Collider Phenomenology of 3HDMs

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Motivations for introducing more than one doublet

- LHC: Higgs (doublet) seen (very SM-like), no BSM
- No fundamental reason for only one doublet (ignore singlet, not seen)
- Hierarchy of the Yukawa couplings
- Sources of *CP* violation
- Source of FCNCs
- Axion models with Peccei-Quinn symmetry
- Dark matter candidates (IHDMs)

N-Higgs Doublet Models (NHDMs)

N copies of the Higgs doublet with identical quantum numbers:

$$\Phi_\alpha = \begin{pmatrix} \phi_\alpha^+ \\ \frac{1}{\sqrt{2}}(\rho_\alpha + i\eta_\alpha) \end{pmatrix}, \qquad \alpha = 1, 2, \cdots N$$

The most general potential

$$V = Y_{ab}(\Phi_a^\dagger \Phi_b) + Z_{abcd}(\Phi_a^\dagger \Phi_b)(\Phi_c^\dagger \Phi_d)$$

contains $N^2(N^2+3)/2$ free parameters.

All Abelian symmetries realisable in NHDM have been found.
[Ivanov, et al., J.Phys.A 45,215201 (2012)]

- 3HDM and symmetries

In 3HDMs, all finite symmetries are known

$$Z_2, \quad Z_3, \quad Z_4, \quad Z_2 \times Z_2, \quad D_6, \quad D_8, \quad A_4, \quad S_4, \quad \Delta(54)/Z_3, \quad \Sigma(36)$$

[Ivanov, et al., Eur.Phys.J.C 73,2309 (2013)]

- Some credentials

Popular 3HDMs, Private Higgs model:
[Weinberg,et al. Phys.Rev.D15,1958 (1977)], [Paschos, Phys.Rev.D15,1966 (1977)]
[Adler, Phys.Rev.D60,015002 (1999)], [Zee,et al., Phys.Lett.B666,491 (2008)]

Groups with triplet representations A_4, S_4:
[Ma, et al., Phys.Lett.B 552, (2003)], [Altarelli, et al., Nucl.Phys.B 720, (2005)]
[Lam, Phys.Rev.Lett. 101, (2008)], [Morisi, et al., Phys.Rev.D 80, (2009)]
[King, et al., Phys.Lett.B 687, (2010)]

3HDMs

- Experiment: search for NP through the Higgs sector high on agenda.
- Guided by existence of 3 generations of fermions we pick the 3HDM, assigning one doublet to be the SM one, we are left with two inert doublets plus one Higgs doublet (I(2+1)HDM).

We previously studied full list of symmetries in 3HDMs:

[V. Keus, S.F. King and SM, JHEP 1401, 052 (2014)

The I(2+1)HDM

We study the 3HDMs with $(0, 0, v)$ VEV alignment symmetric under:

- continuous Abelian groups

$$U(1), \quad U(1) \times U(1), \quad U(1) \times Z_2,$$

- finite Abelian groups

$$Z_2 \text{ (2HDM standard)}, \quad Z_3, \quad Z_4, \quad Z_2 \times Z_2,$$

- finite non-Abelian groups

$$D_6, \quad D_8, \quad A_4, \quad S_4, \quad \Delta(54)/Z_3, \quad \Sigma(36).$$

The DM in each case is protected by either the original symmetry of the potential or the remnant of the symmetry after EWSB.

[Keus, et al., JHEP 1401 (2014) 052]

Constructing the (Z_2 symmetric) I(2+1)HDM

Start with the phase invariant potential:

$$V_0 = -|\mu_i^2|(\Phi_i^\dagger \Phi_i) + \lambda_{ii}(\Phi_i^\dagger \Phi_i)^2 + \lambda_{ij}(\Phi_i^\dagger \Phi_i)(\Phi_j^\dagger \Phi_j) + \lambda'_{ij}(\Phi_i^\dagger \Phi_j)(\Phi_j^\dagger \Phi_i)$$

and add the terms

$$V_{Z_2} = -\mu_{12}^2(\Phi_1^\dagger \Phi_2) + \lambda_1(\Phi_1^\dagger \Phi_2)^2 + \lambda_2(\Phi_2^\dagger \Phi_3)^2 + \lambda_3(\Phi_3^\dagger \Phi_1)^2 + h.c.$$

that ensure the Z_2 symmetry generated by

$$g^{Z_2} = (-,-,+)$$

where

$$\Phi_\alpha = \begin{pmatrix} H_\alpha^\pm \\ \frac{1}{\sqrt{2}}\left(H_\alpha^0 + iA_\alpha^0\right) \end{pmatrix}, \quad \alpha = 1,2,3$$

where 1,2 are inert, 3 is active.

