Scalars in a Lopsided Doublet Model

By: **Glenn Wouda** – Uppsala University, Sweden

With: **Rikard Enberg** (Uppsala) and **Johan Rathsman** (Lund)

Scalars 2011, Warsaw, Poland

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

http://www.isv.uu.se/thep/

Contents

- The Lopsided Doublet Model
- Spectrum of scalars
- Decays of Lopsided Scalars
- Production of H^+
- Conclusion

Lopsided

What is this?

Def. **“Lopsided”**:

Not even or balanced; not the same on one side as on the other.

Tentative title, article in preparation, might change name later.

The Lopsided Doublet Model

2HDM potential:

$$\begin{aligned}\mathcal{V} =& m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left[m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.} \right] + \frac{1}{2}\lambda_1 \left(\Phi_1^\dagger \Phi_1 \right)^2 \\ &+ \frac{1}{2}\lambda_2 \left(\Phi_2^\dagger \Phi_2 \right)^2 + \lambda_3 \left(\Phi_1^\dagger \Phi_1 \right) \left(\Phi_2^\dagger \Phi_2 \right) + \lambda_4 \left(\Phi_1^\dagger \Phi_2 \right) \left(\Phi_2^\dagger \Phi_1 \right) \\ &+ \left\{ \frac{1}{2}\lambda_5 \left(\Phi_1^\dagger \Phi_2 \right)^2 + \left[\lambda_6 \left(\Phi_1^\dagger \Phi_1 \right) + \lambda_7 \left(\Phi_2^\dagger \Phi_2 \right) \right] \left(\Phi_1^\dagger \Phi_2 \right) + \text{h.c.} \right\}\end{aligned}$$

The potential has a discrete symmetry if the parameters $m_{12}^2 = 0,\ \lambda_{6,7} = 0$, in the so called generic basis (both doublets acquire a *vev*). The symmetry is called Z_2 - parity and works as:

$$\Phi_1 \to \Phi_1,\ \Phi_2 \to -\Phi_2$$

m_{12}^2 breaks the Z_2 - parity softly, and $\lambda_{6,7}$ hard.

The Lopsided Doublet Model cont.

Recall that in the *Inert Doublet Model*, only one doublet, Φ_1, couples to fermions (i.e. only doublet gets a *vev*) and has a potential with exact Z_2 – parity.

What happens if this parity is broken *softly* only?

The minimization condition of the potential becomes

$$m_{11}^2 = -v^2\lambda_1/2$$

$$m_{12}^2 = v^2\lambda_6/2$$

Naively, this seems to be impossible due to fact that the soft breaking parameter is proportional to the hard breaking parameter..

Soft Z_2 - breaking

Using the formalism of Davidson and Haber [1] one can find conditions when Z_2 is only softly broken.

It is possible to have soft breaking even with non-zero λ_6 , provided that the following conditions are fullfilled:

$$(\lambda_1 - \lambda_2)\left[\lambda_{345}(\lambda_6 + \lambda_7) - \lambda_2\lambda_6 - \lambda_1\lambda_7\right] - 2(\lambda_6 - \lambda_7)(\lambda_6 + \lambda_7)^2 = 0$$

$$(\lambda_1 - \lambda_2)m_{12}^2 + (\lambda_6 + \lambda_7)(m_{11}^2 - m_{22}^2) \neq 0$$

Where $\lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5$

These conditions are valid if $\lambda_1 \neq \lambda_2$ in a basis where $\lambda_7 = -\lambda_6$

[1] *Basis-independent methods for the two-Higgs-doublet model, Phys. Rev.* ***D 72****, 035004 (2005)*

Soft Z_2 - breaking cont.

The Model space is thus determined by those quartic couplings (λ_i) that fulfill those conditions.

We have started to investigate the phenomenology for the case
$\lambda_2 = \lambda_1$ and $\lambda_7 = \lambda_6$

The soft breaking of Z_2 induces mixing between the two doublets, thus there is no "inert" doublet.

The doublets are in some sense unbalanced (hence the name "Lopsided").

The amount of soft breaking is thus encoded into the mixing angle (Sin α) between the two doublets when deriving the mass eigenstates.

Spectrum of Scalars

In this Model, the charged scalar H^+ and the pseudoscalar A^0, do not couple to fermions at tree-level which means that flavor constraints do not apply at all to them.

These scalars are thus allowed to be much lighter than in “normal” (type I,II) 2HDM's.

The neutral scalars h,H can be heavier than the SM – like Higgs boson (as usually in 2HDM) due to EWPT.

