

# An additional lighter scalar at the LHC

## Parametrisation and constraints

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## Parametrisation

Aim of the parametrisation

Original Higgs Parametrisation

Inspired Light Scalar Parametrisation

## UV-complete models

2HDM

NMSSM

## Constraints and Results

Constraints

Results

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Many models account for a new lighter scalar in the particle spectrum.

Models we aim at :

- ▶ Models in which a light new scalar arises.
- ▶ Couplings of this light scalar similar to the SM-Higgs

Inspired from parametrisation developped to study the 126 GeV Higgs ([hep-ph:1210.8120](#))

Rescaling BSM couplings to SM ones :

$$g_{hVV} = \kappa_V g_{hVV}^{\text{SM}} \quad ; \quad g_{hff} = \kappa_f g_{hff}^{\text{SM}}$$

$\kappa_t, \kappa_b, \kappa_l, \kappa_V$  defined this way.

Production cross-sections and decay widths are then rescaled :

$$\sigma_{VBF} = \kappa_V^2 \sigma_{VBF}^{\text{SM}} \quad ; \quad \Gamma_{h \rightarrow ff} = \kappa_f^2 \Gamma_{h \rightarrow ff}^{\text{SM}}$$

For particles which don't couple directly to the Higgs (coupling induced by a loop), we choose loop-inspired parameters, for instance for the photon :

- ▶  $\Gamma_{h \rightarrow \gamma\gamma} \propto |A(W) + A(t) + A(NP)|^2$
- ▶  $\kappa_{\gamma\gamma} = \frac{A(NP)}{A(t)}$

and therefore

$$\Gamma_{h \rightarrow \gamma\gamma} \propto |\kappa_V A(W)^{SM} + (\kappa_t + \kappa_{\gamma\gamma}) A(t)^{SM}|^2$$

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for gluons :

- ▶  $\Gamma_{h \rightarrow gg} \propto |(\kappa_t + \kappa_{gg}) A(t)^{SM} + \kappa_b A(b)^{SM}|^2$

For the lighter scalar, we define each parameter in the same way, with the SM corresponding scalar being a Higgs of the same mass :

- ▶ Light Scalar :  $\kappa_{t,1}$ ,  $\kappa_{b,1}$ ,  $\kappa_{l,1}$ ,  $\kappa_{V,1}$ ,  $\kappa_{\gamma\gamma,1}$ ,  $\kappa_{gg,1}$
- ▶ 126 GeV Higgs :  $\kappa_{t,2}$ ,  $\kappa_{b,2}$ ,  $\kappa_{l,2}$ ,  $\kappa_{V,2}$ ,  $\kappa_{\gamma\gamma,2}$ ,  $\kappa_{gg,2}$

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# 2HDM :

- ▶ Two  $SU(2)$  scalar doublets
- ▶ Modified scalar potential
- ▶ Modified symmetry breaking
- ▶ Modified physics !

Potential :

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

- ▶ v.e.v. :  $(v_1, v_2) \rightarrow (v, 0)$   $\rightarrow$  Angle  $\beta$
- ▶ Higgs  $\mathcal{CP}$ -even mass eigenstates  $\rightarrow$  Angle  $\alpha$
- ▶  $\tilde{\alpha} = \beta - \alpha$
- ▶ Additional particles :  $h^0/H^0, A^0, H^\pm$

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	I	II	III	IV
<i>d</i> -quarks	1	2	2	1
<i>u</i> -quarks	1	1	1	1
leptons	1	2	1	2

Index of the doublet to which each left-handed fermions couples

Doublet	1		2	
Higgs	$h^0$	$H^0$	$h^0$	$H^0$
Couplings	$s_{\tilde{\alpha}} - \frac{1}{t_\beta} c_{\tilde{\alpha}}$	$c_{\tilde{\alpha}} - \frac{1}{t_\beta} s_{\tilde{\alpha}}$	$s_{\tilde{\alpha}} + t_\beta c_{\tilde{\alpha}}$	$c_{\tilde{\alpha}} + t_\beta s_{\tilde{\alpha}}$

