Twin Higgs Portal Dark Matter

Based on work with David Curtin, SG

2101.11019 [hep-ph]

ONE SLIDE SUMMARY

We extend the Twin Higgs framework to include a singlet scalar particle that acts like dark matter.

We treat the scalar as a thermal relic and compute its expected direct detection cross section

The pNGB nature of the (SM-like) Higgs suppresses the direct detection cross section, relative to benchmark Higgs portal WIMP models

ONE SLIDE SUMMARY

We extend the Twin Higgs framework to include a singlet scalar particle that acts like dark matter.

We treat the scalar as a thermal relic and compute its expected direct detection cross section

The pNGB nature of the (SM-like) Higgs suppresses the direct detection cross section, relative to benchmark Higgs portal WIMP models

+ extra suppression from asymmetric reheating!

TWIN HIGGS MODELS

Motivation:

Solve the (little) hierarchy problem via color-neutral top partners

Lagrangian:

Z. Chacko, H. -S. Goh, R. Harnik, hep-ph/0506256

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}_A} + \mathcal{L}_{\mathrm{SM}_B}$$

- Complete or partial SM copy
- **singlet** under SM charges

$$\mathbb{Z}_2 : A \leftrightarrow B$$

$$H = (H_A, H_B)^T$$

$$V = \lambda \left(H^\dagger H - \frac{f_0^2}{2} \right)^2 + \text{breaking terms}$$

SU(4) symmetric

explicit or dynamical, required for Higgs pheno

Twin Higgs Mechanism

1) $\langle H \rangle = \frac{1}{\sqrt{2}} f$ → $SU(4) \to SU(3)$

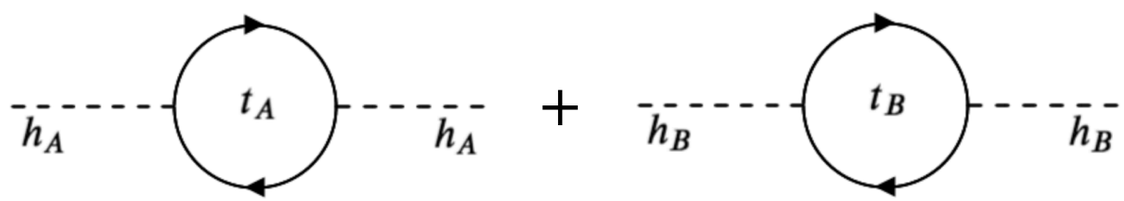
125 GeV Higgs is pNGB of broken SU(4)

Twin Higgs Mechanism

1) $\langle H \rangle = \frac{1}{\sqrt{2}} f$ → $SU(4) \to SU(3)$

125 GeV Higgs is pNGB of broken SU(4)

2)



accidental SU(4) symmetry!

$$\Delta V = \frac{3}{8\pi^2}\Lambda^2\left(\lambda_A^2 H_A^\dagger H_A + \lambda_B^2 H_B^\dagger H_B\right) = \frac{3\lambda^2}{8\pi^2}\Lambda^2 H^\dagger H$$

125 GeV Higgs protected at 1 loop

Introducing:

TWIN HIGGS PORTAL DARK MATTER

Start with Twin Higgs potential:

$$V = \underbrace{\lambda\left(H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2}\right)^2}_{\text{SU(4) symmetric}} + \underbrace{\kappa\left(\left(H_A^\dagger H_A\right)^2 + \left(H_B^\dagger H_B\right)^2\right) + \sigma f_0^2 H_A^\dagger H_A}_{\text{explicit breaking terms}}$$

$$V = \lambda \left(H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left(\left(H_A^\dagger H_A \right)^2 + \left(H_B^\dagger H_B \right)^2 \right) + \sigma f_0^2 H_A^\dagger H_A$$

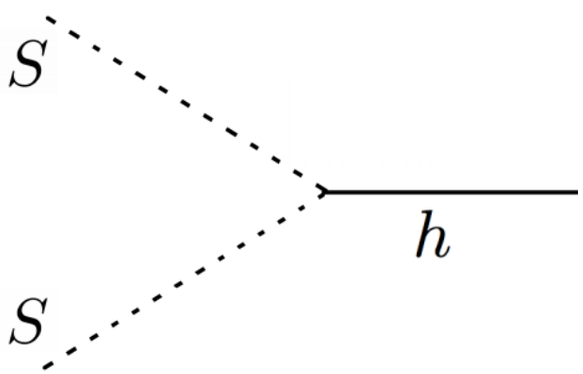
$$+ \frac{1}{2} \mu_S^2 S^2 + \frac{1}{2} \lambda_{HS} S^2 \left(H_A^\dagger H_A + H_B^\dagger H_B \right)$$

Add a singlet scalar

$$V = \lambda\left(H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2}\right)^2 + \kappa\left(\left(H_A^\dagger H_A\right)^2 + \left(H_B^\dagger H_B\right)^2\right) + \sigma f_0^2 H_A^\dagger H_A$$

$$+\frac{1}{2}\mu_S^2 S^2 + \frac{1}{2}\lambda_{HS} S^2\left(H_A^\dagger H_A + H_B^\dagger H_B\right)$$

Get *suppressed coupling* to pNGB Higgs

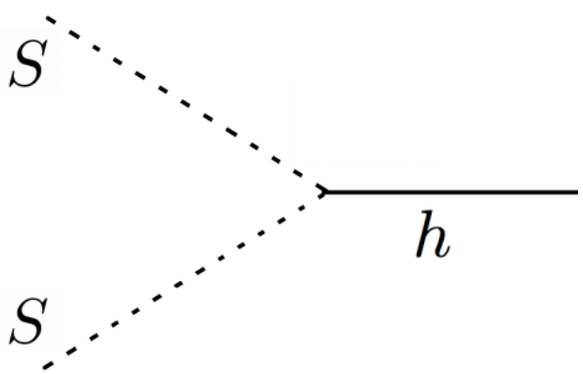


$$= \quad i\lambda_{HS}\left(\frac{\kappa}{\lambda}\right) v\left(1 - 2v^2/f^2\right)\left(1 - v^2/f^2\right) + \mathcal{O}\left(\frac{\kappa^2}{\lambda^2}\right)$$

$$V = \lambda\left(H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2}\right)^2 + \kappa\left(\left(H_A^\dagger H_A\right)^2 + \left(H_B^\dagger H_B\right)^2\right) + \sigma f_0^2 H_A^\dagger H_A$$

$$+\frac{1}{2}\mu_S^2 S^2 + \frac{1}{2}\lambda_{HS} S^2\left(H_A^\dagger H_A + H_B^\dagger H_B\right)$$

