Optimizing the charged Higgs searches in $W^{\pm}b\bar{b}$ final states

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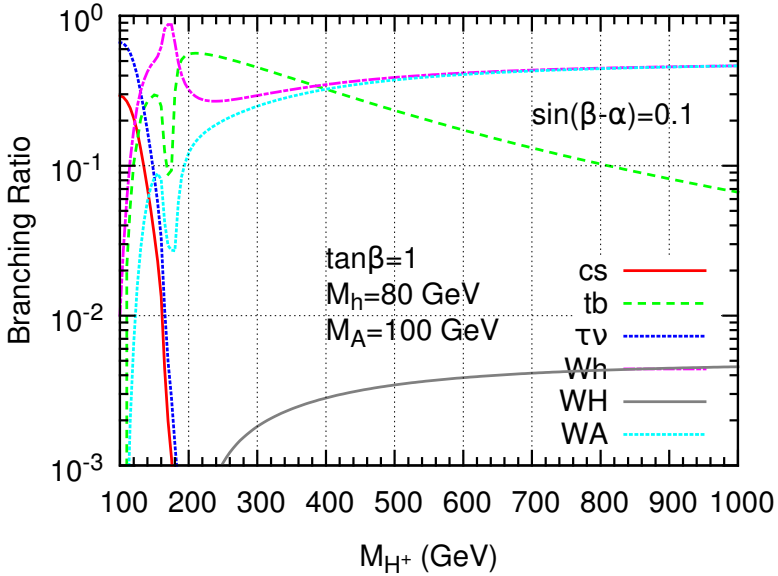
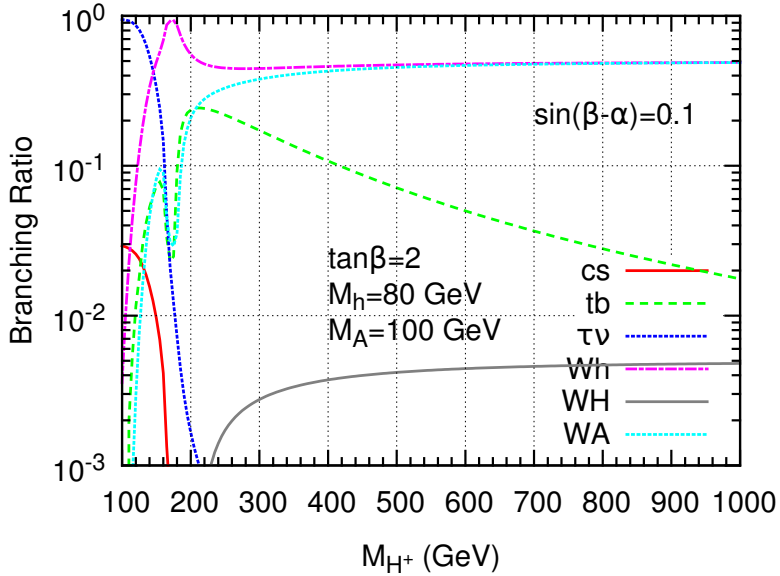
Charged Higgs Bosons

- Charged Higgs is predicted in various extensions of Higgs sector,
  $\Rightarrow$ 2HDM is one of them
- Depending on how 2 doublets couple with SM particles, there can be 4 distinct 2HDMS, namely, type I, type II, type Y andd type X,
- Phenomenology of $H^{\pm}$ in each model is distinct and thus lead to different prediction of X-sections and BRs,
- When $M_{H^{\pm}} < M_{\text{top}}$,
  $\Rightarrow$ $H^{\pm}$ is produced from the decay of tops in top-pair production
  $\Rightarrow$ Decays dominantly via the $\tau^{\pm}\nu$ mode
- When $M_{H^{\pm}} > M_{\text{top}}$,
  $\Rightarrow$ Dominant $H^{\pm}$ production is in association with a single top,
  $\Rightarrow$ Decays in this region depends on mass spectrum of the model,

Signal





We consider the process ($pp \to tH^- X$ + charge conjugate).

