Charged Higgs Decays Into a $W^{\pm}$ and a Non-SM-like Higgs

The Forgotten Channels

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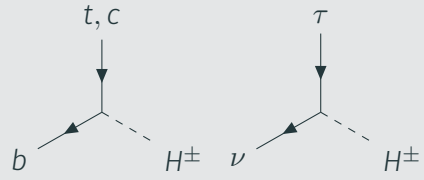
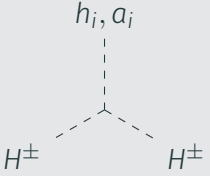
based on `2103.07484`

How to Search For Charged Higgs Bosons?

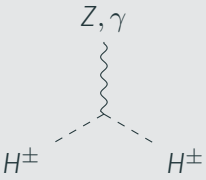
Fermionic Couplings



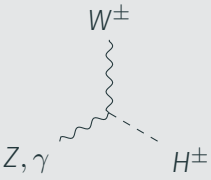
Triple Higgs Couplings



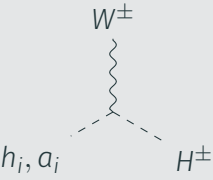
Radiative EW



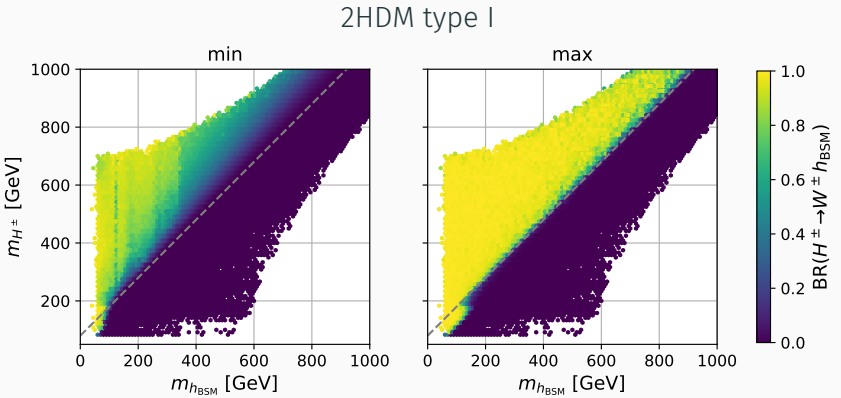
Mixed EW



Higgs EW Couplings



Fermionic and Bosonic Decays of $H^{\pm}$



$H^{\pm} \to tb, cs$

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

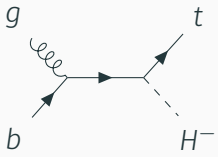
$H^{\pm} \to W^{\pm} h_{\text{BSM}}$

$H^{\pm} \to W^{\pm} A$

$H^{\pm} \to W^{\pm} h_{125}$

- parameter points fulfill experimental and theoretical constraints
- parameter scan performed using ScannerS [Mühlleitner et al. 2007.02985]
- branching ratios including off-shell t and W from HDECAY [Djouadi et al. 1801.09506]

t-Associated Charged Higgs Production



$$\propto \left(\frac{1}{\tan\beta}\right)^2$$ in type I and LS

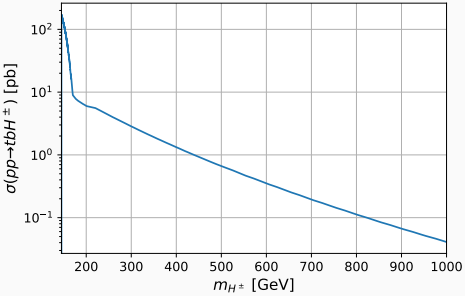
- *high mass*: 4FS/5FS matched NLO calculation for the high mass region

  [Degrande et al. 1507.02549]

