

Title: Charged Higgs phenomenology beyond the MSSM

Date: Oct 30, 2009 11:15 AM

URL: <http://pirsa.org/09100159>

Abstract: TBA

Outline

Introduction: the Higgs sector

Charged Higgs in the MSSM and experimental studies

Other models:

- Lepton-specific two Higgs doublet model
- Flipped two Higgs doublet model
- Two-doublet model for neutrino masses

Conclusions

Introduction: the Standard Model Higgs mechanism on one slide

Introduce a single complex SU(2)-doublet scalar field Φ .

Scalar potential $V = -\mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$ triggers electroweak symmetry breaking:

$$\Phi = \begin{pmatrix} \phi^+ \\ (v + \phi^{0,r} + i\phi^{0,i})/\sqrt{2} \end{pmatrix} \quad \text{with } v = \sqrt{\frac{\mu^2}{\lambda}}.$$

Physical Higgs is $h^0 = \phi^{0,r}$.

Would-be Goldstone bosons are $G^0 = \phi^{0,i}$, $G^\pm = \phi^\pm$ and can be gauged away ("eaten by the W and Z ").

Covariant derivative term $(\mathcal{D}^\mu\Phi)^\dagger(D_\mu\Phi)$ gives weak boson masses

$$M_W^2 = \frac{g^2v^2}{4}, \quad M_Z^2 = \frac{(g^2+g'^2)v^2}{4}.$$

Yukawas $\mathcal{L} = -y_{ij}^d\bar{d}_{Ri}\Phi Q_{Lj} - y_{ij}^u\bar{u}_{Ri}\tilde{\Phi}Q_{Lj} - y_{ij}^\ell\bar{e}_{Ri}\Phi L_{Lj} + h.c.$ give fermion mass matrices $m_{ij}^f = y_{ij}^f v/\sqrt{2}$; diagonalizing gives fermion masses (with y_{ij}^f diagonalized automatically); CKM matrix from mismatch between u_L and d_L rotations.

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Two automatic features of the Standard Model:

1) Custodial symmetry preserved at tree level:

$$\frac{M_W}{M_Z \cos \theta_W} = 1 \quad \text{where } \cos \theta_W \equiv \frac{g}{\sqrt{g^2 + g'^2}}.$$

Maintained in extended Higgs sectors if they contain only doublets (and singlets).

Two-doublet models: covariant derivative terms become

$$\mathcal{L} \supset (\mathcal{D}^\mu \Phi_1)^\dagger (D_\mu \Phi_1) + (\mathcal{D}^\mu \Phi_2)^\dagger (D_\mu \Phi_2)$$

Gauge boson masses become

$$M_W^2 = \frac{g^2 v_1^2}{4} + \frac{g^2 v_2^2}{4}, \quad M_Z^2 = \frac{(g^2 + g'^2) v_1^2}{4} + \frac{(g^2 + g'^2) v_2^2}{4}$$

Preserves $\frac{M_W}{M_Z \cos \theta_W} = 1$; requires $v_1^2 + v_2^2 = v_{\text{SM}}^2$.

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Preserves $\frac{M_W}{M_Z \cos \theta_W} = 1$; requires $v_1^2 + v_2^2 = v_{\text{SM}}^2$.

With two doublets we have four more scalar degrees of freedom:

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

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

Mass eigenstates:

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

Can rotate by angle β to "Higgs basis": $s \equiv \sin(\beta - \alpha)$, $c \equiv \cos(\beta - \alpha)$

$$\begin{pmatrix} G^+ \\ (v_{\text{SM}} + (sh^0 + cH^0) + iG^0)/\sqrt{2} \end{pmatrix} \quad \begin{pmatrix} H^+ \\ ((ch^0 - sH^0) + iA^0)/\sqrt{2} \end{pmatrix}$$

Gauge couplings:

$$\gamma H^+ H^-, ZH^+ H^-, W^- H^+ A^0, W^- H^+ (ch^0 - sH^0)$$

Two automatic features of the Standard Model:

2) No flavor-changing neutral Higgs couplings.

Generic multi-Higgs-doublet model:

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

Mass matrix for down-type quarks: $m_{ij}^d = (y_{ij}^d v_1 + \tilde{y}_{ij}^d v_2) / \sqrt{2}$.

Diagonalizing m_{ij}^d does *not* in general diagonalize y_{ij}^d and \tilde{y}_{ij}^d separately; leads to flavor-changing neutral Higgs couplings.

Flavor-changing neutral Higgs couplings are forbidden if each type of fermion (u , d , ℓ) gets its mass from exactly one Higgs doublet: called “natural flavor conservation.” [Glashow & Weinberg;

Paschos; 1977]

One doublet: $\mathcal{L} = -y_{ij}^d \bar{d}_{Ri} \Phi Q_{Lj} - y_{ij}^u \bar{u}_{Ri} \tilde{\Phi} Q_{Lj} - y_{ij}^\ell \bar{e}_{Ri} \Phi L_{Lj} + h.c.$

Two doublets: four ways to assign fermion couplings (u, d, ℓ):

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

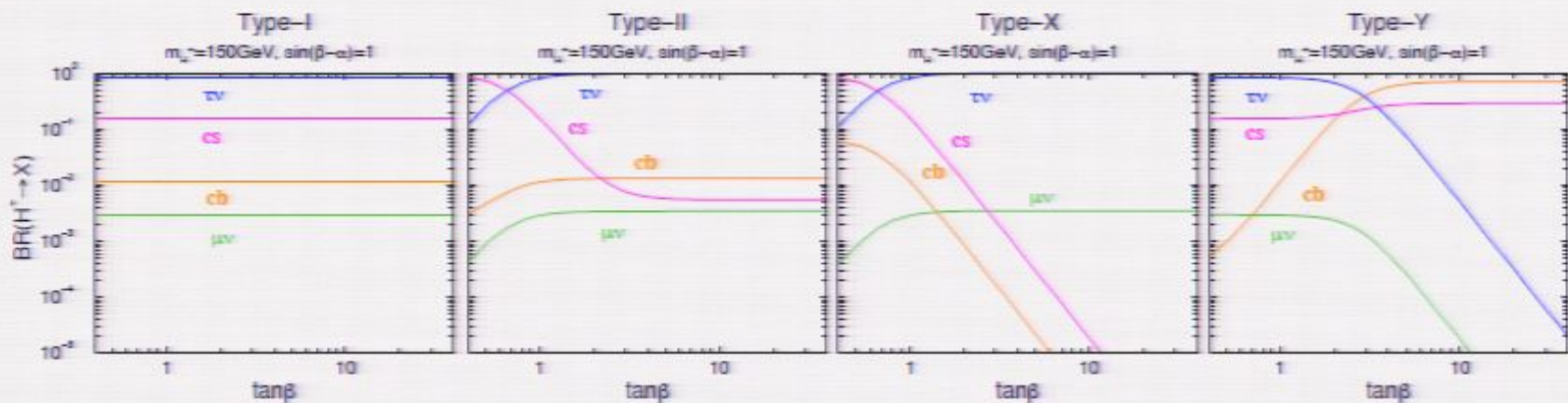
Charged Higgs couplings to fermions (all $\times \frac{ig}{\sqrt{2}M_W}$):

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

Physics controlled by $\tan \beta$ and M_{H^+} .

Most experimental studies: Type II model (same as in MSSM).

Model	$H^+ \bar{u}_i d_j$	$H^+ \bar{\nu}_i l_i$
Type I	$V_{ij}(\cot \beta m_{ui} P_L - \cot \beta m_{dj} P_R)$	$\cot \beta m_{li} P_R$
Type II	$V_{ij}(\cot \beta m_{ui} P_L + \tan \beta m_{dj} P_R)$	$\tan \beta m_{li} P_R$
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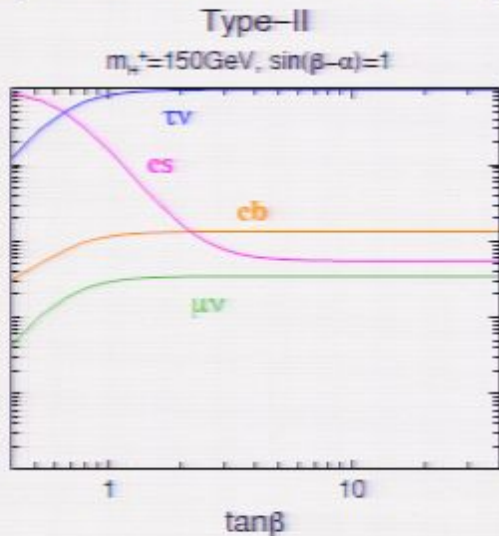
Aoki et al, Phys. Rev. D80, 015017(2009)

LEP, Tevatron, and LHC

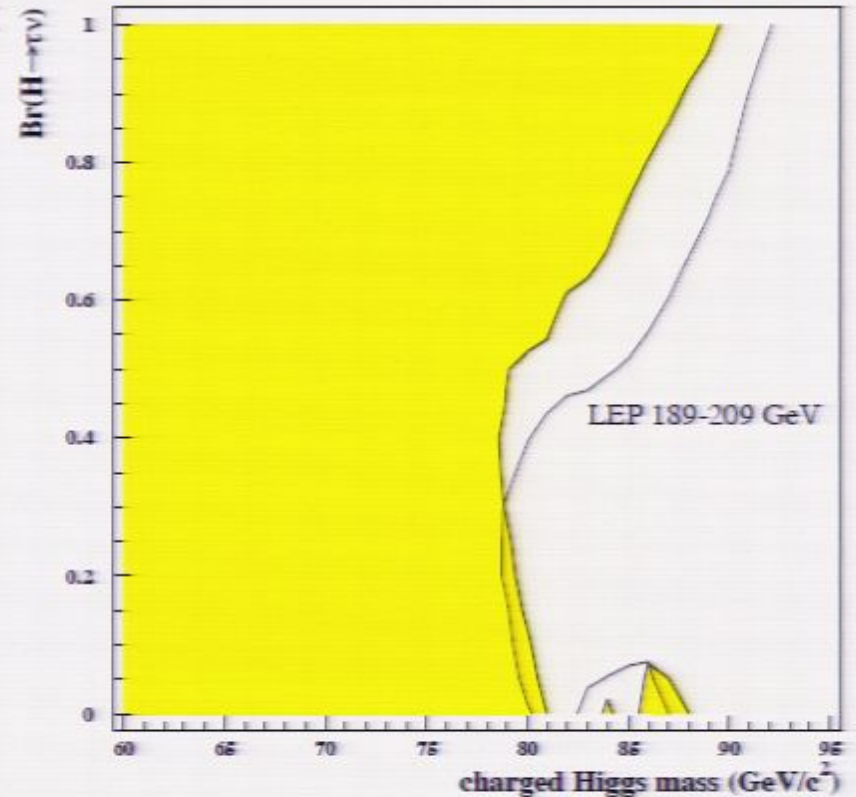
LEP combined limit, assuming
 $BR(H^+ \rightarrow \tau\nu) + BR(H^+ \rightarrow c\bar{s}) = 1$:

$$M_{H^+} > 78.6 \text{ GeV}$$

(89.6 GeV for $BR(H^+ \rightarrow \tau\nu) = 1$)



