전남대학교
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Two Topics in Higgs Physics

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♠ *Two Topics*

1. Unitarity in W–b scattering

2. Almost degenerate Higgses

Unitarity in W–b scattering

It's about charged Higgs production in 2HDMs

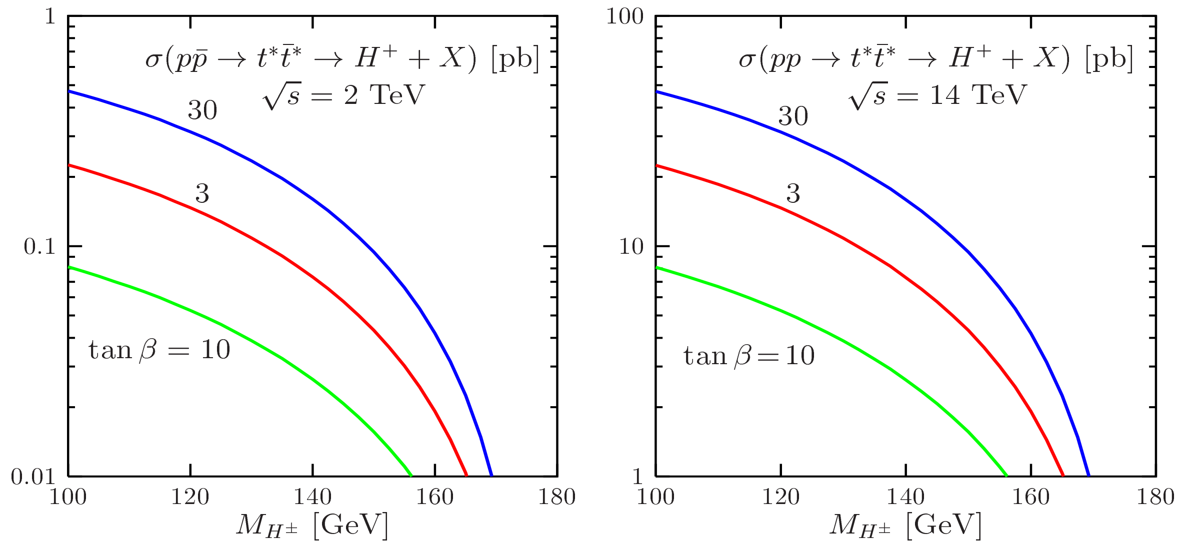
* based on A. Arhrib, K. Cheung, JSL, C.-T. Lu, JHEP 1605 (2016) 093 [arXiv:1509.00978]

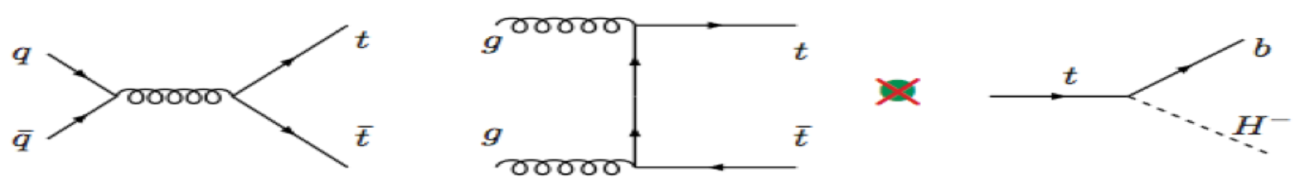
♠ *Preliminary*

- The production of the charged Higgs bosons The Anatomy of electro-weak symmetry breaking. II. The Higgs bosons in the minimal supersymmetric model : Abdelhak Djouadi Phys.Rept. 459 (2008) 1-241, hep-ph/0503173
  - Production from top quark decays
  - The gb and gg fusions
  - The single charged Higgs production process
  - The pair and associated production processes

♠ *Preliminary*

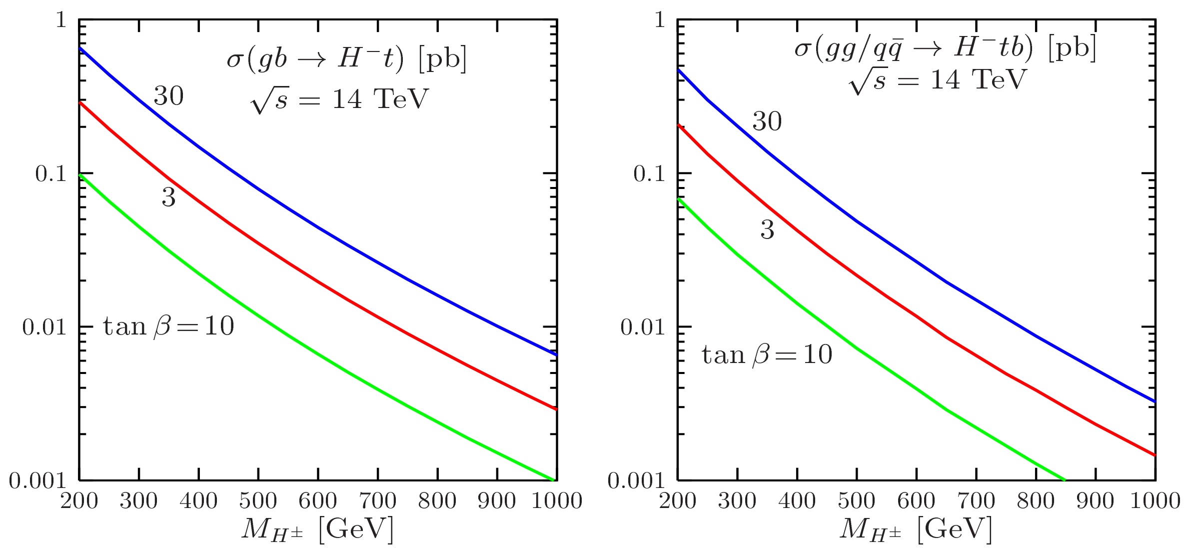
- Production from top quark decays: $M_{H^\pm} \lesssim m_t$

