Two-portal Dark Matter

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Abstract

We propose a dark matter model in which a fermionic dark matter (DM) candidate communicates with standard model particles through two distinct portals: Higgs and vector portals. The dark sector is charged under a $U(1)'$ gauge symmetry while the standard model has a leptophobic interaction with the dark vector boson. The leading contribution of DM-nucleon elastic scattering cross section begins at one-loop level. The model meets all the constraints imposed by direct detection experiments provided by LUX and XENON100, observed relic abundance according to WMAP and Planck, and the invisible Higgs decay width measured at the LHC. It turns out that the dark matter mass in the viable parameter space can take values from a few GeV up to 1 TeV. In addition, we can find in the constrained regions of the parameter space a DM mass of $\sim$ 34 GeV annihilating into $b$ quark pair, which explains the Fermi-LAT gamma-ray excess.

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1 Introduction

Cosmological observations indicate unequivocally that dark matter (DM) makes up about one quarter of the whole mass content of our Universe [1,2]. The big question however is what dark matter is made of and what would be the fundamental interaction of its constituents with ordinary matter.

Direct detection experiments are designed to probe dark matter (DM) elastic scattering off nuclei. In this regards, underground LUX [3] and XENON100 [4] dark matter experiments so far have found no signal on these type of interactions, even though they provide us with an upper limit on the elastic scattering cross section. Recent observation of galactic center gamma-ray excess (GCE), given its intensity and spatial morphology, is in accord with that comes out as a result of dark matter annihilation in the galactic center (GC) [5–11]. There is a large number of models in the literature suggested in order to explain the gamma-ray excess but among them are models with dark matter, annihilating predominantly into b quark pair and on top of that can evade stringent bounds from direct detection experiments [12–18].

Moreover, motivated by new physics scenarios beyond the standard model (SM) focusing on the grand unified theories (see e.g., [19–23]), there are models with DM candidate annihilating via an intermediate neutral gauge boson $Z'$ [24–32].

There are many models where the SM and DM sectors interact through only one portal, in the sense that there are only one type of mediator (e.g. scalar or vector) to connect the two sectors. Although models with two similar mediators [33, 34] have been considered but no model with two different portals (mediators) has been investigated. In this work we propose for the first time a dark matter model with two distinct portals: Higgs and vector ones.

We introduce a two-portal model in which the dark sector consists of a Dirac fermion as a weakly interacting massive particle (WIMP) dark matter candidate, a complex scalar field as the first mediator, both of them charged under a new $U(1)'$ gauge symmetry. Obviously the fermion dark matter is coupled to the dark gauge boson ($Z'$) covariantly. In addition, we assume that the SM quarks are also charged under the $U(1)'$. Thus, the $Z'$ field interacts as well with SM particles, hence the second mediator of the model.

The present article has the following structure. In the next section we introduce our model in detail. In section 3 we compute the SM-Higgs invisible decay width within the model and address the constraints on the invisible decay width from the LHC measurements. We derive a formula for the DM-nucleon cross section in section 4. In section 5 we discuss on the DM relic density within the thermal freeze-out mechanism and our numerical computations for the relic abundance and DM-nucleon interaction are discussed in section 6. In section 7 we find regions in the viable parameter space of two-portal model that can explain the Galactic gamma-ray excess given the recent Fermi-LAT data analysis. We finally finish with a conclusion.
2 The Model

We introduce a dark matter model which has the property of having DM-SM interaction through two different portals, i.e. the vector portal and the Higgs portal. We will show section 4 that there is no tree level DM scattering off nuclei and the Feynman diagram begins with a one-loop contribution which turns out to be suppressive. A two-portal dark matter model can therefore be designed in order to be consistent with the direct detection experiments systematically at the level of Lagrangian. This is reminiscent to the velocity suppressed models for elastic scattering processes but in a different way.

