Doublet-Triplet Dark Matter with Neutrino Masses
COMHEP 2016

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1803

Outline:

- Motivation
- The doublet-triplet fermion model
- The doublet-triplet scalar model
- Phenomenology of the mixed scenario
- Conclusions

Motivation: Dark Matter

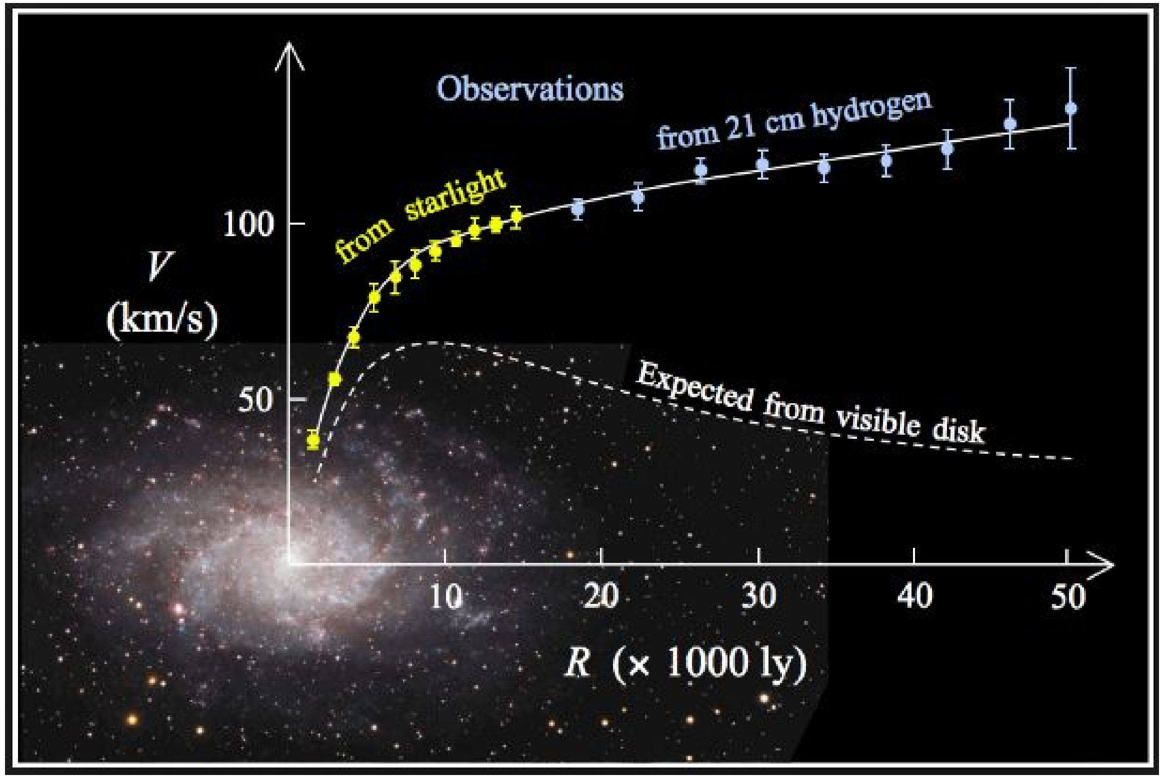

Image credit: Wikipedia

Motivation: Dark Matter

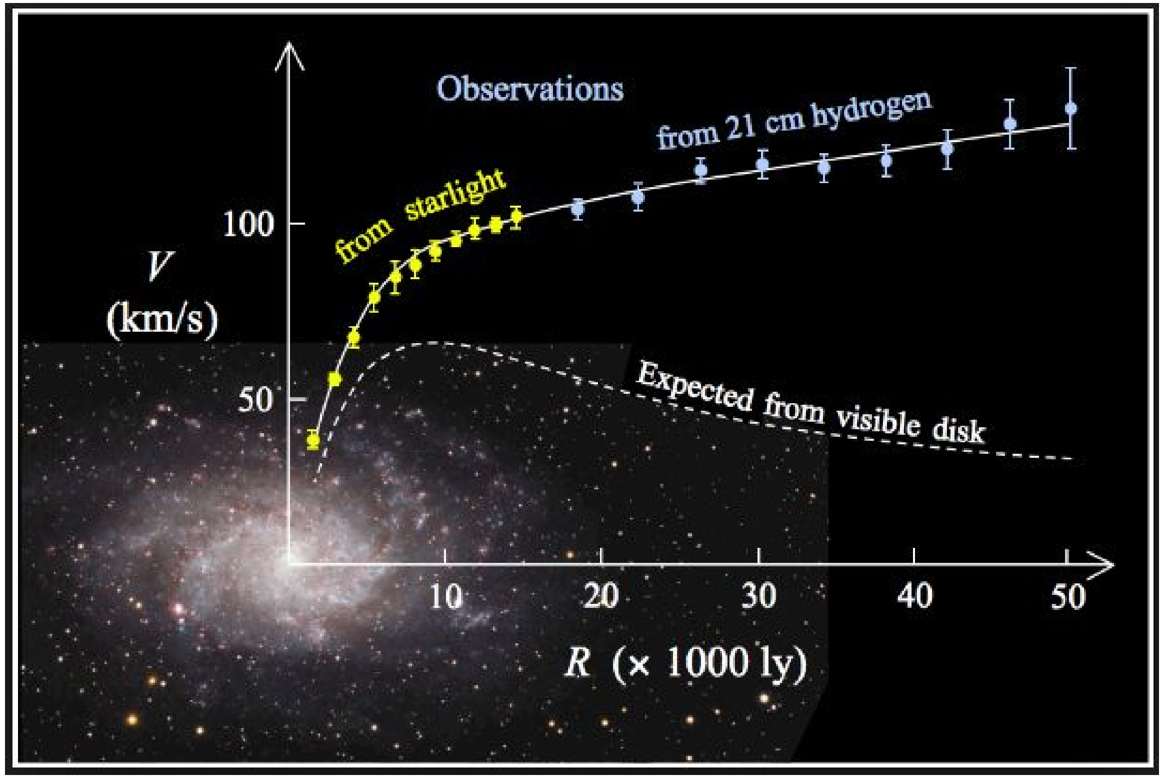

Image credit: Wikipedia

- Dark matter accounts for 25% of matter-energy content of the universe.
- Must be neutral, cold and stable (at least in cosmological scales).
- No particle within the Standard Model fulfills these criteria.

Motivation: Neutrino Masses

Image credit: www.nobelprize.org

- Neutrino oscillation data shows that neutrinos must have masses .
- It is not possible to accommodate this fact within the Standard Model.

