Triplet Extension of the MSSM and its Higgs Physics

Germano Nardini

Universität Bielefeld

SUSY 2013

Based on
A. Delgado, G.N., M. Quirós
arXiv:1207.6596 , arXiv:1303.0800

Outline

1. Introduction
   - The model
2. Higgs Phenomenology
   - Spectrum
   - Features of the decoupling limit
   - Features at small m_A
3. Conclusion

Motivation

- No clear discrepancies between data and SM predictions with $m_h \simeq 126$ GeV
- If we do not give up with the (Planck/GUT - EW) hierarchy problem, SUSY is (one of) the favourite UV option
- In the MinimalSSM $m_h \simeq 126$ GeV requires "heavy" stop sector ⇒ Little Hierarchy Problem, i.e. some fine-tuning
- Non-minimalSSM models can alleviate this problem as they can enhance the tree-level Higgs mass via

  D–terms: Extra gauge interactions

  F–terms: Extra scalar sector (singlets and/or triplets)

If $\Gamma(h \to \gamma\gamma)$ is confirmed by future data. . .

. . . the extra charged fermions in the triplet superfield are (potentially) largely coupled to the Higgs and can make the job

The Y=0 Triplet Extension (Espinosa&Quiros'92)

$$\Sigma = \begin{pmatrix} \xi^0/\sqrt{2} & -\xi_2^+ \\ \xi_1^- & -\xi^0/\sqrt{2} \end{pmatrix}, \quad \Delta W = \lambda H_1 \cdot \Sigma H_2 + \frac{1}{2}\mu_\Sigma tr\Sigma^2 + \mu H_1 \cdot H_2$$

- T parameter bound requires $\langle \xi^0 \rangle \lesssim 4$ GeV which imposes (unless of fine-tuning)

$$|A_\lambda|, \, |\mu| \, , |\mu_\Sigma| \lesssim \frac{m_\Sigma^2 + \lambda^2 v^2/2}{10^2 \;\lambda v}$$

- This hierarchy implies decoupling between ξ^0 and H_1, H_2

Mass boost: $V(H_1, H_2) \simeq V_{MSSM} + \lambda^2 |H_1^0 H_2^0|^2$

(other tripl. SUSY extens. in E.J.Chun&al,1209.1303; Z.Kang&al,1301.2204)

The relevant spectrum

- Heavy scalar triplet [$\gtrsim 1$ TeV]
- Minimiz. conditions

$$m_3^2 = m_A^2 \sin\beta\cos\beta \;, \qquad m_Z^2 = \frac{m_2^2 - m_1^2}{\cos 2\beta} - m_A^2 + \frac{\lambda^2}{2} v^2$$

- CP-odd/charged Higgses [no preferences]

$$m_A^2 = m_1^2 + m_2^2 + 2|\mu|^2 + \frac{\lambda^2}{2} v^2 \;, \qquad m_{H^\pm}^2 = m_A^2 + m_W^2 + \frac{\lambda^2}{2} v^2$$

- Charginos [$\mathcal{O}(100\,\text{GeV})$ if diphoton excess]

$$\left(\tilde{W}^-, \tilde{H}_1^-, \tilde{\xi}_1^-\right) \mathcal{M}_{ch}^{\pm} \begin{pmatrix} \tilde{W}^+ \\ \tilde{H}_2^+ \\ \tilde{\xi}_2^+ \end{pmatrix} , \quad \mathcal{M}_{ch}^{\pm} = \begin{pmatrix} M_2 & g v_2 & 0 \\ g v_1 & \mu & -\lambda v_2 \\ 0 & -\lambda v_1 & \mu_\Sigma \end{pmatrix}$$

The relevant spectrum

- CP-even Higgs masses (basis h_2, h_1)

$$\mathcal{M}_0^2 = \begin{pmatrix} m_A^2 \cos^2\beta + m_Z^2 \sin^2\beta & (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin 2\beta/2 \\ (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin 2\beta/2 & m_A^2 \sin^2\beta + m_Z^2 \cos^2\beta \end{pmatrix}$$