The details of the model comes in the following: beside having a scalar field that mixes with the SM Higgs via the Higgs portal, to have a vector portal interaction, we assume a $U(1)'$ gauge theory in the dark sector as the simplest model including a gauge boson. We also assume that only the SM quarks (but not the leptons) are charged under the $U(1)'$, in other words we are dealing with a leptophobic vector portal interaction.

The total Lagrangian consists of the standard model part, the dark sector and the interactions between these two sector:

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{DM} + \mathcal{L}_{int},$$

where the SM covariant derivative acting on the quarks must now be modified as

$$D_{\mu}^{SM} \rightarrow D_{\mu}^{SM} = D_{\mu}^{SM} - ig' z Z'_{\mu},$$

where $z$ is the dark charge of the quark field that the covariant derivative acts on.

The dark matter Lagrangian consists of a fermionic dark matter and a complex scalar field both charged under $U(1)'$:

$$\mathcal{L}_{DM} = -\frac{1}{4} F_{\mu\nu}^{\prime} F^{\prime\mu\nu} + \bar{\chi} \left( i\gamma^\mu D_{\mu}^{\prime} - m_{\chi} \right) \chi + \left( D_{\mu}^{\prime} \phi \right) \left( D^{\mu} \phi \right)^* - m_{\phi}^2 (\phi \phi^*) - \frac{1}{4} \lambda (\phi \phi^*)^2,$$

where the dark sector covariant derivative is given by

$$D_{\mu}^{\prime} = \partial_{\mu} - ig' \frac{z}{2} Z_{\mu}^{\prime}.$$

We assume that the interaction of the standard model particles with the $U(1)'$ gauge boson $Z_{\mu}^{\prime}$ is leptophobic. In other words, none of the leptons in SM are charged under $U(1)'$. The $\mathcal{L}_{int}$ therefore is written as:

$$\mathcal{L}_{int} = -\lambda (\phi \phi^*) \left( HH^\dagger \right) + g' \frac{z_{Q_L}}{2} Z_{\mu}^{\prime} \bar{Q}_L \gamma^\mu Q_L + g' \frac{z_{u_R}}{2} Z_{\mu}^{\prime} \bar{u}_R \gamma^\mu u_R + g' \frac{z_{d_R}}{2} Z_{\mu}^{\prime} \bar{d}_R \gamma^\mu d_R,$$

where $Q_L$, $u_R$ and $d_R$ are respectively left-handed quark doublet, right-handed up-quark singlet and left-handed down-quark singlet. The couplings of the light quarks $u,d,...$ with $Z_{\mu}^{\prime}$ are considered to be negligible. Therefore, by $z_{Q_L}$, $z_{u_L}$ and $z_{u_R}$ we mean the dark charge of only the third quark family i.e. the $t$ and $b$ quarks. Having introduced dark gauge boson, $Z_{\mu}^{\prime}$, interacting with SM and DM fermionic
Figure 1: Two-portal SM-DM interactions: the dark matter candidate indirectly can interact with standard model through a Higgs and a vector portal. In this model the dark matter can interact directly with only one of the mediators i.e. the dark vector boson.

currents, one should note that new anomalies from triangle Feynman diagrams may arise. However, it can be shown that assigning appropriate dark charges for quarks can lead to an anomaly-free theory\(^1\).

The outcome is that the dark matter scattering off nuclei lacks the tree level contribution (see Fig. 1) and remains suppressed as expected from direct detection experiments. The anomaly-free conditions put constraints on the top and bottom quark \(U(1)'\) charges: \(z_{Q_L} = -2\), \(z_{u_R} = +2\) and \(z_{d_R} = +2\). Substituting these charges in Eq. (5) the \(\mathcal{L}_{\text{int}}\) becomes:

\[
\mathcal{L}_{\text{int}} = -\lambda_1 (\phi \phi^*) \left( HH^\dagger \right) + g' Z'_\mu \bar{t} \gamma^\mu \gamma^5 t + g' Z'_\mu \bar{b} \gamma^\mu \gamma^5 b. \tag{6}
\]

The \(\mathcal{L}_{\text{int}}\) consists of the Higgs portal where the scalar field interacts with the SM-Higgs quadratically, and the vector portal where the dark gauge boson interacts with third family quarks axially.