- $m_{H^\pm} \lesssim m_t$: matched NLO calculation

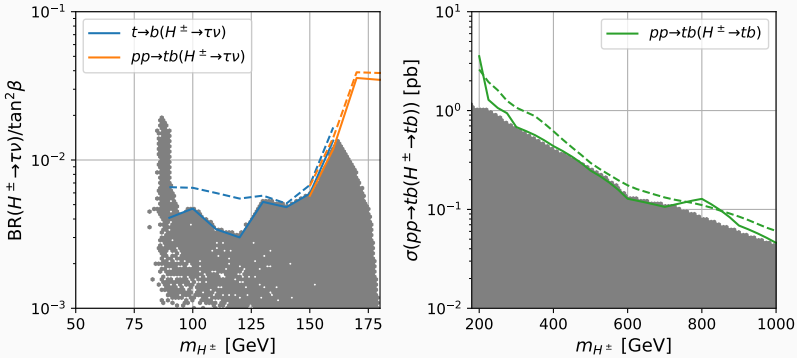
  [Degrande et al. 1607.05291]

- *low mass*: $pp \to t\bar{t}$, $t \to H^+ b$
  $\approx 803\,\text{fb} \cdot 2\,\text{BR}_{t\to H^+b}(1 - \text{BR}_{t\to H^+b})$



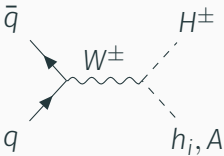
$\tan\beta = 1$

Current Impact of LHC Charged Higgs Searches

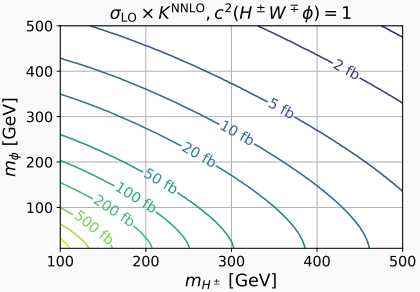


Current strongest searches for $H^\pm \to \tau\nu$ [ATLAS 1807.07915] and $H^\pm \to tb$ [ATLAS 2102.10076].

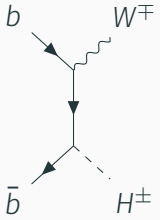
Bosonic Charged Higgs Production



$$\propto c^2(H^\pm W^\mp h_i/A)$$



σ_{LO} MG5, K^{NNLO} VH@NNLO

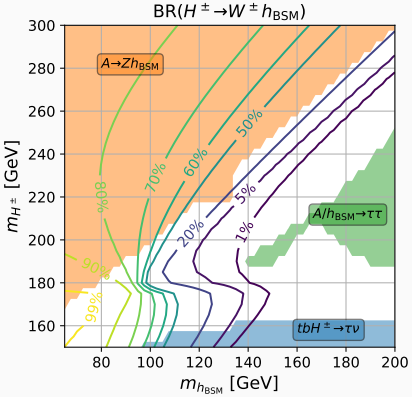


$$\propto \left(\frac{1}{\tan\beta}\right)^2$$

- aNNLO corrections for $b\bar{b} \to H^\pm W^\mp$
  [Kidonakis 1704.08549]
- contributions from $gg \to H^\pm W^\mp$ negligible unless resonant A/h_i
- $\sigma(\tan\beta = 1) \approx$ 350 fb@100 GeV − 5 fb@500 GeV

Benchmark Scenarios for Charged Higgs Searches — cH(Wh_{BSM})

$$c(h_{\text{BSM}}VV) = 0, \quad m_A = m_{H^\pm}, \quad \tan\beta = 3, \quad m_{12}^2 = 500\,\text{GeV}^2, \quad \text{type I}$$

