Vector Dark Matter Via Higgs Portal

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Vector DM Higgs Portal

$$\mathcal{L} \supset \lambda_{hVV} H^\dagger H V^\mu V_\mu$$

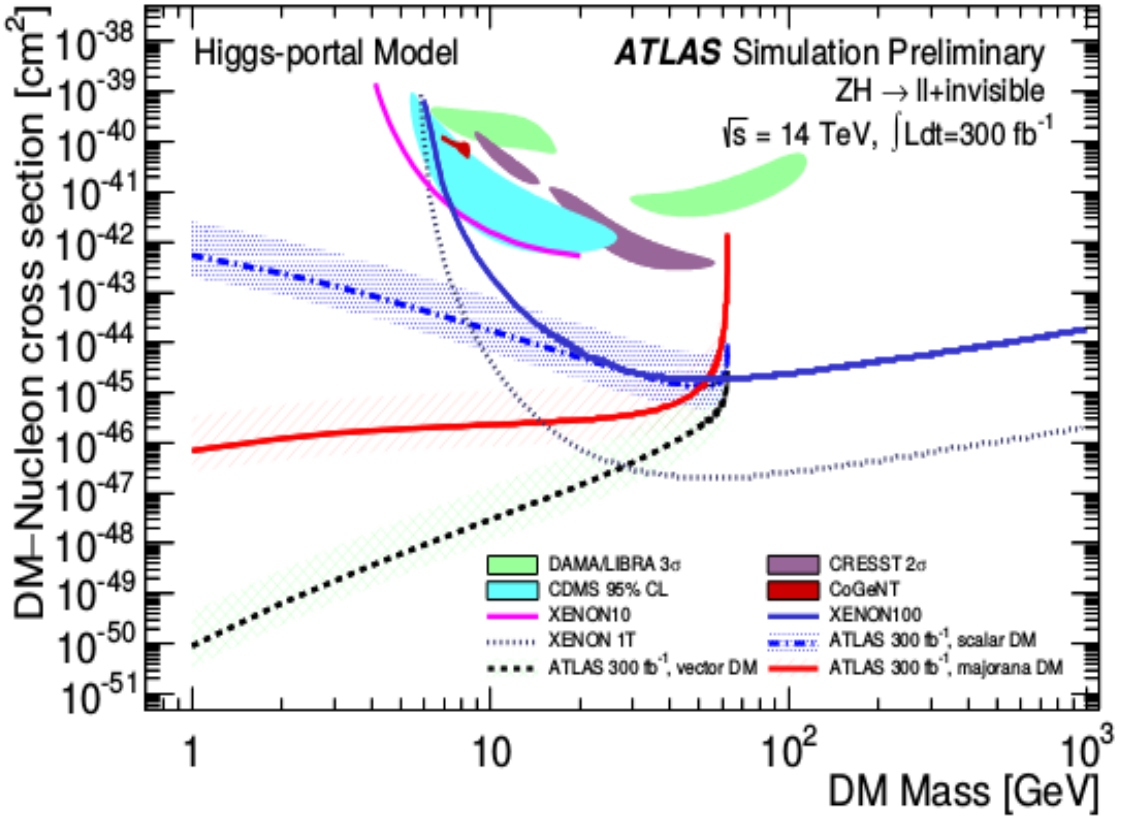
- dim-4, but not renormalizable and not gauge invariant. Should be treated as an EFT.
- Observables have unphysical behavior

$$\sigma^{SI}_{V-N} = \frac{\lambda^2_{hVV}}{16\pi m_h^4} \frac{m_N^4 f_N^2}{(M_V + m_N)^2}$$

$$\Gamma^{\text{inv}}_{h\to VV} = \frac{\lambda^2_{hVV} v^2 m_h^3 \beta_V}{256\pi M_V^4} \left(1 - 4\frac{M_V^2}{m_h^2} + 12\frac{M_V^4}{m_h^4}\right)$$

Djoudi et.al. [arXiv: 1112.3299]

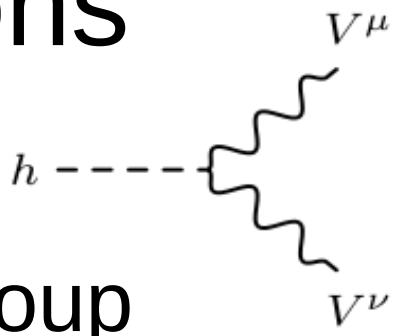
Higgs width in direct detection plane



taking ATLAS 14TeV 300fb-1 90%CL sensitivity: BR(h->inv) < 0.19

ATLAS Collaboration [arXiv: 1402.3244]
See also:
CMS Collaboration [arXiv: 1404.1344]