- After including radiative corrections $\Delta\mathcal{M}_{\tilde{t}}^2(h_t)$ and $\Delta\mathcal{M}_{\Sigma}^2(\lambda)$ (also in the min.condts) [$m_h = 126$ GeV]

$$\begin{pmatrix} h_2 \\ h_1 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

Coupling ratios $\quad r_{\mathcal{H}XX} = g_{\mathcal{H}XX}/g_{hXX}^{\rm SM} \quad (\mathcal{H} = h, H)$

r^0_{hVV}	r^0_{HVV}	r^0_{htt}	r^0_{Htt}	r^0_{hdd}	r^0_{Hdd}
$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	$\dfrac{\cos\alpha}{\sin\beta}$	$\dfrac{\sin\alpha}{\sin\beta}$	$-\dfrac{\sin\alpha}{\cos\beta}$	$\dfrac{\cos\alpha}{\cos\beta}$

Decoupling limit $m_A \to \infty$

If $m_A \gg m_h \ldots$

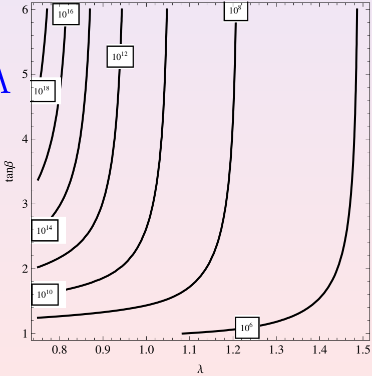
Decoupling limit $m_A \to \infty$

Tree-level Higgs mass

$$m_h^2 = m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta/2$$

Little hierarchy problem pushes towards small $\tan\beta$ and large λ, but perturbation theory may break down at the scale Λ

Λ



curves:
$10^{18}, 10^{16}, 10^{14}, \ldots, 10^{6}$

Decoupling limit $m_A \to \infty$

Signal strength $\mathcal{R}_{\gamma\gamma}$ $[= BR(h \to \gamma\gamma)/BR(h \to \gamma\gamma)_{\rm SM}]$

$$\frac{\partial}{\partial \log v} \log \det \mathcal{M}_{ch}(v) = -\frac{v^2(\lambda^2 M_2 + g^2 \mu_\Sigma)\sin 2\beta}{M_2 \mu \mu_\Sigma - \frac{1}{2}\lambda^2 v^2 (\lambda^2 M_2 + g^2 \mu_\Sigma)\sin 2\beta}$$

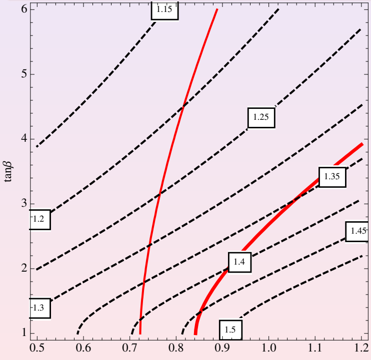
- ATLAS: 1.65 ± 0.30; CMS: $0.8 - 1.1 \pm 0.3$
- Loop-induced process which is sensitive to new charged particles
- New triplet charged fermion can enhance $R_{\gamma\gamma}$ ($\lesssim 1.1$ via MSSM charginos; e.g. Casas,Moreno,Rolbiecki,Zaldivar '13)
- As no (large) modifications in the Higgs production exist for $m_A \to \infty$, the diphoton enhancement is (easily implemented from the QED eff.pot. Ellis&al,79; Shifman&al,79; Carena&al,12)

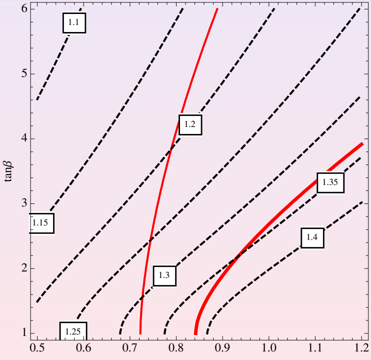
$$R_{\gamma\gamma} = \left| 1 + \left(\frac{4}{3} \frac{\partial}{\partial \log v} \log \det \mathcal{M}_{ch}(v) \right) / \left(A_1(\tau_W) + \frac{4}{3} A_{1/2}(\tau_t) \right) \right|^2$$

