Exploring new physics through an extended Higgs sector

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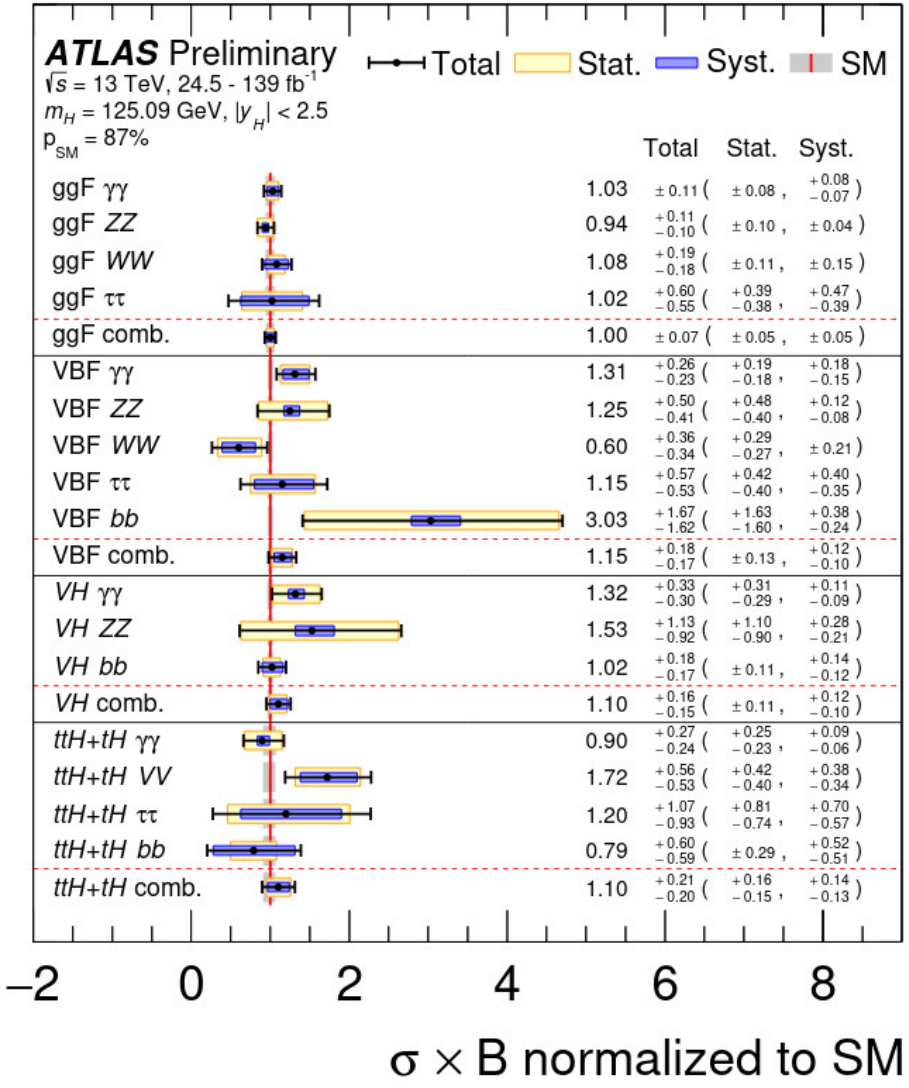
The Higgs sector

ATLAS-CONF-2020-027, August 3, 2020

- Higgs discovery
- Absence of BSM signals in colliders
- Precise measurements could give clues to BSM physics