- The charged Higgs H^+ decays via:
  $\Rightarrow H^+ \to W^+ h \ (h \to b\bar{b})$
  $\Rightarrow H^+ \to W^+ H \ (H \to b\bar{b})$
  $\Rightarrow H^+ \to W^+ A \ (A \to b\bar{b})$
  $\Rightarrow H^+ \to t\bar{b} \ (t \to W^+ b)$
  Thus, all $H^\pm$ decays eventually lead to $pp \to W^+W^- b\bar{b}\bar{b}$ final state
- $W^\pm$'s decays are such that one of the W boson decays to a lepton (e or μ) and the other one decays to two light jets.

Backgrounds

- The main background processes considered in this analysis are following:
  1. $W^+W^-b\bar{b}b$,
  2. $W^+W^-b\bar{b}j$,
  3. W^+W^-bjj,

- The dominant background is $W^+W^-b\bar{b}j$ process having cross section of about $\sim$ 800 pb at LHC14,
  $\Rightarrow$ Includes $t\bar{t} + jets$ processes

- The irreducible background consist of $W^+W^-b\bar{b}b$ process $\sim 30pb$,
  $\Rightarrow$ Includes all single top processes like tW^-h, tW^-Z etc

- The other background is W^+W^-bjj and can be sufficiently suppressed by the cuts imposed.

- Background and signal events have been generated with `MADGRAPH5`.

Acceptance

All the events should satisfy the following acceptance cuts:

- **Acceptance cuts:**
  1. Accept events with at least one lepton (e or μ), 3 b-jets, at least 2 light jets and missing energy,
  2. Leptons must have transverse momentum $p_T > 30$ GeV and rapidity $|\eta| < 2.5$,
  3. All jets must have following E_T and η requirements:
  $$E_{Tjet} > 30 \text{ GeV}, |\eta| < 2.5$$
  4. All pairs of jets and lepton plus jets should be well separated with each other by:
  $$\Delta R_{jj,jb,bb,\ell j,\ell b} \geq 0.4 \text{ where } \Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

Selection

After the acceptance, we apply some customized cuts to suppress the background and enhance the signal purity.

1. H_T **Cut:** Defining $H_T = p_T^{\ell^\pm} + \sum_j p_T^j$
   As the signal contains a heavy particle, H_T distribution for signal peaks at large values.
   $\rightarrow$ Instrumental in suppressing background

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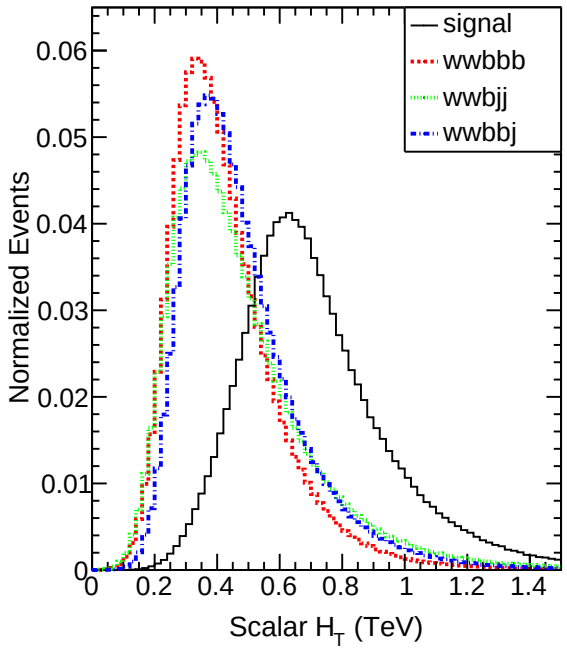