Dark matter in the I(2+1)HDM

The VEV alignment $\langle \Phi_i \rangle = (0, 0, v)$ respects the Z_2 symmetry: lightest neutral fields from the inert doublets, $H_{1,2}, A_{1,2}$ are viable DM candidates.

$$\Phi_\alpha = \begin{pmatrix} H^\pm_\alpha \\ \frac{1}{\sqrt{2}}\left(H^0_\alpha + iA^0_\alpha\right) \end{pmatrix}, \quad \alpha = 1, 2$$

Notes:

- To make sure whole Lagrangian is Z_2 symmetric, assign even Z_2 parity to all SM particles, identical to Z_2 parity of only doublet coupling to them, i.e., active ϕ_3.
- With this parity assignment FCNCs are avoided as extra doublets are forbidden to decay to fermions by Z_2 conservation.

Higgs sector of the I(2+1)HDM

Free parameters

- μ_3, λ_{33}: Higgs field parameters, given by Higgs mass,

$$m_h^2 = 2\mu_3^2 = 2\lambda_{33} v^2 \quad (v \equiv v_{\rm SM}).$$

- $\mu_1, \mu_2, \mu_{12}, \lambda_{31}, \lambda_{23}, \lambda'_{31}, \lambda'_{23}, \lambda_2, \lambda_3$: mass parameters and couplings of inert scalars to visible sector, 9 parameters (can be determined by 6 masses and 3 mixing angles):

$$-10 \ \ \mathrm{TeV}^2 < \mu_1^2, \mu_2^2, \mu_{12}^2 < 10 \ \mathrm{TeV}^2,$$
$$-0.5 < \lambda_{31}, \lambda_{23}, \lambda'_{31}, \lambda'_{23}, \lambda_2, \lambda_3 < 0.5.$$

- $\lambda_{11}, \lambda_{22}, \lambda_{12}, \lambda'_{12}$: inert self-interactions (NB: relic density calculations do not depend on these, bounds would come from collider limits)

$$0 < \lambda_{11}, \lambda_{22}, \lambda_{12}, \lambda'_{12} < 0.5.$$

Higgs sector of the I(2+1)HDM

Physical Higgs states

- One active one: $h_{\rm SM}$ + $G^0(G^\pm)$ Goldstones to make $Z(W^\pm)$ massive.
- Two generations of inert ones: $(H_1, A_1, H_1^\pm)$ chosen lighter than $(H_2, A_2, H_2^\pm)$ $\rightarrow$ H_1 being the lightest, i.e., the DM candidate:

$$m_{H_1} < m_{H_2}, m_{A_{1,2}}, m_{H^\pm_{1,2}} \quad (\text{implies } 2\lambda_2, 2\lambda_3 < \lambda'_{23}, \lambda'_{31} < 0).$$

1. Introduce matrix

$$R_{\theta_i} = \begin{pmatrix} \cos\theta_i & \sin\theta_i \\ -\sin\theta_i & \cos\theta_i \end{pmatrix}, \qquad \theta_i = \theta_h, \theta_a, \theta_c,$$

$\theta_{h(a)[c]}$ rotation angles of scalar(pseudo-scalar)[charged] inert sector.

2. Can express mass spectrum in terms of $\Sigma = 4\mu_{12}^4 + (\mu_1^2 - \Lambda_{\phi_1} - \mu_2^2 + \Lambda_{\phi_2})^2$ (same for $\Sigma'^{('')}$ vs $\Lambda'^{('')}_{\phi_i}$, $i = 1, 2$)

Higgs sector of the I(2+1)HDM

with

$$\Lambda_{\phi_1} = \frac{1}{2}(\lambda_{31} + \lambda'_{31} + 2\lambda_3)v^2 \qquad \Lambda_{\phi_2} = \frac{1}{2}(\lambda_{23} + \lambda'_{23} + 2\lambda_2)v^2$$

$$\tan 2\theta_h = \frac{2\mu_{12}^2}{\mu_1^2 - \Lambda_{\phi_1} - \mu_2^2 + \Lambda_{\phi_2}}$$

$$\Lambda'_{\phi_1} = \frac{1}{2}(\lambda_{31})v^2 \qquad \Lambda'_{\phi_2} = \frac{1}{2}(\lambda_{23})v^2$$

$$\tan 2\theta_c = \frac{2\mu_{12}^2}{\mu_1^2 - \Lambda'_{\phi_1} - \mu_2^2 + \Lambda'_{\phi_2}}$$

$$\Lambda''_{\phi_1} = \frac{1}{2}(\lambda_{31} + \lambda'_{31} - 2\lambda_3)v^2 \qquad \Lambda''_{\phi_2} = \frac{1}{2}(\lambda_{23} + \lambda'_{23} - 2\lambda_2)v^2$$

$$\tan 2\theta_a = \frac{2\mu_{12}^2}{\mu_1^2 - \Lambda''_{\phi_1} - \mu_2^2 + \Lambda''_{\phi_2}}$$

