

Revisiting Inert Doublet Model Parameters



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1 Introduction

After the discovery of the Higgs particle around 125 GeV, a wide window opened in the field of particle physics for exploring the properties of the Higgs boson. This discovery demonstrated that the SM effectively explains observed phenomena at the electroweak scale. However, the SM fails to address several issues, such as non-zero neutrino masses, dark matter (DM), and gravitational interactions. This has spurred the search for new physics beyond the Standard Model (BSM), often by extending the SM to include additional real or complex singlets, doublets, or triplet Higgs fields.

Recently, an excess has been observed for the di-photon Higgs decay, which we are attempting to explain within the framework of the Inert Doublet model. In this proceeding examines how current Di-photon ($\mu_{\gamma\gamma}$) and recent Z-photon ($\mu_{\gamma Z}$) signal measurements constrain the IDM parameter space, particularly the coupling hH^+H^- . Additionally, it provides updated insights into the impact of extra scalars on radiative corrections to the triple Higgs coupling hhh at the one-loop level.

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Y. Tayalati, M. Gouighri (eds.), *The First African Conference on High Energy Physics*, Springer Proceedings in Physics 425,

https://doi.org/10.1007/978-3-031-88933-2_21

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2 The Model

The Inert Doublet Model (IDM) extends the Standard Model (SM) Higgs sector by introducing a dark matter (DM) candidate [1–3]. It is a variant of the 2HDM with an exact Z_2 symmetry. This involves adding an inert scalar doublet, H_2 , to the SM Higgs doublet, H_1 . Notably, H_2 has odd parity under the Z_2 symmetry, resulting in no coupling with fermions and no vacuum expectation value. The physical parametrization of the scalar doublets has the form

$$H_1 = \begin{pmatrix} G^+ \\ (v + h + iG)/\sqrt{2} \end{pmatrix}, \quad H_2 = \begin{pmatrix} H^+ \\ (S + iA)/\sqrt{2} \end{pmatrix}, \quad (1)$$

The Higgs potential is given by:

$$\begin{aligned} V_{\text{IDM}} = & \mu_{11}^2 H_1^\dagger H_1 + \mu_{22}^2 H_2^\dagger H_2 + \eta_1 (H_1^\dagger H_1)^2 + \eta_2 (H_2^\dagger H_2)^2 \\ & + \eta_3 (H_1^\dagger H_1) (H_2^\dagger H_2) \\ & + \eta_4 (H_1^\dagger H_2) (H_2^\dagger H_1) + \frac{1}{2} \eta_5 \left[(H_1^\dagger H_2)^2 + (H_2^\dagger H_1)^2 \right], \end{aligned} \quad (2)$$

Where μ_{11}^2 and μ_{22}^2 represent mass terms, and $\eta_{i=1\dots 5}$ denote quartic couplings. When the electroweak symmetry is broken, H_1 acquires its vacuum expectation value $\text{VEV} \langle H_1 \rangle_0 = v \text{ GeV}$, while H_2 maintains a vanishing $\text{VEV} \langle H_2 \rangle_0 = 0$. The IDM consists of six free parameters that we have chosen as:

$$\mathcal{P} = \{\mu_{22}^2, \eta_2, m_h, m_S, m_A, m_{H^\pm}\} \quad (3)$$

The scalar bosons masses are given by:

$$m_h^2 = 2\eta_1 v^2 = -2\mu_{11}^2, \quad (4)$$

$$m_S^2 = \mu_{22}^2 + \eta_L v^2, \quad (5)$$

$$m_A^2 = \mu_{22}^2 + \eta_S v^2, \quad (6)$$

$$m_{H^\pm}^2 = \mu_{22}^2 + \frac{1}{2} \eta_3 v^2. \quad (7)$$

where the new expressions $\eta_{L,S}$ are as follows

$$\eta_L = \frac{1}{2} (\eta_3 + \eta_4 + \eta_5), \quad \eta_S = \frac{1}{2} (\eta_3 + \eta_4 - \eta_5) \quad (8)$$

3 Results and Discussions

This section explores the impact of new measurement on the parameter space and the trilinear coupling η_{hhh} within the IDM. They applied renormalisation techniques to following process

$$h(q) \rightarrow h(k_1) + h(k_2) \quad (9)$$

and showed its sensitivity to the effects of NP BSM. Here, with the aim of approaching IDM towards such measures, we revisit the additional contribution of the following process.