Get *suppressed coupling* to pNGB Higgs



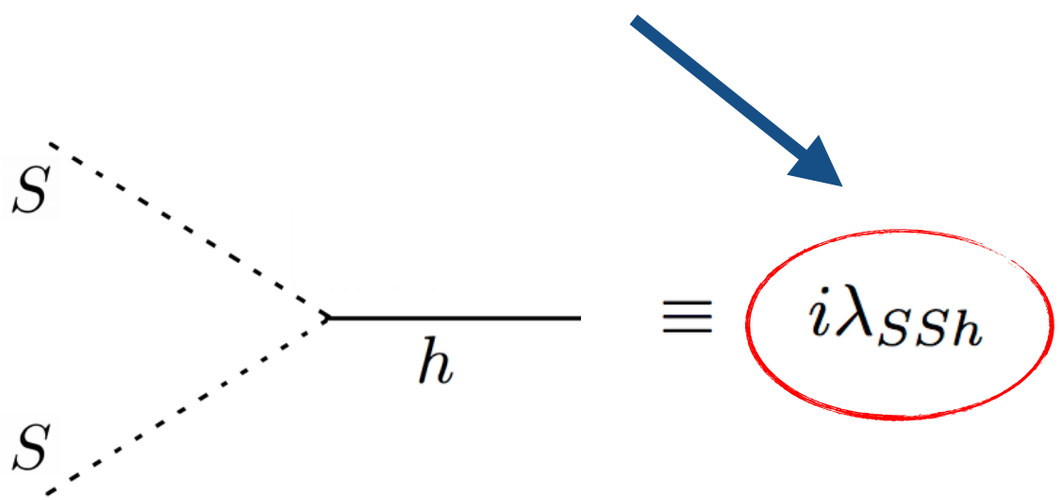
$$= \quad i\lambda_{HS}\underbrace{\left(\frac{\kappa}{\lambda}\right)}_{\text{explicit } SU(4) \text{ breaking}} v\underbrace{\left(1 - 2v^2/f^2\right)}_{\text{explicit } \mathbb{Z}_2 \text{ breaking } \left(v = f/\sqrt{2} \text{ in } \mathbb{Z}_2 \text{ limit}\right)}\left(1 - v^2/f^2\right) + \mathcal{O}\left(\frac{\kappa^2}{\lambda^2}\right)$$

… proportional to explicit breaking parameters.

$$V = \lambda\left(H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2}\right)^2 + \kappa\left(\left(H_A^\dagger H_A\right)^2 + \left(H_B^\dagger H_B\right)^2\right) + \sigma f_0^2 H_A^\dagger H_A$$

$$+\frac{1}{2}\mu_S^2 S^2 + \frac{1}{2}\lambda_{HS} S^2\left(H_A^\dagger H_A + H_B^\dagger H_B\right)$$

Get *suppressed coupling* to pNGB Higgs



… proportional to explicit breaking parameters.

Why does this matter?

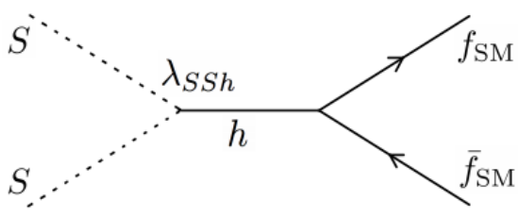
Why does this matter?

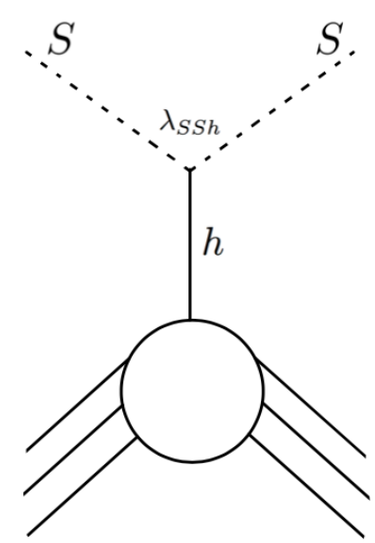
- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

Why does this matter?

- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

$\text{Low energy } (m_S \ll m_h):$

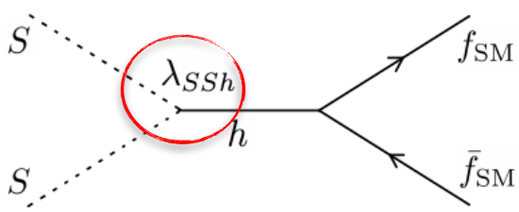


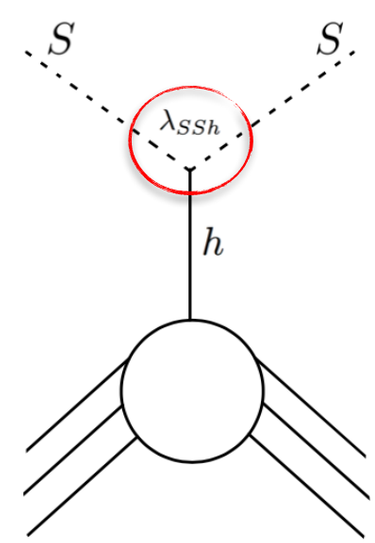


Why does this matter?

- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

$\text{Low energy } (m_S \ll m_h):$



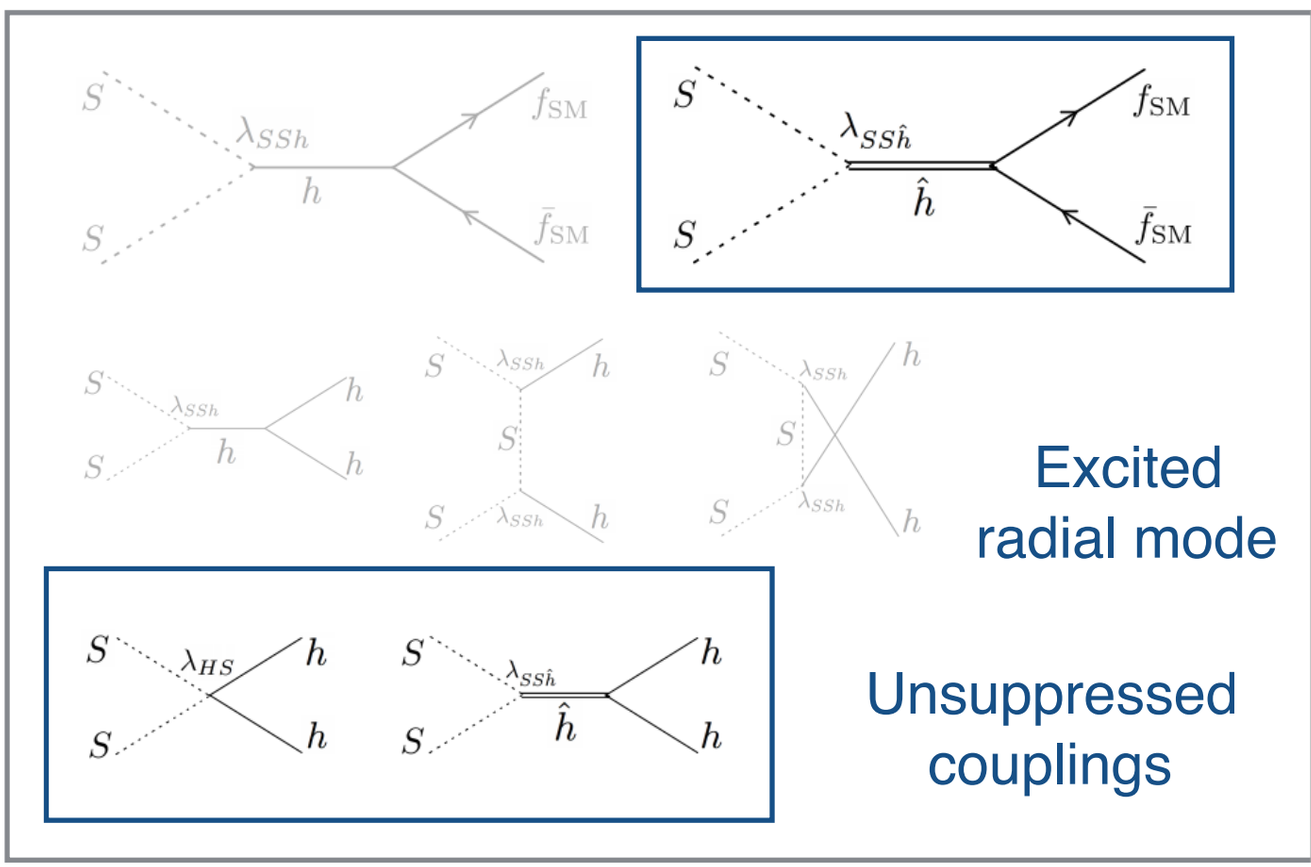


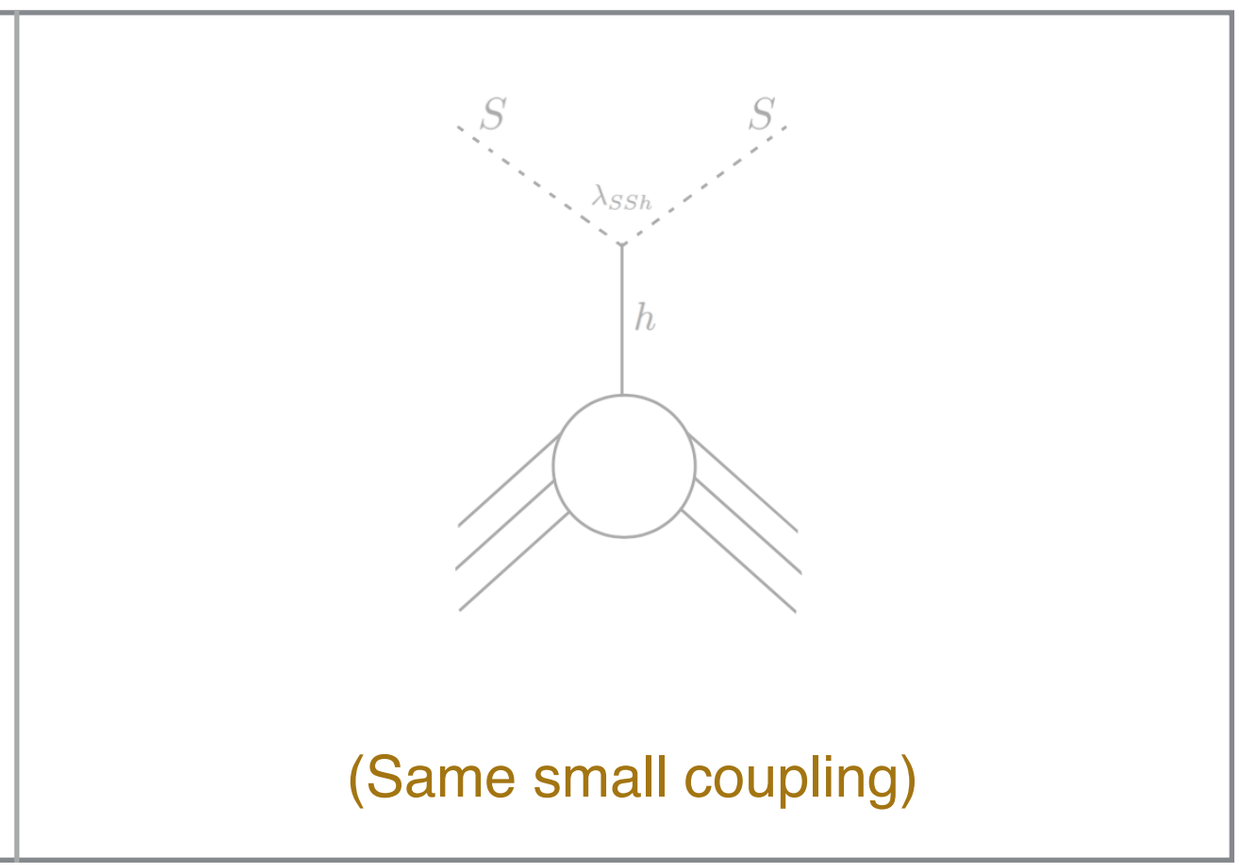
Same small coupling mediates both

Why does this matter?

- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

High energy $(m_S \gtrsim m_h)$:

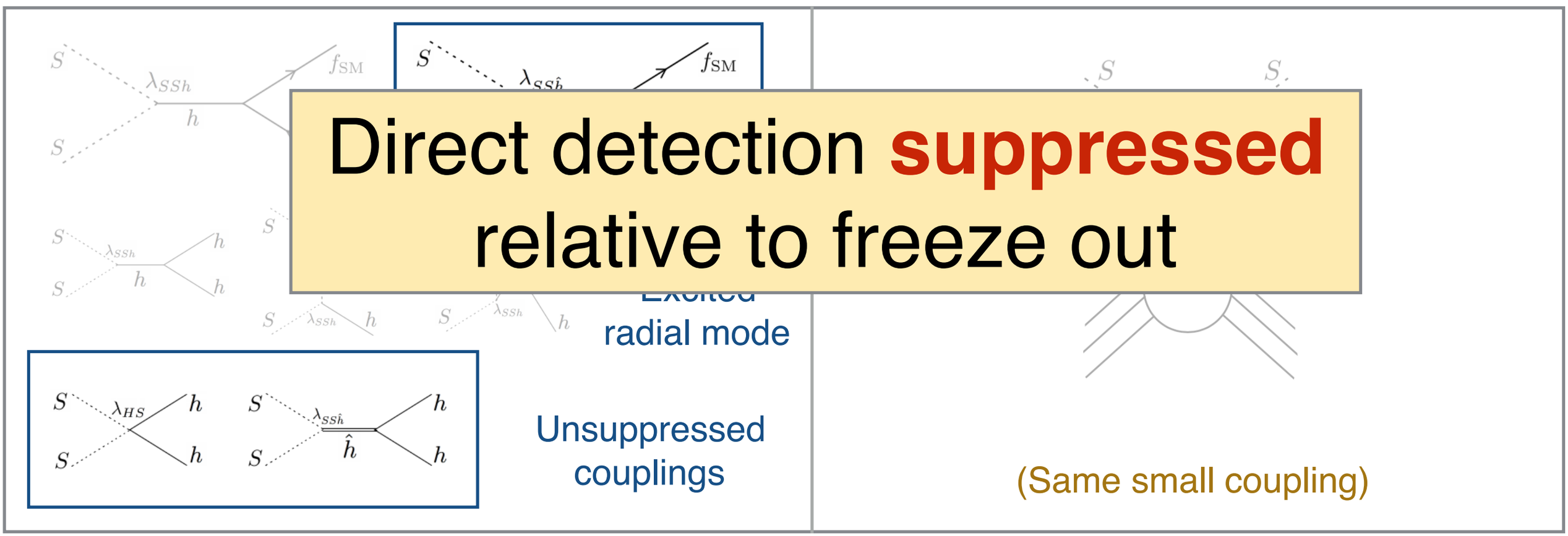




Why does this matter?

- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

High energy $(m_S \gtrsim m_h)$:



Direct detection **suppressed** relative to freeze out

Excited radial mode

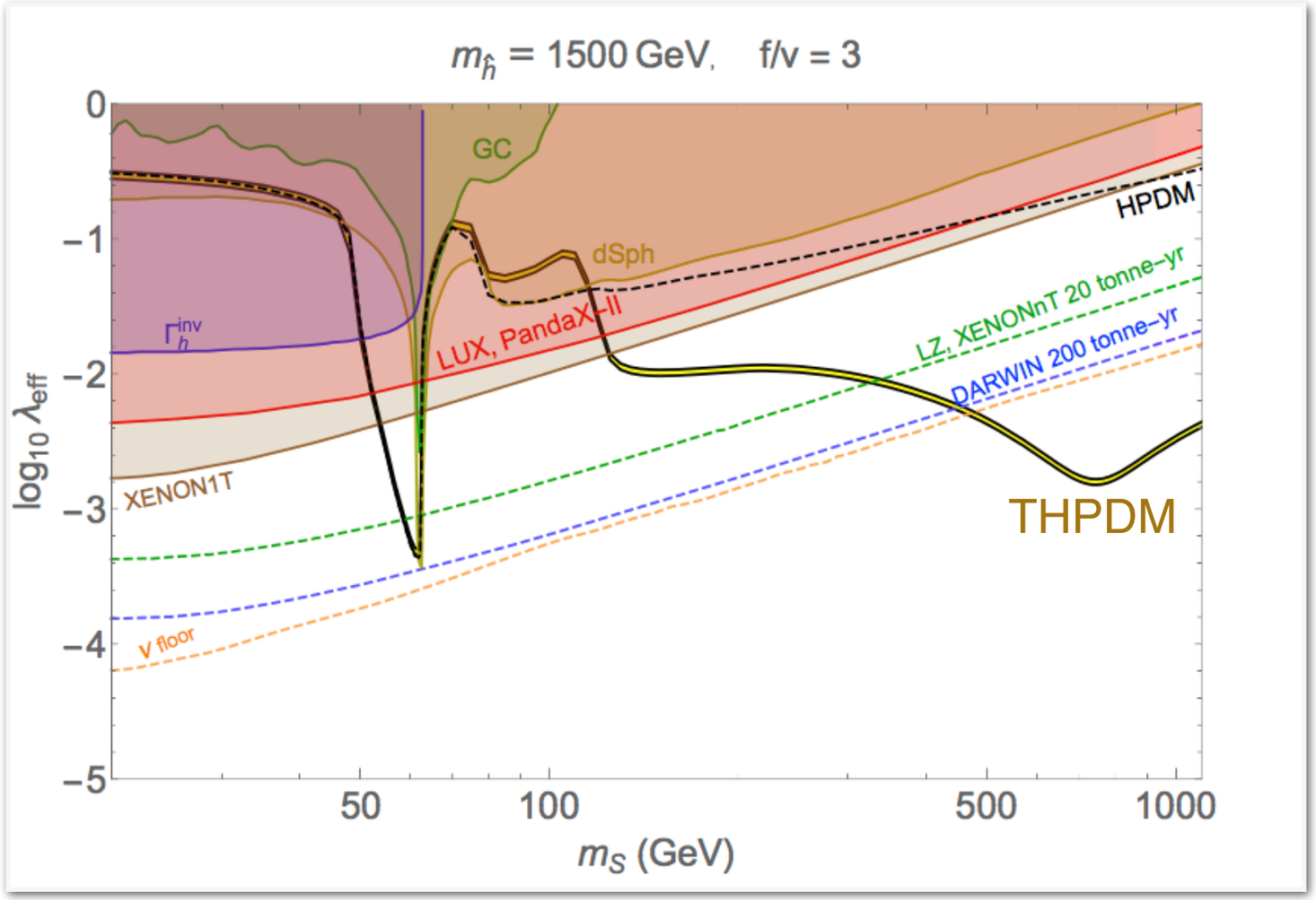
Unsuppressed couplings

(Same small coupling)

