Inert Higgs dark matter in the G2HDM

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References: 1512.00229 (JHEP), 1512.07268 (NPB), 1708.02355 (EPJC), 1806.05632 (PRD), 1901.XXXXX, 1902.XXXXX

Outline

Motivations

DM in the G2HDM

DM Phenomenology

- Relic density and Direct detection
- LHC search
- Indirect detection

Conclusions

Three unknown questions and discrete symmetry

1. After the Standard Model (SM) Higgs discovery, does there exist other scalar particles?

2. What is dark matter (DM)?
   (Discrete Z2 symmetry is needed.)

3. Where does the tiny neutrino mass come from?
   (Discrete Z2 symmetry is needed.)

Motivation (I):
DM in 2HDM --- inert doublet Higgs model

2HDM is a good model because its simple extension of SM scalar sector, yet with rich phenomenology, freely to adopt various Yukawa types: Type 1,2,X,Y, and Inert Higgs.

ONLY Inert doublet Higgs contains DM candidate.

An unexplained Z2 discrete symmetry is needed to do so.

Motivation (II):
left-right alignment

1. A wonder of the standard model (SM) is why the left and right representation is not symmetric. Understanding the origin of parity.

2. No Right handed neutrino in SM. It is automatically introduced by SU(2)H.

A new continuous gauge symmetry SU(2)H to align 2HDM as new doublet is used to replace the artificial discrete Z2 symmetry.

(Now left and right representation is a complete symmetric.)

Dark Matter in G2HDM

G2HDM:

Gauged Two Higgs doublet Model

Matter Fields	$SU(3)_C$	$SU(2)_L$	$SU(2)_H$	$U(1)_Y$	$U(1)_X$
$Q_L = (u_L \ \ d_L)^T$	3	2	1	1/6	0
$U_R = (u_R \ \ u_R^H)^T$	3	1	2	2/3	1
$D_R = (d_R^H \ \ d_R)^T$	3	1	2	$-1/3$	-1
$L_L = (\nu_L \ \ e_L)^T$	1	2	1	$-1/2$	0
$N_R = (\nu_R \ \ \nu_R^H)^T$	1	1	2	0	1
$E_R = (e_R^H \ \ e_R)^T$	1	1	2	-1	-1
χ_u	3	1	1	2/3	0
χ_d	3	1	1	$-1/3$	0
χ_ν	1	1	1	0	0
χ_e	1	1	1	-1	0
$H = (H_1 \ \ H_2)^T$	1	2	2	1/2	1
$\Delta_H = \begin{pmatrix} \Delta_3/2 & \Delta_p/\sqrt{2} \\ \Delta_m/\sqrt{2} & -\Delta_3/2 \end{pmatrix}$	1	1	3	0	0
$\Phi_H = (\Phi_1 \ \ \Phi_2)^T$	1	1	2	0	1

TABLE I. Matter field contents and their quantum number assignments in G2HDM.

Extra gauge groups:

SU(2)H * U(1)X

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Horizontal Symmetry:

Adding a new right handed fermion in order to form a doublet. (mimic SM format.)

Embedding two Higgs doublets to be a new doublet, similar to left handed particles.

Like SM right handed fermions, introducing two SM singlet Higgs but forming as a SU(2)H doublet.

Unlike Left-Right (LR) symmetric models, complex gauge fields are electrically neutral.

Comparison with LR symmetric models

LR Symmetry

$$U_L \begin{pmatrix} h_1^0 & h_2^+ \\ h_1^- & h_2^0 \end{pmatrix} U_R^\dagger$$

$$U_R \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$W_R^\pm$ and Z_R

SU(2)H Symmetry

$$U_L \begin{pmatrix} h_1^0 & h_2^0 \\ h_1^- & h_2^- \end{pmatrix} U_R^\dagger \qquad U_R \begin{pmatrix} H_1 \\ H_2 \end{pmatrix}$$

$$U_R \begin{pmatrix} u_R \\ u_R^H \end{pmatrix} \qquad U_R \begin{pmatrix} d_R^H \\ d_R \end{pmatrix}$$

$W'^{\{p,m\}}$ and Z'

Unlike Left-Right (LR) symmetric models, the complex gauge fields are electrically neutral.

Anomaly cancelation:

We have to introduce x_u , x_d , x_nu and x_e to cancel those of right-handed ones from uH_R, dH_R, nuH_R, and eH_R respectively.

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Dark Matter candidates

@ New neutrinos:

Kinematics and symmetry.

@ Doublet and Triplet Higgs:

symmetry (inert Higgs)

@ SU(2)H gauge boson W':

SM charged neutral.

