Impact of light dark matter on Higgs physics

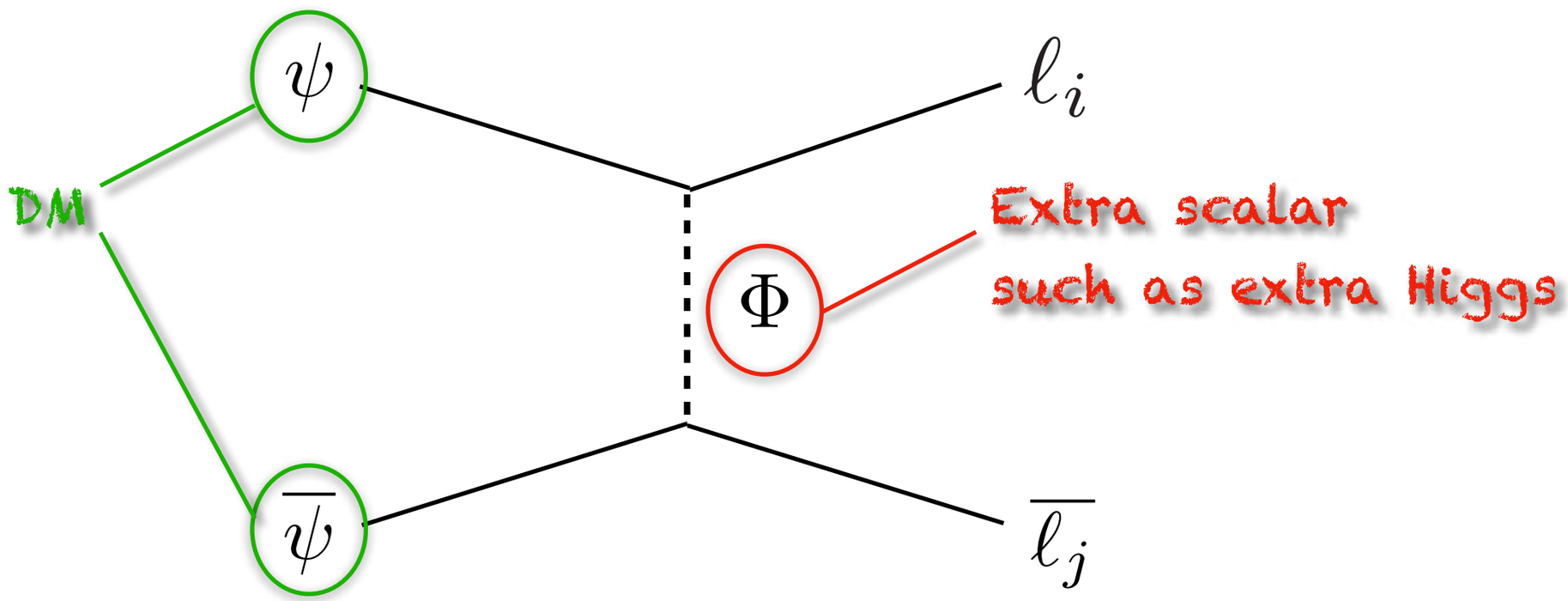
Yuji Omura (Kindai Univ.)

based on the collaboration with
S. Okawa
(arXiv: 2011.04788)

Introduction

I am studying phenomenology in <u>lepton portal DM models</u>

with J. Kawamura and S. Okawa
(arXiv: 2002.12534)



- DM couples to only leptons.
- There are many types:

  DM is scalar or fermion.

Interesting points

- Setup is very simple, and could be interrupted as effective models of many extended SMs.

- Strong bound from DM direct detection can be evaded at the tree level, but at the one-loop …

See arXiv: 2002.12534 with J. Kawamura and S. Okawa

- muon g-2 is enhanced in some setups.

- The mediator predicts characteristic signals, especially, related to 125 GeV Higgs.

