Charged Higgs phenomenology beyond the MSSM

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Based on:

H.E.L. and D. MacLennan, Phys. Rev. D79, 115022 (2009)

H.E.L. and D. MacLennan, Phys. Rev. D81, 075016 (2010)

Introduction: two Higgs doublet models

With two Higgs doublets we have four extra scalar degrees of freedom compared to the Standard Model:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ (v_1 + \phi_1^{0,r} + i\phi_1^{0,i})/\sqrt{2} \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ (v_2 + \phi_2^{0,r} + i\phi_2^{0,i})/\sqrt{2} \end{pmatrix}$$

with $v_1^2 + v_2^2 = v_{\rm SM}^2 = 4M_W^2/g^2$ and $v_2/v_1 \equiv \tan\beta$.

Mass eigenstates:

$$\begin{aligned} h^0 &= -\sin\alpha\,\phi_1^{0,r} + \cos\alpha\,\phi_2^{0,r}, & H^0 &= \cos\alpha\,\phi_1^{0,r} + \sin\alpha\,\phi_2^{0,r} \\ A^0 &= -\sin\beta\,\phi_1^{0,i} + \cos\beta\,\phi_2^{0,i}, & G^0 &= \cos\beta\,\phi_1^{0,i} + \sin\beta\,\phi_2^{0,i} \\ H^+ &= -\sin\beta\,\phi_1^{+} + \cos\beta\,\phi_2^{+}, & G^+ &= \cos\beta\,\phi_1^{+} + \sin\beta\,\phi_2^{+} \end{aligned}$$

This talk: phenomenology of H^+.

An automatic feature of the Standard Model:

Yukawas $\mathcal{L} = -y^d_{ij}\bar{d}_{Ri}\Phi Q_{Lj} - y^u_{ij}\bar{u}_{Ri}\tilde{\Phi} Q_{Lj} - y^\ell_{ij}\bar{e}_{Ri}\Phi L_{Lj} +$ h.c. give fermion mass matrices $m^f_{ij} = y^f_{ij} v/\sqrt{2}$; diagonalizing gives fermion masses (with y^f_{ij} diagonalized automatically).
No flavour-changing neutral Higgs couplings.

Generic multi-Higgs-doublet model:

$$\mathcal{L}_{\rm Yuk} \supset -y^d_{ij}\bar{d}_{Ri}\Phi_1 Q_{Lj} - \tilde{y}^d_{ij}\bar{d}_{Ri}\Phi_2 Q_{Lj} + h.c.$$

Mass matrix for down-type quarks: $m^d_{ij} = (y^d_{ij} v_1 + \tilde{y}^d_{ij} v_2)/\sqrt{2}$.
Diagonalizing m^d_{ij} does *not* in general diagonalize y^d_{ij} and $\tilde{y}^d_{ij}$ separately; leads to flavour-changing neutral Higgs couplings.

Can forbid flavour-changing neutral Higgs couplings by requiring that each type of fermion (u, d, ℓ) gets its mass from exactly one Higgs doublet: called "natural flavour conservation."

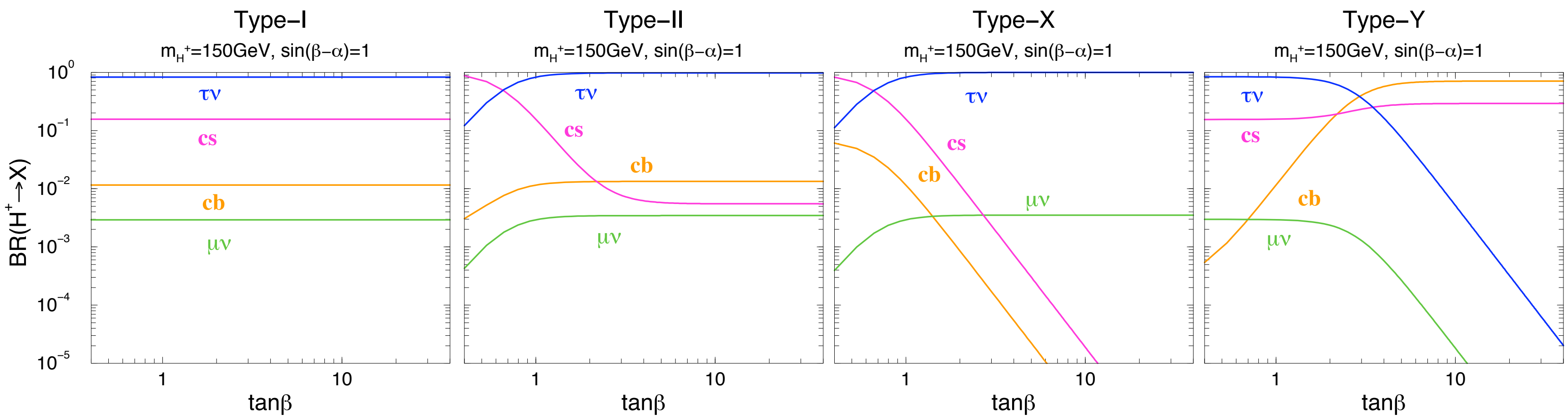
[Glashow & Weinberg; Paschos; 1977]