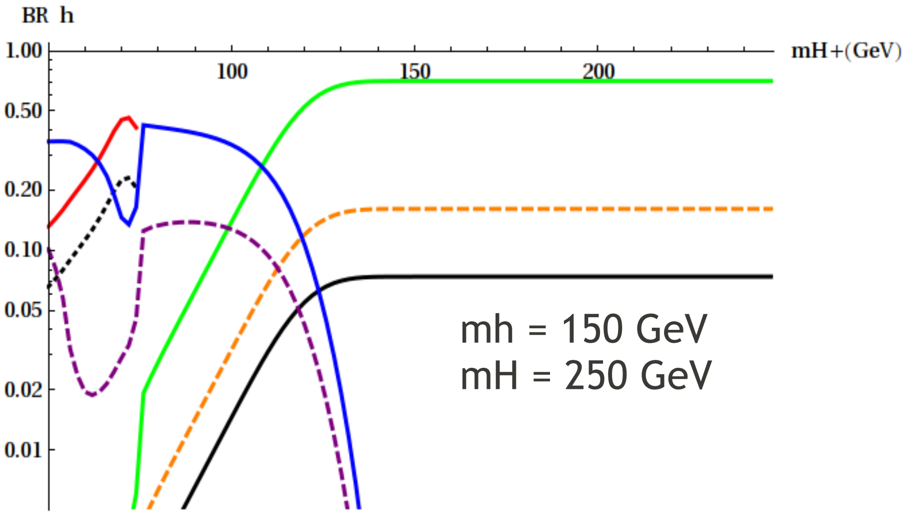
$$H = \Phi_1 \mathrm{Cos}\,\alpha + \Phi_2 \,\mathrm{Sin}\,\alpha$$

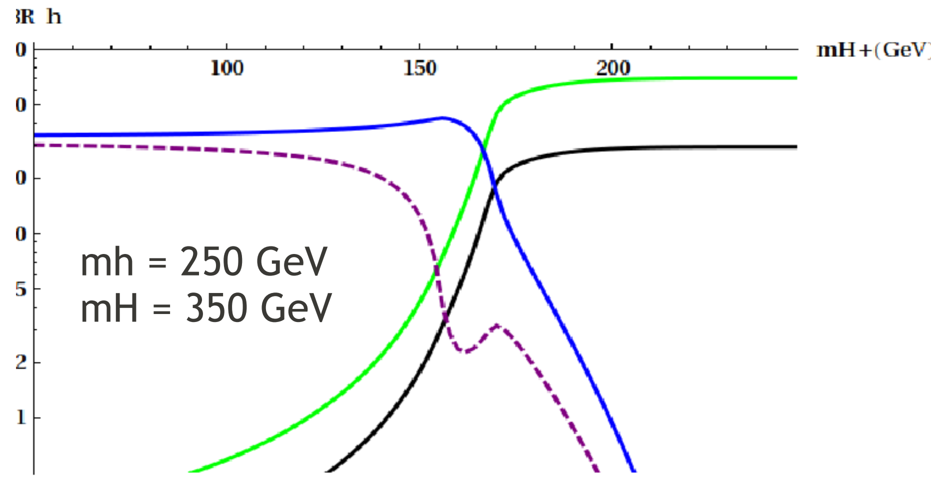
$$h = -\Phi_1 \,\mathrm{Sin}\,\alpha + \Phi_2 \,\mathrm{Cos}\,\alpha$$

$$m_H > m_h$$

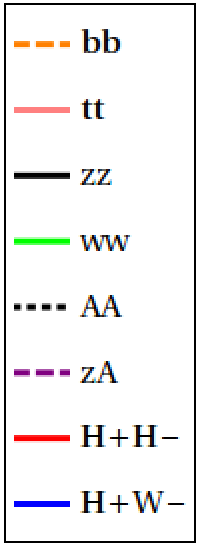
H^+ and A^0 can not decay into a pair of fermions at tree level, however they can do so at one-loop order (which is not possible in the IDM).