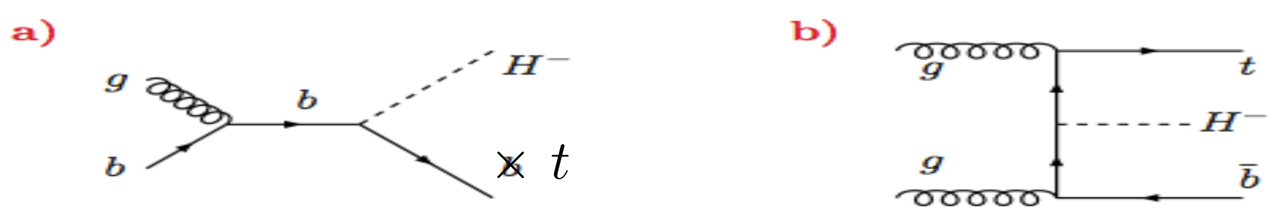




♠ *Preliminary*

- The gb and gg fusions in LO: $M_{H^\pm} \gtrsim m_t$

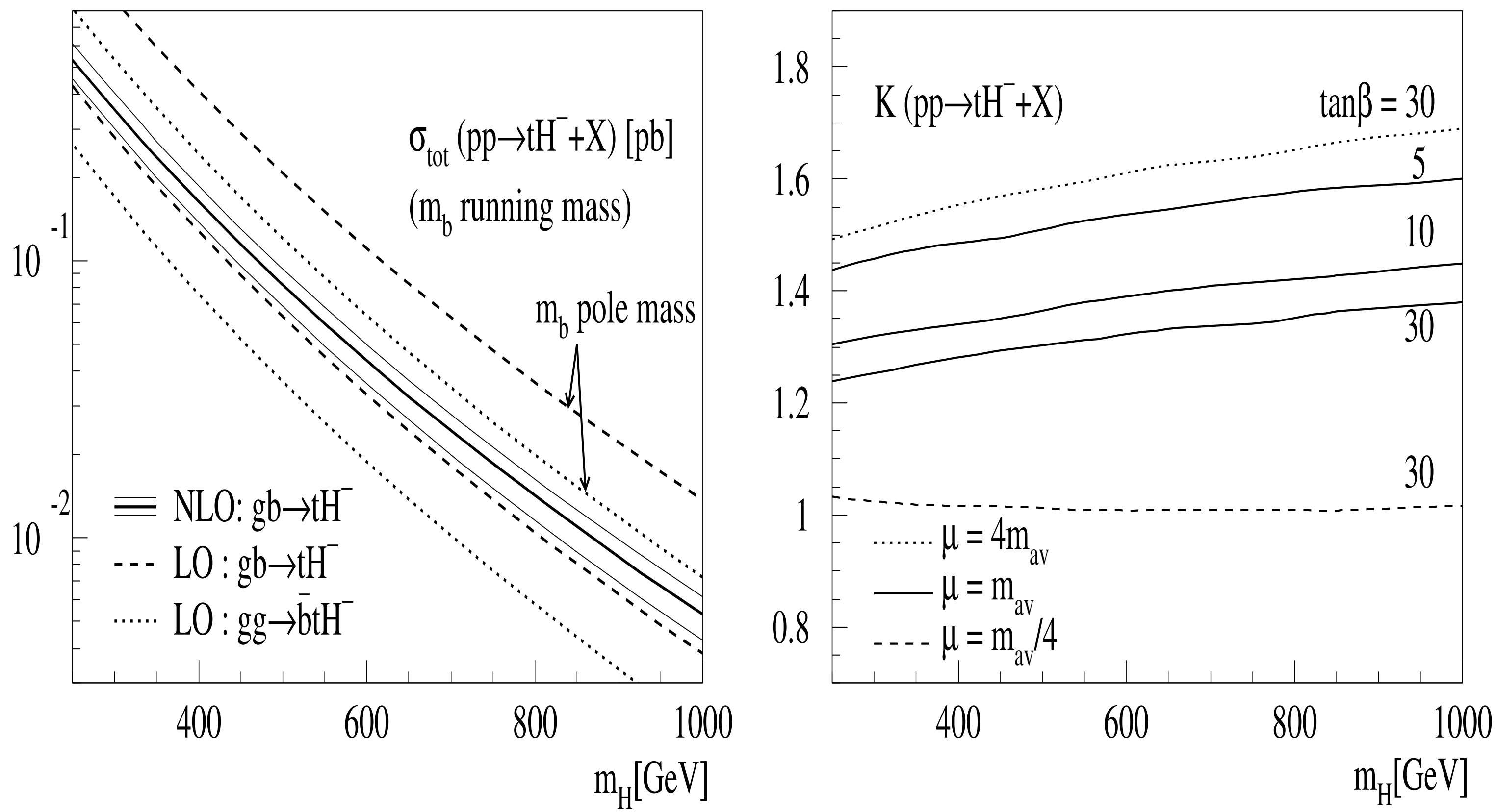




In fact, the process $gg \to H^- t\bar{b}$ is in fact simply part of the NLO QCD corrections to $gb \to H^- t$ when the momentum of the additional final $b$quark is integrated out

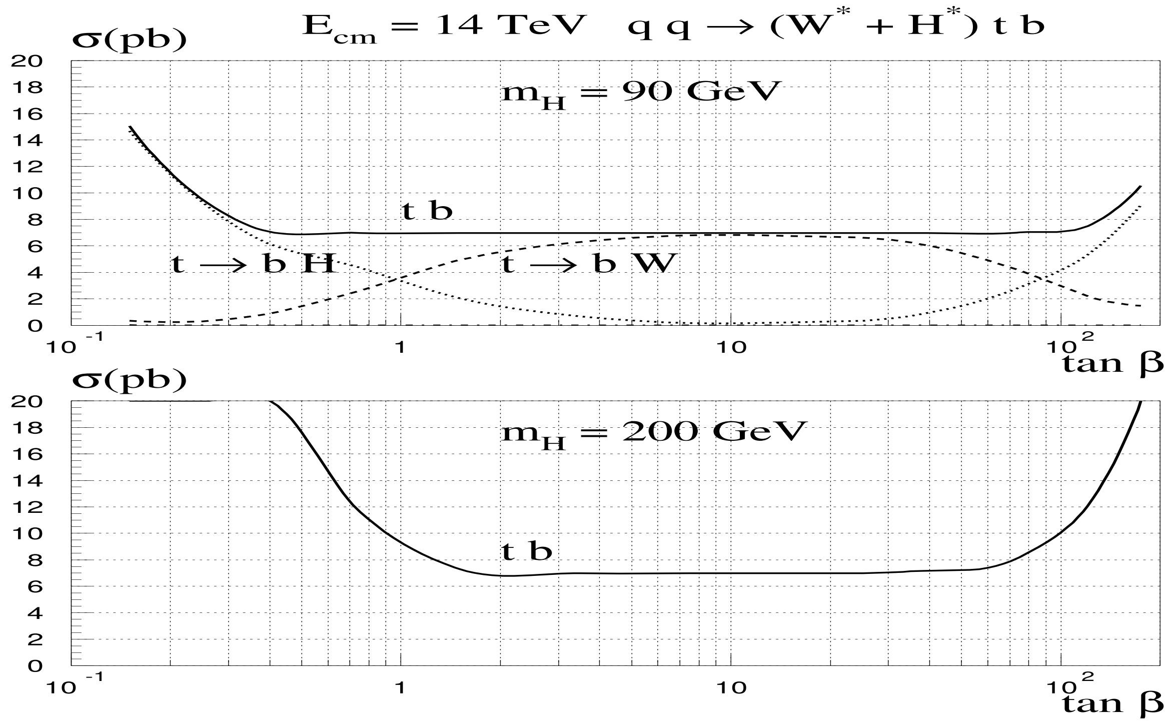
♠ *Preliminary*

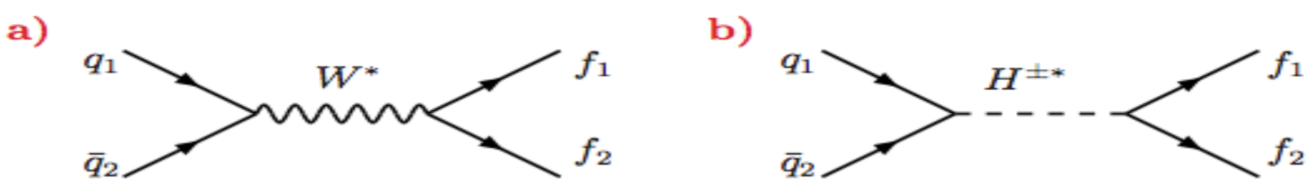
- The gb fusion: $M_{H^\pm} \gtrsim m_t$ NLO corrections with $m_{\rm av} = (m_t + M_{H^\pm})/2$



♠ *Preliminary*

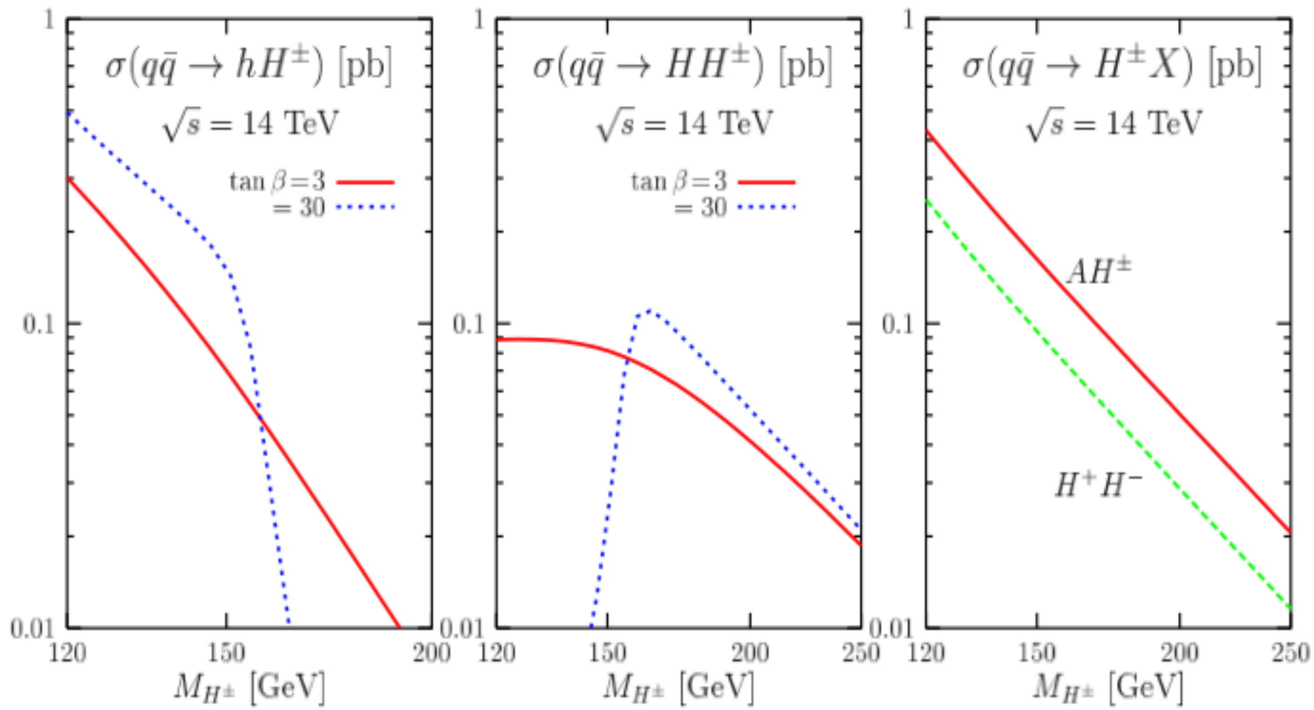
- The single production: *$pp \to tb\,, \tau\nu$ huge background .... extremely difficult*