UV-complete constructions



1) Charge Higgs under dark gauge group

2) Introduce new scalar which mixes with Higgs

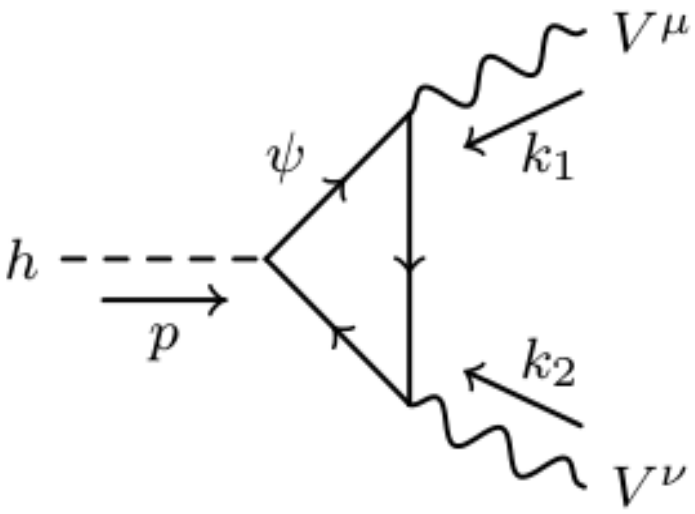
$$D^\mu \Phi^\dagger D_\mu \Phi, H^\dagger H \Phi^\dagger \Phi \rightarrow \sin\theta \; h V^\mu V_\mu$$

hVV coupling related to V mass, giving expected behavior in observables ✓

e.g. Baek et.al. [arXiv:1212.2131], Farzan et.al. [arXiv:1207:4272], Hambye [arXiv:0811.0172]

3) Radiatively generated

A Toy Model



- Imagine integrating out a heavy fermion
- Similar to hGG/hFF, except:
  - Vector is massive, resulting in term 'B'
  - Yukawa not simply related to fermion mass

$$\mathcal{L}_{loop} = -\frac{1}{4} A h V^{\mu\nu} V_{\mu\nu} - \frac{1}{2} B h V^{\mu} V_{\mu}$$

$$A, B \sim \frac{y_\psi}{m_\psi} \neq \frac{1}{v}$$

UV completion: Requirements

1) Anomaly free

2) Ensure stability of DM candidate (e.g. prevent kinetic mixing with SM gauge groups)

3) visible Higgs width is unaffected (e.g. gluons/photons)

UV Completion: Matter content

	$(SU(2), U(1), U(1)')$		$(SU(2), U(1), U(1)')$
$\psi_{1\alpha}$	$(2, 1/2, Q)$	$\psi_{2\alpha}$	$(2, 1/2, -Q)$
$\chi_{1\alpha}$	$(2, -1/2, -Q)$	$\chi_{2\alpha}$	$(2, -1/2, Q)$
$n_{1\alpha}$	$(1, 0, -Q)$	$n_{2\alpha}$	$(1, 0, Q)$
Φ	$(1, 0, NQ)$		

$$-\mathcal{L}_{int} = m(\epsilon^{ab}\psi_{1a}\chi_{1b} + \epsilon^{ab}\psi_{2a}\chi_{2b}) + m_n n_1 n_2$$

$$+y_\psi(\epsilon^{ab}\psi_{1a}H_b n_1 + \epsilon^{ab}\psi_{2a}H_b n_2) + y_\chi(\chi_1 H^* n_1 + \chi_2 H^* n_2) + h.c.$$

1) Anomalies are canceled within these pairs

2) U(1)' charge conjugation symmetry protects kinetic mixing

3) Higgs doesn't interact with new charged fermions

Purpose of Scalar

	$(SU(2), U(1), U(1)')$		$(SU(2), U(1), U(1)')$
$\psi_{1\alpha}$	$(2, 1/2, Q)$	$\psi_{2\alpha}$	$(2, 1/2, -Q)$
$\chi_{1\alpha}$	$(2, -1/2, -Q)$	$\chi_{2\alpha}$	$(2, -1/2, Q)$
$n_{1\alpha}$	$(1, 0, -Q)$	$n_{2\alpha}$	$(1, 0, Q)$
Φ	$(1, 0, NQ)$		