Inert Higgs Dark Matter Candidate

$G = \{G_H^p, H_2^{0*}, \Delta_p\}$, one can write down the inert Higgs block

$$\mathcal{M}_0'^2 = \begin{pmatrix} M_{\Phi\Delta} v_\Delta + \frac{1}{2}\lambda'_{H\Phi} v^2 & \frac{1}{2}\lambda'_{H\Phi} v v_\Phi & -\frac{1}{2} M_{\Phi\Delta} v_\Phi \\ \frac{1}{2}\lambda'_{H\Phi} v v_\Phi & M_{H\Delta} v_\Delta + \frac{1}{2}\lambda'_{H\Phi} v_\Phi^2 & \frac{1}{2} M_{H\Delta} v \\ -\frac{1}{2} M_{\Phi\Delta} v_\Phi & \frac{1}{2} M_{H\Delta} v & \frac{1}{4 v_\Delta}\left(M_{H\Delta} v^2 + M_{\Phi\Delta} v_\Phi^2\right) \end{pmatrix} . \quad (1)$$

The exact dark matter component is given by

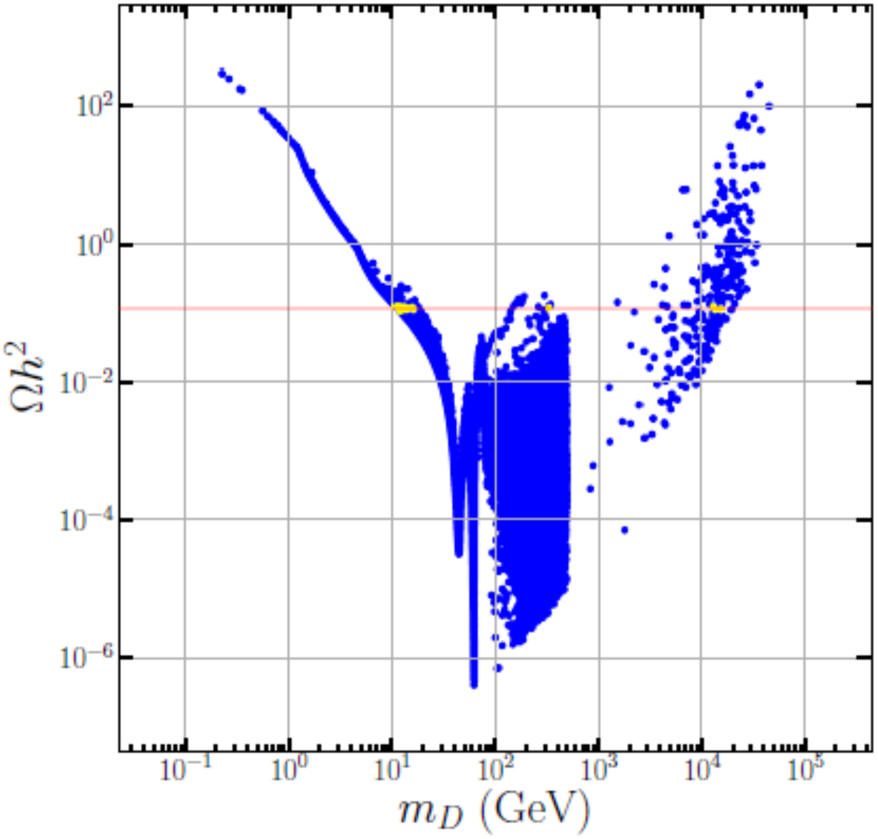
$$D = \mathcal{O}_{12}^D G_H^p + \mathcal{O}_{22}^D H_2^{0*} + \mathcal{O}_{32}^D \Delta_p . \quad (2)$$

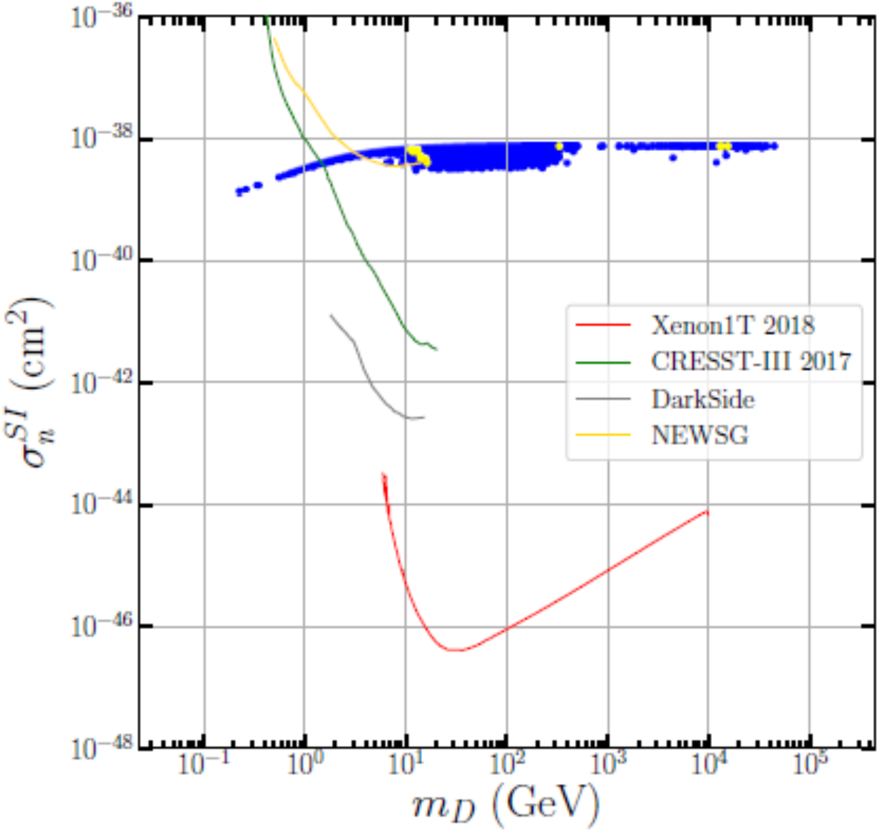
Since G_H^p is massless Goldstone boson, the WIMP DM here will only be either doublet or triplet.

