An additional lighter scalar at the LHC

Parametrisation and constraints

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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 :

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

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 :

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

and therefore

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

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

for gluons :

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

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 : $\kappa_{t,2},\ \kappa_{b,2},\ \kappa_{l,2},\ \kappa_{V,2},\ \kappa_{\gamma\gamma.2},\ \kappa_{gg,2}$

2HDM :

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

Potential :

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

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

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	I	II	III	IV
d-quarks	1	2	2	1
u-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}	$m_{H^\pm}$	$\sin(\beta-\alpha)$
$[70, 120]$ GeV	125 GeV	$[300, 1000]$ GeV	$[300, 1000]$ GeV	$[-1, 1]$

$\tan\beta$	λ_6	λ_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):

$\tan\beta$	μ_{eff}	λ	κ
$[1, 50]$	$[100, 600]$ (GeV)	$[0, 0.7]$	$[0, 0.3]$

A_λ	A_κ	A_t
$[-1, 1]$ (TeV)	$[-1, 1]$ (TeV)	$[-4, 4]$ (TeV)

Constraints on m_{H^0} : 125.5 ± 3 GeV

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 :

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

LEP : HiggsBound library (Website)

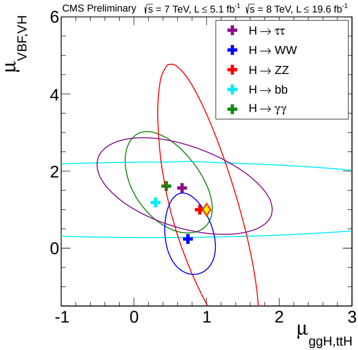
Flavor constraints

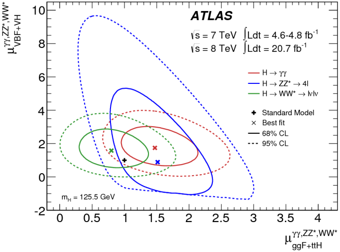
- $\text{Br}(B_s \to \mu\mu) \in (2.9 \pm 1.4)10^{-8}$
- $\text{Br}(b \to s\gamma) \in (3.43 \pm 0.9)10^{-4}$
- $\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma)/\Gamma(\bar{B}^\pm \to \bar{K}^{*\pm}\gamma)$ asymmetry $\in [-0.017, 0.089]$
- $\Delta M(B_d) \in [0.35, 0.67]$
- $\Delta \frac{1}{2}(g-2)_\mu = a_\mu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

Calculations : SuperIso, arXiv:0808.3144
Constraints : HFAG (Website)

LHC Higgs Coupligs 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 χ^2 distribution.
- E xclusion level from $\Delta\chi^2$ test $< 95\% CL$

Results

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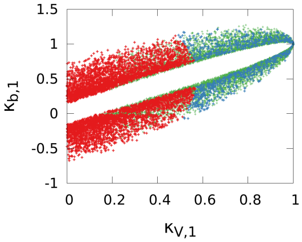
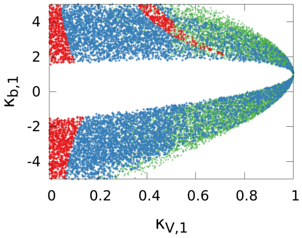
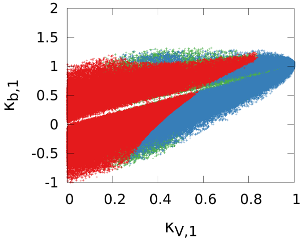
Results

Which regions of the parameter space might still allowed ?
Possible prospect of such regions at the LHC ?

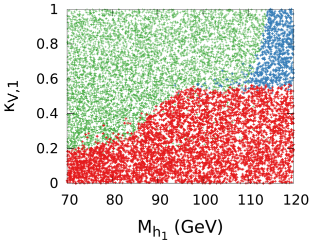
- Convenient to notice that $\kappa_{V,1}\kappa_{f,1} + \kappa_{V,2}\kappa_{f,2} = 1$ in all 2HDMs.
- LHC ➞ $\kappa_{f,2} \approx \pm 1$ ➞ constraints on $\kappa_{f,1}$

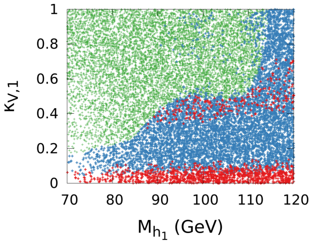


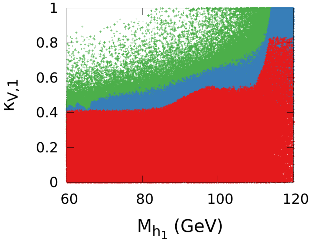




Type I 2HDM NMSSM Type II 2HDM







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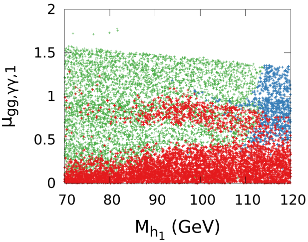

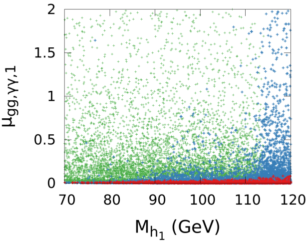

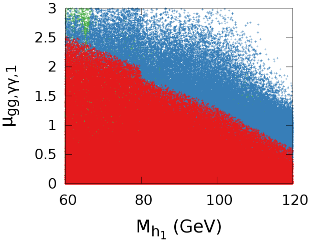

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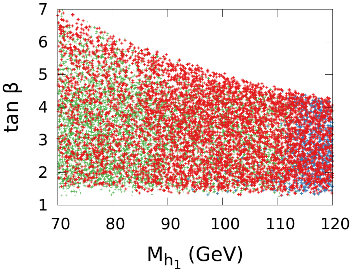
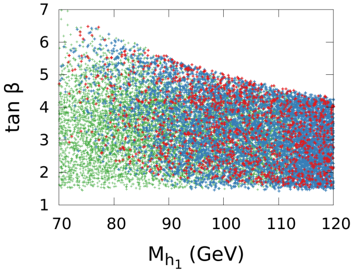
Conclusion & prospects

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

Highlight need to extend LHC Higgs analysis

Comparison of various models with same parameters


7
6
5
4
3
2
1
tan β
70
80
90
100
110
120
M_{h_1} (GeV)


7
6
5
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70
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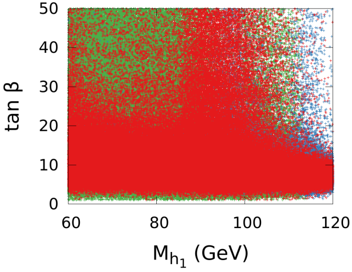
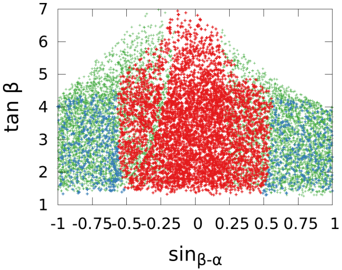
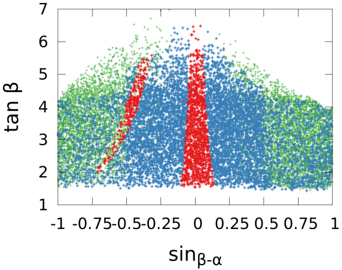
M_{h_1} (GeV)


50
40
30
20
10
0
tan β
60
80
100
120
M_{h_1} (GeV)



Type I 2HDM



Type II 2HDM