Dark Matter versus $h \to \gamma\gamma$ and $h \to \gamma Z$ with supersymmetric triplets

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Outline

Introduction

Motivation

- Higgs found at the LHC with a mass of 126 GeV is SM-like.
- The minimal SUSY model requires heavy stops or large stop mixing (fine-tuning).
- Non-minimal SUSY models can rise the Higgs mass at tree level.
- Minimal extensions: Singlets (NMSSM) or Triplets ($Y = 0, \pm 1$).
- New EW sector $\rightarrow$ Dark Matter/Collider phenomenology.

Model

Addition of a $Y = 0$ $SU(2)_L$ triplet superfield.

$$\Sigma = \begin{pmatrix} \xi^0/\sqrt{2} & -\xi_2^+ \\ \xi_1^- & -\xi^0/\sqrt{2} \end{pmatrix}$$

The total superpotential reads

$$W_{\rm TMSSM} = W_{\rm MSSM} + \lambda H_1 \cdot \Sigma H_2 + \frac{1}{2}\mu_\Sigma {\rm Tr}\Sigma^2,$$

and the soft-breaking Lagrangian

$$\mathcal{L}_{\rm TMSSM_{SB}} = \mathcal{L}_{\rm MSSM_{SB}} + m_4^2 {\rm Tr}(\Sigma^\dagger \Sigma) + [B_\Sigma {\rm Tr}(\Sigma^2) + \lambda A_\lambda H_1 \cdot \Sigma H_2 + h.c].$$

Electroweak precision observables impose $\langle \xi^0 \rangle \lesssim 4$ GeV which implies

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

If $A_\lambda, \mu, \mu_\Sigma$ at EW scale, then $m_\Sigma \gtrsim 2$ TeV

Higgs Sector

Decoupled scalar triplet ξ^0 ($m_\Sigma \gtrsim 5$ TeV)

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

In the decoupling limit, $m_A \to \infty$

- Mass of the lightest Higgs state

$$m^2_{h,tree} = m_Z^2 \cos^2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta$$

- Couplings of the lightest Higgs state → SM-like (except loop-induced processes)

Loop-induced couplings

- $h \to gg$

  Heavy Squarks $\to$ SM-like ggh coupling. The gluon fusion Higgs production is SM-like.

- $h \to \gamma\gamma$ / $h \to Z\gamma$

  New fields in the EW sector $\to$ Deviation from the SM couplings.

$$M^{tree}_{\tilde{\chi}^{\pm}} = \begin{pmatrix} M_2 & gv\sin\beta & 0 \\ gv\cos\beta & \mu & -\lambda v\sin\beta \\ 0 & \lambda v\cos\beta & \mu_\Sigma \end{pmatrix}$$

$h \to \gamma\gamma$ / $h \to Z\gamma$

$$R_{\gamma\gamma} = \left| 1 + \frac{A^{\gamma\gamma}_{\widetilde{\chi}^{\pm}_{1,2,3}}}{A^{\gamma\gamma}_W + A^{\gamma\gamma}_t} \right|^2 \qquad R_{Z\gamma} = \left| 1 + \frac{A^{Z\gamma}_{\widetilde{\chi}^{\pm}_{1,2,3}}}{A^{Z\gamma}_W + A^{Z\gamma}_t} \right|^2$$

$$A^{\gamma\gamma}_{\widetilde{\chi}^{\pm}_{1,2,3}} = \sum_{i=1}^{3} \frac{2m_W}{\sqrt{2}m_{\widetilde{\chi}^{\pm}_i}} (g^L_{h\widetilde{\chi}^+_i\widetilde{\chi}^-_i} + g^R_{h\widetilde{\chi}^+_i\widetilde{\chi}^-_i}) A_{1/2}(\tau_{\widetilde{\chi}^{\pm}_i})$$

$$A^{Z\gamma}_{\widetilde{\chi}^{\pm}_{1,2,3}} = \sum_{j,k=1}^{3} \frac{g_2 m_{\widetilde{\chi}^{\pm}_j}}{g_1 m_Z} f\left(m_{\widetilde{\chi}^{\pm}_j}, m_{\widetilde{\chi}^{\pm}_k}, m_{\widetilde{\chi}^{\pm}_k} \right) (g^L_{h\widetilde{\chi}^+_i\widetilde{\chi}^-_i} + g^R_{h\widetilde{\chi}^+_i\widetilde{\chi}^-_i})(g^L_{Z\widetilde{\chi}^+_i\widetilde{\chi}^-_i} + g^R_{Z\widetilde{\chi}^+_i\widetilde{\chi}^-_i})$$

$$\boxed{A^{\gamma\gamma}_W = -8.3 \quad A^{\gamma\gamma}_t = 1.9} \quad \boxed{A^{Z\gamma}_W = -12 \quad A^{Z\gamma}_t = 0.6}$$