DM Phenomenology

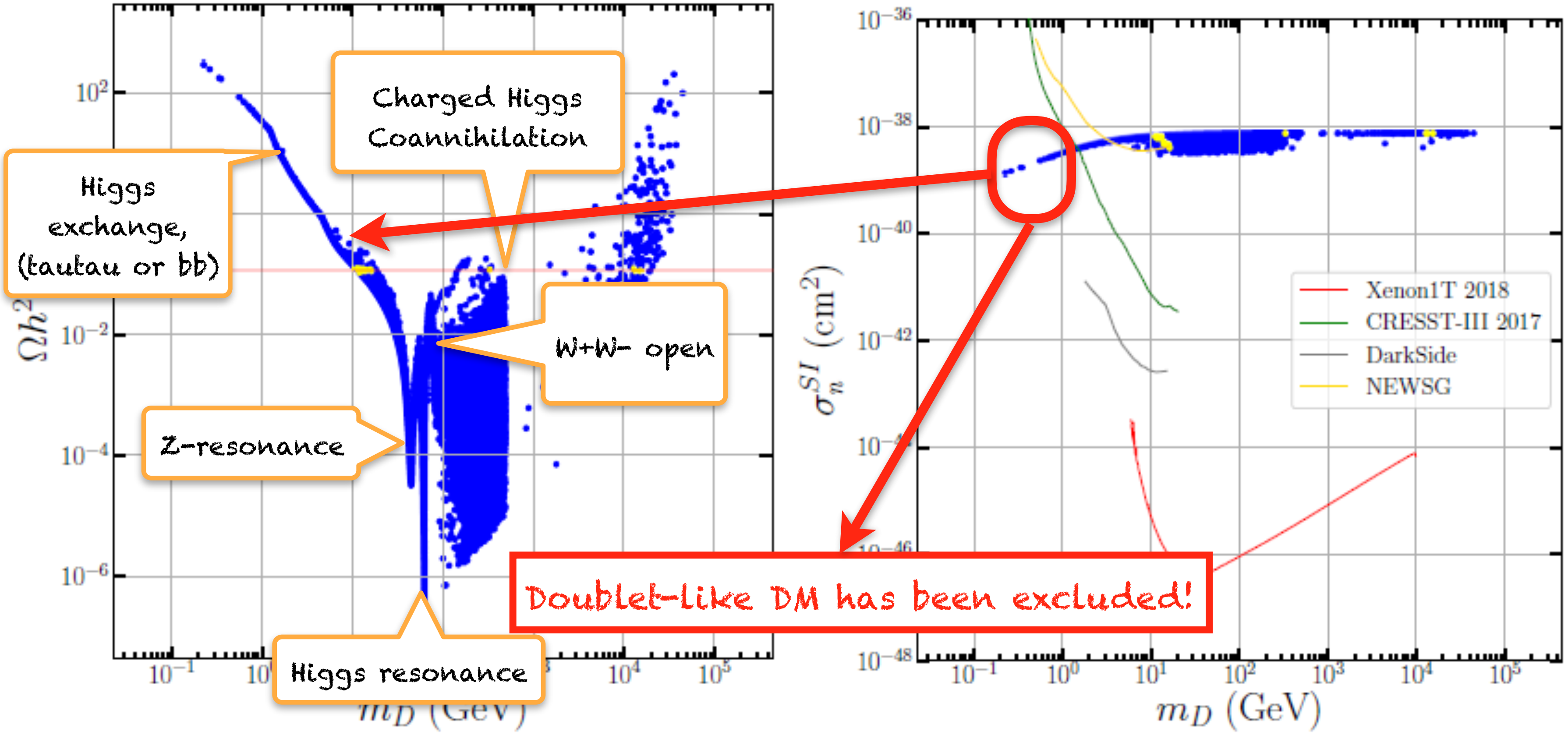
! As simplicity, we set all the new fermion masses to 10 TeV.

