierarchy problem, neutrino oscillation, baryon asymmetry, nature of dark matter/energy)

Additional Higgs bosons are predicted by BSM theories : 2HDM, NMSSM

Neutral Higgs (**h/H/A**) and charged Higgs bosons (**$H^{\pm}$/$H^{\pm\pm}$**).

Many searches for BSM higgs at LHC with full Run-II dataset with a wide mass range.

Some latest BSM Higgs searches at CMS

- Heavy neutral Higgs boson searches:

  Decays to observed SM Higgs boson and another higgs boson:
  $H \rightarrow h(125)h \rightarrow bb\tau\tau$ [CMS-PAS-HIG-20-014]

- Charged Higgs boson searches:

  Single charged Higgs boson : **$H^{\pm} \rightarrow cs$ [CMS Phy.Rev.D 102 072001]**

  Single and double charged Higgs bosons:

  $H^{\pm} \rightarrow W^{\pm}Z$ and $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ [CMS arxiv:2104.04762]

Heavy neutral Higgs boson: $H \to h(125) h_s \to bb\tau\tau$ [CMS-PAS-HIG-20-014]

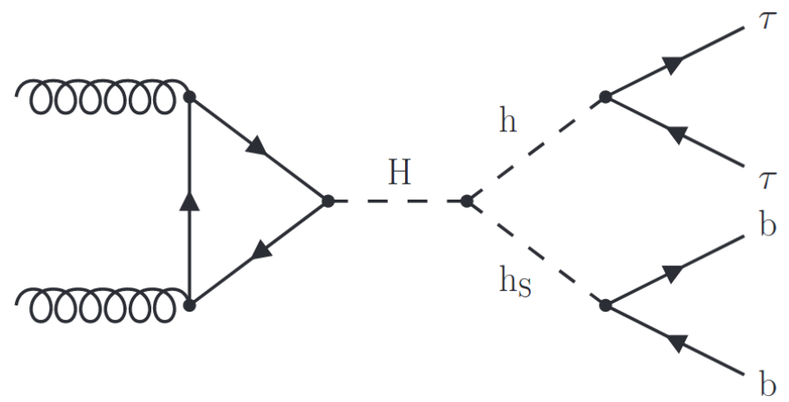
$m_{hs} < m_H - m_h$

First BSM search for a heavy neutral Higgs boson decaying to a standard model Higgs boson and a neutral Higgs boson.

Analysed full Run-II data sample : **137 fb^{-1}**

For τ pairing: **eτ$_h$, μτ$_h$, τ$_h$τ$_h$** final states.

1 or 2 b-jets are considered.



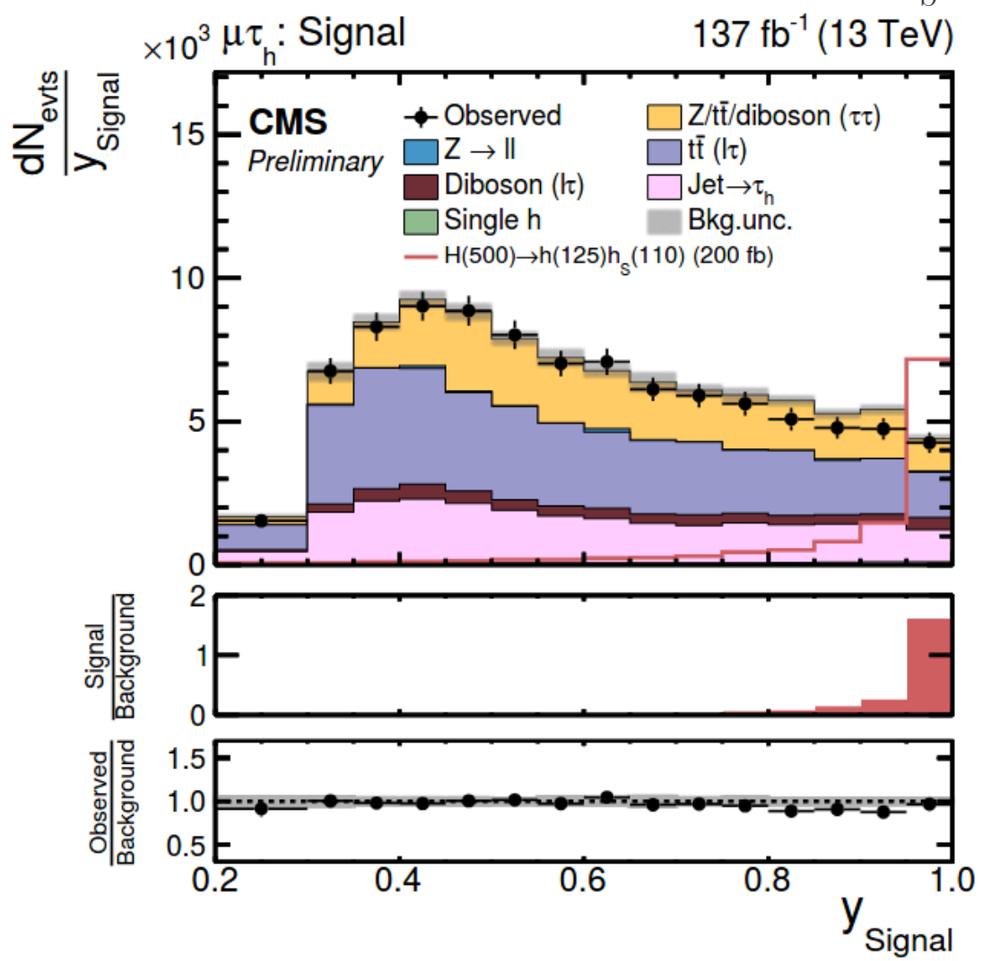
Event selection :