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2. **Hadronic** W **candidate:** Search for light jets, taking in pairs

$$\chi^2 = |m_{jj} - m_{W^\pm}|,$$

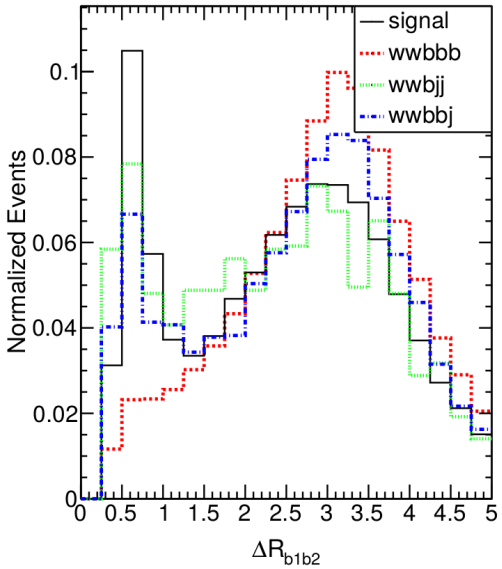
   Pair of jets having minimum χ^2 is used to reconstruct the hadronic W_{had}

3. **Leptonic** W**:** Impose the mass constraint $m_{\ell\nu} = m_{W^\pm}$ to obtain p_ν. Using p_ν and p_ℓ, the momentum of the leptonic W_{lep} is obtained. We select events within

$$|m_{jj} - m_{W^\pm}| < 25 \text{ GeV},$$

Reconstruction of $W^{\pm}h$ and $W^{\pm}A$ Signal

- Reconstruction of neutral Higgs boson



- We look at ΔR separation between pair of b jets,
- h/A is expected to be boosted,
  $\Rightarrow$ Leading to a pair of b jets with very small ΔR separation
- Select pair of b jets with ΔR_{min} and reconstruct h/A with it,

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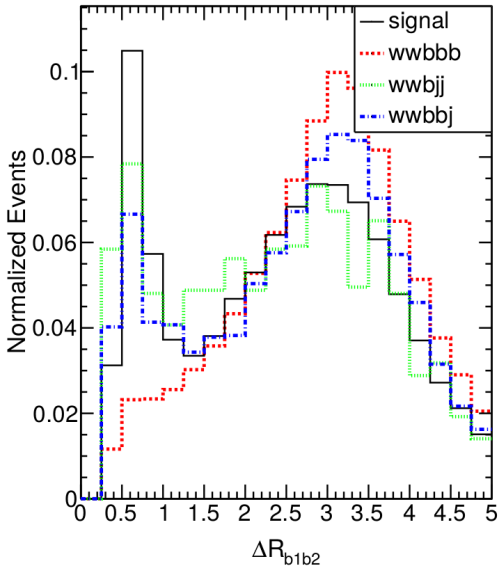

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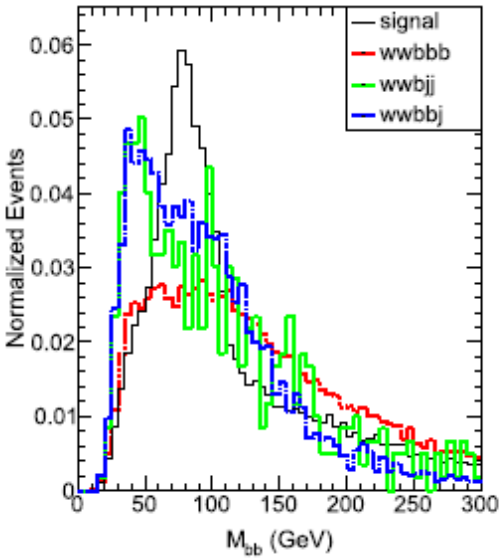
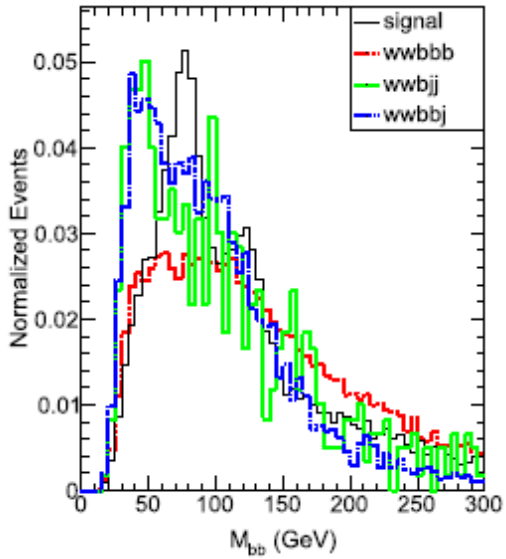
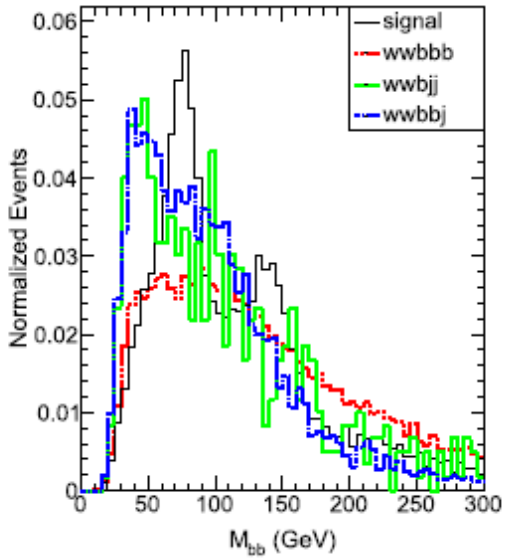