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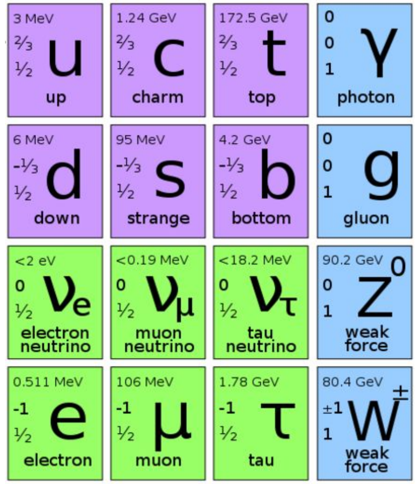
We need physics beyond the Standard Model !

Motivation: How is the new sector connected to the SM?



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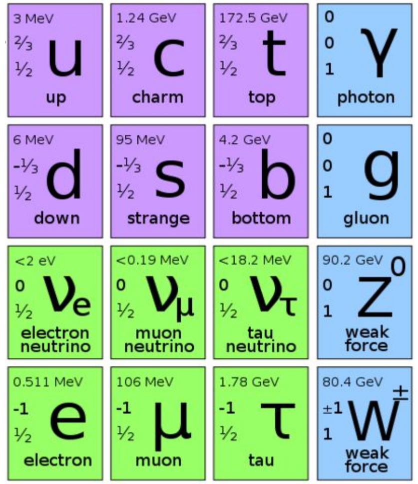
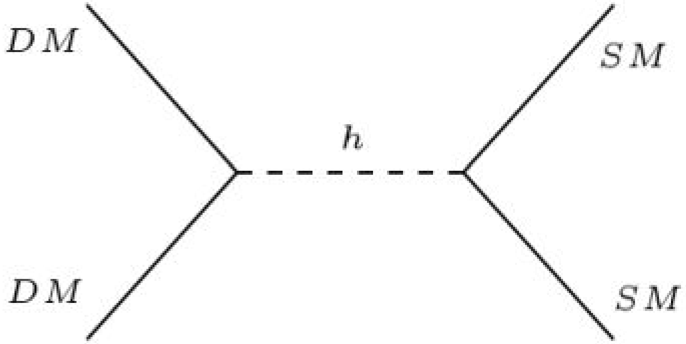


Higgs portal



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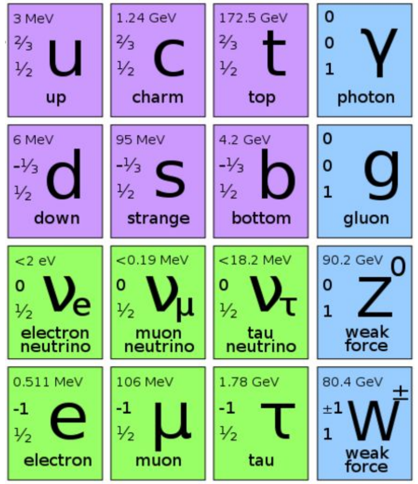


Singlet

Doublet

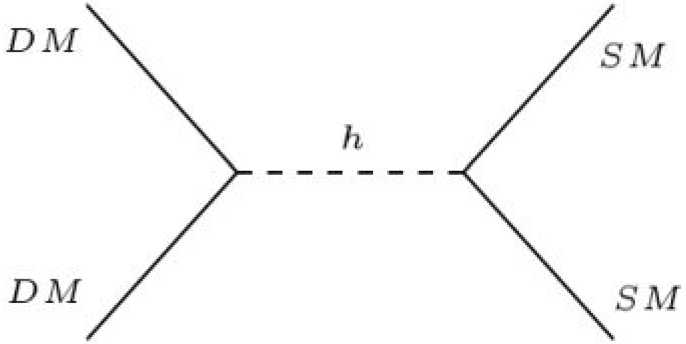
Higher representations

Scalar, Fermion, Vector

Patt 2006, 0605188

Freytas, PRD 2015

Higgs portal



Mixed

Dobulet Triplet Fermion, Doublet Triplet Scalar

Doublet-Triplet fermion: The model

$$\psi_L = \begin{pmatrix} \psi_L^0 \\ \psi_L^- \end{pmatrix} \qquad \psi_R = \begin{pmatrix} \psi_R^0 \\ \psi_R^- \end{pmatrix}$$

Vector-like doublet, Y=1

$$\Sigma_L \equiv \sqrt{2}\Sigma_L^i \tau^i = \begin{pmatrix} \Sigma_L^0/\sqrt{2} & \Sigma_L^+ \\ \Sigma_L^- & -\Sigma_L^0/\sqrt{2} \end{pmatrix}$$

Majorana triplet

Doublet-Triplet fermion: The model

Similar to the Wino Higgsino in SUSY

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Majorana triplet

Both odd under the Z_2
The SM fields are even

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Majorana triplet

$$\mathcal{L}_F = \mathrm{Tr}[\bar{\Sigma}_L i\gamma^\mu D'_\mu \Sigma_L] - \frac{1}{2}\mathrm{Tr}(\bar{\Sigma}_L^c M_\Sigma \Sigma_L + \mathrm{h.c.}) + \bar{\psi} i\gamma^\mu D_\mu \psi - M_\psi(\bar{\psi}_R \psi_L + \mathrm{h.c.})$$

$$\mathcal{L}_Y = -y_1 H_1^\dagger \overline{\Sigma_L^c} \epsilon \psi_R^c + y_2 \overline{\psi_L^c} \epsilon \Sigma_L H_1 + \mathrm{h.c.}$$

Freytas, PRD 2015

Dedes, PRD 2014

PRD 2015

Doublet-Triplet fermion: The spectrum

In the basis: $\Xi^0 = (\Sigma_L^0, \psi_L^0, \psi_R^{0c})^T$ **And with** $y_1 = y_2 = y$

$$\mathbf{M}'_{\Xi^0} = \begin{pmatrix} M_\Sigma & yv & 0 \\ yv & M_\psi & 0 \\ 0 & 0 & -M_\psi \end{pmatrix}$$

Doublet-Triplet fermion: The spectrum

No corrections to the oblique parameter T

In the basis: $\Xi^0 = (\Sigma_L^0, \psi_L^0, \psi_R^{0c})^T$

And with $\boldsymbol{y_1 = y_2 = y}$

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Decoupled eigenvalue!

$$m_{\chi_1^0} = -M_\psi$$

DM candidate !