- Solely to break U(1)'
- But could also:
  - Cause new fermions to mix with SM leptons (N=±1)
  - Contribute to mixing between new fermions (N=±2)
  - Mix with Higgs

$$\lambda H^\dagger H \Phi^\dagger \Phi$$

Observables from Toy Model

$$\Gamma(h \to VV) = \frac{\sqrt{1-4m_V^2/m_h^2}}{64\pi m_h}\left[|A|^2 m_h^4\left(1-4\frac{m_V^2}{m_h^2}+6\frac{m_V^4}{m_h^4}\right)\right.$$

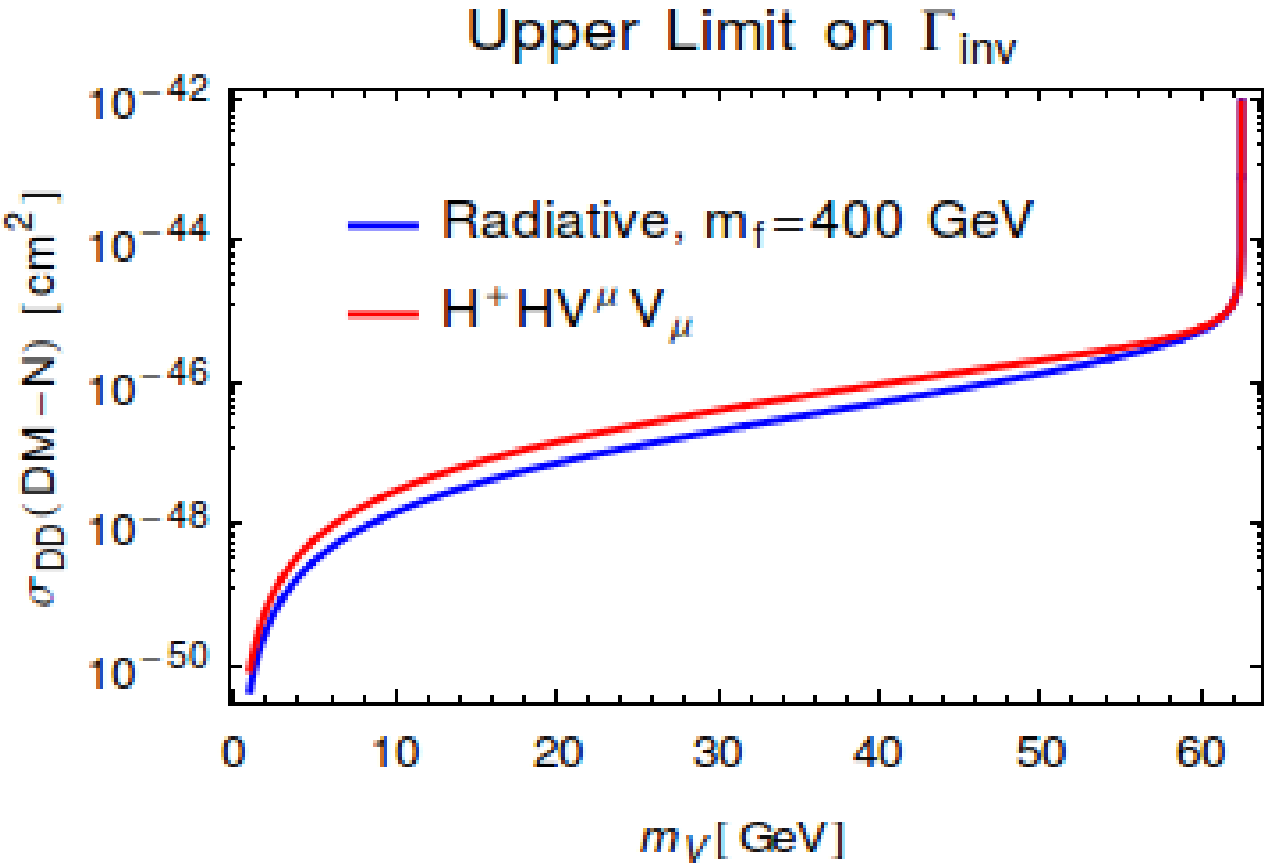
$$\left.+3(A^*B+AB^*)m_h^2\left(1-2\frac{m_V^2}{m_h^2}\right)+\frac{1}{2}|B|^2\frac{m_h^4}{m_V^4}\left(1-4\frac{m_V^2}{m_h^2}+12\frac{m_V^4}{m_h^4}\right)\right]$$

for small m_V, $|B| \sim m_V^4$

$$\sigma(VN \to VN) = \frac{1}{4\pi m_h^4}\left(\frac{f_n}{v}\right)^2\left(\frac{m_N^2}{m_N+m_V}\right)^2|B-Am_V^2|^2$$