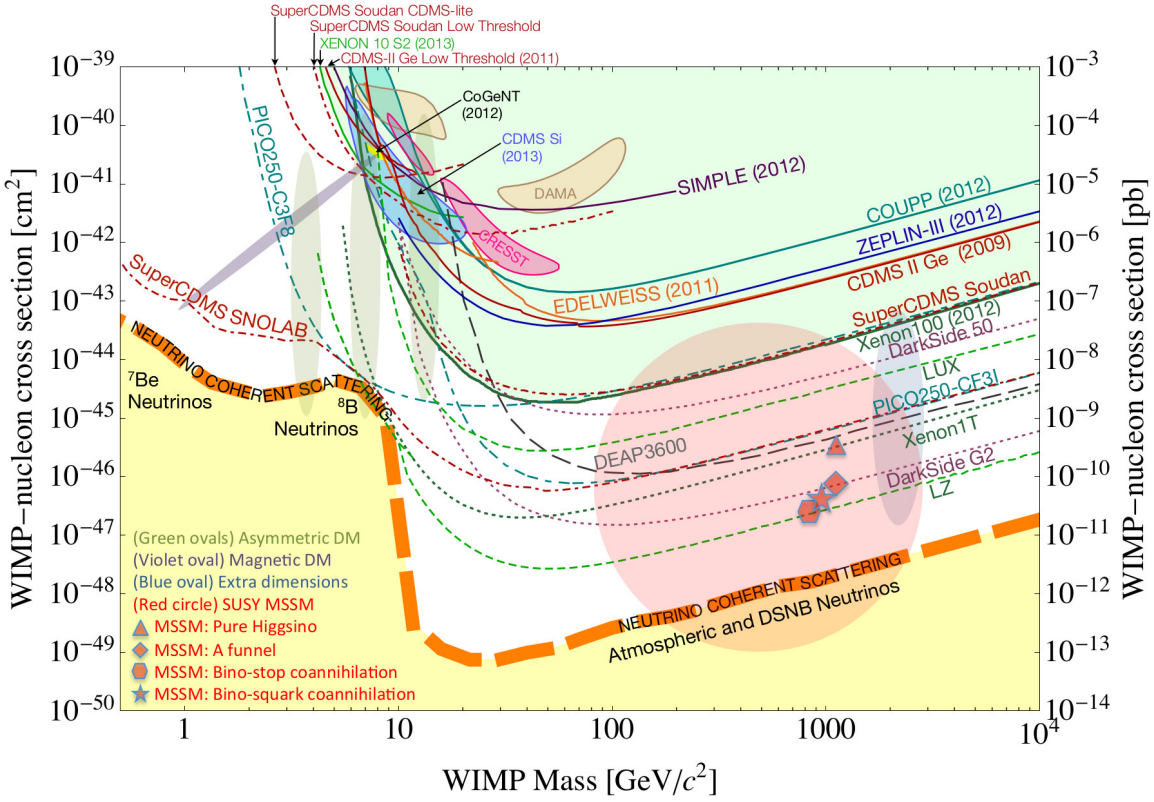


Dark Matter candidates

WIMPs (**W**eakly **I**nteractive **M**assive **P**articles)

- Still among the most popular explanation for Dark Matter
- Under strong pressure from direct detection experiments.

P. Cushman, *et al.* "Working Group Report: WIMP Dark Matter Direct Detection," [arXiv:1310.8327 [hep-ex]].



Blind Spots

$\Rightarrow$ Elastic cross section is suppressed by some kind of cancellations.

$\Rightarrow$ An extended Higgs sector, a usual feature of many BSM frameworks.

How the appearance of blind spots changes when the Higgs sector is a 2HDM?

The model

$$
\begin{aligned}
-\mathcal{L} \quad \supset \quad & \frac{1}{2} M_S S S + M_D D_1 D_2 + y_1^1 S D_1 \bar{\Phi}_1 + y_2^1 S D_2 \Phi_1 \\
& + y_1^2 S D_1 \bar{\Phi}_2 + y_2^2 S D_2 \Phi_2 + h.c.
\end{aligned}
$$

where $\bar{\Phi}_{1,2} = i\sigma_2 \Phi_{1,2}^*$.

Two Higgs doublets, Φ_1, Φ_2, with hypercharges $Y = 1/2$
Two fermionic $SU(2)$ doublets D_1, D_2 with hypercharge $+1/2$, $-1/2$

Blind Spots

Fermion mass eigenstates: χ_i^0. Physical Higgs states: h_0, H^0

$$-\mathcal{L} \supset y_{h\chi_i\chi_i} h^0 \chi_i^0 \chi_i^0 + y_{H^0\chi_i^0\chi_i^0}$$

Analytical expressions for the effective couplings, in terms of $h_{1,2}$

$$y_{h_a\chi_i\chi_i} = \pm\frac{1}{2}\frac{\partial m_{\chi_i^0}}{\partial v_a}, \qquad \frac{\partial}{\partial v_a}\left|\mathcal{M} - m_{\chi_i^0} I\right| = 0$$

It is straightforward to obtain the blind spots region.

