# Charged Higgs boson in the $W^{\pm}H_{obs}$ channel at the LHC

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*Based on* arXiv:1412.5814, *with* R Enberg, W Klemm, S Moretti and G Wouda

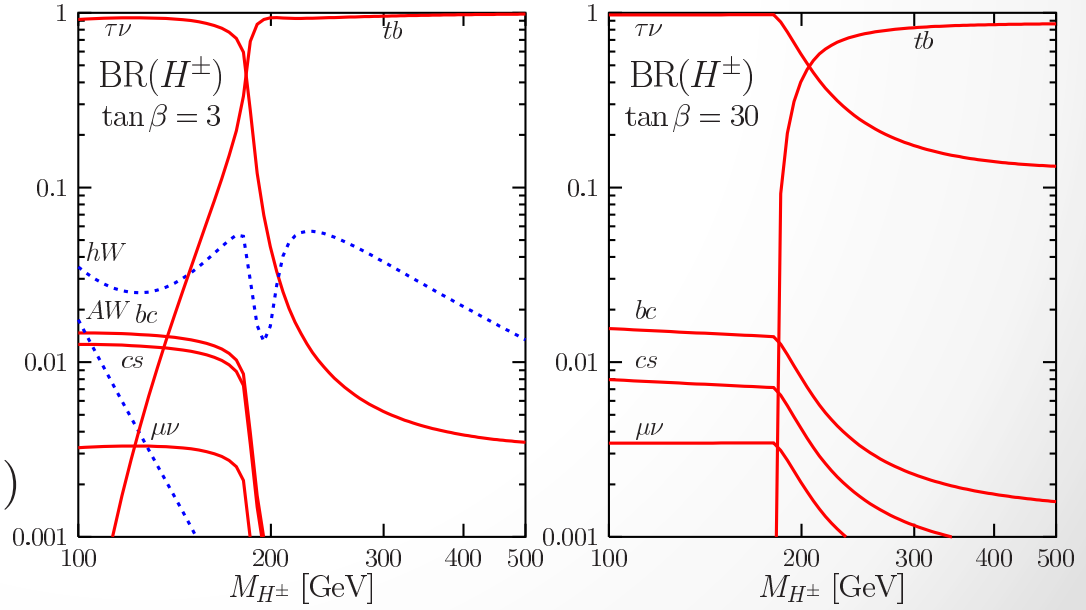
# $H^{\pm}$ at the LHC

- Predicted in many models beyond the SM
- $m_{H\pm} > m_t + m_b$: $H^{\pm} \rightarrow tb$ most dominant but difficult, especially for $tan\beta \sim 1 - 3$ in SUSY
- $H^{\pm} \rightarrow W^{\pm}H_{obs}$ can have an appreciable BR

$$pp \rightarrow tH^{\pm} + X$$

$$g^2_{qH^{\pm}} = m_b^2 \tan^2\beta + m_t^2 \cot^2\beta$$

$$g_{H_i H^+ W^-} = \frac{g_2}{2}(\cos\beta S_{i2} - \sin\beta S_{i1})$$




[Djouadi, hep-ph/0503173]

# Semileptonic channel

- $pp \rightarrow (b)tH^{\pm} \rightarrow (b)W^{\pm}bW^{\pm}H_{obs}$
- One $W^{\pm}$ decays hadronically, the other leptonically
- $H_{obs}$ decays into a pair of $b$'s
- ≥ 3 $b$-jets, ≥ 2 light jets, 1 charged lepton, missing $E_T$
- Main selection inefficiencies:
  - $b$-tagging ~ $\varepsilon_b^2$
  - 2 BR($W^{\pm} \rightarrow l\nu$) BR($W^{\pm} \rightarrow jj$) ≈ 29%
- Overall ~ 1% cross section before cuts

Backgrounds (generated with Madgraph 5)