Values of the couplings in each type

Using calculator 2HDMC ([hep-ph:0902.0851](#)), we calculated the values of the kappas for random parameters in the following region :

$m_{h^0}$	$m_{H^0}$	$m_{A^0}$	$m_{H^\pm}$	$\sin(\beta - \alpha)$
$[\text{70, 120}] \text{ GeV}$	$125 \text{ GeV}$	$[300, 1000] \text{ GeV}$	$[300, 1000] \text{ GeV}$	$[-1, 1]$
$\tan \beta$	$\lambda_6$	$\lambda_7$	$m_{12}^2$	Yukawa type
$[\frac{1}{50}, 50]$	0	0	0	I-IV

# NMSSM :

- ▶ Extension of the MSSM
- ▶ More flexible phenomenology
- ▶ Theoretical advantages

Using NMSSMTools ([Website](#)):

$\tan \beta$	$\mu_{\text{eff}}$	$\lambda$	$\kappa$
[1, 50]	[100, 600] (GeV)	[0, 0.7]	[0, 0.3]
$A_\lambda$	$A_\kappa$	$A_t$	
[-1, 1] (TeV)	[-1, 1] (TeV)	[-4, 4] (TeV)	

Constraints on  $m_{H^0}$  :  $125.5 \pm 3$  GeV

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To test these models, we use a set of constraints from various fields :

- ▶ Theoretical (2HDM)
- ▶ EWPT
- ▶ Flavor physics
- ▶ LEP searches
- ▶ LHC couplings measurements

# Theoretical Constraints (2HDM), EWPT & Light Higgs LEP exclusions

Theoretical : Unitarity, Perturbativity, Stability

EWPT :

- ▶  $S \in [-0.10, 0.11]$
- ▶  $T \in [-0.10, 0.13]$
- ▶  $U \in [-0.03, 0.19]$

(bounds : PDG ([Website](#)))

LEP : HiggsBound library ([Website](#))

# Flavor constraints

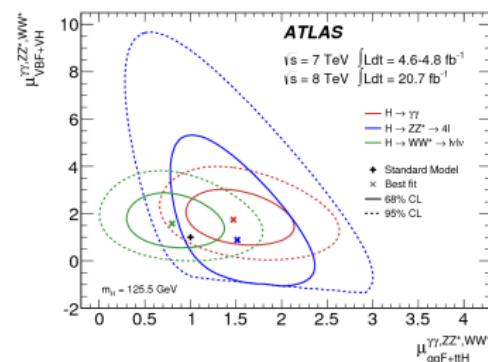
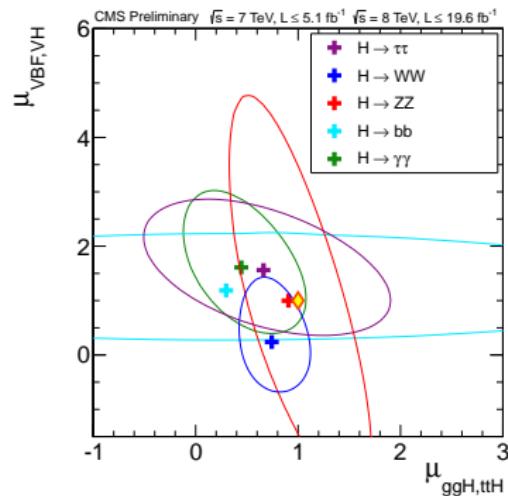
- ▶  $\text{Br}(B_s \rightarrow \mu\mu) \in (2.9 \pm 1.4)10^{-8}$
- ▶  $\text{Br}(b \rightarrow s\gamma) \in (3.43 \pm 0.9)10^{-4}$
- ▶  $\Gamma(\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma)/\Gamma(\bar{B}^\pm \rightarrow \bar{K}^{*\pm}\gamma)$  asymmetry  $\in [-0.017, 0.089]$
- ▶  $\Delta M(B_d) \in [0.35, 0.67]$
- ▶  $\Delta \frac{1}{2}(g - 2)_\mu = a_\mu \in \pm 4.5 \ 10^{-9}$