	Type I	Type II	Leptonic	Flipped
Φ_1	$-$	d, ℓ	ℓ	d
Φ_2	u, d, ℓ	u	u, d	u, ℓ

Charged Higgs couplings to fermions (all $\times \frac{ig}{\sqrt{2}M_W}$):

Model	$H^+\bar{u}_i d_j$	$H^+\bar{\nu}_i \ell_i$
Type I	$V_{ij}(\cot\beta\, m_{ui} P_L - \cot\beta\, m_{dj} P_R)$	$\cot\beta\, m_{\ell i} P_R$
Type II	$V_{ij}(\cot\beta\, m_{ui} P_L + \tan\beta\, m_{dj} P_R)$	$\tan\beta\, m_{\ell i} P_R$
Leptonic	$V_{ij}(\cot\beta\, m_{ui} P_L - \cot\beta\, m_{dj} P_R)$	$\tan\beta\, m_{\ell i} P_R$
Flipped	$V_{ij}(\cot\beta\, m_{ui} P_L + \tan\beta\, m_{dj} P_R)$	$\cot\beta\, m_{\ell i} P_R$

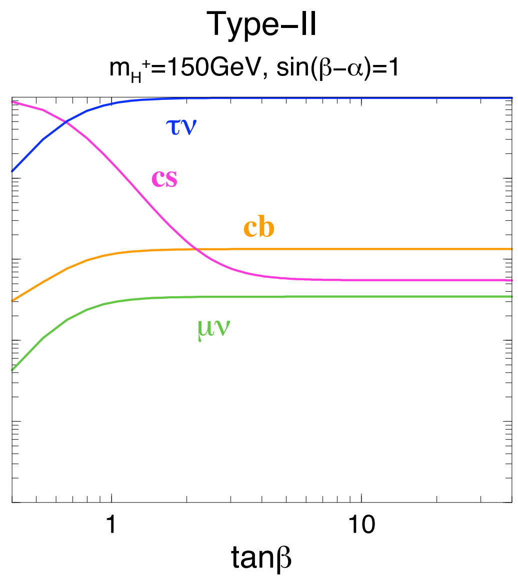
Resulting H^+ branching fractions: controlled by $\tan\beta$ and M_{H^+}



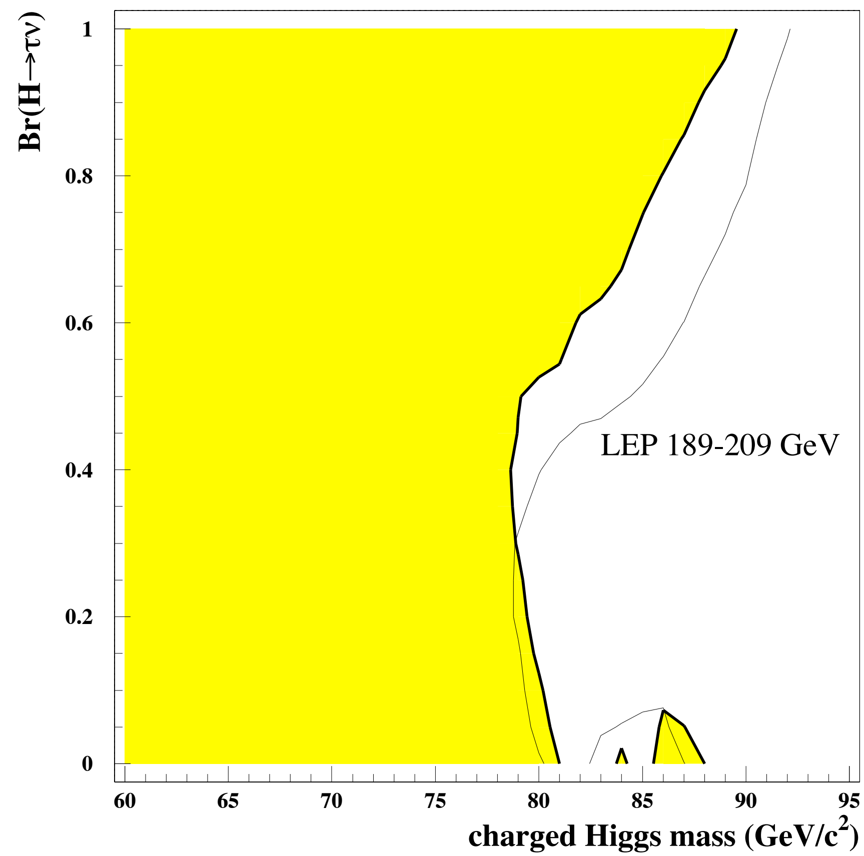
Aoki et al, Phys. Rev. D80, 015017(2009)