Relic density and Direct detection: Doublet-like

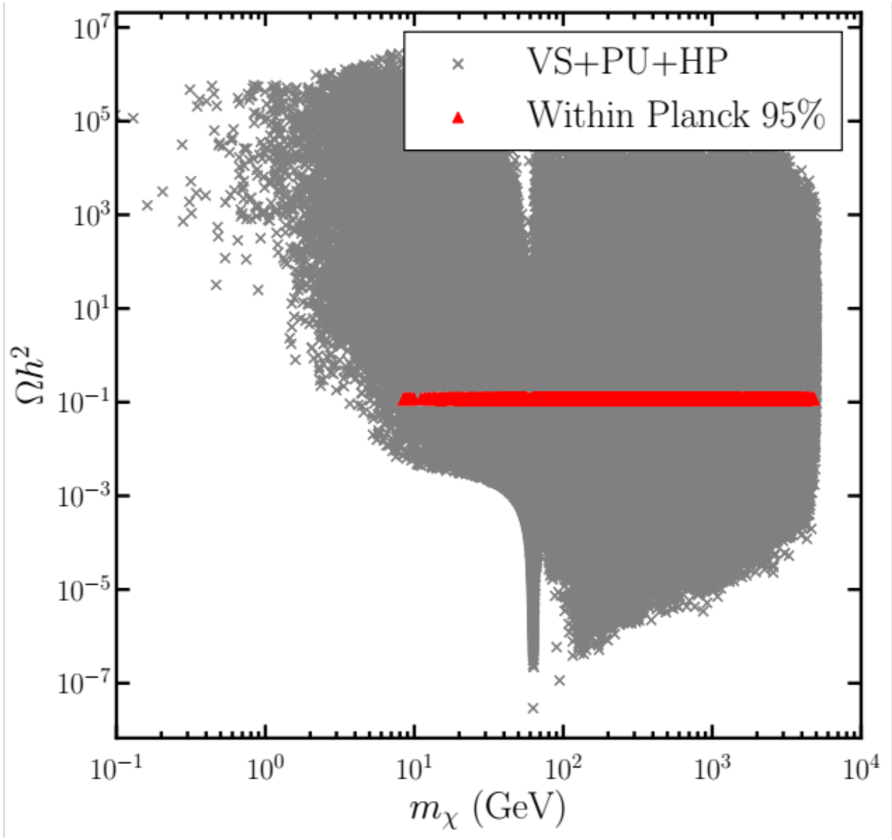


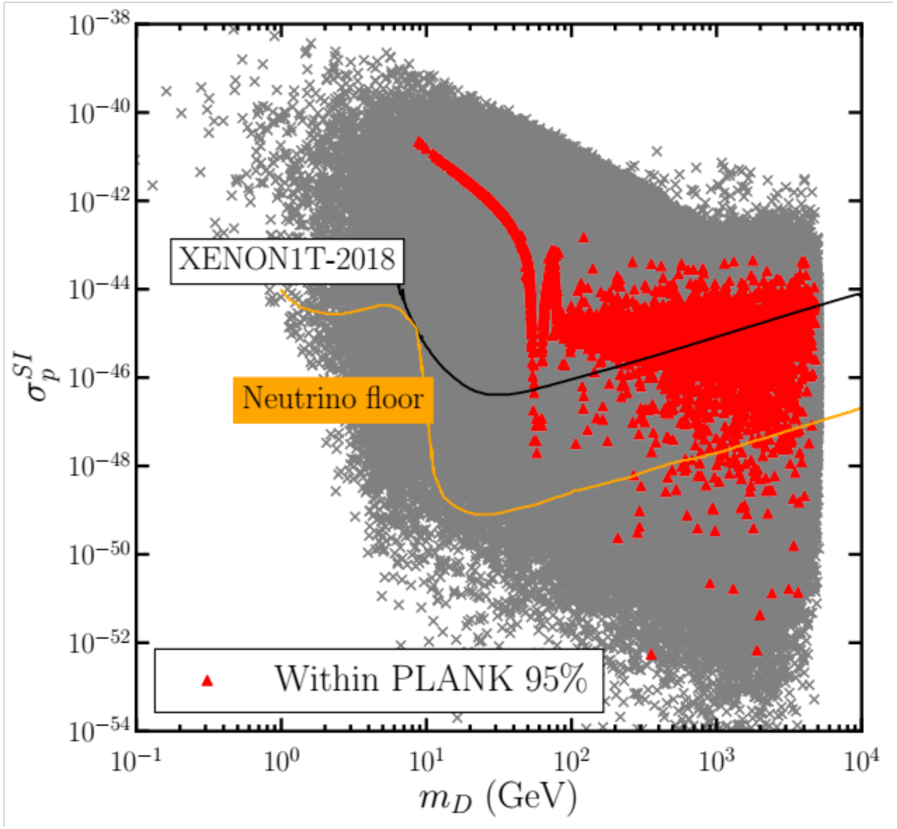


Relic density and Direct detection: Doublet-like

