Dark matter search in the Z_3 symmetric I(2+1)HDM

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Motivation

Although the SM is such a successful theory, there are some problems in the SM, for example: What is the Dark Matter?

Z_3-Symmetric 3HDM

The **3HDMs models** are more tractable than higher multiplicity NHDMs as all possible finite symmetries have been identified. This model may **shed light on the flavour problem**. The low and medium mass regions for the DM candidate which are excluded in the I(1+1)HDM are revived in the I(2+1)HDM.

The 3HDM with two Inert scalar doublets and an active Higgs one, hence termed I(2+1)HDM, in the presence of a discrete Z_3 acting upon the three Higgs doublets.

$$\phi_1 = \begin{pmatrix} H_1^+ \\ \frac{H_1^0 + iA_1^0}{\sqrt{2}} \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} H_2^+ \\ \frac{H_2^0 + iA_2^0}{\sqrt{2}} \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} H_3^+ \\ \frac{H_3^0 + v + iA_3^0}{\sqrt{2}} \end{pmatrix} \tag{1}$$

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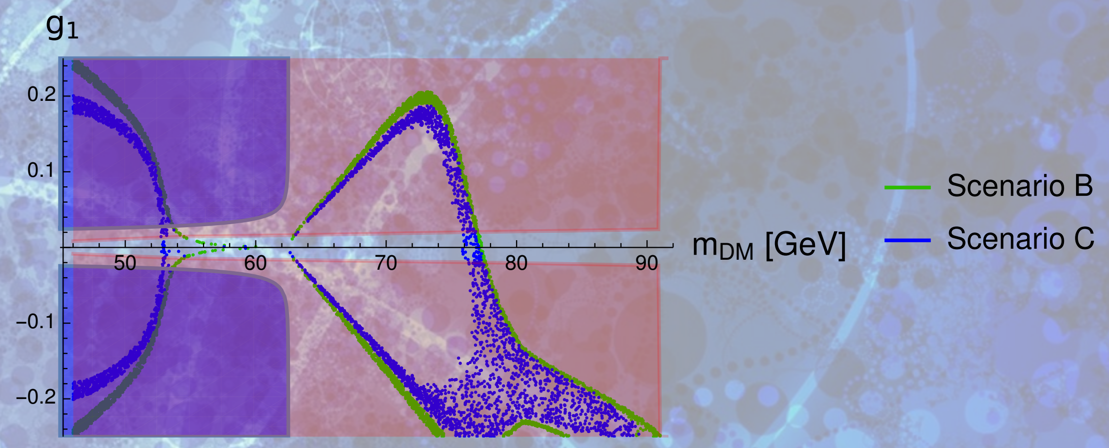
The vacuum condition that the point $(\phi_1^0, \phi_2^0, \phi_3^0) = (0, 0, v/\sqrt{2})$ becomes the minimum of the potential leads to the relation $v^2 = \mu_3^2/\lambda_{33}$. we find two mass-degenerate states H_1 and A_1, and H_2 and A_2.

Results



The effect of the experimental constraints on the parameter space of benchmark scenarios B and C. The pink-shaded regions are excluded by direct and indirect detection experiments while purple-shaded regions are excluded by the Higgs invisible branching ration bounds. The relic density was calculated using microMegas, they are presented in green and blue.

Conclusion

We have instead adopted a Z_3 symmetry which, combined with the (0, 0, v) structure for the doublet VEVs. In this set-up, two mass-degenerate inert spin-less bosons of opposite CP, which are the lightest amongst the dark particles, contribute identically to DM phenomenology.

We have three doublets field that transform under Z_3

$$\phi_1 \to \omega\phi_1\,, \quad \phi_2 \to \omega^2\phi_2\,, \quad \phi_3 \to \phi_3\,, \qquad \omega = e^{2\pi i/3}. \tag{2}$$

The scalar potential:

$$\begin{aligned}
V &= V_0 + V_{Z_3}, \qquad (3)\\
V_0 &= -\mu_1^2(\phi_1^\dagger\phi_1) - \mu_2^2(\phi_2^\dagger\phi_2) - \mu_3^2(\phi_3^\dagger\phi_3) + \lambda_{11}(\phi_1^\dagger\phi_1)^2 + \lambda_{22}(\phi_2^\dagger\phi_2)^2\\
&+ \lambda_{33}(\phi_3^\dagger\phi_3)^2 + \lambda_{12}(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_{23}(\phi_2^\dagger\phi_2)(\phi_3^\dagger\phi_3) + \lambda_{31}(\phi_3^\dagger\phi_3)(\phi_1^\dagger\phi_1)\\
&+ \lambda'_{12}(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) + \lambda'_{23}(\phi_2^\dagger\phi_3)(\phi_3^\dagger\phi_2) + \lambda'_{31}(\phi_3^\dagger\phi_1)(\phi_1^\dagger\phi_3)\\
V_{Z_3} &= \lambda_1(\phi_2^\dagger\phi_1)(\phi_3^\dagger\phi_1) + \lambda_2(\phi_1^\dagger\phi_2)(\phi_3^\dagger\phi_2) + \lambda_3(\phi_1^\dagger\phi_3) + h.c. \qquad (4)
\end{aligned}$$