H^+ search at LEP

LEP combined limit, assuming
$BR(H^+ \to \tau\nu) + BR(H^+ \to c\bar{s}) = 1$:
$M_{H^+} > 78.6$ GeV
(89.6 GeV for $BR(H^+ \to \tau\nu) = 1$)



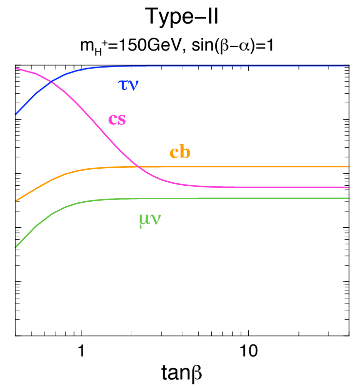
Aoki et al, Phys. Rev. D80, 015017(2009)



ADLO, hep-ex/0107031

Separate OPAL analysis for $BR(H^+ \to \tau\nu) = 1$:
$M_{H^+} \geq 92.0$ GeV Abbiendi et al [OPAL], Eur. Phys. J. C32, 453 (2004)

H^+ search at the Tevatron



Aoki et al (2009)

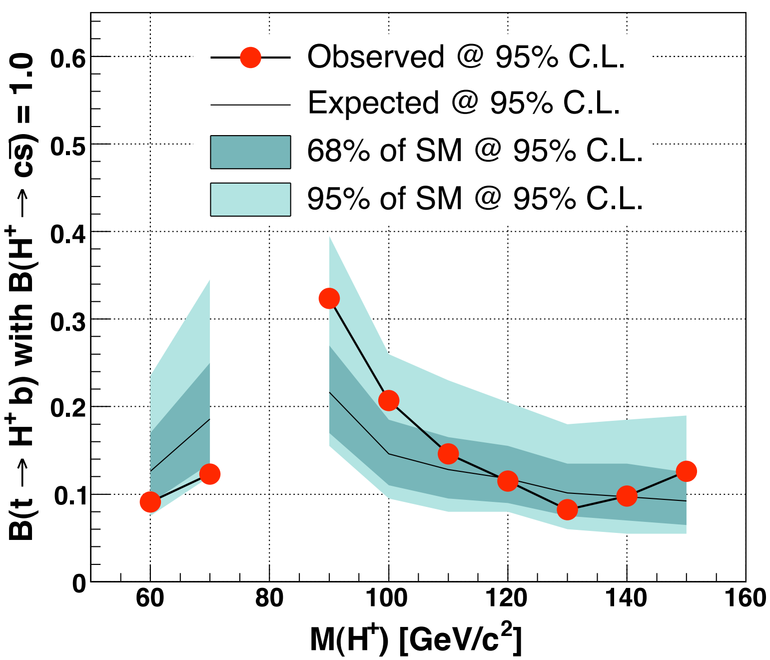
Tevatron search for charged Higgs in top decay

