Towards a way to distinguish between IHDM and the Scotogenic at CLIC

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A study about the phenomenology of IHDM and Scotogenic model and how the contributions could be very different using the same observable.

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1 Introduction

The Scotogenic Model \cite{1} is an appealing candidate to solve some of the problems of the Standard Model (SM) since this model includes radiatively induced neutrino masses and a WIMP-like (Weakly interacting massive particle) Dark Matter (DM) candidate which can be either a scalar or a fermion. In the scalar sector, the Scotogenic model includes the features contained at the Inert Doublet Model \cite{2} (IHDM), which have been widely studied in the literature. In this work, we studied an specific collider signal of the Scotogenic Model and the differences and resemblances between this model and the IHDM. We are considering signals that can be produced in future linear colliders as CLIC through the collision between electrons and positrons, reaching a maximum of energy close to 3 [TeV].

2 The Models

2.1 Inert Higgs Doublet Model

IHDM includes a second Inert Higgs doublet field that will be named $\eta$. Additionally, a discrete $Z_2$ symmetry is added, in order to make the lightest particle of the new field completely stable giving a possible scalar DM candidate. The new scalar field $\eta$ is odd under $Z_2$ symmetry, while the SM particles are even. Thus, no tree level Flavor Changing Neutral Currents (FCNC) appear due to the new symmetry is forbidding some interactions in the Lagrangian, avoiding new Yukawa interactions terms between $\eta$ and the fermions of the SM.

The most general renormalizable CP conserving scalar potential for IHDM is

$$V = m_1^2 \phi^\dagger \phi + m_2^2 \eta^\dagger \eta + \lambda_1 (\phi^\dagger \phi)^2 + \lambda_2 (\eta^\dagger \eta)^2 + \lambda_3 (\phi^\dagger \phi)(\eta^\dagger \eta) + \lambda_4 (\phi^\dagger \eta)(\eta^\dagger \phi) + \frac{\lambda_5}{2} (\phi^\dagger \eta)^2 + \frac{\lambda_6}{2} (\eta^\dagger \phi)^2.$$  \hspace{1cm} \hspace{1cm} (1)

Keeping the potential stable, one needs to establish the following conditions

$$\lambda_1, \lambda_2 > 0, \hspace{1cm} \lambda_3, \lambda_3 + \lambda_4 - |\lambda_5| > -2 \sqrt{\lambda_1 \lambda_2}. \hspace{1cm} (2)$$

and due to we want to fix the real particle of the $\eta$ field as the Dark Matter candidate, we add the next constrains.

$$\lambda_4 + \lambda_5 < 0, \hspace{1cm} \lambda_5 < 0. \hspace{1cm} (3)$$

Computing the mass matrix elements at tree level the nonzero terms will be

$$m_{\pm}^2 = m_2^2 + \frac{\lambda_3}{2} v^2, \hspace{1cm} (4)$$
\[ m_R^2 = m_2^2 + \frac{\lambda_3}{2} v^2 + \left( \frac{\lambda_4 + \lambda_5}{2} \right) v^2, \]  
(5) 
\[ m_I^2 = m_2^2 + \frac{\lambda_3}{2} v^2 + \left( \frac{\lambda_4 - \lambda_5}{2} \right) v^2. \]  
(6)

where \( m_\pm, m_R, m_I \) are the masses of the doublet inert field \( \eta \).

### 2.2 Scotogenic Model

The Scotogenic model is considered one of the simplest models containing a Dark Matter candidate and generating small neutrino mass at 1-loop level. The model contains a doublet scalar field \( \eta \) (the same content at the model the IHDM) and three singlet fermionic fields \( N_i \) \((i = 1, 2, 3)\) which are odd under \( Z_2 \). The full particle content of the model is listed in the Table 1. The \( \eta^0 \) neutral particles and the \( N_i \) particles of the model will contribute giving mass to the neutrinos at one loop (Figure 1). The resulting formula for the neutrino mass matrix is

\[ M_{\nu,ij} = \frac{h_{ik} h_{jk}}{16\pi^2} M_k \left[ \frac{m^2_R}{m^2_R - M_k^2} \ln \frac{m^2_R}{M_k^2} - \frac{m^2_I}{m^2_I - M_k^2} \ln \frac{m^2_I}{M_k^2} \right]. \]  
(7)

The scalar potential in Scotogenic model is given by the equation 1. The new terms appearing in the Lagrangian of the Scotogenic model are a Majorana mass term given by \(-1/2(\bar{N}^i M_{ij} N^{jC})\), and a Yukawa coupling \( L_{Yukawa} = -h_{ij} \bar{N}_i R (i\sigma^2 \eta^*)^\dagger L_j + h.c.\). Notice that for both models, the field \( \eta_R \) is considered as the DM candidate. Problems could appear in the Scotogenic model when at some energy scale \( m^2_2 \) could become negative breaking the \( Z_2 \) symmetry [3]. Studying additional considerations to [3] the problem of breaking the \( Z_2 \) symmetry can be safely avoided.
Table 1: Particle content and quantum numbers of the model.

|       | $SU(2)_L$ | $Y$ | $Z_2$ | $l$ |
|-------|-----------|-----|-------|-----|
| $L$   | 2         | -1  | +     | 1   |
| $e$   | 1         | -2  | +     | 1   |
| $\phi$ | 2   | 0   | -     | 0   |
| $N$   | 1         | 0   | -     | 0   |
| $\eta$ | 2  | 1   | -     | 0   |

3 Results

The cross section $e^+e^- \rightarrow \eta^+\eta$ was obtained using Madgraph [5] and preparing the prospect for the future searches at CLIC experiment [4] to see the differences in the IHDM and Scotogenic model. The Feynman diagrams displayed below in Figure 2 show the contributions of each model. On the other hand, the plot generated (see Figure 3) is based on the BP given in Table [2]. Therefore, those values are in agreement with neutrino physics and preserve $Z_2$ symmetry unbroken.

Finally, other signals will be study in future giving our attention to some restrictions that concern to Dark Matter.

In conclusion, one can notice that the number of events for both models are slightly different when the mass of the new fermions are in the order of the 1 [TeV]. Nevertheless, when the new Yukawas values are of the $10^{-1}$ order the contribution of the Scotogenic model will result in a destructive.

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$M_{N1} = M_{N2} = [800, 1000]$ GeV
$M_{N3} = 1000$ GeV
$m_2 = 800$ GeV
$m_{\nu_1}^2 = [0, 0.001]$ GeV
$\lambda_1 = 0.26$
$\lambda_2 = [0, 0.5]$
$\lambda_3 = 0.1$
$\lambda_4 = -0.1$
$\lambda_5 = -10^{-9}$

Table 2: Parameter space that was used for the generation of the plot in Figure 3.

Figure 3: Plot that represent the number of events for the two different models.

References

[1] E. Ma. Phys. Rev. D 73, 077301 (2006).
[2] M. A. Diaz et al, Advances in High Energy Physics, 8278375 (2015).
[3] A. Merle et al, JHEP 11 (2015) 148
[4] CLICdp collaboration. PoS EPS-HEP2017 (2018)
[5] J. Alwall et al., JHEP 1407, 079 (2014) [arXiv:1405.0301 [hep-ph]].