Higgs sector of the I(2+1)HDM

- Possible mass spectrum is

m_h^2	$2\mu_3^2$
$m_{H_2^\pm}^2$	$(-\mu_1^2 + \Lambda'_{\phi_1} - \mu_2^2 + \Lambda'_{\phi_2} + \sqrt{\Sigma'})/2$
$m_{H_1^\pm}^2$	$(-\mu_1^2 + \Lambda'_{\phi_1} - \mu_2^2 + \Lambda'_{\phi_2} - \sqrt{\Sigma'})/2$
$m_{A_2}^2$	$(-\mu_1^2 + \Lambda''_{\phi_1} - \mu_2^2 + \Lambda''_{\phi_2} + \sqrt{\Sigma''})/2$
$m_{A_1}^2$	$(-\mu_1^2 + \Lambda''_{\phi_1} - \mu_2^2 + \Lambda''_{\phi_2} - \sqrt{\Sigma''})/2$
$m_{H_2}^2$	$(-\mu_1^2 + \Lambda_{\phi_1} - \mu_2^2 + \Lambda_{\phi_2} + \sqrt{\Sigma})/2$
$m_{H_1}^2$	$(-\mu_1^2 + \Lambda_{\phi_1} - \mu_2^2 + \Lambda_{\phi_2} - \sqrt{\Sigma})/2$
$m_{G^0}^2, m_{G^\pm}^2$	0

Higgs sector of the I(2+1)HDM

Theoretical constraints

1) Positivity of mass eigenstates

- $\mu_3^2 > 0$
- $-2\mu_1^2 + \lambda_{31} v^2 > 0$
- $-2\mu_1^2 + (\lambda_{31} + \lambda'_{31}) v^2 > 0$
- $-2\mu_1^2 + (\lambda_{31} + \lambda'_{31} - 2\lambda_3) v^2 > 0$
- $-2\mu_2^2 + \lambda_{23} v^2 > 0$
- $-2\mu_2^2 + (\lambda_{23} + \lambda'_{23}) v^2 > 0$
- $-2\mu_2^2 + (\lambda_{23} + \lambda'_{23} - 2\lambda_2) v^2 > 0$
- $-2\mu_1^2 - 2\mu_2^2 + (\lambda_{31} + \lambda_{23}) v^2 > 4|\mu_{12}^2|$
- $-2\mu_1^2 - 2\mu_2^2 + (\lambda_{31} + \lambda_{23} + \lambda'_{31} + \lambda'_{23}) v^2 > 4|\mu_{12}^2|$
- $-2\mu_1^2 - 2\mu_2^2 + (\lambda_{31} + \lambda_{23} + \lambda'_{31} + \lambda'_{23} - 2\lambda_3 - 2\lambda_2) v^2 > 4|\mu_{12}^2|$

Higgs sector of the I(2+1)HDM

2) Bounded-ness of V

- $\lambda_{11}, \lambda_{22}, \lambda_{33} > 0$
- $\lambda_{12} + \lambda'_{12} > -2\sqrt{\lambda_{11}\lambda_{22}}$
- $\lambda_{23} + \lambda'_{23} > -2\sqrt{\lambda_{22}\lambda_{33}}$
- $\lambda_{31} + \lambda'_{31} > -2\sqrt{\lambda_{33}\lambda_{11}}$

Also require parameters V_{Z_2} be smaller than V_0 ones:

- $|\lambda_1|, |\lambda_2|, |\lambda_3| < |\lambda_{ii}|, |\lambda_{ij}|, |\lambda'_{ij}|, \quad i \neq j : 1, 2, 3$

3) Positive-definite-ness of Hessian

- $\mu_3^2 > 0$
- $-2\mu_2^2 + (\lambda_{23} + \lambda'_{23})v^2 > 0 \;\&\; \quad -2\mu_1^2 + (\lambda_{31} + \lambda'_{31})v^2 > 0$
- $\left(-2\mu_1^2 + (\lambda_{31} + \lambda'_{31})v^2\right)\left(-2\mu_2^2 + (\lambda_{23} + \lambda'_{23})v^2\right) > 4\mu_{12}^4$

4) Unitarity like in the SM

Higgs sector of the I(2+1)HDM

Experimental constraints (LEP)
Searches for Higgs states give

- $m_{H_i^\pm} + m_{H_i,A_i} > m_{W^\pm}$ (1)
- $m_{H_i} + m_{A_i} > m_Z$
- $2m_{H_i^\pm} > m_Z$

- $m_{H_i^\pm} > 70 \quad \text{GeV}.$ (2)

Searches for charginos and neutralinos translate to

- $m_{H_i} < 80 \quad \text{GeV} \quad \text{and} \quad m_{A_i} < 100 \quad \text{GeV}$

and

- $m_{A_i} - m_{H_i} > 8 \quad \text{GeV}.$ (3)

(Limit enforced for any pair CP-even/odd pair.)