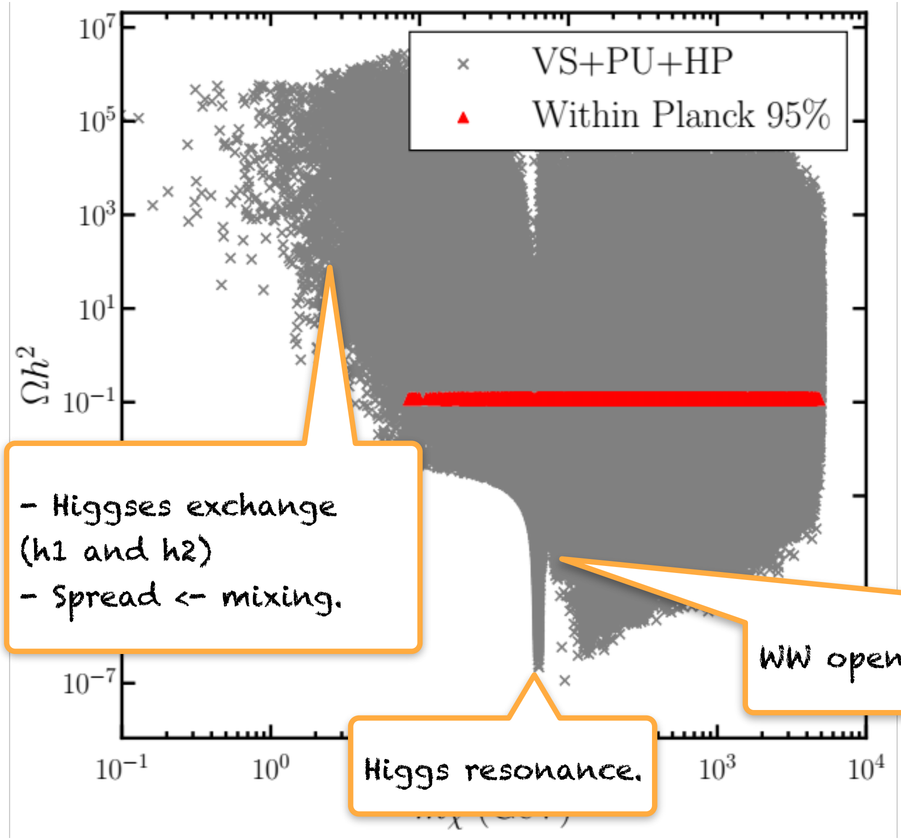


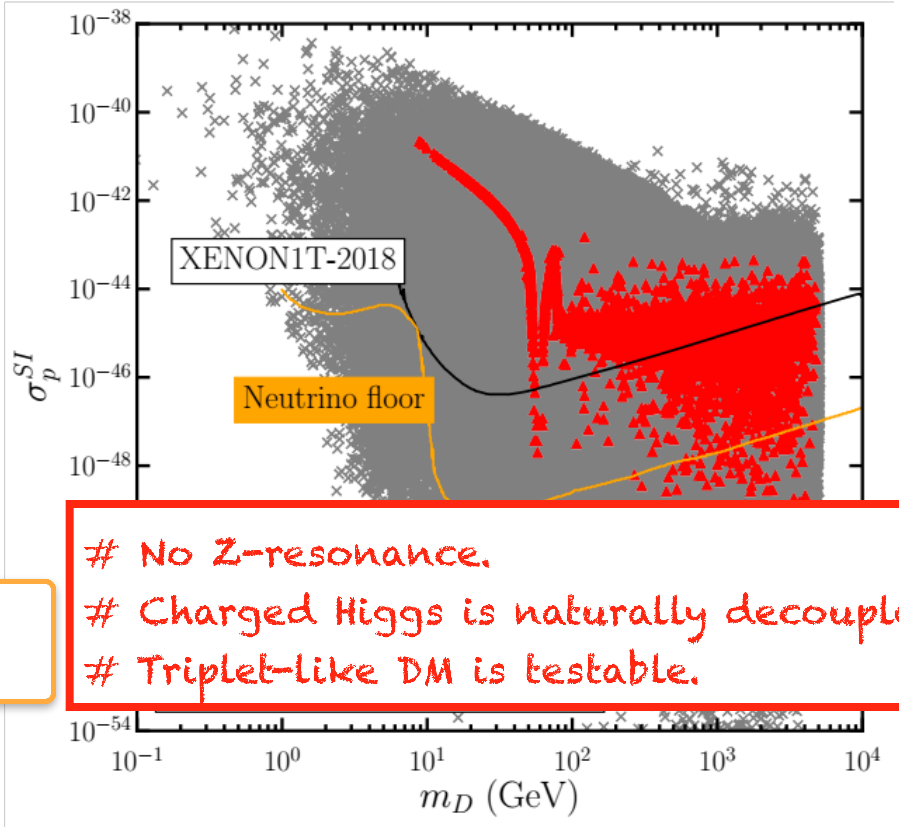
Relic density and Direct detection: Triplet-like