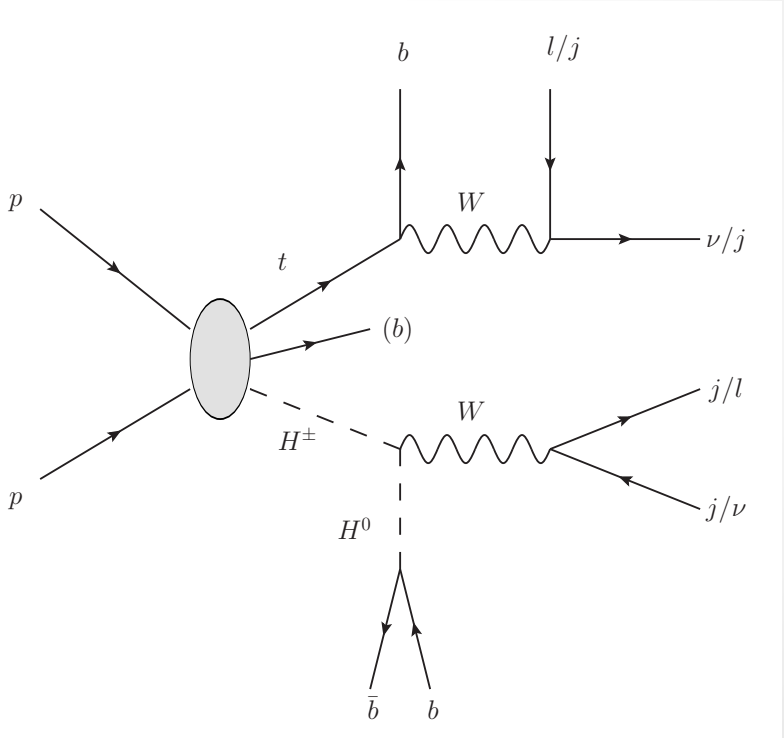
- $t(b)W^{\pm}g$ - overall largest
- $t(b)W^{\pm}H$ - smaller but irreducible
- $t(b)W^{\pm}Z$ - smallest for heavier $H^{\pm}$

# Event analysis

Signal with MATCHIG/Pythia 6
➔ Pythia 8 ➔ Delphes

Reconstruction and cuts:

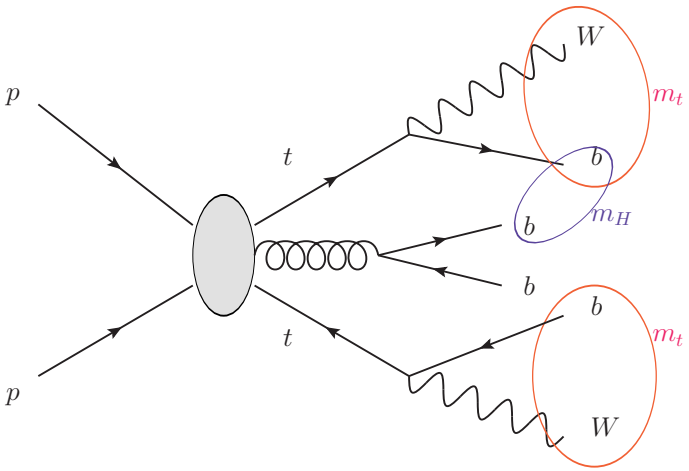
- $p_T > 20$ GeV, $|\eta| \leq 2.5$, $\Delta R > 0.4$
- Light jets – identify hadronic $W^{\pm}$ ($m_{jj} = m_W \pm 30$ GeV)
- Reconstruct leptonic $W^{\pm}$ using lepton + missing $E_T$
- Identify $H_{obs}$ ➔ $b.b$-bar ($m_{bb} = m_H \pm 15$ GeV)
- Reconstruct the top using the remaining $b$-jet
- Veto events with additional top



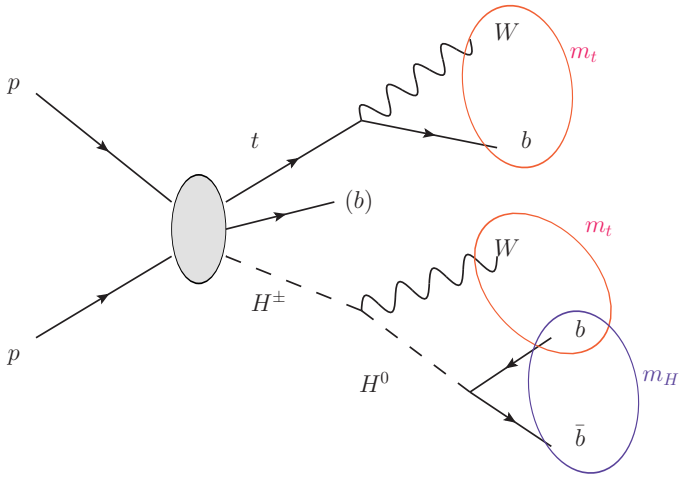
# Top veto(es)

