A vector-like Top quark Portal to a minimal non-Abelian Vector Dark Matter (TPVDM)

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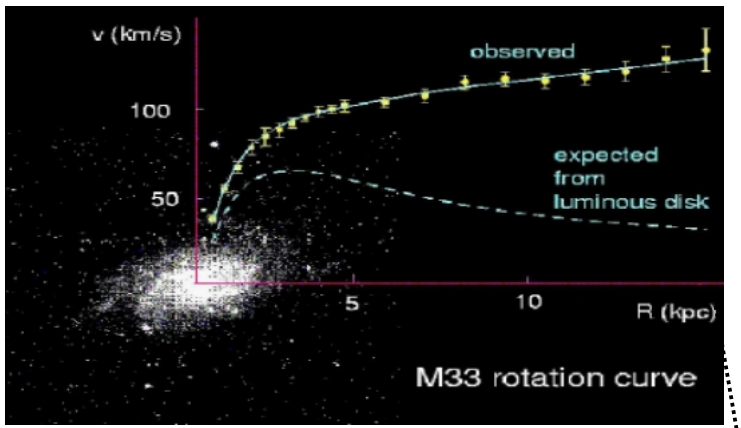
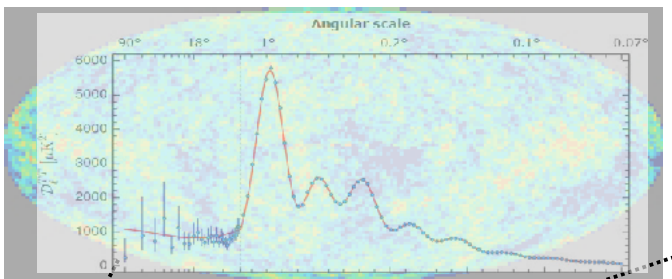
Based on 2203.04681 and 2204.03510 with
A. Belyaev, A. Deandrea, S. Moretti, L. Panizzi, NT

The existence of Dark Matter is confirmed by several independent observations at cosmological scale

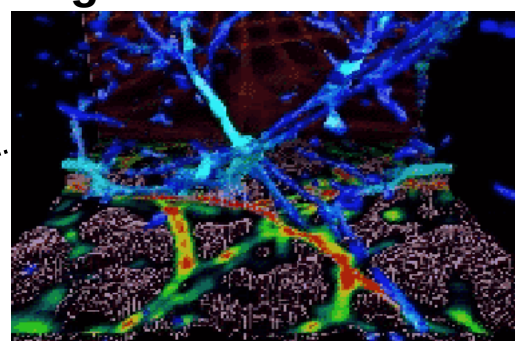
Galactic rotation curves

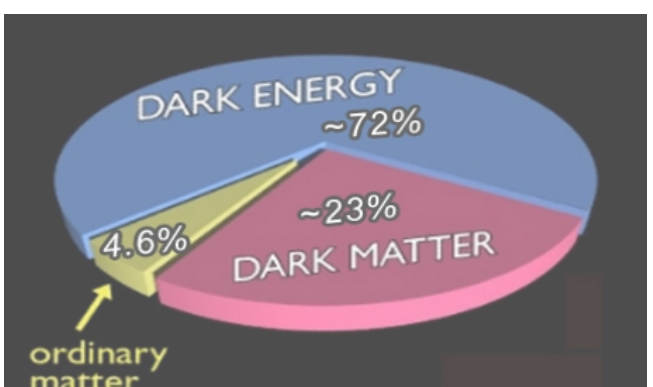


CMB: WMAP and PLANCK

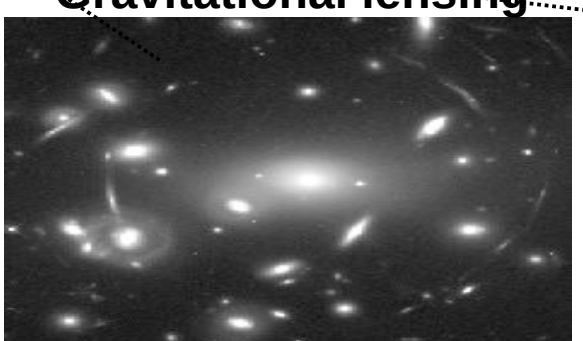


Large Scale Structures



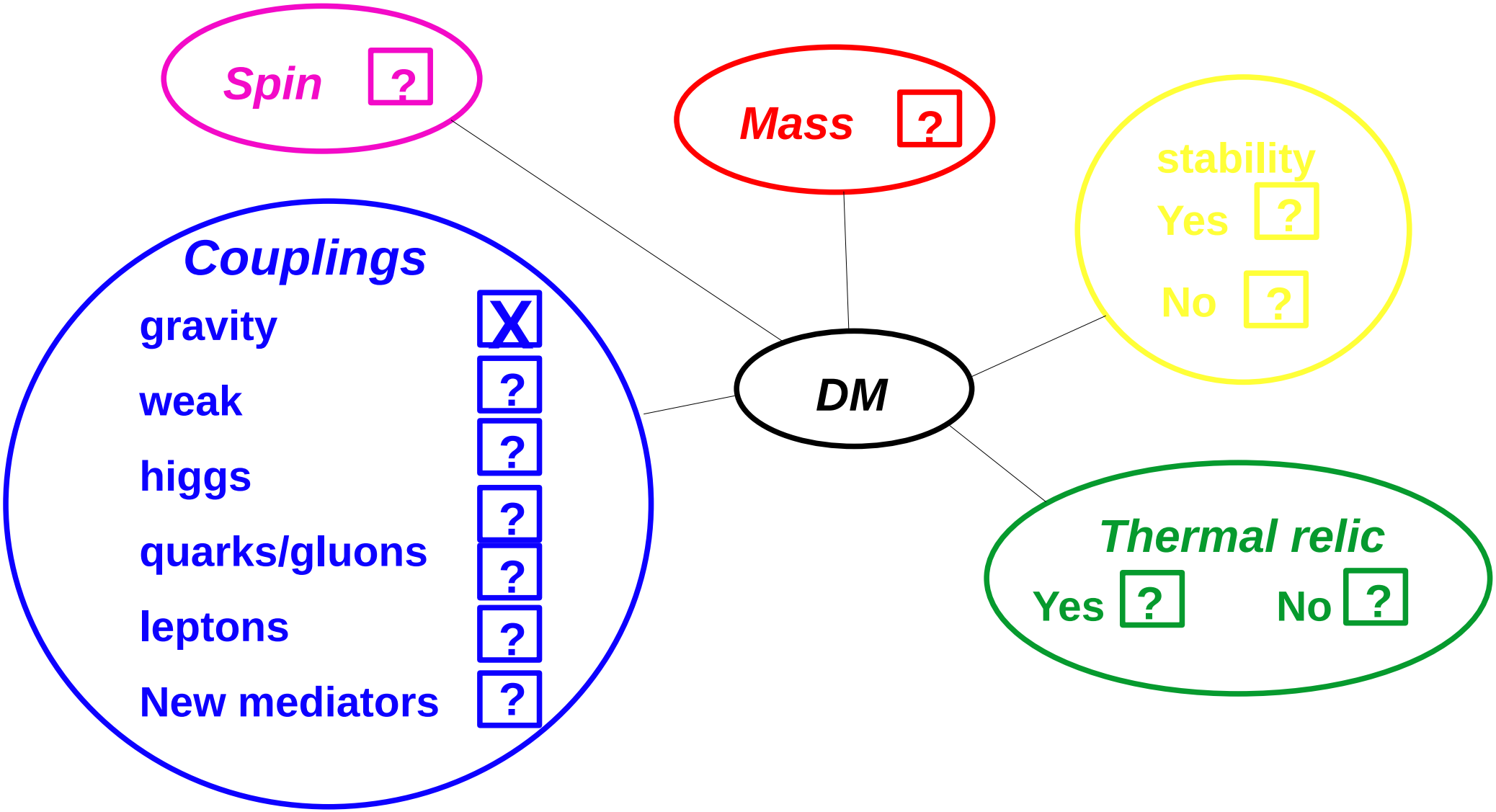


Gravitational lensing



Bullet cluster

We know that it interacts only with Gravity?



Most of them rely on Higgs-portal to dark sector!

VDM have been less studied compared to SDM and FDM

VDM is well motivated by gauge principle like in SM.