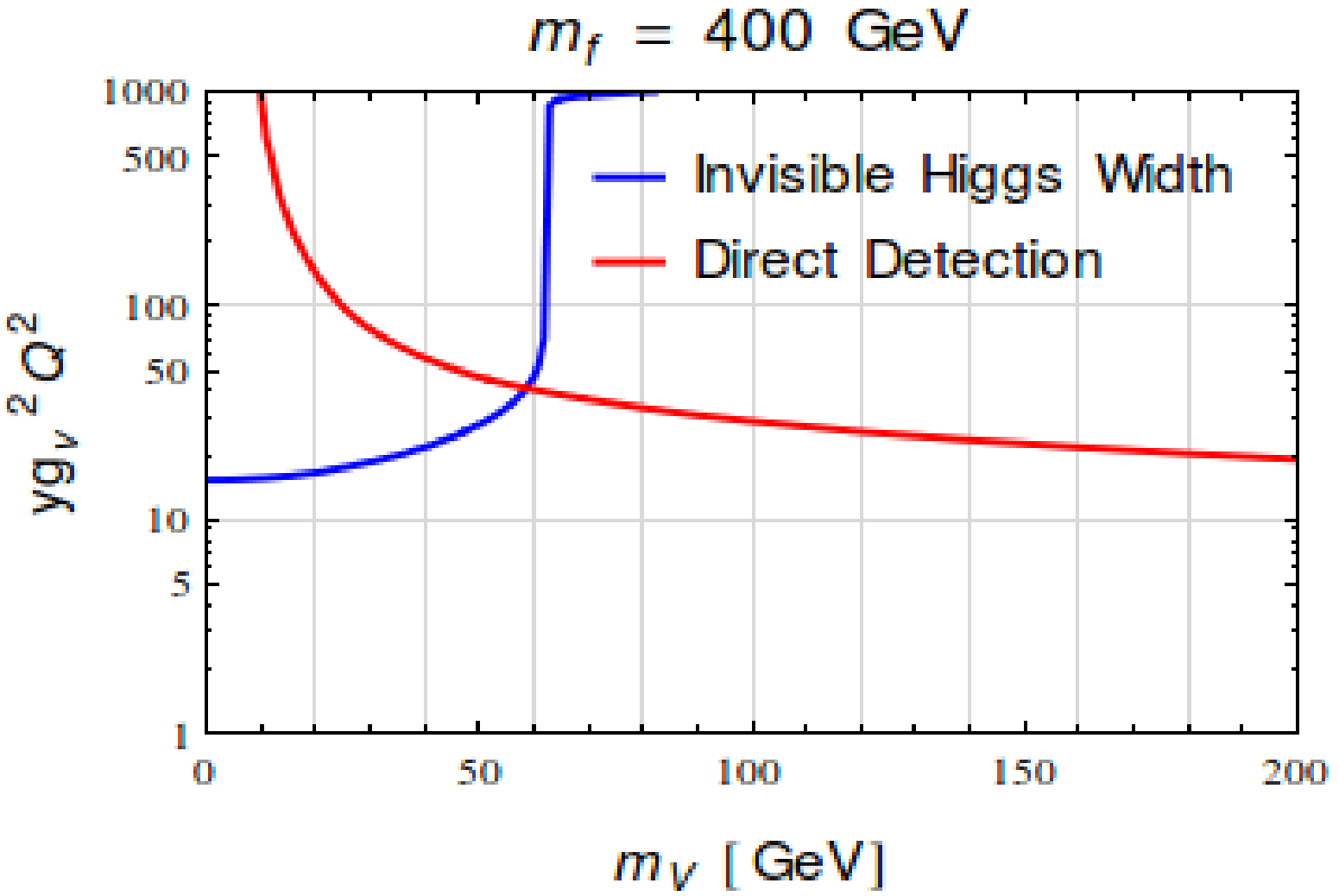
for $m_V \to 0$: $|B| \to 0$, $|A| \to$ constant