The scalar field \(\phi\) does not interact directly with the DM particle \(\chi\) but interacts with that only through another mediator of the model i.e. the dark gauge boson \(Z'\). On the other hand, the gauge boson mediator interacts directly with the dark matter particle which can be seen by following the red line in Fig. 1. The scalar field \(\phi\) and the gauge boson \(Z'\) are connected to SM respectively via the Higgs portal and via an interaction with the third family of quarks (vector portal). The novelty of the current model is that there are two distinct mediators at the same time which makes a bridge between the DM sector and the SM sector. Schematically these interactions are shown in Fig. 1.

\(^1\)For some details on anomaly-free conditions in the extended SM including \(U(1)'\) interactions with no additional fermions see [35]. In our model we have an additional fermion that is the dark matter Dirac field. Taking equal dark charges for left- and right-handed components of the Dirac dark fermion \(z_{\chi_L} = z_{\chi_R}\) we lead to the same anomaly-free conditions mentioned above.
The SM-Higgs potential is given by
\[ V_H = -\mu_H \left( HH^\dagger \right) - \lambda_H \left( HH^\dagger \right)^2, \] (7)
where the Higgs doublet takes on a non-zero vacuum expectation value (vev),
\[ H = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + \tilde{h} \end{pmatrix}. \] (8)
We assume that the scalar mediator also takes a non-zero vev,
\[ \langle \phi \rangle = v' \Rightarrow \phi = v' + \frac{1}{\sqrt{2}} \tilde{h}'. \] (9)
\( \tilde{h} \) and \( \tilde{h}' \) are respectively the SM-Higgs and the scalar field fluctuations around their vacuum expectation values.

After substituting Eq. (9) in Eq. (3) and expanding the Lagrangian, the mass of the dark gauge boson turns out to be \( g' v' / \sqrt{2} \). As may be followed in [16] the masses of the SM-Higgs particle \( h \) and the scalar mediator \( h' \) can be obtained by diagonalizing the mass matrix,
\[ M = \frac{\tilde{h}}{\tilde{h}'} \begin{pmatrix} 2\lambda_H v'^2 & \sqrt{2}\lambda_1 v v' \\ \sqrt{2}\lambda_1 v v' & 2\lambda v'^2 - \frac{1}{2} \lambda_1 v'^2 \end{pmatrix}, \] (10)
where we have used the following relations coming from minimizing the potential,
\[ m^2_\phi = -\lambda v'^2 - \lambda_1 v^2, \] (11)
\[ \mu^2_H = -\lambda_H v'^2 - \lambda_1 v'^2. \] (12)
We can redefine the scalars \( \tilde{h} \) and \( \tilde{h}' \) by introducing a mass mixing angle in order to get a diagonalized mass matrix,
\[ h = \sin (\theta) \tilde{h} + \cos (\theta) \tilde{h}', \] (13)
\[ h' = \cos (\theta) \tilde{h} - \sin (\theta) \tilde{h}', \] (14)
with the mixing angle \( \theta \) being
\[ \tan (\theta) = \frac{1}{1 + \sqrt{1 + y^2}}, \quad y = \frac{2m^2_{\tilde{h},\tilde{h}'}}{m^2_{h} - m^2_{h'}}. \] (15)
The masses of the redefined scalar fields read,
\[ m^2_{h,h'} = \frac{m^2_{h} + m^2_{h'}}{2} \pm \frac{m^2_{h} - m^2_{h'}}{2} \sqrt{1 + y^2}. \] (16)
The standard model Higgs is denoted here by $h$ with mass $m_h = 125$ GeV and $h'$ is our singlet scalar. With the application of Eq. (15) and Eq. (16) we can obtain the quartic couplings as a function of SM-Higgs mass, singlet scalar mass, the mixing angle and the vacuum expectation values $v$ and $v'$,