In this talk,

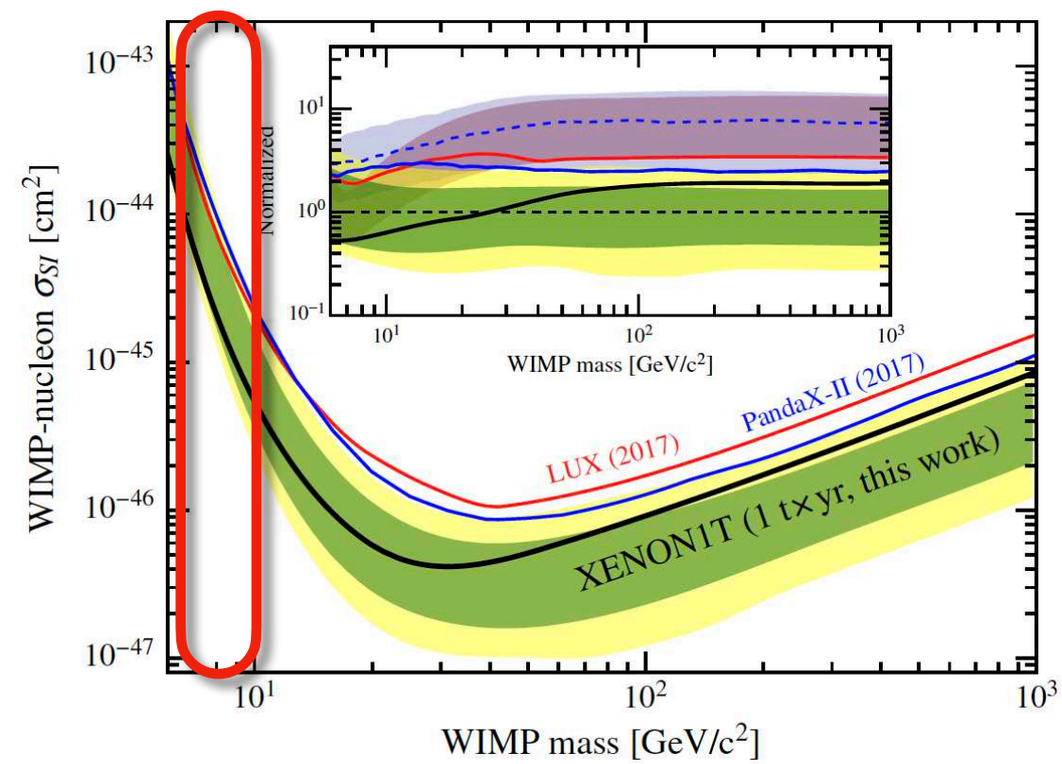
・introduce <u>our recent results</u> based on arXiv:2011.04788 (collaboration with S.Okawa).

Focus on light DM region,

$$10\mathrm{MeV} \leq m_{DM} \leq 10\mathrm{GeV}$$

that can evade the strong bound from direct detection.

PRL121,111302



・discuss our prediction for Higgs signals, as well as DM signals.

Setup

Matter content

	Fields	spin	$SU(3)$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$	stabilize DM Z_2
	Q_L^i	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$\frac{1}{6}$	0	$+$
	u_R^i	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$\frac{2}{3}$	0	$+$
	d_R^i	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$-\frac{1}{3}$	0	$+$
	ℓ_L^i	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-\frac{1}{2}$	1	$+$
	e_R^i	$1/2$	$\mathbf{1}$	$\mathbf{1}$	-1	1	$+$
DM	ψ_L	$1/2$	$\mathbf{1}$	$\mathbf{1}$	0	1	$-$
	ψ_R	$1/2$	$\mathbf{1}$	$\mathbf{1}$	0	1	$-$
	Φ	1	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{2}$	0	$+$
extra	Φ_ν	1	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{2}$	0	$-$