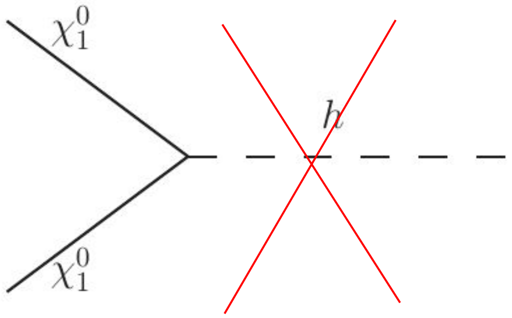
$$m_{\chi_2^0} = m_{\chi_1^\pm}$$

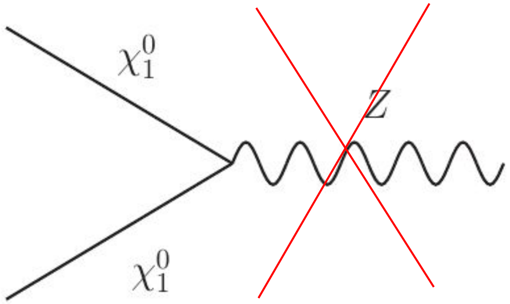
$$m_{\chi_3^0} = m_{\chi_2^\pm}$$

$$m_{\chi_1^\pm, \chi_2^\pm} = \frac{1}{2}\left[M_\psi + M_\Sigma \mp \sqrt{(M_\psi - M_\Sigma)^2 + 2y^2v^2}\right]$$

Doublet-Triplet fermion: Phenomenology

Dark matter χ_1^0





Doublet-Triplet fermion: Phenomenology

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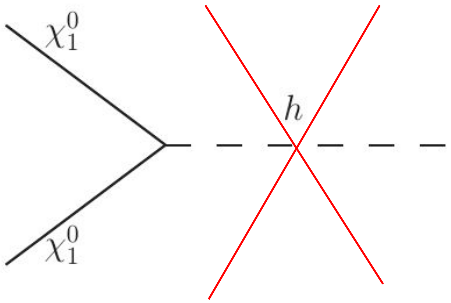
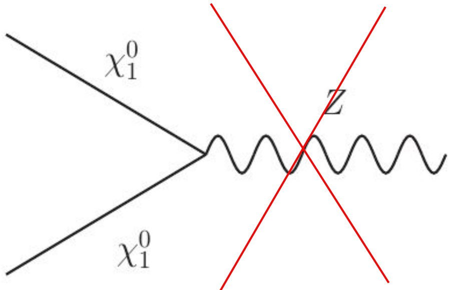
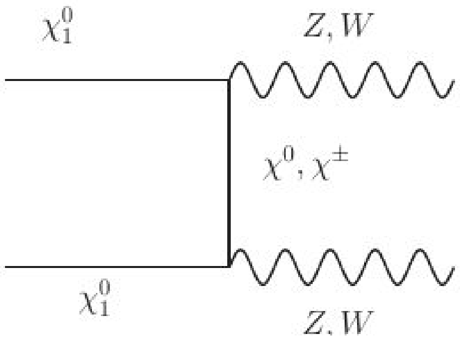
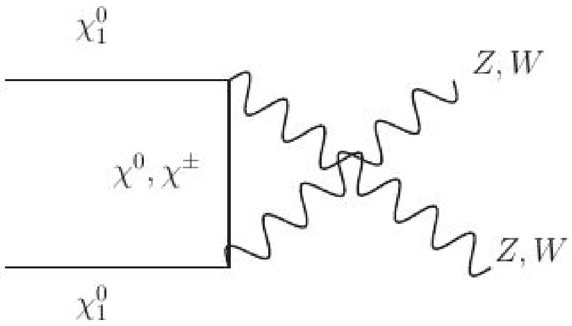




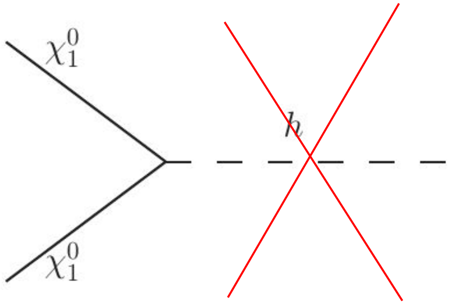


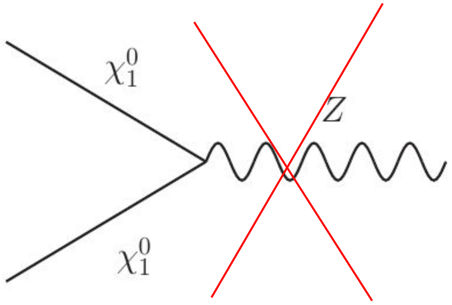


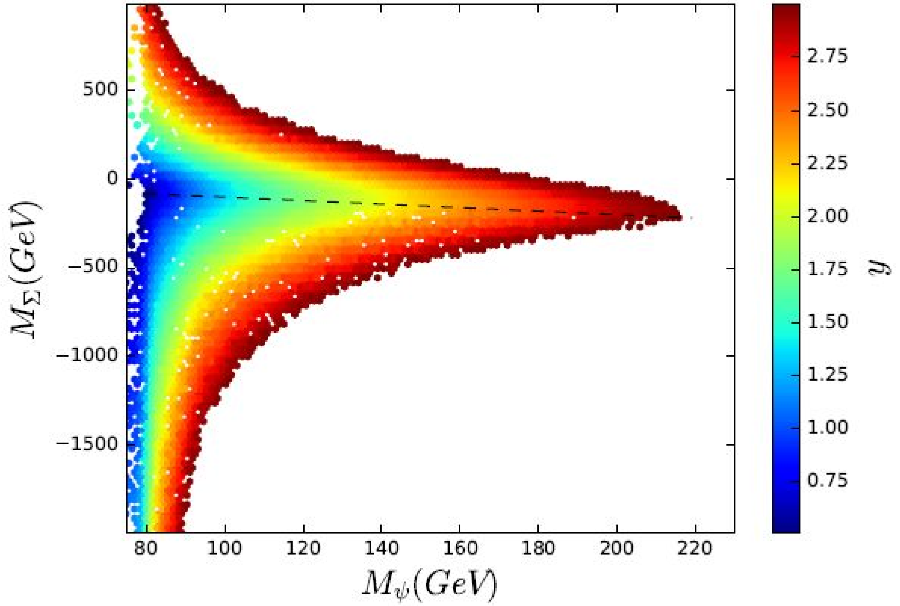
Annihilation through t and u-channels
Suppressed!!