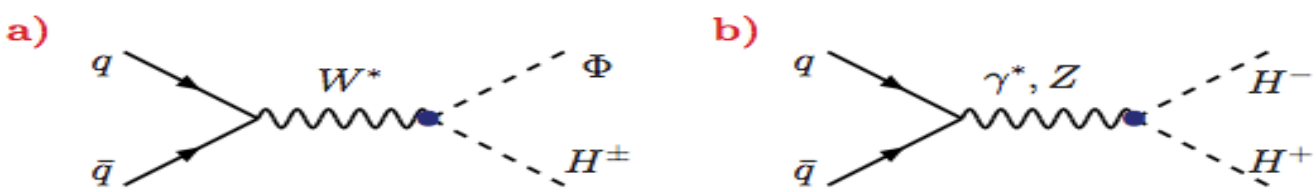




♠ *Preliminary*

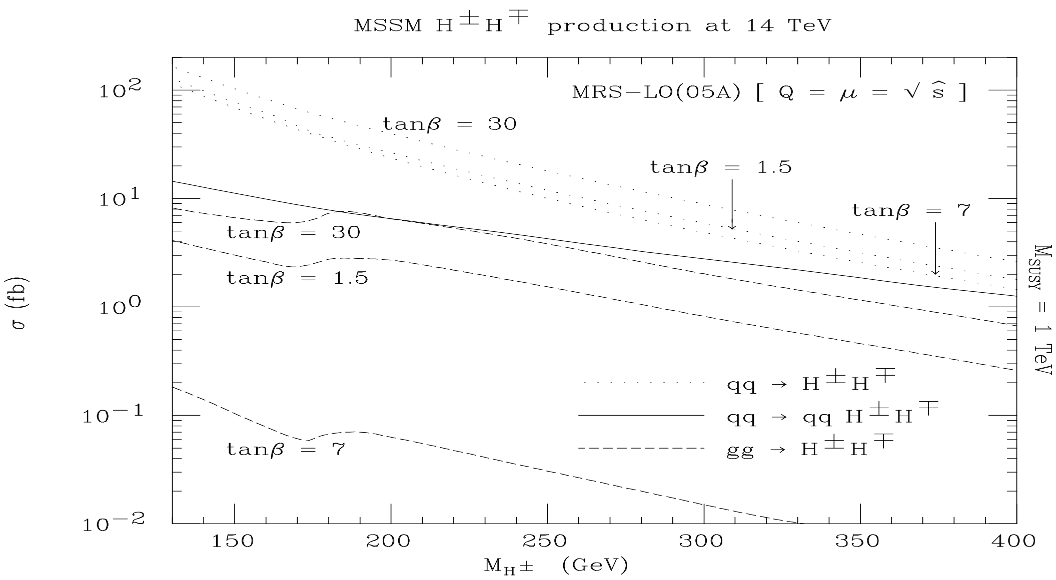
- The pair production 1: $g^2_{H_iVV} + |g_{H_iH^+W^-}|^2 = 1$ *for each* i

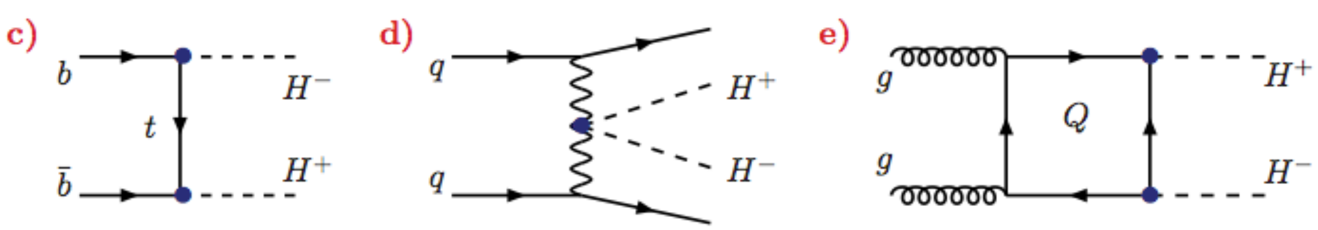




♠ *Preliminary*

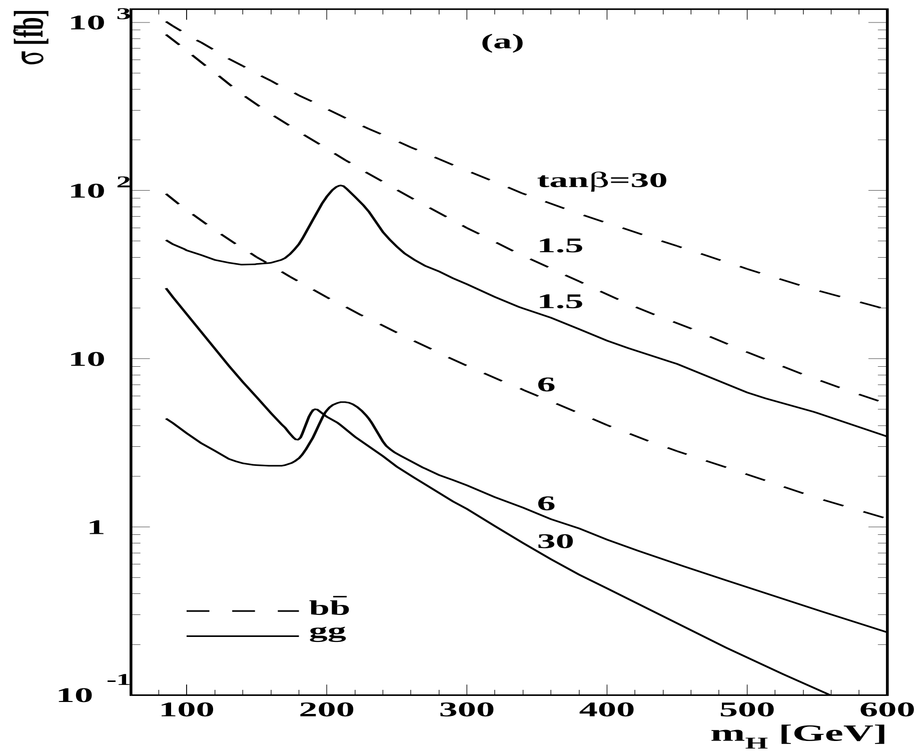
- The pair production 2:

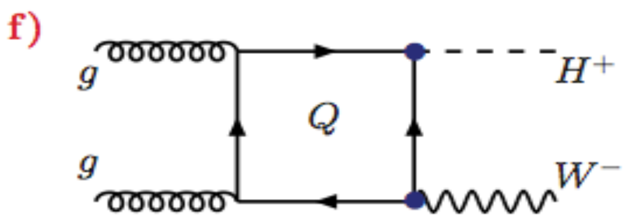


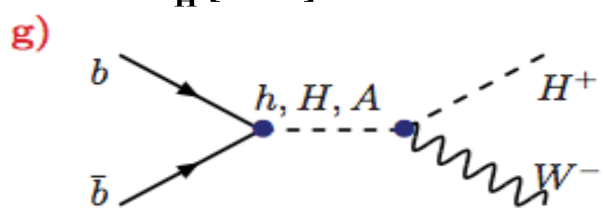


♠ *Preliminary*

- The associated production:





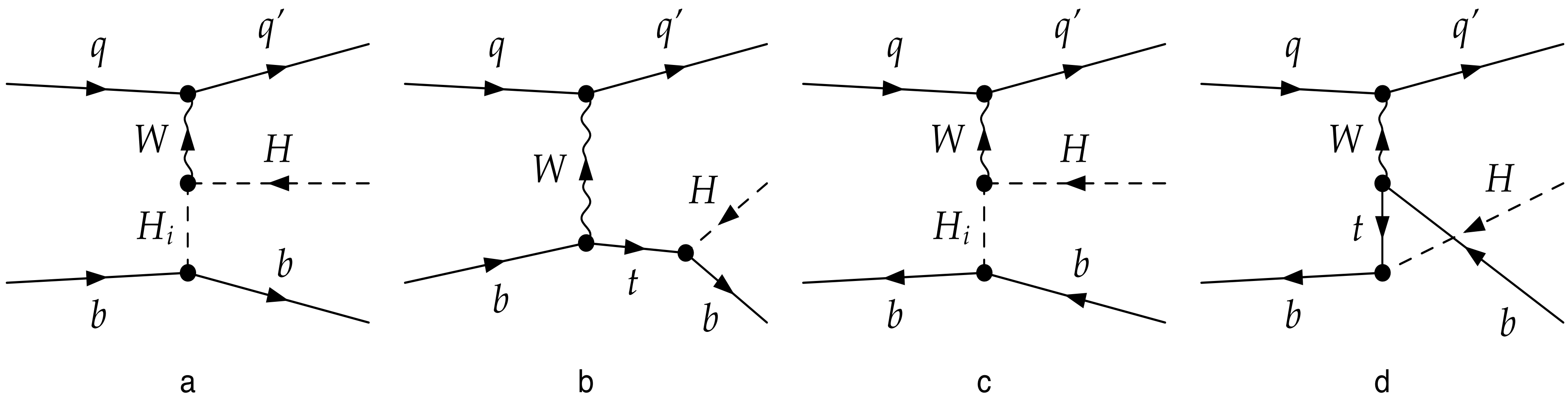


♠ *Preliminary*

- A very brief summary:
  - $M_{H^\pm} \lesssim m_t$: $\sigma(q\bar{q}, gg \to t\bar{t} \to tbH^\pm) \sim 80$ pb for $M_{H^\pm} \sim 150$ GeV
  - $M_{H^\pm} \gtrsim m_t$: $\sigma(gb \to tH^\pm) \sim 1$ pb for $M_{H^\pm} \sim 300$ GeV

♠ *Preliminary*

- A new mechanism (!): W–b scattering? W–Higgs fusion? : $qb \to q'H^+b$ in the MSSM S. Moretti, K. Odagiri PRD55 (1997) 5627, hep-ph/9611374



$$M_{H^\pm} \lesssim m_t \; : \; \sigma(qb \to jbH^\pm)|_{\text{diagram b}} \sim 20 \text{ pb for } M_{H^\pm} \sim 150 \text{ GeV}$$

$$M_{H^\pm} \gtrsim m_t \; : \; \sigma \lesssim 10^{-2} \text{ pb for } M_{H^\pm} \gtrsim 300 \text{ GeV}$$ *... why so small?*

♠ *Contents*

We wish to study the role of W–Higgs fusion in W–b scattering adopting general 2HDMs

- 2HDM as a minimal model containing $H^{\pm}$
- Analytic understanding of the W-b scattering
- Results
- Summary

♠ *2HDMs*

- 2HDM : minimal model containing $H^{\pm}$ K.Cheung, JSL, P.Y.Tseng, JHEP 1401 (2014) 085, arXiv:1310.3937

$$
\begin{aligned}
\mathrm{V} \;=\; & -\mu_1^2(\Phi_1^\dagger\Phi_1) - \mu_2^2(\Phi_2^\dagger\Phi_2) - m_{12}^2(\Phi_1^\dagger\Phi_2) - m_{12}^{*2}(\Phi_2^\dagger\Phi_1) \\
& +\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\
& +\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)^2 + \frac{\lambda_5^*}{2}(\Phi_2^\dagger\Phi_1)^2 + \lambda_6(\Phi_1^\dagger\Phi_1)(\Phi_1^\dagger\Phi_2) + \lambda_6^*(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_1) \\
& +\lambda_7(\Phi_2^\dagger\Phi_2)(\Phi_1^\dagger\Phi_2) + \lambda_7^*(\Phi_2^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)
\end{aligned}
$$

$$
\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}\,(v_1 + \phi_1^0 + ia_1) \end{pmatrix} ; \quad \Phi_2 = \mathrm{e}^{i\xi} \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}\,(v_2 + \phi_2^0 + ia_2) \end{pmatrix}
$$

♠ 2HDMs

- The 13 parameters of 2HDM

$$v\,,\tan\beta\,,|m_{12}|\,;$$
$$\lambda_1\,,\lambda_2\,,\lambda_3\,,\lambda_4\,,|\lambda_5|\,,|\lambda_6|\,,|\lambda_7|\,;$$
$$\phi_5+2\xi\,,\phi_6+\xi\,,\phi_7+\xi\,,\mathrm{sign}[\cos(\phi_{12}+\xi)]$$

with $m_{12}^2=|m_{12}|^2e^{i\phi_{12}}$ and $\lambda_{5,6,7}=|\lambda_{5,6,7}|e^{i\phi_{5,6,7}}$

– $\mu_{1,2}^2$ are replaced with v and $\tan\beta$ through the CP-even tadpole conditions
– $\sin(\phi_{12}+\xi)$ is fixed by the CP-odd tadpole condition

One may take the convention with $\xi=0$ without loss of generality.

♠ *2HDMs*

- The 3×3 mass matrix in $(\phi_1^0, \phi_2^0, a)^T$ basis

$$\mathcal{M}_0^2 = M_A^2 \begin{pmatrix} s_\beta^2 & -s_\beta c_\beta & 0 \\ -s_\beta c_\beta & c_\beta^2 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \mathcal{M}_\lambda^2$$

$$\frac{\mathcal{M}_\lambda^2}{v^2} = \begin{pmatrix} \begin{array}{l} 2\lambda_1 c_\beta^2 + \Re\mathrm{e}(\lambda_5 \mathrm{e}^{2i\xi}) s_\beta^2 \\ +2\Re\mathrm{e}(\lambda_6 \mathrm{e}^{i\xi}) s_\beta c_\beta \end{array} & \begin{array}{l} \lambda_{34} c_\beta s_\beta + \Re\mathrm{e}(\lambda_6 \mathrm{e}^{i\xi}) c_\beta^2 \\ +\Re\mathrm{e}(\lambda_7 \mathrm{e}^{i\xi}) s_\beta^2 \end{array} & \begin{array}{l} -\frac{1}{2}\Im\mathrm{m}(\lambda_5 \mathrm{e}^{2i\xi}) s_\beta \\ -\Im\mathrm{m}(\lambda_6 \mathrm{e}^{i\xi}) c_\beta \end{array} \\ \begin{array}{l} \lambda_{34} c_\beta s_\beta + \Re\mathrm{e}(\lambda_6 \mathrm{e}^{i\xi}) c_\beta^2 \\ +\Re\mathrm{e}(\lambda_7 \mathrm{e}^{i\xi}) s_\beta^2 \end{array} & \begin{array}{l} 2\lambda_2 s_\beta^2 + \Re\mathrm{e}(\lambda_5 \mathrm{e}^{2i\xi}) c_\beta^2 \\ +2\Re\mathrm{e}(\lambda_7 \mathrm{e}^{i\xi}) s_\beta c_\beta \end{array} & \begin{array}{l} -\frac{1}{2}\Im\mathrm{m}(\lambda_5 \mathrm{e}^{2i\xi}) c_\beta \\ -\Im\mathrm{m}(\lambda_7 \mathrm{e}^{i\xi}) s_\beta \end{array} \\ \begin{array}{l} -\frac{1}{2}\Im\mathrm{m}(\lambda_5 \mathrm{e}^{2i\xi}) s_\beta \\ -\Im\mathrm{m}(\lambda_6 \mathrm{e}^{i\xi}) c_\beta \end{array} & \begin{array}{l} -\frac{1}{2}\Im\mathrm{m}(\lambda_5 \mathrm{e}^{2i\xi}) c_\beta \\ -\Im\mathrm{m}(\lambda_7 \mathrm{e}^{i\xi}) s_\beta \end{array} & 0 \end{pmatrix}$$

with $\lambda_{34} = \lambda_3 + \lambda_4$, $v = gM_W/2$, $a = -s_\beta a_1 + c_\beta a_2$, $H^+ = -s_\beta \phi_1^+ + c_\beta \phi_2^+$,

... and

$$
\begin{aligned}
M_A^2 &= M_{H^\pm}^2 + \frac{1}{2}\lambda_4 v^2 - \frac{1}{2}\Re\mathrm{e}(\lambda_5 \mathrm{e}^{2i\xi}) v^2 \\
M_{H^\pm}^2 &= \frac{\Re\mathrm{e}(m_{12}^2 \mathrm{e}^{i\xi})}{c_\beta s_\beta} - \frac{v^2}{2 c_\beta s_\beta}\Big[\lambda_4 c_\beta s_\beta + c_\beta s_\beta \Re\mathrm{e}(\lambda_5 \mathrm{e}^{2i\xi}) \\
&\qquad + c_\beta^2 \Re\mathrm{e}(\lambda_6 \mathrm{e}^{i\xi}) + s_\beta^2 \Re\mathrm{e}(\lambda_7 \mathrm{e}^{i\xi})\Big]
\end{aligned}
$$

