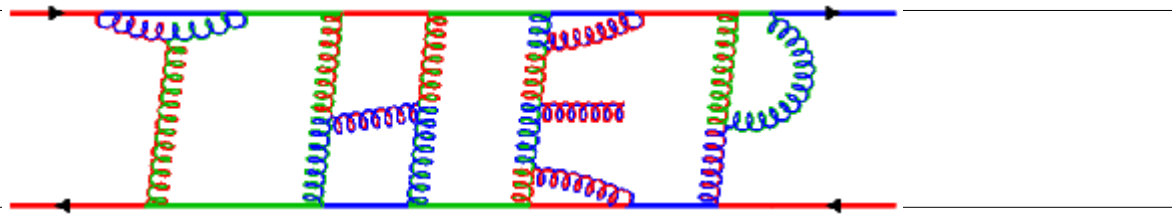


Unusual charged Higgs boson decays

By: Glenn Wouda - Uppsala Universitet

Partikeldagarna 2011, Göteborg

<http://www.isv.uu.se/~wouda/>



<http://www.isv.uu.se/thepp/>



Contents

- Review of direct and indirect experimental limits
- charged Higgs decays to 2 fermions
- 2 gauge bosons
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Disclaimer

By “*Unusual*” I mean everything that is NOT:

$H^+ \rightarrow cs, \tau^+v, tb$

Ok?

Experimental Constraints

Direct (e.g. search for peaks in spectra)

“Model Independent” - but assumptions have to be made:

$m_{H^+} > 0.5 m_Z$, measurement of the Z-width at LEP

$m_{H^+} > 78.8 \text{ GeV}$, from LEP, assuming pair-production and only combinations of $cs, \tau\nu$

$\text{BR}(t \rightarrow H^+ b) > 20\%$, from the Tevatron, assuming $\text{BR}(H^+ \rightarrow cs + \tau^+\nu) = 100\%$
(for the mass of H^+ in the range $\sim 80 - 160 \text{ GeV}$)

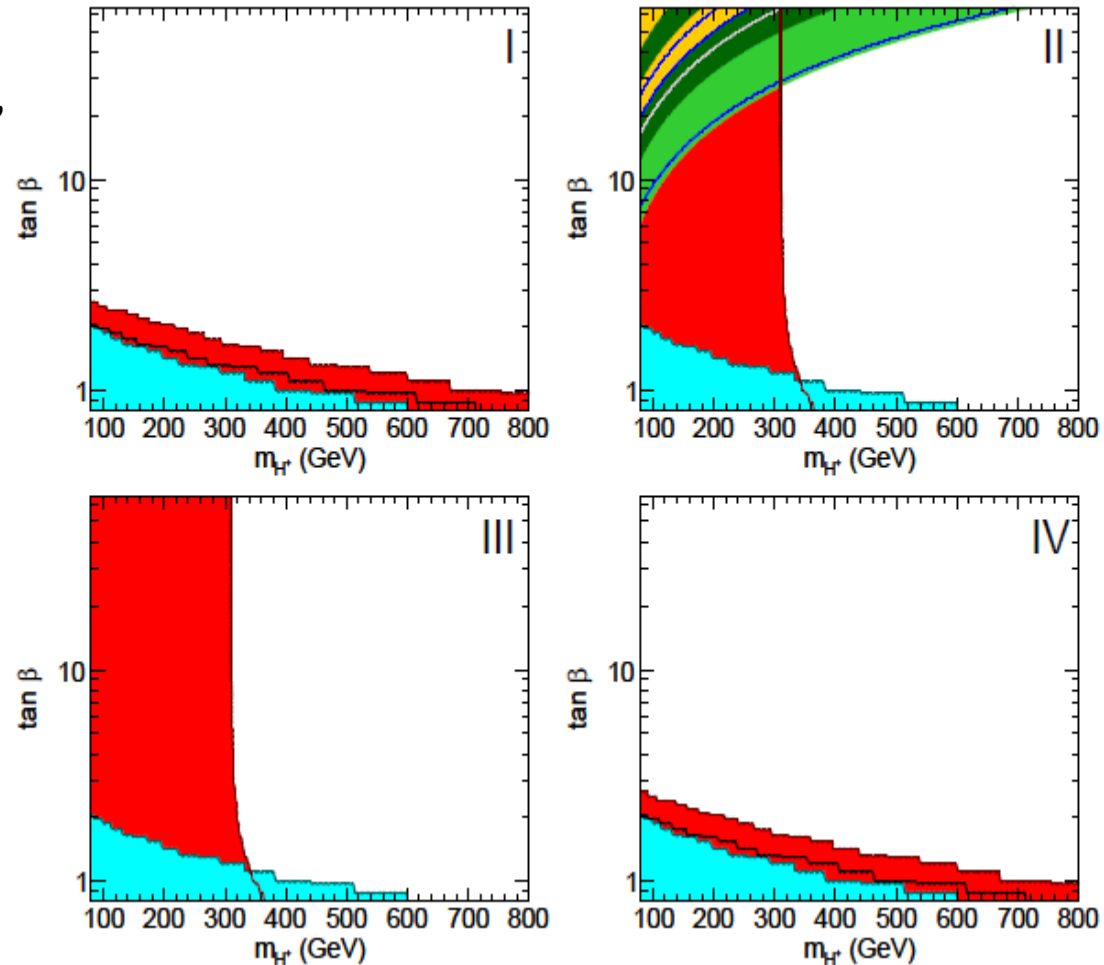
$m_{H^{++}} > 375 \text{ GeV}$, ATLAS, assuming pair production and $\text{BR}(H^{++} \rightarrow \mu^+\mu^+) = 33\%$