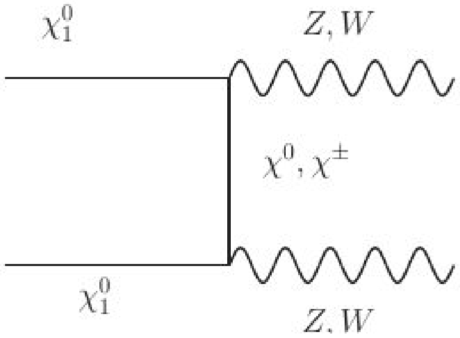
Doublet-Triplet fermion: Phenomenology

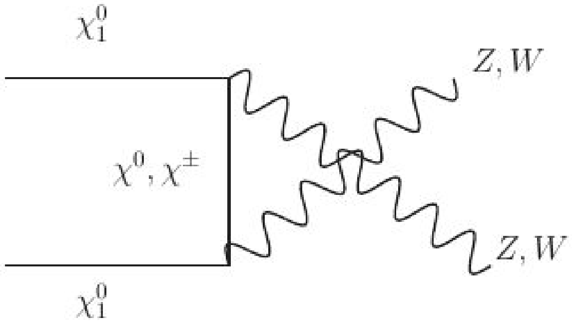
Dark matter χ_1^0











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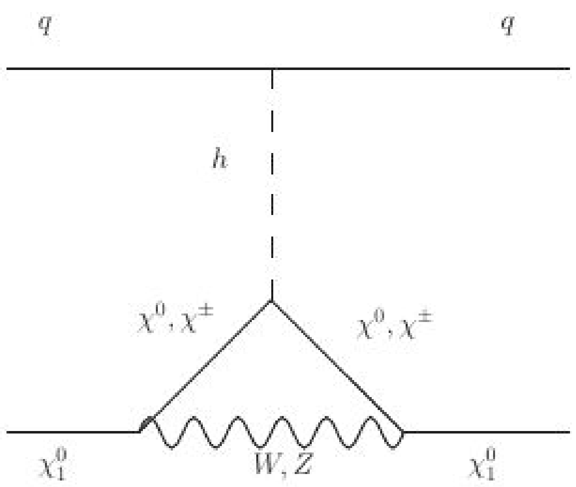
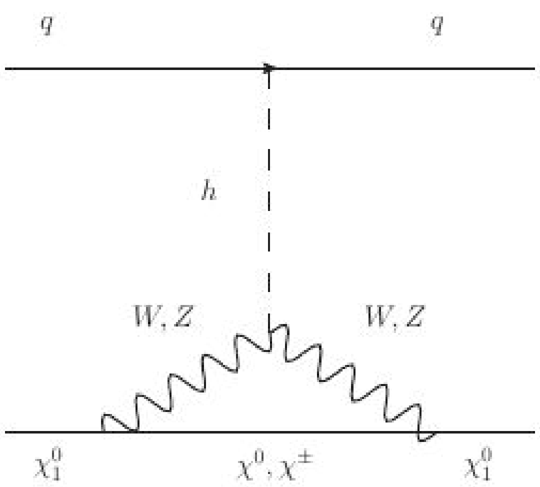
Doublet-Triplet fermion: Phenomenology