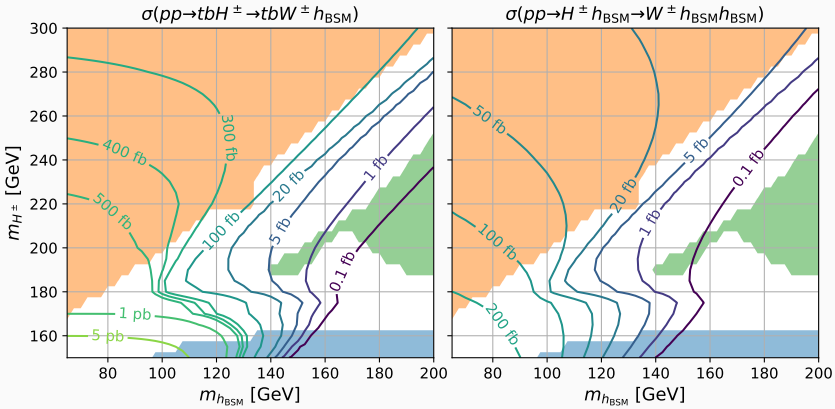


Existing searches

- $A \to Zh_{\text{BSM}}$ [ATLAS 1804.01126, 1712.06518; CMS 1903.00941]
- $A/h_{\text{BSM}} \to \tau\tau$ [ATLAS 2002.12223]
- $tbH^\pm \to \tau\nu$ [ATLAS 1807.07915]

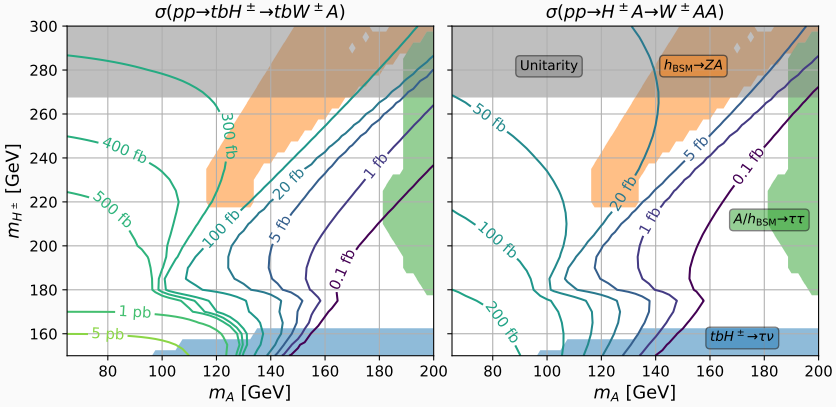
Model dependent complementarity to neutral Higgs searches.

Benchmark Scenarios for Charged Higgs Searches — cH(Wh_{BSM})



$\mathrm{BR}(h_{\mathrm{BSM}} \to b\bar{b}) \approx 80\,\%, \qquad \mathrm{BR}(h_{\mathrm{BSM}} \to \tau^+\tau^-) \approx 8\,\%, \qquad \mathrm{BR}(h_{\mathrm{BSM}} \to \gamma\gamma) \approx 1 \times 10^{-4}$

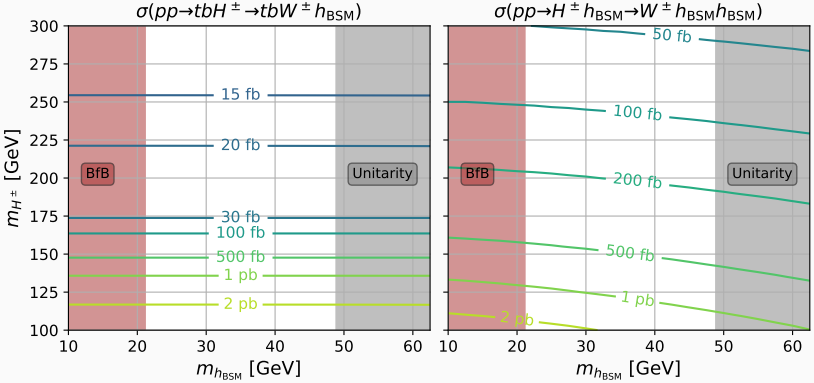
Benchmark Scenarios for Charged Higgs Searches — cH(WA)



- same parameters/rates as cH(Wh_{BSM}) with $h_{\text{BSM}} \leftrightarrow A$
- weaker constraints from neutral Higgs searches