- Diagonalization: $(\phi_1^0, \phi_2^0, a)_\alpha^T = O_{\alpha i}(H_1, H_2, H_3)_i^T$ with $O^T \mathcal{M}_0^2 O = \mathrm{diag}(M_{H_1}^2, M_{H_2}^2, M_{H_3}^2)$

$$
O = \begin{pmatrix} O_{\phi_1 1} & O_{\phi_1 2} & O_{\phi_1 3} \\ O_{\phi_2 1} & O_{\phi_2 2} & O_{\phi_2 3} \\ O_{a1} & O_{a2} & O_{a3} \end{pmatrix} \quad \mathrm{CPC} \underset{\longrightarrow}{\mathrm{with}} \mathrm{H_3{=}A} \quad \begin{pmatrix} -\sin\alpha & \cos\alpha & 0 \\ \cos\alpha & \sin\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}
$$

  - Decoupling limit: $\sin\alpha \to -\cos\beta$, $\cos\alpha \to \sin\beta$

♠ 2HDMs

- After identifying the Yukawa couplings by

$$h_u = \frac{\sqrt{2}m_u}{v}\frac{1}{s_\beta}; \quad h_d = \frac{\sqrt{2}m_d}{v}\frac{1}{\eta_1^d c_\beta + \eta_2^d s_\beta}; \quad h_l = \frac{\sqrt{2}m_l}{v}\frac{1}{\eta_1^l c_\beta + \eta_2^l s_\beta},$$

one can easily obtain the following Higgs-fermion-fermion interactions

$$\begin{aligned} -\mathcal{L}_{H_i \bar{f} f} &= \frac{m_u}{v}\left[\bar{u}\left(\frac{O_{\phi_2 i}}{s_\beta} - i\,\frac{c_\beta}{s_\beta}O_{ai}\,\gamma_5\right)u\right]H_i \\ &+ \frac{m_d}{v}\left[\bar{d}\left(\frac{\eta_1^d O_{\phi_1 i} + \eta_2^d O_{\phi_2 i}}{\eta_1^d c_\beta + \eta_2^d s_\beta} - i\,\frac{\eta_1^d s_\beta - \eta_2^d c_\beta}{\eta_1^d c_\beta + \eta_2^d s_\beta}O_{ai}\,\gamma_5\right)d\right]H_i \\ &+ \frac{m_l}{v}\left[\bar{l}\left(\frac{\eta_1^l O_{\phi_1 i} + \eta_2^l O_{\phi_2 i}}{\eta_1^l c_\beta + \eta_2^l s_\beta} - i\,\frac{\eta_1^l s_\beta - \eta_2^l c_\beta}{\eta_1^l c_\beta + \eta_2^l s_\beta}O_{ai}\,\gamma_5\right)l\right]H_i \end{aligned}$$

and

$$
\begin{aligned}
-\mathcal{L}_{H^\pm \bar{u} d} \quad = \quad & -\frac{\sqrt{2} m_u}{v} \left(\frac{c_\beta}{s_\beta} \right) \bar{u}\, P_L\, d\, H^+ - \frac{\sqrt{2} m_d}{v} \left(\frac{\eta_1^d s_\beta - \eta_2^d c_\beta}{\eta_1^d c_\beta + \eta_2^d s_\beta} \right) \bar{u}\, P_R\, d\, H^+ \\
& -\frac{\sqrt{2} m_l}{v} \left(\frac{\eta_1^l s_\beta - \eta_2^l c_\beta}{\eta_1^l c_\beta + \eta_2^l s_\beta} \right) \bar{\nu}\, P_R\, l\, H^+ \ + \ \mathrm{h.c.}
\end{aligned}
$$

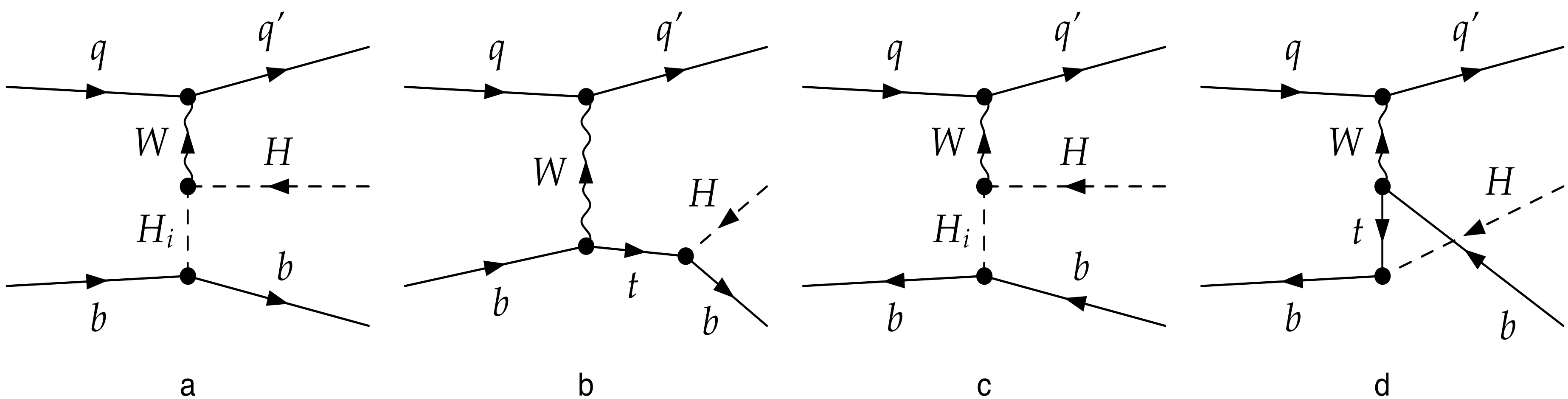
- Classification of 2HDMs satisfying the Glashow-Weinberg condition which guarantees the absence of tree-level FCNC

	2HDM I	2HDM II	2HDM III	2HDM IV
η_1^d	0	1	0	1
η_2^d	1	0	1	0
η_1^l	0	1	1	0
η_2^l	1	0	0	1

♠ *Process*

- The $2 \to 3$ processes $qb \to q'H^+b$ and $q\bar{b} \to q'H^+\bar{b}$ with $(q,q') = (u,d),(c,s)$.

The processes with $(\bar{q},\bar{q}') = (\bar{d},\bar{u}),(\bar{s},\bar{c})$ are understood.

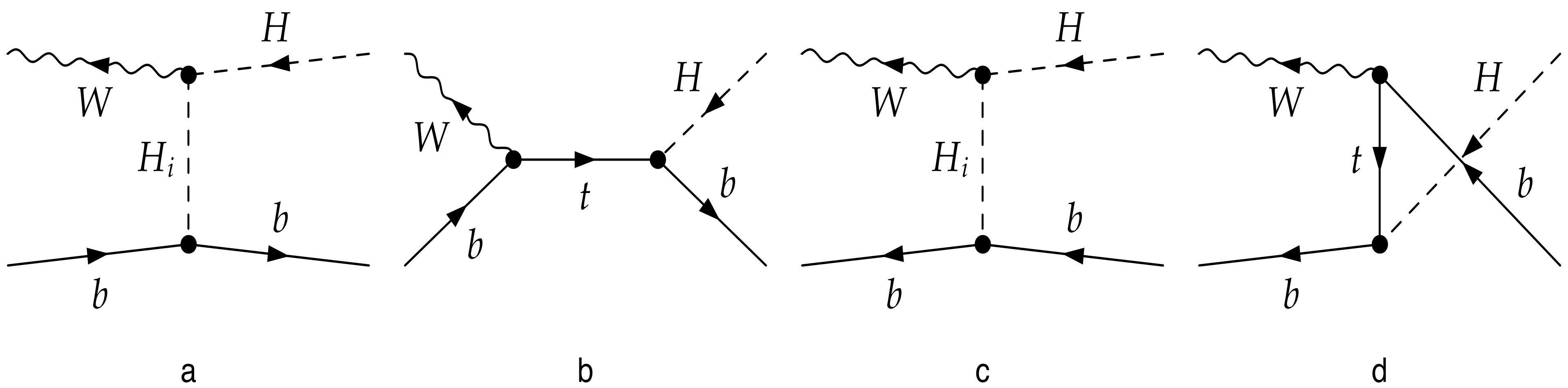


  - a, c : t-channel H_i exchanges $\leftarrow$ W-H_i fusion into H^+
  - b : s-channel top exchange $\leftarrow$ single top$^{(*)}$ production decaying into $H^+\,b$
  - d : u-channel top exchange

♠ *Process*

- The $2 \to 2$ subprocesses in the effective W approximation:

$$W^+(q_1)\ b(p_1) \to H^+(q_2)\ b(p_2)\,; \quad W^+(q_1)\ \bar{b}(p_1) \to H^+(q_2)\ \bar{b}(p_2)$$



  - $(b)\ :\ s = (p_1 + q_1)^2 = (p_2 + q_2)^2$
  - $(a), (c)\ :\ t = (p_1 - p_2)^2 = (q_2 - q_1)^2$
  - $(d)\ :\ u = (p_1 - q_2)^2 = (p_2 - q_1)^2$