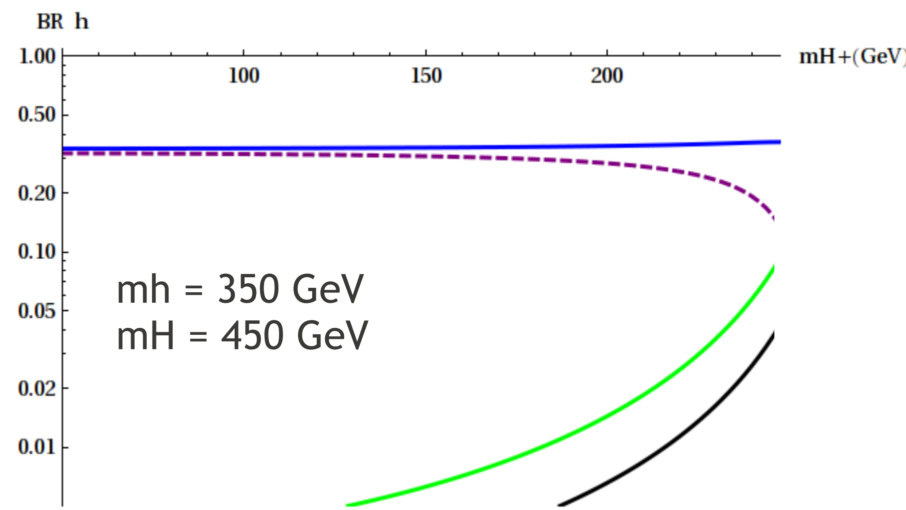
Decays of h





X-axis = mH^+

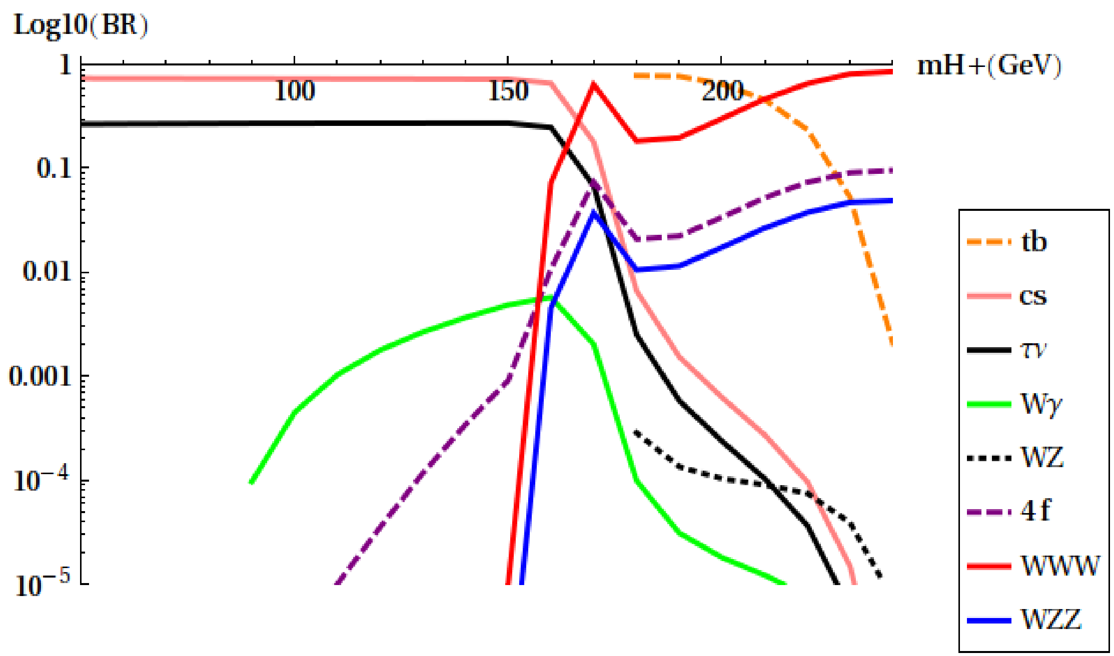


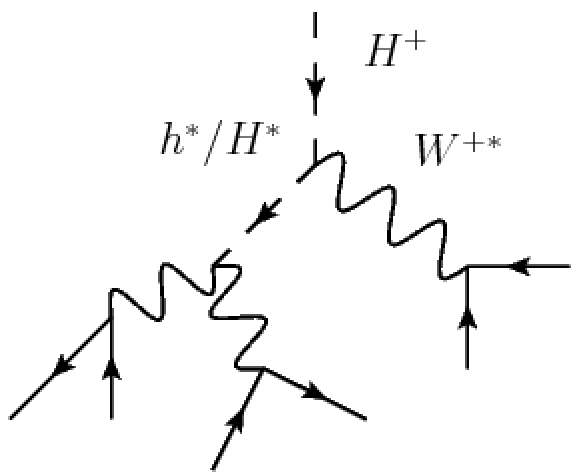


Decays of H^+

1-loop order processes vs. tree-level proc. with off-shell internal propagators.

1-loop processes calculated with FeynArts, FormCalc, LoopTools, details will be discussed in upcoming article. Tree-level processes calculated with MadGraph 5.



