Twisted Higgs Phenomenology at Hadron Colliders

Michel Herquet

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"Don't think experimentalists like MSSM (only) because SUSY is a bright idea, they like it because two dimensional exclusion plots are easy to draw"

An (anonymous) experimentalist friend about the $(m_{A^0}, \tan\beta)$ plane

Problem: How to restrict enough the number of free parameters in your model to make it attractive ?

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Solution 2: Bottom up approaches $\rightarrow$ model with many free parameters (e.g. 2HDM) and phenomenologically motivated symmetries.
Tip: the SM is a not-so-bad source of inspiration

Outline

1. CP and custodial symmetries
2. A twisted 2HDM scenario
3. Phenomenology at hadron colliders

The CP symmetry

In the SM:

$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

CP invariant since

$$(\mathcal{CP}) \phi(t, \vec{x}) (\mathcal{CP})^\dagger = \phi^*(t, -\vec{x})$$

In the 2HDM (Higgs basis $\langle \phi_1^0 \rangle = v$ and $\langle \phi_2^0 \rangle = 0$):

$$\begin{aligned} (\mathcal{CP}) \phi_1(t, \vec{r}) (\mathcal{CP})^\dagger &= \phi_1^*(t, -\vec{r}) \\ (\mathcal{CP}) \phi_2(t, \vec{r}) (\mathcal{CP})^\dagger &= e^{i\xi} \phi_2^*(t, -\vec{r}) \end{aligned}$$

The custodial symmetry

In the SM:

$$\phi \leftrightarrow M \equiv \begin{pmatrix} \phi^0 & -\phi^- \\ \phi^+ & (\phi^0)^* \end{pmatrix} \quad , \quad \phi^\dagger \phi = \mathrm{Tr}(M^\dagger M)$$

invariant under $SU(2)_L \times SU(2)_R$

$$M \to M' = U_L M U_R^\dagger$$

In the 2HDM (Higgs basis $\langle M_1 \rangle = v\mathbb{I}$ and $\langle M_2 \rangle = 0$):

$$M_1 \to U_L M_1 U_R^\dagger \quad , \quad M_2 \to U_L M_2 V_R^\dagger$$

$$V_R = \exp(-i\gamma T_R^3)\, U_R \exp(i\gamma T_R^3)$$

Phys. Rev. Lett. ***98****: 251802, 2007. hep-ph/0703051*
J.-M. Gérard and M.H.

CP and custodial symmetries in 2HDMs

Generalized CP eigenstates:

$$\phi_1^\dagger\phi_1,\ \phi_2^\dagger\phi_2,\ \cos(\xi)\mathrm{Re}(\phi_1^\dagger\phi_2)+\sin(\xi)\mathrm{Im}(\phi_1^\dagger\phi_2)\rightarrow \text{even}$$

$$-\sin(\xi)\mathrm{Re}(\phi_1^\dagger\phi_2)+\cos(\xi)\mathrm{Im}(\phi_1^\dagger\phi_2)\rightarrow \text{odd}$$

Generalized custodial invariants:

$$\phi_1^\dagger\phi_1,\ \phi_2^\dagger\phi_2,\ \cos(\gamma)\mathrm{Re}(\phi_1^\dagger\phi_2)+\sin(\gamma)\mathrm{Im}(\phi_1^\dagger\phi_2)$$

Three cases

1. $\xi = \gamma$: Usual scenario, $m_{H^\pm} = m_{A^0}$, h^0 and H^0 mix. MSSM in the decoupling limit since $m^2_{H^\pm} = m^2_{A^0} + m^2_{W^\pm}$

2. $\xi = \pi - \gamma$: Twisted scenario, $m_{H^\pm} = m_{H^0}$, h^0 and A^0 are orthogonal.

3. $\xi \neq \gamma, \pi - \gamma$: decoupled doublet with $m_{H^\pm} = m_{A^0} = m_{H^0}$

Constraints on a twisted scenario

Theoretical constraints: Vacuum stability, unitarity and perturbativity.

$$m^2_{h^0} \gtrsim m^2_{H^\pm} - m^2_{A^0} \text{ and } m_{h^0} \lesssim 500 \text{ GeV}$$

Indirect constraints: EW precision parameters, B physics, $(g-2)_\mu$, $Z \to b\bar{b}$