los estados propios de masa CP-par y CP-impar pueden ser escritos en términos del ángulo θ_h,

$$\begin{aligned}
\mathbf{H}_1 &\equiv \cos\theta_h\, H_1^0 + \sin\theta_h\, H_2^0 \qquad & \mathbf{A}_1 &\equiv \cos\theta_h\, A_1^0 - \sin\theta_h\, A_2^0\\
\mathbf{H}_2 &\equiv -\sin\theta_h\, H_1^0 + \cos\theta_h\, H_2^0 \qquad & \mathbf{A}_2 &\equiv \sin\theta_h\, A_1^0 + \cos\theta_h\, A_2^0\\
\mathbf{H}_1^\pm &\equiv H_1^{0\pm} & \mathbf{H}_2^\pm &\equiv H_2^{0\pm}
\end{aligned} \tag{5}$$

además se tiene el campo $\mathbf{h} = H_3^0$ con masa $m_h^2 = 2\mu_3^2 = 2\lambda_{33}v^2$

The parameters:

Parameters in the potential: μ_i^2 and λ_i

Physical parameters: $m_{H_1}, m_{H_2}, m_{H_1}^\pm, m_{H_2}^\pm, g_1 = g_{hH_1H_1}/v, g_2 = g_{hH_1H_2}/v$, the mixing angle θ_h

Constraints

Vacuum stability, bounded from below, Perturbativity, global minimum, tree-level unitarity. Invisible Higgs decays.

Benchmarks scenarios:

In the low mass region 45 GeV $\leq m_{DM} = m_{H_1} = m_{A_1} \leq$ 100 Gev (B and C) and for the heavy mass region,$m_{DM} >$ 100 GeV (G) we devise the following benchmark scenarios in the $\theta_h = \pi/4$ limit, using the notation:

$$\Delta_n = m_{H_2} - m_{H_1}, \qquad \Delta_c = m_{H_1^\pm} - m_{H_1}, \qquad \delta_c = m_{H_2^\pm} - m_{H_1^\pm}. \tag{6}$$

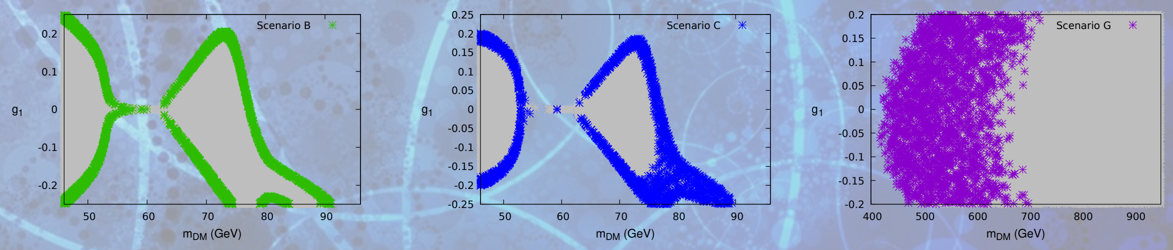
The relic abundance of DM. We use the one measured by Planck $\Omega_{DM}h^2 = 0.1198 \pm 0.0027$. For two DM candidates H_1 and A_1, the prediction of the total relic density is given by $\Omega_{DM}h^2 = \Omega_{DM_1}h^2 + \Omega_{DM_2}h^2$

		scenario B	scenario C	scenario G
$\lambda_{11} = 0.13$	$-0.2 < g_1 < 0.2$	Δ_n =50 GeV	Δ_n =10 GeV	Δ_n =2 GeV
$\lambda_{22} = 0.11$	$-0.2 < g_2 < 0.2$	Δ_c =60 GeV	Δ_c =50 GeV	Δ_c =0.8 GeV
$\lambda_{12} = 0.12$	$-0.1 < \lambda_2 < 0.1$	δ_c =10 GeV	δ_c =1 GeV	δ_c =0.5 GeV
$\lambda'_{12} = 0.12$				
$\lambda_1 = 0.1$				