References : 1, 2, 3

Experimental Constraints cont.

Indirect (e.g. loop contributions to meson decays)

- Fermion couplings vs. m_{H^+} is constrained
- Can be performed in a “model independent” fashion and then be applied to different models (at least in theory)
- Figure shows results for 4 different THDM's
- Type-II models (e.g. MSSM) $m_{H^+} > 300$ GeV



References : 4

$H^+ \rightarrow 2 \text{ Fermions}$

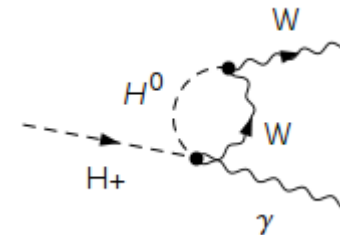
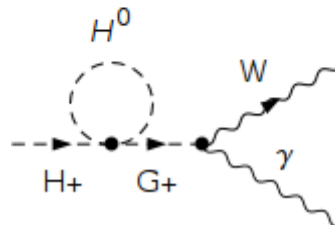
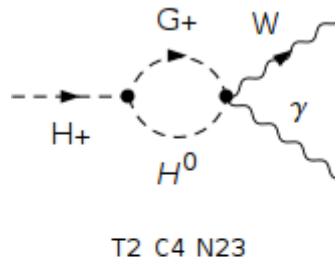
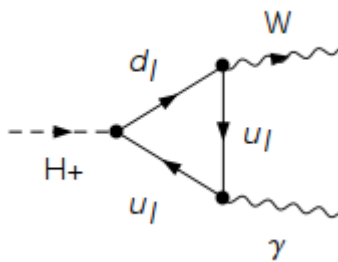
- Why has one considered $H^+ \rightarrow cs$ & $\tau^+ \nu$ in direct searches?
- If H^+ comes from a doublet, which contributes to m_f ($f \neq \nu$), then $C_{H^+ ff'} \sim m_f (m_{f'}) \implies$
- $$\text{BR}(H^+ \rightarrow cs) \approx \text{BR}(H^+ \rightarrow \tau^+ \nu) \gg \text{BR}(H^+ \rightarrow \mu^+ \nu) \gg \text{BR}(H^+ \rightarrow e^+ \nu)$$
- But if H^+ comes from a **triplet** representation of $SU(2)$ or a fermiophobic doublet, then **the above statement is not true anymore.**
- If triplet provides neutrino masses (e.g. *Seesaw type-II*), then $C_{H^+ l \nu} \sim m_\nu$
Which **does not have a unique mass hierarchy**;
 $m_{\nu_\tau} > m_{\nu_\mu} > m_{\nu_e}$ with $m_{\nu_\tau} / m_{\nu_\mu} = m_\tau / m_\mu$?
- Furthermore in triplet models, $C_{H^+ qq'} \sim$ doublet (*i.e.* G^+) component of $H^+ \sim v_3/v$
- In fermiophobic models either $C_{H^+ ff'} = 0$ to all orders or is loop generated
- Many “options” out there!

