Exploring the Higgs sector of a most natural NMSSM

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with Barbieri, Buttazzo, Kannike, Sala '13

A natural perspective

SM is an **effective** field theory up to Λ

$\downarrow$

- Light scalar unnatural, $m_h^2 \sim c\Lambda^2$
- Cure this with **symmetries** (SUSY, shift symmetry)
- Symmetries must be broken at some $\Lambda_{\rm NP}$
- To avoid a tuning larger than $\Delta \longrightarrow \Lambda_{\rm NP} \lesssim 400 \text{ GeV}\sqrt{\Delta}$

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1) All natural BSM theories predict deviations in Higgs couplings.
2) Many BSM theories predict extended Higgs sector.

a famous example, (N)MSSM

Why the NMSSM?

$$W \supset \lambda S H_1 H_2 + f(S)$$

Good news,

- Tree-level contribution to Higgs mass $m_h^2 \sim m_Z^2 s_{2\beta}^2 + \lambda^2 v^2 c_{2\beta}^2$
- Small tuning $\Delta \lesssim 10$ [e.g. Gherghetta et al '12]
- In general, relevant example of extended Higgs sector: 3 CP-even scalars

Challenges,

- Depending on $f(S)$ many models and a plethora of parameters
- Phenomenological studies mainly based on benchmark models

Is there a simple parametrization?

If yes, can we constrain NMSSM Higgs sector with LHC data?

CP-even scalars

$$\mathcal{M}^2 = \begin{pmatrix} m_Z^2 c_\beta^2 + m_A^2 s_\beta^2 & \left(2v^2\lambda^2 - m_A^2 - m_Z^2\right) c_\beta s_\beta & vM_1 \\ \left(2v^2\lambda^2 - m_A^2 - m_Z^2\right) c_\beta s_\beta & m_A^2 c_\beta^2 + m_Z^2 s_\beta^2 + \delta_t^2 & vM_2 \\ vM_1 & vM_2 & M_3^2 \end{pmatrix}$$

Analytical expressions for mixing angles from current to mass eigenstates

$$\delta, \gamma, \sigma = \delta, \gamma, \sigma(m_{h_1}^2, m_{h_2}^2, m_{h_3}^2; m_{H^\pm}^2, \lambda, t_\beta)$$

We shall study configurations like

1 parameter less

$\boxed{m_{h_1} = 126\ \mathrm{GeV}}$

new state(s)	
$h_1 = h_{\mathrm{LHC}}$	$h_1 = h_{\mathrm{LHC}}$
	new state

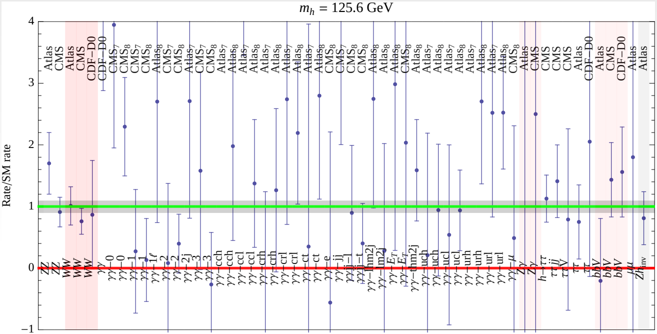
being all determined by m_{h_2},m_{h_3} and few relevant parameters.

Fitting the Higgs

Tree-level effects in Higgs couplings

$$g_{hVV} = c_\gamma c_\delta, \quad g_{ht\bar{t}} = c_\gamma(c_\delta + s_\delta \cot\beta), \quad g_{hb\bar{b}} = c_\gamma(c_\delta - s_\delta \tan\beta)$$

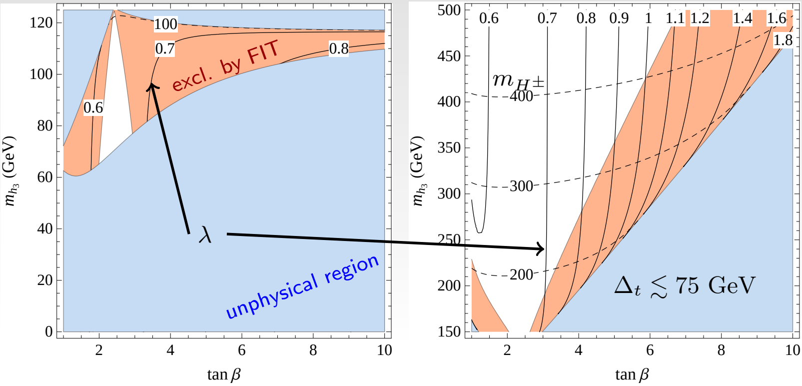
We can constrain δ, γ, t_β!