Reduced direct detection

$$\Omega_{\rm DM} h^2 = 0.120 \pm .001$$

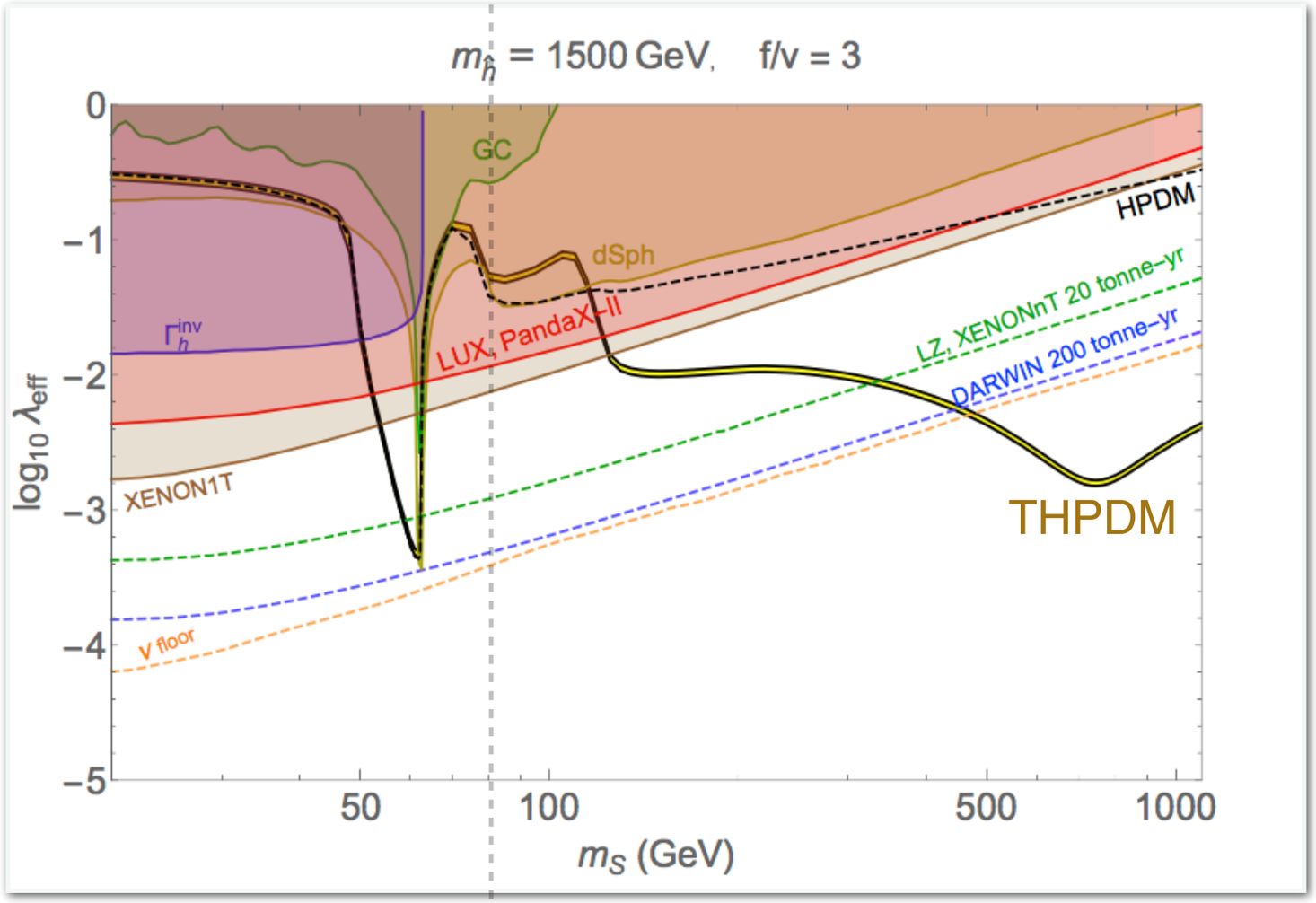
Planck 2018, astro-ph/1807.06209



Reduced direct detection

$$\Omega_{\rm DM} h^2 = 0.120 \pm .001$$

Planck 2018, astro-ph/1807.06209



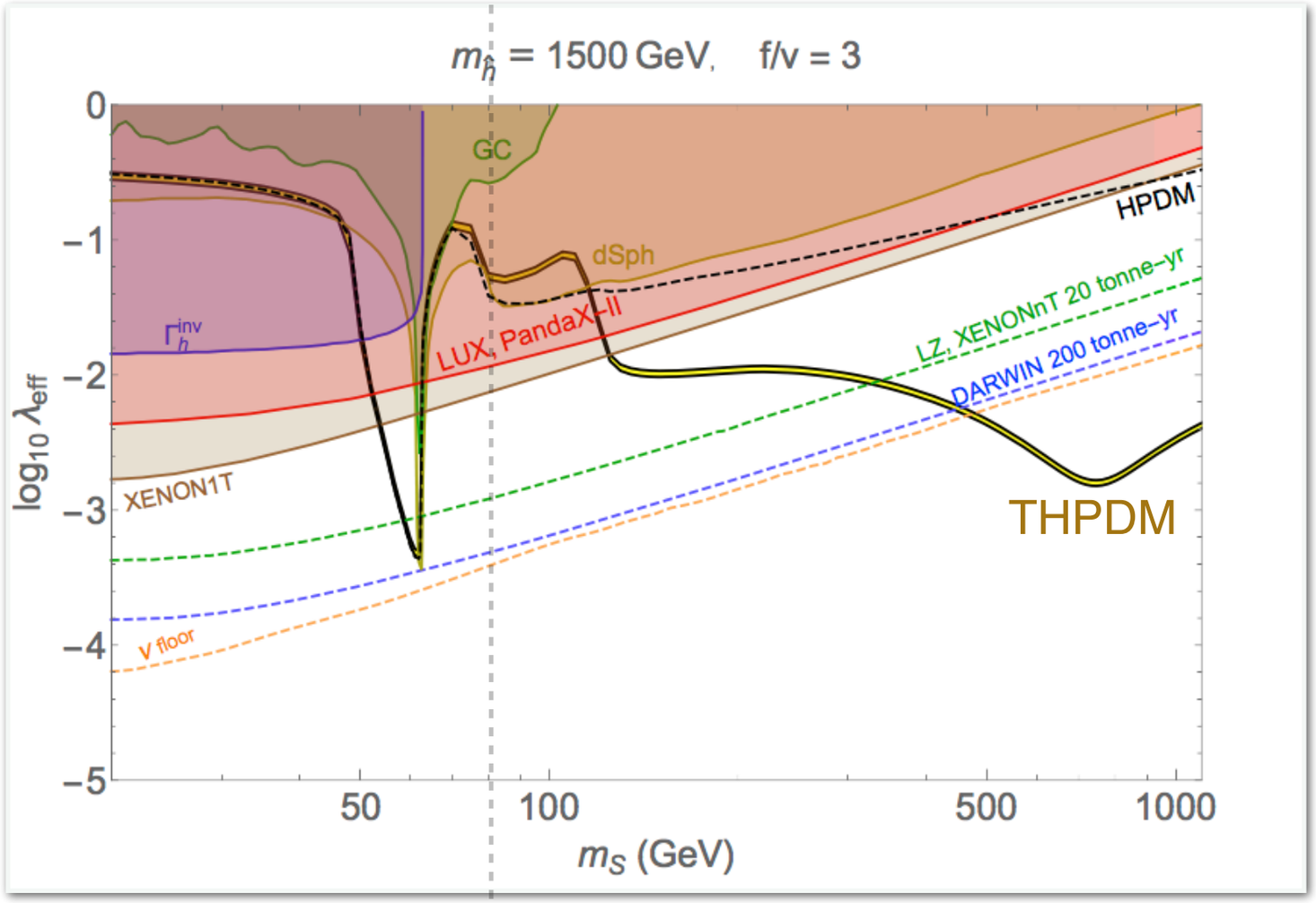
- Freezes out via λ_{SSh}
- DD proceeds via λ_{SSh}

Maps on to regular Higgs portal WIMP scenario

Reduced direct detection

$$\Omega_{\rm DM} h^2 = 0.120 \pm .001$$

Planck 2018, astro-ph/1807.06209



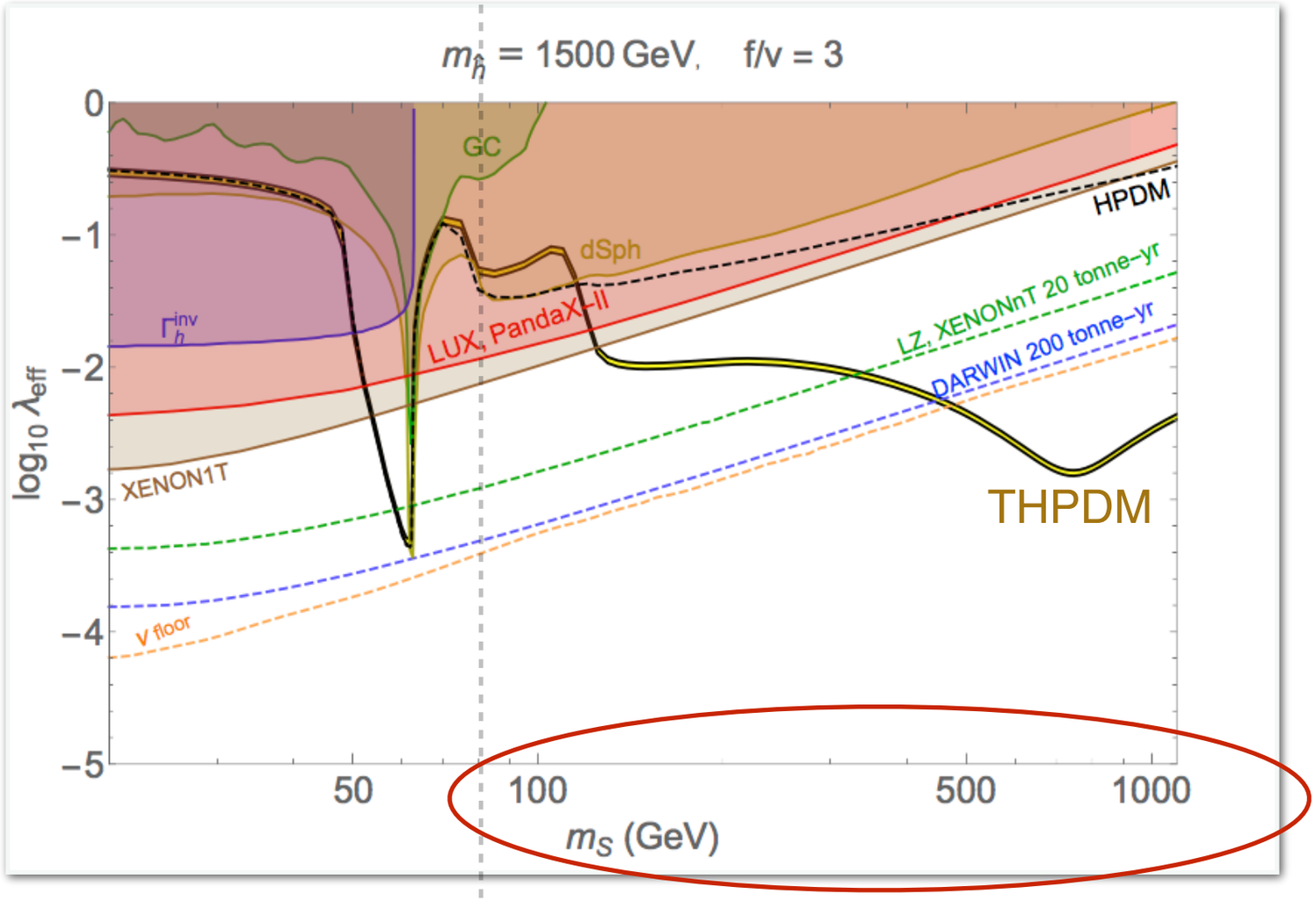
- Freezes out via λ_{SSh}
- DD proceeds via λ_{SSh}

Maps on to regular Higgs portal WIMP scenario

- Freezes out through unsuppressed coupling λ_{HS}
- DD proceeds via λ_{SSh}

Direct detection suppressed — possibilities for **next gen** experiments!