Two wrongs *DO* make a right

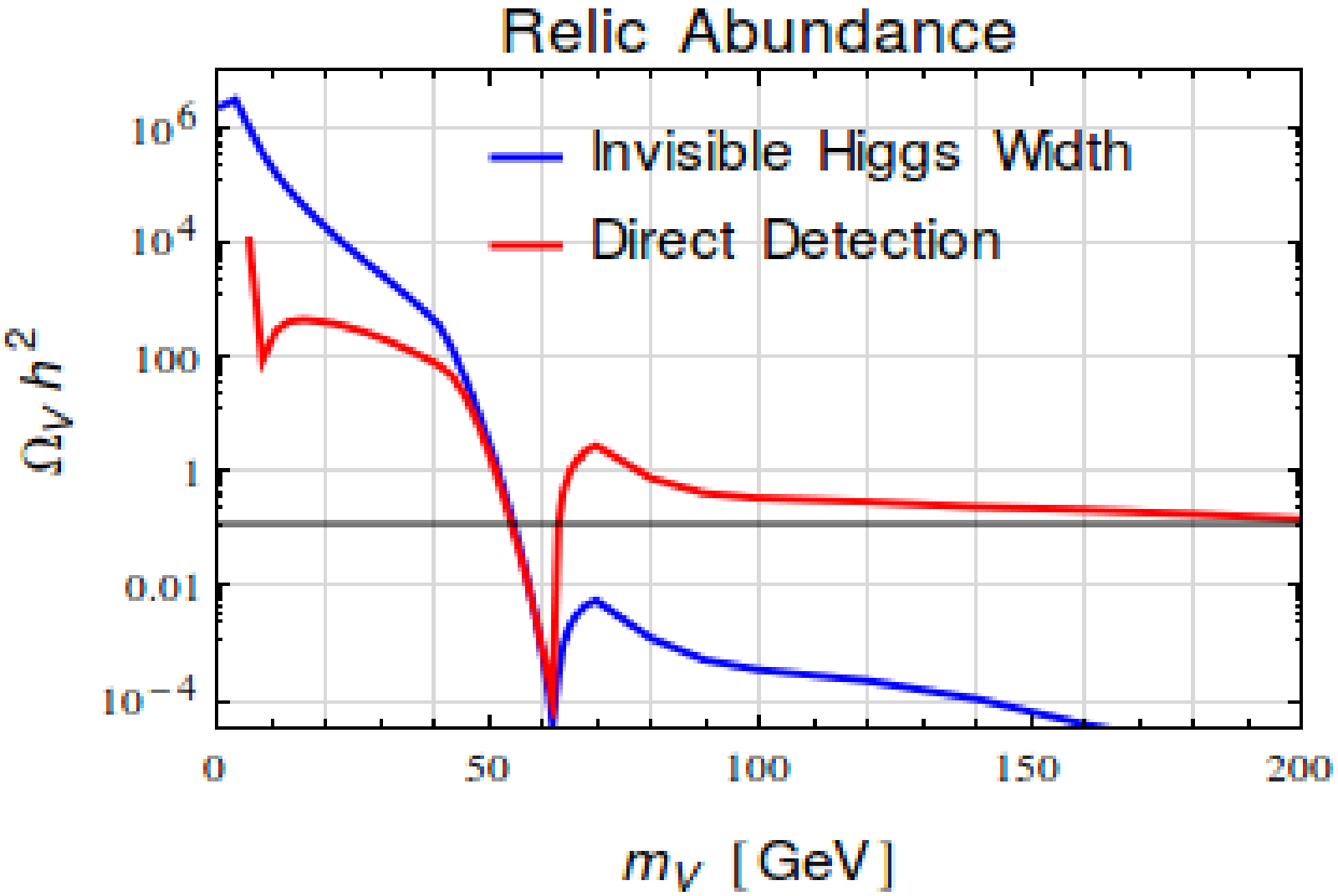


(taking ATLAS 14TeV 300fb-1 90%CL sensitivity: BR(h->inv) < 0.19)

ATLAS Collaboration arXiv:1402.3244



-Invisible Higgs width: VBF Higgs (CMS Collaboration [arXiv:1404.1344])
including off-shell Higgs contributions (Endo et.al. [arXiv:1407.6882])
-Direct Detection: LUX Collaboration [arXiv:1310.8214]


Relic Abundance
Invisible Higgs Width
Direct Detection
$\Omega_V h^2$
10^6
10^4
100
1
0.01
10^{-4}
0
50
100
150
200
m_V [GeV]

Necessity of Full Matter Content

- If the two heavier states are not much heavier than the first
- Description of all box diagrams, which allow other annihilation channels for large DM mass as well as photon lines

Summary

- Higgs portal should be treated as EFT
- Viable UV completions are easily constructed for the Vector DM portal
- Relic abundance is difficult to get with the radiative portal. Though including mixing and other loop level processes can help.

Thanks!
Questions?