♠ *Process*

- The relevant interactions:

$$
\begin{aligned}
\mathcal{L}_{H_i\bar{b}b} &= -\frac{g m_b}{2 m_W}\,\bar{b}\,(g_i^S + i\,g_i^P\,\gamma_5)\,b\,H_i\,, \\
\mathcal{L}_{H^\pm tb} &= +\frac{g m_b}{\sqrt{2} m_W}\,\bar{b}\,(c_L\,P_L + c_R\,P_R)\,t\,H^- \;+\; \text{h.c.}\,, \\
\mathcal{L}_{W^\pm tb} &= -g/\sqrt{2}\,(\bar{t}\gamma_\mu P_L\,b)\,W^{+\mu} + \text{h.c.}\,, \\
\mathcal{L}_{H_i H^\pm W^\pm} &= -\frac{g}{2}\,(S_i + iP_i)\,\left[H^-\left(i\,\overleftrightarrow{\partial}_\mu\right)H_i\right]\,W^{+\mu} \;+\; \text{h.c.}
\end{aligned}
$$

  - Type-independent couplings:

$$
S_i = c_\beta O_{\phi_2 i} - s_\beta O_{\phi_1 i}\,, \quad P_i = O_{ai}\,,
$$

– Types II and IV

$$c_L = \tan\beta\,, \quad c_R = \frac{m_t}{m_b}\frac{1}{\tan\beta}\,; \quad g_i^S = \frac{O_{\phi_1 i}}{c_\beta}\,, \quad g_i^P = -\tan\beta O_{ai}$$

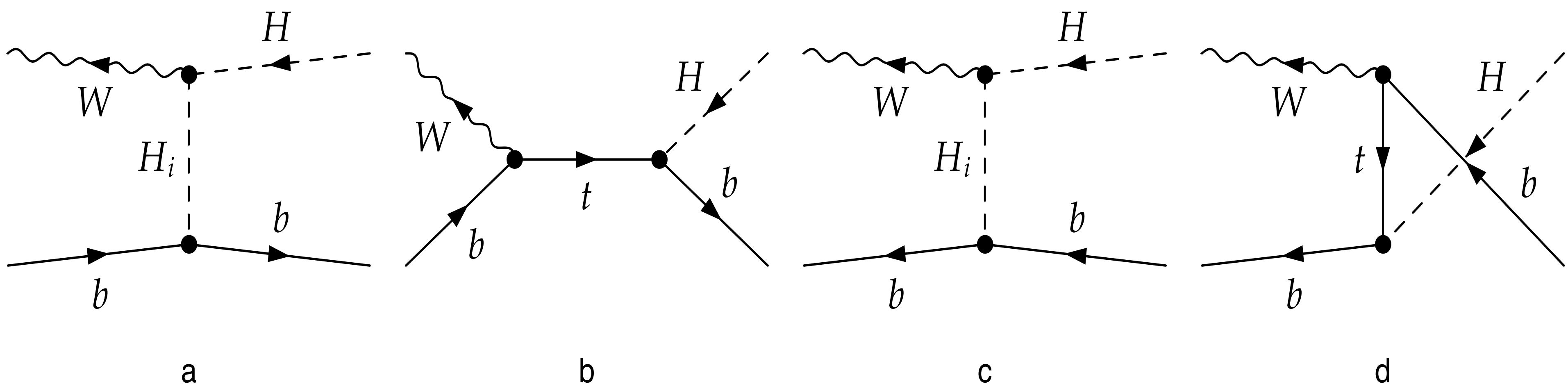
– Types I and III

$$c_L = -\frac{1}{\tan\beta}\,, \quad c_R = \frac{m_t}{m_b}\frac{1}{\tan\beta}\,; \quad g_i^S = \frac{O_{\phi_2 i}}{s_\beta}\,, \quad g_i^P = \frac{O_{ai}}{\tan\beta}$$

♠ Process

- The $2 \to 2$ subprocesses in the effective W approximation:

$$W^+(q_1)\, b(p_1) \to H^+(q_2)\, b(p_2)\,; \quad W^+(q_1)\, \bar{b}(p_1) \to H^+(q_2)\, \bar{b}(p_2)$$



$$\mathcal{M}_{(a)}^{H_i} = -\frac{g^2 m_b}{4 m_W (t - M_{H_i}^2)} (S_i + iP_i)\,(q_2 + p_{H_i})^\mu \epsilon_\mu(q_1)\ \left[\bar{u}(p_2)\left(g_i^S + i g_i^P \gamma_5\right) u(p_1)\right]$$

$$\mathcal{M}_{(b)} = -\frac{g^2 m_b C_v}{2 m_W (s - m_t^2)} \left[c_L\, \bar{u}(p_2)\, \not{p}_t\, \not{\epsilon}(q_1) P_L u(p_1) \ + \ c_R\, m_t\, \bar{u}(p_2) \not{\epsilon}(q_1) P_L u(p_1)\right]$$

$\epsilon^\mu(q_1)$ denotes the polarization vector of W^+ boson

- In the high-energy limit, $s, |t|, |u| \gg m_W^2, m_t^2, M_{H_i}^2, M_{H^\pm}^2$, we find that

$$\mathcal{M} = \mathcal{M}_{(b)} + \sum_i \mathcal{M}_{(a)}^{H_i} \approx \frac{g^2 m_b}{4m_W^2}\left\{ \left[\sum_i (S_i g_i^S - P_i g_i^P) \ + \ i\sum_i (S_i g_i^P + P_i g_i^S)\right] \bar{u}(p_2) P_R u(p_1) \right.$$
$$\left. + \left[\left(2\,c_L + \sum_i (S_i g_i^S + P_i g_i^P)\right) \ + \ i\sum_i (-S_i g_i^P + P_i g_i^S)\right] \ \bar{u}(p_2) P_L u(p_1)\right\}$$

where we have taken the longitudinally polarized W or $\epsilon^\mu(q_1) \approx q_1^\mu / m_W = (p_t^\mu - p_1^\mu)/m_W$ with $p_t^2 = s$ and $p_{H_i}^2 = t$.

- The amplitude squared in the high-energy limit:

$$\overline{|\mathcal{M}|^2} \propto \left\{ \left|2\,c_L + \sum_i (S_i g_i^S + P_i g_i^P)\right|^2 + \left|\sum_i (S_i g_i^S - P_i g_i^P)\right|^2 \right.$$
$$\left. + \left|\sum_i (-S_i g_i^P + P_i g_i^S)\right|^2 + \left|\sum_i (S_i g_i^P + P_i g_i^S)\right|^2 \right\} (-t)$$

♠ Process

- *Sum rules required by the absence of unitarity-breaking terms*:

$$2\,c_L + \sum_i (S_i g_i^S + P_i g_i^P) = 0\,, \quad \sum_i S_i g_i^S = \sum_i P_i g_i^P\,,$$

$$\sum_i S_i g_i^P = \sum_i P_i g_i^S = 0$$

  - Type II and IV: $c_L = \tan\beta$

$$\sum_i S_i g_i^S = \sum_i (O_{\phi_2 i} O_{\phi_1 i} - \tan\beta O_{\phi_1 i}^2) = -\tan\beta\,,$$

$$\sum_i P_i g_i^P = -\tan\beta \sum_i O_{ai}^2 = -\tan\beta\,, \sum_i S_i g_i^P = \sum_i P_i g_i^S = 0$$

  - Type I and III: $c_L = -1/\tan\beta$

$$\sum_i S_i g_i^S = \sum_i (O_{\phi_2 i}^2/\tan\beta - O_{\phi_1 i} O_{\phi_2 i}) = 1/\tan\beta\,,$$

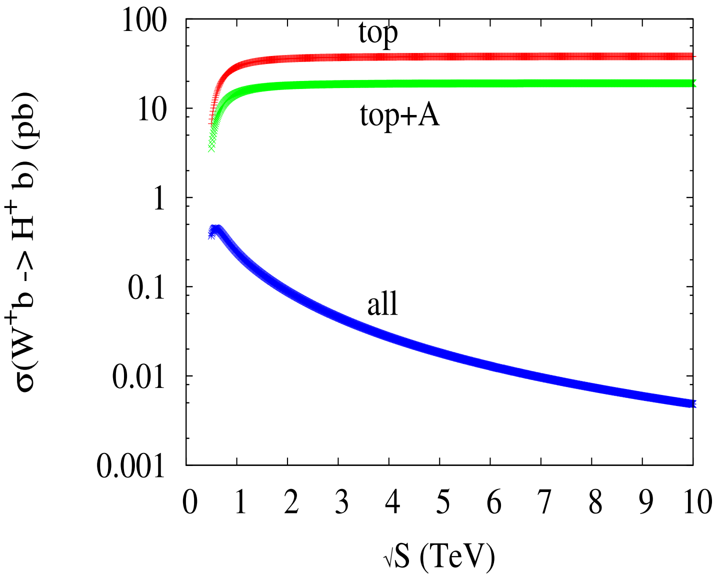
$$\sum_i P_i g_i^P = \sum_i O_{ai}^2/\tan\beta = 1/\tan\beta\,, \sum_i S_i g_i^P = \sum_i P_i g_i^S = 0$$