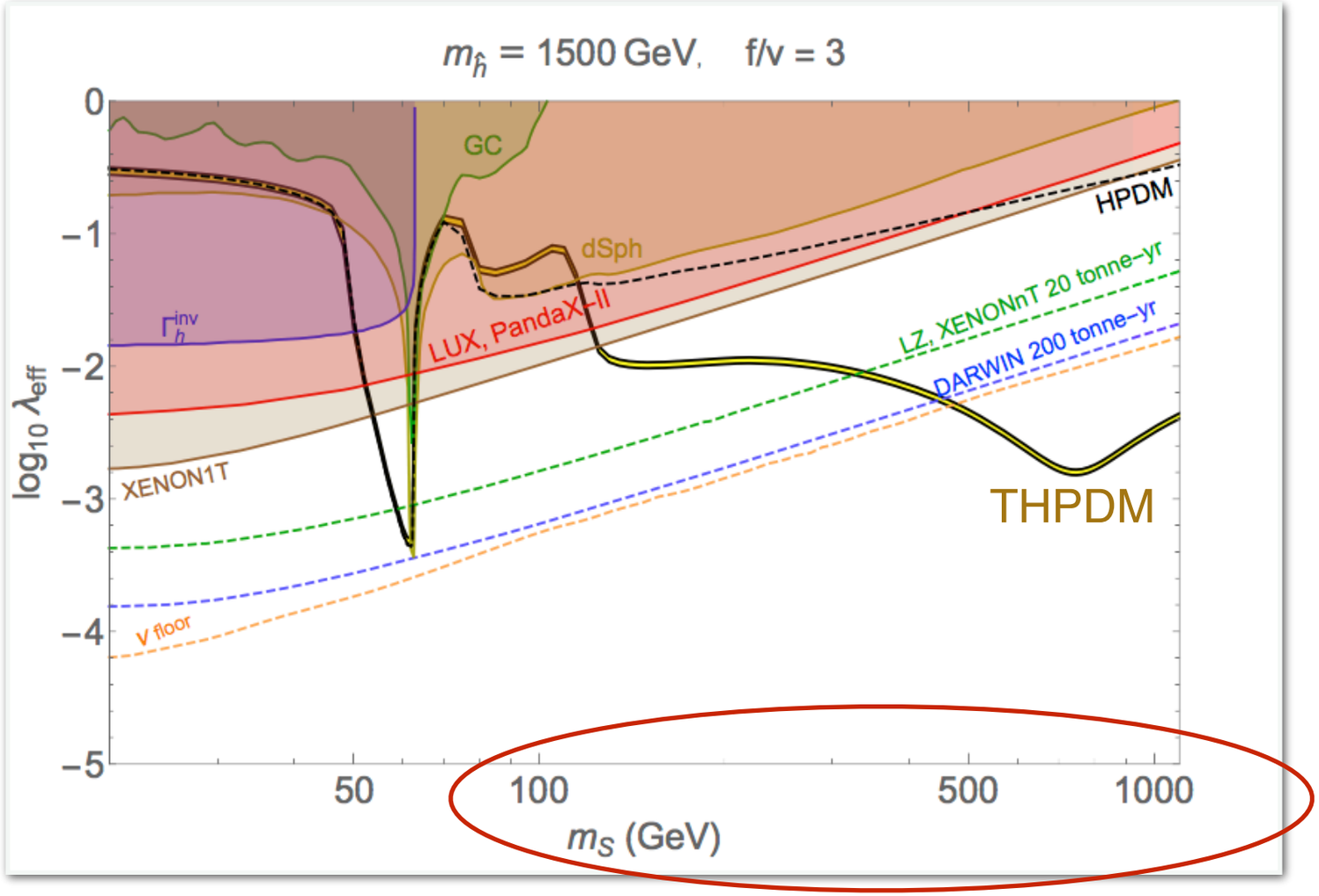
Is there reason to assume we live here?



- Freezes out through unsuppressed coupling λ_{HS}
- DD proceeds via λ_{SSh}

Direct detection possible in **next generation** experiments!

Is there reason to assume we live here?

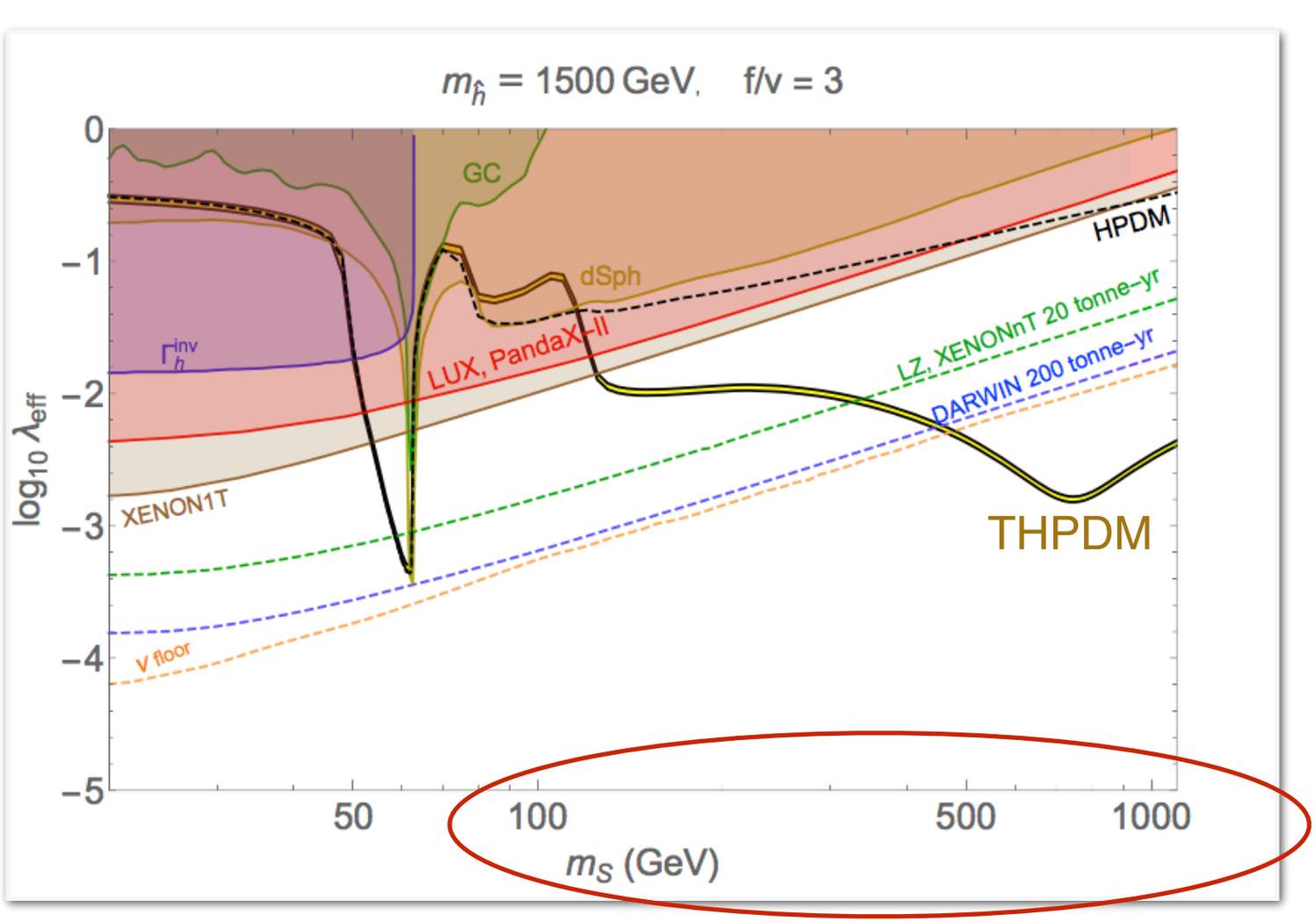


Yes! Natural mass scale for S is $\mathcal{O}(f)$:

$$V_S = \frac{1}{2}\mu_S^2 S^2 + \frac{1}{2}\lambda_{HS} S^2 \left(H_A^\dagger H_A + H_B^\dagger H_B\right)$$

- want natural tree level mass: $m_S^2 = \mu^2 + \lambda_{HS} f^2$
- unsuppressed radial mode coupling generates $\mathcal{O}(f)$ mass corrections at loop level

Is there reason to assume we live here?