Type I : $m_{h^0} \lesssim 300$ GeV, $\tan\beta \lesssim 0.3$

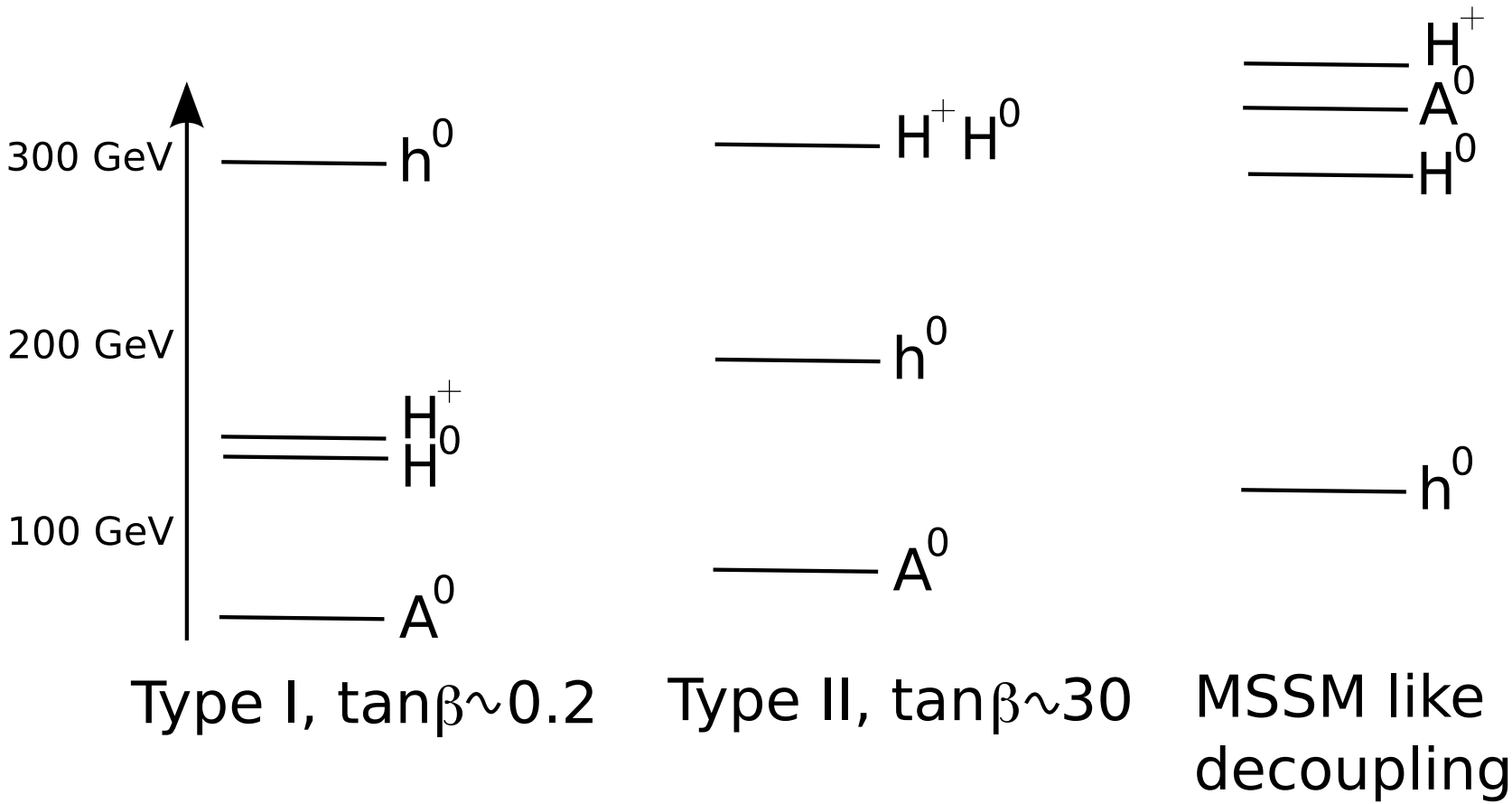
Type II : $m_{h^0} \lesssim 400$ GeV, $\tan\beta \gtrsim 10$

$m_{H^\pm, H^0} \gtrsim 300$ GeV, $m_{A^0} \gtrsim 50$ GeV

Direct constraints: $m_{H^0} + m_{A^0} \gtrsim 150$ GeV and $BR(t \to H^+ b) \times BR(H^+ \to c\bar{s}, \tau^+ \nu_\tau) \lesssim 30\%$

Interesting scenarios ?