Final state	Electron/Muon	τ_h
$e\tau_h$	$p_T > 25(26, 28, 33)$ GeV $\lvert\eta\rvert < 2.1$ $I^e_{rel} < 0.15$	$p_T > 35(30)$ GeV $\lvert\eta\rvert < 2.3$ $D_{jet}(70\%), D_e(10^{-4}), D_\mu(10^{-3})$
$\mu\tau_h$	$p_T > 20(23, 25)$ GeV $\lvert\eta\rvert < 2.1$ $I^\mu_{rel} < 0.15$	$p_T > 35(30)$ GeV $\lvert\eta\rvert < 2.3$ $D_{jet}(70\%), D_e(10^{-2}), D_\mu(10^{-4})$
$\tau_h\tau_h$	–	$p_T > 40$ GeV $\lvert\eta\rvert < 2.1$ $D_{jet}(70\%), D_e(10^{-2}), D_\mu(10^{-3})$

Event Classification :

Event categorisation and signal extraction is based on Neural Network (NN) based multi classification.

5 event categories by choosing M_H = 500 GeV and $100 < m_{hs} < 150$ GeV

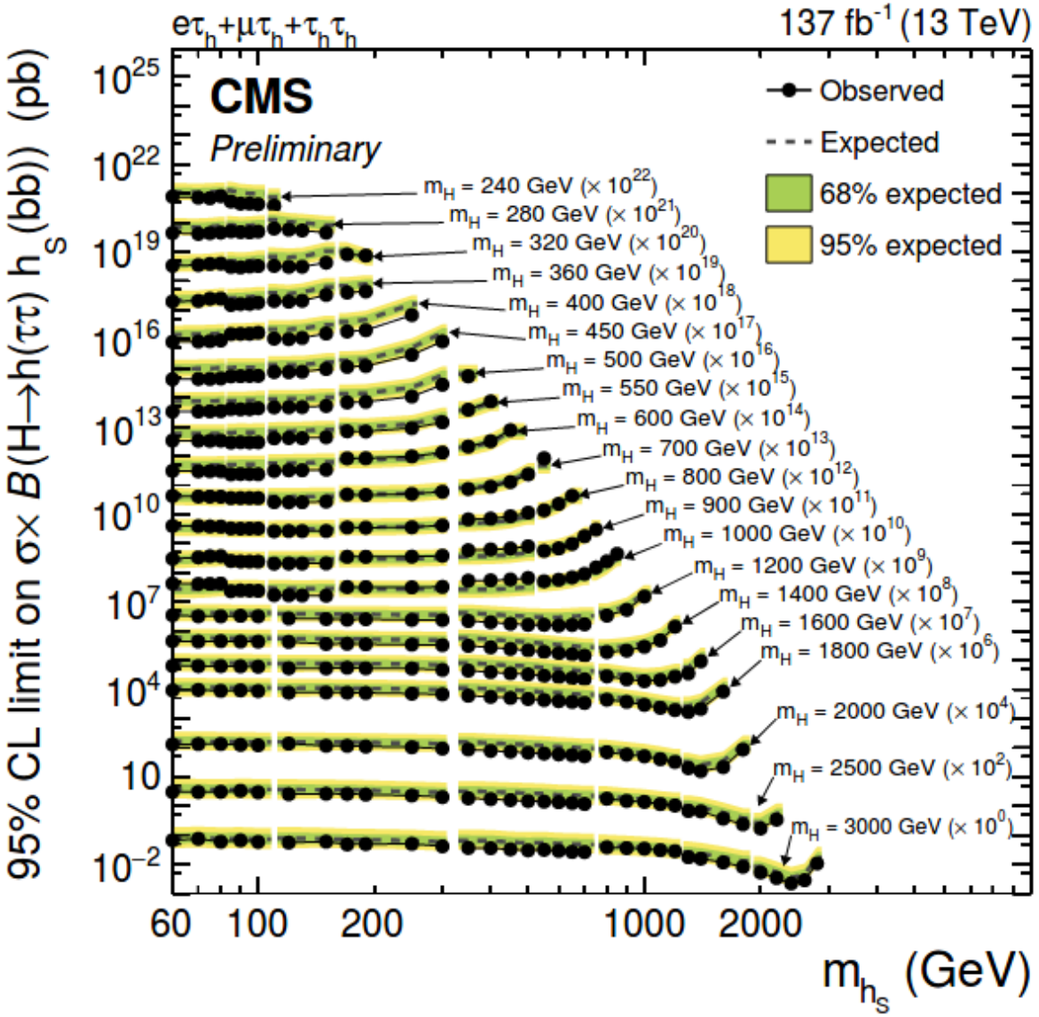


[NN output for μτ$_h$ signal]

Heavy neutral Higgs boson : H → h(125)h_s → bbττ (Cont.)