Vast majority of unexplored parameter space corresponds to most natural DM mass scale!

Last point:

Last point:

Some Twin Higgs models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$ constraints

This can be solved by **diluting** the twin radiation through late-time decays to mostly SM final states, known as asymmetric reheating

This dilutes the DM, further reducing the expected coupling:

Last point:

Some Twin Higgs models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$ constraints

This can be solved by **diluting** the twin radiation through late-time decays to mostly SM final states, known as asymmetric reheating

This dilutes the DM, further reducing the expected coupling:

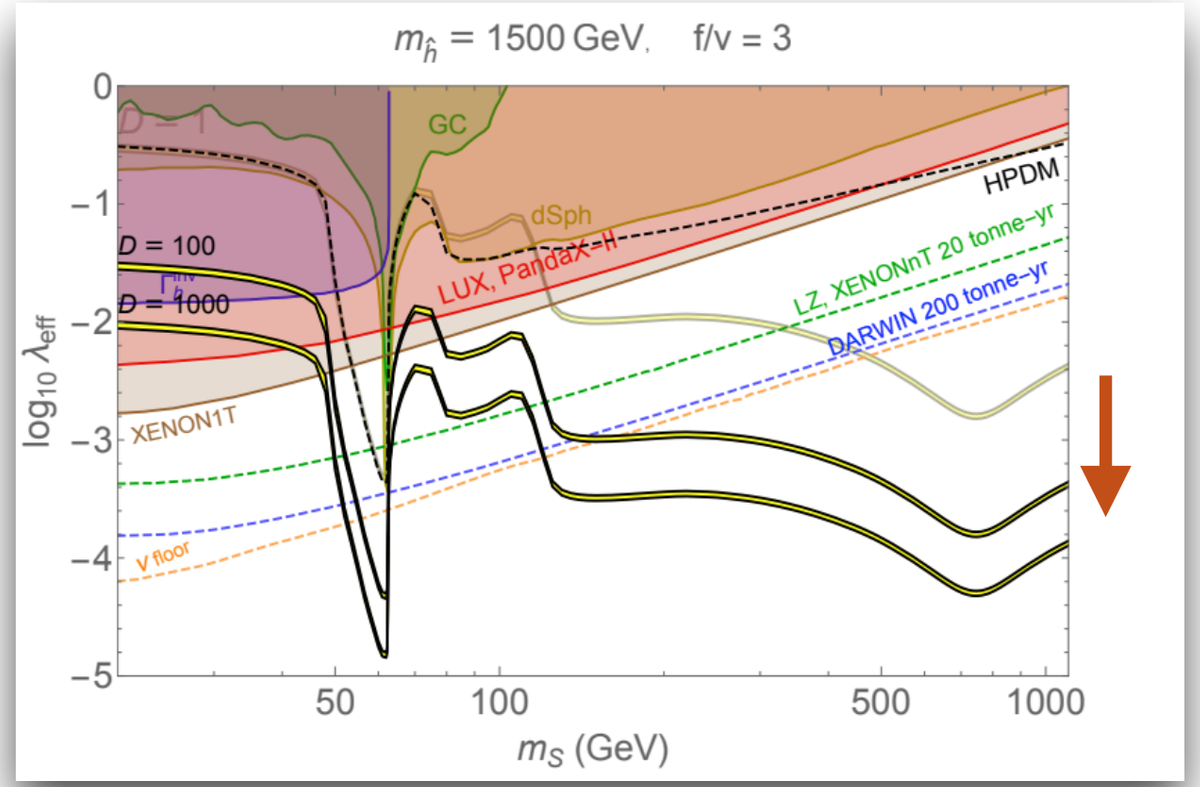
$$\Omega \to \Omega/D \quad \longrightarrow \quad \lambda_{HS} \to \lambda_{HS}/\sqrt{D}$$

Last point:

Some Twin Higgs models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$ constraints

This can be solved by **diluting** the twin radiation through late-time decays to mostly SM final states, known as asymmetric reheating

This dilutes the DM, further reducing the expected coupling:



THPDM + AR:
cosmologically valid
for all twin spectra!

CONCLUSION

We extended the Twin Higgs framework to include a singlet scalar DM candidate

CONCLUSION

We extended the Twin Higgs framework to include a singlet scalar DM candidate

The pNGB nature of the Higgs leads to suppressed direct detection signals for the most natural DM mass scale

CONCLUSION

We extended the Twin Higgs framework to include a singlet scalar DM candidate

The pNGB nature of the Higgs leads to suppressed direct detection signals for the most natural DM mass scale

CONCLUSION

The model is valid for any Twin Higgs spectrum — incorporating asymmetric reheating further suppresses direct detection

We extended the Twin Higgs framework to include a singlet scalar DM candidate

The pNGB nature of the Higgs leads to suppressed direct detection signals for the most natural DM mass scale

CONCLUSION

The model is valid for any Twin Higgs spectrum — incorporating asymmetric reheating further suppresses direct detection

Thanks!

hep-ph/2101.11019

EXTRAS

ASYMMETRIC REHEATING

Cosmology issues in Twin Higgs

- DD suppression valid for **all** Twin Higgs models…
- … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$
- Solve with *asymmetric reheating:*

nuMTH: Z. Chacko, N. Craig, P. J. Fox, R. Harnik hep-ph/1611.07975
XMTH: N. Craig, S. Koren, T. Trott hep-ph/1611.07977

Cosmology issues in Twin Higgs

- DD suppression valid for **all** Twin Higgs models…
- … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$
- Solve with *asymmetric reheating:*

nuMTH: Z. Chacko, N. Craig, P. J. Fox, R. Harnik hep-ph/1611.07975
XMTH: N. Craig, S. Koren, T. Trott hep-ph/1611.07977

- Introduce weakly interacting, **massive**, long-lived particle with preferential decays to SM
- Freezes out relativistically, dominates cosmology at late times
- Decays at late times
- Dilutes twin sector radiation contribution to $\Delta N_{\rm eff}$

Cosmology issues in Twin Higgs

- DD suppression valid for **all** Twin Higgs models…
- … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\rm eff}$
- Solve with *asymmetric reheating:*