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



ADLO, hep-ex/0107031

Separate OPAL analysis for $BR(H^+ \rightarrow \tau\nu) = 1$:

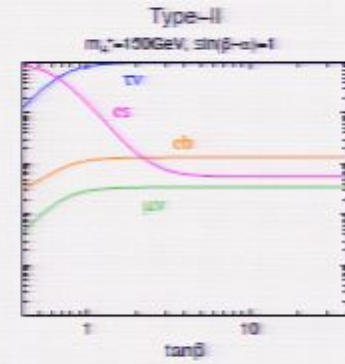
$$M_{H^+} \geq 92.0 \text{ GeV} \text{ Abbiendi et al [OPAL], Eur. Phys. J. C32, 453 (2004)}$$

LEP, Tevatron, and LHC

Tevatron search for charged Higgs in top decay

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

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

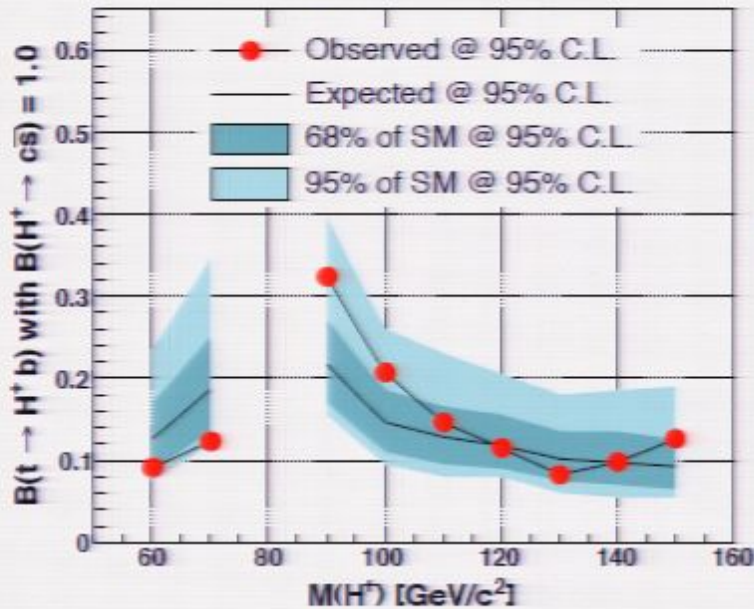


Aoki et al (2009)

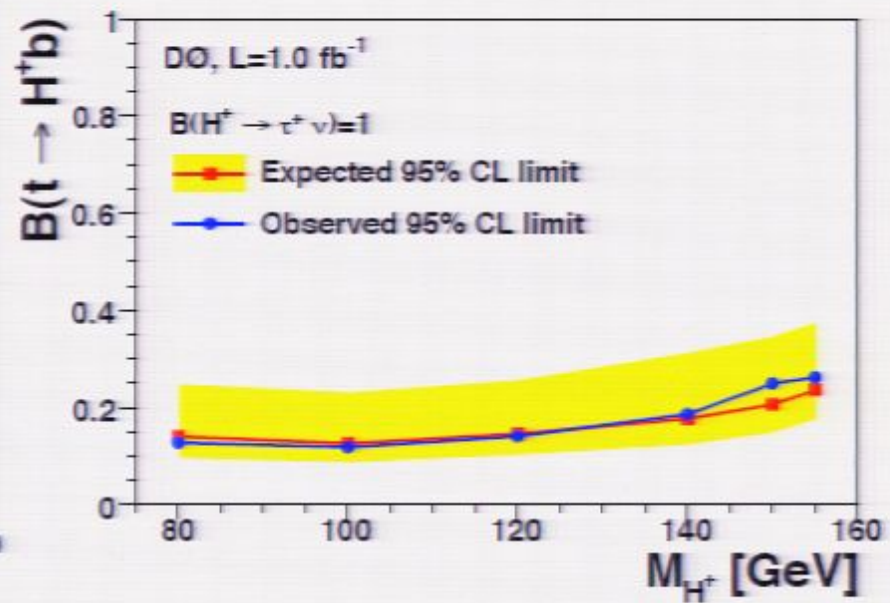
$$BR(H^+ \rightarrow c\bar{s}) = 1$$

Look for $M_{jj} \neq M_W$

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



CDF, PRL103, 101803 (2009)



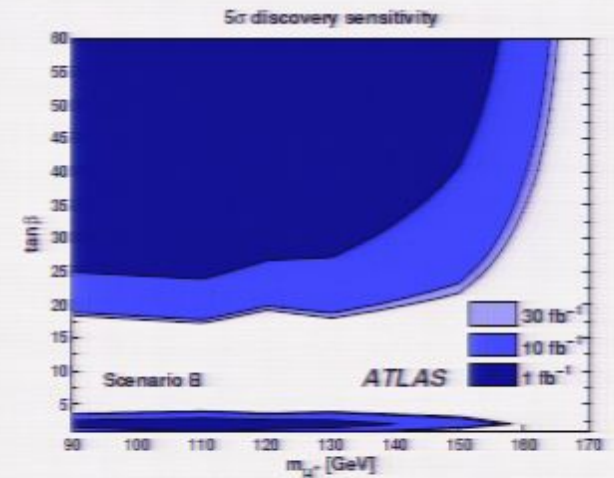
DZero, arXiv:0908.1811

LEP, Tevatron, and LHC

LHC search prospects: Type II 2HDM

Light charged Higgs:

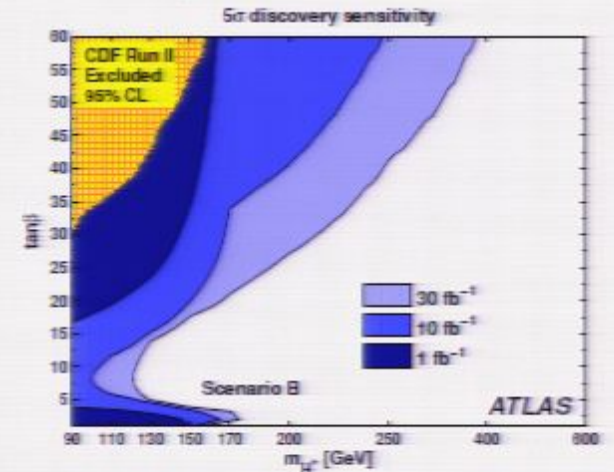
top decay $t \rightarrow H^+ b$ with $H^+ \rightarrow \tau \nu$



ATLAS CSC book, arXiv:0901.0512

Heavy charged Higgs:

associated production tH^+ with $H^+ \rightarrow tb$

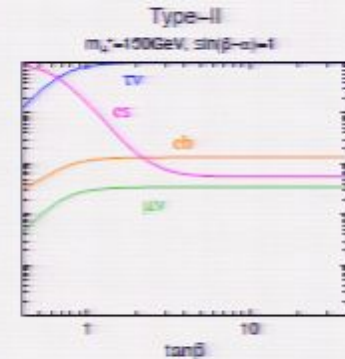


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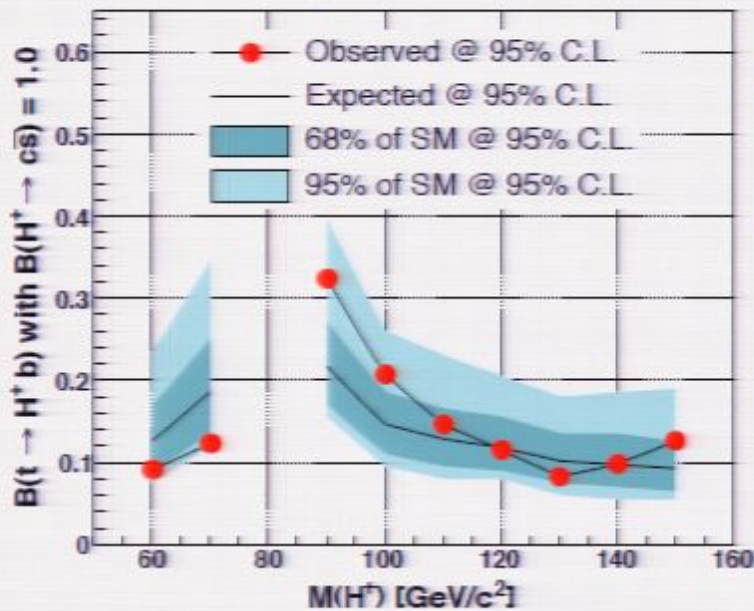


Aoki et al (2009)