Direct Detection: Main annihilation channels



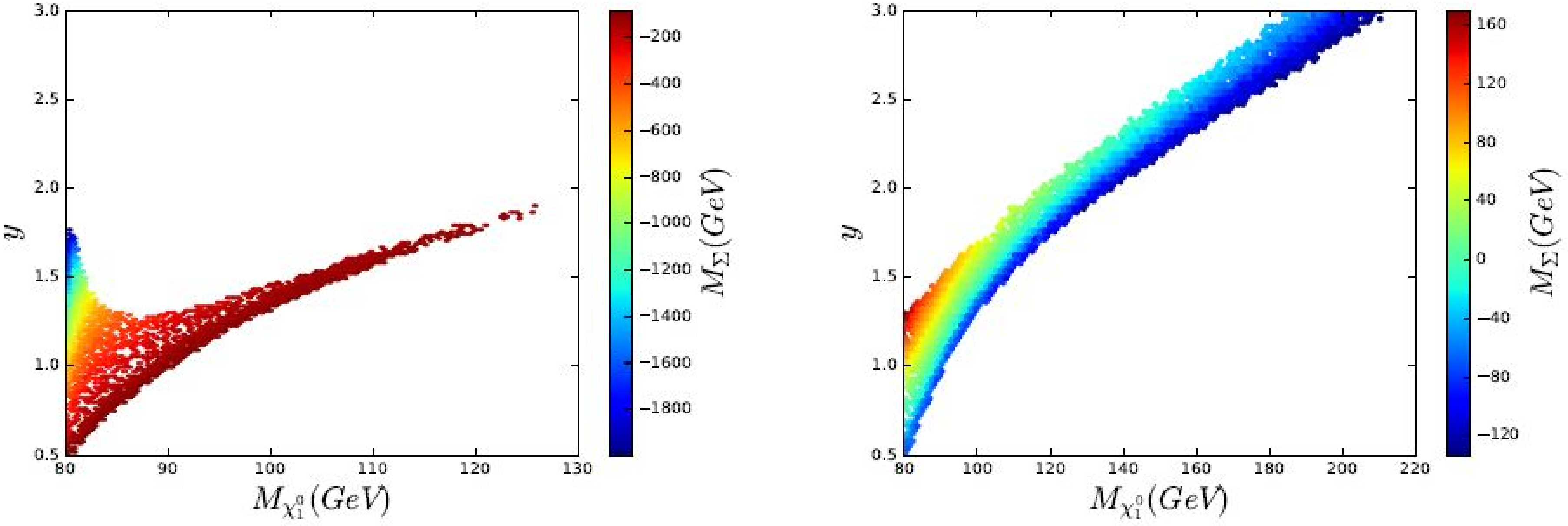


$$\frac{\delta y}{2}\chi_1^0\chi_1^0 h$$

Freitas, PRD, 2015

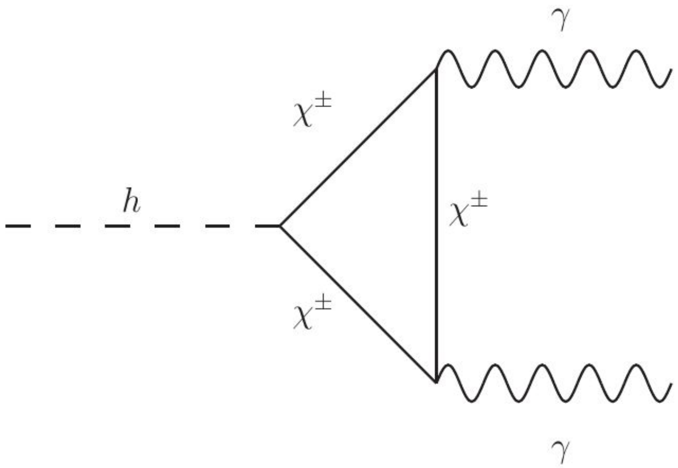
Doublet-Triplet fermion: Phenomenology

Direct detection including LUX 2016 results



Doublet-Triplet fermion: Phenomenology

Higgs diphoton decay rate



$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}} = \left| 1 + \frac{1}{A_{\rm SM}} \frac{y^2 v^2}{m_{\chi^\pm_>} - m_{\chi^\pm_<}} \left[\frac{A_F(\tau_>)}{m_{\chi^\pm_>}} - \frac{A_F(\tau_<)}{m_{\chi^\pm_<}} \right] \right|^2$$

Doublet-Triplet fermion: Phenomenology

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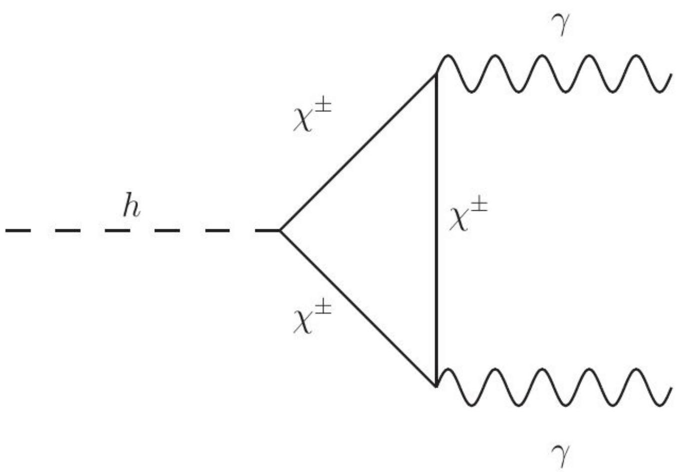

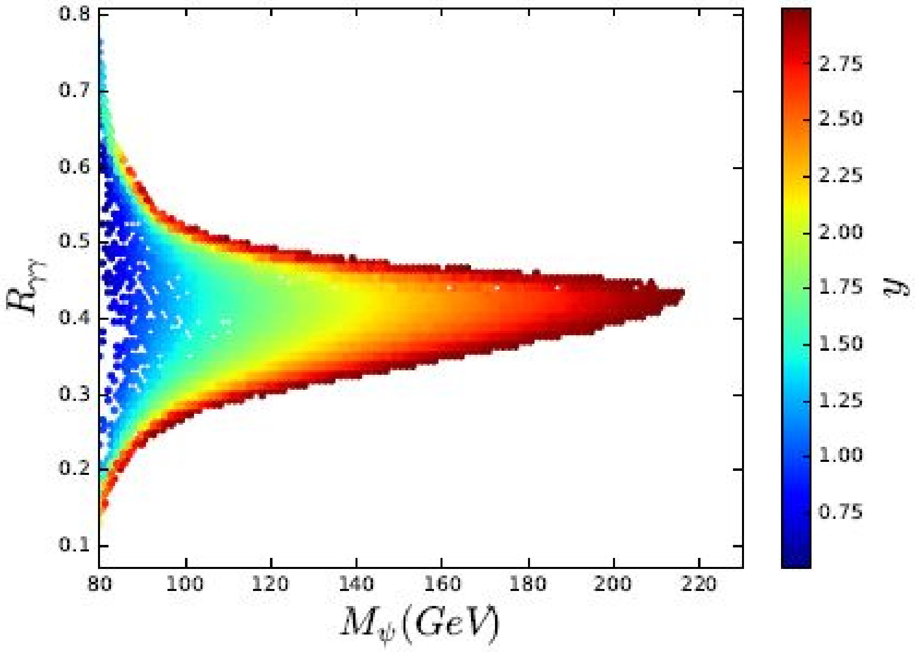

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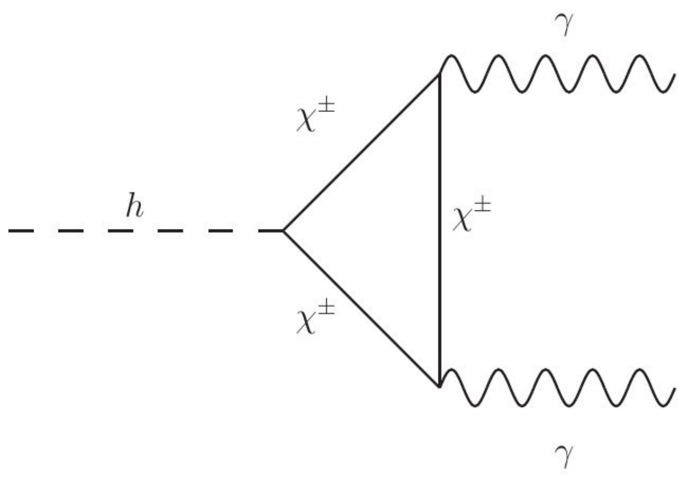

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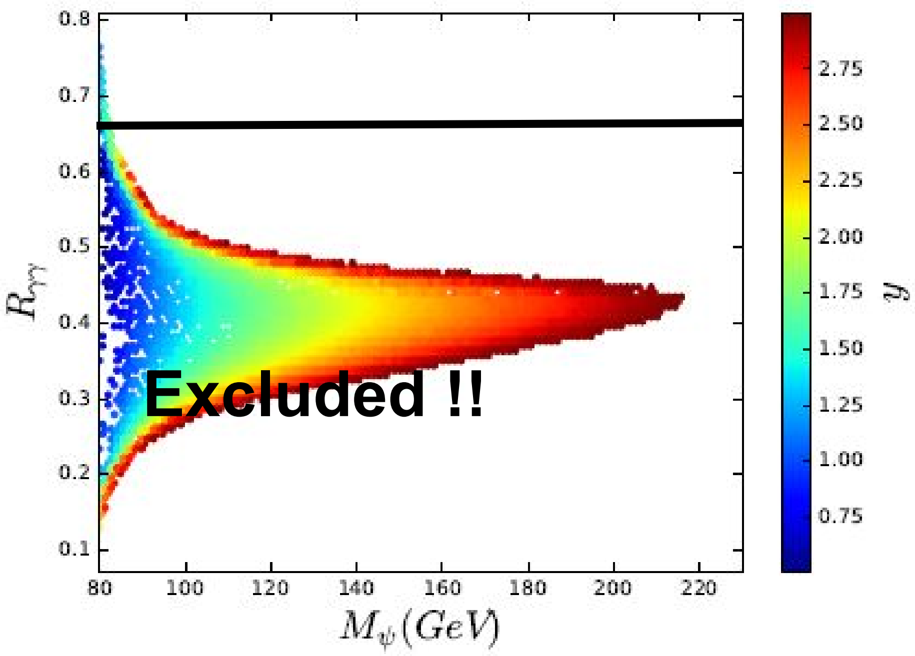
ATLAS and CMS (2016)