Abelian VDM

Lebedev, Lee, Mambrini 1111.4482 Baek, Ko, Park , Senaha 1212.2131

DiFranzo, Fox,Tait 1512.06853 Farzan, Akbarieh 1207.4272 , …

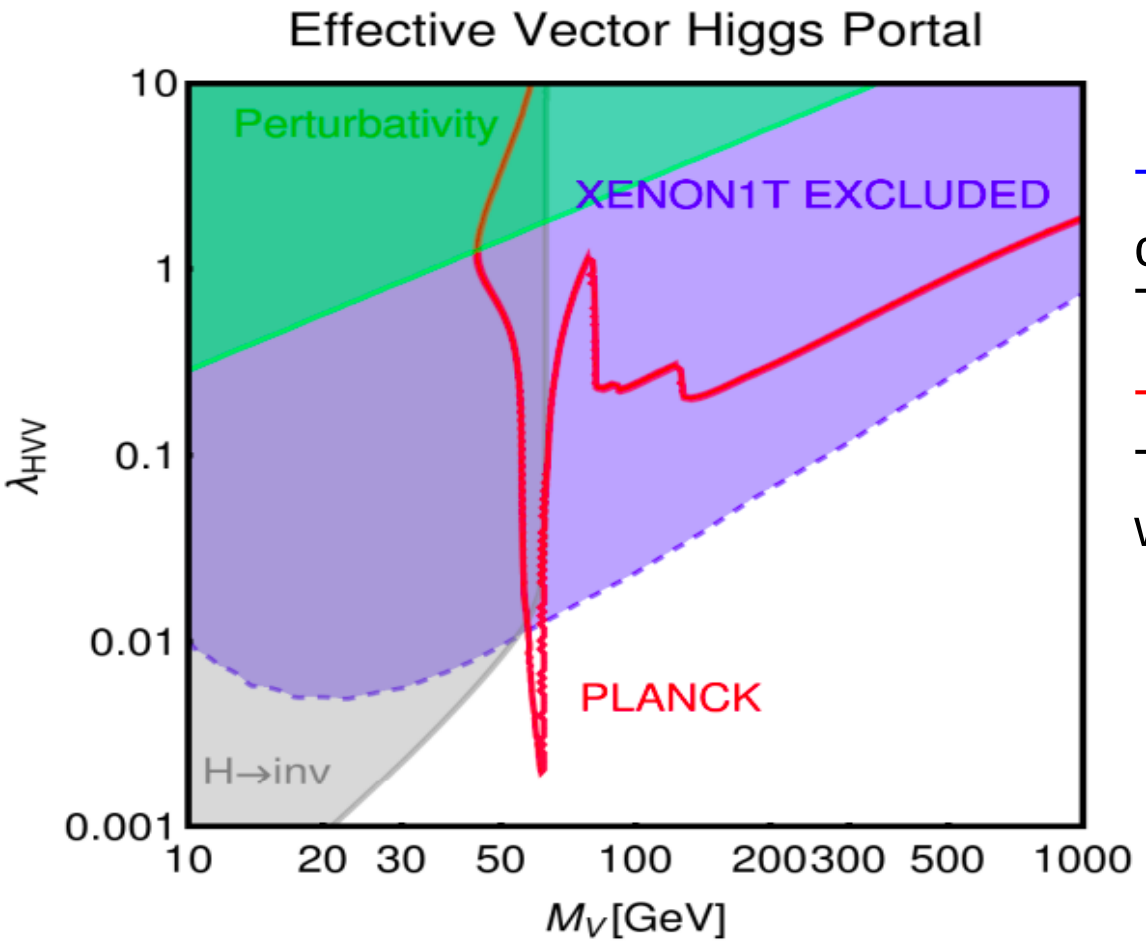
Non-abelian VDM

Hambye 0811.0172 Diaz-Cruz & Ma 1007.2631

Fraser, Ma & Zakeri 1409.1162 Ko & Tang 1609.02307, ...

A VDM with Scalar Portal is very constraint!

Why Fermionic Portal models instead of a Scalar-Portal ones?



Arcadi, Djouadi, Kado 2001.10750

The blue region excluded by constraint from XENON1T sets up The *upper* limit on the coupling.

The red line corresponds to the points That provide the relic density 0.12 which set the *lower* limit on the coupling.

The allowed parameter space of Higgs portal VDM model is *VERY CONSTRAINTED* by PLANCK, XENON and LHC searches.

Adding new ingredients

We need new ingredients: $G_{SM} \times SU(2)_D \times U(1)^{Global}_{Y_D}$

Dark group: $SU(2)_D \times U(1)^{Global}_{Y_D}$

1. Vector-Like Fermion Ψ
2. Gauge bosons V^D_μ
3. Complex scalar Φ_D

DSM: $SU(2)_D \times U(1)^{Global}_{Y_D} \rightarrow U(1)^{Global}_{Q_D}$

$$Q_D = T_{3D} + Y_D$$

D symmetry: $U(1)^{Global}_{Q_D} \supset Z_2$

$$Z_2 : (-1)^{Q_D}$$

D symmetry implies the DM stability

Fermions	$SU(2)_L$	$U(1)_Y$	$SU(2)_D$	$\mathbb{Z}_2$
$f^{SM}_L = \begin{pmatrix} f^{SM}_{u,\nu} \\ f^{SM}_{d,\ell} \end{pmatrix}_L$	**2**	$\frac{1}{6}, -\frac{1}{2}$	**1**	+
u^{SM}_R, ν^{SM}_R	**1**	$\frac{2}{3}, 0$	**1**	+
d^{SM}_R, ℓ^{SM}_R	**1**	$-\frac{1}{3}, -1$	**1**	+
$\Psi = \begin{pmatrix} f_D \\ F \end{pmatrix}$	**1**	Q	**2**	− +

New mediator

Adding new ingredients

Scalars	$SU(2)_L$	$U(1)_Y$	$SU(2)_D$	$\mathbb{Z}_2$
$\Phi_H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$	**2**	$1/2$	**1**	$+$
$\Phi_D = \begin{pmatrix} \phi_D^+ \\ \phi_D^0 \end{pmatrix}$	**1**	0	**2**	$-$ $+$

Vectors	$SU(2)_L$	$U(1)_Y$	$SU(2)_D$	$\mathbb{Z}_2$
$W_\mu = \begin{pmatrix} W_\mu^+ \\ W_\mu^3 \\ W_\mu^- \end{pmatrix}$	**3**	0	**1**	$+$ $+$ $+$
B_μ	**1**	0	**1**	$+$
$V_\mu^D = \begin{pmatrix} V_D \\ V' \\ V_D^* \end{pmatrix}$	**1**	0	**3**	$-$ $+$ $-$

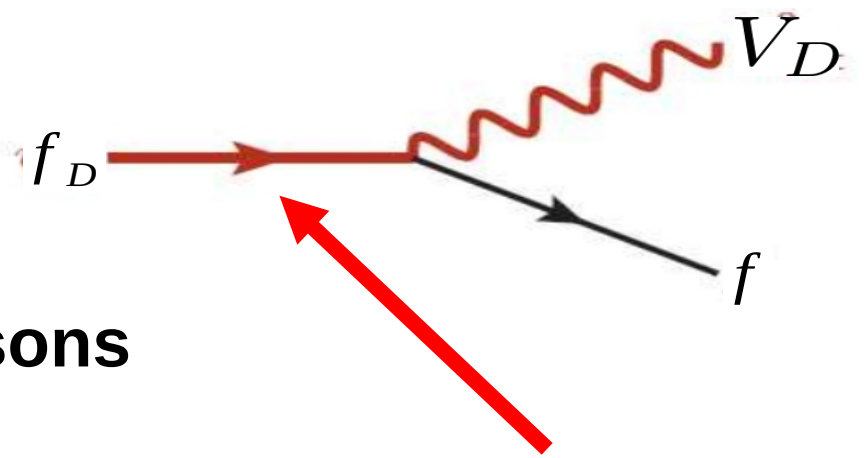
Giving Mass to DM

The Fermionic Portal is generated by the Yukawa term

Since Ψ is charged under $SU(2)_D$ and mix with SM fermion via the Yukawa

$$L_D \supset i\,\bar{\Psi}\,\gamma_\mu D^\mu \Psi - y'\,\bar{\Psi}_L \Phi_D f_R^{SM}$$

$$\Psi = \begin{pmatrix} f_D \\ F \end{pmatrix}$$



Masses of new gauge bosons

- **At tree-level:**

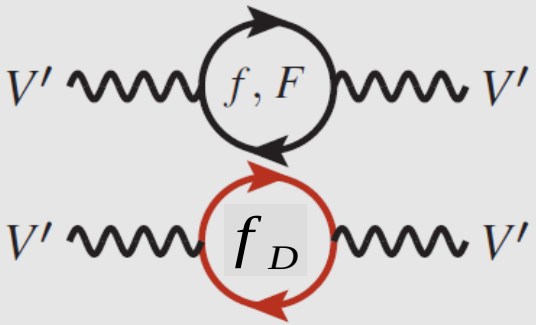
$$m_{V'} = m_{V_D} = \frac{g_D v_D}{2}$$

Fermionic Portal

Mass correction will affect the relic density and Indirect detection

- **At loop-level:**

Different loop corrections:
($V^0_{D\pm} \equiv V_D$ and $V^0_{D0} \equiv V'$)