$$
\lambda_H = \frac{m_{h'}^2 \sin^2 \theta + m_h^2 \cos^2 \theta}{2v'^2},
$$

$$
\lambda = \frac{m_{h'}^2 \cos^2 \theta + m_h^2 \sin^2 \theta}{v'^2/2} - \frac{v^2}{v'^2} \lambda_1,
$$

$$
\lambda_1 = \frac{m_h^2 - m_{h'}^2}{2\sqrt{2}vv'} \sin 2\theta.
$$

(17)

The vacuum stability of the potential brings in the following constraints on the couplings; $\lambda_H > 0$, $\lambda v'^2 > \lambda_1 v^2$ and $v'^2 (\lambda_H \lambda - 2\lambda_1^2) > v^2 \lambda_1 \lambda_H$. In our numerical analysis we will choose $m_{\chi}, m_{h'}, \theta, v'$ and $g'$ as free parameters.

3 Invisible Higgs Decay

There are two new decay channels for the SM-Higgs which can modify the total decay width of the Higgs boson within the SM. The current measurement of total decay width for the 125 GeV Higgs reads, $\Gamma_{\text{SM} Higgs} \sim 4$ MeV. In case the dark gauge boson is light enough such that $m_{Z'} < m_h/2$ the Higgs boson is kinematically allowed to undergo the following invisible decay

$$
\Gamma_{\text{inv}}(h \to Z'Z') = \frac{\sin^2 \theta g'^4}{16\pi m_h} (1 - 4m_{Z'}^2/m_h^2)^{1/2}.
$$

(18)

In addition when we consider light scalar boson with $m_{h'} < m_h/2$, another decay channel is plausible for the SM-Higgs with

$$
\Gamma_{\text{inv}}(h \to h'h') = \frac{c^2}{128\pi m_h} (1 - 4m_{h'}^2/m_h^2)^{1/2},
$$

(19)

where

$$
c = 3\sqrt{2}\lambda v' \cos^2 \theta \sin \theta + 12\lambda_H v \cos \theta \sin^2 \theta - 6\lambda_1 v \cos \theta \sin^2 \theta + 2\lambda_1 v \cos \theta + 6\sqrt{2}\lambda_1 v' \sin^2 \theta - 4\sqrt{2}\lambda_1 v' \sin \theta.
$$

(20)

We thus expect the total Higgs decay width to modify as

$$
\Gamma_{\text{tot} Higgs} = \cos^2 \theta \Gamma_{\text{SM} Higgs} + \Theta(m_h - 2m_{Z'}) \Gamma(h \to Z'Z') + \Theta(m_h - 2m_{h'}) \Gamma(h \to h'h'),
$$

(21)

where $\Theta$ is the step function. There exist an experimental upper limit for the invisible branching ratio of the 125 GeV Higgs decay investigated at the LHC, $Br_{\text{inv}} \lesssim 0.35$. In our numerical analysis when applicable, we restrict ourself into the parameter space which satisfies the condition $\Gamma_{\text{inv}}/\Gamma_{\text{tot} Higgs} \lesssim 0.35$. 

6
4 Direct Detection

The tree level DM-quark elastic scattering is suppressed because dark vector boson interaction with light quarks are assumed to be negligible. As depicted in Fig. 2, the first leading contribution to the elastic scattering amplitude is obtained through a one-loop interaction coupled to the SM-Higgs and the Higgs-like scalar where the DM particle and dark gauge vector run in the loop. The DM-quark scattering amplitude is obtained as

\[
\mathcal{M} = \frac{-4i g v_0}{v_H} \left[ \frac{\sin^2 \theta}{q^2 - m_h^2} - \frac{\cos^2 \theta}{q^2 - m_{h'}^2} \right] \bar{q} q \times \int \frac{d^4 q}{(2\pi)^2} \frac{\bar{\chi}(p_2) \gamma_\mu (g + m_\chi) \gamma^\mu \chi(p_1)}{[(p_2 - q)^2 - m_{Z'}^2][(p_1 - q)^2 - m_{Z'}^2][q^2 - m_\chi^2]}.
\]