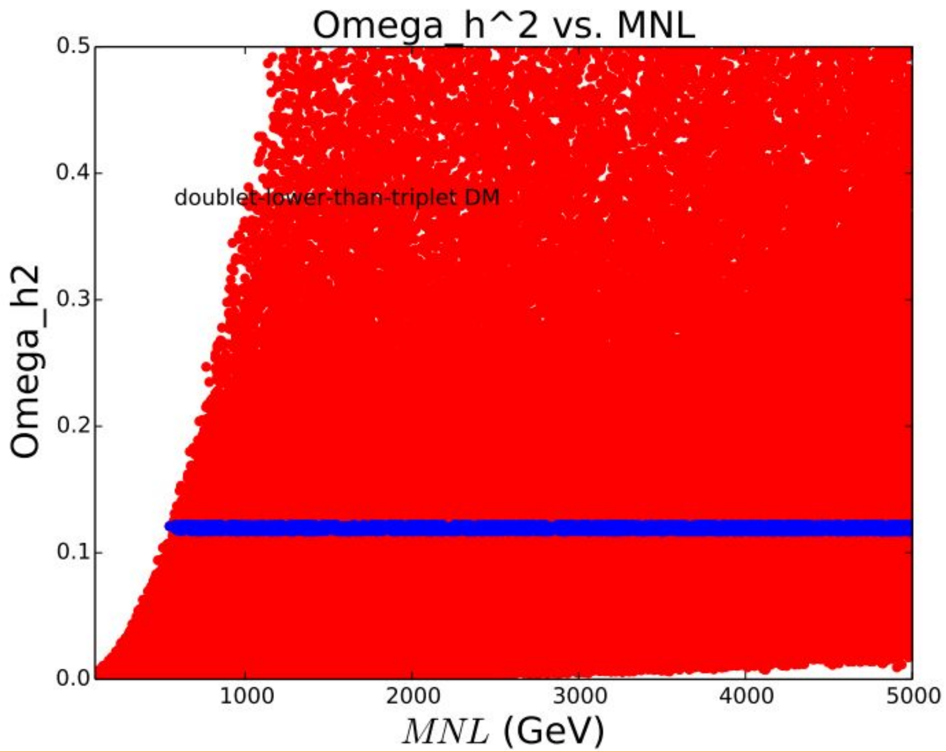
Doublet-Triplet Scalar: The Model

$$H_2 = \begin{pmatrix} H^+ \\ \frac{H^0 + iA^0}{\sqrt{2}} \end{pmatrix}$$

$$\Delta = \frac{1}{2} \begin{pmatrix} \Delta_0 & \sqrt{2}\,\Delta^+ \\ \sqrt{2}\,\Delta^- & -\Delta_0 \end{pmatrix}$$

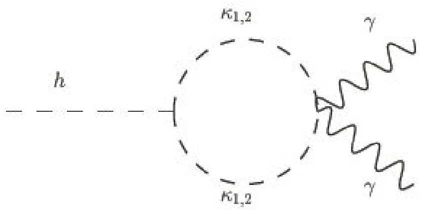
Both odd under Z_2 symmetry

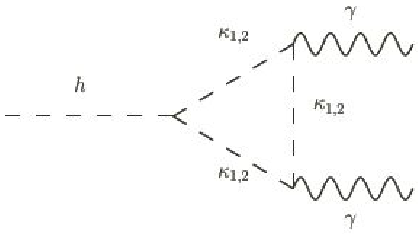
DM near (or at) the TeV scale



Doublet-Triplet fermion-scalar:Higgs diphoton decay rate

$$R = \left| 1 + \frac{1}{A_{SM}} \frac{\lambda_3}{4m_{\kappa_1}^2} A_0\left(\frac{m_h^2}{4m_{\kappa_1}^2}\right) + \frac{1}{A_{SM}} \frac{\lambda_3'}{4m_{\kappa_2}^2} A_0\left(\frac{m_h^2}{4m_{\kappa_2}^2}\right) + \frac{1}{A_{\rm SM}} \frac{y^2 v^2}{m_{\chi^\pm_>} - m_{\chi^\pm_<}} \left[\frac{A_F(\tau_>)}{m_{\chi^\pm_>}} - \frac{A_F(\tau_<)}{m_{\chi^\pm_<}} \right] \right|^2$$





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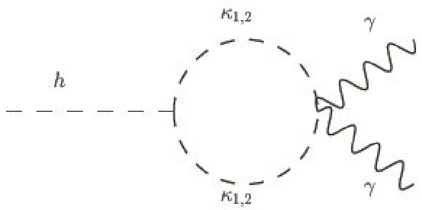
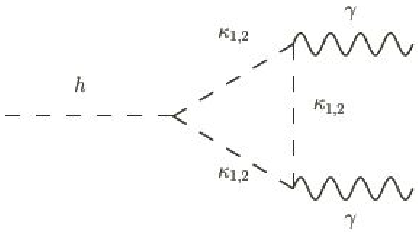




The Scan

Perturbativity

$$0 < \lambda_2, \lambda_\Delta < \frac{4\pi}{3}\ , -1.0 < \lambda_3, \lambda_3' < 4\pi$$

No-coannihilations

$$1.2 < m_{\kappa_1,\kappa_2}/m_{\chi_1^0} < 3.0\ , 1.2 < m_{\eta_1,\eta_2}/m_{\chi_1^0} < 3.0$$