Higgs sector of the I(2+1)HDM

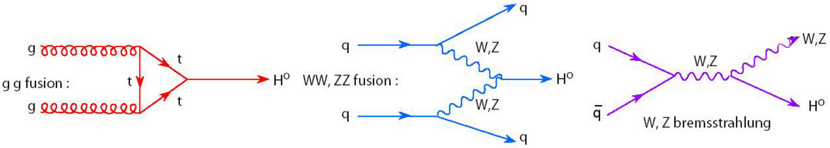
Invisible Higgs decay limits (LHC)

1. Direct detection limits:

• ATLAS limits in Zh channel: BR($h \to$ invisible) $<$ 65% at 95% CL
• CMS limits in Zh channel: BR($h \to$ invisible) $<$ 75% at 95% CL
• CMS limits in VBF channel: BR($h \to$ invisible) $<$ 69% at 95% CL

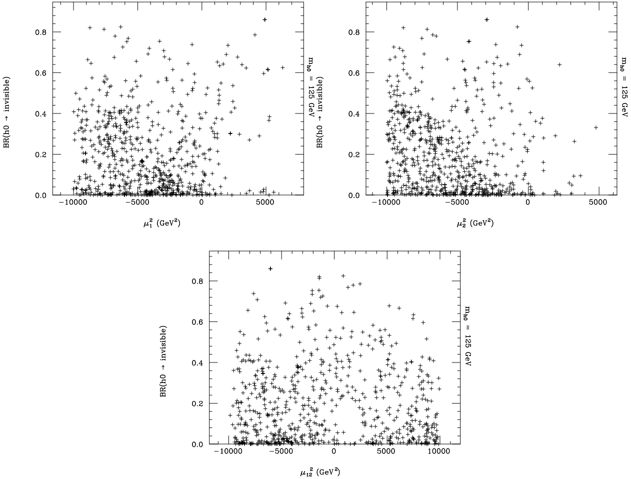
2. Global fits on Higgs signal strengths:

• Higgs boson with SM couplings but additional invisible decay modes: BR($h \to$ invisible) $<$ 20% (or so) at 95% CL