Search range explored :

M_H : 240 – 3000 GeV, m_{hs} : 60 – 2800 GeV



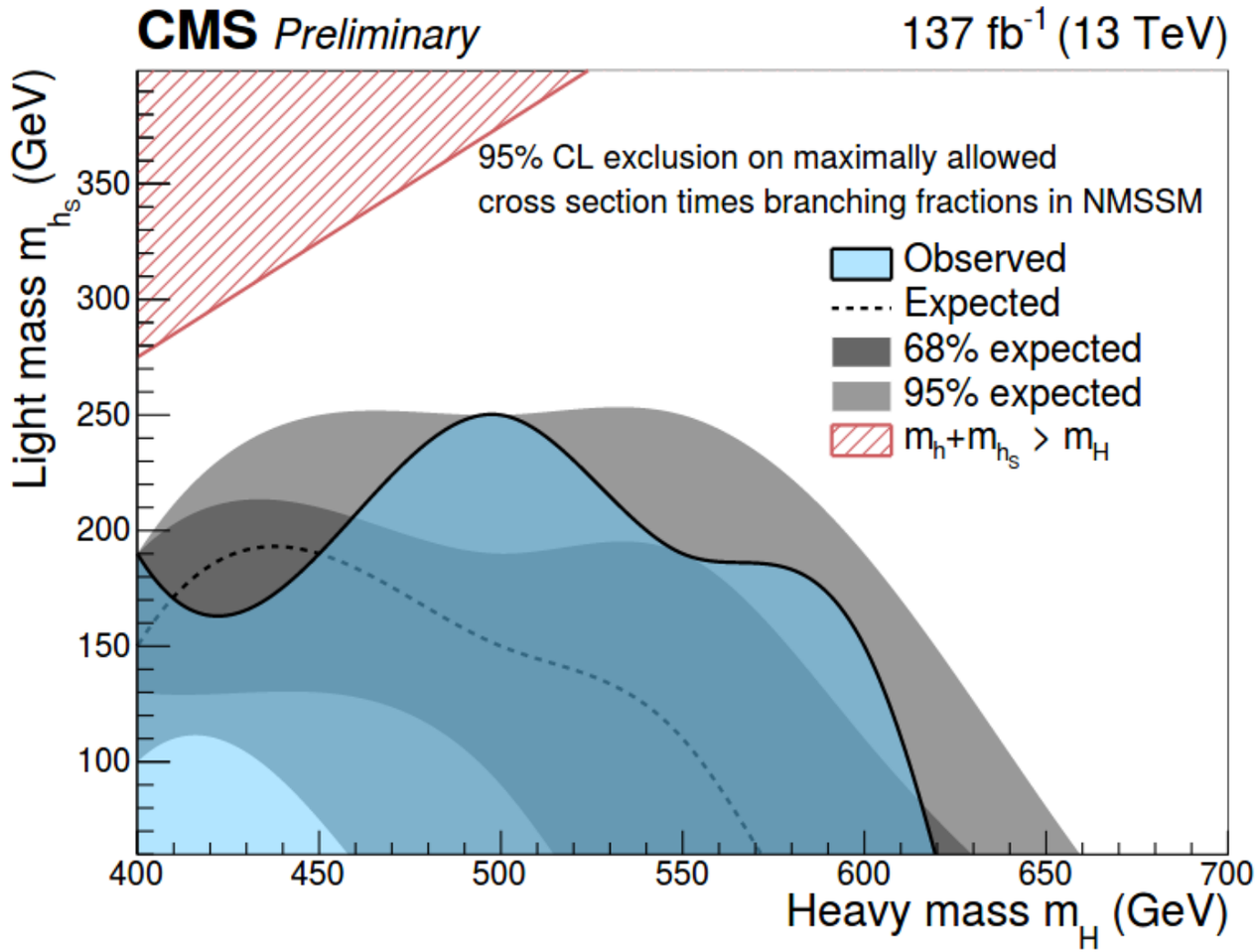
No signal has been observed.

95% confidence level upper limit on σ x BR:

125 fb at m_H = 240 GeV

2.7 fb at m_H = 3000 GeV

Interpretation in NMSSM



Exclusion on the maximally allowed ranges for **σ x BR (H → h(tt)h_s (bb)) :**

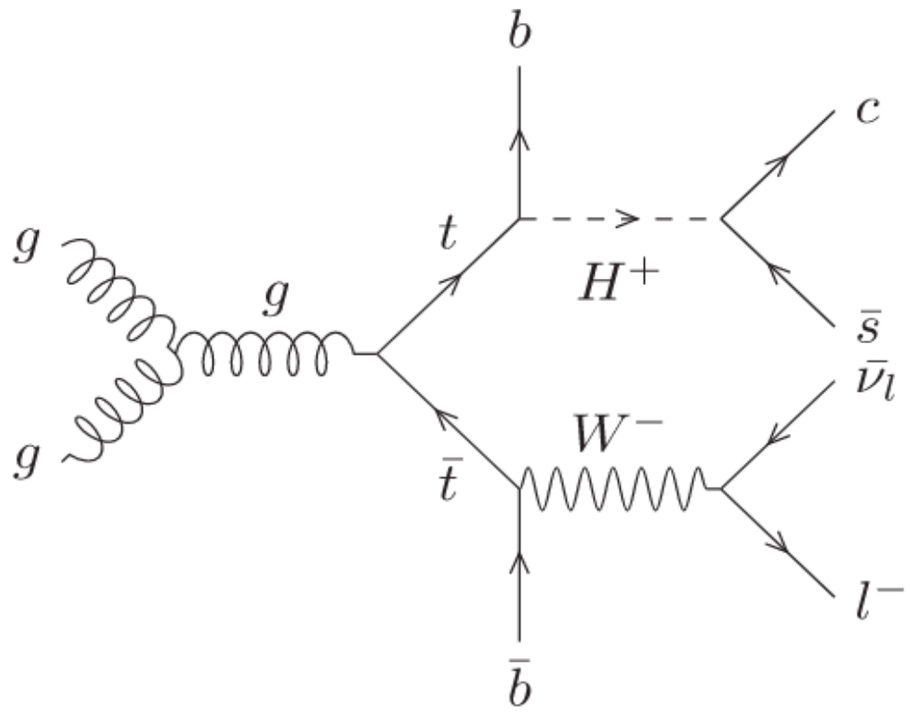
Constrained for masses of **m_H ~ 400 – 620 GeV** and **m_{hs} ~ 60 - 250 GeV**