Type-II model: coupling for $t \to bH^+$ is

$$\frac{ig}{\sqrt{2}M_W} V_{tb}(\cot\beta\, m_t P_L + \tan\beta\, m_b P_R)$$

BR$(H^+ \to c\bar{s}) = 1$

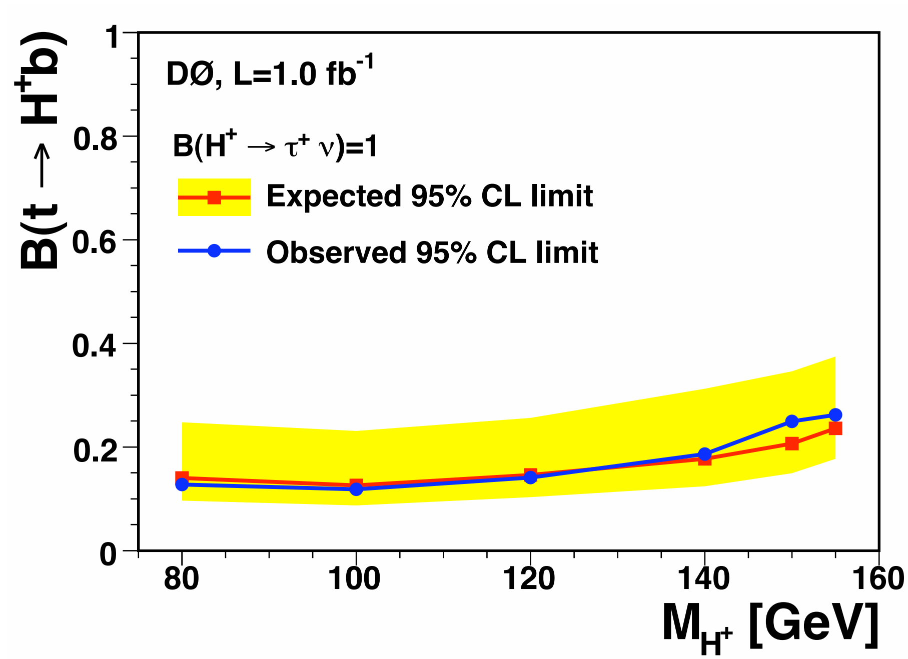
Look for $M_{jj} \neq M_W$



CDF, PRL103, 101803 (2009)

BR$(H^+ \to \tau\nu) = 1$

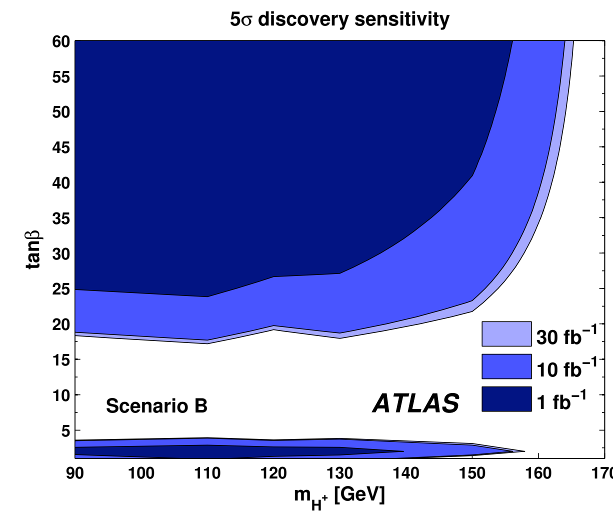
BR$(H^+ \to jj) > 0$ also studied



DZero, arXiv:0908.1811

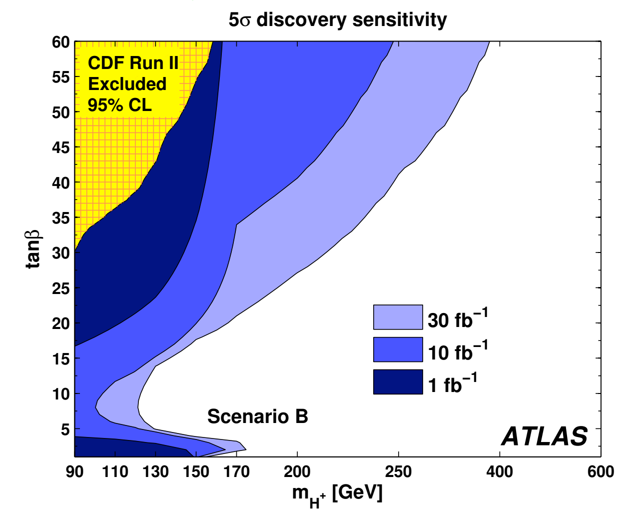
H^+ search at LHC

LHC search prospects: Type II 2HDM



Light charged Higgs:
top decay $t \to H^+ b$ with $H^+ \to \tau\nu$

ATLAS CSC book, arXiv:0901.0512



Heavy charged Higgs:
associated production tH^+ with $H^+ \to \tau\nu$
(BR($\tau\nu$) $\sim$ 10% even above tb threshold)
$H^+ \to tb$ also contributes but less sensitive

Lepton-specific two Higgs doublet model

Model	$H^+\bar{u}_i d_j$	$H^+\bar{\nu}_i \ell_i$
Type II	$V_{ij}(\cot\beta\, m_{ui} P_L + \tan\beta\, m_{dj} P_R)$	$\tan\beta\, m_{\ell i} P_R$
Leptonic	$V_{ij}(\cot\beta\, m_{ui} P_L - \cot\beta\, m_{dj} P_R)$	$\tan\beta\, m_{\ell i} P_R$