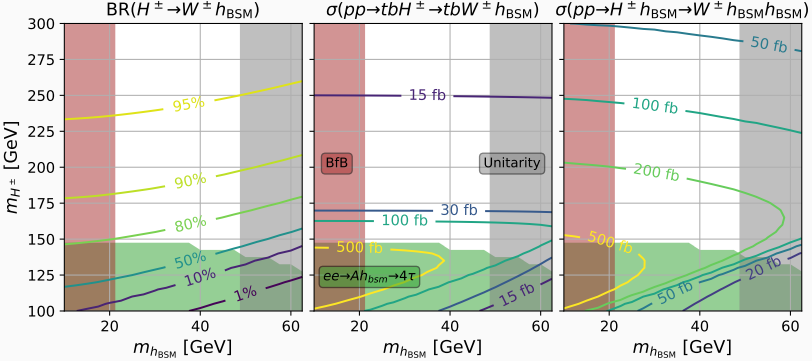
Benchmark Scenario with a light h_{BSM} — cH($Wh^{\text{light}}_{\text{BSM}}$)

Can we have even lighter spectra that allow for boosted final states?



- $2m_{h_{\text{BSM}}} < 125\,\text{GeV}$ requires tuning of m_{12}^2, large $\tan\beta$ and slight misalignment
- h_{BSM} decay modes: $bb \approx 80\,\%$, $\gamma\gamma \approx 10\,\%$

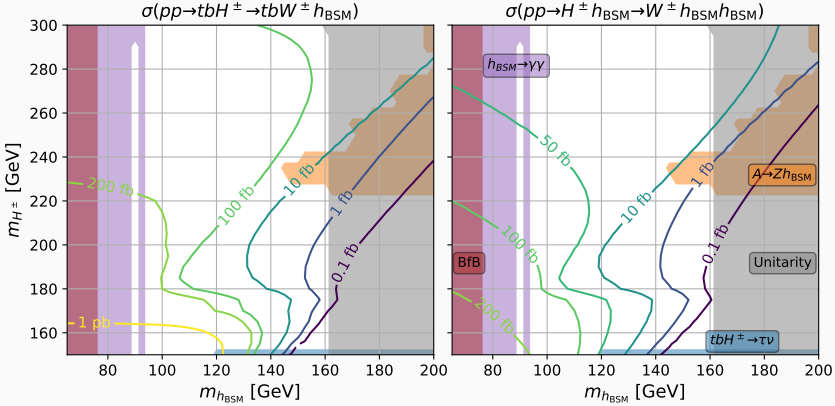
In Case You Like Taus — cH($Wh^{\ell\text{phil}}_{\text{BSM}}$)



- same as cH($Wh^{\text{light}}_{\text{BSM}}$) but in the lepton-specific 2HDM
- BR($h_{\text{BSM}} \to \tau\tau$) = 1

Heavy Gauge Boson Final States — cH($Wh^{\text{fphob}}_{\text{BSM}}$)

Fermiophobic limit for $h_{\text{BSM}} \Rightarrow h_{\text{BSM}} \to \gamma\gamma, WW, ZZ$



Summary

In many BSM models, bosonic $H^\pm$ decay modes — in particular $H^\pm \to W^\pm h_{\text{BSM}}/A$ — can be very competitive with the fermionic decay modes targeted by current searches.

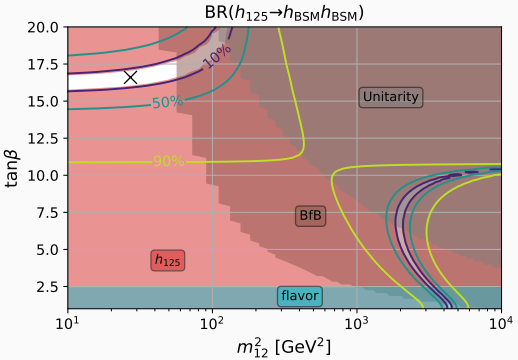
We propose 2HDM benchmark scenarios for charged Higgs production at the LHC that

- can be probed by complementary searches in fermionic and bosonic $H^\pm$ production and decay modes,
- feature a variety of different decays for the involved neutral scalars.