Single charged Higgs boson : $H^{\pm} \rightarrow cs$

[CMS Phy.Rev.D 102 072001]

First Search at LHC performed in the process of top quark pair Production.

$t \rightarrow H^{\pm} b$, $t \rightarrow bw$



Event selection:

Final state contains:

charged lepton + MET (p_T^{miss}) + at least 4 jets

2 bjets, one c jet and one light-flavor jet

Search sensitivity is enhanced by choosing one bjet tagged to charm quarks.

Muon (electron) with **p_T > 26 (30) GeV** and **$|\eta|$ < 2.4 (2.5)**.

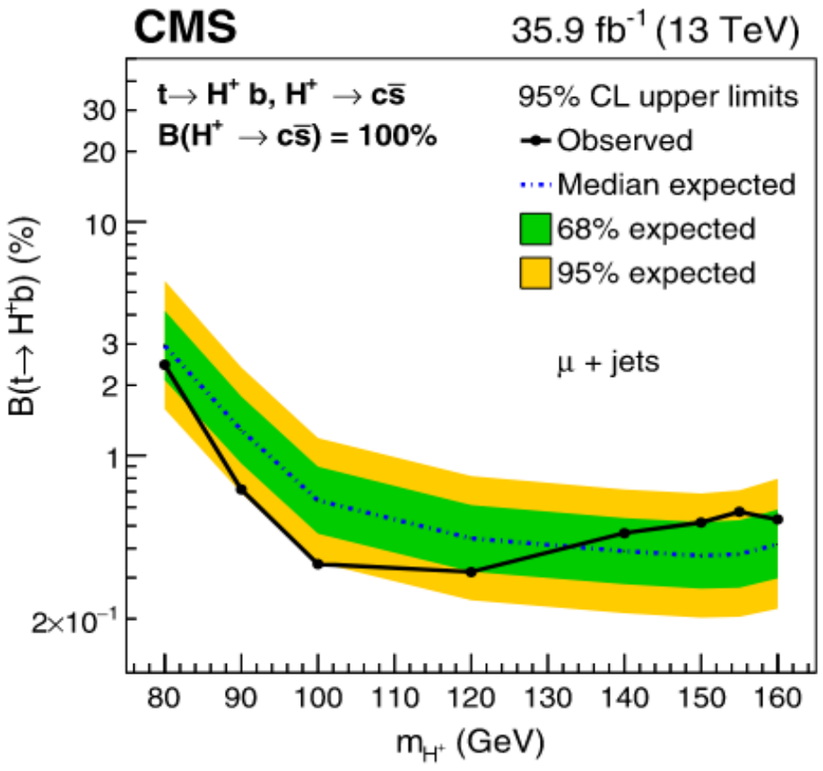
Muon isolation **< 0.15**.

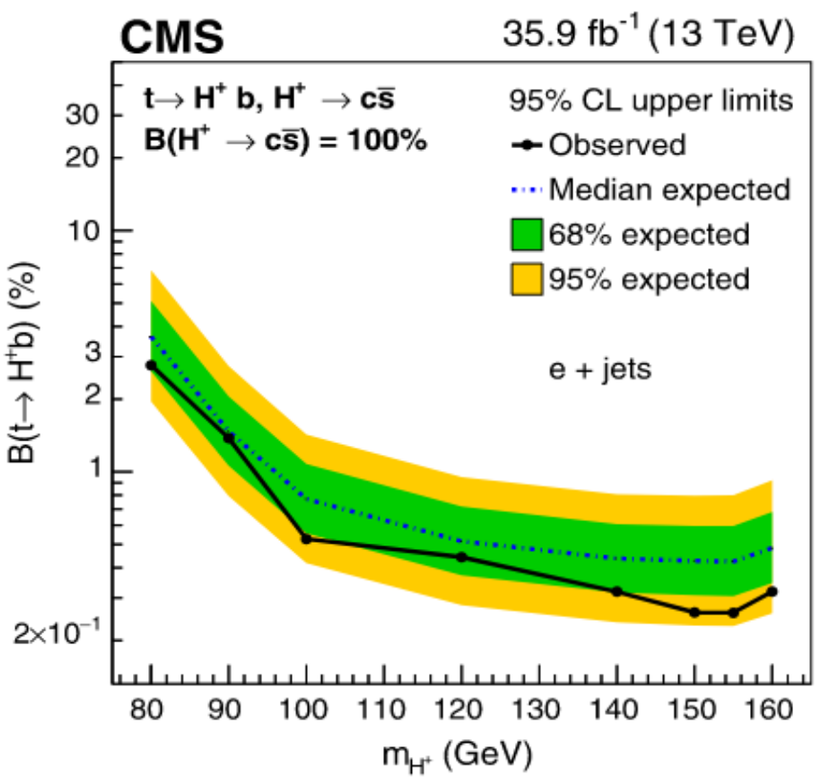
Electron isolation **< 0.08 (0.07)** barrel(endcap) region.

