Higgs phenomenology in the triplet extension of the MSSM

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

Outline

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 $\Rightarrow$ 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

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

- 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) [$m_h = 126\,\text{GeV}$]

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

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

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

Decoupling limit $m_A \to \infty$

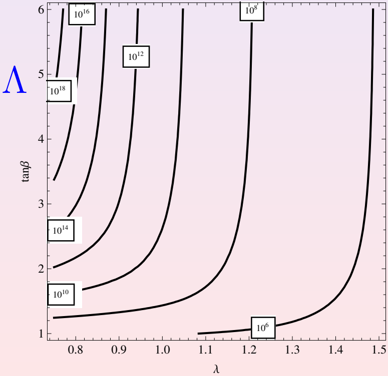
If $m_A \gg m_h$ ...

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



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; see Kraml's talk)
- As no modification in the Higgs production for $m_A \to \infty$, diphoton enhancement (easily implemented from the QED eff.pot. Ellis&al,79; Shifman&al,79; Carena&al,12)

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

Decoupling limit $m_A \to \infty$

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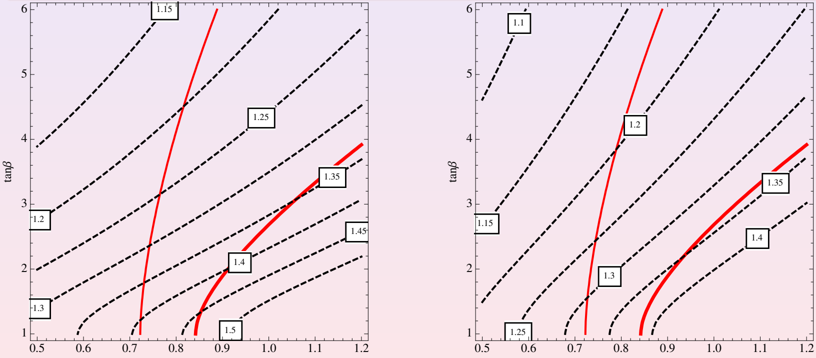


$M_2 = 250$ GeV $\quad$ X_t =4, **0**; $m_Q = 700$ GeV $\quad$ $M_2 = 750$ GeV

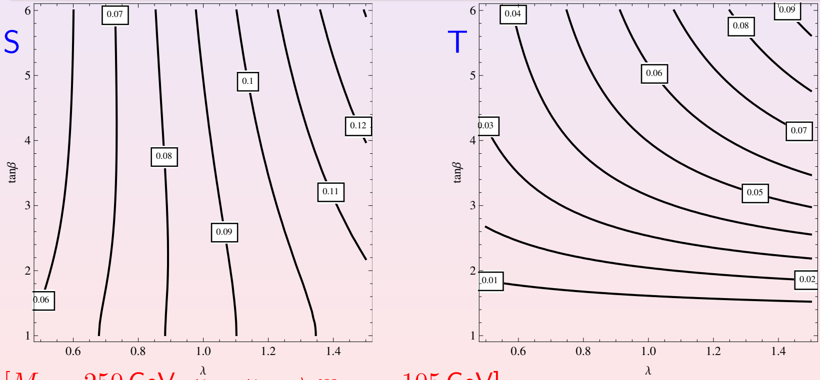
$\mu = \mu_\Sigma \to m_{\chi_1^\pm} \sim 105$ GeV

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

- 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

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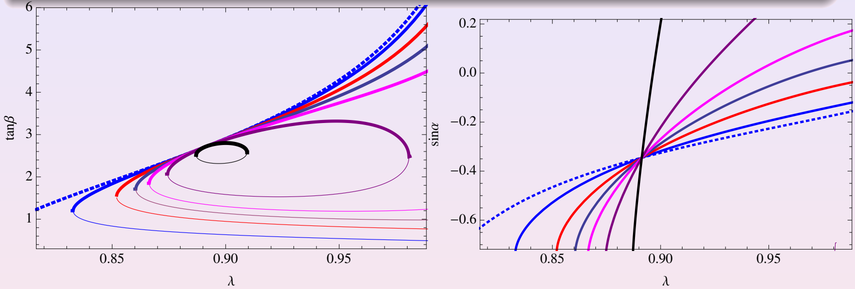
Small m_A

$\tan\beta(\lambda)$ 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} ($M_3 = 1$ TeV, $m_{\tilde{b}} = 700$ 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

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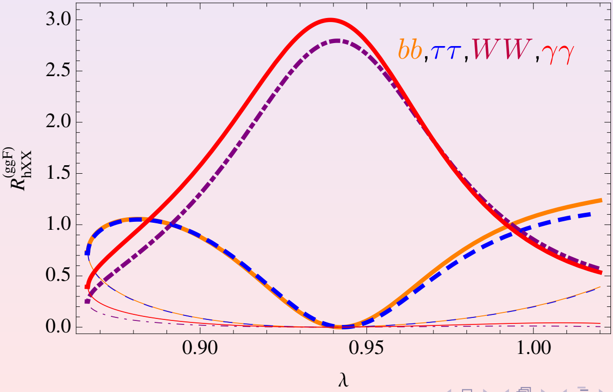