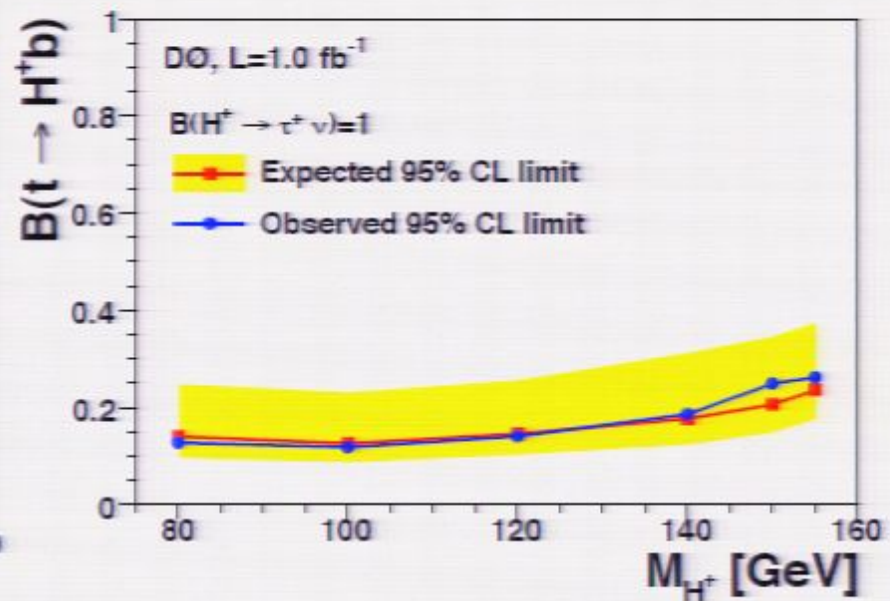
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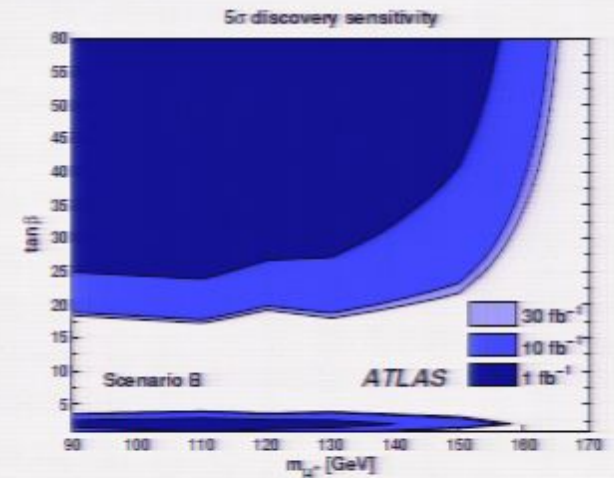
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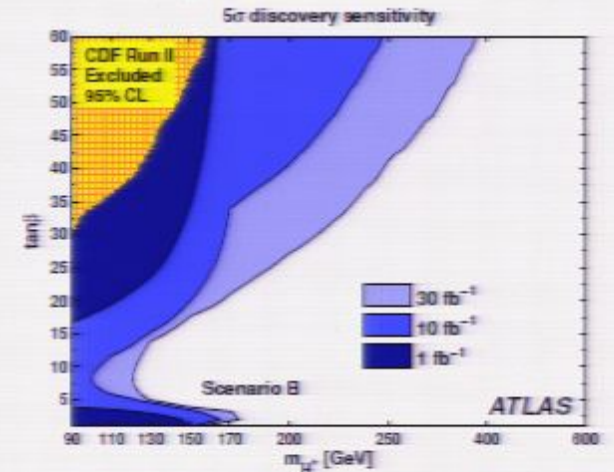
top decay $t \rightarrow H^+ b$ with $H^+ \rightarrow \tau \nu$



ATLAS CSC book, arXiv:0901.0512

Heavy charged Higgs:

associated production tH^+ with $H^+ \rightarrow tb$



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 $b \rightarrow s \gamma$ 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 $t \rightarrow H^+ b$, $t H^+$ 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

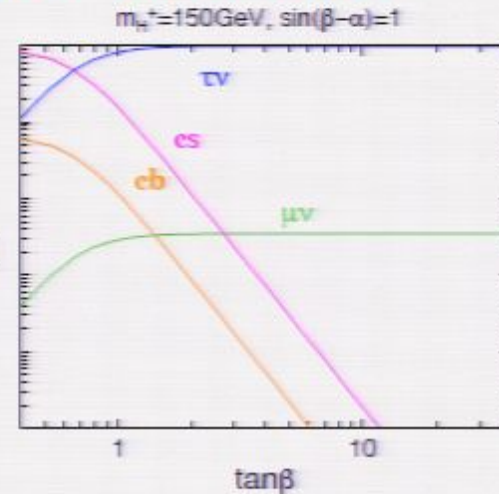
Below the tb threshold:
decays almost entirely to $\tau\nu$.

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

Use LEP limit from OPAL:

$$M_{H^+} \geq 92.0 \text{ GeV}$$

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



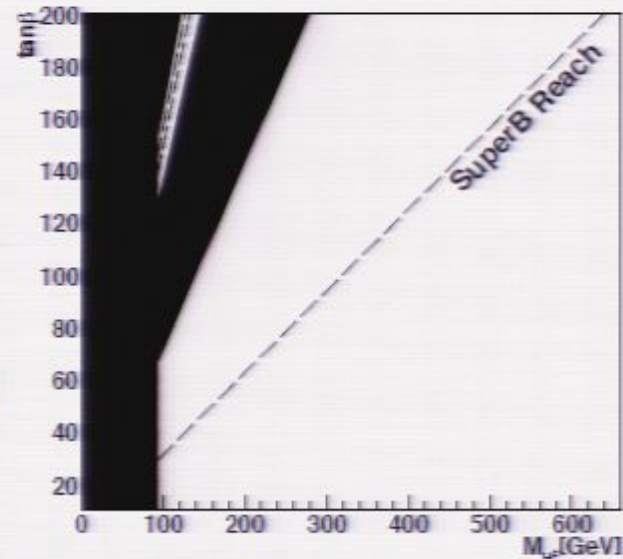
$\tau \rightarrow e\nu\bar{\nu}$ VS $\tau \rightarrow \mu\nu\bar{\nu}$:

Tree-level charged Higgs exchange affects lepton universality.

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

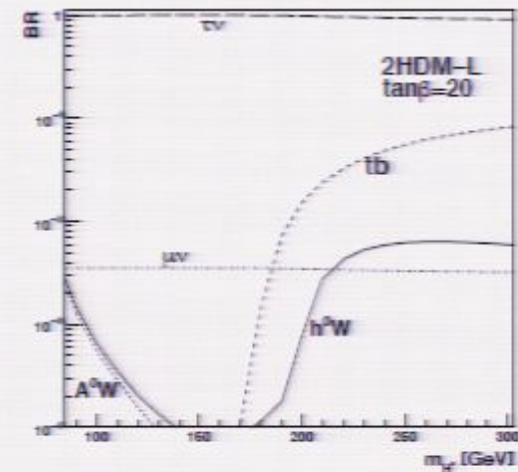
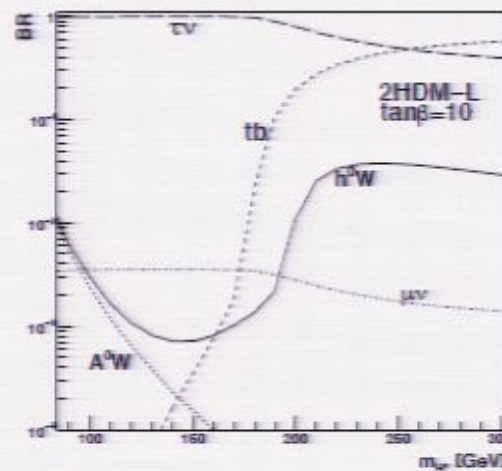
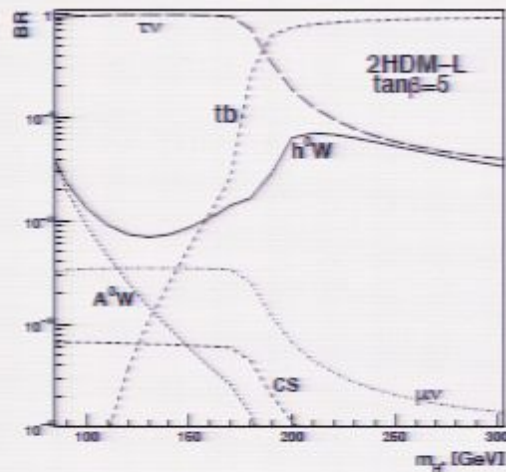
$$M_{H^+} \geq 1.4 \tan\beta \text{ GeV}$$

(plus allowed sliver: 0.61–0.73 $\tan\beta$ GeV)



Lepton-specific two Higgs doublet model: LHC prospects

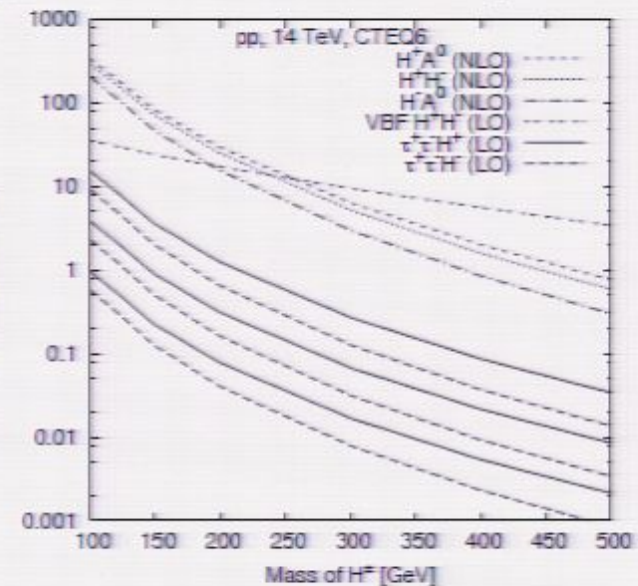
Decays are to $\tau\nu$; also tb above threshold for $\tan\beta$ not too large.