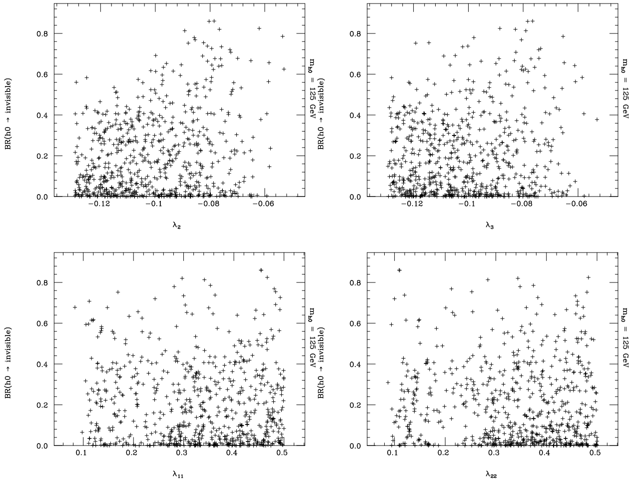


Results for the I(2+1)HDM

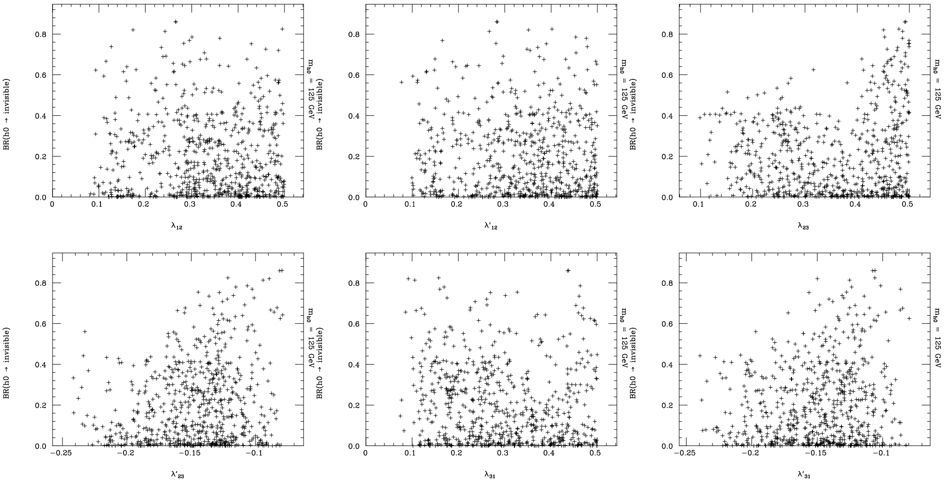
- $h(\equiv h_{\rm SM}) \to$ invisible ($m_h = 125$ GeV).



Results for the I(2+1)HDM



Results for the I(2+1)HDM



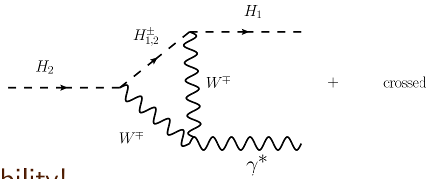
Results for the I(2+1)HDM

- However, most striking I(2+1)HDM signal is radiative decays of heavy inert Higgs states into DM candidate:

$$h \to H_1 H_2, \qquad h \to H_2 H_2,$$

wherein

$$H_2 \to H_1(\equiv \mathrm{DM})\ \gamma^*(\to e^+ e^-)$$

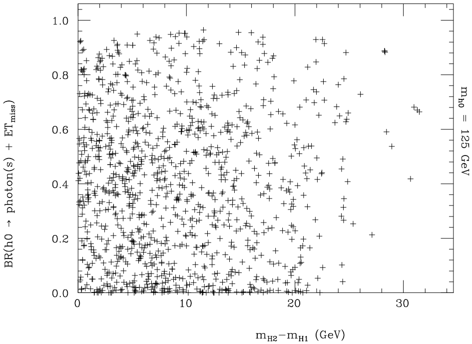


with 100% probability!

- A_1, $H_1^{\pm}$, A_2 and $H_2^{\pm}$ never involved (H_1 and H_2 always lightest inerts).

Results for the I(2+1)HDM

- Search for EM showers, one or two at a time, alongside significant missing (transverse) energy, $E^T_{\rm miss}$ from DM pair.



- Can enable I(2+1)HDM to be distinguished from I(1+1)HDM, as here CP-conservation prevents such radiative decays.

Constructing the I(1+2)HDM

- Z_2-symmetric 3HDM potential, assign $Z_2 = +1$ to 2 active doublets and -1 to inert doublet plus $\tilde{Z}_2$ in active sector to avoid FCNCs
- Structure is 2HDM-like ($h_{\rm SM}$, H, A & $H^\pm$) plus $H_0^\pm$, A_0 & H_0 inert (either of the neutrals can be DM depending on mass hierarchy), VEV is $(0, v_1, v_2)$ with $\tan\beta = v_1/v_2$ & α mixing angle between CP-evens
- Similar formulae to I(2+1)HDM obtained for theoretical constraints
- However, unitarity much more involved
  1. In high energy limit $\mathrm{Im}(a_J) = |a_J|^2$ implies a_J on a circle with radius and center of $1/2$ and $(0, 1/2)$ in the complex plane, respectively
  2. Can require for the tree level amplitude of a_J
$$|\mathrm{Re}(a_J)| < \frac{1}{2}$$
  3. All possible $S_1 S_2 \to S_3 S_4$ processes (S_i's any Goldstone, active or inert (pseudo)scalar) contribute to a_J which is given by four point-interaction
  4. Hence, only s-wave amplitude ($J = 0$) can contribute to scattering process: hence apply inequality above to the case of $J = 0$