Discriminating variable: $m_{WH}$

- *Veto first*: before any assignment of *b*-jets, veto event if two tops can be reconstructed
- *Veto second*: find $m_{bb} \sim 125$ GeV, veto event if two tops are found using the remaining jets

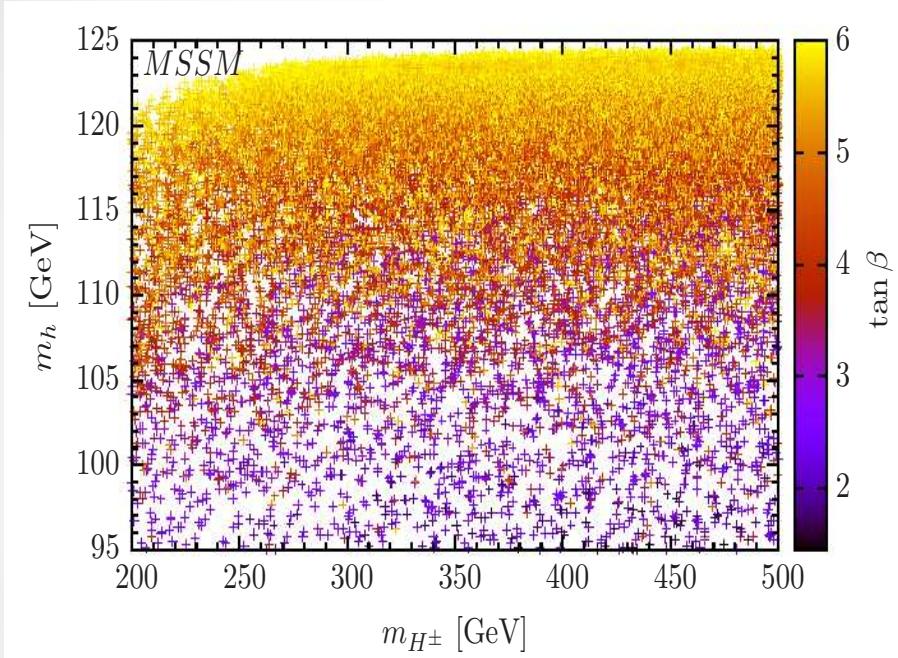


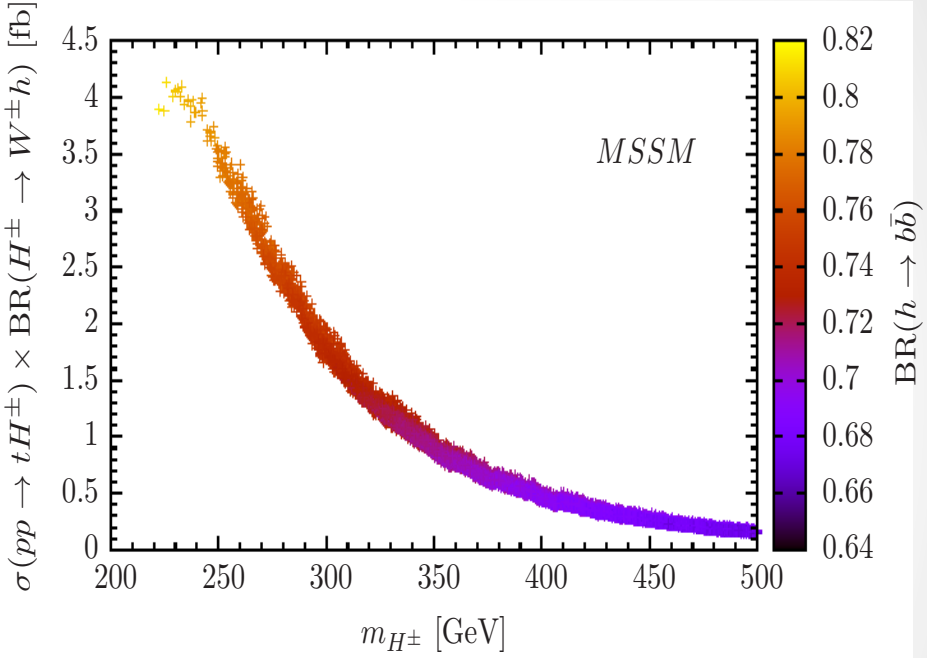

Background mimics signal




Signal mimics background (light $m_{H^{\pm}}$)

# MSSM




- Difficult to obtain $m_h$ ~ 125 GeV without large *tanβ*