S. de Visscher, J.-M. Gérard, V. Lemaitre, F. Maltoni and M.H. Review in preparation.



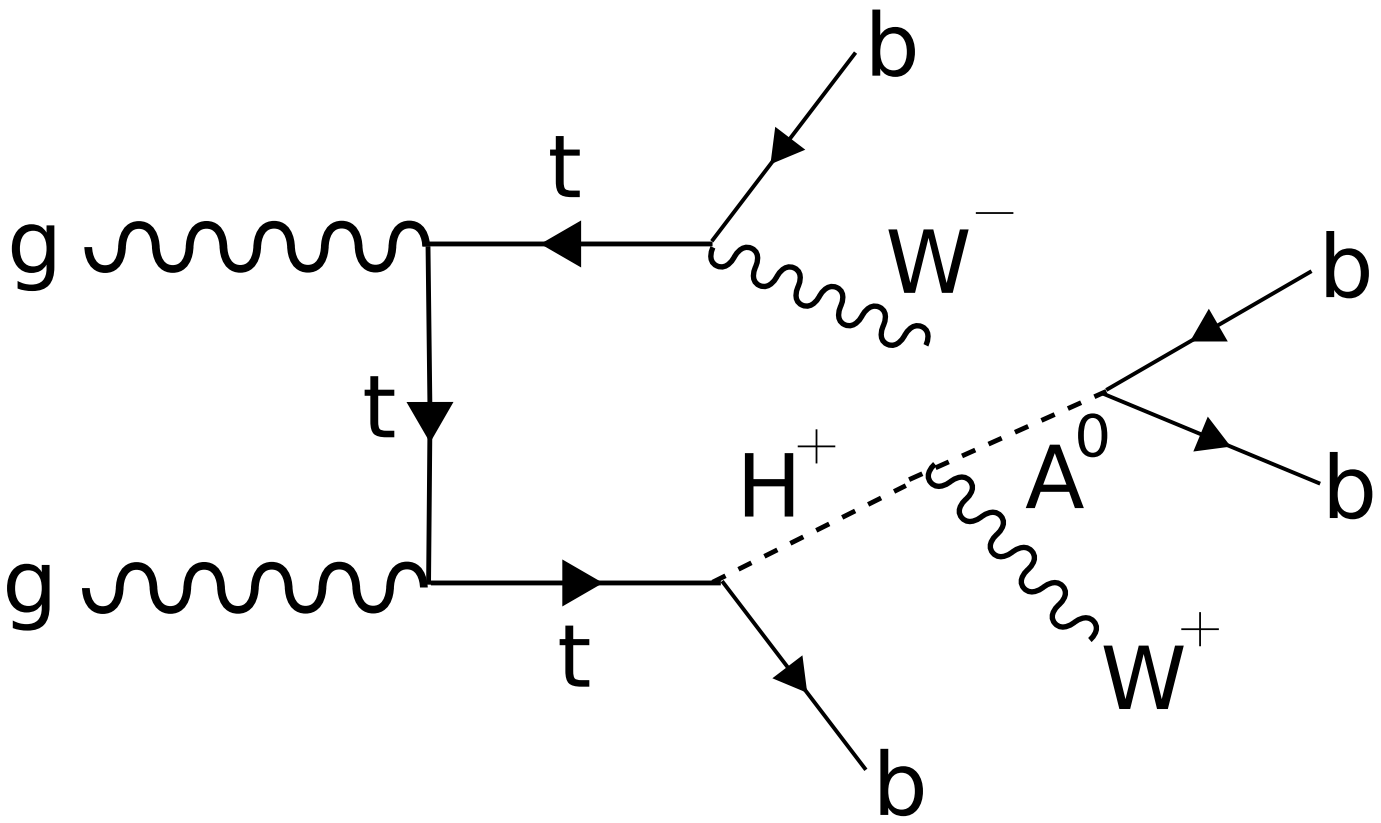
Type I, tanβ∼0.2 Type II, tanβ∼30 MSSM like decoupling

Interesting decays

1. $h^0 \to A^0 A^0$ with BRs from 0.1 to 1 depending on masses. $BR(A^0 \to \bar{b}b) \simeq 0.9$
2. $H^\pm \to W^\pm A^0$, $H^0 \to Z^0 A^0$ both dominant if allowed
3. $h^0 \to H^0 H^0, H^+ H^-$ if kinematically allowed, with typical BRs $\simeq 0.2 - 0.3$

All signals studied with the generic 2HDM implementation in MadGraph/MadEvent v4

$H^{\pm} \longrightarrow W^{\pm} A^0$ with top(s)