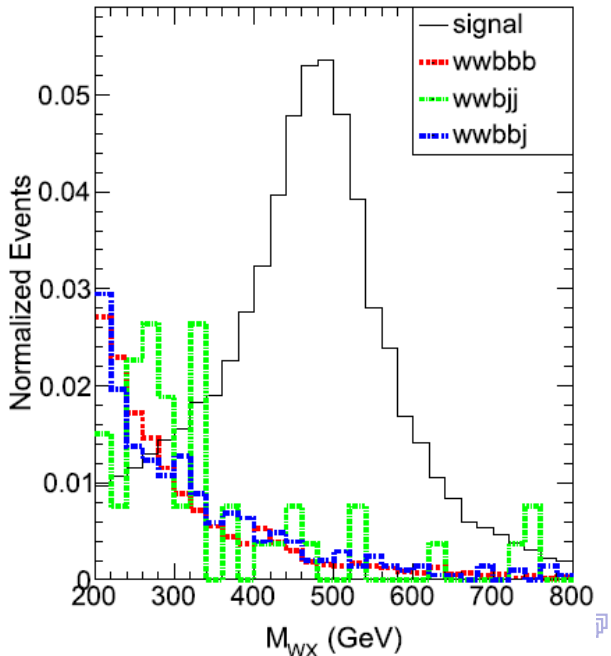




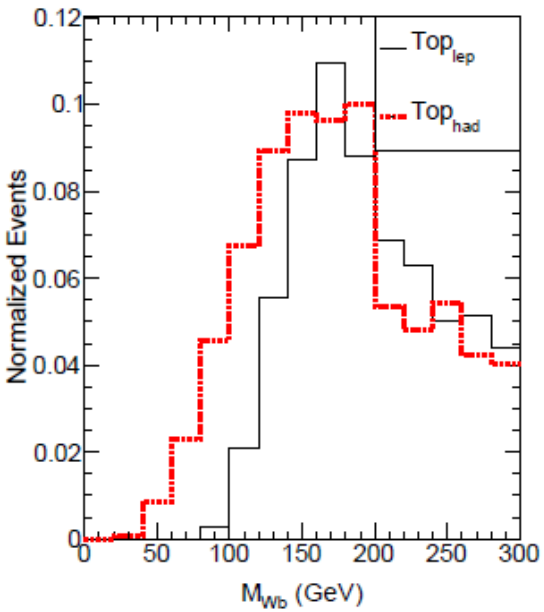
Reconstruction of $W^{\pm}h$ and $W^{\pm}A$ Signal (contd.)