Decoupling limit $m_A \to \infty$

Signal strength $\mathcal{R}_{\gamma\gamma}$ $\quad [= BR(h \to \gamma\gamma)/BR(h \to \gamma\gamma)_{\rm SM}]$

$$\frac{\partial}{\partial \log v} \log \det \mathcal{M}_{ch}(v) = - \frac{v^2(\lambda^2 M_2 + g^2 \mu_\Sigma) \sin 2\beta}{M_2 \mu \mu_\Sigma - \frac{1}{2}\lambda^2 v^2 (\lambda^2 M_2 + g^2 \mu_\Sigma) \sin 2\beta}$$





$M_2 = 250$ GeV $\qquad X_t = 4$, **0**; $m_Q = 700$ GeV $\qquad M_2 = 750$ GeV

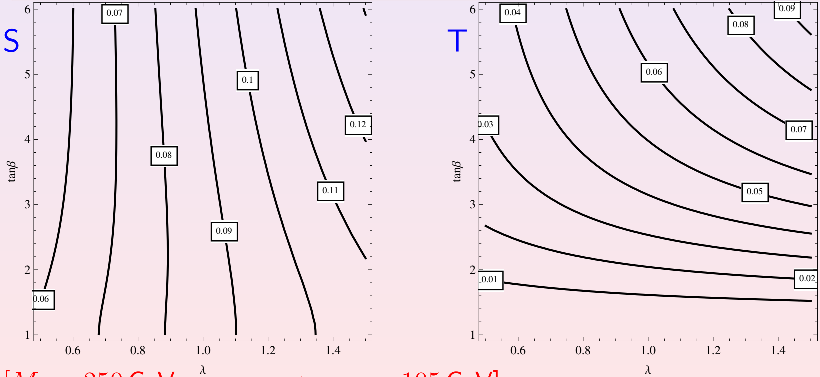
$\mu = \mu_\Sigma \to m_{\chi_1^\pm} \sim 105$ GeV

Decoupling limit $m_A \to \infty$

S and T parameters (due to EWKinos)

$$\alpha S = \frac{s_W^2 \lambda^2}{10\pi^2} \frac{m_W^2}{\mu^2} \left[1 + \frac{19}{24}\sin 2\beta\right] + \mathcal{O}(g^4)\ , \qquad S = 0.04 \pm 0.09$$

$$\alpha T = \frac{3\lambda^2}{128\pi^2} \frac{m_W^2}{\mu^2} \cos^2 2\beta + \mathcal{O}(g^4)\ , \qquad T = 0.07 \pm 0.08$$



$[M_2 = 250\,\text{GeV},\ \mu = \mu_\Sigma \to m_{\chi_1^\pm} \sim 105\,\text{GeV}]$

Small m_A

And now let us

DECREASE m_A

without upsetting the h Higgs signatures

Small m_A (similar idea in C.Wagner'talk)

- CP-even Higgs masses (basis h_2, h_1)

$$\mathcal{M}_0^2 = \begin{pmatrix} m_A^2 \cos^2\beta + m_Z^2 \sin^2\beta & (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin 2\beta/2 \\ (\lambda^2 v^2 - m_A^2 - m_Z^2)\sin 2\beta/2 & m_A^2 \sin^2\beta + m_Z^2 \cos^2\beta \end{pmatrix}$$

$$\begin{pmatrix} h_2 \\ h_1 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