$H^+ \rightarrow 2$ gauge bosons

- For $m_{H^+} < m_t$ an interesting signal would be $H^+ \rightarrow W^+ \gamma$
- For $m_{H^+} > m_t$ an interesting signal would be $H^+ \rightarrow W^+ Z$

$H^+ \rightarrow W^+ \gamma$

- The coupling $\gamma H^+ W^-$ must be absent at tree-level due to (classical) conservation of j^μ_{EM} (i.e. photon couples only to particle-antiparticle pairs)
- Quantum mechanically, this coupling can be generated via Loops:



+ many more ...

$H^+ \rightarrow 2$ gauge bosons cont.

$$H^+ \rightarrow W^+ Z$$

- This coupling can exist at tree-level, in general it is given by:

$$g^2 \kappa / 2 \cos \theta_W$$

where

$$\kappa^2 = \sum_{Y,T} Y^2 [4T(T+1) - Y^2] v_{T,Y}^2 - \frac{[\sum_{Y,T} 2Y^2 v_{T,Y}^2]^2}{\sum_{Y,T} [4T(T+1) - Y^2] v_{T,Y}^2 c_{T,Y}}$$

$$c_{T,Y} = 1 \text{ (1/2)} \quad \text{for complex (real) representations}$$

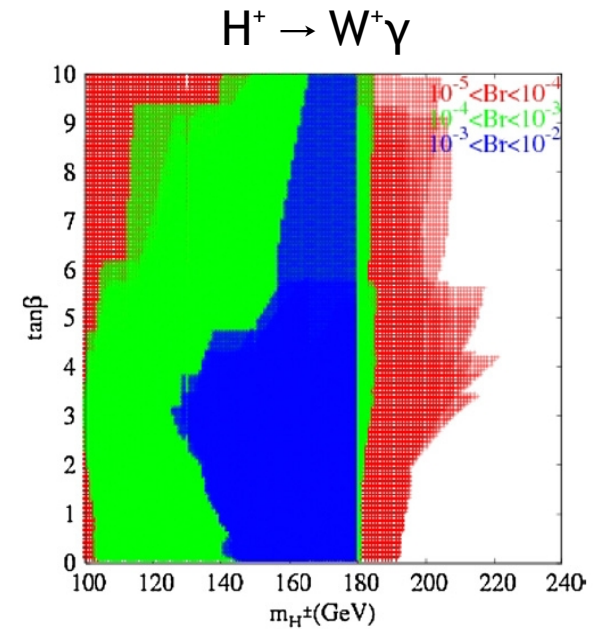
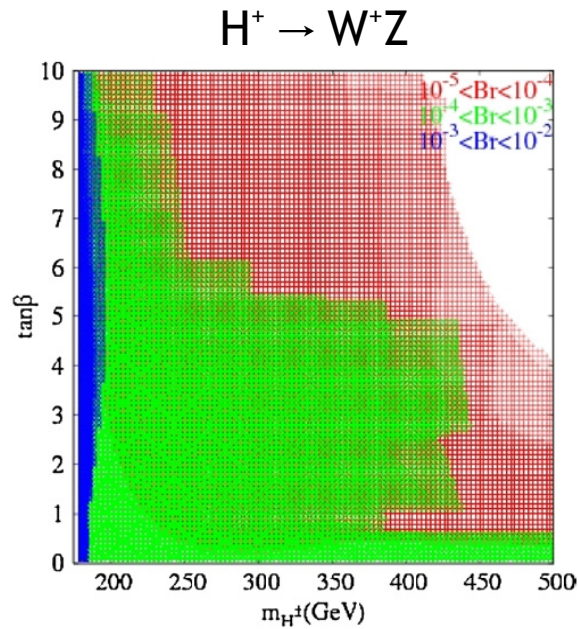
$H^+ \rightarrow 2$ gauge bosons cont.

- One does not get a tree-level coupling for the “common” doublet models, e.g. MSSM and THDMs type-I,II,III,IV
- Arises in many triplet models, such as seesaw type-II, where $\text{BR}(H^+ \rightarrow W^+Z)$ can be important if $v_3 > 0.1$ MeV
- Is also generated at loop-level with similar diagrams as for $W^+\gamma$

$H^+ \rightarrow 2$ gauge bosons cont.