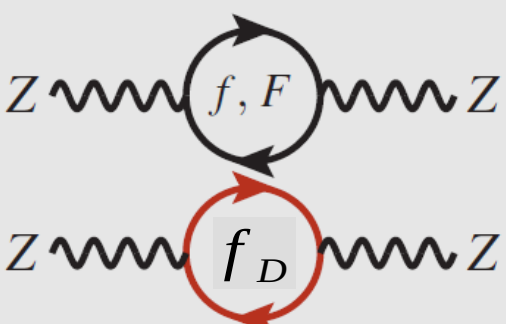


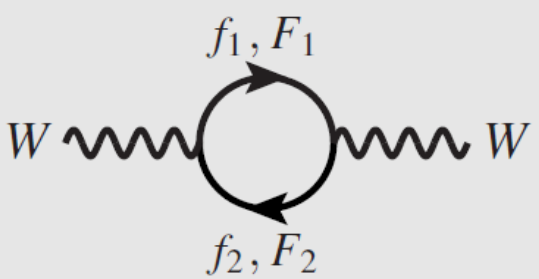
Similar diagrams appear for Kinetic mixing (backup slides)

$$m_{V_D} - m_{V'} \simeq \frac{g_D^2}{32\pi^2} \frac{m_F^2 - m_{f_D}^2}{m_{V_D}} > 0 \quad \text{for} \quad m_F \gg m_f, m_{V_D}$$

- **Effect for W/Z boson masses**

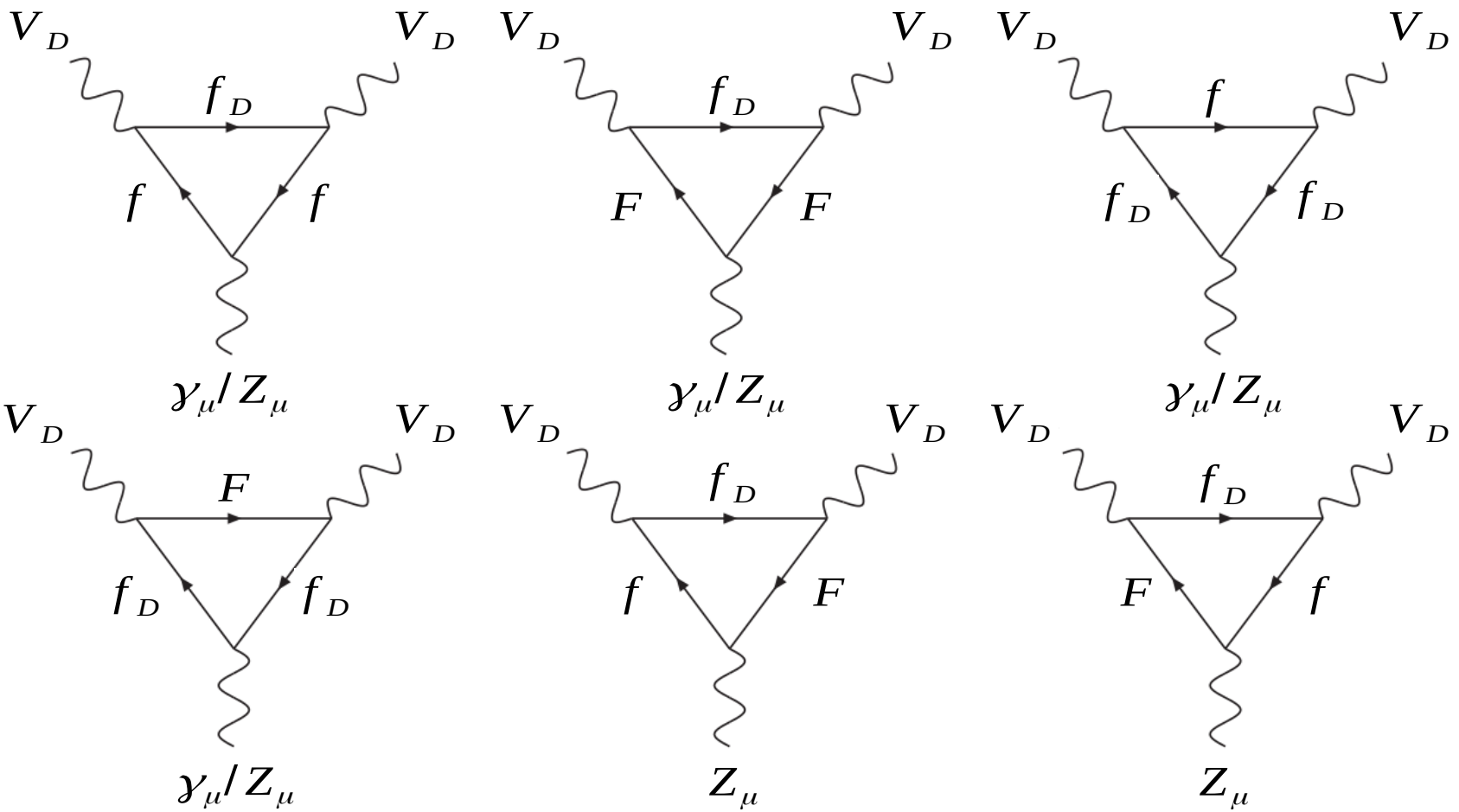
Modifications to SM
different for Z and W





Multipole and Kinetic mixing play a role in Direct detection

- **There is no interaction between dark matter and nucleon at tree level**



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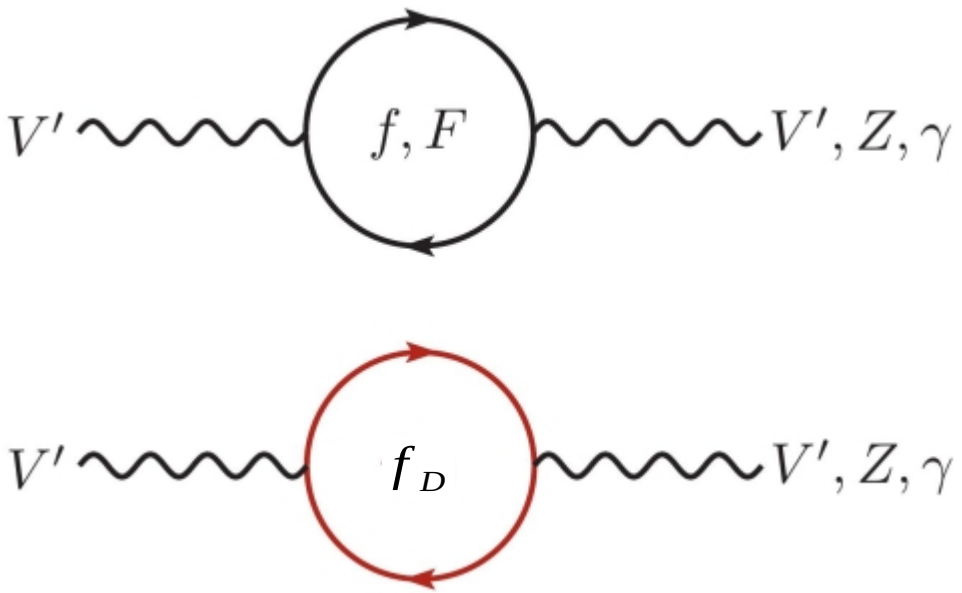
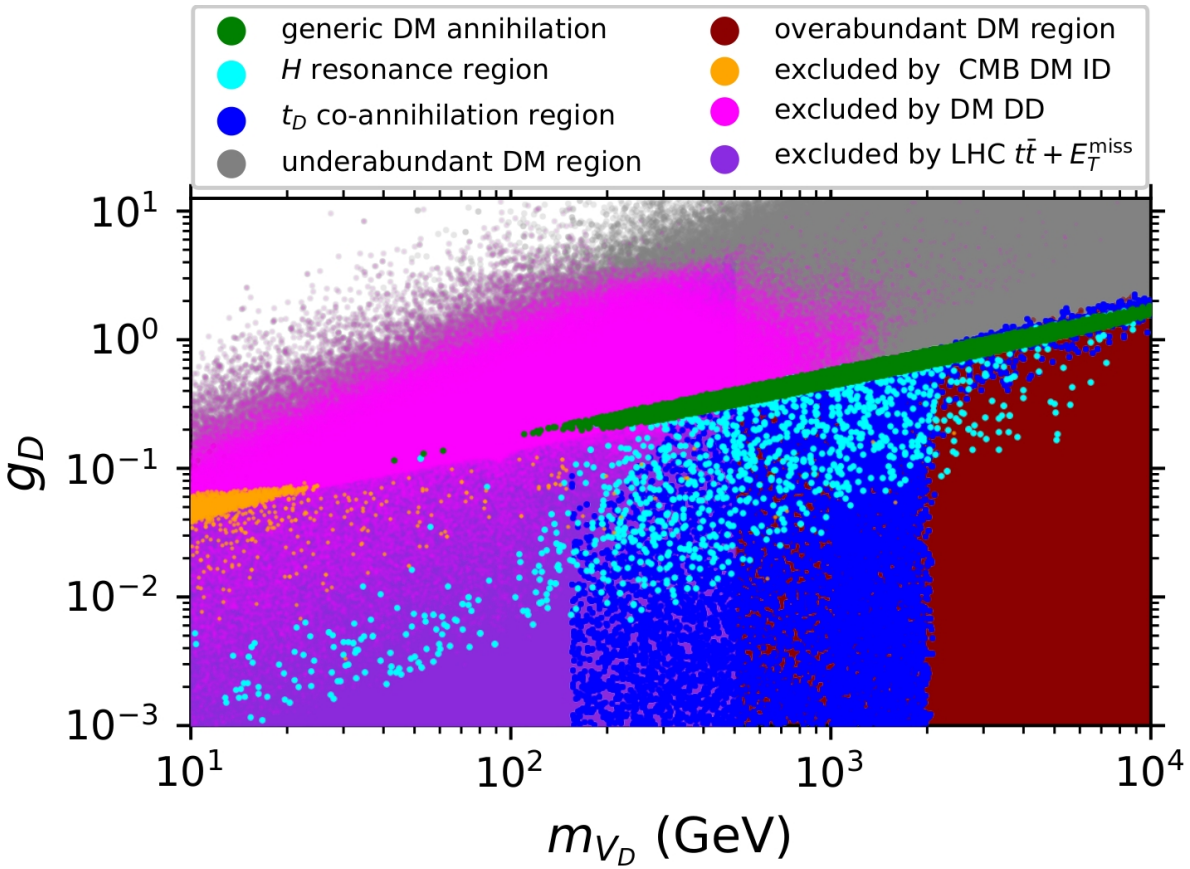