Top Candidate:

1. Choose one of the $W^{\pm}$ and remaining b-jet to find the
$$|m_{W^{\pm}b} - m_t| < 30 \text{ GeV}.$$
2. Repeat the above step with other $W^{\pm}$ candidate.
3. The $W^{\pm}$ boson which provides the better solution is selected and other is retained to reconstruct $H^{\pm}$ boson.
4. **Charged Higgs Candidate $H^{\pm}$:** Finally, reconstruct $H^{\pm}$ from the remaining W and the reconstructed h



Reconstruction of tb Signal



Reconstruction of two top candidates:

1. Choose one W and loop over 3 b jets. Wb pair having closest to top invariant mass is kept,
2. Repeat step 1 with other W and remaining b jets to find 2nd top candidate,

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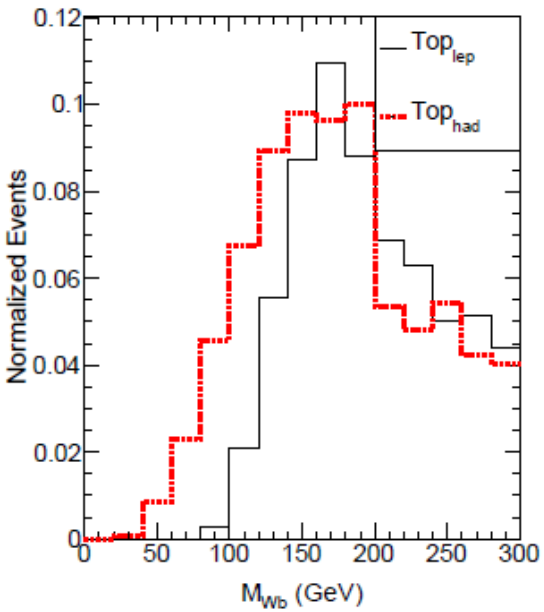

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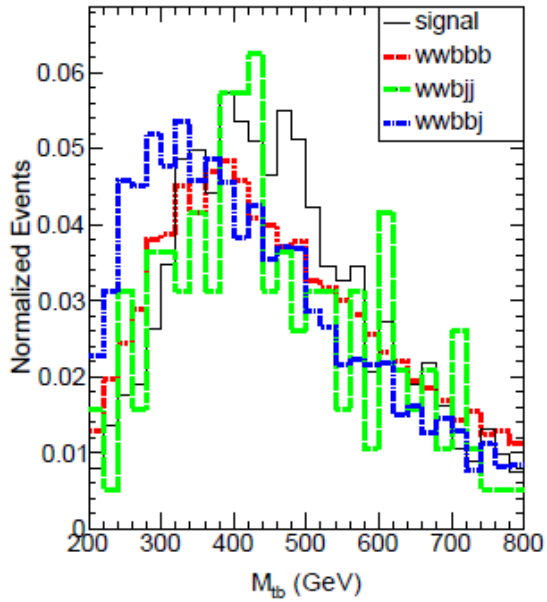
Reconstruction of charged Higgs candidate:

- With 2 reconstructed tops, select one and pair with remaining b jet,
- repeat step 1 with 2nd top candidate,
- The one which gives invariant mass closest to $M_{H^\pm}$ is chosen as $H^\pm$ candidate.



Signal significance

For $W^{\pm}X$ signal

Cuts	σ [fb]				
	Signal	$WWbbb$	$WWbbj$	$WWbjj$	Total Background
C9: $\lvert M_{bb} - M_h \rvert < 20$ GeV	8.4	292.7	24.8	11.4	328.9
C10: $\lvert M_{Wb} - M_t \rvert < 30$ GeV	6.6	260.6	20.3	8.7	289.7
C11: $\lvert M_{Wh} - M_{H^+} \rvert < 100$ GeV	6.4	109.3	10.3	8.5	128.1
S/B					5.4%
$S/\sqrt{B}$ with 100 fb^{-1}					5.9

For tb signal

Cuts	σ [fb]				
	Signal	$WWbbb$	$WWbbj$	$WWbjj$	Total Background
C9′: $\lvert M_{Wb} - M_t \rvert < 30$ GeV	2.6	209.1	13.6	4.1	226.8
C10′: $\lvert M_{tb} - M_{H^+} \rvert < 100$ GeV	1.4	175.3	8.9	3.2	187.4
S/B					0.75%
$S/\sqrt{B}$ with 3000 fb^{-1}					5.7

$\Rightarrow$ $W^{\pm}X$ signal is sensitive with only 100 fb^{-1} while for tb mode, one needs 3000 fb^{-1} of integrated luminosity.