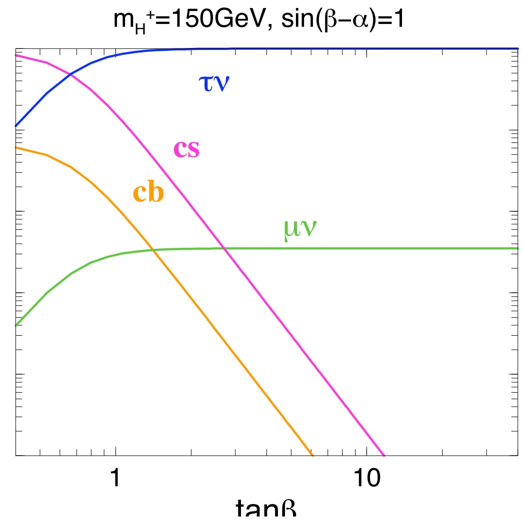
Couplings to quarks: $\propto \cot\beta$, same pattern as Type I 2HDM.
- Constraint from $b \to s\gamma$ same as in Type-I model: $\tan\beta \gtrsim 4(2)$ for $M_{H^+} = 100(500)$ GeV. [Su & Thomas, PRD79, 095014 (2009)]
- Production rates in $t \to H^+ b$, tH^+ associated production suppressed by $\cot^2\beta$.

Couplings to leptons: $\propto \tan\beta$
- Decays to taus usually dominate
- Model used as "messenger" of dark matter for PAMELA/ATIC positron excess [Goh, Hall & Kumar, JHEP 05 (2009) 097]

Lepton-specific two Higgs doublet model: constraints

Below the tb threshold:
decays almost entirely to $\tau\nu$.

[Plot: Aoki et al, PRD80, 015017(2009)]

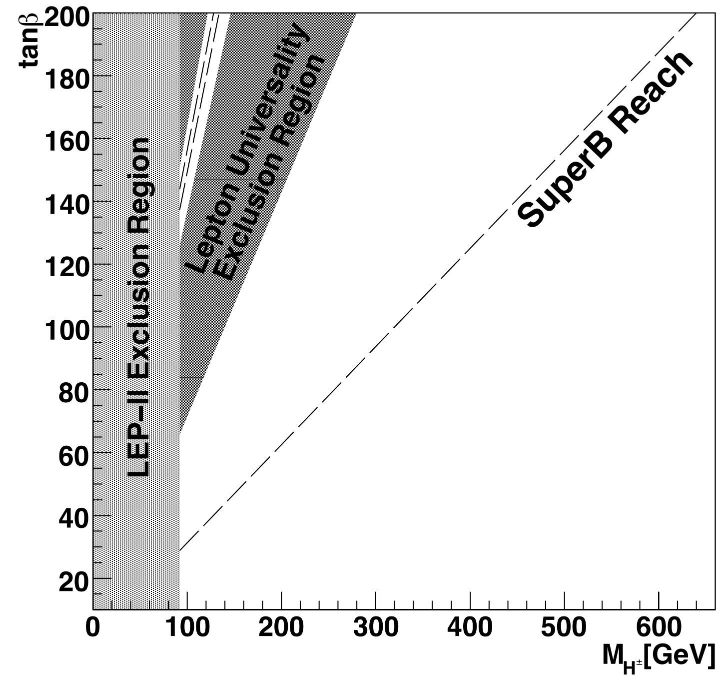


Use LEP limit from OPAL:
$M_{H+} \geq$ 92.0 GeV

Abbiendi et al [OPAL], EPJC32, 453 (2004)

$\tau \to e\nu\bar{\nu}$ vs $\tau \to \mu\nu\bar{\nu}$:
Tree-level charged Higgs exchange affects lepton universality.

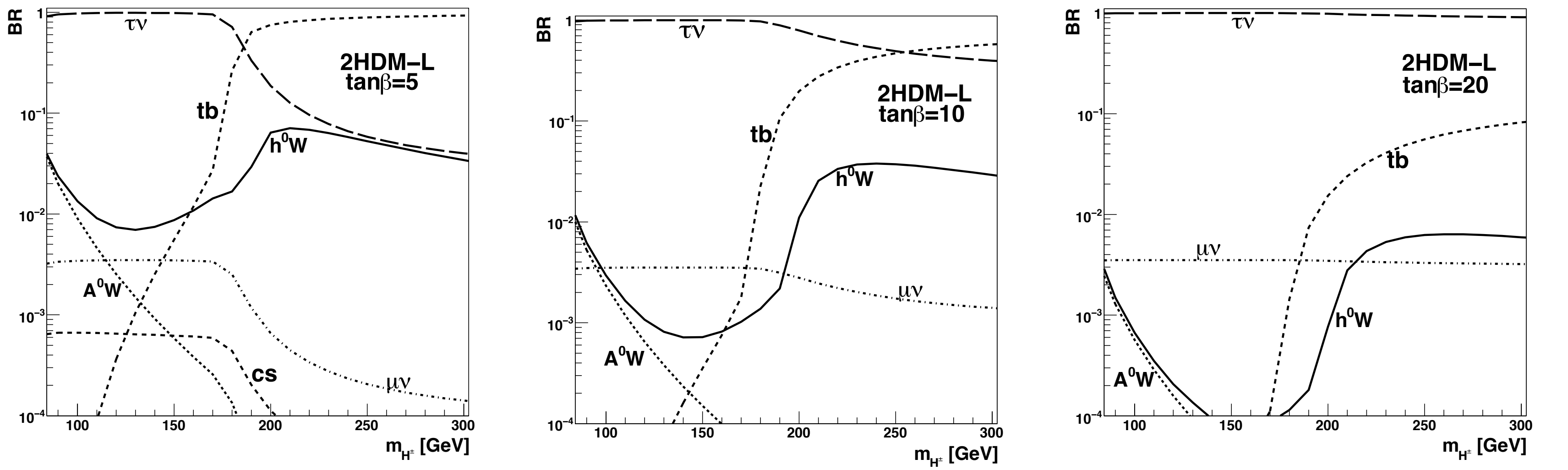
[Plot: HEL & D. MacLennan, PRD79, 115022 (2009)]