Calculations : SuperIso, [arXiv:0808.3144](https://arxiv.org/abs/0808.3144)

Constraints : HFAG ([Website](#))

# LHC Higgs Couplings Measurements

Constraints from individual CMS and ATLAS decay modes :



- ▶ ATLAS and CMS collaboration give data under the form of exclusion regions in the signal strength per production mode plane (VBF vs ggH)
- ▶ Fit of the contours with ellipses
- ▶ Extrapolation of the resulting equivalent distribution (gaussian)
- ▶ Combination of all decay modes to get a global PDF
- ▶ Calculation for a specific model and comparison to the exclusion level for an  $n$  dof  $\chi^2$  distribution.
- ▶ Exclusion level from  $\Delta\chi^2$  test  $< 95\%CL$

# Results

Which regions of the parameter space might still be allowed ?  
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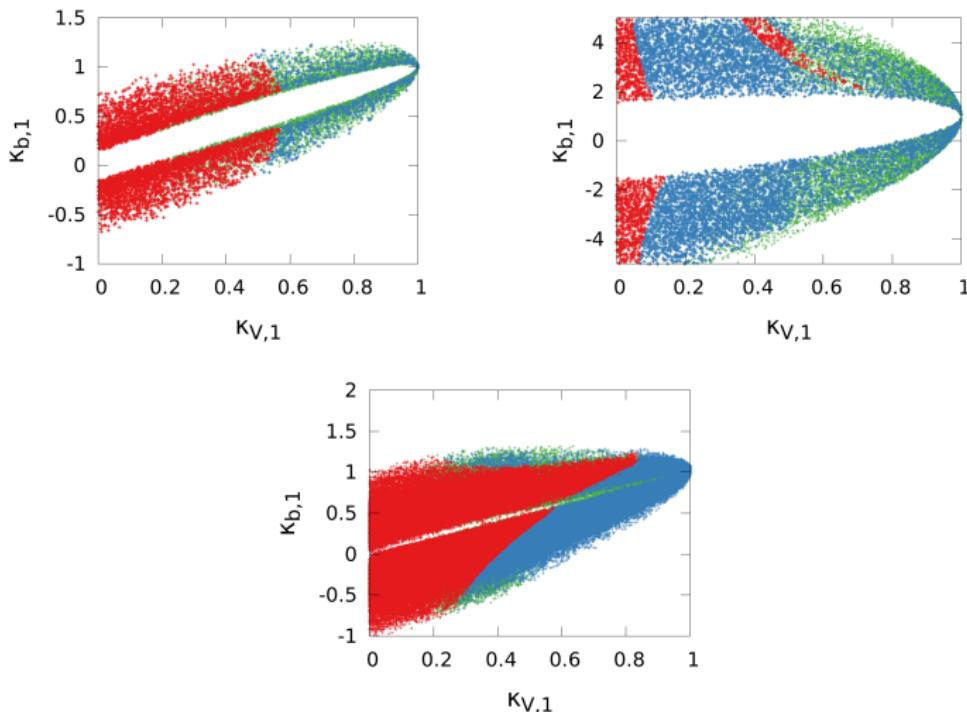
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Color code : All points pass tests up to flavor