We then perform the loop integral at \( q^2 = 0 \) to get the effective scattering amplitude

\[
\mathcal{M}_{\text{eff}} = \frac{g^4 v_0}{4\pi^2 m_\chi} \left[ \frac{\cos^2 \theta}{m_q^2} - \frac{\sin^2 \theta}{m_{h'}^2} \right] (\bar{q} q)(\bar{\chi} \chi) \equiv \alpha_q (\bar{q} q)(\bar{\chi} \chi),
\]

where

\[
S(\beta) = -2 + \beta \log \beta - \frac{\beta^2 - 2\beta - 2}{\sqrt{\beta^2 - 4}} \log \frac{\sqrt{\beta} + \sqrt{\beta - 4}}{\sqrt{\beta} - \sqrt{\beta - 4}},
\]

and \( \beta = (\frac{m_{h'}}{m_\chi})^2 \). In order to find the DM-nucleon elastic scattering cross section one needs to evaluate the nucleonic matrix element. However, at the vanishing momentum transfer, the classical assumption that the nucleonic matrix element with quark current is proportional to the nucleonic matrix element with nucleon current \([38-40]\)

\[
\sum_q \alpha_q \langle N_f | \bar{q} q | N_i \rangle \equiv \alpha_N \langle N_f | \bar{N} N | N_i \rangle,
\]

in which

\[
\alpha_N = m_N \left( \sum_{q=u,d,s} f^N_{1q} \frac{\alpha_q}{m_q} + \frac{2}{27} f^N_{1g} \sum_{q=c,b,t} \frac{\alpha_q}{m_q} \right).
\]
The scalar couplings $f^N_{Tq}$ and $f^N_{Tg}$ are responsible for the low energy strong interaction and nucleon mass is denoted by $m_N$. In the numerical computation in section 6 we shall use for the scalar couplings the following values \[ f^p_u = 0.0153, \quad f^p_d = 0.0191, \quad f^p_s = 0.0447. \] (27)

Spin-independent (SI) total cross section of DM-nucleon elastic scattering is finally achieved as

\[ \sigma_{N_{Si}} = \frac{4\alpha^2 N\mu_{\chi N}^2}{\pi}, \] (28)

where $\mu_{\chi N}$ is the reduced mass of the DM-nucleon system.

5 Relic Abundance

The fermionic dark matter candidate in the model laid out earlier is of WIMP type DM whose present day density, the so called relic density, is a remnant from freeze-out epoch in the early Universe. The freeze-out mechanism is based on the assumption that dark particles had been in thermal equilibrium in the early time at temperatures $T \gtrsim m_{DM}$. In an expanding Universe the annihilation rate of dark particles into SM particles slows down and there is an epoch with $T \lesssim m_{DM}$ after which this rate descends below the Hubble expansion rate. On the other hand, from this time on dark particles are not kinematically allowed to get reproduced. Thus, in effect, the number density of dark particles, $n_{\chi}$, remains asymptotically constant within the comoving volume.

The leading DM annihilation reactions which are necessary to determine the relic density are shown in Fig. 3. In this figure the first and third annihilations occur via a $Z'$ boson exchange in s-channel: $\chi\chi \to \bar{b}b, \bar{t}t, Z'h, Z'h'$, while the second diagram shows annihilation with an intermediate DM via t- and u-channel: $\chi\chi \to Z'Z'$. The Boltzmann equation provides us with the evolution of DM number density in terms of thermal averaged annihilation cross sections $\langle \sigma_{ann}v_{rel} \rangle$ as

\[ \frac{dn_{\chi}}{dt} + 3Hn_{\chi} + \langle \sigma_{ann}v_{rel} \rangle [n_{\chi}^2 - (n_{\chi}^{EQ})^2] = 0, \] (29)