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

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

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



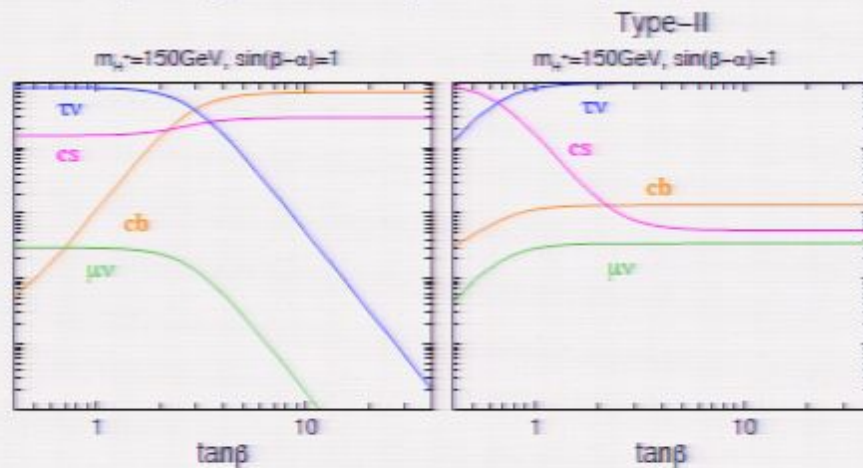
Flipped two Higgs doublet model

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Couplings to quarks: same pattern as Type II 2HDM.

- Constraint from $b \rightarrow s \gamma$ same as in Type-II model, $M_{H^+} \gtrsim 200\text{--}300$ GeV [modulo cancellations with other flavor-violating contributions]
- Production rates in $t \rightarrow H^+ b$, $t H^+$ associated production same as in Type-II.

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



For $\tan \beta \gtrsim 3$:

$H^+ \rightarrow c\bar{b}$ about 2/3,

$H^+ \rightarrow c\bar{s}$ about 1/3

$H^+ \rightarrow \tau\nu \sim 0.9$ for $\tan \beta \lesssim 3$.

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

Flipped two Higgs doublet model: constraints

Limits from LEP: Can't use LEP combined: DELPHI and L3 actively rejected bs : no good for $H^+ \rightarrow c\bar{b}$.

OPAL and ALEPH just selected jets:

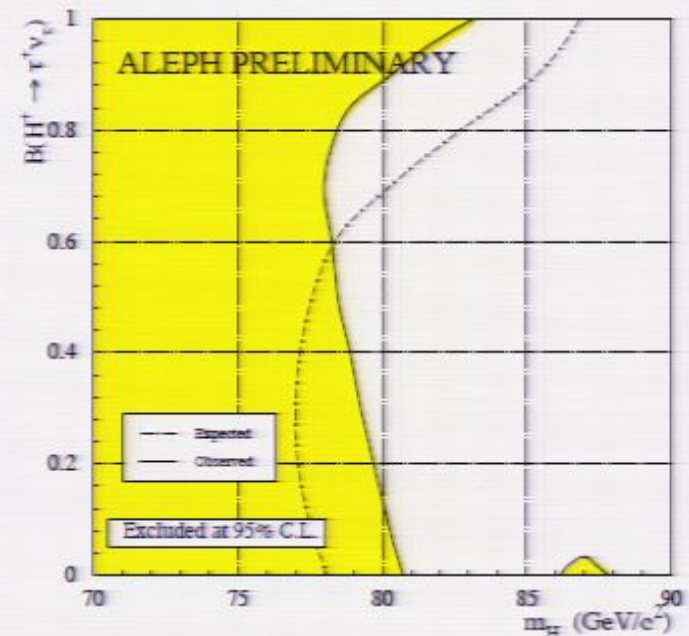
assumption is $\text{BR}(H^+ \rightarrow \tau\nu) + \text{BR}(H^+ \rightarrow q\bar{q}') = 1$.

$M_{H^+} > 78.0$ GeV overall

83.4 GeV for $\text{BR}(H^+ \rightarrow \tau\nu) = 1$,

80.7 GeV for $\text{BR}(H^+ \rightarrow \tau\nu) = 0$

P. Colas [ALEPH], CERN-ALEPH-2001-016



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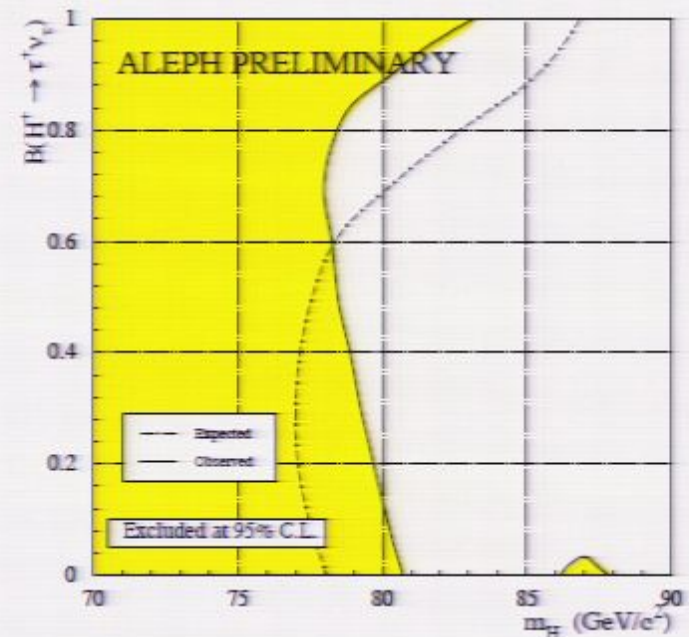
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P. Colas [ALEPH], CERN-ALEPH-2001-016



Flipped two Higgs doublet model: constraints

Top quark decay at the Tevatron:

For $\tan\beta \sim 1$, H^+ branching ratios about the same as in Type II model. Use Tevatron limits from $D\bar{D}$ directly.

For $\tan\beta \gtrsim 3$, $H^+ \rightarrow c\bar{b} + c\bar{s} \simeq 1$. Translate CDF limits on $BR(t \rightarrow H^+b)$ with $BR(H^+ \rightarrow c\bar{s}) = 1$. $H^+ \rightarrow c\bar{b}$ should have only slightly worse M_{jj} resolution.

M_{H^+} (GeV)	allowed $\tan\beta$ range
100	1.40–28.8
120	1.10–26.2
150	0.53–65.8

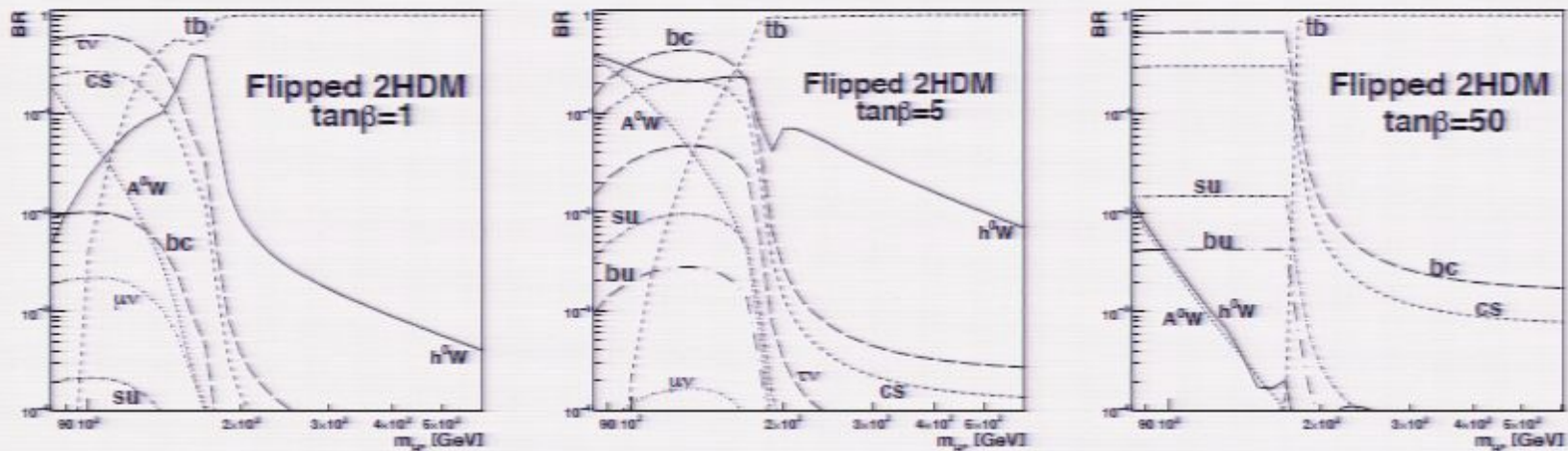
PRELIMINARY HEL & D. MacLennan, in preparation

Flipped two Higgs doublet model: LHC prospects

Production couplings to quarks are identical to Type II 2HDM.

Below tb threshold, decays are to $\tau\nu$ for $\tan\beta < 3$, $cb + cs$ for $\tan\beta > 3$.

Above tb threshold, decays to tb always dominate.



HEL & D. MacLennan, in preparation

Flipped two Higgs doublet model: LHC prospects

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

Heavy charged Higgs: $H^+ \rightarrow tb$ decay dominates; tH^+ associated production cross section same as Type II model. Studies carry over verbatim.

5σ discovery prospects (30 fb^{-1}): [based on [ATLAS](#)]

$\tan\beta$	M_{H^+} range accessible (GeV)
30	180–200
45	180–250
60	180–300

Two-doublet model for neutrino masses

S.M. Davidson and H.E.L., arXiv:0906.3335

New field content:

3 right-handed two-component neutrinos ν_{R_i} (EW singlets)

Second scalar doublet Φ_2 , same EW charges as SM Higgs

New symmetry: global U(1)

ν_{R_i} and Φ_2 have charge +1; all SM fields uncharged

$M\nu_R\nu_R$ Majorana mass term forbidden by global U(1).