Unitarity in the I(1+2)HDM

1) Neutral channels
   - There are 12[6] channels with $(Z_2, \tilde{Z}_2) = (+,+)[(+,-)]$: $H_i^+ H_i^-$, $A_i A_i/\sqrt{2}$, $H_i H_i/\sqrt{2}$ and $A_i H_i$ ($i = 0,\ 1,\ 2$ $[H_1^+ H_2^-,\ H_1^- H_2^+,\ A_1 A_2,$ $H_1 H_2,\ A_1 H_2$ and $H_1 A_2]$
   - Other states with $(-,+)$ and $(-,-)$ by replacing the subscript $X_1 Y_2 \to X_0 Y_1$ and $X_1 Y_2 \to X_0 Y_2$
2) Singly-charged channels
   - There are 6[4] channels with $(Z_2, \tilde{Z}_2) = (+,+)[(+,-)]$: $(H_i^+ A_i, H_i^+ H_i)$ $(i = 0, \ldots 2)[(H_1^+ A_2, H_1^+ H_2, H_2^+ A_1, H_1^+ H_2)]$
   - As above to obtain $(-,+)$ and $(-,-)$
2) Doubly-charged channels
   - There are 3[3] channels with $(Z_2, \tilde{Z}_2) = (+,+)[(+,-)]$: $(H_i^+ H_i^+)/\sqrt{2}$ $(i = 0, \ldots 2)[H_1^+ H_2^+,\ H_0^+ H_1^+,\ H_0^+ H_2^+]$
   - Ditto to obtain $(-,+)$ and $(-,-)$

Unitarity in the I(1+2)HDM

1) Experimental constraints (LEP & LHC) as in I(2+1)HDM for inerts plus 2HDM HiggsBounds/HiggsSignals on actives
2) Here ought to consider $X = S$, T and U parameters:

$$\Delta X[\text{I(1+2)HDM}] = \Delta X_{\text{A}} + \Delta X_{\text{I}},$$

- Δ's are known, need adjusting to 3HDM, eg,

$$\Delta S_{\text{A}} = \frac{1}{4\pi}\Big\{ s^2_{\beta-\alpha} F'(m_Z^2; m_H, m_A) - F'(m_Z^2; m_{H^\pm}, m_{H^\pm})$$

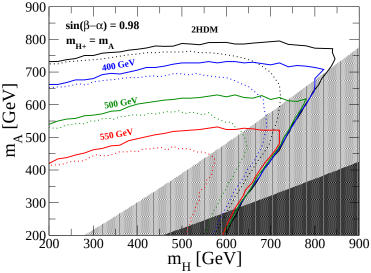
$$+ c^2_{\beta-\alpha}\Big[F'(m_Z^2; m_h, m_A) + F'(m_Z^2; m_H, m_Z) - F'(m_Z^2; m_h, m_Z)\Big]$$

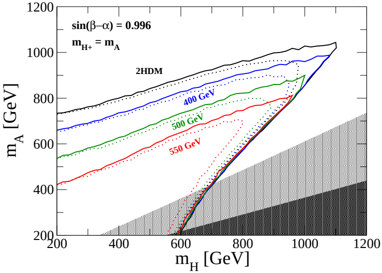
$$+ 4m_Z^2 c^2_{\beta-\alpha}\Big[G'(m_Z^2; m_H, m_Z) - G'(m_Z^2; m_h, m_Z)\Big]\Big\}$$

$$\Delta S_{\text{I}} = \frac{1}{4\pi}\Big[F'(m_Z^2; m_{\eta_H}, m_{\eta_A}) - F'(m_Z^2; m_{\eta^\pm}, m_{\eta^\pm})\Big]$$

3) Assume $\Delta S = 0.05 \pm 0.09$, $\Delta T = 0.08 \pm 0.07$ and $\Delta_U = 0$

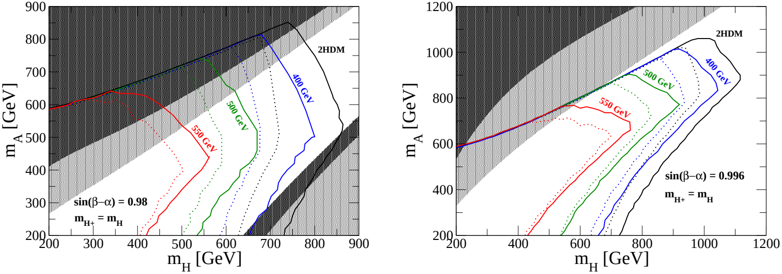
Unitarity in the I(1+2)HDM





Here, $m_{H_0^\pm} = m_{H_0}$, $m_{A_0} = 63$ GeV and $\tan\beta = 1$ in the dotted contours while it is scanned over the range $1 \leq \tan\beta \leq 30$ in the solid ones. M^2 in the range of $M^2 = m_H^2 \pm 1$ TeV^2. Outside regions from each contour excluded by unitarity and vacuum stability. Light and dark shaded regions excluded by S, T and U in the 2HDM and I(1+2)HDM, respectively.

Unitarity in the I(1+2)HDM



Same as previously, but take $m_{H^\pm} = m_H$ instead of $m_{H^\pm} = m_A$.

- Larger excluded regions on 3HDM parameter space can be obtained with $\sin(\beta - \alpha) \neq 1$ as compared to those in 2HDMs.

