Dark matter phenomenology in two higgs doublet model with complex scalar singlet

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Motivation

- Extensions of the two higgs doublet model (THDM) with scalar singlets under SM accomodates a dark matter (DM) candidate, baryogenesis and gravitational waves.

Dorsch et.al JCAP05 (2017) 052,
Drozd et.al JHEP11 (2014) 105,
Dey et.al JHEP 09 (2019) 004

- We study the prospects of dark matter in the context of THDM+complex singlet.

The Model

- Consider a softly broken Z_2 symmetric THDM and conserved Z_2' symmetric singlet potential.
- The quantum numbers of the fields are

Particles	Z_2	Z_2'
Φ_1	$+1$	$+1$
Φ_2	-1	$+1$
S	$+1$	-1

Table: The quantum numbers of the Higgs doublets Φ_1, Φ_2 and complex singlet S under $Z_2 \times Z_2'$.

The Scalar Potential

$$V_{THDMCS} = V_{THDM} + V_S + V_{HS}$$

$$V_{THDM} = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - (m_{12}^2\Phi_1^\dagger\Phi_2 + h.c) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2$$
$$+\frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + (\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)^2 + h.c.)$$

$$V_S = m_S^2 S^\dagger S + (\frac{m_{S'}^2}{2}S^2 + h.c) + (\frac{\lambda_1''}{24}S^4 + h.c) + \frac{\lambda_1''}{6}(S^2(S^\dagger S)$$
$$+ h.c) + \frac{\lambda_3''}{4}(S^\dagger S)^2$$

$$V_{HS} = [S^\dagger S(\lambda_1'\Phi_1^\dagger\Phi_1 + \lambda_2'\Phi_2^\dagger\Phi_2)] + [S^2(\lambda_4'\Phi_1^\dagger\Phi_1 + \lambda_5'\Phi_2^\dagger\Phi_2) + h.c]$$

Baum,Shah JHEP 12 (044) 2018

- Free parameters of the model are

$$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, m_{12}^2, \alpha, \tan\beta, \lambda_1', \lambda_2', \lambda_4', \lambda_5', \lambda_1'', \lambda_3'', m_S^2, m_{S'}^2$$

- The Higgs sector same as in the THDM, i.e, $h, H, A, H^{\pm}$ where h, H are the two CP-even scalars, A, the pseudoscalar and charged Higgs $H^{\pm}$.

Higgs(es) as portal to dark matter

- The CP-even higgses couple to the DM at tree-level.
- Relevant couplings of the higgses to the DM,

$$\lambda_{hSS^*} \propto i \frac{1}{\sqrt{1+\tan^2\beta}}(\lambda_1' \sin\alpha - \lambda_2' \cos\alpha \tan\beta)$$

$$\lambda_{HSS^*} \propto -i \frac{1}{\sqrt{1+\tan^2\beta}}(\lambda_1' \cos\alpha + \lambda_2' \sin\alpha \tan\beta)$$

Here, v is the vacuum expectation value (vev) such that $v^2 = v_1^2 + v_2^2$ where v_i ($i = 1, 2$) refers to the vev's of the Higgs doublets Φ_i.

Phenomenological constraints

- Relic density, $\Omega h^2 \leq 0.12$.
- Spin independent (SI) DM-nucleon direct detection cross section from XENON-1T.
- Lightest CP-even Higgs mass $\simeq 125$ GeV.
- Collider limits on heavy higgses from LHC and LEP.
- Flavour physics constraints: BR(B$\to s\gamma$), BR(B$\to \mu^+\mu^-$).

Simulation details

Model implementation/adoption in the following codes:

- Model building: `SARAH`
- Spectrum Generator: `SARAH-SPheno`
- DM constraints: `micrOMEGAs`
- Higgs constraints: `HiggsBounds` and `HiggsSignals`
- Flavour constraints and tree-level unitarity constraints: `SPheno`

Benchmark scenario

Parameters	**BP1**
m_{12}^2	-1.014$\times 10^5$
λ_1	0.233
λ_2	0.249
λ_3	0.389
λ_4	-0.167
λ_5	0.001
λ_1''	0.1
λ_3''	0.1
λ_1'	0.04
λ_2'	0.04
λ_4'	0.1
λ_5'	0.1
m_h	125.07
m_H	724.4
m_A	724.4
$m_{H^\pm}$	728.3
$\tan\beta$	5
m_χ	338.9
Ωh^2	0.059
$\sigma_{DD}^n \times 10^{11}$ (pb)	7.55