where, $n_{\chi}^{EQ}$ is the DM number density at equilibrium condition and $H$ is the Hubble parameter. In order to determine the present value of the number density and therefore the relic density one should solve numerically the Boltzmann equation at freeze-out condition which is when the dark particles are away from equilibrium.
Figure 4: Spin independent elastic scattering cross section of DM with proton is shown as a function of DM mass. All the points displayed in the plot respect constraints from observed relic density and invisible Higgs decay width measurement. The anticipated upper limit bounds on the elastic scattering cross section imposed by LUX and XENON100 experiments are placed to make comparison.

We first implement our model into the program LanHEP [42] to give us all the basic vertices and Feynman rules of our model. Later on to analyze the DM relic density we employ the package MicrOMEGAs [41] which requires our output files from LanHEP program. To check the validity of our model implementation into LanHEP, we utilize the program CalcHEP [43] using our LanHEP outputs to calculate the annihilation cross sections. From this we found agreements with our analytical calculations done for the relevant annihilation cross sections.

6 Numerical Analysis

In this section we will find the viable region in the parameter space which respect observed relic density, invisible higgs decay width measurement and constraints from direct detection experiments. We consider in our parameter space as independent free variables: \( m_\chi, m_{h'}, g', v' \) and \( \theta \). Throughout our study we keep fixed the SM-Higgs mass as \( m_h = 125 \text{ GeV} \) and the SM-Higgs vacuum expectation value as \( v = 246 \text{ GeV} \). To move on, we fix two variables out of five independent free parameters. Chosen are \( \sin \theta = 0.01 \) and \( v' = 800 \text{ GeV} \). It is then ensured that with these choices and the range of the masses we will pick out for the singlet scalar, the quartic couplings will respect bounds from perturbativity and vacuum stability conditions when relations in Eq. (17) are applied.

We begin our scan over the parameter space by generating random values of
order \sim 10^5 for three free parameters in the ranges: \(1 \text{ GeV} < m_\chi < 1 \text{ TeV}, \) \(40 \text{ GeV} < m_{h'} < 160 \text{ GeV} \) and \(0.01 < g' < 1. \) Given the mass relation \(Z' = g'v'/\sqrt{2}, \) the \(Z' \) boson mass will then lie in the range \(5.6 \text{ GeV} < Z' < 565 \text{ GeV}. \) We then use the combined results from Planck [1] and WMAP [2], \(0.1172 < \Omega h^2 < 1226, \) to exclude large regions in the parameter space which are inconsistent with these observations. At the same time, when \(m_{Z'}/m_{h'} < m_h/2 \) we check further to make sure each generated point in the parameter space can fulfill the upper limit constraint on the invisible higgs decay width.

Using the formula provided by Eq. (28) we compute the DM-proton elastic scattering cross section in terms of DM mass among the allowed parameter space. Our results for the elastic scattering cross section are summarized in Fig. 4 for a wide range of the DM mass. It is evident from this figure that in our model there exist viable region in the model parameter space with DM elastic scattering cross section well below the LUX and XENON100 bounds. Therefore we emphasize here on an interesting feature of the two-portal model that the dark particle can evade direct detection in the range of DM mass from a few GeV up to 1 TeV.

7 Galactic Gamma-Ray Excess

The gamma-ray excess observed in the GC from the analyses of the Fermi Large Area Telescope (Fermi-LAT) data is one of the places to look for the trace of the dark matter signals. Among other disfavored scenarios such as millisecond pulsars and cosmic-rays sources, the annihilation of the dark matter (which is more accumulated in the center of the Galaxy) into SM particles explains well the observed gamma-ray excess.

After it was worked out in [5] where the excess reported for the first time, more accurate analyses were implemented by different groups confirming the original results [6, 10, 44].