We use the code of [Giardino, Kannike, Masina, Raidal, Strumia '13]

S-decoupled

$\sigma, \gamma \to 0,\ m_{h_2} \to \infty$

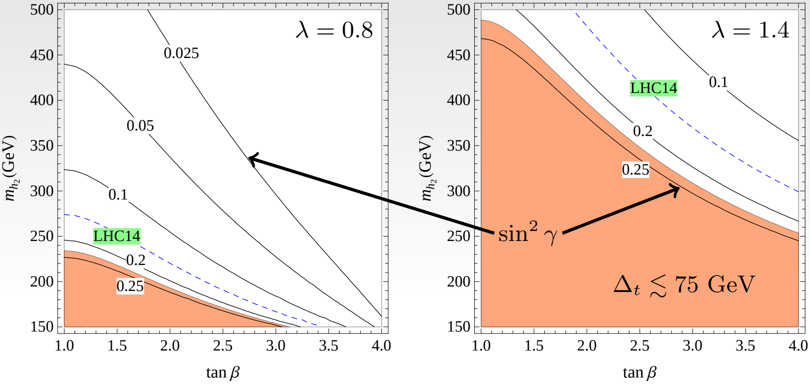


[LHC14 with 300/fb will strongly constrain this scenario]
[Mixing with the doublet disfavored (In MSSM the situation is even worse)]

H-decoupled, $m_{h_2} > 126$ GeV

$\sigma, \delta \to 0$, $m_{h_3}, m_{H^\pm} \to \infty$

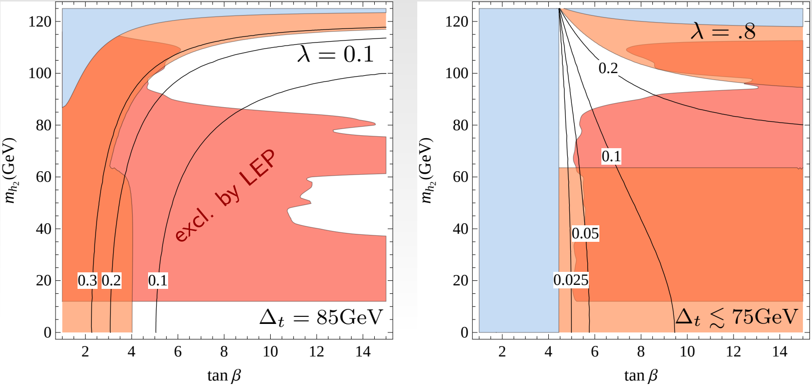
All the couplings rescaled by a common factor c_γ $[\sin^2\gamma < 0.22$ @95%$]$



[In every point of the plane we can compute $\mu(h_2 \to ii)$]

H-decoupled, $m_{h_2} < 126$ GeV

$\sigma, \delta \to 0$, $m_{h_3}, m_{H^\pm} \to \infty$



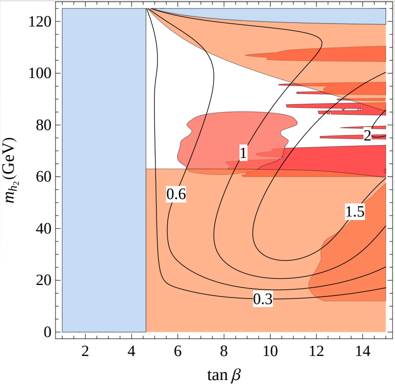
[For the low mass region, LEP bound on $h_2 \to b\bar{b}$]

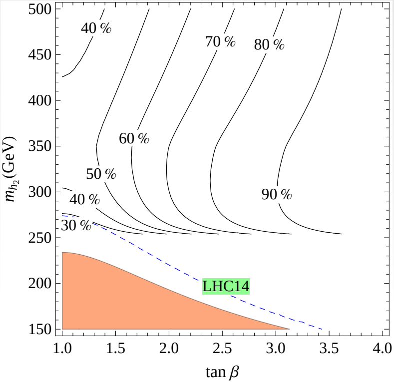
H-decoupled: signals

$\mu(h_2 \to \gamma\gamma)/\mu_{\rm SM}$

$\mathrm{BR}(h_2 \to hh)$

$m_{h_3} = 500\ \mathrm{GeV}, s_\sigma^2 = .001$





here $\lambda = 0.8$ and $\Delta_t = 75\ \mathrm{GeV}$

[$R(h_2 \to \gamma\gamma)$ interesting at LHC, Badziak, Olechowski, Pokorski '13]

NMSSM CP-even scalar sector after LHC7-8

$h_{\rm LHC}$ mostly mixed with the doublet, "S-decoupled"

- λ constrained to be smallish
- Notice also that $m_{H^\pm} > 300$ GeV, from flavor tests.

$h_{\rm LHC}$ mostly mixed with the singlet, "H-decoupled"

- λ can be largish (and $\tan\beta$ small)
- $m_{h_2} > m_h$ practically not constrained for $\lambda \lesssim 1$
- Further improvements in the precision will marginally affect our results

Fully mixed situation allowed if close to the picture "H-decoupled".