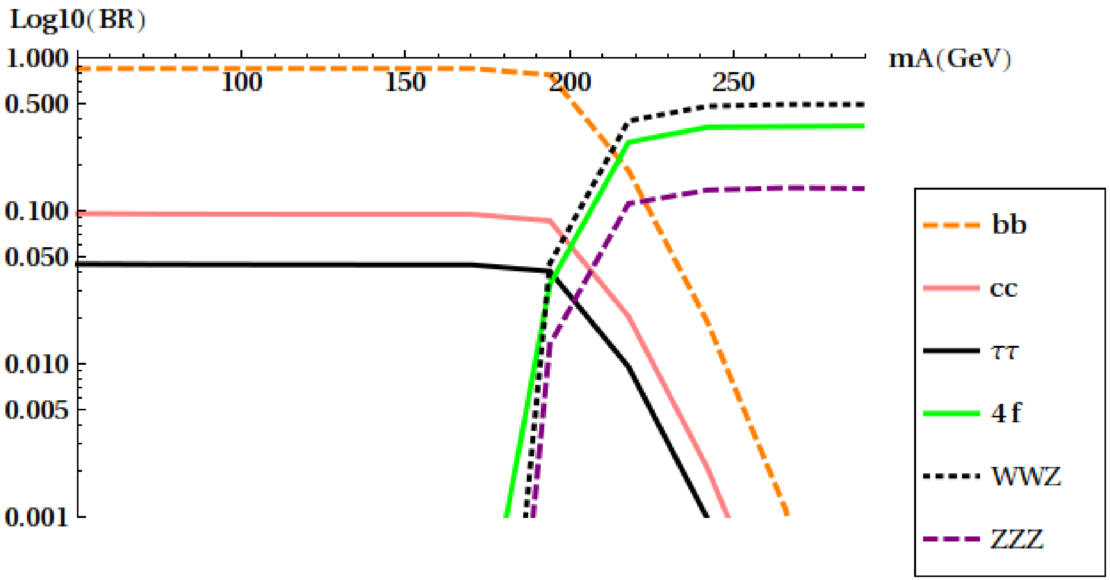


Sin α = 0.5, m22 = 200 GeV, mh = 150, mH = 250, mA = mHp

2 fermion final states dominate over 4,6 F final states as long as h,H are off shell. Exception is $H^+ \rightarrow tb$ which can dominate over 4,6 F if m_{22} is “large”.

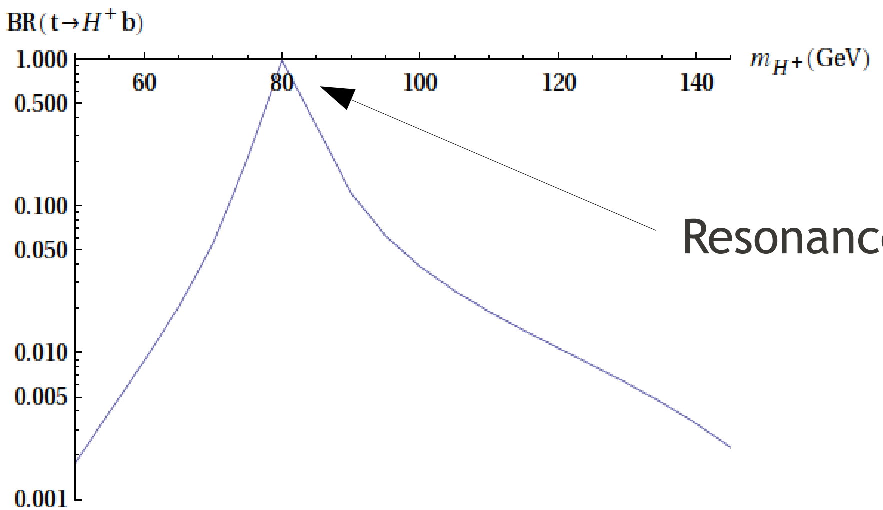
Decays of A^0

Similar results as for H^+, i.e. 2F dominates over 4,6F



mh = 150, mH = 250, mHp = mA, m22 = 50 GeV, sin α = 0.5

Top quark → H^+b Decay



Resonance due to loop diagrams with H^+ - W^+ mixing

mh = 150, mH = 300, m22 = 50, mA = mHp, Sin α = 0.5

Except for $mH^+ \approx mW^+$, the branching ratio is negligible compared to $t \to W^+b$.

Production of H^+ mainly in vector boson fusion, Drell-Yan and h,H decays

Conclusions

This model has a very different phenomenology:

- h,H can be heavier than in the SM
- H^+ and A^0 can be lighter than “standard” 2HDM
- Decay Channels and Branching Ratios can also be very different
- H^+ not produced through tbH^+ vertex (the usual channels as in e.g. MSSM)
- $mH^+ \approx mW^+$ is ruled out though

For more details, see PoS(Charged 2010)032 in Proceedings of Science, and upcoming article