Full cxns and br data for the scenarios are available as arXiv ancillary files.

2103.07484

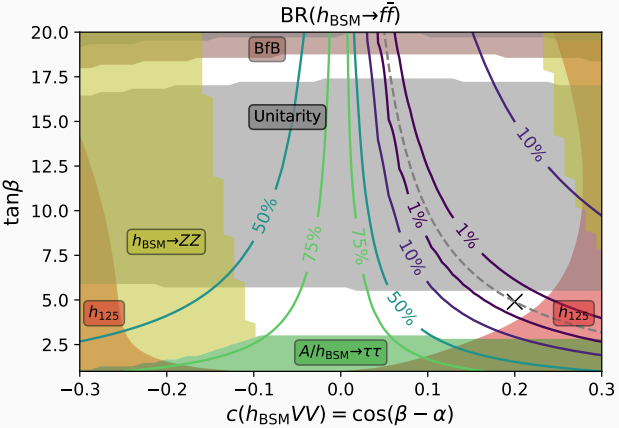
Tuning Away $h_{125} \to h_{\text{BSM}} h_{\text{BSM}}$ in cH($Wh^{\text{light}}_{\text{BSM}}$) and cH($Wh^{\ell\text{phil}}_{\text{BSM}}$)



$$m_{h_{\text{BSM}}} = 30\,\text{GeV},\ m_A, m_{H^\pm} = 200\,\text{GeV}$$

$$g_{h_1 h_1 h_2} = 0: \quad m^2_{12} = \frac{(m^2_{h_2} + 2m^2_{h_1}) c_\alpha s_\alpha}{3\frac{c_\alpha s_\alpha}{c_\beta s_\beta} - 1}$$

Realizing the Fermiophobic Limit for cH($Wh^{\text{fphob}}_{\text{BSM}}$)



$m_{h_{\text{BSM}}} = 150\,\text{GeV}$, $m_A, m_{H^\pm} = 200\,\text{GeV}$

Sum Rules and the Alignment Limit in Generatl Doublet Extensions

Well-known sum rule for the CP-even neutral Higgs bosons h_j:

$$\sum_j c^2(h_j VV) = 1 \xrightarrow[\text{alignment}]{c^2(h_{125}VV)\to 1} c^2(h_{j,\text{BSM}}VV) \to 0$$

Related sum-rules for the charged Higgs bosons $H_i^\pm$:

$$\sum_i g^2(H_i^\pm W^\mp h_j) = \frac{g^2}{4}\left(1 - c^2(h_j VV)\right) \xrightarrow[\text{alignment}]{c^2(h_{125}VV)\to 1} \begin{cases} g^2(H_i^\pm W^\mp h_{125}) \to 0 \\ \sum_i g^2(H_i^\pm W^\mp h_{j,\text{BSM}}) \to \frac{g^2}{4} \end{cases}$$

$$\sum_i g^2(H_i^\pm W^\mp a_j) = \frac{g^2}{4}$$

The $H^\pm h_{j,\text{BSM}} W^\mp$ couplings are maximized in the alignment limit.

Charged Higgs Bosons in the 2HDM

The 2HDM features two CP-even neutral scalars $h_{125,\mathrm{BSM}}$ a CP-odd neutral scalar A and a single set of charged Higgs bosons $H^{\pm}$.

Bosonic Charged Higgs couplings in the 2HDM

$$c^2(h_{125}VV) \to 1 \Rightarrow \begin{cases} c^2(h_{\mathrm{BSM}}VV) \to 0 \\ g^2(H^{\pm}W^{\mp}h_{125}) \to 0 \\ g^2(H^{\pm}W^{\mp}h_{\mathrm{BSM}}) \to g^2(H^{\pm}W^{\mp}A) = \frac{g^2}{4} \end{cases}$$

How does this compare to the fermionic couplings?

Fermion Couplings in the 2HDM

In type I all Higgs-fermion couplings are $\propto 1/\tan\beta$.