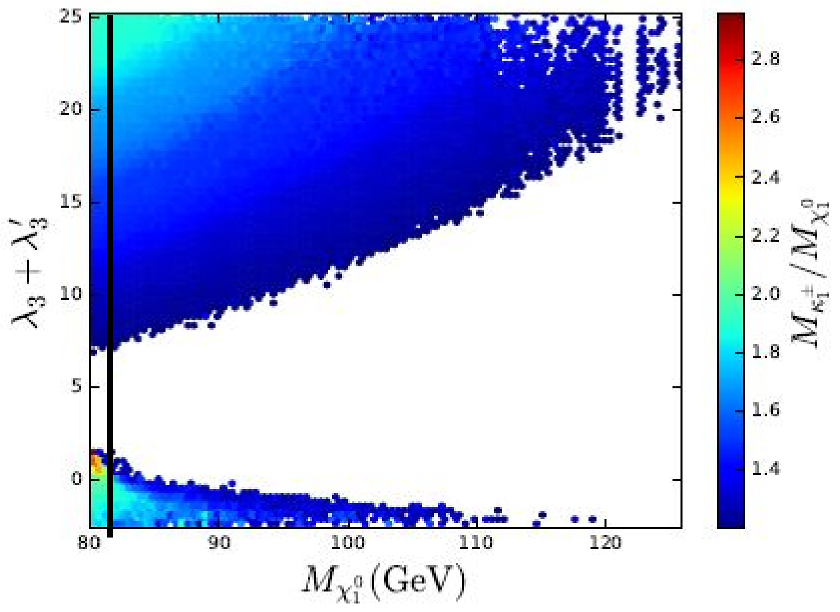
No STU corrections

$$m_{A^0} = m_{\eta_1}\ , \mu = 0$$

Doublet-Triplet fermion-scalar:Higgs diphoton decay rate

Scan Results: All points satisfy relic abundance, direct detection and Higgs diphoton decay rates

$M_\Sigma < -M_\psi$



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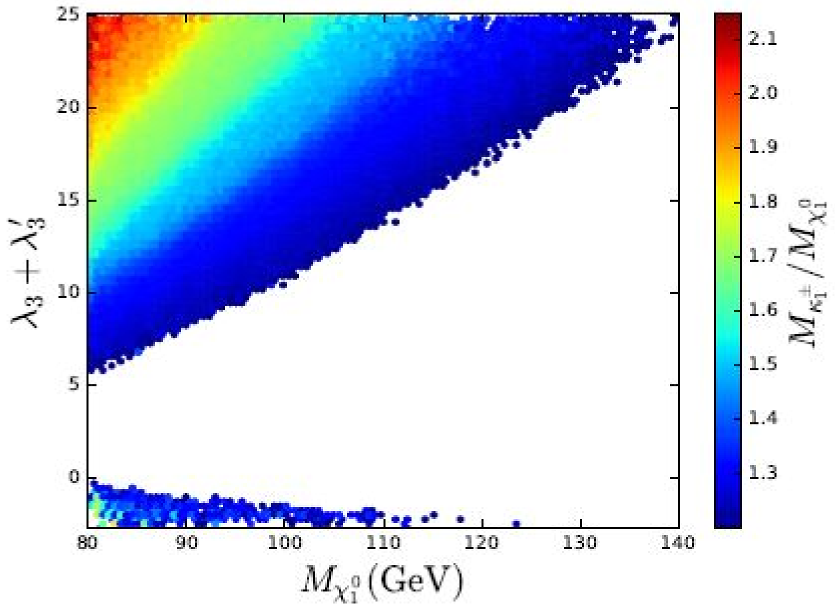

Doublet-Triplet scalar-fermion:Neutrino masses

$$\mathcal{L} \supset -y_1 H_1^\dagger \overline{\Sigma_L^c} \epsilon \psi_R^c + y_2 \overline{\psi_L^c} \epsilon \Sigma_L H_1 - \zeta_i \bar{L}_i \Sigma_L^c \tilde{H}_2 - \rho_i \bar{\psi}_L H_2 e_{Ri} - f_i \overline{L_i} \Delta \psi_R + \text{h.c.}$$

No neutrino masses at tree level

Doublet-Triplet scalar-fermion:Neutrino masses

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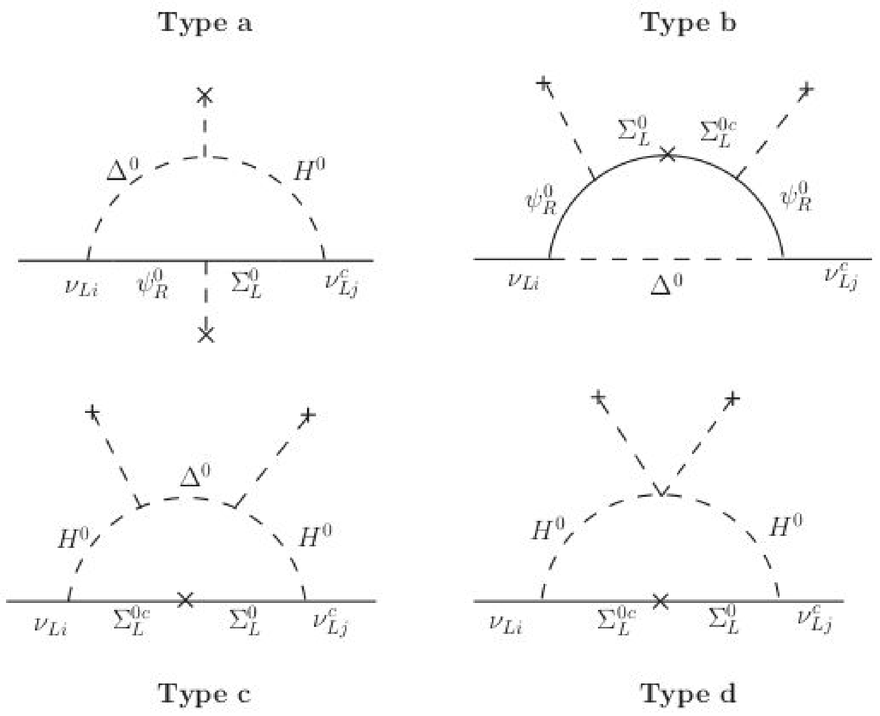

No neutrino masses at tree level

Radiative neutrino masses in four different topologies.