- Signal cross section barely reaches 4 fb for the highest allowed *tanβ* at the 14 TeV LHC
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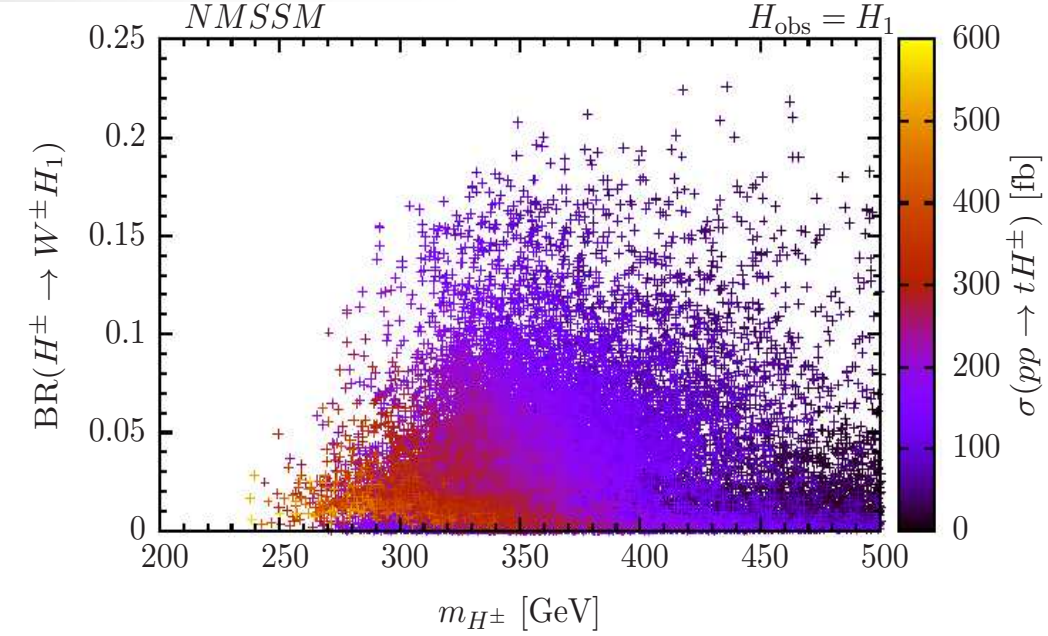
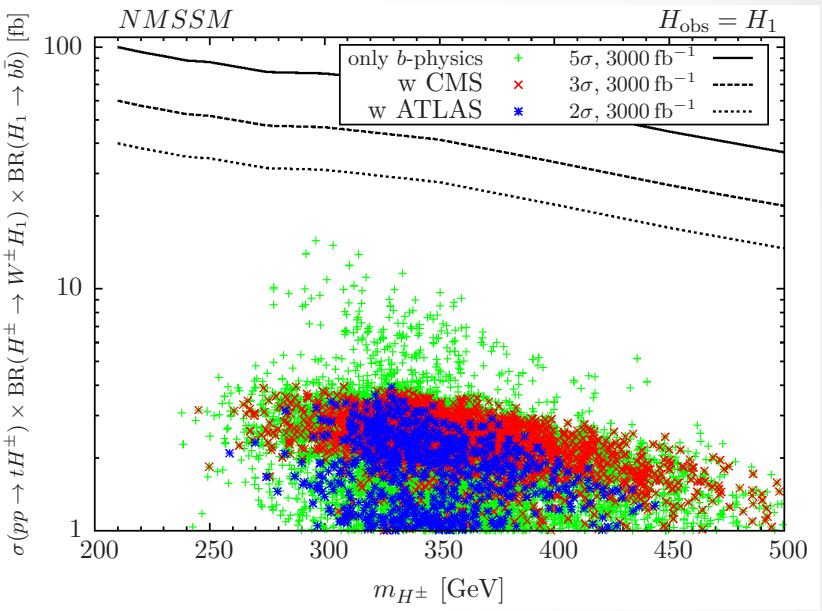
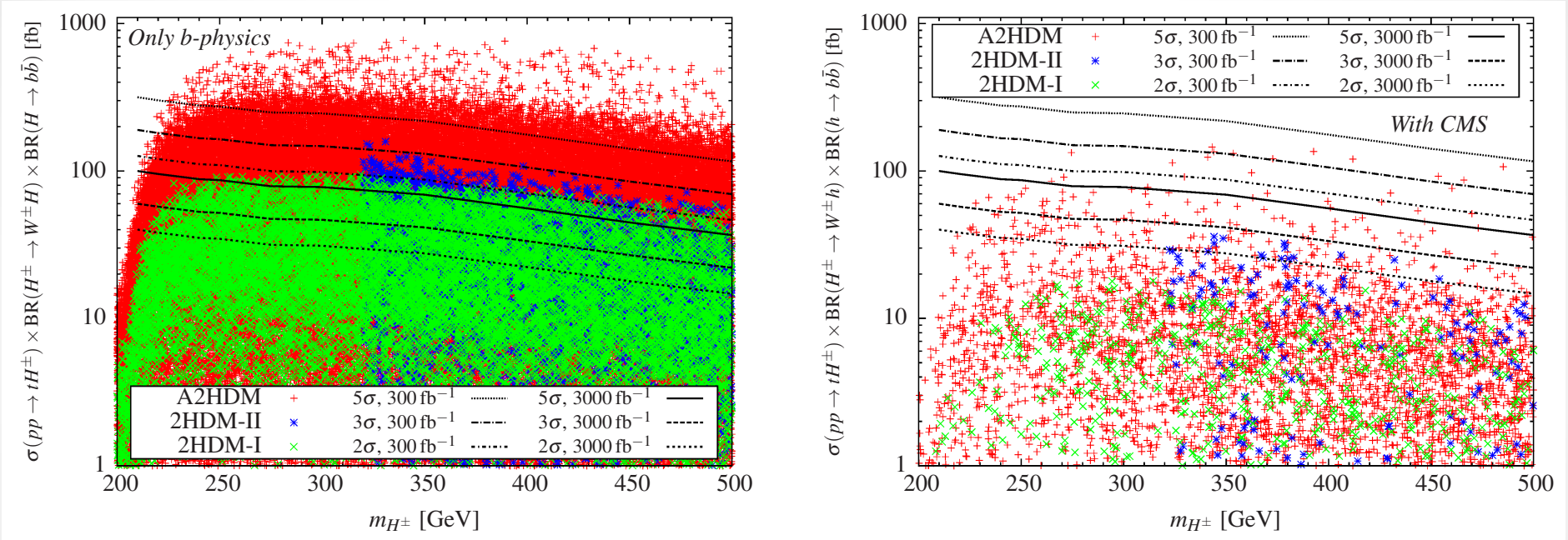
# NMSSM