$M_{H+} \geq 1.4 \tan\beta$ GeV
(plus allowed sliver: 0.61–0.73 $\tan\beta$ GeV)

Lepton-specific two Higgs doublet model: LHC prospects

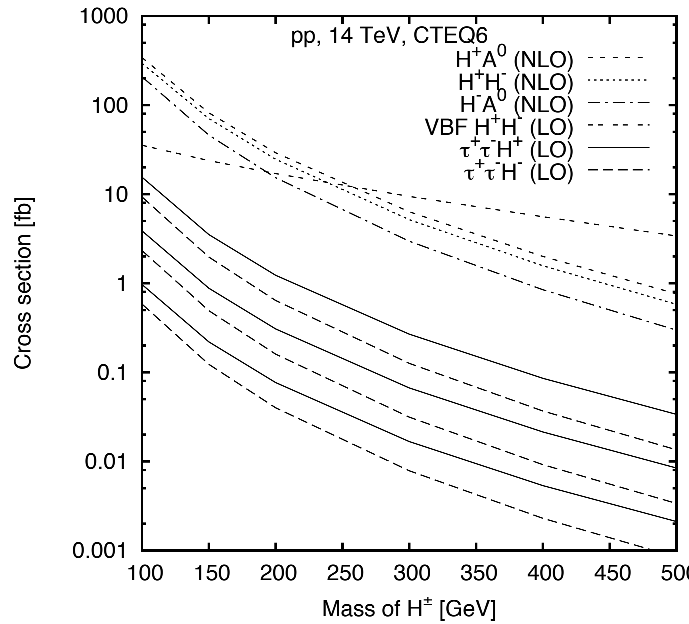
Decays are to $\tau\nu$; also tb above threshold for $\tan\beta$ not too large.



[Plots: HEL & D. MacLennan, PRD79, 115022 (2009)]

Production rates in $t \to H^+ b$, tH^+ associated production suppressed by $\cot^2\beta$.

Have to rely instead on electroweak production: $H^+H^- \to \tau^+\tau^- p_T^{\rm miss}$, $H^\pm A^0/H^0 \to \tau^\pm p_T^{\rm miss} \tau\tau$ $(\mu\mu)$

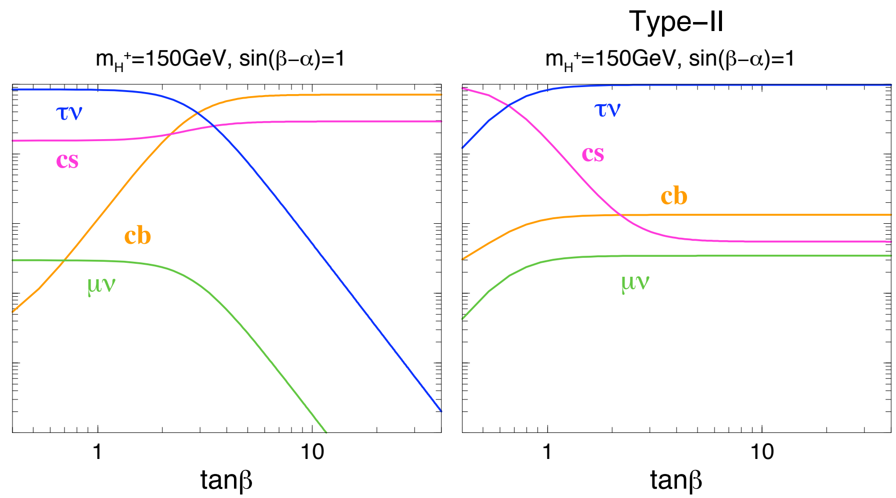


Flipped two Higgs doublet model

Model	$H^+\bar{u}_i d_j$	$H^+\bar{\nu}_i \ell_i$
Type II	$V_{ij}(\cot\beta\, m_{ui} P_L + \tan\beta\, m_{dj} P_R)$	$\tan\beta\, m_{\ell i} P_R$
Flipped	$V_{ij}(\cot\beta\, m_{ui} P_L + \tan\beta\, m_{dj} P_R)$	$\cot\beta\, m_{\ell i} P_R$

Couplings to quarks: same pattern as Type II 2HDM.
- Constraint from $b \to s\gamma$ same as in Type-II model, $M_{H+} \gtrsim$ 200–300 GeV [modulo cancellations with other flavor-violating contributions]
- Production rates in $t \to H^+ b$, tH^+ associated production same as in Type-II.