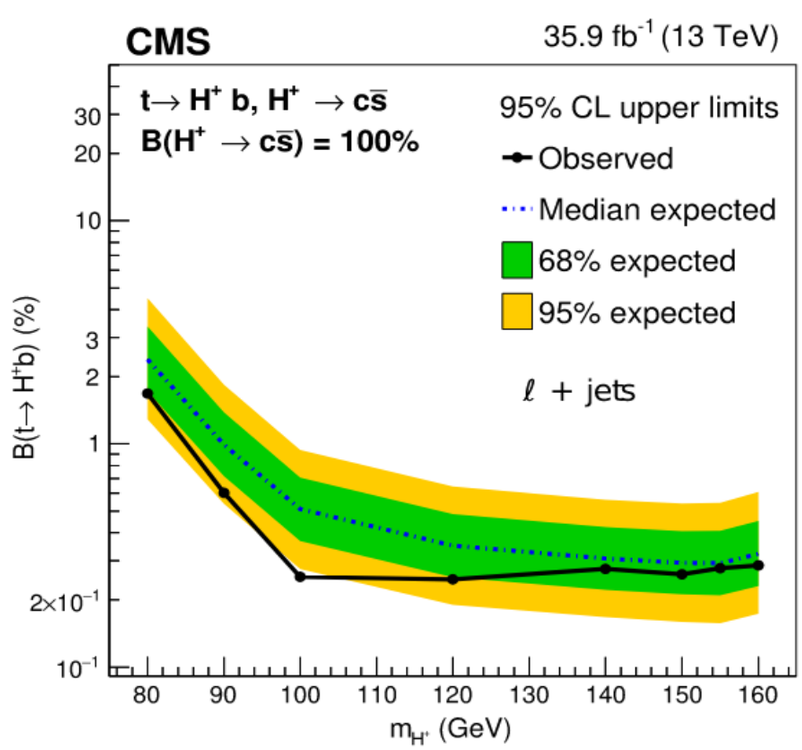
For jets: **p_T^{Jet} > 25 GeV, η^{jet} < 2.4.**

For MET: **p_T^{miss} > 20 GeV.**

Single charged Higgs boson : $H^{\pm} \rightarrow cs$ (cont.)







Results:

No significant excess beyond standard model predictions is found.

Exclusion limit at 95% confidence level on **B (t → H$^+$ b) :**

Assumption: **B (H$^+$ → cs) = 100%**

Charged Higgs boson mass (**m$_H$**) explored: **80 – 160 GeV**

Muon + jets : **2.44%–0.32%**

Electron + jets : **2.77%–0.26%**

Combination (lepton + jets): **1.68%–0.25%**

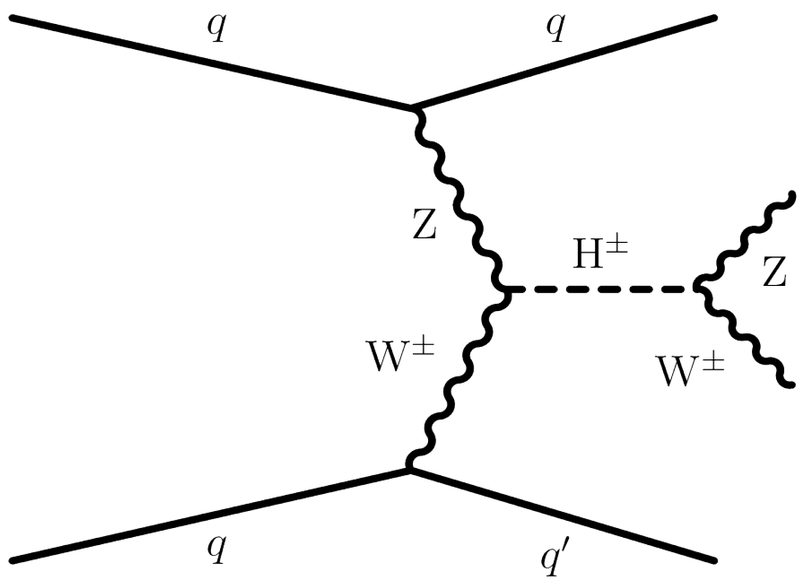
Single and double charged Higgs boson : $H^{\pm} \rightarrow W^{\pm}Z$, $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$

[CMS arxiv:2104.04762]

Charged Higgs boson production process :
Vector Boson Fusion (**VBF**)
Decay products : Vector bosons (**WZ and $W^{\pm}W^{\pm}$**)
Model interpretation: **Georgi–Machacek model**