Constraints from relic density

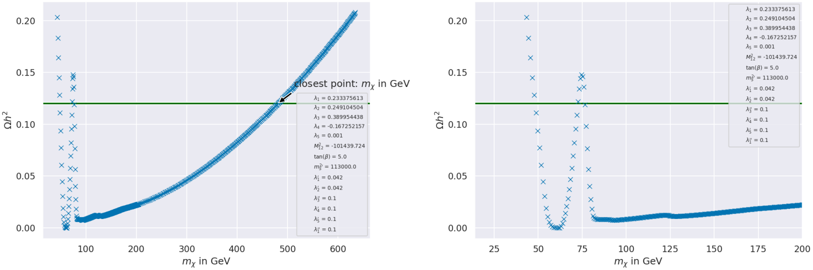

Figure: Variation of the relic density with the mass of the DM candidate, m_χ. Here, the mass parameter m_S^2 is varied.

Constraints from spin independent direct detection cross-section

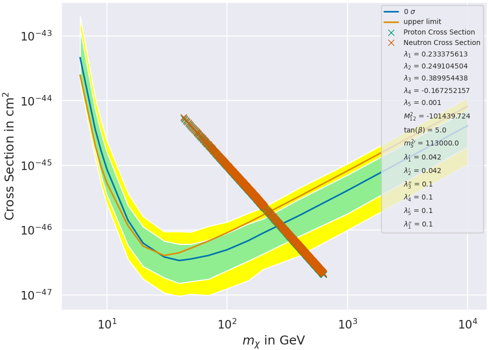

Figure: Variation of the direct detection cross section with the m_χ and compared to the limits from XENON-1T. Here, the mass parameter m_S^2 is varied.

Variation of other parameters

- Recall, the higgs couples to the DM via the portal couplings $\lambda_1', \lambda_2', \lambda_4', \lambda_5'$ and $\tan\beta$.
- We vary each of these parameters to determine the allowed region of parameter space.

Strongest effect on the direct-detection cross section of λ_2' and $\tan\beta$.

Variation of direct detection cross-section with λ_2'

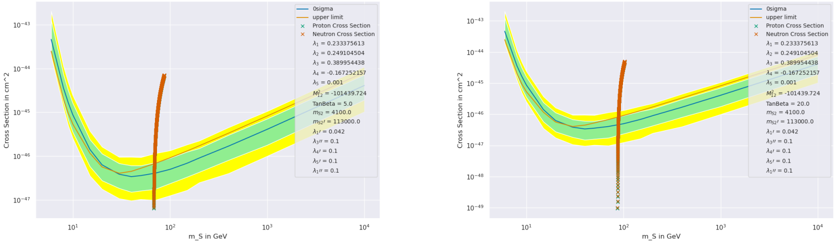

Figure: Variation of the direct detection cross section with m_χ for varying λ_2' for two values of $\tan\beta = 5, 20$ (left,right).

$\implies$ low λ_2' satisfies σ^{SI} easily.

Variation of relic density with tan β

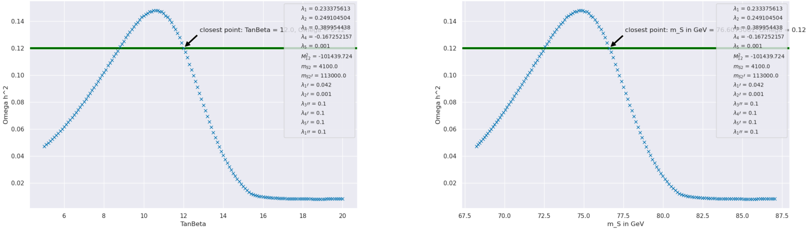

Figure: Variation of relic density with tan β (left) and m_χ (right) for $\lambda'_2 = 0.001$.

$\implies$ light DM candidate with $m_\chi \simeq 77$ GeV fits both thermal relic density and σ^{SI} with varying tan β.

Summary

- Extensions of THDM with complex scalar singlet provides a potential dark matter candidate.
- The higgs sector consists of two CP-even scalar h,H, a pseudoscalar A, and a pair of charged higgses as in the THDM.The DM candidate interacts with the SM via the CP-even scalar higgses at tree-level.
- Stringent constraints on the parameter space from direct detection cross-section. Low λ_2' and slightly large $\tan\beta$ favoured from current data.
- Possible to obtain suitable parameter points allowed by DM constraints, with representative benchmark points in light and heavy mass regions.

Ongoing work

- Collider phenomenology at present and future colliders.
- Model determination and distinction with other extensions.

Thank you!