Couplings to leptons: proportional to $\cot\beta$ instead of $\tan\beta$.



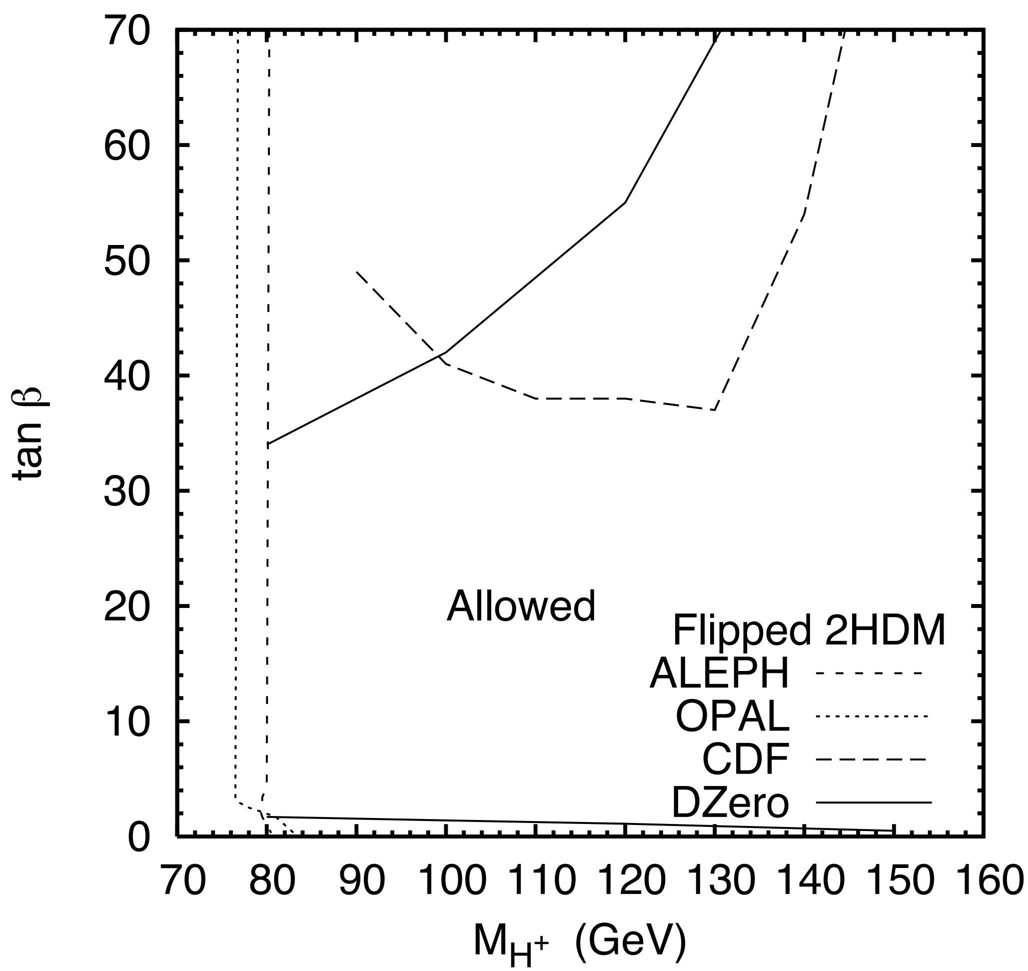
For $\tan\beta \gtrsim 3$:
$H^+ \to c\bar{b}$ about 2/3,
$H^+ \to c\bar{s}$ about 1/3

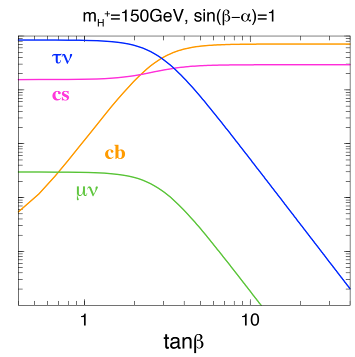
$H^+ \to \tau\nu$ ~0.9 for $\tan\beta \lesssim 3$.