In line with our purpose in this study, we redefine a ratio that involves the previous quantities as,

$$\Delta\Gamma_{hhh} = \frac{\Gamma_{hhh}^{IDM,1} - \Gamma_{hhh}^{IDM,0}}{\Gamma_{hhh}^{IDM,0}} \quad (10)$$

where $\Gamma_{hhh}^{IDM,1}$ is the one loop amplitude and $\Gamma_{hhh}^{IDM,0} = -3m_h^2/v$ represents the trilinear coupling at tree level, identical to the SM value. For more details, we refer the reader to [4, 5].

In the numerical scan, we will take into consideration all theoretical constraints Perturbativity, Vacuum Stability, Charge-breaking minima, Inert Vacuum and Unitarity on the scalar sector of the model as well as LHC experimental measurement such $\mu_{\gamma\gamma}^{exp}$ and $\mu_{Z\gamma}^{exp}$ and the invisible decay of the SM Higgs, as detailed in Ref. [5]. Also, all along our computings, latest version of HiggsBounds-5.10.2. [6] and HiggsSignals-2.6.2. [7] and micromegas-5. [8] have been used.

Figure 1 displays permissible parameter space, indicating viable ranges for m_ϕ and η_3 . At 99%*C.L.*, m_ϕ is constrained to ≤ 500 GeV and $\eta_3 \leq 9$, confirmed by

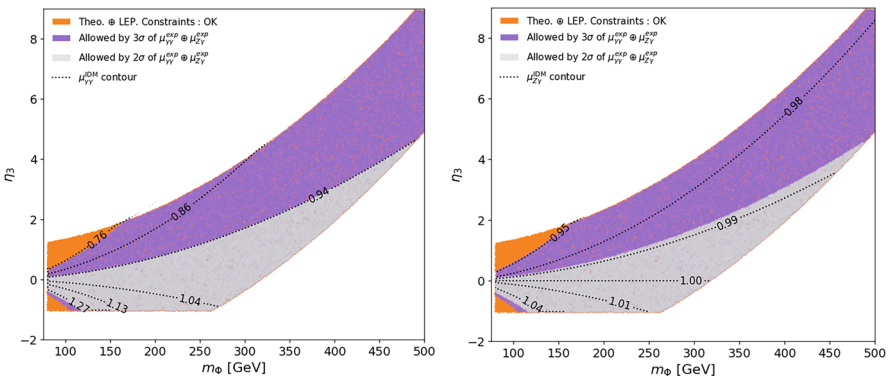


Fig. 1 The correlation between $m_\phi = m_S = m_A = m_{H^\pm}$ and η_3 with the dot-dashed line corresponds to the $\mu_{\gamma\gamma}^{IDM}$ (left) and $\mu_{Z\gamma}^{IDM}$ (right) contours

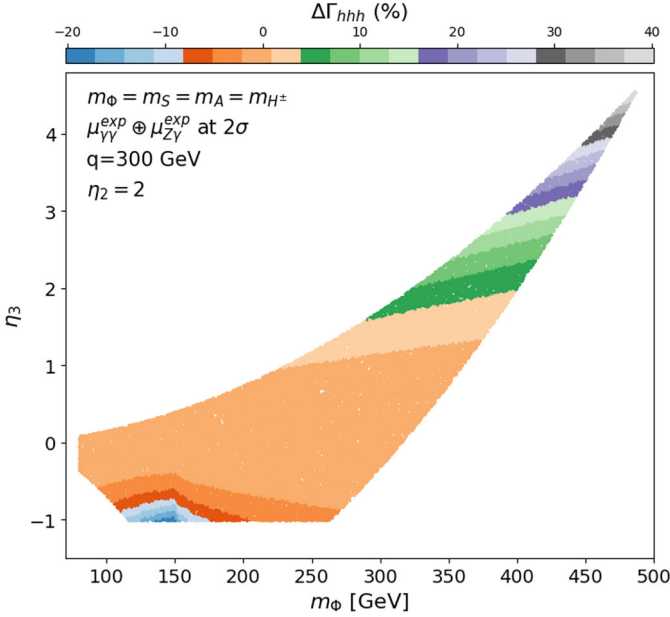


Fig. 2 The $\Delta\Gamma_{hhh}$ variation within the $(\eta_3 - m_\phi)$ plane at 95% .C.L. with $\eta_2 = 2$