- For $H_1$ mass ~ 122 GeV - 128 GeV, higher BR possible
- Imposing the LHC Higgs boson constraints diminishes the sensitivity reachable

# 2HDMs




- $Z_2$-symmetric 2HDMs also greatly affected by the Higgs boson data from the LHC
- A much better sensitivity obtained for the Aligned 2HDM even with an integrated luminosity of 300 fb$^{-1}$

# Conclusions

- The $H^{\pm} \rightarrow W^{\pm} H_{\text{obs}}$ decay channel not as promising for minimal SUSY models as envisaged earlier
- A better sensitivity can be obtained for $Z_2$-symmetric 2HDMs at the 14 TeV LHC – but marred by the LHC Higgs boson data
- Aligned 2HDM could be testable even with 300 $\text{fb}^{-1}$

# Thank you!

# Backup slides

# Parameter ranges: SUSY

$$m_0 \equiv M_{Q_{1,2,3}} = M_{U_{1,2,3}} = M_{D_{1,2,3}} = M_{L_{1,2,3}} = M_{E_{1,2,3}} \,,$$

$$m_{1/2} \equiv 2M_1 = M_2 = \frac{1}{3} M_3 \,,$$

$$A_0 \equiv A_t = A_b = A_\tau \,,$$

| MSSM parameter | Range |
|---|---|
| $m_0$ (GeV) | 500 – 4000 |
| $m_{1/2}$ (GeV) | 300 – 2000 |
| $A_0$ (GeV) | −7000 – 7000 |
| $\mu$ (GeV) | 100 – 2000 |
| $m_A$ (GeV) | 100 – 500 |
| $\tan\beta$ | 1 – 6 |

| NMSSM parameter | Range |
|---|---|
| $m_0$ (GeV) | 500 – 3000 |
| $m_{1/2}$ (GeV) | 300 – 2000 |
| $A_0$ (GeV) | −4000 – 4000 |
| $\tan\beta$ | 1 – 6 |
| $\lambda$ | 0.45 – 0.7 |
| $\kappa$ | 0.2 – 0.5 |
| $\mu_{\rm eff}$ (GeV) | 100 – 200 |
| $A_\lambda$ (GeV) | 0 – 500 |
| $A_\kappa$ (GeV) | −500 – 0 |

# Parameter ranges: $Z_2$-symmetric 2HDMS

| Parameter | 2HDM-I | | 2HDM-II | |
|---|---|---|---|---|
| | $H_{\rm obs} = h$ | $H_{\rm obs} = H$ | $H_{\rm obs} = h$ | $H_{\rm obs} = H$ |
| $m_h\,(\mathrm{GeV})$ | 123 – 127 | 80 – 115 | 123 – 127 | 80 – 115 |
| $m_H\,(\mathrm{GeV})$ | 135 – 500 | 123 – 127 | 135 – 500 | 123 – 127 |
| $m_{H^\pm} = m_A\,(\mathrm{GeV})$ | 135 – 500 | | 320 – 500 | |
| $\tan\beta$ | 1.5 – 6 | | | |
| $\lvert\sin(\beta-\alpha)\rvert$ | 0 – 1 | | | |
| $m_{12}^2\,(\mathrm{GeV}^2)$ | $0 - m_A^2 \cos\beta \sin\beta$ | | | |