Invisible Higgs Decays

Invisible Decay Width

$$\Gamma(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = \frac{G_F m_W^2}{2\sqrt{2}\pi} m_h \left(1 - \frac{4m_{\tilde{\chi}_1^0}^2}{m_h^2}\right)^{3/2} g_{h\chi_1^0\chi_1^0}^2$$

$$g_{h\chi_1^0\chi_1^0} = (N_{12} - \frac{g_1}{g_2} N_{11})(\sin\beta N_{14} - \cos\beta N_{13}) + \frac{\lambda}{g_2} N_{15}(N_{14}\sin\beta + N_{13}\cos\beta)$$

$$R_{XY} \equiv [\mathrm{BR}(h \to XY)/\mathrm{BR}_{\mathrm{SM}}(h \to XY)] \times [1 - \mathrm{BR}(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)]$$

$$\mathcal{M}_{\tilde{\chi}^0}^{tree} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_1 v_2 & 0 \\ 0 & M_2 & \frac{1}{2}g_2 v_1 & -\frac{1}{2}g_2 v_2 & 0 \\ -\frac{1}{2}g_1 v_1 & \frac{1}{2}g_2 v_1 & 0 & -\mu & -\frac{1}{2}v_2\lambda \\ \frac{1}{2}g_1 v_1 & -\frac{1}{2}g_2 v_2 & -\mu & 0 & -\frac{1}{2}v_1\lambda \\ 0 & 0 & -\frac{1}{2}v_2\lambda & -\frac{1}{2}v_1\lambda & \mu_\Sigma \end{pmatrix}$$

Analysis: Machinery

SARAH

⇒ Lagrangian TMSSM. Diagonalization, RGE's ...

SPheno

⇒ SUSY Spectrum (Full 1 loop, 2 loop corrections for the Higgs, low energy observables, ...)

CPSuperH

⇒ Passarino-Veltman functions

micrOMEGAS

⇒ Relic Abundance, direct detection cross sections

Analysis: Machinery

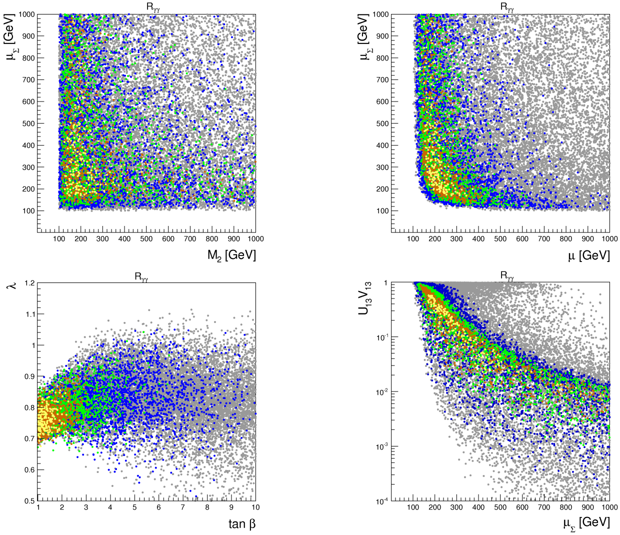
Multinest

$$p(\theta_i|d) \propto \mathcal{L}(d|\theta_i)\pi(\theta_i), \quad \{\theta_i\} = \{M_1, M_2, \mu, \mu_\Sigma, \widetilde{m}, \tan\beta, \lambda\}$$

NS parameters	Prior range
$\log_{10}(M_1/\mathrm{GeV}), \log_{10}(\mu_\Sigma/\mathrm{GeV})$	$1 \to 3$
$\log_{10}(\mu/\mathrm{GeV}), \log_{10}(M_2/\mathrm{GeV})$	$2 \to 3$
$\widetilde{m}/\mathrm{TeV}$	$0.63 \to 2$
$\log_{10}(\tan\beta)$	$0 \to 1$
λ	$0.5 \to 1.2$

Type	Observable	Measurement/Limit
Collider data	m_h	125.85 ± 0.4 GeV (exp) ± 3 GeV (theo)
	$\Gamma(Z \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0)$	< 2 MeV
	$m_{\widetilde{t}_1}$	> 650 GeV (LHC 90% CL)
	$m_{\widetilde{\chi}_1^+}$	> 101 GeV (LEP 95% CL)
DM data	$\Omega_{\mathrm{DM}} h^2$	0.1186 ± 0.0031 (exp) $\pm 20\%$ (theo)
	$\sigma_{\mathrm{Xe}}^{SI}$	LUX (90% CL)