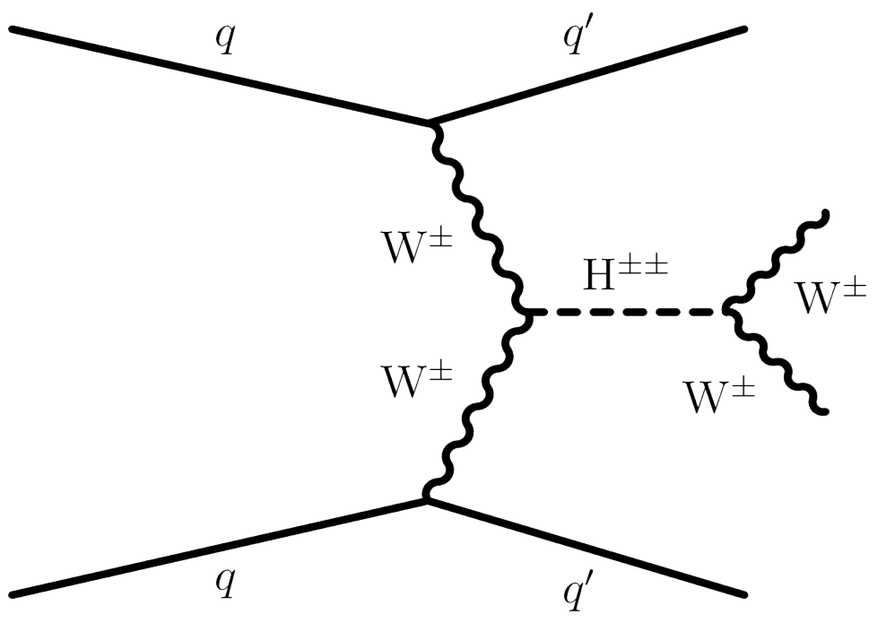
Full Run-II data sample : **137 fb^{-1}**

Search performed in leptonic decay modes:
$W^{\pm}Z \rightarrow l^{\pm}\nu l'^{\pm}l'^{\pm}$, $W^{\pm}W^{\pm} \rightarrow l^{\pm}\nu l'^{\pm}\nu$ (l,l' = e,μ)



Event Selection requirements:

Variable	$W^{\pm}W^{\pm}$	WZ
Leptons	2 leptons, $p_T > 25/20$ GeV	3 leptons, $p_T > 25/10/20$ GeV
p_T^j	>50/30 GeV	>50/30 GeV
$\lvert m_{\ell\ell} - m_Z \rvert$	>15 GeV (ee)	<15 GeV
$m_{\ell\ell}$	>20 GeV	—
$m_{\ell\ell\ell}$	—	>100 GeV
p_T^{miss}	>30 GeV	>30 GeV
b jet veto	Required	Required
τ_h veto	Required	Required
$\max(z_\ell^*)$	<0.75	<1.0
m_{jj}	>500 GeV	>500 GeV
$\lvert \Delta\eta_{jj} \rvert$	>2.5	>2.5



Single and double charged Higgs boson : $H^{\pm} \rightarrow W^{\pm}Z$, $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$

Discrimant between resonant signal and non-resonant background processes:

Diboson transverse mass: $m_{\mathrm{T}}^{\mathrm{VV}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_{z,i}\right)^2}$,

Final discriminant : Bins in [$\mathbf{m_{jj}}$ **x** m_T^{VV}]

A two dimensional distribution for $W^{\pm}W^{\pm}$ signal regions (SR) :

8 bins in m_T^{VV}

[0, 250, 350, 450, 550, 650, 850,1050,∞] GeV

4 bins in m_{jj}

[500, 800, 1200, 1800,∞] GeV

A 2D discriminant for WZ SR :

7 bins in m_T^{VV}

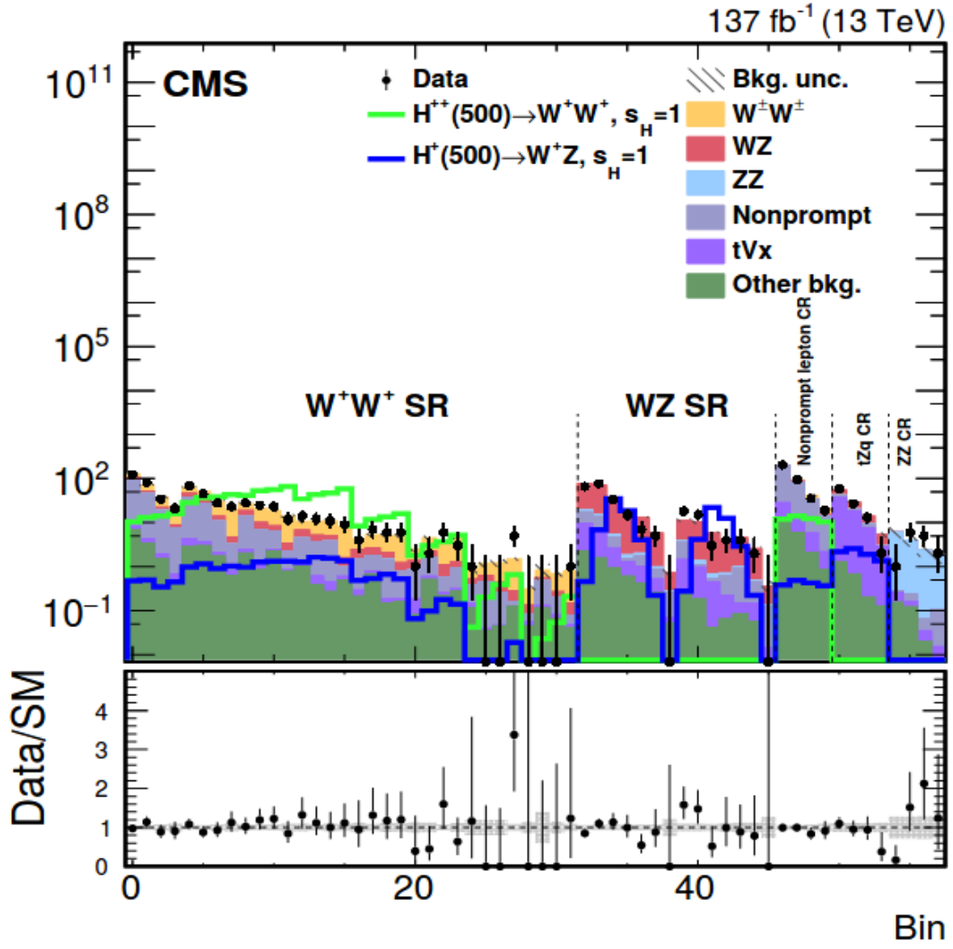
[0, 325, 450, 550, 650, 850, 1350,∞] GeV