- Tree-level h couplings are SM-like if $\alpha = \beta - \pi/2$. With $\mathcal{M}_0^2$:

$$\beta_c = \frac{\pi}{4}\,, \qquad \lambda_c = \sqrt{2}\frac{m_h}{v}$$

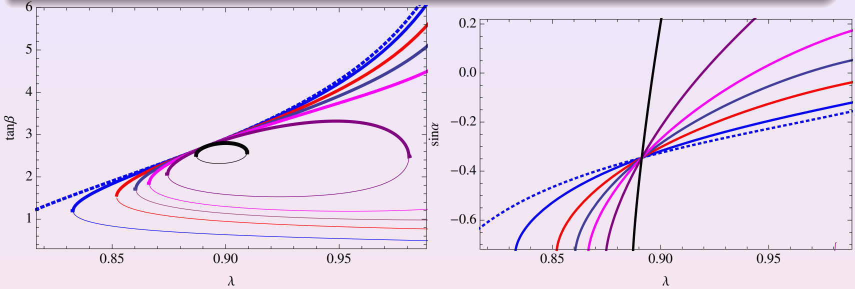
- More generically with $\mathcal{M}^2$, fixing h mass yields (no m_A^4!):

$$A(\tan\beta, \lambda, m_h) m_A^2 + B(\tan\beta, \lambda, m_h) = 0$$

SM-LIKE POINT $(\lambda_c, \tan\beta_c)$ INDEPENDENT OF m_A

Small m_A

$\tan\beta(\lambda)$ and $\sin\alpha(\lambda)$ fixing $m_h = 126$ GeV



Radiative correction $\Delta\mathcal{M}^2_{\tilde{t}}(h_t)$ and $\Delta\mathcal{M}^2_{\Sigma}(\lambda)$ included
($m_Q = 700$ GeV, $A_t = 0$, $m_\Sigma = 5$ TeV).
Curves: $m_A = \infty, 200, 155, 145$,140,135,130 GeV

- No attempt to reproduce data with $m_H = 126$ GeV (but worth to check!)

Small m_A

Signal strengths $\mathcal{R}_{\mathcal{H}XX}$

$$\mathcal{R}_{\mathcal{H}XX} = \frac{\sigma(pp \to \mathcal{H}) BR(\mathcal{H} \to XX)}{[\sigma(pp \to h) BR(h \to XX)]_{SM}}$$

$$\mathcal{R}^{(ggF)}_{\mathcal{H}XX} = \mathcal{R}^{(\mathcal{H}tt)}_{\mathcal{H}XX} = \frac{r^2_{\mathcal{H}tt}\, r^2_{\mathcal{H}XX}}{\mathcal{D}}\,, \quad \mathcal{R}^{(VBF)}_{\mathcal{H}XX} = \mathcal{R}^{(V\mathcal{H})}_{\mathcal{H}XX} = \frac{r^2_{\mathcal{H}WW}\, r^2_{\mathcal{H}XX}}{\mathcal{D}}$$

$$\mathcal{D} = BR(h \to b\,b)_{SM}\, r^2_{\mathcal{H}bb} + BR(h \to gg, cc)_{SM}\, r^2_{\mathcal{H}tt} + BR(h \to \tau\tau)_{SM}\, r^2_{\mathcal{H}\tau\tau} + BR(h \to WW, ZZ)_{SM}\, r^2_{\mathcal{H}WW}$$

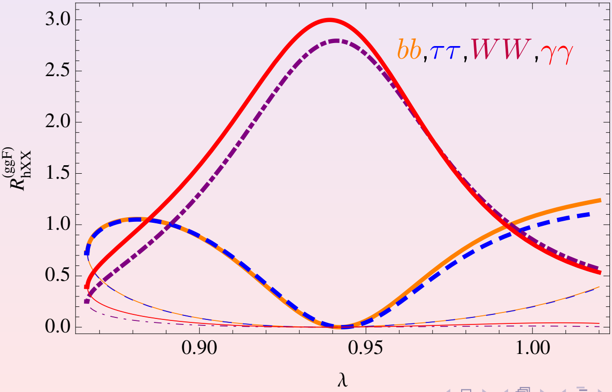
- No extra inv. width, i.e. $m_{\chi_0} \gtrsim m_{\mathcal{H}}/2$
- sbottom-gluino may correct r_{hbb} $(M_3 = 1\text{ TeV}, m_{\tilde{b}} = 700\text{ GeV})$