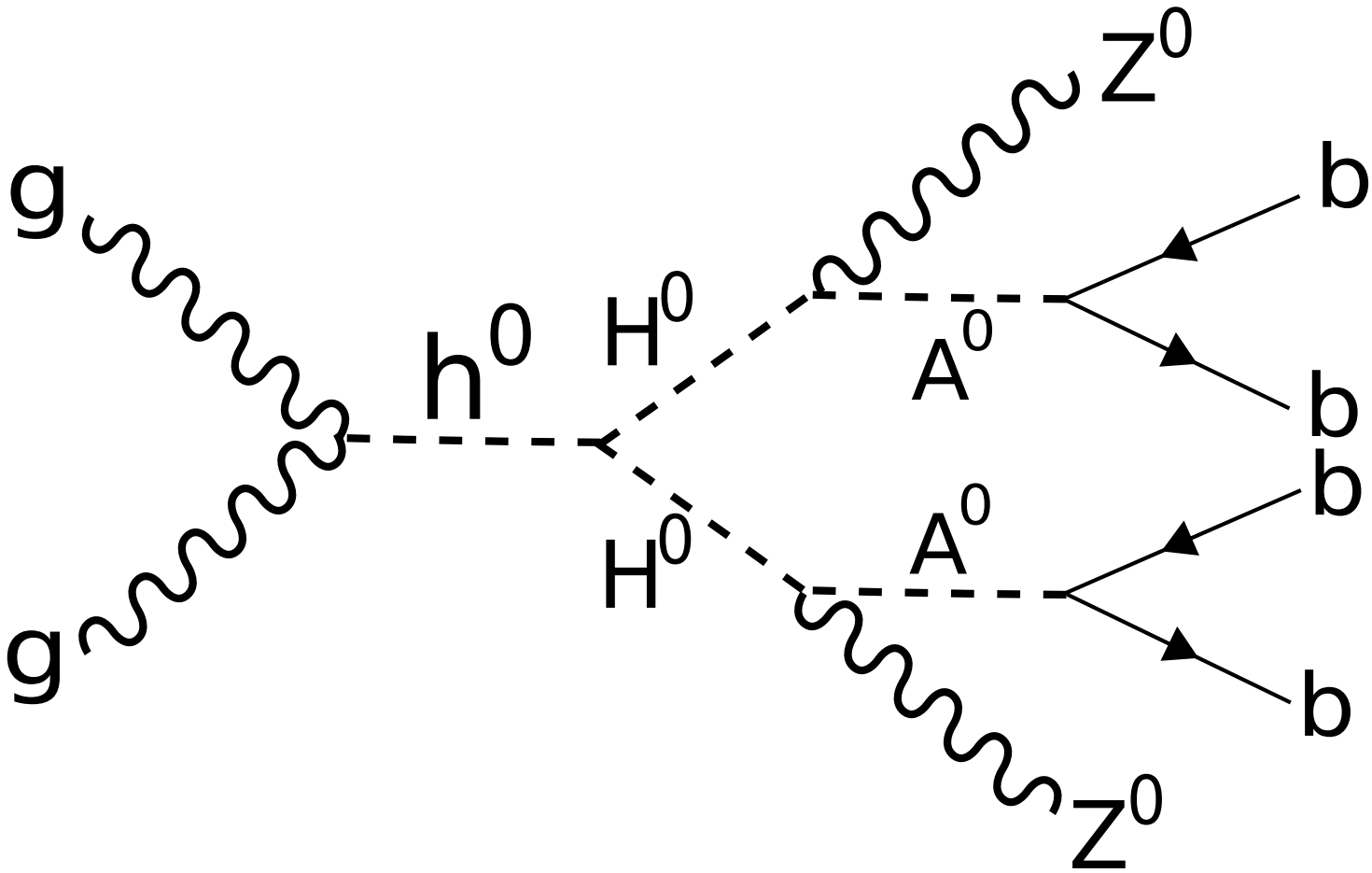
$H^{\pm} \longrightarrow W^{\pm} A^0$ with top(s)

1. For $m_{H^{\pm}} < 160$ GeV: $t \longrightarrow H^+ b$, final state is $W^+ W^- b\bar{b}b\bar{b}$. $\simeq$ 10pb at LHC and 0.1pb at Tevatron.

2. For $m_{H^{\pm}} > 160$ GeV: tH^-, final state is $W^+ W^- b\bar{b}b$. $\simeq$ 0.5pb at LHC.

3. Main background is $t\bar{t}$ + n jets, irreducible if gluon splitting into $b\bar{b}$

$H^0 \to Z^0 A^0$



$H^0 \to Z^0 A^0$

1. From decay $h^0 \to H^0 H^0$, $2Z4b$ final state with cross section around 1pb at LHC.
2. Produced in association with b's (in type II), $b\bar{b}H^0$, $Z4b$ final state with cross section around 5pb at LHC
3. Direct production at Tevatron (in type II), $gg \to H^0$, $Z2b$ final state
4. Low SM backrounds Z+jets and ZZ+jets

Conclusion

1. *CP* and custodial symmetries can be used as guidelines to constrain extended Higgs sectors
2. A non trivial twisted scenario in the 2HDM exists and is viable. Its main features are a light pseudoscalar A^0, a nearly degenerate triplet $(H^0, H^\pm)$ and a heavy SM like Higgs h^0.
3. Unusual and challenging phenomenology at hadron collider

Perspectives

1. Possible role/consequences of a twisted case in larger models (e.g. Left-Right models)
2. Full simulation study of the "golden" signatures
3. Detailed study of Tevatron signal(s)

Twisting Higgs phenomenology

Higgs phenomenology does not always reduce to SM, MSSM or NMSSM-like scenarios

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Stay open to more exotic possibilities