2 bins in m_{jj}

[500, 1500,∞] GeV

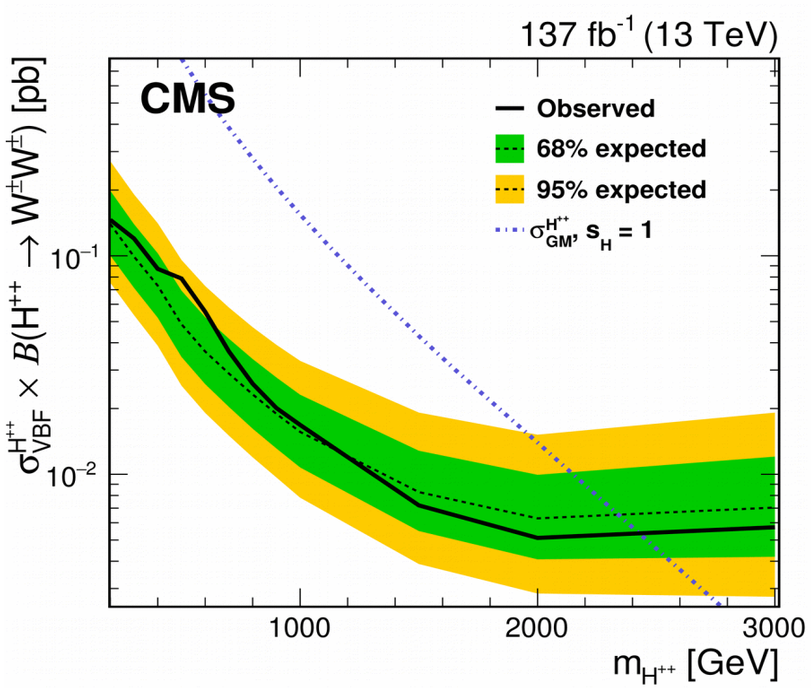
4 bins for Control Regions (**CR**) in m_{jj}