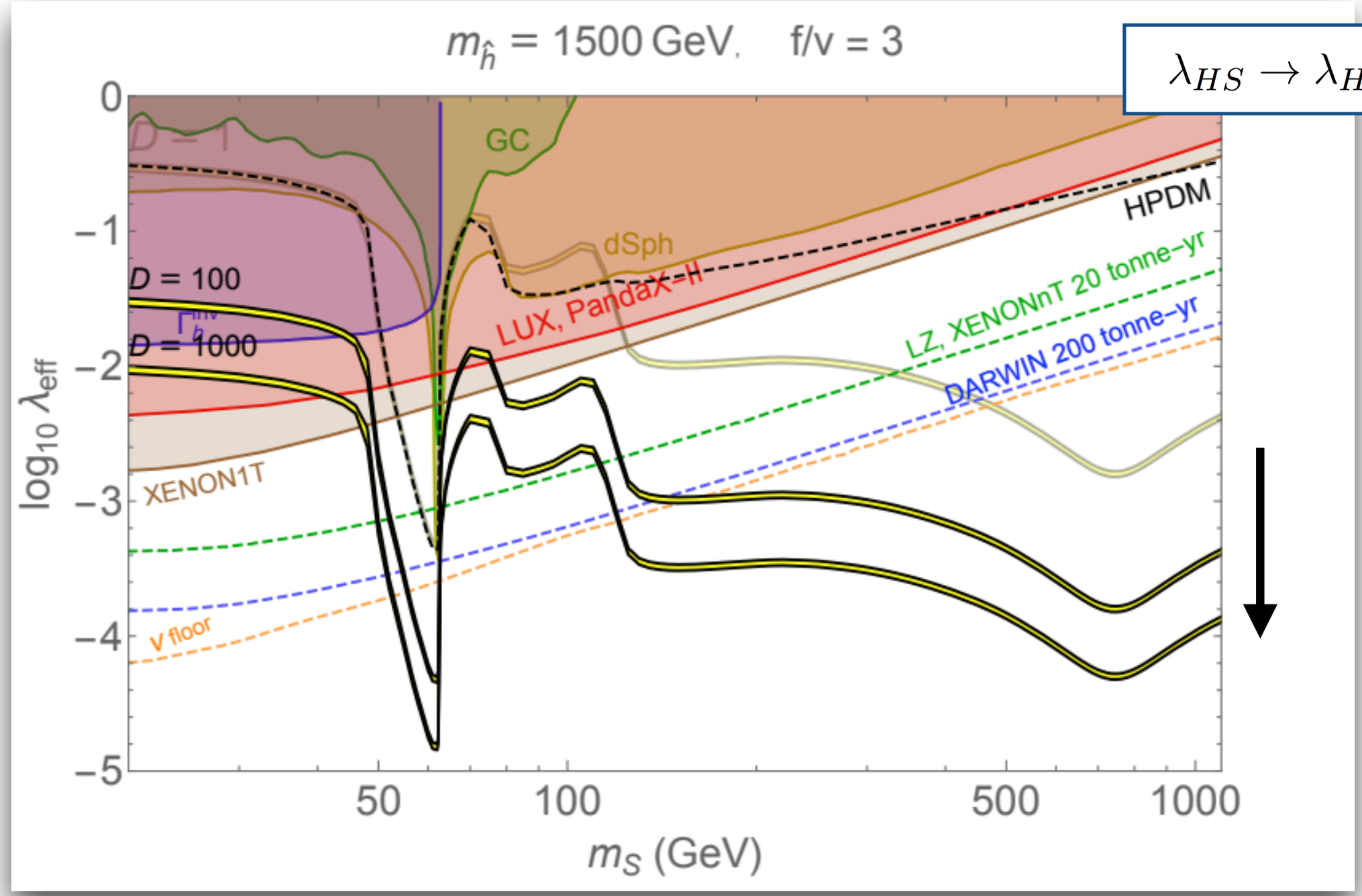
nuMTH: Z. Chacko, N. Craig, P. J. Fox, R. Harnik hep-ph/1611.07975
XMTH: N. Craig, S. Koren, T. Trott hep-ph/1611.07977

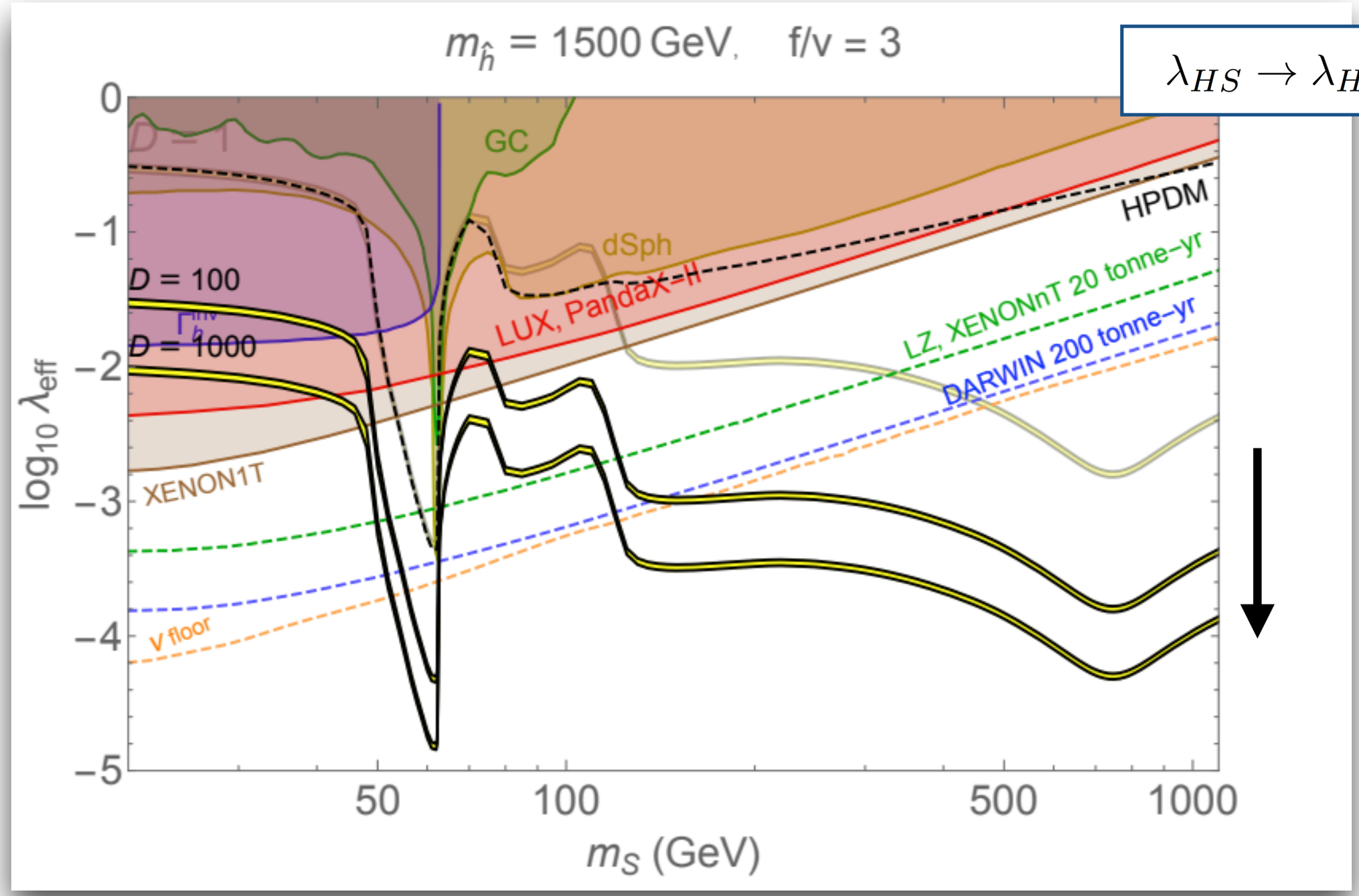
Diluting twin radiation dilutes DM:

$$\Omega \to \Omega/D$$

Further reduces DD predictions:

$$\lambda_{HS} \to \lambda_{HS}/\sqrt{D}$$


$m_{\hat{h}}$ = 1500 GeV, f/v = 3
$\lambda_{HS} \to \lambda_{HS}/\sqrt{D}$
D = 1
D = 100
D = 1000
GC
dSph
HPDM
LUX, PandaX-II
LZ, XENONnT 20 tonne–yr
DARWIN 200 tonne–yr
XENON1T
ν floor
$\log_{10} \lambda_{\rm eff}$
m_S (GeV)
0
−1
−2
−3
−4
−5
50
100
500
1000



Twin Higgs Portal DM
+
asymmetric reheating

→

Model of DM that is cosmologically valid for **any** twin spectrum