Lepton Yukawa couplings: structure fixed by U(1)

$$\mathcal{L}_{Yuk} = -y_{ij}^{\ell} \bar{e}_{R_i} \Phi_1^{\dagger} L_{L_j} - y_{ij}^{\nu} \bar{\nu}_{R_i} \tilde{\Phi}_2^{\dagger} L_{L_j} + \text{h.c.}$$

To generate neutrino masses, break U(1) explicitly:

$$V = m_{11}^2 \Phi_1^{\dagger} \Phi_1 + m_{22}^2 \Phi_2^{\dagger} \Phi_2 - [m_{12}^2 \Phi_1^{\dagger} \Phi_2 + \text{h.c.}] + \frac{\lambda_1}{2} (\Phi_1^{\dagger} \Phi_1)^2 \\ + \frac{\lambda_2}{2} (\Phi_2^{\dagger} \Phi_2)^2 + \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \lambda_4 (\Phi_1^{\dagger} \Phi_2) (\Phi_2^{\dagger} \Phi_1)$$

Φ_2 gets a tiny vev $v_2 \sim \text{eV}$.

Particles and couplings

3 SM neutrinos are Dirac particles; no additional fermionic d.o.f.

4 new scalar degrees of freedom: H^\pm, H^0, A^0

Mixing effects: new scalars $\sim \Phi_2 + \mathcal{O}(v_2/v_1)\Phi_1$: completely negligible

Yukawa couplings of physical scalars:

$$\mathcal{L}_{Yuk} = \frac{m_{\nu_i}}{v_2} H^0 \bar{\nu}_i \nu_i - \frac{i m_{\nu_i}}{v_2} A^0 \bar{\nu}_i \gamma_5 \nu_i - \sqrt{2} \frac{m_{\nu_i}}{v_2} [U_{li}^* H^+ \bar{\nu}_i P_L e_\ell + \text{h.c.}]$$

U_{li} is the Maki-Nakagawa-Sakata-Pontecorvo matrix

Constraint from big bang nucleosynthesis:

$$y_i^\nu \equiv \sqrt{2} \frac{m_{\nu_i}}{v_2} \lesssim \frac{1}{30} \left[\frac{M_{H^+}}{100 \text{ GeV}} \right] \left[\frac{1/\sqrt{2}}{|U_{li}|} \right]$$

a little bigger than SM bottom quark Yukawa coupling

or $v_2 \gtrsim 2 \text{ eV}$ (scales with heaviest neutrino mass).

Phenomenology: decays of new scalars

Fermionic modes: $H^+ \rightarrow \ell^+ \nu$, $A^0/H^0 \rightarrow \nu \bar{\nu}$ (via y'_i)

Bosonic modes: $A^0/H^0 \rightarrow W^+ H^-$ or $H^+ \rightarrow W^+ A^0/H^0$ (gauge int)

depends on masses: $M_A^2 = M_H^2 = M_{H^+}^2 + \lambda_4 v_1^2/2$

Most interesting decays: $H^+ \rightarrow \ell^+ \nu$.

Assume $M_{A,H} > M_{H^+}$: no $H^+ \rightarrow W^+ H^0/A^0$.

$$\Gamma(H^+ \rightarrow \ell^+ \nu) = \frac{M_{H^+}}{8\pi v_2^2} \sum_i m_{\nu_i}^2 |U_{li}|^2$$

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Identical to Φ^+ decay BRs in Type-2 seesaw model.

Two-doublet model for neutrino masses

S.M. Davidson and H.E.L., arXiv:0906.3335

New field content:

3 right-handed two-component neutrinos ν_{R_i} (EW singlets)

Second scalar doublet Φ_2 , same EW charges as SM Higgs

New symmetry: global U(1)

ν_{R_i} and Φ_2 have charge +1; all SM fields uncharged

$M\nu_R\nu_R$ Majorana mass term forbidden by global U(1).

Lepton Yukawa couplings: structure fixed by U(1)

$$\mathcal{L}_{Yuk} = -y_{ij}^{\ell} \bar{e}_{R_i} \Phi_1^{\dagger} L_{L_j} - y_{ij}^{\nu} \bar{\nu}_{R_i} \tilde{\Phi}_2^{\dagger} L_{L_j} + \text{h.c.}$$

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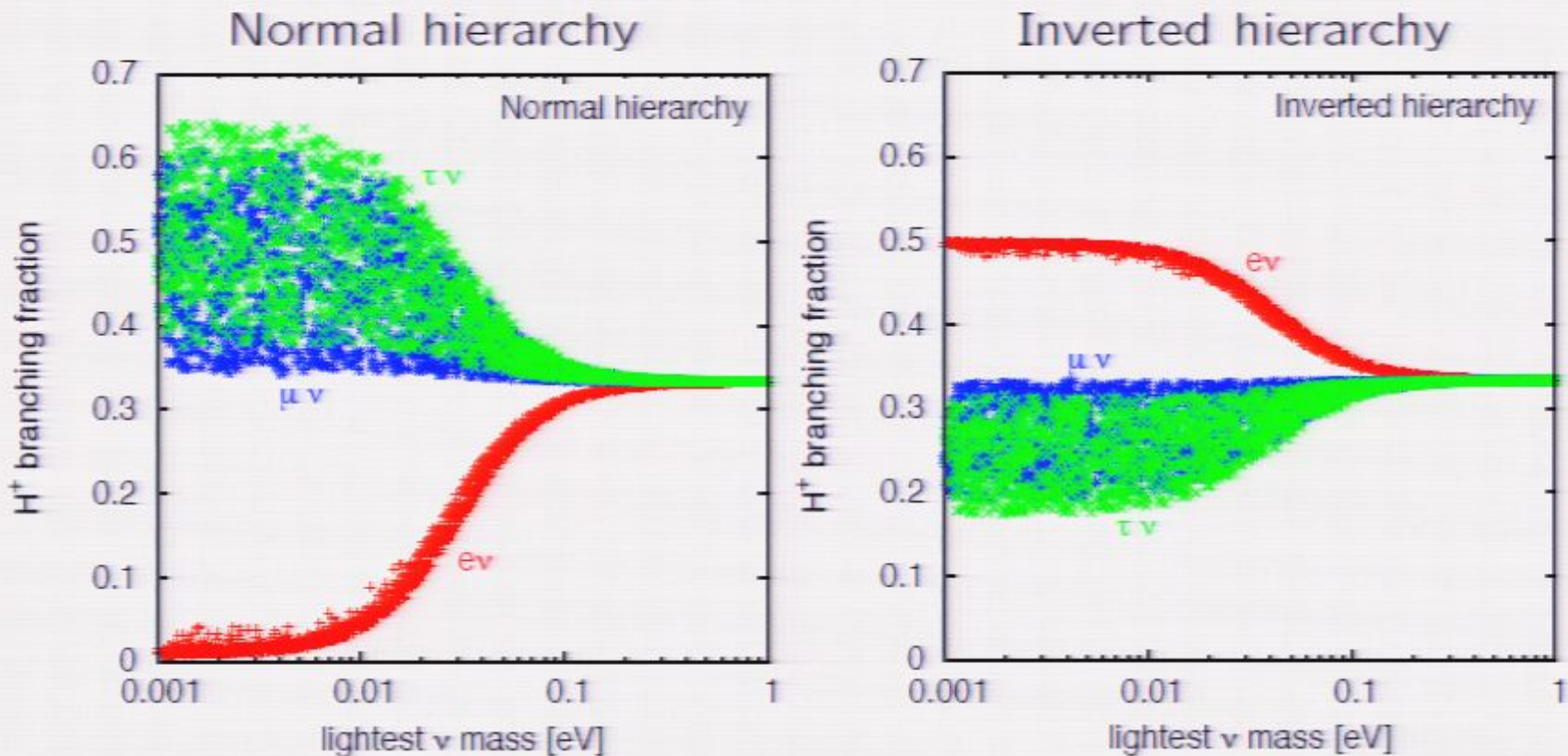
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Behavior controlled by $\theta_{23} \sim 45^\circ$, U_{e3} small.

Normal hierarchy: eigenstate 3 contains half of ν_μ , half of ν_τ , very little ν_e

$$\rightarrow \text{BR}(\mu\nu) \simeq \text{BR}(\tau\nu) \simeq 1/2, \text{BR}(e\nu) \ll 1$$

Inverted hierarchy: eigenstates 1 & 2 contain all of ν_e , half of ν_μ , half of ν_τ

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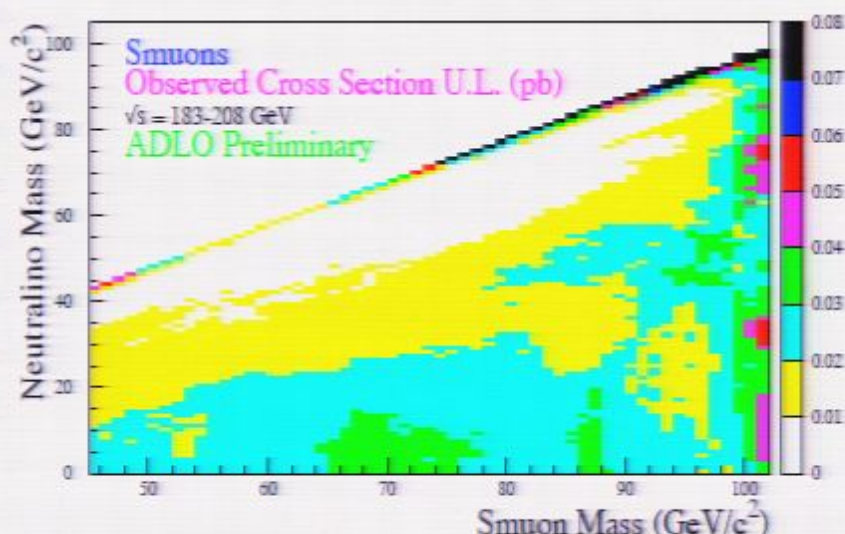
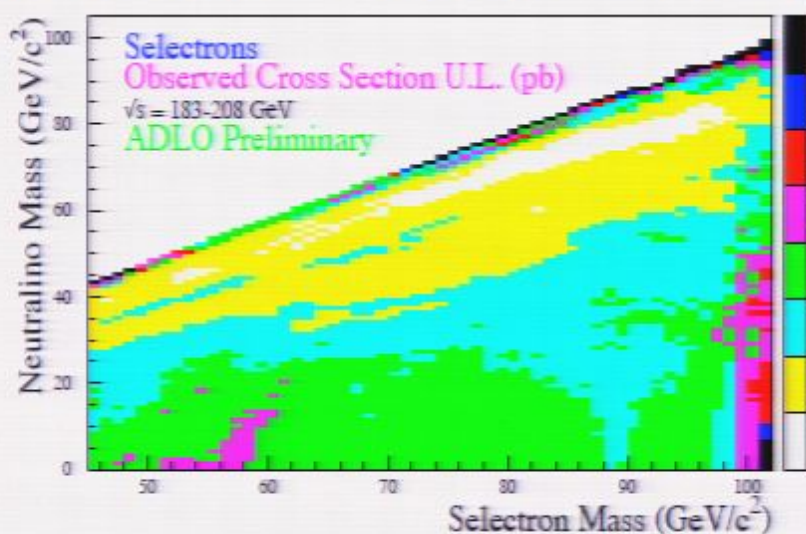
Degenerate spectrum