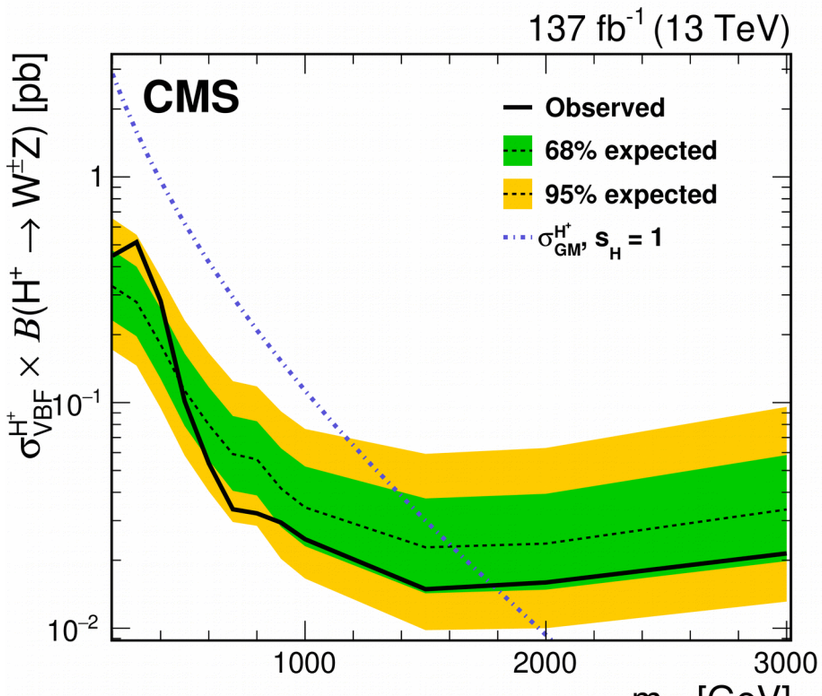
[00, 800, 1200, 1800,∞] GeV

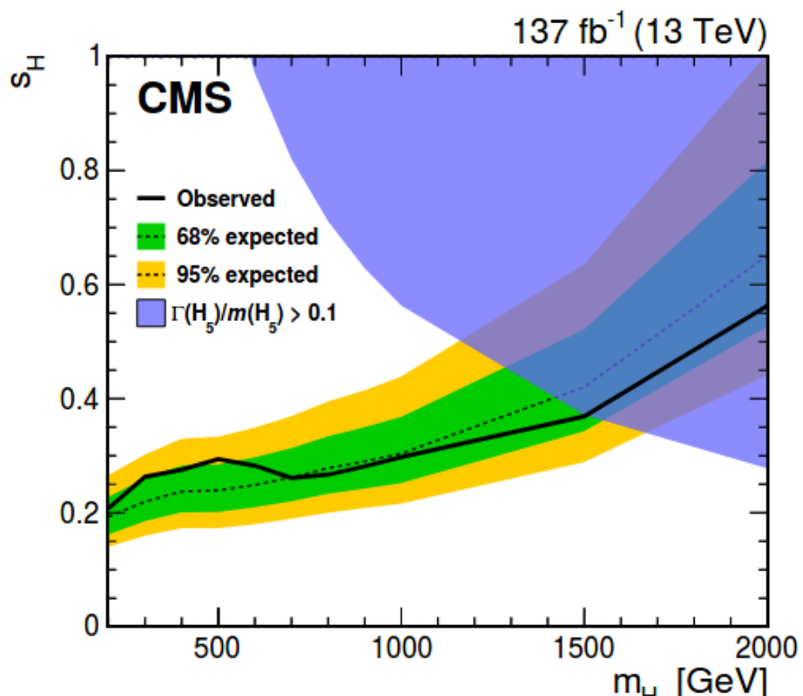


[**Distributions for signal, backgrounds, and data for the bins used in the simultaneousfit.**]

Single and double charged Higgs boson : $H^{\pm} \rightarrow W^{\pm}Z$, $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$







Results:

No significant excess beyond standard model predictions is found.
Charged Higgs boson mass (m_H) explored: **200 – 3000** GeV

Exclusion limits at **95%** confidence level on σ_{VBF} **x B($H^{\pm\pm}$) ($H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$)** and
σ_{VBF} **x B($H^{\pm}$) ($H^{\pm} \rightarrow W^{\pm}z$)** is shown.

The observed limit excludes **GM s_H** values greater than **0.20 – 0.35** for the m_{H5} (**= $H^{\pm}$, $H^{\pm\pm}$**) range from **200 - 1500** GeV

Summary

Extended Higgs sectors in the BSM theories are well motivated to give additional Higgs bosons.

Presented some of the latest BSM Higgs searches using Run-II data at CMS.

More results will be available soon !!

Thank You !!!!

Back up

Single charged Higgs boson : $H^{\pm} \rightarrow cs$ (cont.)

	Loose		Medium		Tight	
Process	μ + jets	e + jets	μ + jets	e + jets	μ + jets	e + jets
$m_{H^+} = 80$ GeV	7690 ± 550	5430 ± 380	6560 ± 490	4700 ± 370	2670 ± 270	1860 ± 180
$m_{H^+} = 90$ GeV	7710 ± 550	5620 ± 400	6770 ± 510	4860 ± 380	2630 ± 260	1870 ± 190
$m_{H^+} = 100$ GeV	7950 ± 590	5550 ± 400	7070 ± 540	4950 ± 360	2770 ± 270	2000 ± 200
$m_{H^+} = 120$ GeV	7620 ± 570	5360 ± 400	6870 ± 510	4780 ± 360	2650 ± 260	1960 ± 190
$m_{H^+} = 140$ GeV	6160 ± 500	4370 ± 360	5420 ± 420	3840 ± 310	2010 ± 210	1500 ± 150
$m_{H^+} = 150$ GeV	4530 ± 390	3230 ± 280	3850 ± 330	2800 ± 250	1340 ± 140	1030 ± 120
$m_{H^+} = 155$ GeV	3700 ± 340	2560 ± 250	2980 ± 270	2230 ± 220	1020 ± 120	766 ± 86
$m_{H^+} = 160$ GeV	2780 ± 270	2080 ± 200	2370 ± 230	1710 ± 180	728 ± 83	510 ± 59
$t\bar{t}$	100540 ± 410	71800 ± 470	73210 ± 320	52340 ± 290	18760 ± 130	13380 ± 130
Single t quark	2750 ± 220	1970 ± 160	1940 ± 160	1400 ± 110	421 ± 35	302 ± 26
QCD multijet	520 ± 130	2120 ± 470	498 ± 98	1460 ± 210	88 ± 28	346 ± 39
W + jets	1360 ± 140	1061 ± 90	950 ± 110	681 ± 58	127 ± 23	102 ± 9
Z/γ + jets	189 ± 18	240 ± 25	132 ± 13	132 ± 14	56 ± 7	31 ± 4
VV	61 ± 9	43 ± 6	56 ± 8	11 ± 4	15 ± 5	3 ± 1
All background	105410 ± 500	77240 ± 690	76780 ± 390	56020 ± 380	19470 ± 140	14160 ± 140
Data	105474	77244	76807	56051	19437	14179

[**Expected event yields for different signal mass scenarios and backgrounds in each of the channels and event categories.The number of events is shown along with its uncertainty, including statistical and systematic effects. The yields of the backgroundprocesses are obtained after a background-only fit to the data.**]