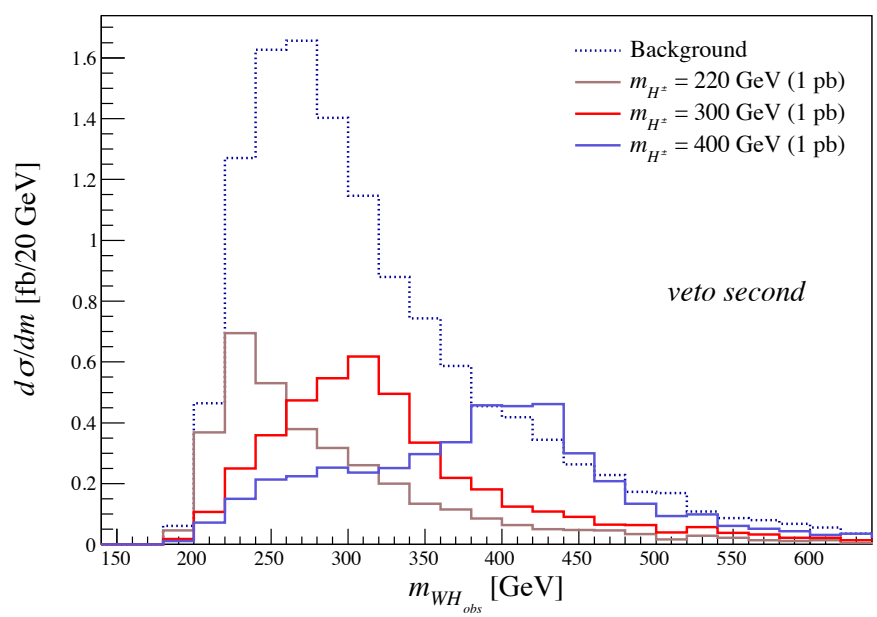
# Parameter ranges: Aligned 2HDM

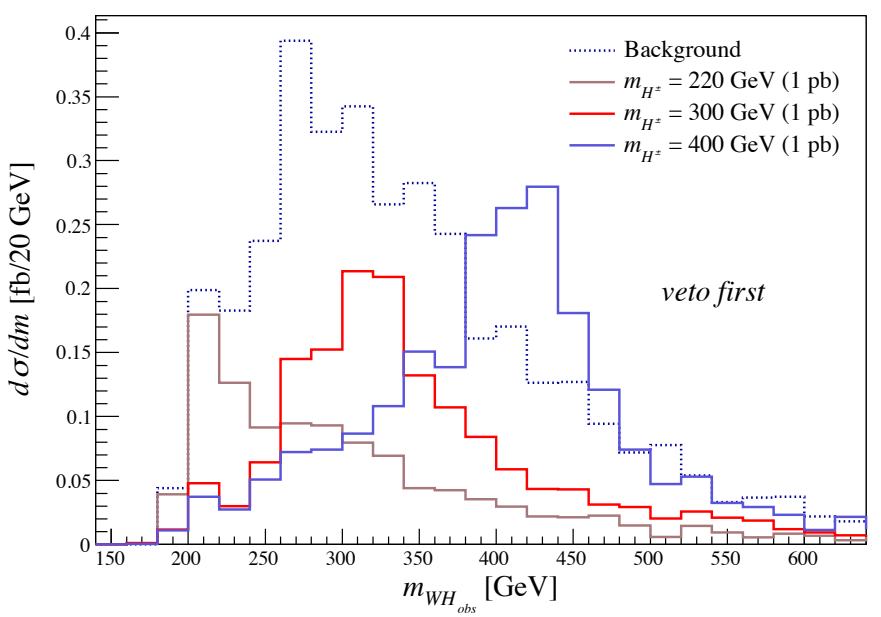
| Parameter | $H_{\rm obs} = h$ | $H_{\rm obs} = h$ |
|---|---|---|
| $m_h$ (GeV) | 123 – 127 | 80 – 115 |
| $m_H$ (GeV) | 135 – 300 | 123 – 127 |
| $m_{H^\pm} = m_A$ (GeV) | 200 – 500 | |
| $\lvert\sin\alpha\rvert$ | 0 – 1 | |
| $\lambda_2$ | $0 - 4\pi$ | |
| $\lambda_3$ | $-\sqrt{\lambda_1\,\lambda_2} - 4\pi$ | |
| $\lvert\lambda_7\rvert$ | $0 - 4\pi$ | |
| $\lvert\beta^{U,D,L}\rvert$ | 0 – 1.57 | |

# Couplings

| | 2HDM-I | 2HDM-II | A2HDM |
|---|---|---|---|
| $g^2_{qH^\pm}$ | $m_b^2\cot^2\beta + m_t^2\cot^2\beta$ | $m_b^2\tan^2\beta + m_t^2\cot^2\beta$ | $m_b^2\tan^2\beta^D + m_t^2\tan^2\beta^U$ |

# Top veto(es)




# Constraints

- $2.63 \times 10^{-4} \leq \mathrm{BR}\left(\overline{\mathrm{B}} \to \mathrm{X_s}\gamma\right) \leq 4.23 \times 10^{-4}$,
- $0.71 \times 10^{-4} < \mathrm{BR}\left(\mathrm{B_u} \to \tau\nu\right) < 2.57 \times 10^{-4}$,
- $1.3 \times 10^{-9} < \mathrm{BR}\left(\mathrm{B_s} \to \mu^+\mu^-\right) < 4.5 \times 10^{-9}$.

## CMS

$\mu^{\gamma\gamma} = 1.13 \pm 0.24$ and $\mu^{ZZ} = 1.0 \pm 0.29$

## ATLAS

$\mu^{\gamma\gamma} = 1.57^{+0.33}_{-0.28}$ and $\mu^{ZZ} = 1.44^{+0.40}_{-0.35}$