Excluded by LEP, Excluded by LHC, Not excluded

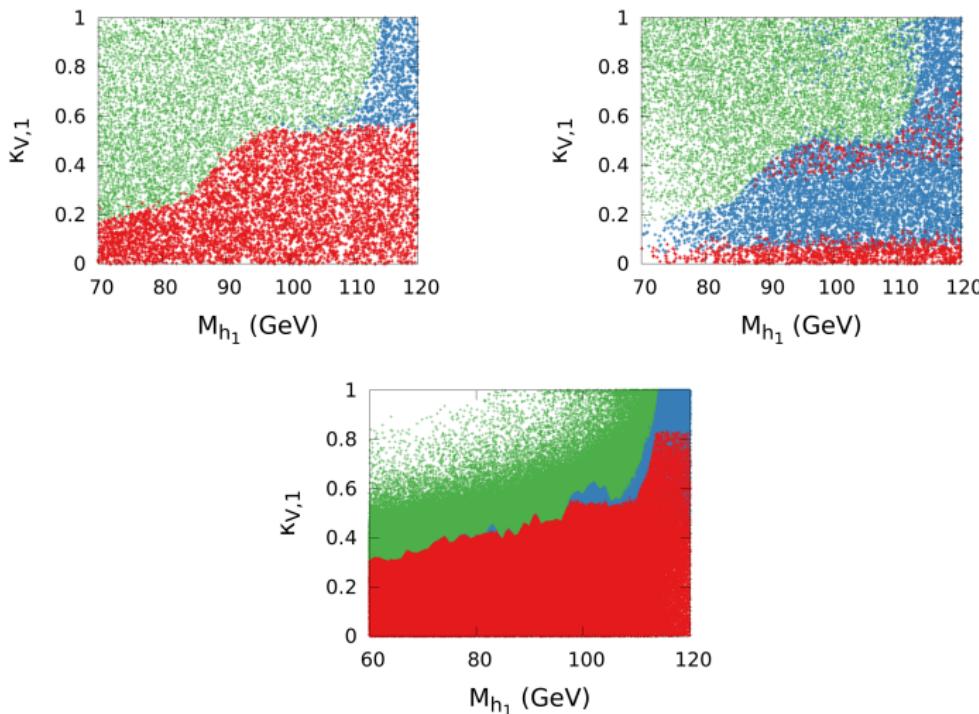


Type I 2HDM

NMSSM

Type II 2HDM

Excluded by LEP, Excluded by LHC, Not excluded

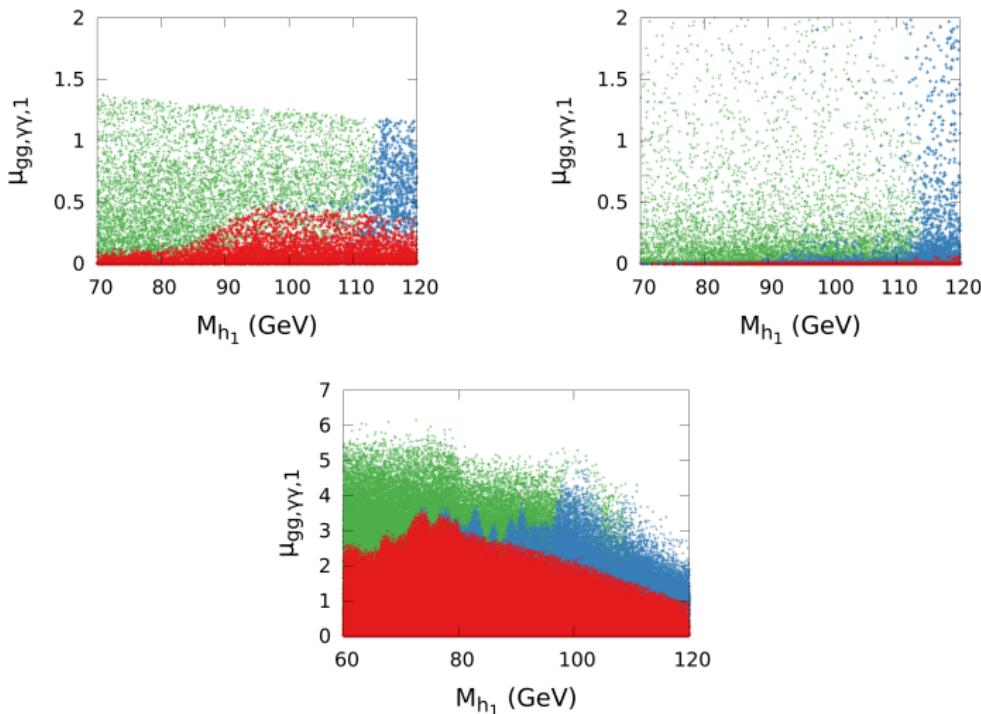


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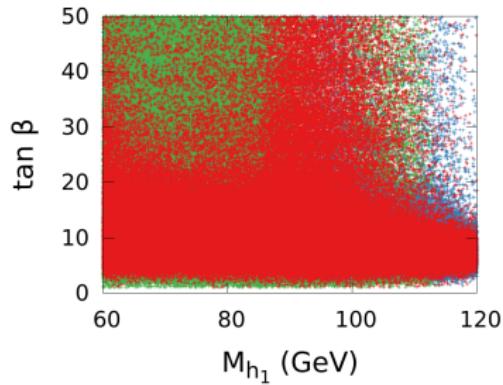
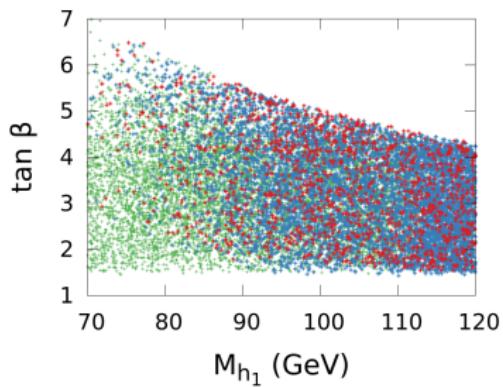