There are a number of surviving regions

A case study of **Vector-Like Top without Scalar Portal**

5D parameter space: $g_D, m_{V_D}, m_{t_D}, m_T, m_{H_D}$



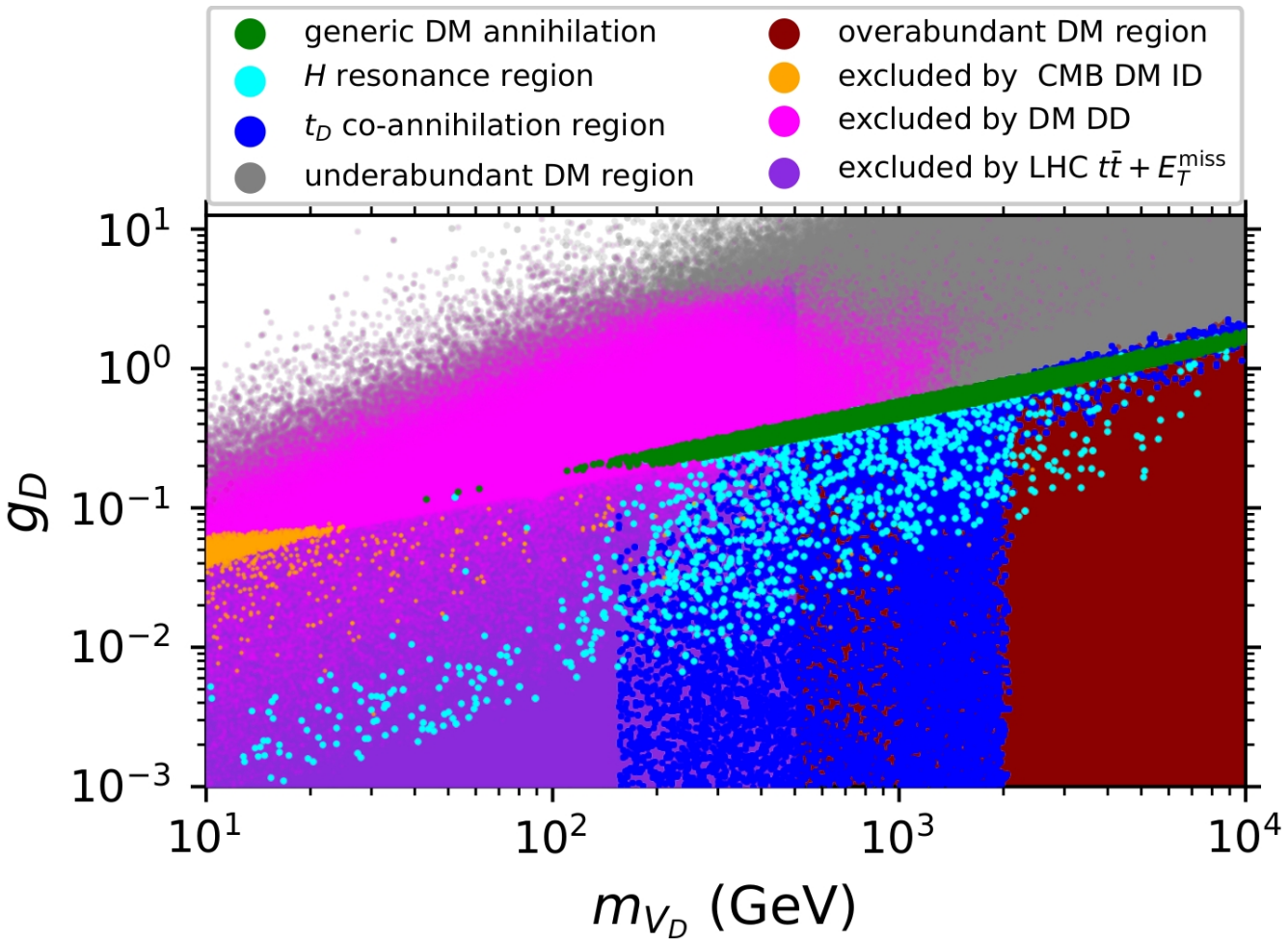
Surviving regions:

1. Green
2. Blue
3. Cyan
4. Grey

Excluded regions:

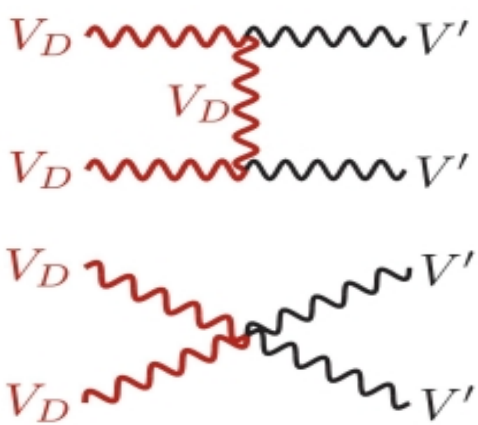
1. White (Perturb.)
2. Dark red (Relic den.)
3. Orange (ID)
4. Magenta (DD)
5. Purple (tt + Emis)