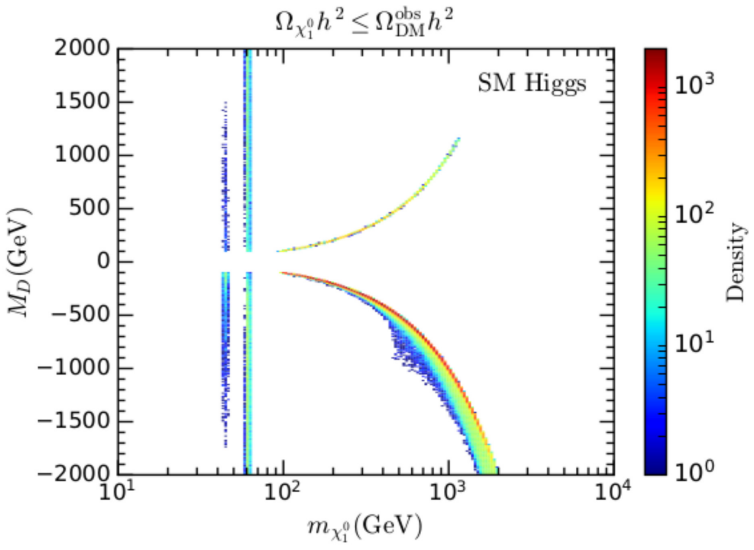
The amplitude for the DM-nucleon scattering $\chi_1^0 N \to \chi_1^0 N$,

$$y_{\rm DD}^{\rm eff} \equiv \sum_q \left[y_{h\chi_1\chi_1} + \frac{m_h^2}{m_H^2} y_{H\chi_1\chi_1} \right] f_q^N$$

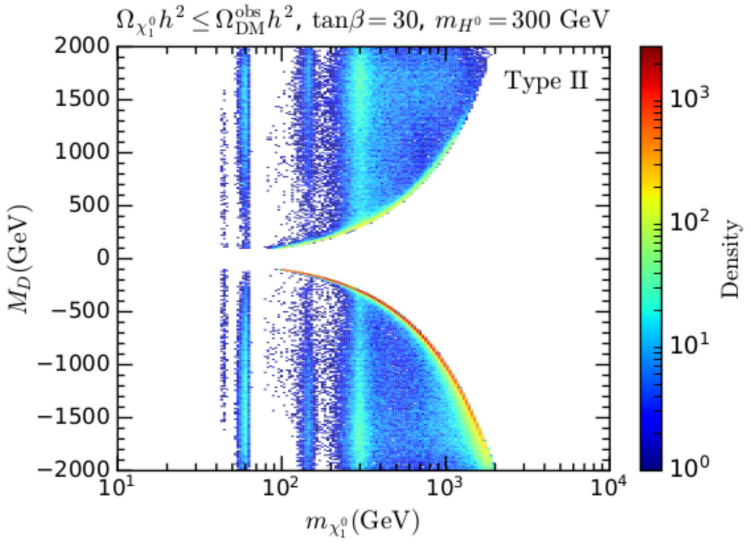
Blind Spots

The alignment limit: The light Higgs is 100 % SM-like

Alignment from decoupling



Alignment without decoupling



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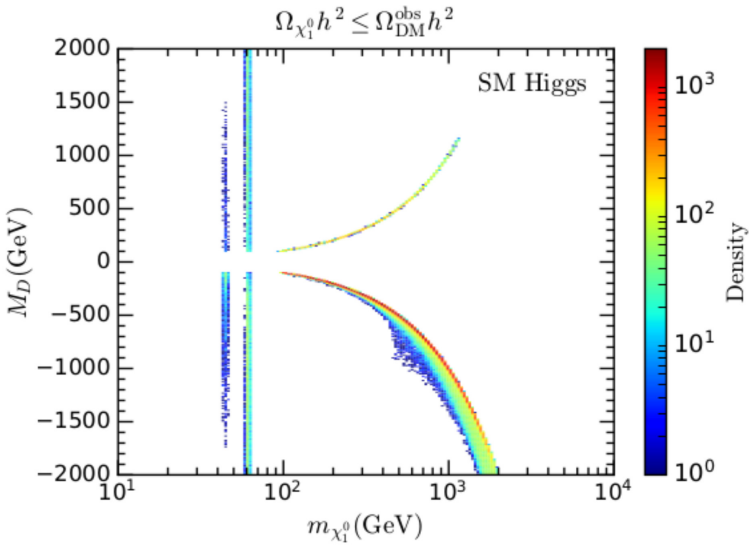