Yukawa sector of the I(1+2)HDM

- Charges of unbroken Z_2 and softly-broken $\tilde{Z}_2$ (against FCNCs)

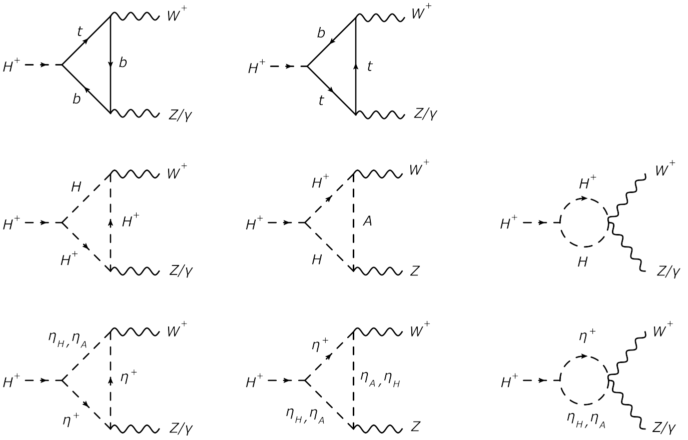
	$(Z_2,\ \tilde{Z}_2)$ charge							
	Φ_1	Φ_2	η	Q_L	L_L	u_R	d_R	e_R
Type-I	$(+,+)$	$(+,-)$	$(-,+)$	$(+,+)$	$(+,+)$	$(+,-)$	$(+,-)$	$(+,-)$
Type-II	$(+,+)$	$(+,-)$	$(-,+)$	$(+,+)$	$(+,+)$	$(+,-)$	$(+,+)$	$(+,+)$
Type-X	$(+,+)$	$(+,-)$	$(-,+)$	$(+,+)$	$(+,+)$	$(+,-)$	$(+,-)$	$(+,+)$
Type-Y	$(+,+)$	$(+,-)$	$(-,+)$	$(+,+)$	$(+,+)$	$(+,-)$	$(+,+)$	$(+,-)$

- Lead to Yukawa couplings as in 2HDMs:

Type-I: one Higgs doublet couples to all fermions
Type-II: one Higgs doublet couples to u-quarks and other to d-ones
Type-X/Lepton-specific: quark couplingsType-I and lepton ones Type-II
Type-Y/Flipped: quark couplings Type II and lepton ones Type-I

$H^\pm \to W^\pm Z/\gamma$ in the I(1+2)HDM

- Assume $\sin(\beta-\alpha)=1$, diagrams surviving are (η_A & $\eta_{H^\pm}$ inert)



$H^\pm \to W^\pm Z/\gamma$ in the I(1+2)HDM

- Collider and flavour constraints

Experiment	95% CL lower lim. on $m_{H^\pm}$	$\tan\beta$	Type	Comments
$b \to s\gamma$	322 GeV	-	II and Y	
	(800, 200, 100) GeV	(1, 2, 2.5)	I and X	
B^0-$\bar{B}^0$	(500, 300, 100) GeV	(1, 1.5, 2)	All	
LEP II	(80, 90) GeV	-	All	$\mathcal{B}_{\tau\nu} + \mathcal{B}_{cs} = 1$, $\mathcal{B}_{\tau\nu} = 1$
$t \to H^\pm b$	(160, 140, 100) GeV	(1, 2, 4)	I	Using 1.3%
at the LHC Run-I	(160, 150, 130) GeV	(1, 2, 4)	X	Using 1.3%

Assume as production mechanisms

- $pp \to t\bar{t}$ $(m_{H^\pm} < m_t)$

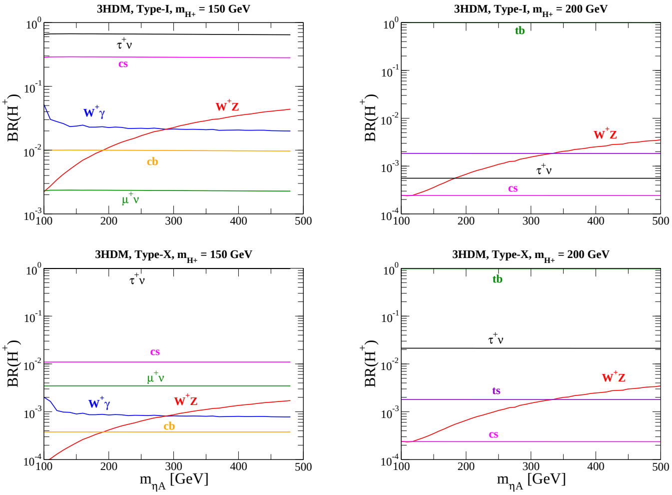
$$\sigma^{\text{top}}_{S,V} = 2 \times \sigma_{t\bar{t}} \times [1 - \text{BR}(t \to H^\pm b)] \times \text{BR}(t \to H^\pm b) \times \text{BR}(H^\pm \to W^\pm V)$$