$$\rightarrow \text{all three BRs} = 1/3.$$

Constraints: LEP limit on H^+H^-

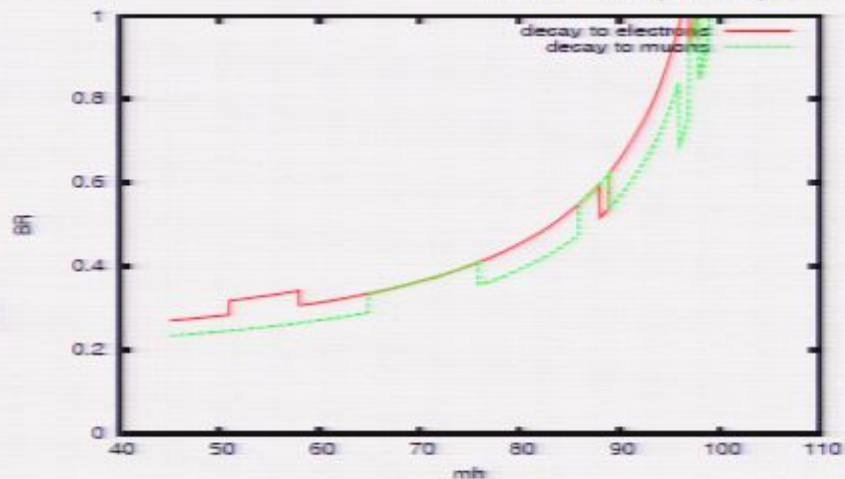
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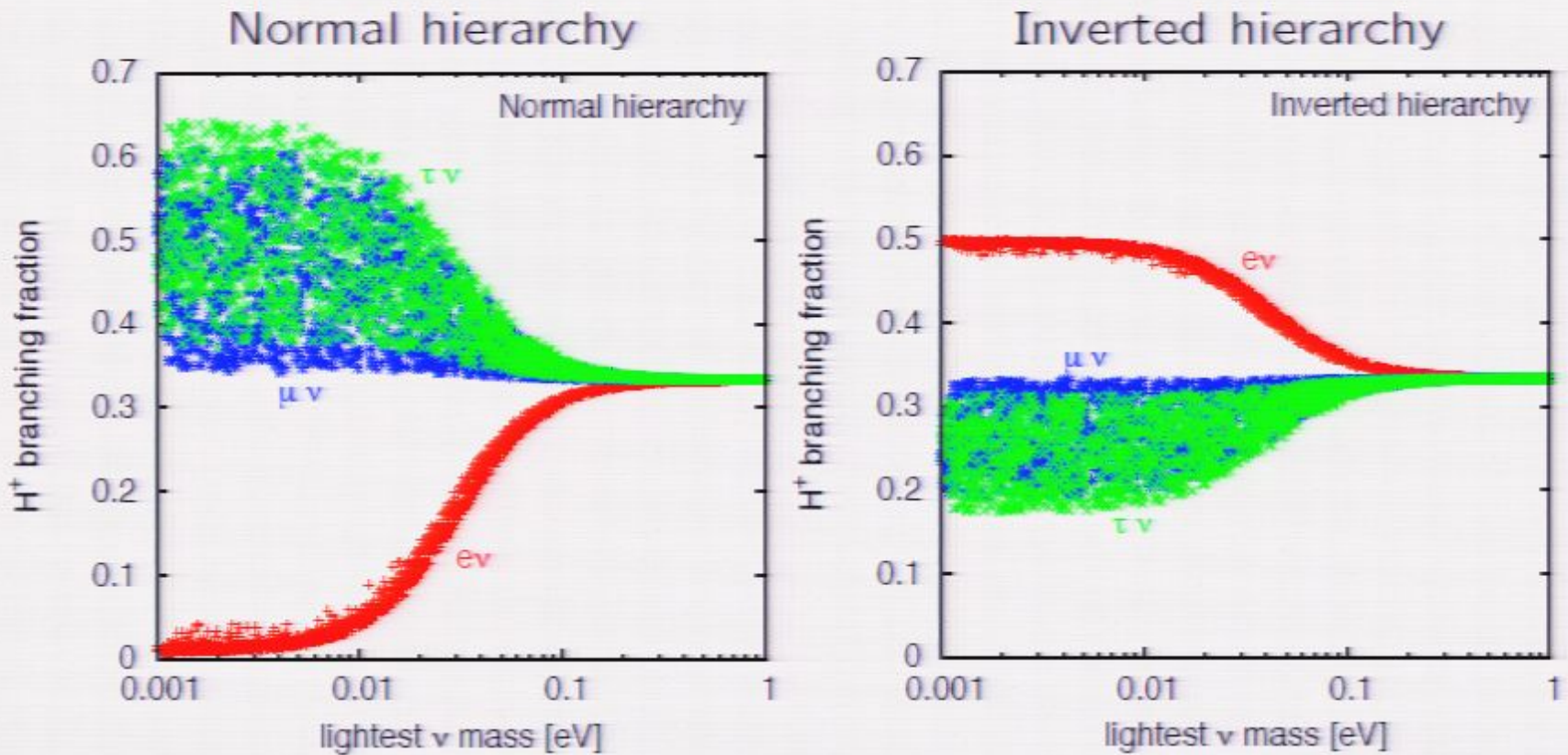
Look at LEP slepton searches instead with massless "neutralino".