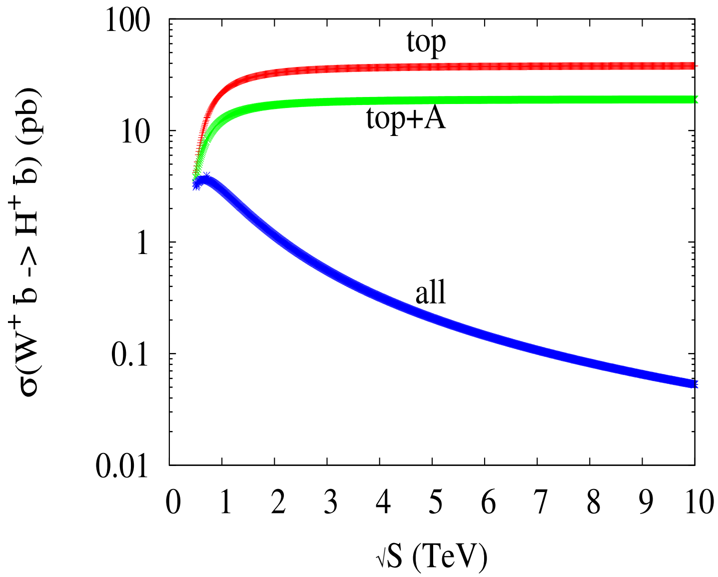
♠ *Process*

- Numerical example: MSSM in the CP conserving $\oplus$ decoupling limit:
  - $c_L = \tan\beta$ (Type II)
  - $H_1 = h$, $H_2 = H$, $H_3 = A$
  - $S_h = \cos(\beta - \alpha)$, $S_H = -\sin(\beta - \alpha)$, $P_A = 1$ with $P_h = P_H = S_A = 0$
  - $S_h \to 0$, $S_H \to -1$; $g_H^S \to \tan\beta$, $g_A^P \to -\tan\beta$

$$\sigma(W^+ b \to H^+ b) \propto \left|2\, c_L + S_H g_H^S + P_A g_A^P\right|^2 + \left|S_H g_H^S - P_A g_A^P\right|^2$$

$$\sigma(W^+b \to H^+b) \propto \left|2\,c_L + S_H g_H^S + P_A g_A^P\right|^2 + \left|S_H g_H^S - P_A g_A^P\right|^2$$





- $\tan\beta = 30$, $M_A = 400$ GeV
- $\sigma(W^+b \to H^+b)\big|_{t\ \mathrm{only}} \propto 4\ \tan^2\beta$
- $\sigma(W^+b \to H^+b)\big|_{t+H\ \mathrm{only}} = \sigma(W^+b \to H^+b)\big|_{t+A\ \mathrm{only}} \propto 2\ \tan^2\beta$
- $\sigma(W^+b \to H^+b)\big|_{t+H+A} \propto \mathcal{O}(m_t^2/s\,,\, M_H^2/|t|\,,\, m_t^2/|u|)$

♠ *Process*

- Comments:
  - The b-initiated process for production of H^+ in $qb \to qH^+b$ suffers from very strong cancellations between the top and the W-H_i diagrams and among the W-H_i diagrams
  - While, for the $\bar{b}$-initiated process, the cancellation is less severe
  - The strong cancellation is dictated by the absence of the unitarity-breaking terms expressed by the sum rules
  - The cross section can be enhanced if we can avoid the cancellations: (i) sizable hierarchy between M_A and M_H, (ii) a 2HDM is not an UV complete theory, and/or $\cdots$

♠ *Results*

- We consider 2HDMs without CP violation, identifying $H_1 = h$, $H_2 = H$, $H_3 = A$ with $M_h = 125$ GeV

- Couplings:
  - $S_1 = S_h = c_\beta O_{\phi_2 1} - s_\beta O_{\phi_1 1} = \cos(\beta - \alpha)$
  - $S_2 = S_H = c_\beta O_{\phi_2 2} - s_\beta O_{\phi_1 2} = -\sin(\beta - \alpha)$
  - $P_3 = P_A = O_{a3} = 1$
  - $P_1 = P_2 = S_3 = 0$ (CPC)

– Yukawa couplings: $gm_b/\sqrt{2}M_W \times \cdots$ (h, H, A), $g/\sqrt{2}M_W \times \cdots$ $(H^{\pm})$

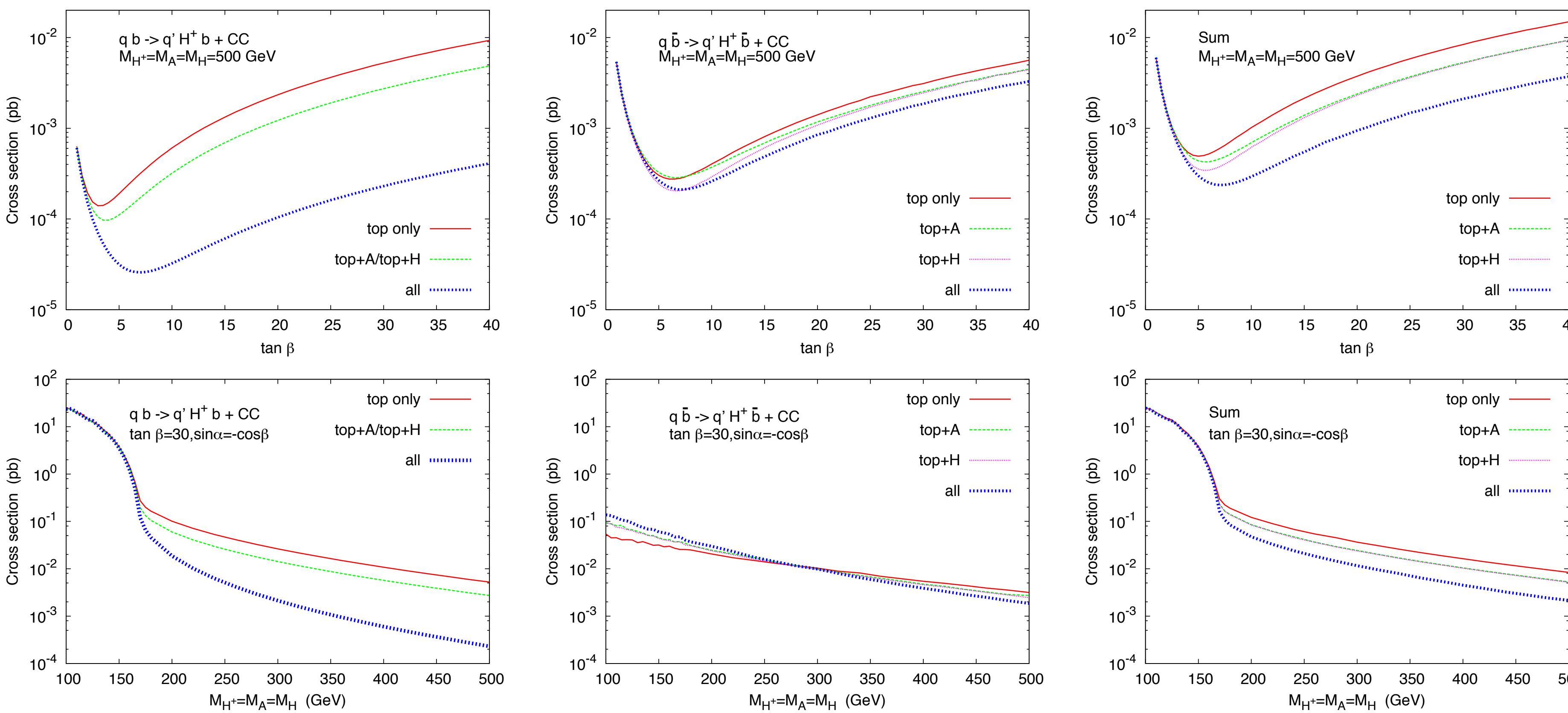
	Type I, III	Type II, IV
$hb\bar{b}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
$Hb\bar{b}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$
$Ab\bar{b}$	$+\cot\beta$	$-\tan\beta$
$H^-t\bar{b}$	$-\frac{m_b}{\tan\beta}P_L + \frac{m_t}{\tan\beta}P_R$	$m_b\tan\beta P_L + \frac{m_t}{\tan\beta}P_R$