- $pp \to H^\pm A$, $pp \to H^\pm H$ and $pp \to H^+H^-$ $(m_{H^\pm} > m_t)$

$$\sigma^{\text{EW}}_{S,V} = (\sigma_{H^\pm A} + \sigma_{H^\pm H} + 2\sigma_{H^+H^-}) \times \text{BR}(H^\pm \to W^\pm V)$$

$H^\pm \to W^\pm Z/\gamma$ in the I(1+2)HDM

- BRs (η_A is inert CP-odd Higgs)



$H^\pm \to W^\pm Z/\gamma$ in the I(1+2)HDM

- Example BRs & Xsecs at LHC Run 2 ($\tan\beta = 2.5$ and $m_{\eta_A} = 400$ GeV)

	Type-I	Type-X
$\mathrm{Br}(t \to H^\pm b)$ [%]	(3.3, 1.10, 4.7×10^{-3})	(3.3, 1.1, 4.7×10^{-3})
$\mathrm{Br}(H^\pm \to W^\pm Z)$ [%]	(0.66, 3.5, 33)	(0.025, 0.14, 1.8)
$\mathrm{Br}(H^\pm \to W^\pm \gamma)$ [%]	(1.6, 2.1, 1.6)	(0.059, 0.081, 0.087)
$\sigma^{\mathrm{top}}_{S,Z}$ [fb]	(390, 700, 29)	(15, 28, 1.6)
$\sigma^{\mathrm{top}}_{S,\gamma}$ [fb]	(940, 420, 1.4)	(35, 16, 0.075)
$\sigma^{\mathrm{EW}}_{S,Z}$ [fb]	(2.3, 7.5, 46)	(0.087, 0.30, 2.5)
$\sigma^{\mathrm{EW}}_{S,\gamma}$ [fb]	(5.5, 4.5, 2.2)	(0.20, 0.17, 0.12)

Numbers in the bracket correspond to $m_{H^\pm}$ =130, 150 and 170 GeV.

Summary

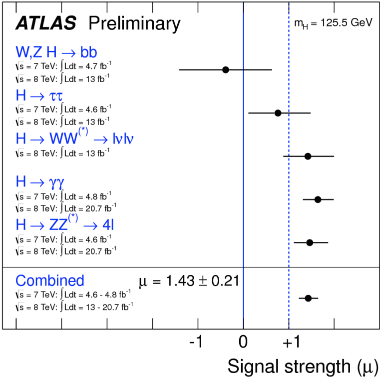
- NHDMs are good for you!
- Our 3HDMs can be well motivated on various grounds.
- These models (with inerts) contain viable DM candidates leading to a relic abundance in agreement with the observed data (talk by Dorota).
- The Z_2 symmetric 3HDMs with inerts also contain *non-SM & non-2HDM* features in the Higgs sector which are testable at the LHC:
    1. SM-like $h \to$ invisibles decay rate can be very large on non-fine-tuned regions of parameter space, whichever 3HDM.
    2. Likewise for SM-like Higgs radiative decays into DM in I(2+1)HDM: $h \to \gamma E_T^{\mathrm{miss}}$ or $h \to \gamma\gamma E_T^{\mathrm{miss}}$.
    3. In the I(1+2)HDM you get rates for $H^\pm \to W^\pm Z/\gamma$ decays $O(100)$ times larger than in the 2HDM (talk by Diana).
- All theoretical constraints worked out, including Unitarity.
- Tools exist: LanHEP/CalcHEP implementation (also including CPV) to appear on the HEPMDB, http://www.hepmdb.soton.ac.uk/.

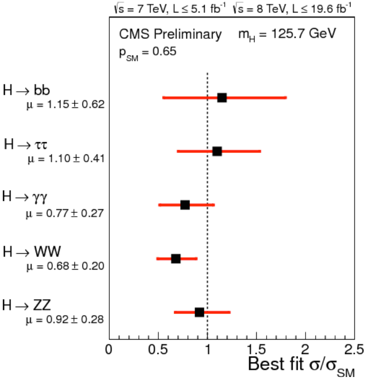
Backup slides

Backup slides

Are there any BSM hints?

Deviations from the SM hint at a non-minimal Higgs sectors.





Many non-minimal Higgs sectors have been studied:

[Accomando et al., arXiv:hep-ph/0608079]