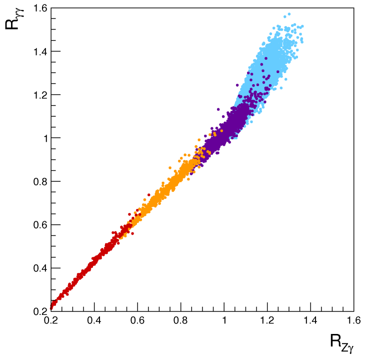
$R_{\gamma\gamma}$ and $R_{\gamma Z}$

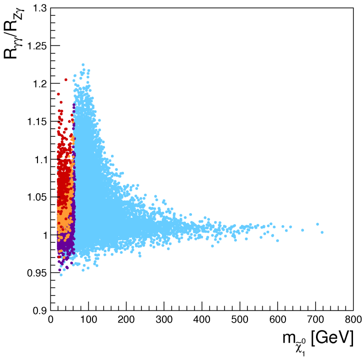


$R_{\gamma\gamma} <$ 1.1, 1.2, 1.3, 1.4 and $R_{\gamma\gamma} >$ 1.4

$R_{\gamma\gamma}$ and $R_{\gamma Z}$

BR$_{inv}$ <1%, 20%, 50% and BR$_{inv}$ >50%.



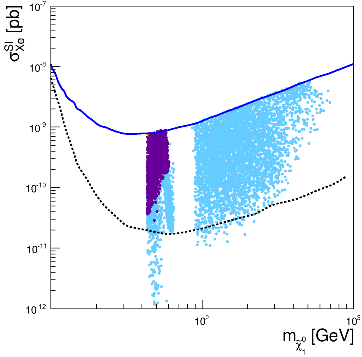


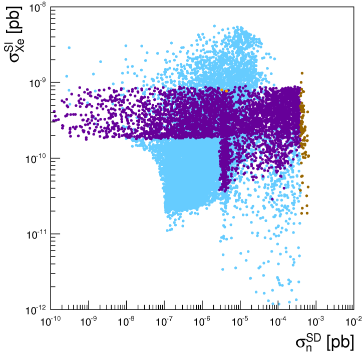
Enhancement up to 60% for $R_{\gamma\gamma}$ and 40% for $R_{Z\gamma}$

Correlation in $h \to \gamma\gamma$ and $h \to Z\gamma$ channels!!

Dark Matter. Neutralino Phenomenology

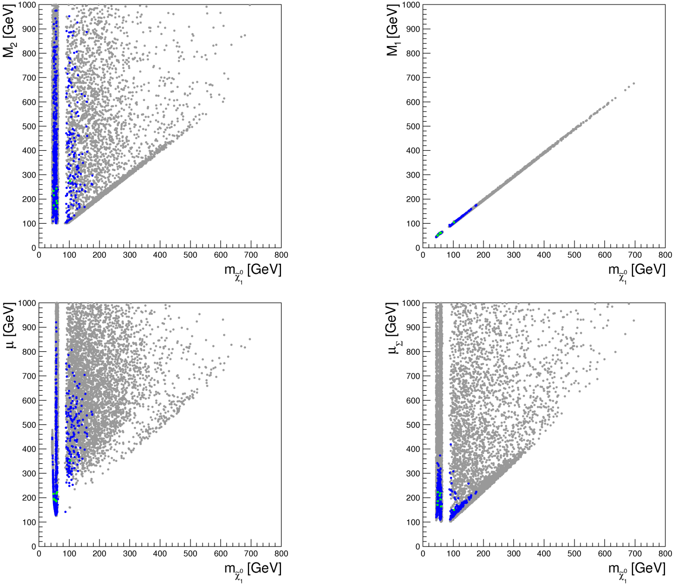
Lightest Neutralino is a viable DM candidate in the Z, h resonances and in the well-tempered region.



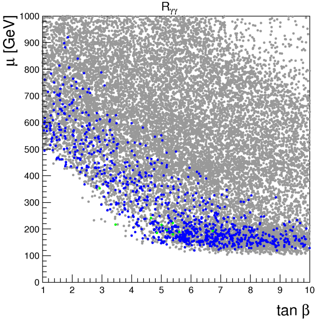


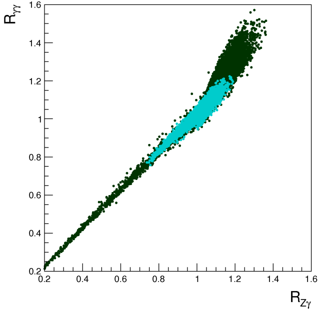
[Brown points at odds with the XENON100 exclusion bound for σ_n^{SD}]

Dark Matter. Neutralino Composition



Dark Matter.





DM constraints reduce the enhancement up to 20%.

Conclusions

Conclusions

- The triplet extension achieves a Higgs mass of 126 GeV reducing the fine-tuning.
- Loop induced processes in Higgs Physics may deviate from the SM ones.
- [No DM Pheno] Large enhancement in the decays $h \to \gamma\gamma$ (60%) and $h \to Z\gamma$ (40%). Both channels are correlated.
- [With DM Pheno] Lightest neutralino is a viable DM candidate in different regions.
- [With DM Pheno] Constraints on SI cross-section coming from LUX reduces $R_{\gamma\gamma}$ and $R_{Z\gamma}$

Thank you for your attention!