LEPSUSYWG/04-01.1

Put in $e^+e^- \rightarrow H^+H^-$ xsec, read off upper limit on BRs





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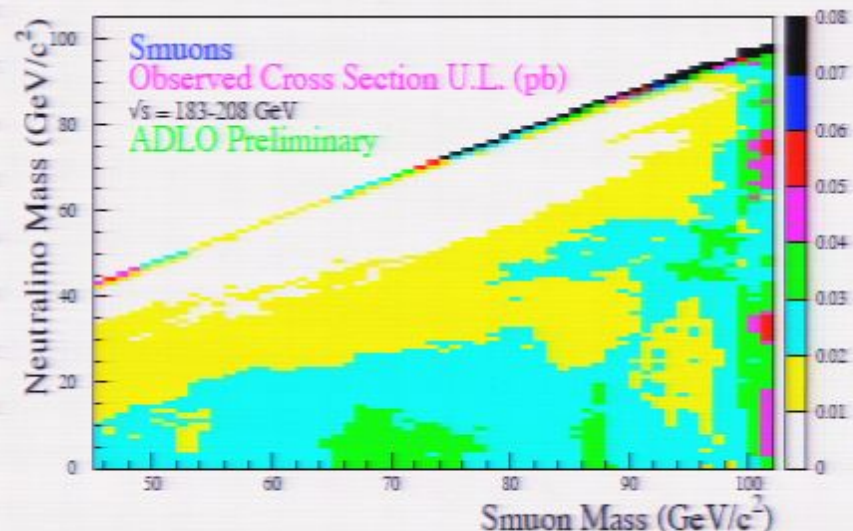
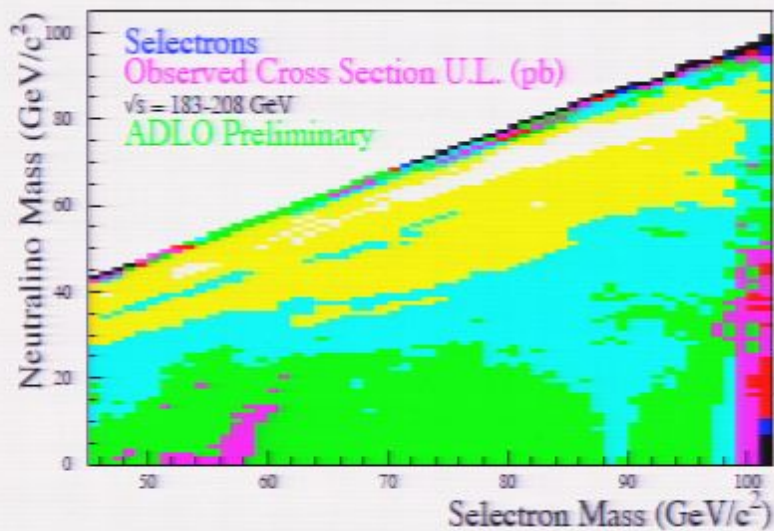
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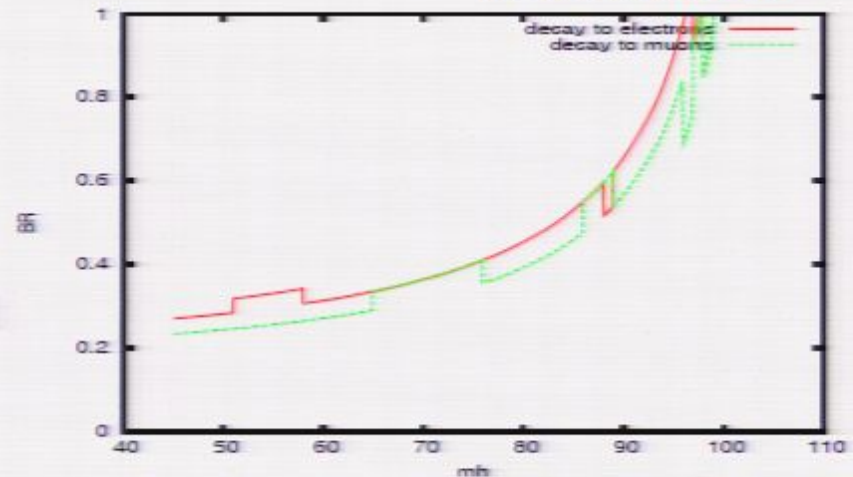
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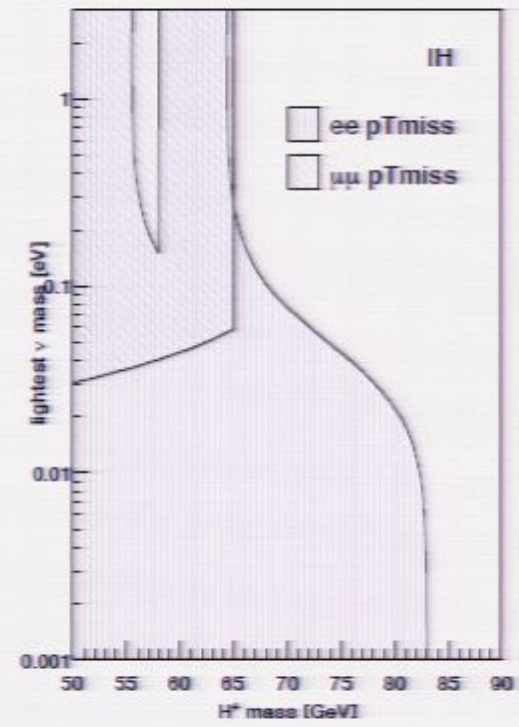
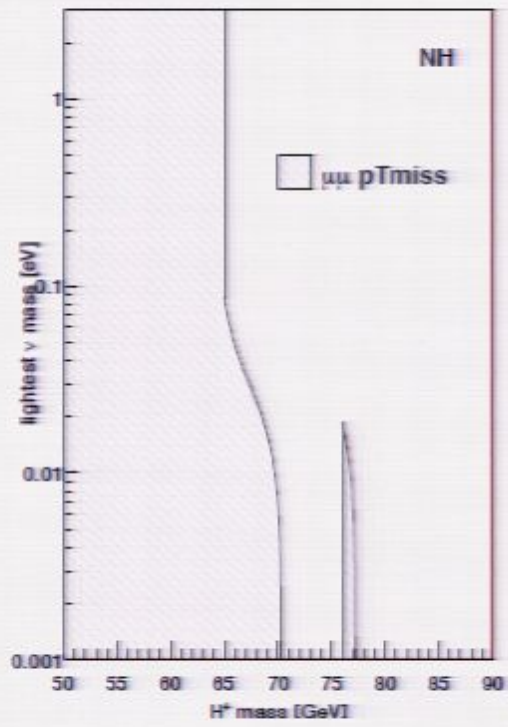
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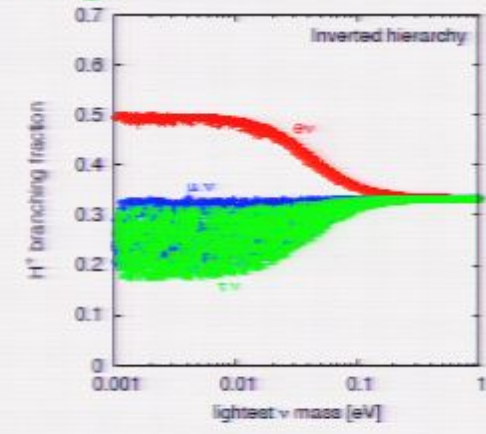
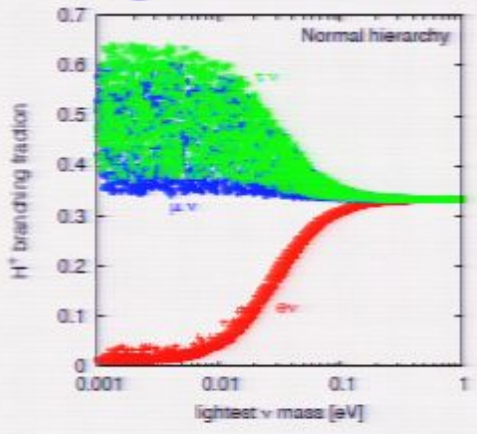
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NH: $\mu\mu p_T^{miss}$ channel strongest

IH: $ee p_T^{miss}$ channel strongest



Phenomenology: LHC prospects

Rely on pair production: $pp \rightarrow H^+H^-$, $H^\pm A^0/H^0$, A^0H^0

- No coups to quarks; $H^+ \ell_L^- \nu_R$ coupling $\lesssim 1/30$ (BBN constraint)
- Single production $\sim g^2 v_2$: super tiny

H^+ BR to $\mu\nu$ or $e\nu$ always $\geq 1/3$: $\ell^+ \ell^- p_T^{miss}$ signature

Nice feature: H^+H^-Z coupling.

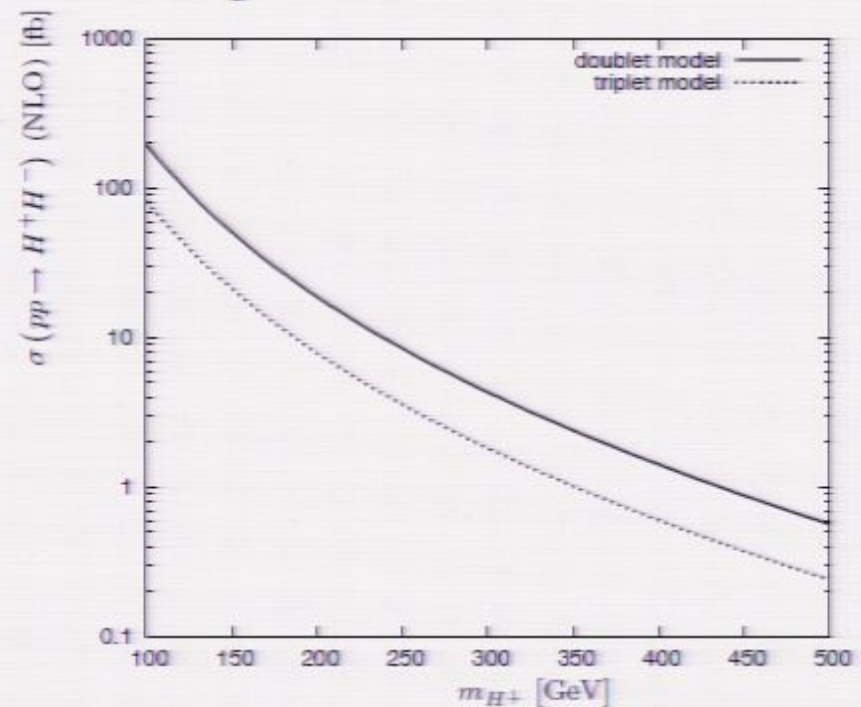
This model: SU(2) doublet:

$$g_{H^+H^-Z} = \frac{e}{s_W c_W} \left(\frac{1}{2} - s_W^2 \right)$$

Type-2 seesaw: SU(2) triplet:

$$g_{\Phi^+\Phi^-Z} = \frac{e}{s_W c_W} (0 - s_W^2)$$

Doublet cross section $\sim 2.5\times$ larger than triplet.



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S.M. Davidson and H.E.L., work in progress

Signal: $pp \rightarrow H^+H^- \rightarrow \mu^+\mu^- p_T^{\text{miss}}, e^+e^- p_T^{\text{miss}}, e^\pm\mu^\mp p_T^{\text{miss}}$

Major backgrounds: $W^+W^-, t\bar{t}, ZZ, Z\gamma$

Selection cuts:

Both leptons $p_T > 20$ GeV; $p_T^{\text{miss}} > 30$ GeV

Veto jets with $p_T > 30$ GeV (kills most of $t\bar{t}$ background)

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$H'_T \equiv p_T^{\ell^+} + p_T^{\ell^-} + p_T^{\text{miss}} > 200$ (600) GeV [for $M_{H^+} = 100$ (300) GeV]

Looks promising for discovery of $M_{H^+} = 100$ GeV with 30 fb^{-1}
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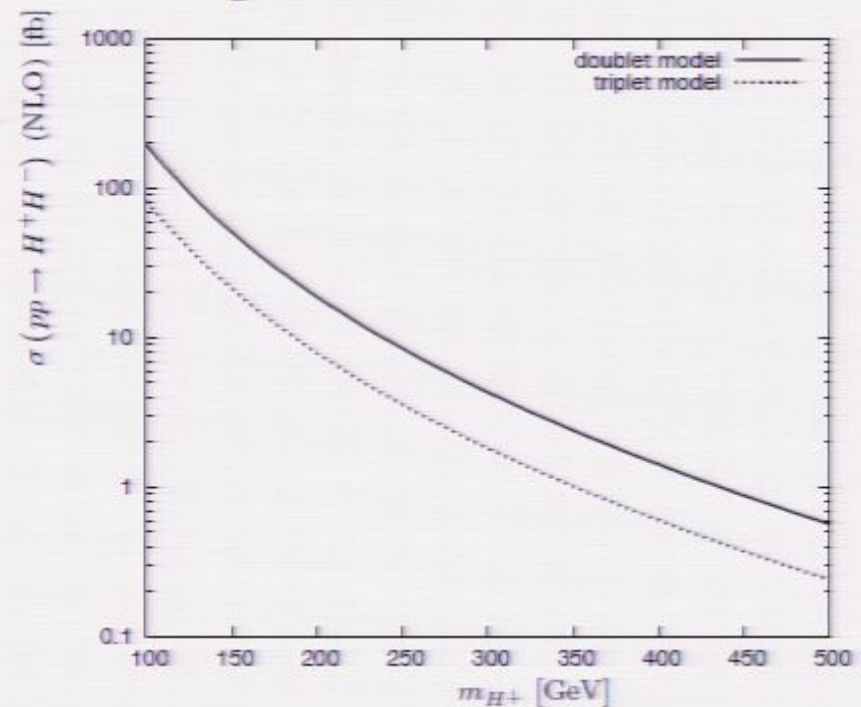
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Conclusions

LHC studies for charged Higgs are well-developed... for the Type II model (and to some extent for Type I).