Small m_A

$m_A = 140$ GeV, $\mu = \mu_\Sigma = 250$ GeV, $m_{\chi^\pm} = 104$ GeV

Signal strengths $\mathcal{R}_{hXX}$ from ggF and htt

$$\mathcal{R}_{\mathcal{H}XX} = \frac{\sigma(pp \to \mathcal{H})BR(\mathcal{H} \to XX)}{[\sigma(pp \to h)BR(h \to XX)]_{SM}}$$

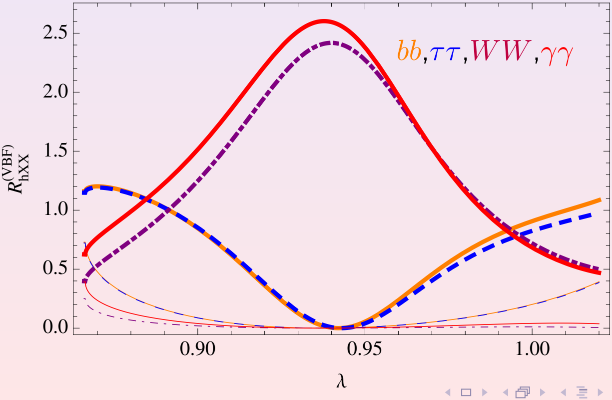


Small m_A

$m_A = 140$ GeV, $\mu = \mu_\Sigma = 250$ GeV, $m_{\chi^\pm} = 104$ GeV

Signal strengths $\mathcal{R}_{hXX}$ from VBF and Vh

$$\mathcal{R}_{\mathcal{H}XX} = \frac{\sigma(pp \to \mathcal{H}) BR(\mathcal{H} \to XX)}{[\sigma(pp \to h) BR(h \to XX)]_{SM}}$$

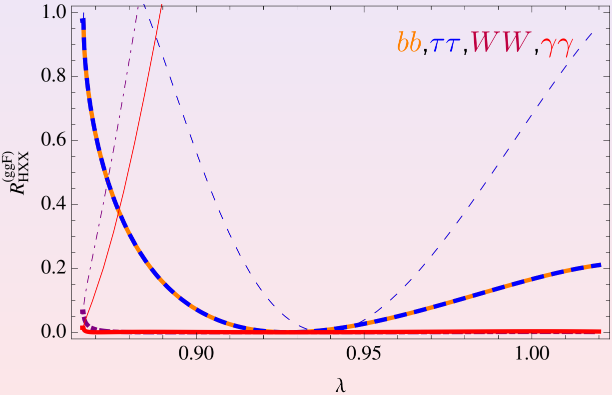


Small m_A

$m_A = 140$ GeV, $\mu = \mu_\Sigma = 250$ GeV, $m_{\chi^\pm} = 104$ GeV

Signal strengths $\mathcal{R}_{HXX}$ from ggF and htt

$$\mathcal{R}_{\mathcal{H}XX} = \frac{\sigma(pp \to \mathcal{H}) BR(\mathcal{H} \to XX)}{[\sigma(pp \to h) BR(h \to XX)]_{SM}}$$



- Further reduction if $m_{\chi^0} \lesssim m_H/2$ ($m_H \sim 138$ GeV)

Conclusion

- Triplet extension alleviates the fine-tuninig with respect to the MSSM
- At very small m_A there are 2 region around $\lambda \approx 0.9$ and $\lambda \approx 1$ that mimic the signal strength of a SM Higgs. The exact values depend on m_Σ, m_Q and m_U.
- Some small deviations from a pure SM Higgs (e.g. $\gamma\gamma$, bb, $\tau\tau$) can also be encompassed without need of modifying other rates
- The argument to prove the existence of the SM-like point is quite generic and can be extended to other models (e.g. singlet exts.)