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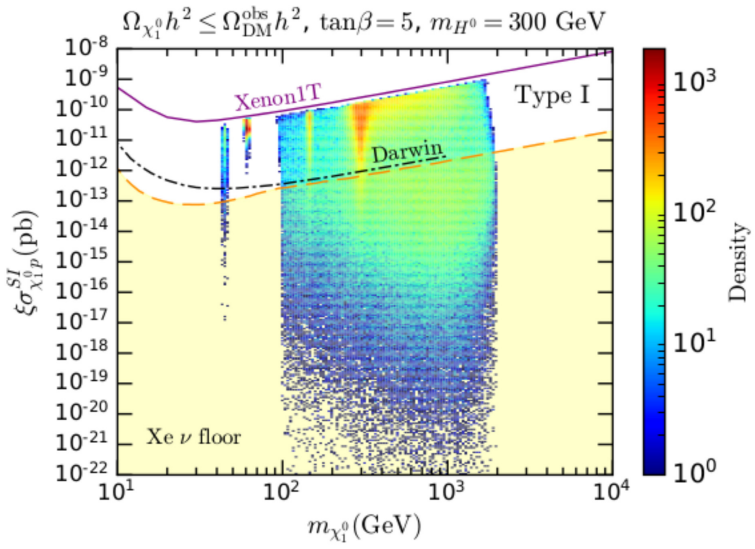


2HDM singlet portal to DM

Let us consider an scenario where:

⇒ The DM sector consist of a single particle, a majorana fermion

⇒ The Higgs sector comprises two Higgs doublets.

$$
\begin{aligned}
-\mathcal{L}_\chi \quad \supset \quad & \frac{1}{2} M \bar{\chi}\chi + \frac{1}{2\Lambda}\bar{\chi}\chi \left(\hat{y}_1 |\Phi_1|^2 + \hat{y}_2 |\Phi_2|^2 + (\hat{y}_3 \bar{\Phi}_1 \Phi_2 + \text{h.c.})\right) \\
& + \frac{1}{2\Lambda}\bar{\chi}\gamma_5\chi \left(\hat{y}_4 \bar{\Phi}_1 \Phi_2 + \text{h.c.}\right)
\end{aligned}
$$

In the alignment limit

$$
-\mathcal{L}_{\text{tril}} \supset \frac{v}{2\Lambda}\bar{\chi}\chi \left(y_1 h^0 + y_3 H^0\right) + y_4 \frac{v}{2\Lambda} i\bar{\chi}\gamma_5\chi \; A + \text{h.c.}
$$

On top there are quartic interaction that are going to be important.