Green region dominated by generic DM annihilation channel

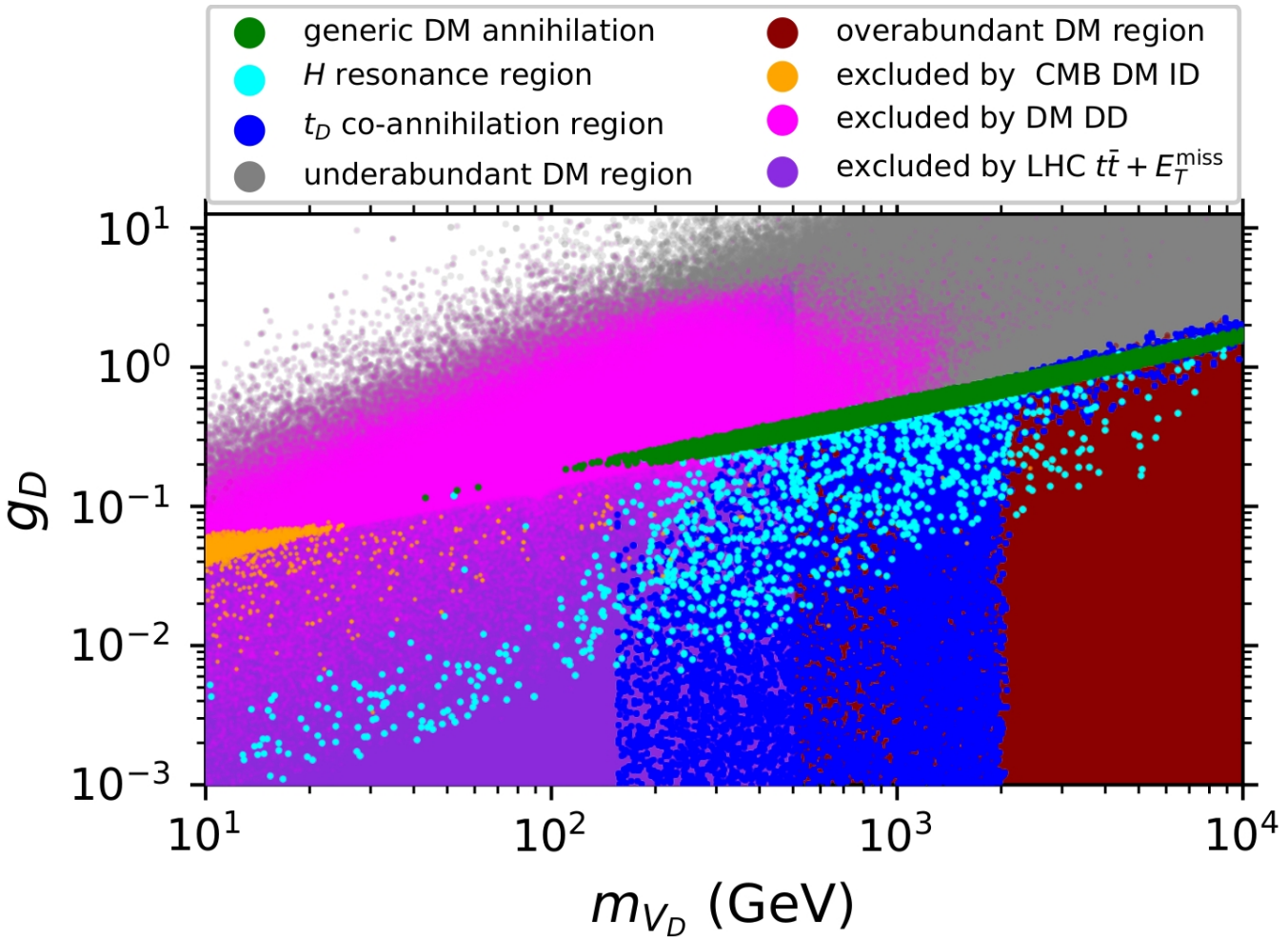


Green points mean:

1. Relic den. Within 10% around 0.12
2. not excluded by DD, ID and collider constraints

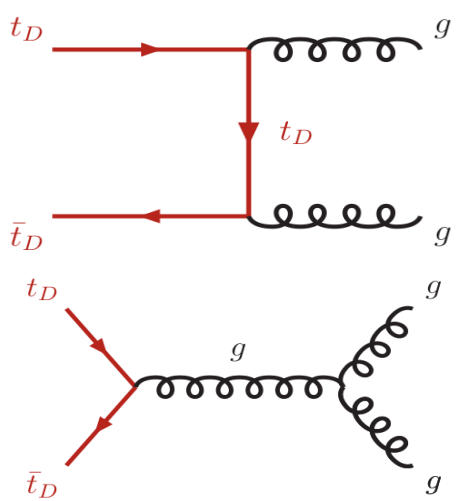


Blue region dominated by co-annihilation channel

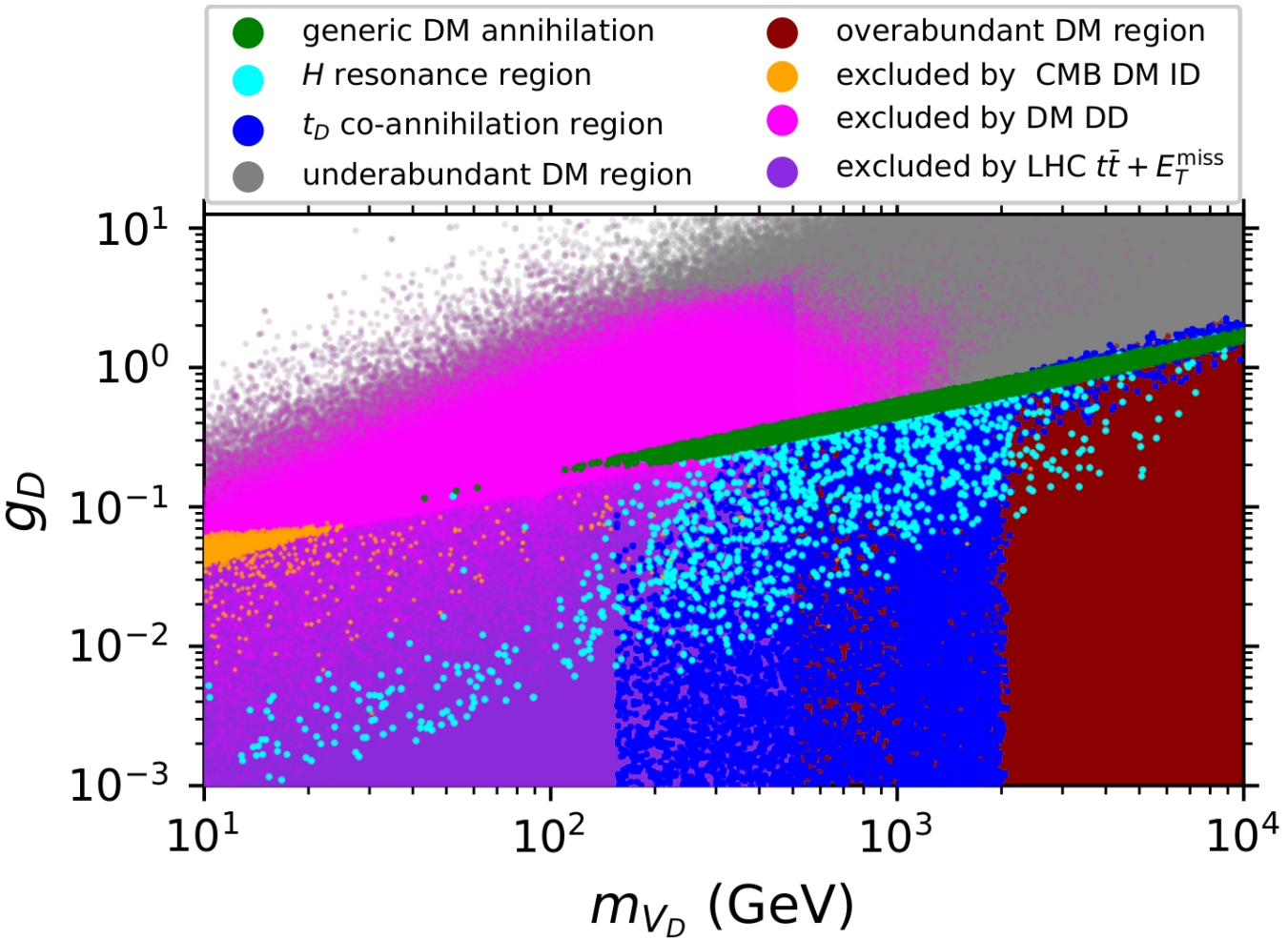


Blue points mean:

1. Relic den. Within 10% around 0.12
2. not excluded by DD, ID and collider constraints

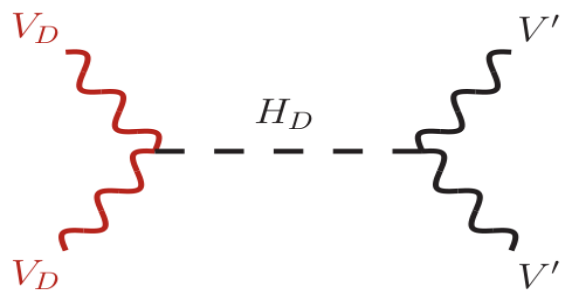


Cyan region dominated by HD resonance channel



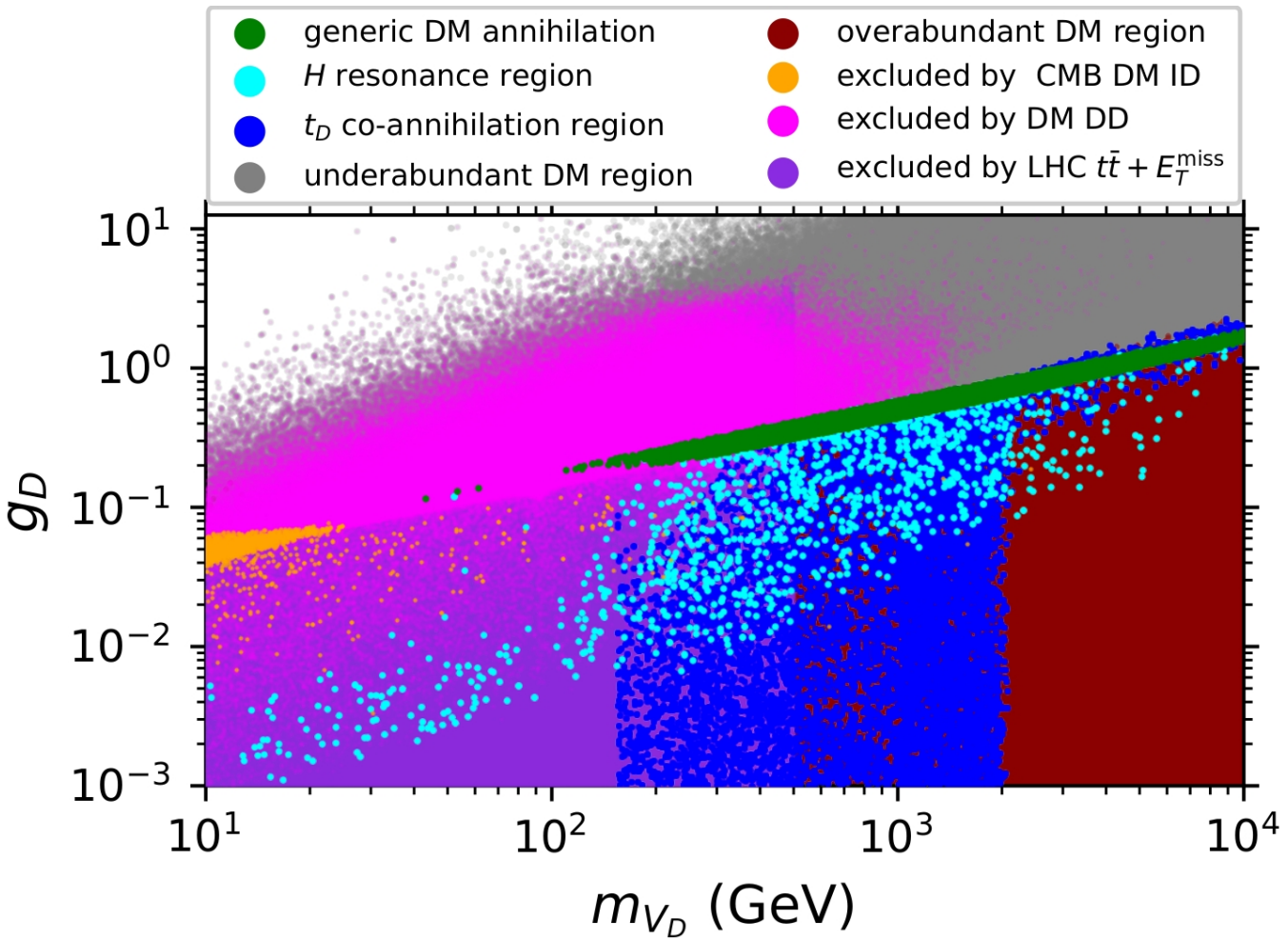
Cyan points mean:

1. Relic den. Within 10% around 0.12
2. not excluded by DD, ID and collider constraints



$$m_{V_D} \rightarrow \frac{m_{H_D}}{2}$$

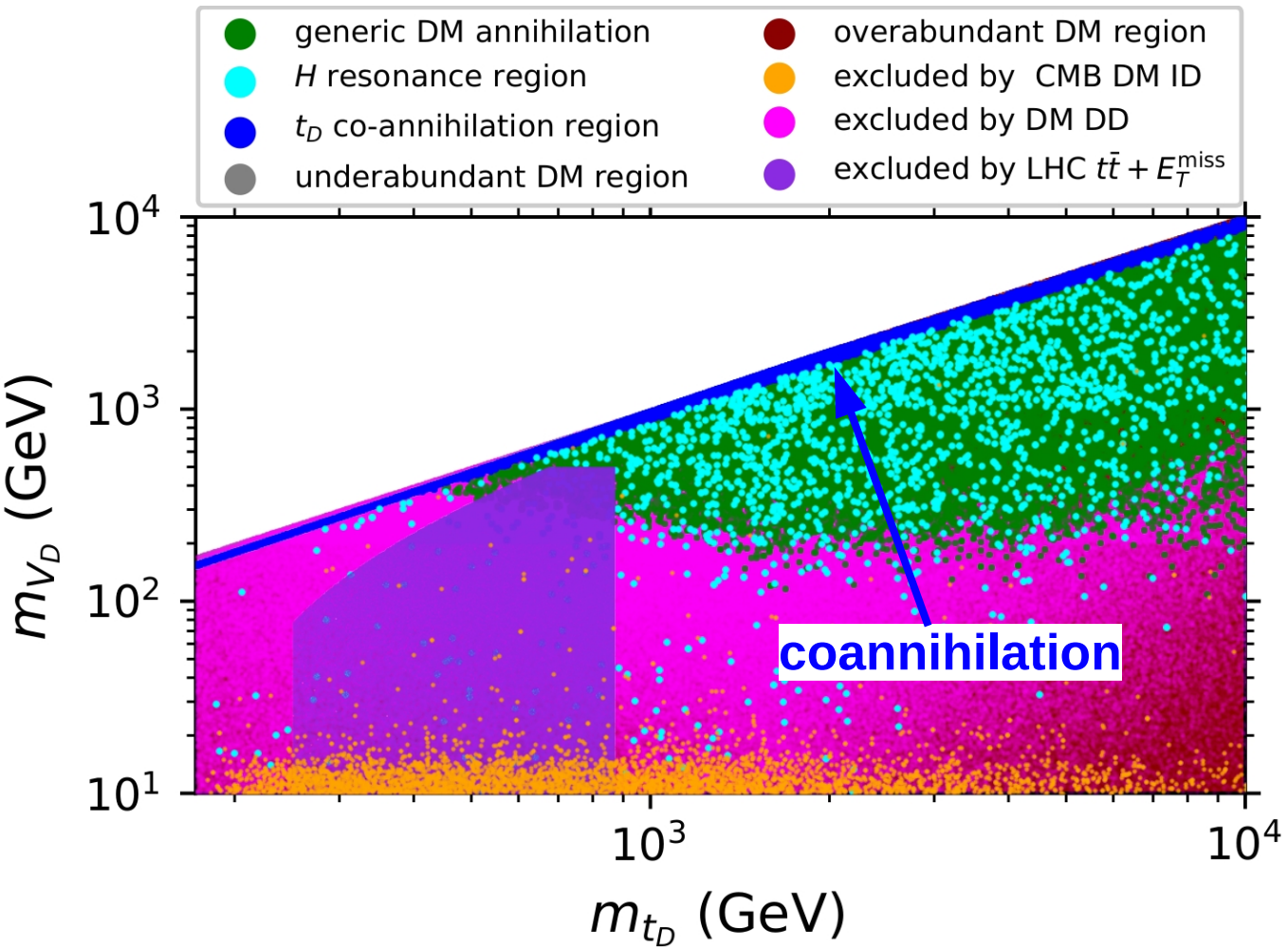
Grey region has under-abundunt relic den.



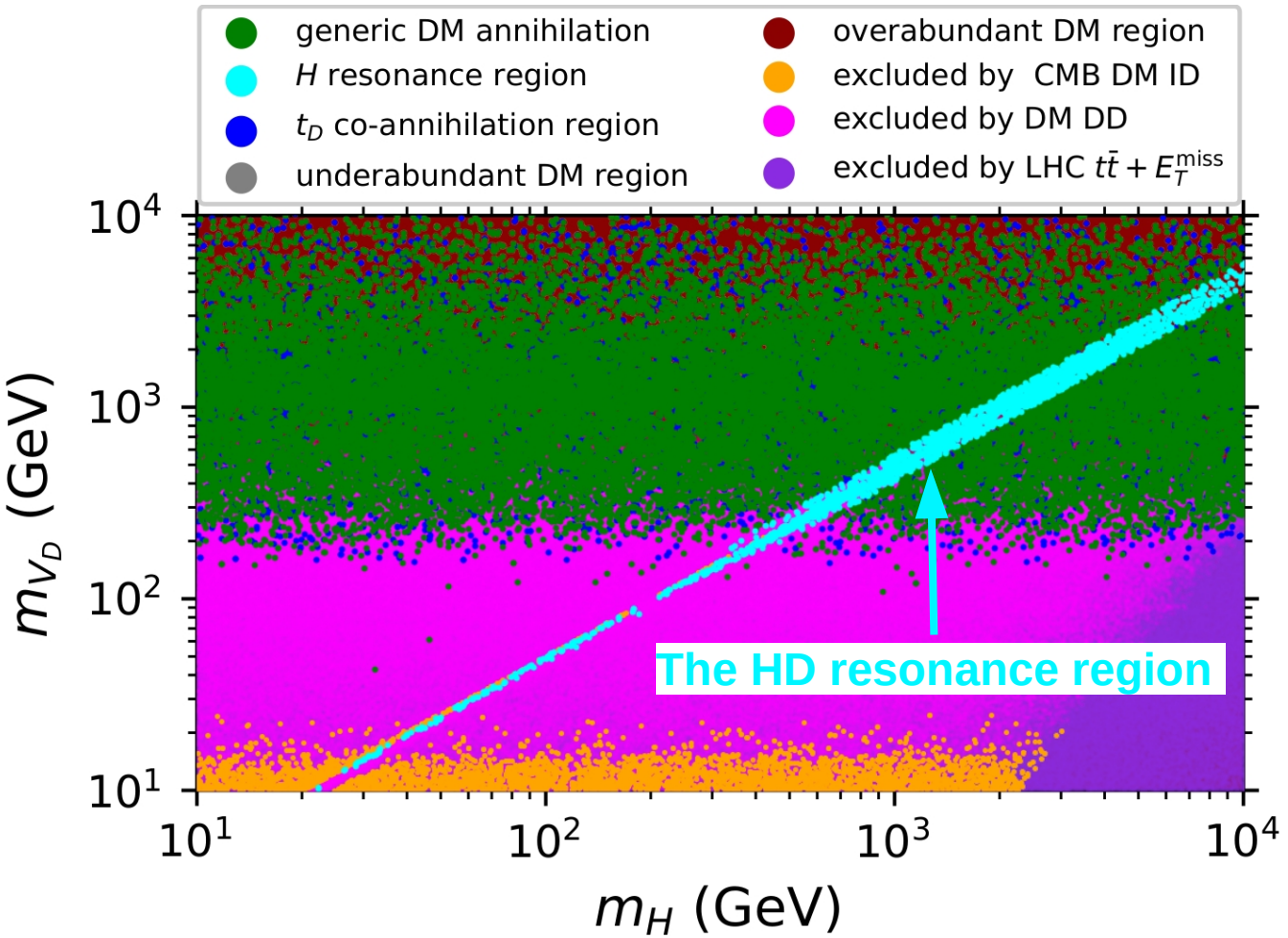
Grey points mean:

1. Relic den. less than 0.12
2. not excluded by DD, ID and collider constraints

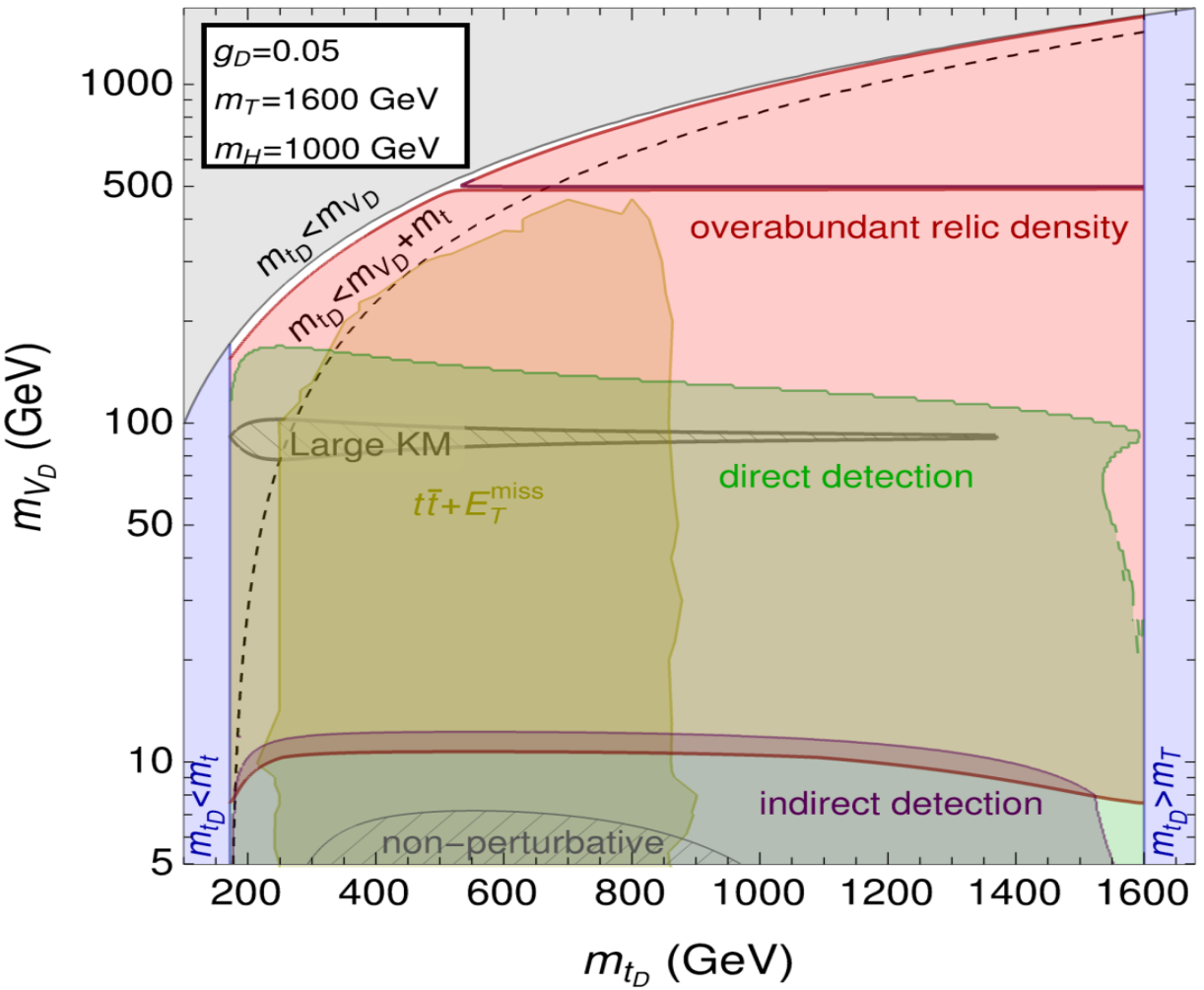
Coann. And HD resonance are clearer in other projected planes



Coann. And HD resonance are clearer in other projected planes



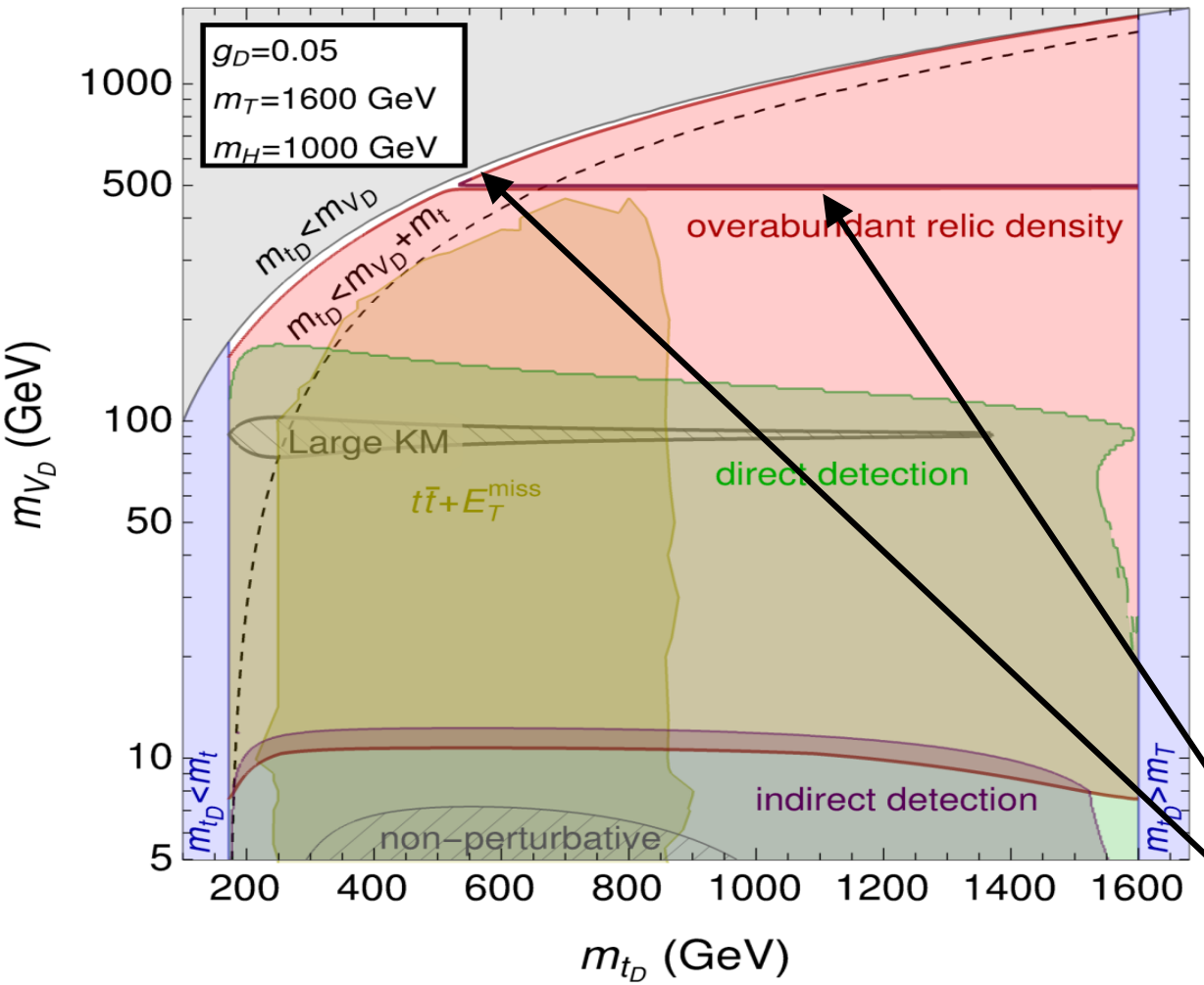
Let's have a closer look into the parameter space