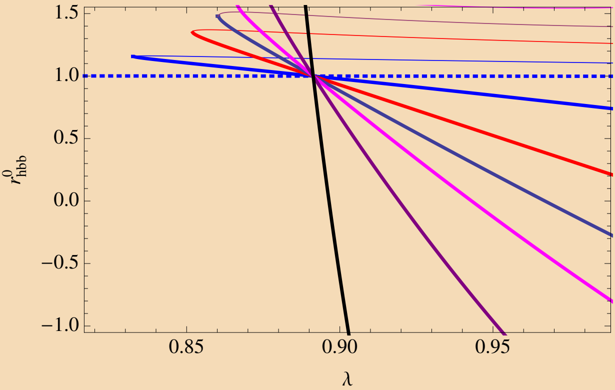
The extra Higgs sector may be at the EW scale but hidden

and only tiny deviations in $\mathcal{R}_{hXX}$ may be present

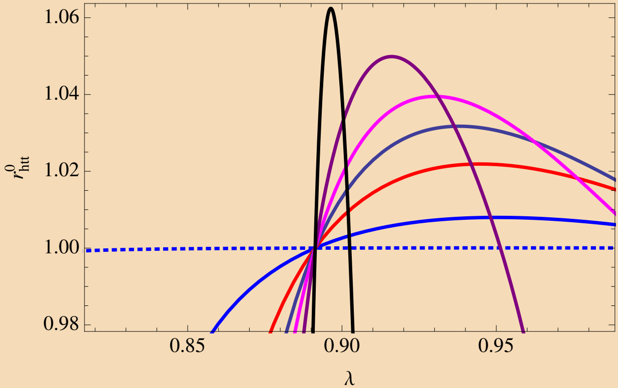
- Dedicated analyses on $H^\pm$ and A are worthwhile (generalizations of L.Diaz Cruz and M.Battaglia's talks)

EXTRAS

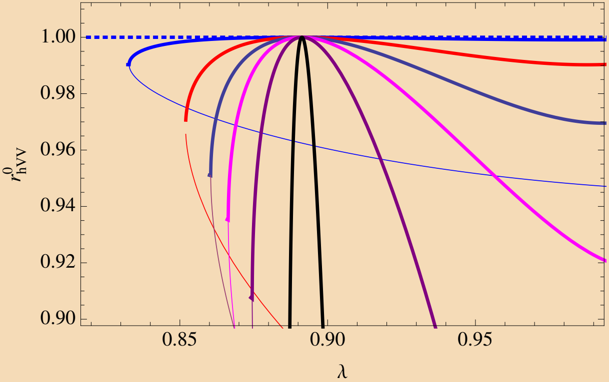
Plot of r_{hdd}



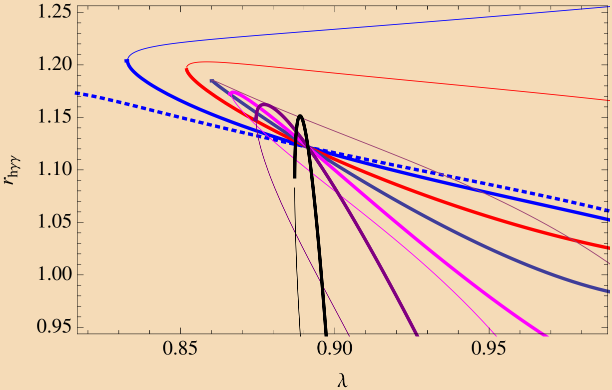
Plot of r_{htt}



Plot of r_{hVV}



Plot of $r_{h\gamma\gamma}$



$m_{\chi_1^\pm} = 104$ GeV (solid line), $m_{\chi_1^\pm} = 150$ GeV with $\mu = \mu_\Sigma = 300$ GeV (dashed line) and $m_{\chi_1^\pm} = 200$ GeV with $\mu = \mu_\Sigma = 350$ GeV (dotted line)