Other charged Higgs coupling patterns lead to different signal processes – both production and decay.

For some channels, LHC studies can be reinterpreted directly.

- Flipped 2HDM: $H^+ \rightarrow t\bar{b}$

For others, new phenomenological & experimental studies needed.

- Neutrino mass model: $H^+H^- \rightarrow \ell^+\ell^{(\prime)-}p_T^{\text{miss}}$ promising

- Lepton-specific 2HDM: can we do anything with $H^+H^- \rightarrow \tau\tau$?

Phenomenology: LHC prospects

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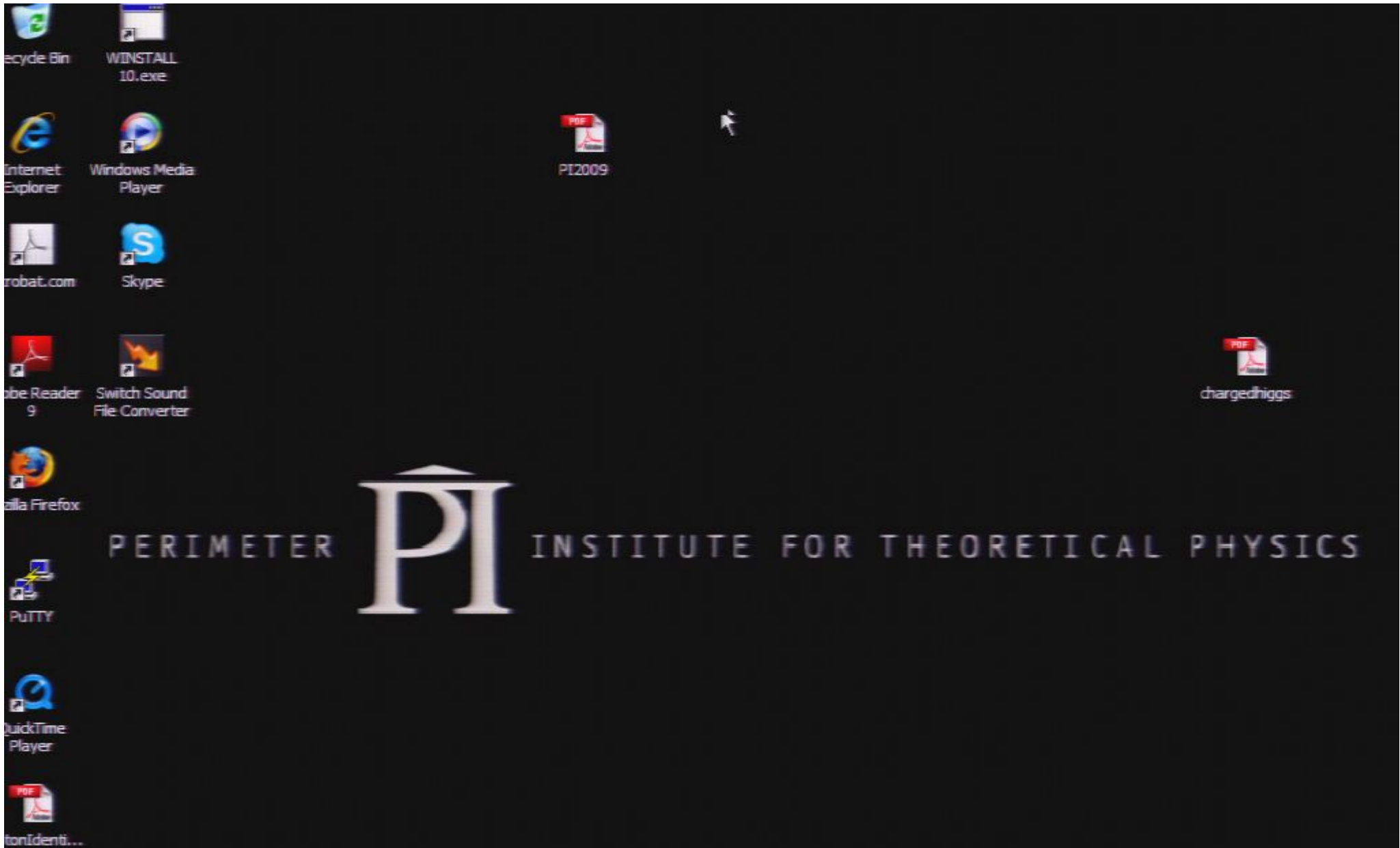
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PHYSICS



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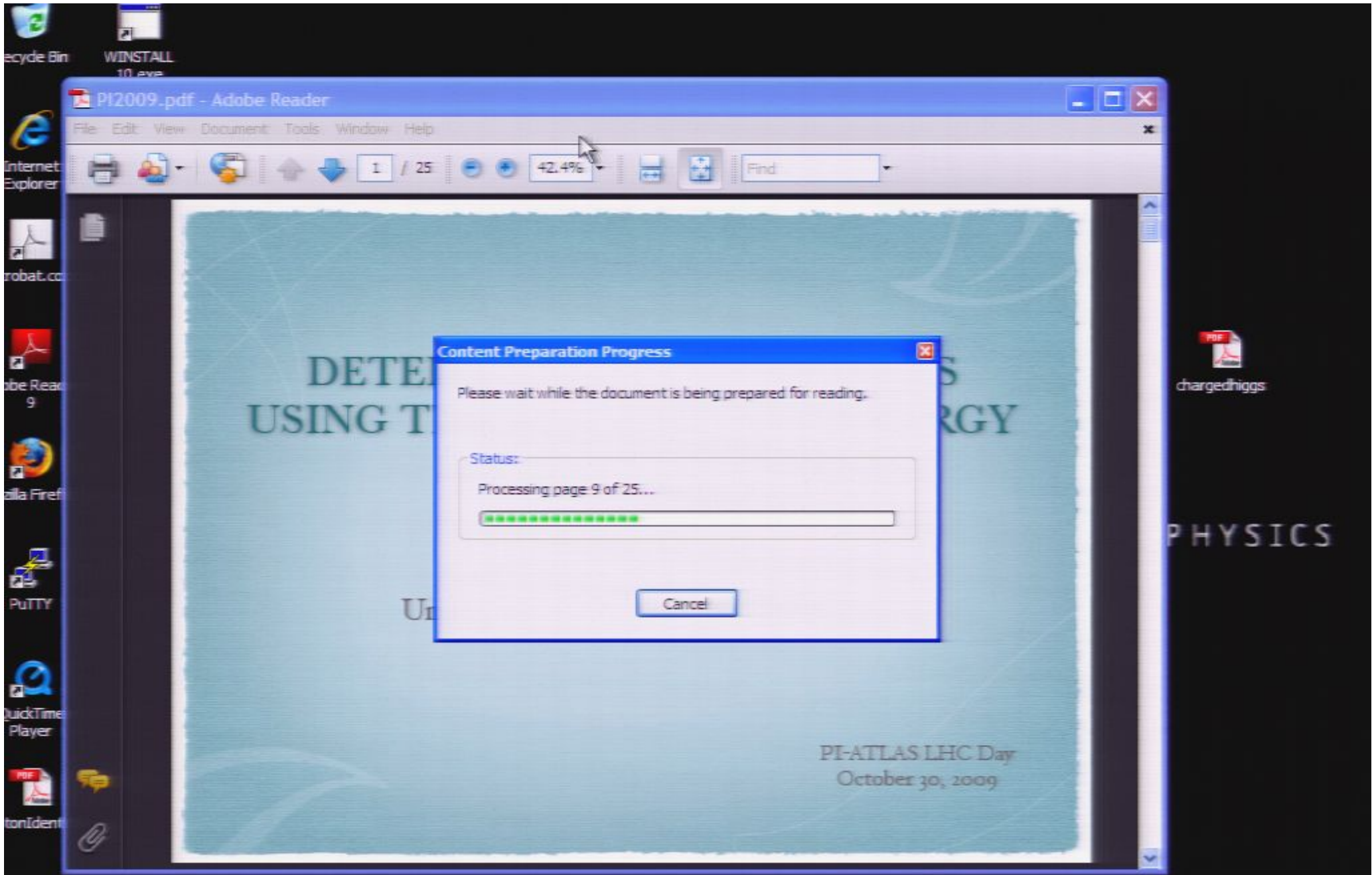
The image shows a Windows desktop environment with several icons on the left side, including Recycle Bin, WINSTALL, Internet Explorer, and various PDF files. A window titled "PI2009.pdf - Adobe Reader" is open, displaying a presentation slide. The slide has a light blue background with a grid pattern and contains the following text:

**DETERMINING Z' COUPLINGS
USING THE LHC AND LOW-ENERGY
EXPERIMENTS**

Frank Petriello
University of Wisconsin, Madison

PI-ATLAS LHC Day
October 30, 2009

On the right side of the desktop, there is a PDF icon labeled "chargediggs" and the word "PHYSICS" in large, spaced-out letters.



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