Choosing benchmark points as follows:

- To reflect the weak or strong interaction between Dark and SM sector
- To avoid the LHC constraint on VL top
- To accommodate the dark Higgs resonance valley

The allowed regions are located at HD funnel and coann. regimes



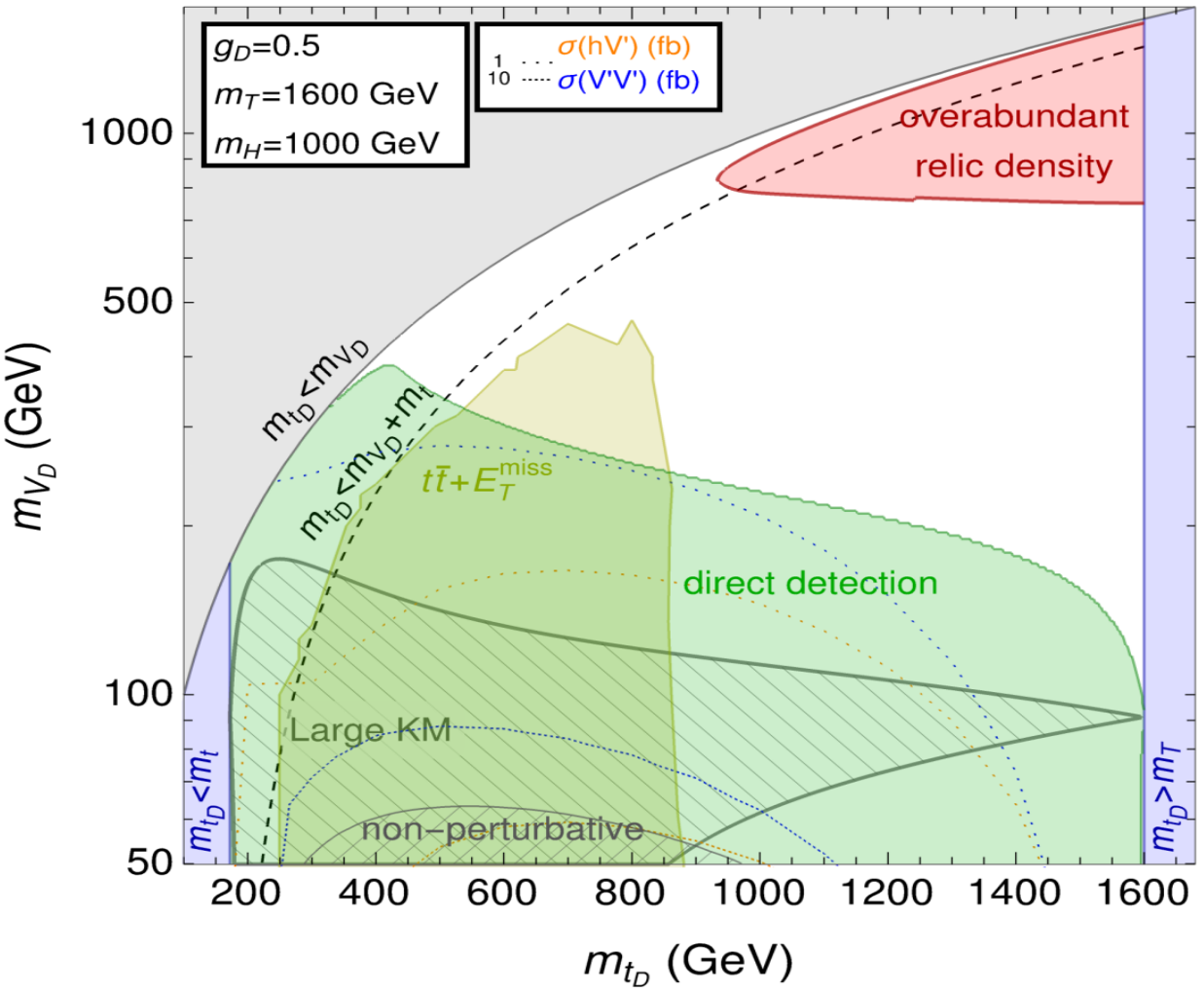
All coloured regions are excluded:

- Red by relic den.
- Green by DD
- Purple by ID
- Orange by collider search
- hatched by one-loop constraints

White indicated allowed region:

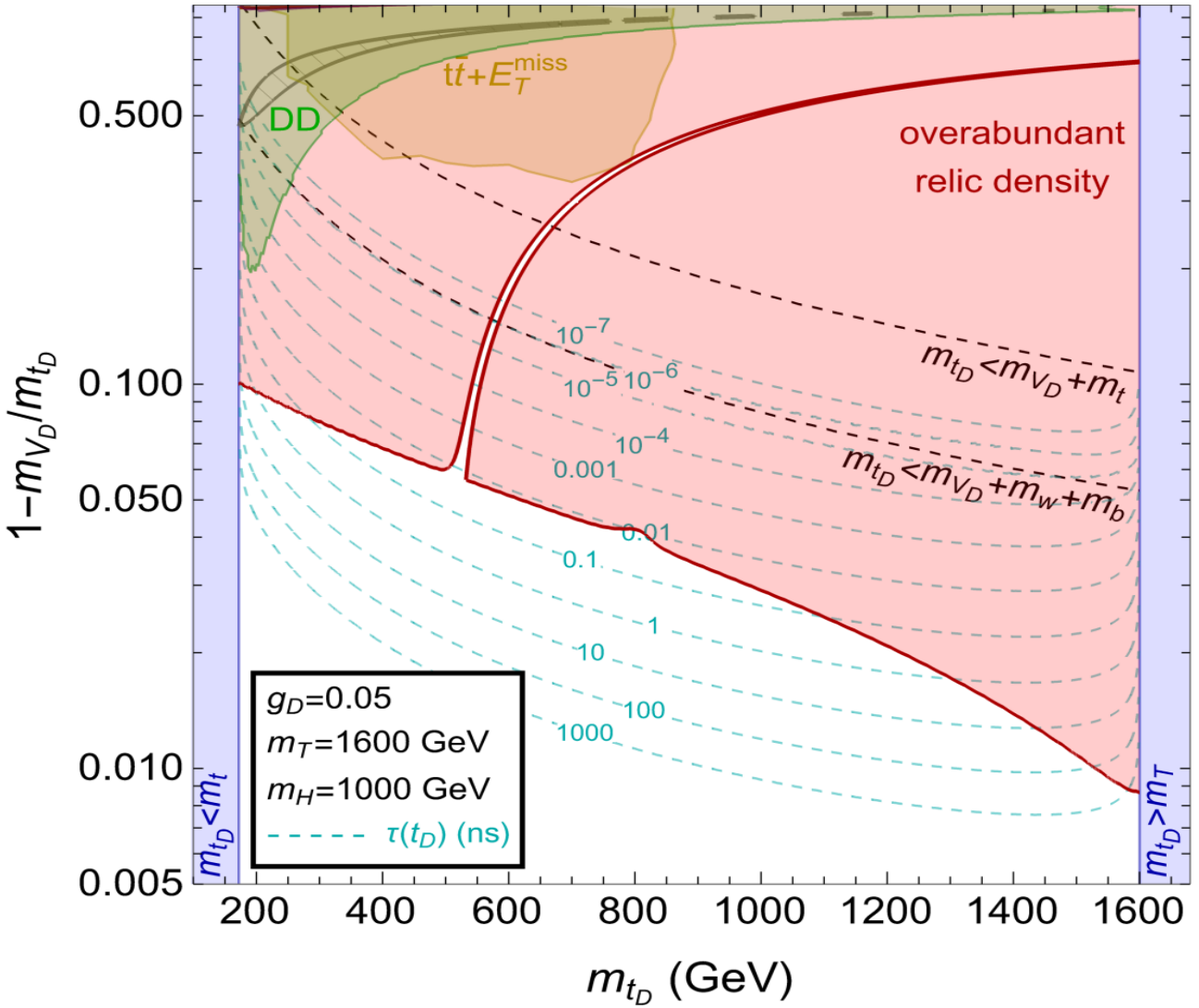
- HD funnel
- Coannihilation

We have more survived region when increasing gD



The parameter space are more allowed when increasing the coupling gD

The VL-top can be a long-lived particle



TD can be long-lived in

$$m_{t_D} < m_{V_D} + m_W + m_b$$

$$\tau \sim 1\, ns$$

Summary & Outlook

- We propose a new class of model in which the Higgs-portal is not required.
- There are many possible implications in both collider and cosmological studies
- A case study on top-portal scenario provides multiple phenomenological predictions
  - collider signatures: tt+Emiss, V', V'H, long-lived and VL-top t_D

Future directions:

- Muon g-2 anomaly (See Alexander Belyaev's talk on Friday)
- Phase transition & gravitational waves from DSB (ongoing)
- Freeze-in DM (ongoing)
- Neutrino physics (ongoing)
- Flavour, W-mass anomalies etc.

Thank you!