the gray region. Narrowing to $\pm 2\sigma$ reveals a smaller area (orange) up to 488 GeV, ruling out enhancements for $Br(h \rightarrow Z\gamma)/SM$ and $Br(h \rightarrow \gamma\gamma)/SM$ above 4.5% and 27%, respectively. Experimental validation requires a positive μ_{22}^2 .

Figure 2 focuses on $\mu_{\gamma\gamma, \gamma Z}^{exp}$ at 2σ C.L., showing reduced parameter space and diminished radiative corrections, particularly for m_ϕ near 485 GeV. $|\Delta\Gamma_{hhh}|$ increases steadily over η_3 , peaking around $\eta_3 = -1$ for $m_\phi \approx 150$ GeV.

4 Conclusion

In this paper, we revisit the Inert Doublet Model (IDM) as an extension of Beyond the Standard Model (BSM), focusing on the two decay modes, $\gamma\gamma$ and $Z\gamma$. We examine the implications of current data on the signal strengths $\mu_{\gamma\gamma, \gamma Z}^{exp}$ for various physical observables. In addition, the effects on the radiative corrections to the triple Higgs coupling hhh at the one-loop level. Our results suggest that $\gamma\gamma$ may constrain the permissible parameter space for the IDM.

References

1. N.G. Deshpande, E. Ma, Pattern of symmetry breaking with two Higgs doublets. *Phys. Rev. D* **18**, 2574 (1978). <https://doi.org/10.1103/PhysRevD.18.2574>
2. Q.H. Cao, E. Ma, G. Rajasekaran, Observing the dark scalar doublet and its impact on the standard-model Higgs Boson at colliders. *Phys. Rev. D* **76**, 095011 (2007). <https://doi.org/10.1103/PhysRevD.76.095011>
3. R. Barbieri, L.J. Hall, V.S. Rychkov, Improved naturalness with a heavy Higgs: an alternative road to LHC physics. *Phys. Rev. D* **74**, 015007 (2006). <https://doi.org/10.1103/PhysRevD.74.015007>
4. A. Arhrib, R. Benbrik, J. El Falaki, A. Jueid, Radiative corrections to the triple Higgs coupling in the inert Higgs doublet model. *J. High Energy Phys.* **12**, 007 (2015). [https://doi.org/10.1007/JHEP12\(2015\)007](https://doi.org/10.1007/JHEP12(2015)007)
5. H. Abouabid, A. Arhrib, A. Hmissou, L. Rahili, Revisiting inert doublet model parameters. *Eur. Phys. J. C* **84**(6), 632 (2024). <https://doi.org/10.1140/epjc/s10052-024-13014-y>
6. P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein, K.E. Williams, *HiggsBounds – 4*: improved tests of extended Higgs sectors against exclusion bounds from LEP, the Tevatron and the LHC. *Eur. Phys. J. C* **74**(3), 2693 (2014). <https://doi.org/10.1140/epjc/s10052-013-2693-2>
7. P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein, *HiggsSignals*: confronting arbitrary Higgs sectors with measurements at the Tevatron and the LHC. *Eur. Phys. J. C* **74**(2), 2711 (2014). <https://doi.org/10.1140/epjc/s10052-013-2711-4>
8. G. Belanger, F. Boudjema, A. Pukhov, A. Semenov, micrOMEGAs: a tool for dark matter studies. *Nuovo Cim. C* **033N2**, 111–116 (2010). <https://doi.org/10.1393/ncc/i2010-10591-3>

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