Summary and Conclusions

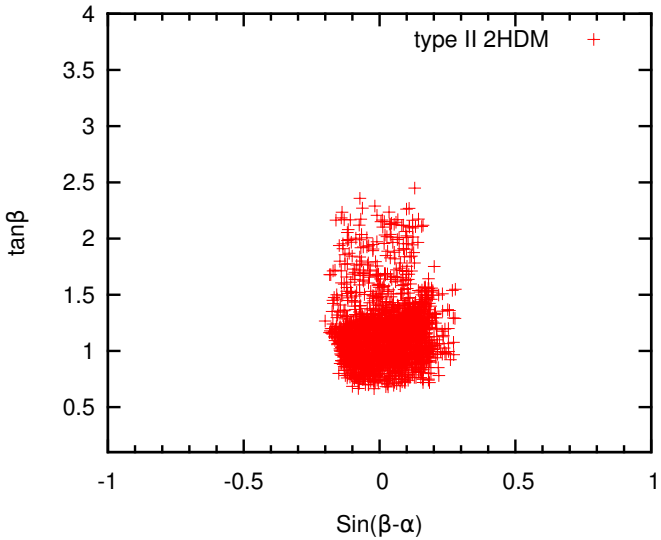
- We study the bosonic decays of charged Higgs in tH^- production at the LHC,
- Both tb mode and $W^{\pm}X$ modes lead to same final $W^+W^-b\bar{b}b$ state,
- Motivation being to extract the each signal from the $W^+W^-b\bar{b}b$ final state,
- We conclude that $W^{\pm}X$ signal is more easier to reconstruct and robust to background,
- Achieves a better significance even with small integrated luminosity.

Back-up Slides

Allowed parameter space

We consider H to be SM like Higgs particle and take following values of other parameters:

- M_h =80 GeV,
- $M_A = 150$ GeV,
- $M_{H^\pm}$=500 GeV
- Vary $\tan\beta$, $\sin(\beta - \alpha)$



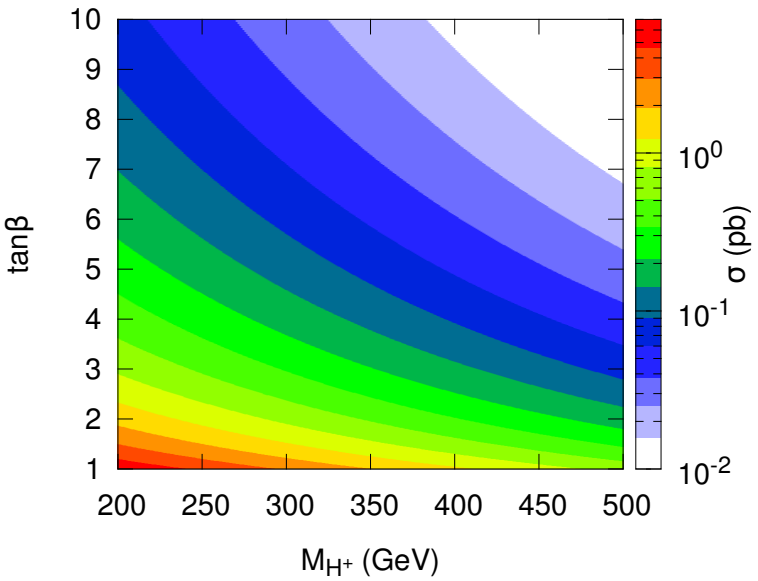
Tools we have used:

1. ScannerS,
2. HiggsBounds,
3. HiggsSignals,
4. 2HDMC

Decay Channels of a Heavy charged Higgs

- Current search for $H^{\pm}$ focus on the tb mode in the heavy $H^{\pm}$ region,
- Bosonic decays via $W^{\pm}X, (X \equiv h/H/A)$ of $H^{\pm}$ opens a new realm in the search of $H^{\pm}$,
- Reconstruction of the signal in the tb mode is quite difficult and also it is dominated by large $t\bar{t}$ backgrounds,
- For the signal in $W^{\pm}X$ mode can be relatively easily reconstructed,
- While both decays lead to $W^{\pm}b\bar{b}$ final states, the backgrounds can be handled with much more authority in the bosonic decays