2HDM singlet portal to DM

DM annihilation channels

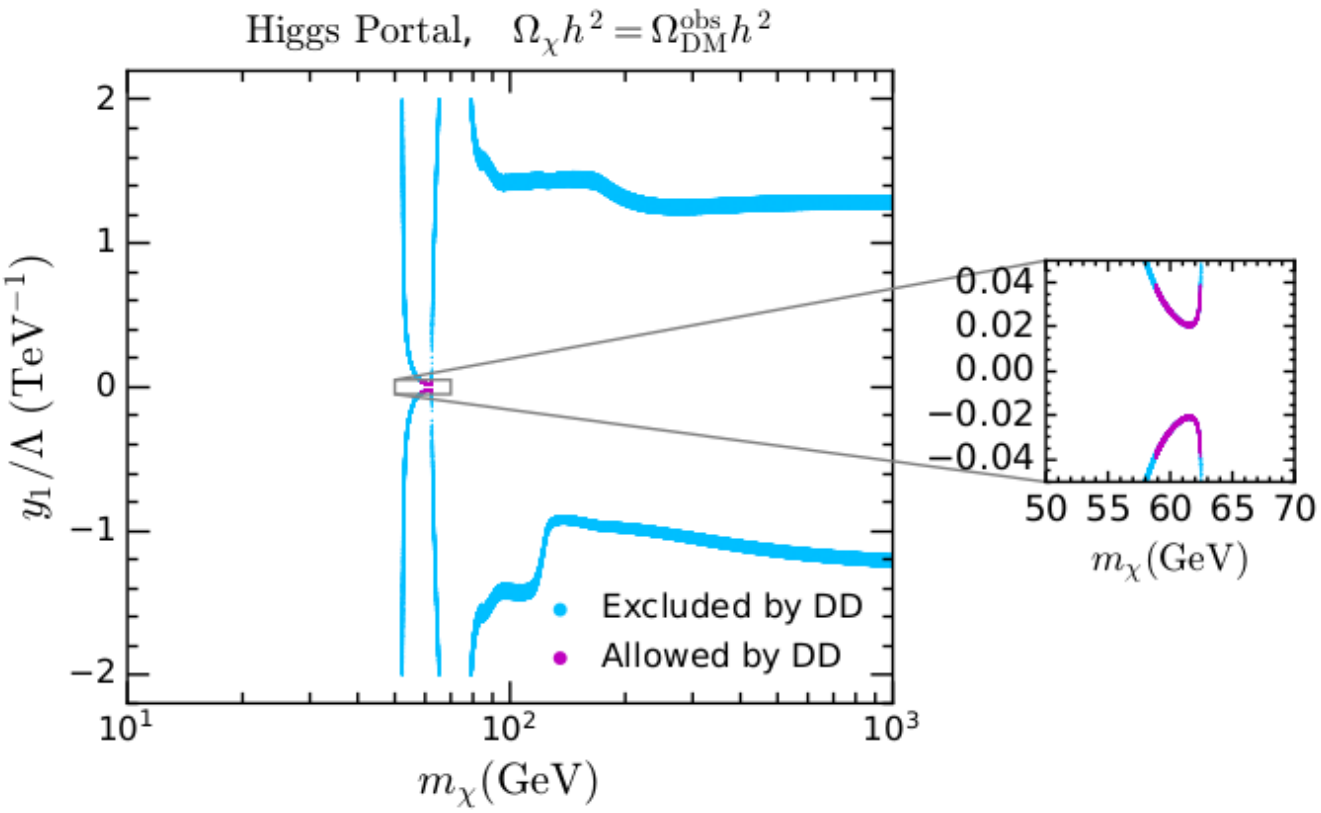
$$
\begin{aligned}
y_1 &: \quad \chi\chi \to h^0 \to \mathrm{SM\ SM}, \quad \chi\chi \to h^0 h^0, \quad \chi\chi \to ZZ, \quad \chi\chi \to W^+W^-, \\
y_2 &: \quad \chi\chi \to H^0 H^0, \quad \chi\chi \to AA, \quad \chi\chi \to H^+H^-, \\
y_3 &: \quad \chi\chi \to H^0 \to \mathrm{SM\ SM}, \quad \chi\chi \to h^0 H^0, \quad \chi\chi \to ZA, \quad \chi\chi \to W^\pm H^\mp, \\
y_4 &: \quad \chi\chi \to A \to \mathrm{SM\ SM}, \quad \chi\chi \to h^0 A, \quad \chi\chi \to H^0 A, \quad \chi\chi \to ZH^0, \quad \chi\chi \to W^\pm H^\mp.
\end{aligned}
$$

The amplitude of spin-independent DM-nucleon scattering $\chi N \to \chi N$,

$$
B_N \equiv \sum_q \left[y_1 + \frac{m_h^2}{m_H^2} C_q \; y_3 \right] f_q^N,
$$