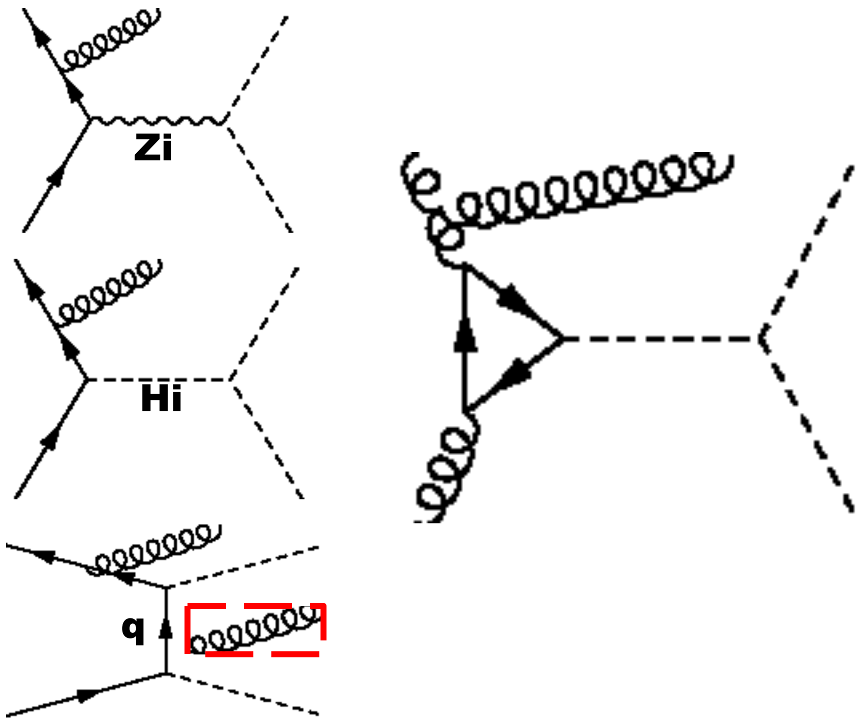
Relic density and Direct detection: Triplet-like





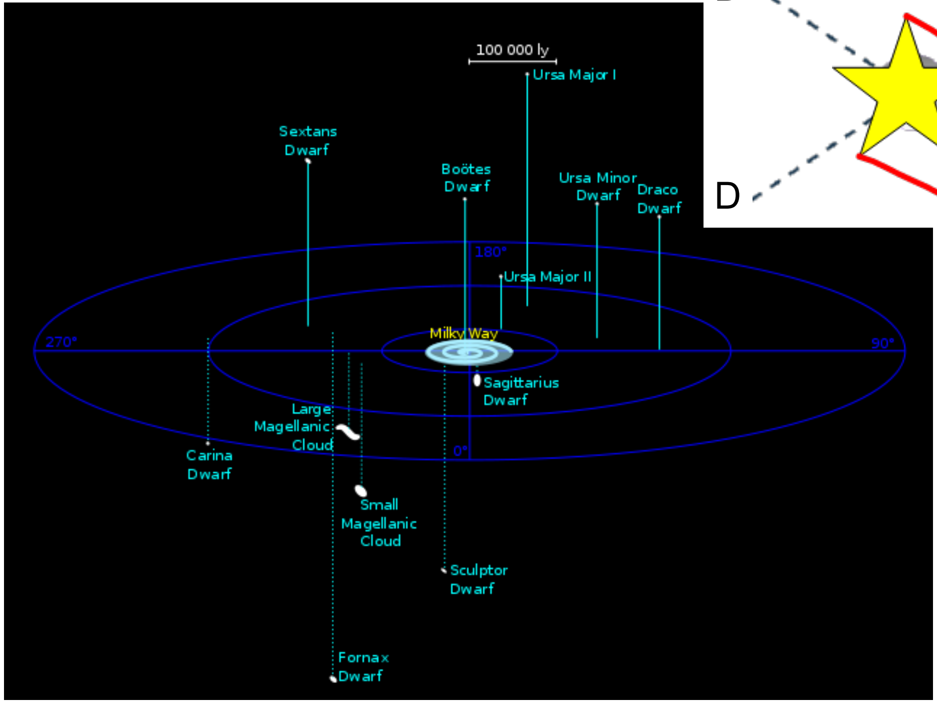
No Z-resonance.
Charged Higgs is naturally decoupled.
Triplet-like DM is testable.