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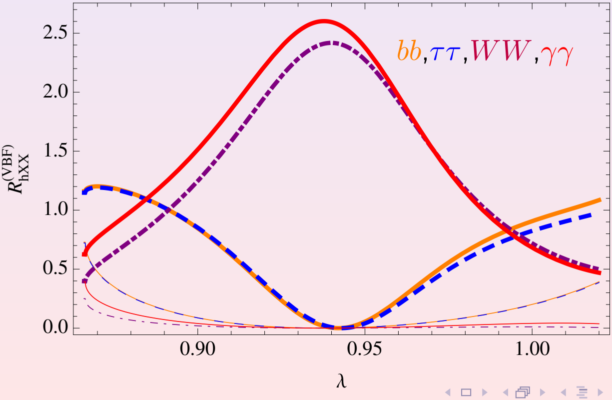

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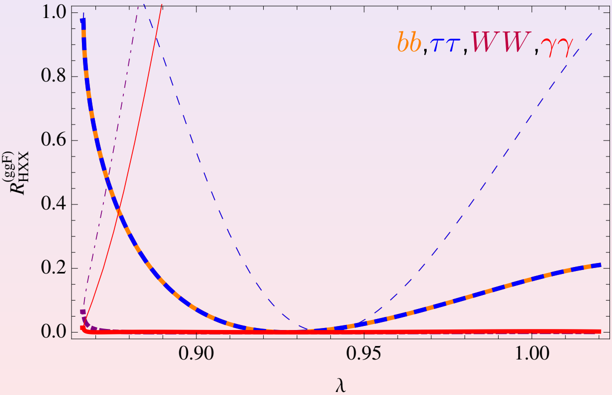

- Further reduction if $m_{\chi 0} \lesssim m_H/2$ ($m_H \sim$138 GeV)

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.
- 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 extra Higgs sector may be at the EW scale but hidden
- More data and analyses on $H^{\pm}$ and A are worthwhile
- Good alternative to singlet extensions

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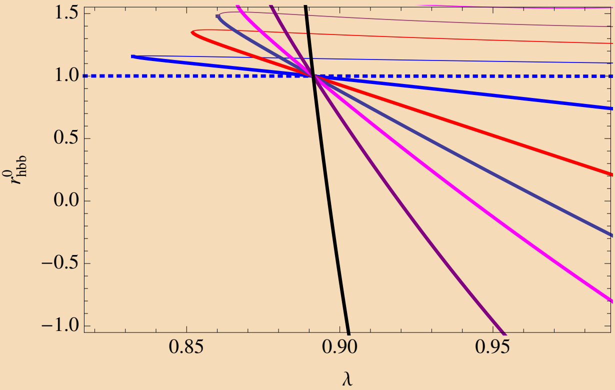
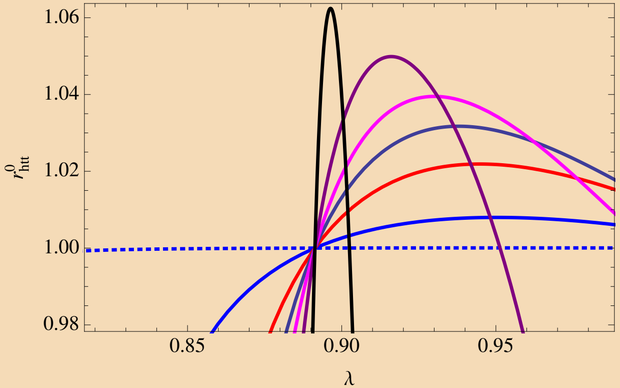
EXTRAS

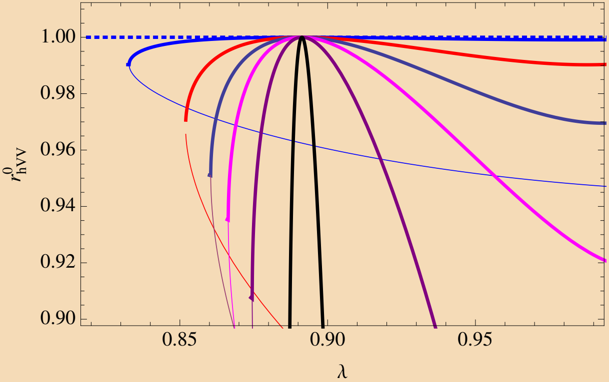
Plot of r_{hdd}



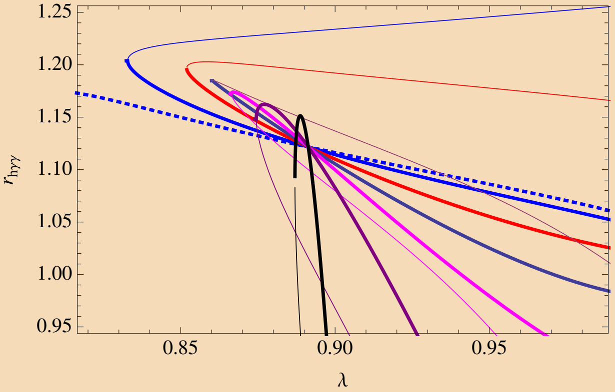
Plot of r_{htt}



Plot of r_{hVV}



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



$m_{\chi_1^\pm} = 104\,\text{GeV}$ (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)