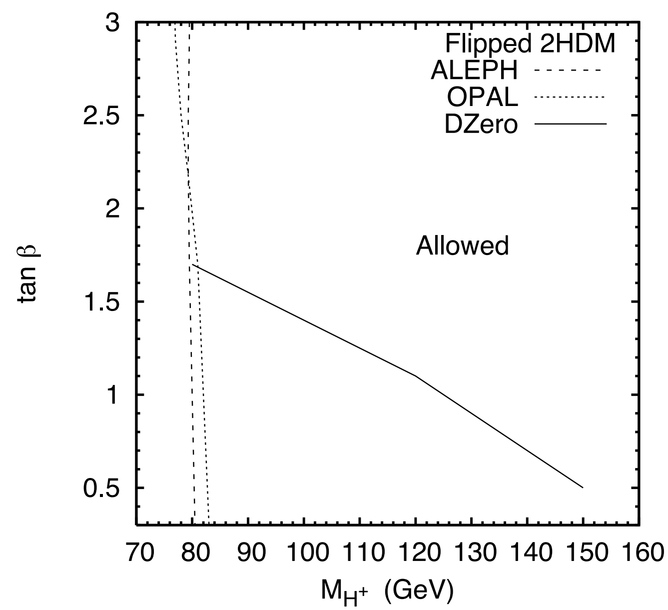
[Plots: Aoki et al, PRD80, 015017(2009)]

Flipped two Higgs doublet model: constraints

LEP: $H^+ \to \tau\nu$ or $c\bar{b}$: use best individual experiment.
Tevatron: $t \to H^+ b$ same as Type-II; translate limits for new BRs.





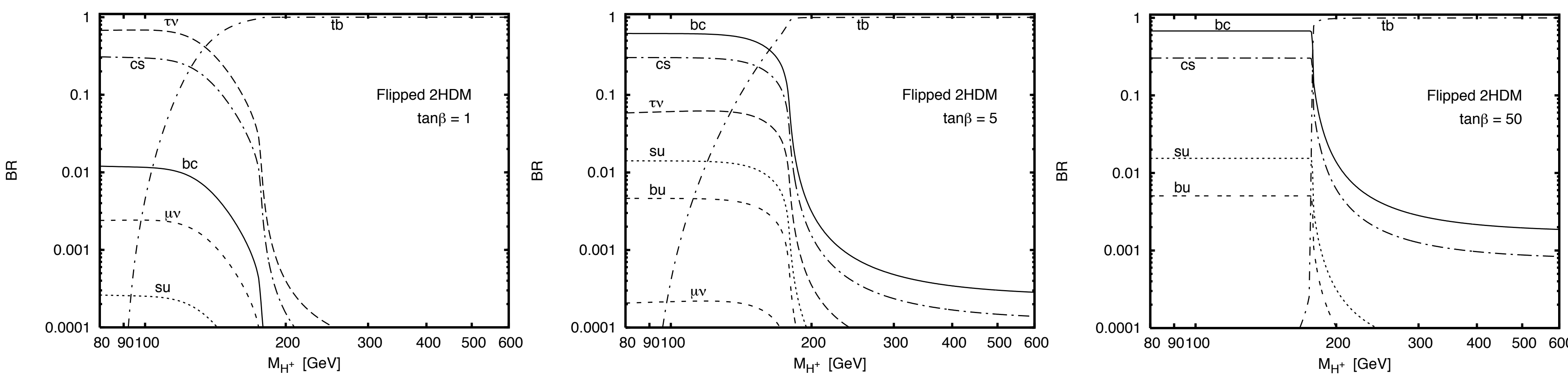


HEL & D. MacLennan, PRD81, 075016 (2010)

Flipped two Higgs doublet model: LHC prospects

Light charged Higgs: BR($t \to H^+ b$) same as Type II model, but $H^+ \to cb$, cs at large $\tan\beta$! LHC studies with $H^+ \to \tau\nu$ not applicable. Need $t\bar{t}$, $t \to H^+ b$, $H^+ \to jj$ for LHC.

Heavy charged Higgs: $H^+ \to tb$ decay always dominates; $H^+ \to \tau\nu$ negligible. ATLAS: $tH^+, H^+ \to tb$ limited by background uncertainty. Can this be improved?



HEL & D. MacLennan, PRD81, 075016 (2010)

Conclusions

LEP, Tevatron, and LHC studies are well-developed for the Type II model (and to some extent for Type I).

Some can be reinterpreted directly for other models using charged Higgs coupling patterns.

New coupling patterns point to new search channels.
- Flipped 2HDM: $t \to H^+ b$ with $H^+ \to jj$ at LHC
- Lepton-specific 2HDM: can we do anything with $H^+ H^- \to \tau\tau$?

Charged Higgs search at LHC is not easy!