- Free parameters: $\tan\beta$, M_H, M_A, $M_{H^{\pm}}$, $\sin\alpha$. We are taking the decoupling $\sin\alpha = -\cos\beta$ mostly

- We have checked the results of our calculation against those obtained by `MadGraph`, found an excellent agreement

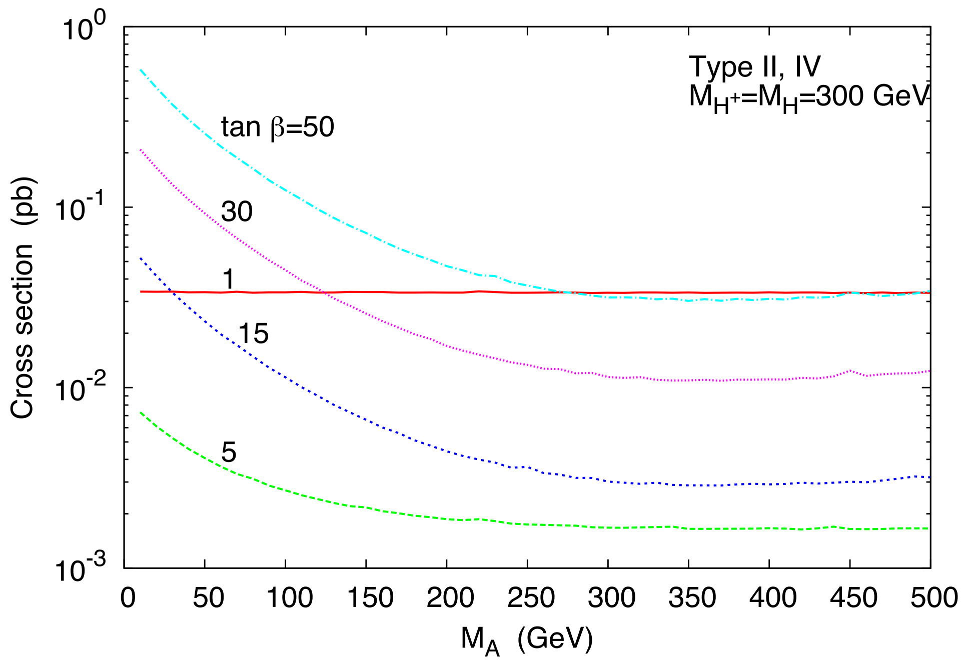
♠ *Results*

- Type II $\sigma(pp \to jH^{\pm}b/\bar{b})$ at LHC-14: $\tan\beta$ (Upper) ; $M_A = M_H = M_{H^\pm}$ (Lower) ; $qb \to q'H^+b + c.c.$ (left), $q\bar{b} \to q'H^+\bar{b} + c.c.$ (middle), total sum (right)



♠ *Results*

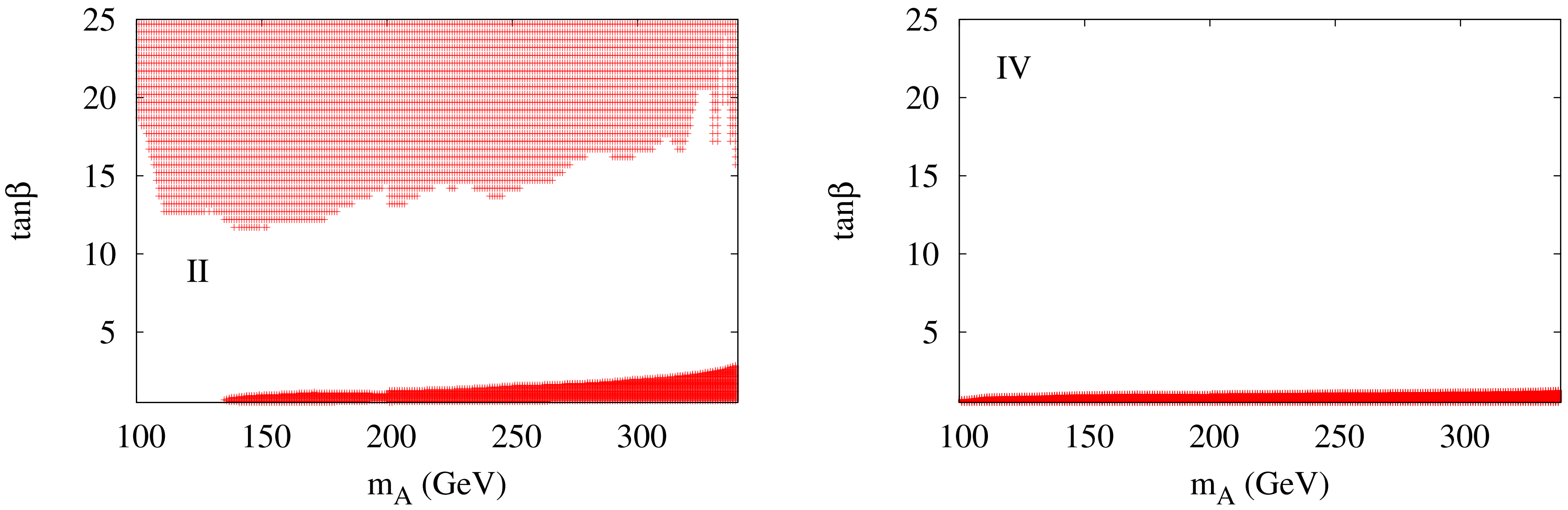
- Type II, IV: $M_A \neq M_H = M_{H^\pm}$



The larger cross section for the lager values of $\tan\beta$ when $M_A \leq M_H = M_{H^\pm}$

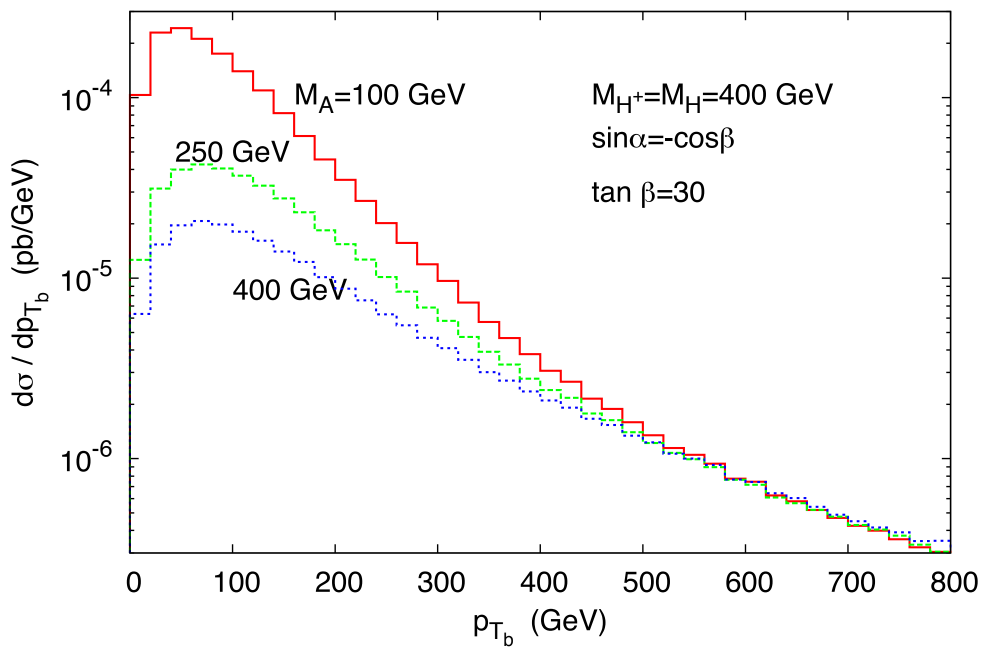
♠ *Results*

- Constraints from ATLAS : $gg \to A \to \tau^+\tau^-$ JHEP **1411**, 056 (2014),[arXiv:1409.6064]



♠ *Results*

- Discriminating $W^{\pm}$-Higgs fusion from the top-exchange processes



♠ *Summary*

- The b-initiated process for production of H^+ in $qb \to qH^+b$ suffers from a very strong cancellation between the top diagram and the W-H_i diagrams

- The strong cancellation is dictated by the absence of the unitarity-breaking terms and we find the sum rules expressed by the relevant Higgs couplings

- For $M_{H^\pm} \leq m_t - m_b$ the top diagram completely dominates through the s-channel single-top production. However, when $M_{H^\pm} > m_t - m_b$, the W-H_i fusion diagrams also contribute

- The process $pp \to jH^\pm b/\bar{b}$ would be more interesting for type II and IV (especially type IV) : $\sigma \sim O(100 - 300)$ fb for $\tan\beta = 30 - 50$ and $M_A = 50 - 100$ GeV

- One may make use of the special kinematics, e.g, the p_{T_b} distribution, to discriminate between the top and the W-H_i fusion diagrams