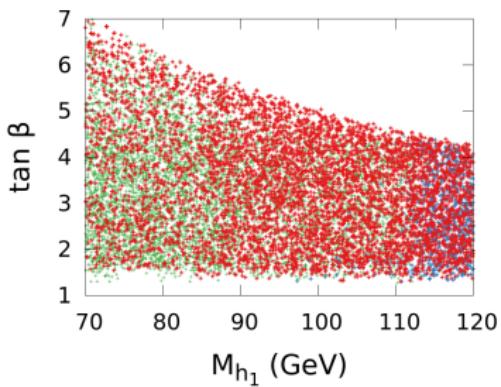


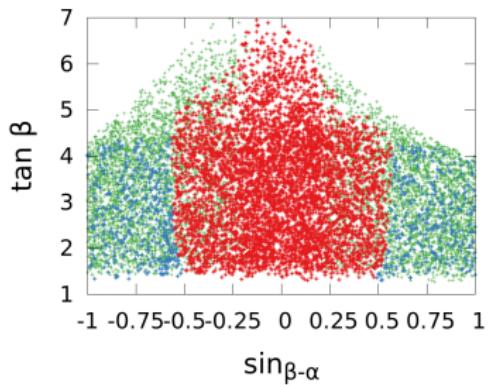
# Conclusion & prospects

Interesting phenomenology in those models, especially type 1 2HDM and NMSSM

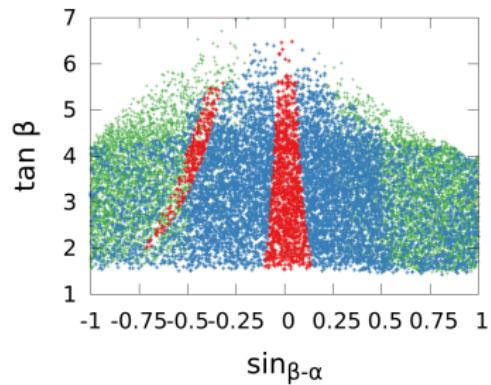
Highlights the need to extend LHC Higgs analysis

Comparison of various models with same parameters





Type I 2HDM



Type II 2HDM