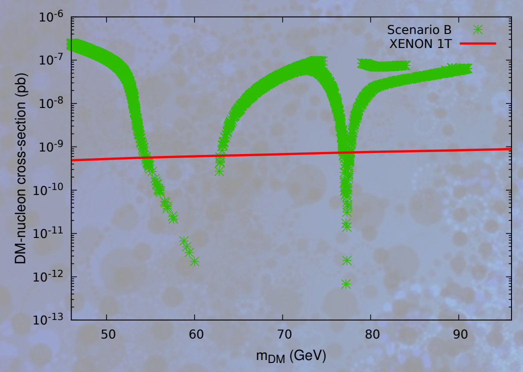
Results

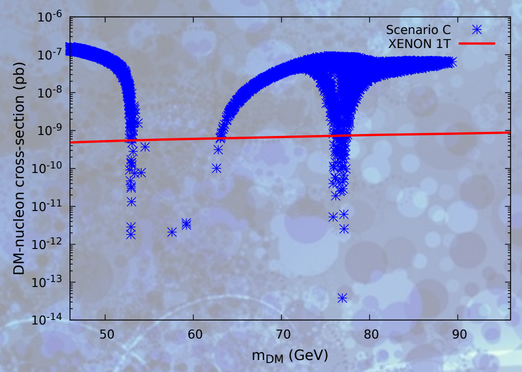
Relic densities

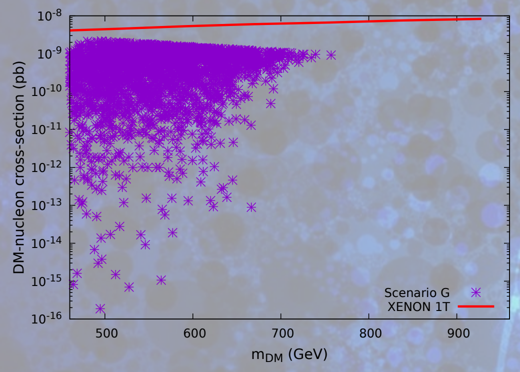
Regions where the model produces the DM relic density in 3σ



Direct detection Limits

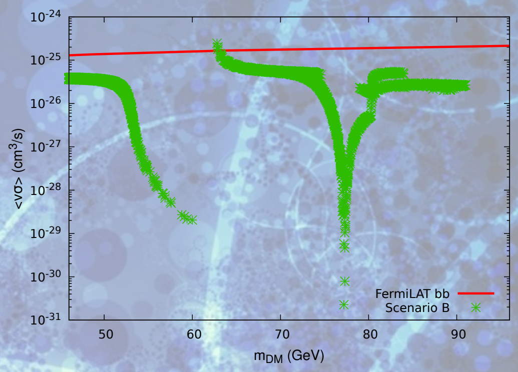


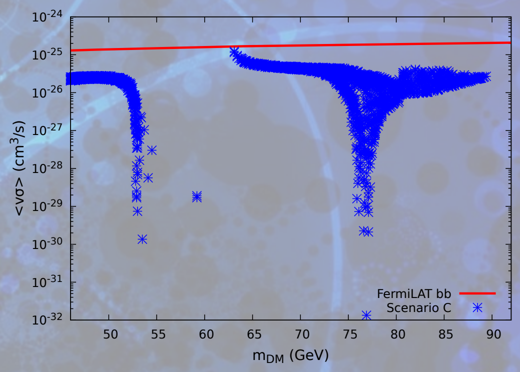


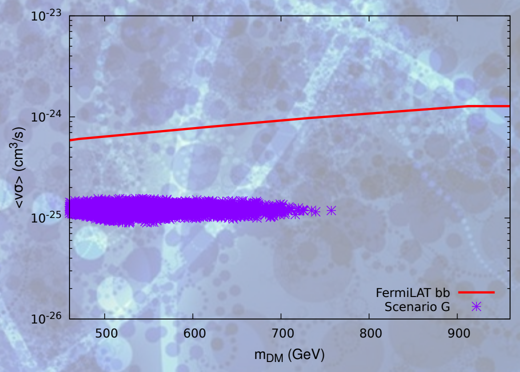


Direct detection bounds on the points that saturate the relic density. The solid red line corresponds to the current XENON1T limit above which any point is ruled out.

Indirect detection Limits







Indirect detection bounds on the points that saturate the relic density. The solid red line corresponds to the current FermiLAT limit above which any point is ruled out.