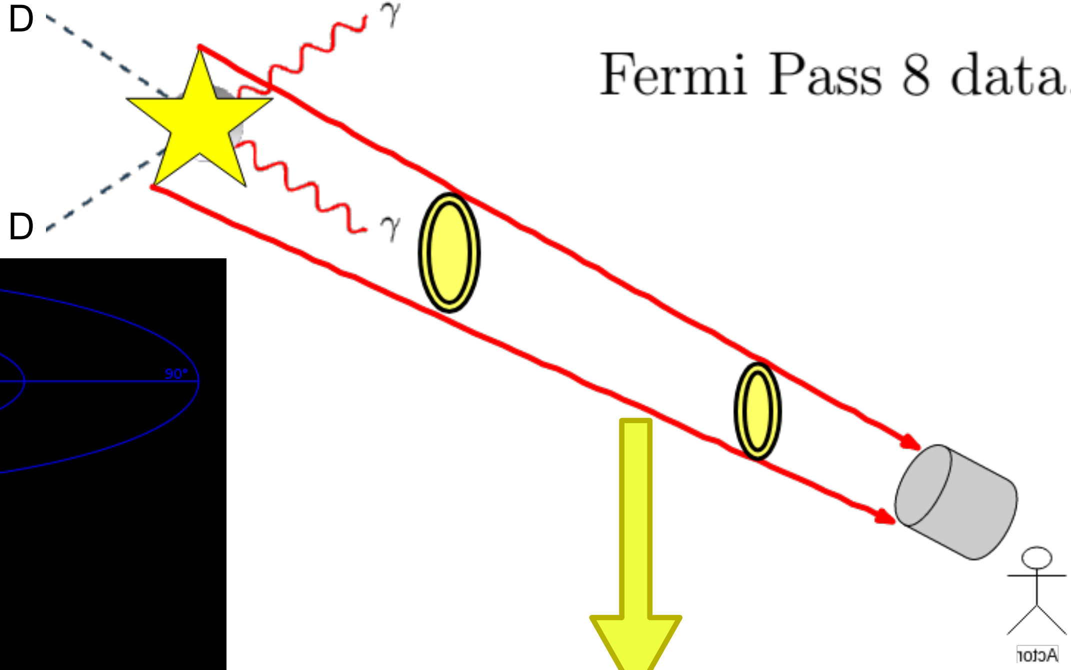
LHC search: mono-jet and Higgs invisible decay



- Triplet DM does not couple to Zi strongly.
- If the Hi exchange dominates, the constraint power is much weaker than DM DD.
- The mono-jet predicted event number is two order magnitudes lower than LHC current data.
- Higgs invisible decay constraint is stronger than mono-jet when DM mass less than Higgs mass. Again, we found it is weaker than DM DD.