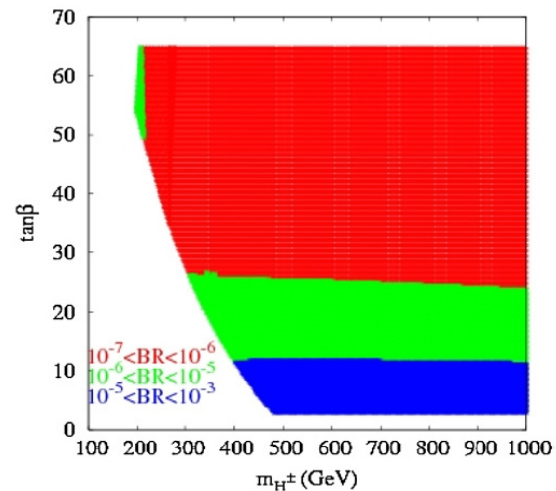
THDM type-II

- **BLUE** : $10^{-3} < BR < 10^{-2}$
- scanned for “reasonable” values for the other parameters

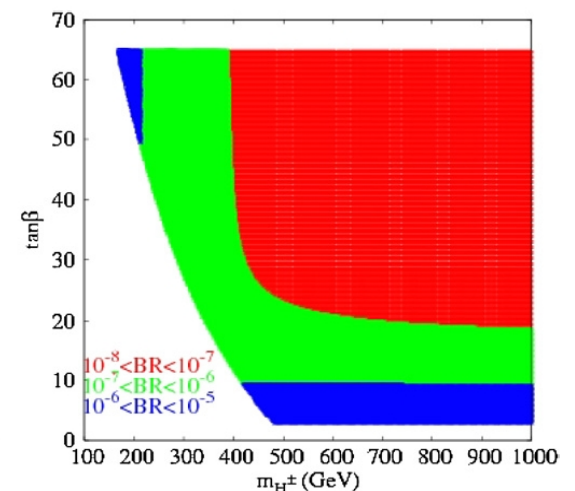


MSSM

- scanned for “reasonable” values for the other parameters
- especially $H^+ \rightarrow W^+\gamma$ is much smaller in MSSM



BLUE : $10^{-5} < BR < 10^{-3}$



BLUE : $10^{-6} < BR < 10^{-5}$

References : 10

“Lopsided” doublet model

- Model presented by Me together with Johan Rathsman (Lund) and Rikard Enberg (Uppsala) and is work in progress
- THDM where **only one doublet couples to fermions** (“ $\tan\beta = 0$ ”)
- The **two doublets mix** due to **soft breaking** of a discrete Higgs flavor symmetry
- Loosely, this is the IDM with inclusion of $m_{12}^2 \phi_1^+ \phi_2 + h.c.$ terms
- The scalars from the fermiphobic doublet (among them H^+) **couples to 2 fermions at 1-loop level** due to mixing with the doublet with tree-level fermion couplings
- This is a model where $H^+ \rightarrow W^+ \gamma / Z$ **proceeds at the same order in couplings** as the decay $H^+ \rightarrow 2$ fermions
- Current activity: How to calculate $\Gamma(H^+ \rightarrow W^+ \gamma / Z)$ and $\Gamma(H^+ \rightarrow 2 f)$, highly non-trivial task, mainly due to $H^+ W^+ / G^+$ mixing.

Charged Higgs \rightarrow Higgs W^+

- Will not discuss this so much, since require at least one new not discovered particle
- Highly model dependent, many parameters to tweak (quartic couplings in the Higgs potential etc.) to obtain allowed process due to kinematics
- Coupling is $g * \textit{Mixing Angles}$

Conclusions

- One **should not** view “the” charged Higgs boson as a particle with global properties, is highly model dependent! We must remember this.
- **Fermiophobic** doublet models could have **2 gauge bosons as important decay mode**, since there these could proceed at the same order in the couplings.
- **Triplets** (and other SU(2) representations) can have $H^+ \rightarrow W^+Z$ important since coupling exists!
(However, these models usually don't generate $\rho = 1$ at tree-level!)
- Charged particles are **smoking guns**, one should look for them in as many ways possible!

References

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11) Charged Scalars in a Lopsided doublet model, PoS(Charged 2010)032