In this section we examine the two-portal model discussed in the last sections for the gamma-ray excess. The region of interest (ROI) we use in our computation is that of considered in [10], i.e. at Galactic latitudes \(2^\circ \leq |b| \leq 20^\circ \) and Galactic longitudes \(|l| \leq 20^\circ \) known as Inner Galaxy.

Let us briefly review the material we use to obtain the gamma-ray spectrum from dark matter annihilation.

The flux of the gamma-ray produced by annihilation of dark matter into SM particles is given by

\[
\Phi(E_\gamma, \psi) = \frac{\langle \sigma v \rangle}{8\pi m_{DM}^2} \frac{dN_{\gamma}}{dE_\gamma} \int_{\text{l.o.s}} \rho^2(r)dl, \tag{30}
\]

where \(\langle \sigma v \rangle\) is the velocity averaged total annihilation cross section, \(m_{DM}\) denotes the mass of the dark matter and \(dN_{\gamma}/dE_\gamma\) is the gamma energy spectrum produced per annihilation. The integral of the density squared is performed over the line-of-sight (l.o.s). The dark matter density as a function of \(r\), the distance from the center of the Galaxy, is given by \(\rho(r)\). This density function is assumed to be spherically symmetric.
The DM mass \( m_{\text{DM}} = 34 \) GeV is more compatible with Fermi-LAT data analysis \([10]\). and is given by the generalized Navarro-Frenk-White (NFW) halo profile \([45, 46]\),

\[
\rho(r) = \rho_0 \frac{(r/r_s)^{-\gamma}}{(1 + r/r_s)^{3-\gamma}},
\]

with the local dark matter density \( \rho_0 = 0.4 \) GeV/cm\(^3\) and the radius scale \( r_s = 20 \) kpc. Due to high uncertainty in the dark matter density near the center of our Milky Way galaxy, the inner slope parameter takes values in range \( \gamma = 1 - 1.3 \).

We use micrOMEGAs to compute the gamma-ray spectrum for dark masses \( m_{\text{DM}} \sim 20, 34, 44 \) GeV that are picked out from the viable parameter space obtained in the previous section (see Fig. 4). The gamma slop parameter is chosen \( \gamma = 1.15 \) for \( m_{\text{DM}} = 20 \) GeV and \( \gamma = 1.3 \) for \( m_{\text{DM}} = 34, 44 \) GeV. The annihilation cross section that we obtain for different masses are \( \langle \sigma v \rangle = 2.14 \times 10^{-26} \) cm\(^3\) s\(^{-1}\) for \( m_{\text{DM}} = 20 \) GeV, \( \langle \sigma v \rangle = 2.41 \times 10^{-26} \) cm\(^3\) s\(^{-1}\) for \( m_{\text{DM}} = 34 \) GeV and \( \langle \sigma v \rangle = 2.34 \times 10^{-26} \) cm\(^3\) s\(^{-1}\) for \( m_{\text{DM}} = 44 \) GeV. In Fig. 5 we have plotted the energy spectrum of the gamma production for the masses mentioned above. As seen in this figure the DM mass \( m_{\text{DM}} = 34 \) GeV has a better agreement with the Fermi-LAT data analysis performed in \([10]\).
8 Conclusions

In this paper we have proposed a fermionic dark matter model with two Higgs and $Z'$ portals gauged under $U(1)'$ symmetry. The $Z'$ dark gauge boson beside coupling to the fermion DM has leptophobic interaction with the SM particles. The $Z'$ coupling with the light quarks has also been considered negligible, resulting in a suppressed DM-nucleon interaction. The leading contribution to the DM-nucleon elastic scattering comes from a one-loop Feynman diagram shown in Fig. 2.

An interesting upshot is that we find a wide range of DM mass from a few GeV to 1 TeV in the viable parameter space respecting all constraints from observed relic abundance, direct detection bounds and invisible Higgs decay width.

The dark matter annihilation into SM particles results in the gamma-ray energy spectrum that fits best with the Fermi-LAT data for DM mass $m_{DM} = 34$ GeV.

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