Doublet-Triplet scalar-fermion:Neutrino masses

Neutrino mass-matrix

$$M^{\nu} = \Lambda_{\zeta}\zeta_i\zeta_j + \Lambda_f f_i f_j + \Lambda_{f\zeta}(\zeta_i f_j + f_i\zeta_j)$$

The matrix has zero determinant, only two massive majorana neutrinos

Doublet-Triplet scalar-fermion:Neutrino masses

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The matrix has zero determinant, only two massive majorana neutrinos

It is possible to parametrize all the relevant new Yukawas in terms of neutrino observables and one free Yukawa

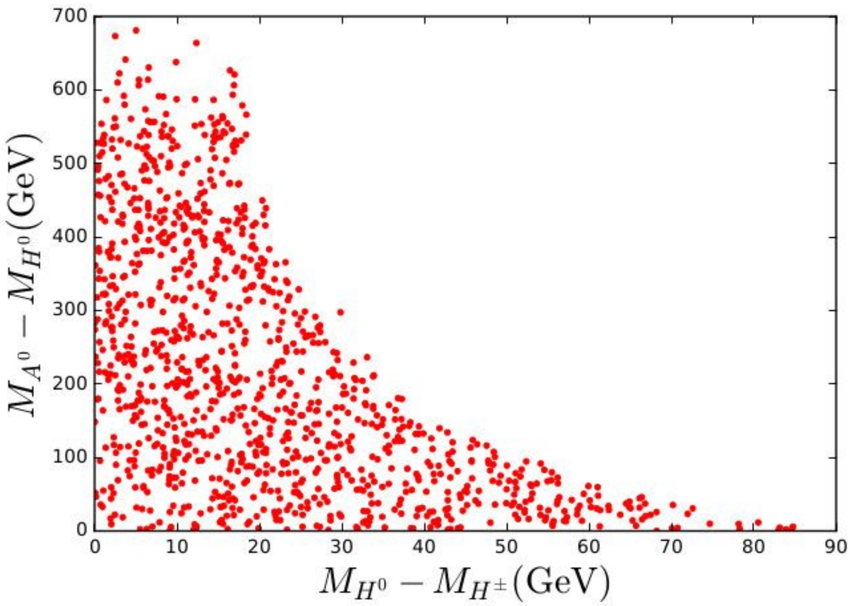
ζ_1 ← **Free Yukawa**

Conclusions:

- The doublet-triplet fermion model may account for the DM of the universe at the electroweak scale, when the Yukawa couplings to the Higgs y_1 and y_2 are the same.
- The model is mostly excluded because it generates a too low Higgs diphoton decay rate.
- When a doublet and a triplet scalar are included the correct decay rate might be achieved in two ways $\lambda_3 + \lambda_3' \leq 0$ or $\lambda_3 + \lambda_3' \geq 5$
- Neutrino masses are not generated at tree level, but it is possible to generate them at one-loop with only two massive neutrinos.

Backup: STU

Oblique parameter S and T in the doublet scalar



For the doublet-triplet scalar no additional corrections since $\mu = 0$

For the doublet triplet fermions no additional corrections since y_1=y_2 hence the T parameter is protected and it was found in Dedes PRD 2014 that the S parameter contribution is small.

Backup:Neutrino masses

$$\Lambda_\zeta = \frac{1}{32\pi^2}\frac{1}{2}\sum_{k=1}^{3} m_{\chi_k^0}\,(U_{1k})^2\left[c_\alpha^2 F_1(m_{\eta_1}^2, m_{\chi_k^0}^2) + s_\alpha^2 F_1(m_{\eta_2}^2, m_{\chi_k^0}^2) - F_1(m_{A^0}^2, m_{\chi_k^0}^2)\right]$$

$$\Lambda_f = \frac{1}{16\pi^2}\frac{1}{4}\sum_{k=1}^{3} m_{\chi_k^0}\,(U_{3k})^2\left[s_\alpha^2 F_2(m_{\eta_1}^2, m_{\chi_k^0}^2) + c_\alpha^2 F_2(m_{\eta_2}^2, m_{\chi_k^0}^2)\right]$$

$$\Lambda_{\zeta f} = \frac{1}{32\pi^2}\left[\frac{1}{2}s_\alpha c_\alpha \sum_{k=1}^{3} m_{\chi_k^0}\; U_{1k}U_{3k}\left[F_1(m_{\eta_2}^2, m_{\chi_k^0}^2) - F_1(m_{\eta_1}^2, m_{\chi_k^0}^2)\right]\right.$$
$$\left. + s_\beta c_\beta \sum_{k=1}^{2} m_{\chi_k^\pm}\; V_{1k}^L V_{2k}^{R*}\left[F_1(m_{\kappa_1}^2, m_{\chi_k^\pm}^2) - F_1(m_{\kappa_2}^2, m_{\chi_k^\pm}^2)\right]\right]$$

Backup:Neutrino masses

Parametrization:
For the case of normal hierarchy

ζ_1 — Free Yukawa

$$f_i = \frac{\pm}{\Lambda_f}\left(\sqrt{-\Lambda_f\Lambda_\zeta\zeta_i^2 + \Lambda_f m_2 e^{i\alpha/2}V_{i2}^{*2} + \Lambda_f m_3 V_{i3}^{*2} + \Lambda_{\zeta f}^2\zeta_i^2}\right) - \frac{\Lambda_{\zeta f}\zeta_i}{\Lambda_f}, \qquad i = 1,2,3.$$

$$\zeta_j = \pm\left(\frac{\sqrt{\Lambda_f^2 e^{i\alpha/2}m_2 m_3(\Lambda_f\Lambda_\zeta - \Lambda_{\zeta f}^2)(V_{13}^*V_{j2}^* - V_{12}^*V_{j3}^*)^2(-\Lambda_f\Lambda_\zeta\zeta_1^2 + m_2V_{12}^{*2}e^{i\alpha/2}\Lambda_f + m_3V_{13}^{*2}\Lambda_f + \Lambda_{\zeta f}^2\zeta_1^2)}}{(\Lambda_f^2\Lambda_\zeta - \Lambda_f\Lambda_{\zeta f}^2)(e^{i\alpha/2}m_2V_{12}^{*2} + m_3V_{13}^{*2})}\right.$$

$$\left.\pm\frac{\left(e^{i\alpha/2}m_2\, V_{12}^*V_{j2}^* + m_3V_{13}^*V_{j3}^*\right)(\Lambda_f^2\Lambda_\zeta\zeta_1 - \Lambda_f\Lambda_{\zeta f}^2\zeta_1)}{(\Lambda_f^2\Lambda_\zeta - \Lambda_f\Lambda_{\zeta f}^2)(e^{i\alpha/2}m_2V_{12}^{*2} + m_3V_{13}^{*2})}\right)$$

Backup: Collider searches

Part of the parameter space of the doublet-triplet fermion will be explored 13 TeV and 30 fb^{-1} the whole region will be probed at 300 fb^{-1} **JHEP 1509 (2015) 015.** Due to the presence of the scalars we expect modifications in the trilepton plus missing energy search.