2HDM singlet portal to DM

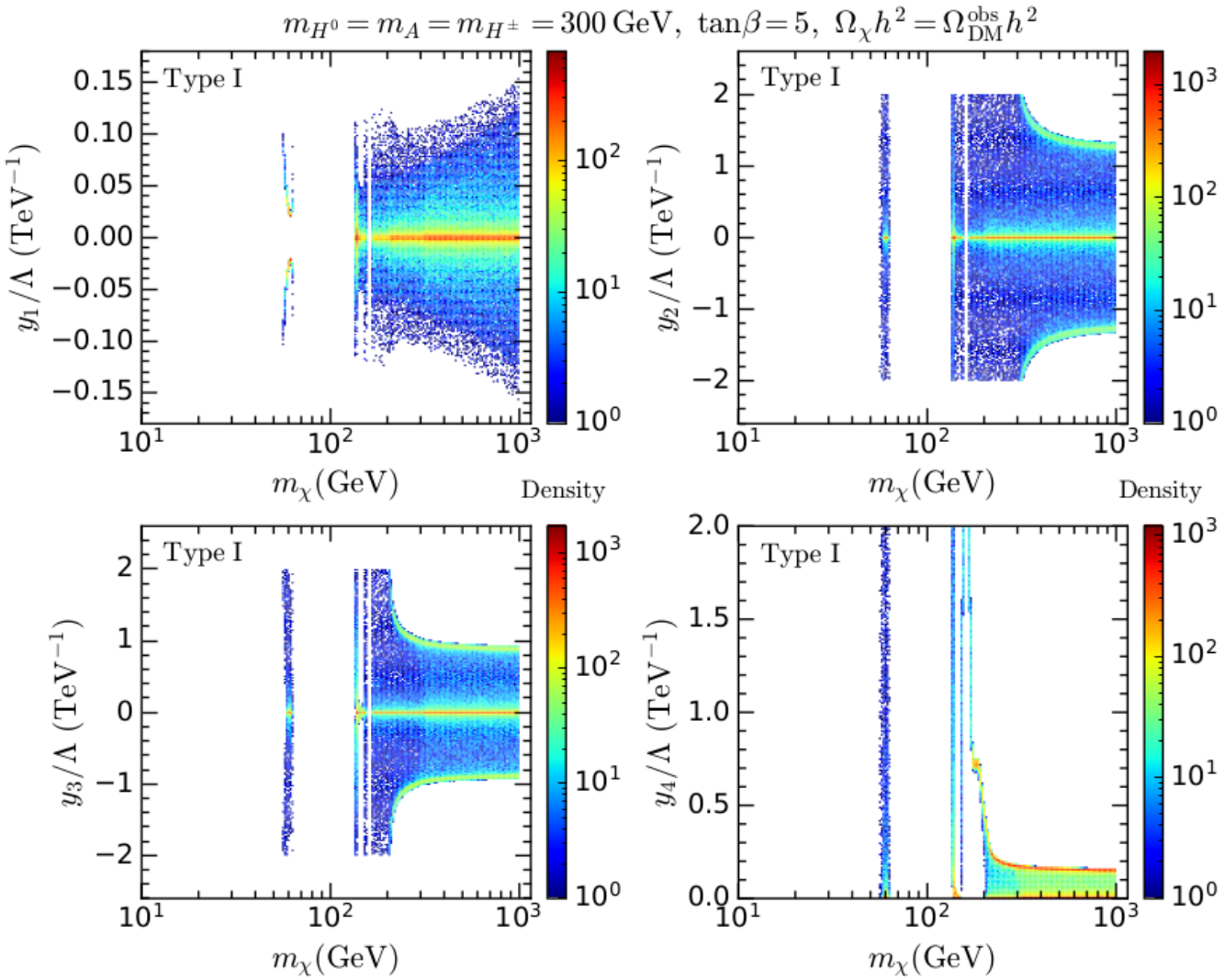
Alignment with decoupling



y_1 controls all the relevant processes.

2HDM singlet portal to DM

Alignment without decoupling



Higgs portal to DM

M. E. Cabrera, *et.al* [arXiv:1912.01758 [hep-ph]], [arXiv:2011.09101 [hep-ph]]

- Blind spots with non minimal Higgs sector: in a generic 2HDM
- A non minimal Higgs sector disentangle annihilation and elastic scattering processes.
- The presence of the extra Higgs states enable new paths for resonant DM annihilation, safe from Direct Detection experiments.

The assumption of an extended Higgs sector has a great potential to rescue theoretically appealing WIMP scenarios.

My interests

- Investigating the nature of Dark Matter
- The Higgs sector as a window to BSM physics
- Collider phenomenology
  1. BSM searches with boosted objects in LHC.
  2. Exploring DM scenarios in colliders.

Gracias por su atención