Cross section for $tH^{\pm}$ prodcution



- Cross section at LHC14 for type I 2HDM
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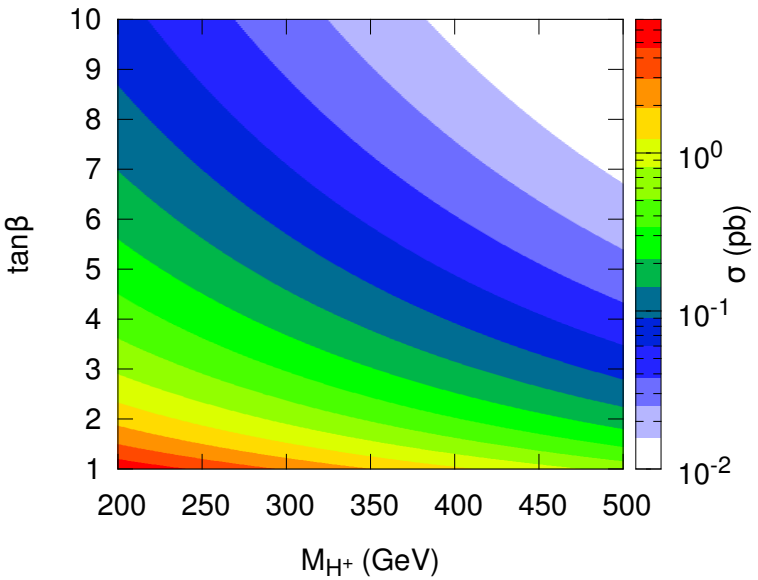

- Cross section at LHC14 for type I 2HDM
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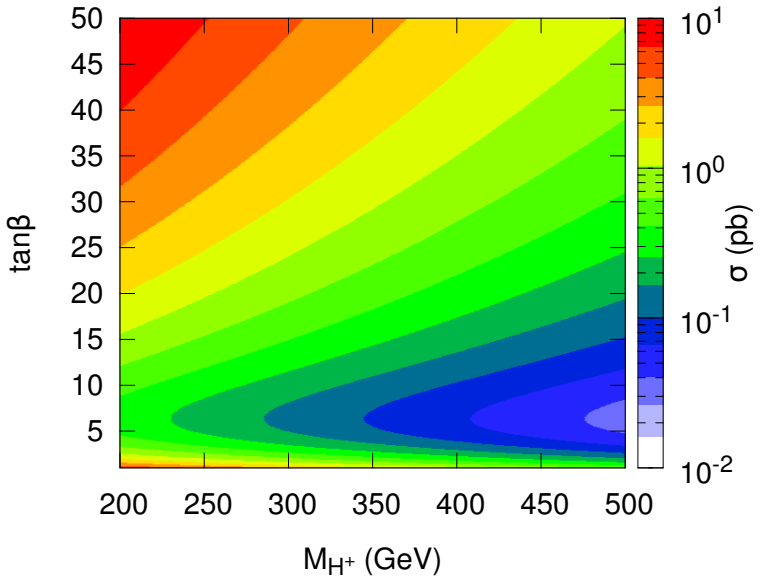
- Cross section at LHC14 for type II 2HDM
- $\sigma \propto (M_t^2 \cot\beta^2 + M_b^2 \tan\beta^2)$
- At large $\tan\beta$ σ is restored due to 2nd term



Branching ratios of $H^{\pm}$

Couplings:

$$g_{H^{\pm}h^0W^{\mp}} = \frac{g\cos(\beta-\alpha)}{2}(p_{h^0} - p_{H^{\pm}})^{\mu},$$
$$g_{H^{\pm}H^0W^{\mp}} = \frac{g\sin(\beta-\alpha)}{2}(p_{H^0} - p_{H^{\pm}})^{\mu},$$
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