DM indirect detection

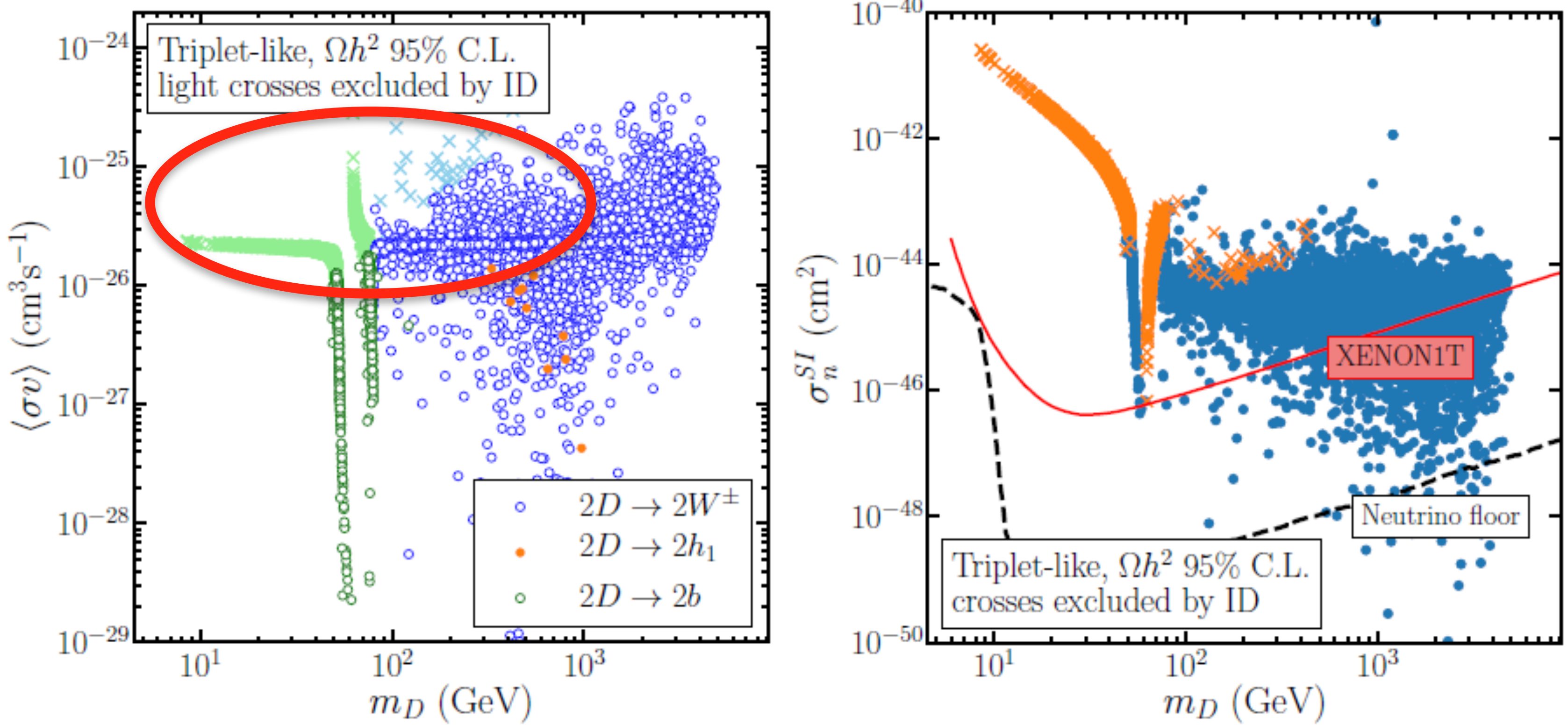




Fermi Pass 8 data.

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{\langle \sigma v \rangle}{8\pi m_D^2} \times J \times \sum_{\text{ch}} \text{BR(ch)} \times \frac{dN_\gamma^{\text{ch}}}{dE_\gamma}$$

DM indirect detection



Only Higgs resonance and some WW final state open are sensitive to dSphs gamma ray data.

Summary and outlook

- First comprehensive DM search in G2HDM is performed.
- Inert Higgs DM with decoupled new fermions is studied.
- Doublet-like DM is completely excluded.
- Triplet-like DM is testable but the DM mass shall be greater than 50 GeV.
- Mono-jet is not so sensitive in this model.
- In the future, we will study other candidates such as W' DM.

Backup

Symmetry Breaking

$$H_1 = \begin{pmatrix} G^+ \\ \frac{v+h}{\sqrt{2}} + iG^0 \end{pmatrix} \quad , \quad \Phi_H = \begin{pmatrix} G_H^p \\ \frac{v_\Phi+\phi_2}{\sqrt{2}} + iG_H^0 \end{pmatrix} \quad , \quad \Delta_H = \begin{pmatrix} \frac{-v_\Delta+\delta_3}{2} & \frac{1}{\sqrt{2}}\Delta_p \\ \frac{1}{\sqrt{2}}\Delta_m & \frac{v_\Delta-\delta_3}{2} \end{pmatrix}$$

$$H_2 = (H_2^+ \; H_2^0)^T.$$

$\Psi_G \equiv \{G^+, G^0, G_H^p, G_H^0\}$ are Goldstone bosons

$\Psi \equiv \{h, H_2, \Phi_1, \phi_2, \delta_3, \Delta_p\}$ are the physical fields

- We have 6 Goldstone bosons, absorbed by 3 SM gauge bosons and 3 $\mathrm{SU(2)_H}$ ones, yielding the massless photon and dark photon

- We have the mixing between $\{h, \delta_3, \phi_2\}$ and $\{G_H^p, \Delta_p, H_2^{0*}\}$ due to:

$$\begin{aligned} V_{\rm mix}(h, \delta_3, \phi_2) \supset\; & + M_{H\Delta}\left(\frac{1}{2}H_1^\dagger H_1 \Delta_3\right) + \lambda_{H\Delta}\left(H_1^\dagger H_1\right)\left(\frac{1}{2}\Delta_3^2\right) \\ & + \lambda_{H\Phi}\left(H_1^\dagger H_1\right)\left(\Phi_2^*\Phi_2\right) + \lambda_{\Phi\Delta}\left(\Phi_2^*\Phi_2\right)\left(\frac{1}{2}\Delta_3^2\right) \\ & - M_{\Phi\Delta}\left(\frac{1}{2}\Phi_2^*\Phi_2\Delta_3\right) \end{aligned}$$

$$\begin{aligned} V_{\rm mix}(G_H^p, \Delta_p, H_2^{0*}) \supset\; & + M_{H\Delta}\left(\frac{1}{\sqrt{2}}H_1^\dagger H_2 \Delta_p + \frac{1}{\sqrt{2}}H_2^\dagger H_1 \Delta_m\right) \\ & - M_{\Phi\Delta}\left(\frac{1}{\sqrt{2}}\Phi_1^*\Phi_2\Delta_p + \frac{1}{\sqrt{2}}\Phi_2^*\Phi_1\Delta_m\right) \end{aligned}$$