Relevant couplings

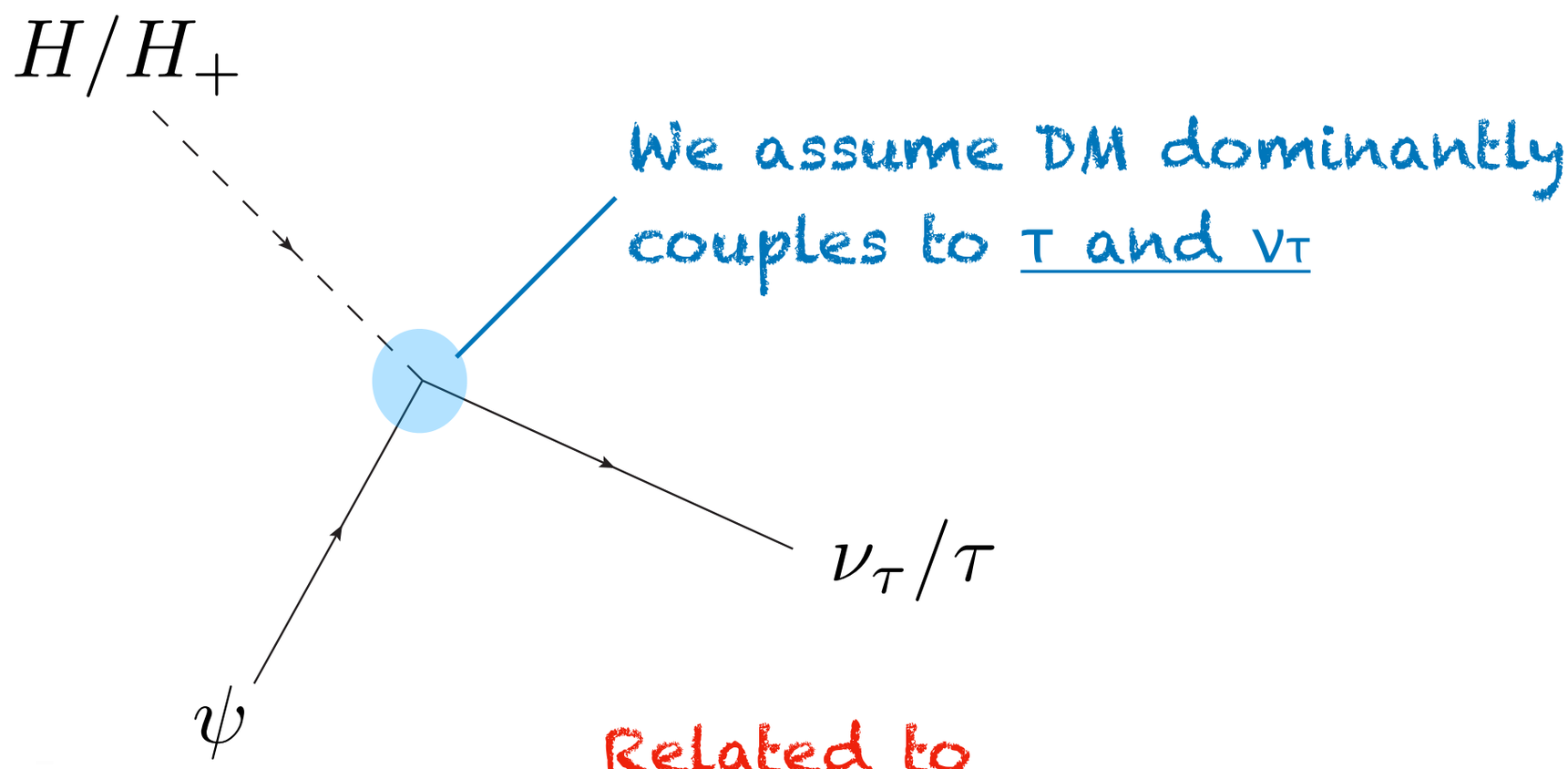
$$-\mathcal{L}_\ell = y_\nu^i \, \overline{\ell_L^i} \, \widetilde{\Phi}_\nu \, \psi_R + h.c.$$

After EWSB

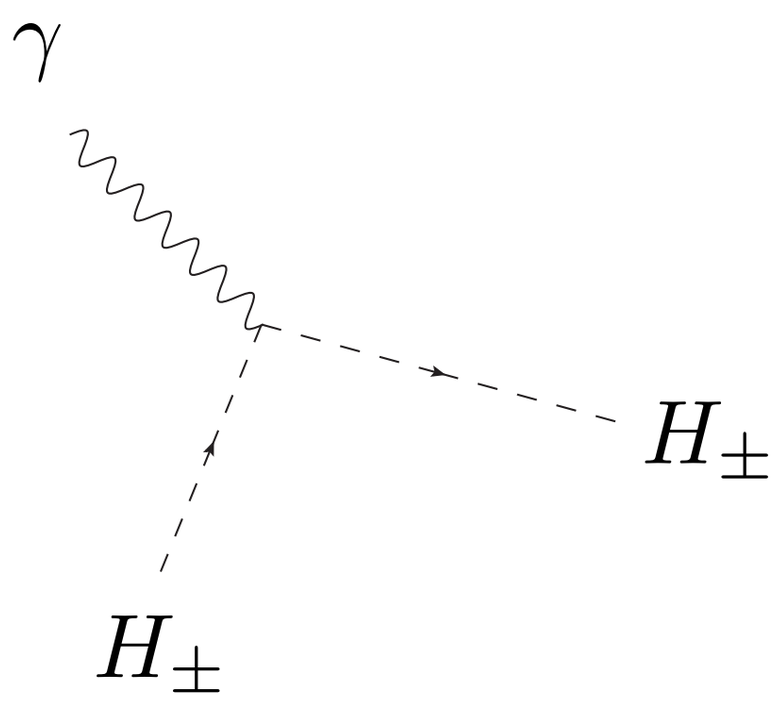
$$-\mathcal{L}_\ell = y_\nu^i \left[\frac{1}{\sqrt{2}} \overline{\nu_L^i} (H - iA) \psi_R - \overline{e_L^i} H^- \psi_R \right] + h.c.$$

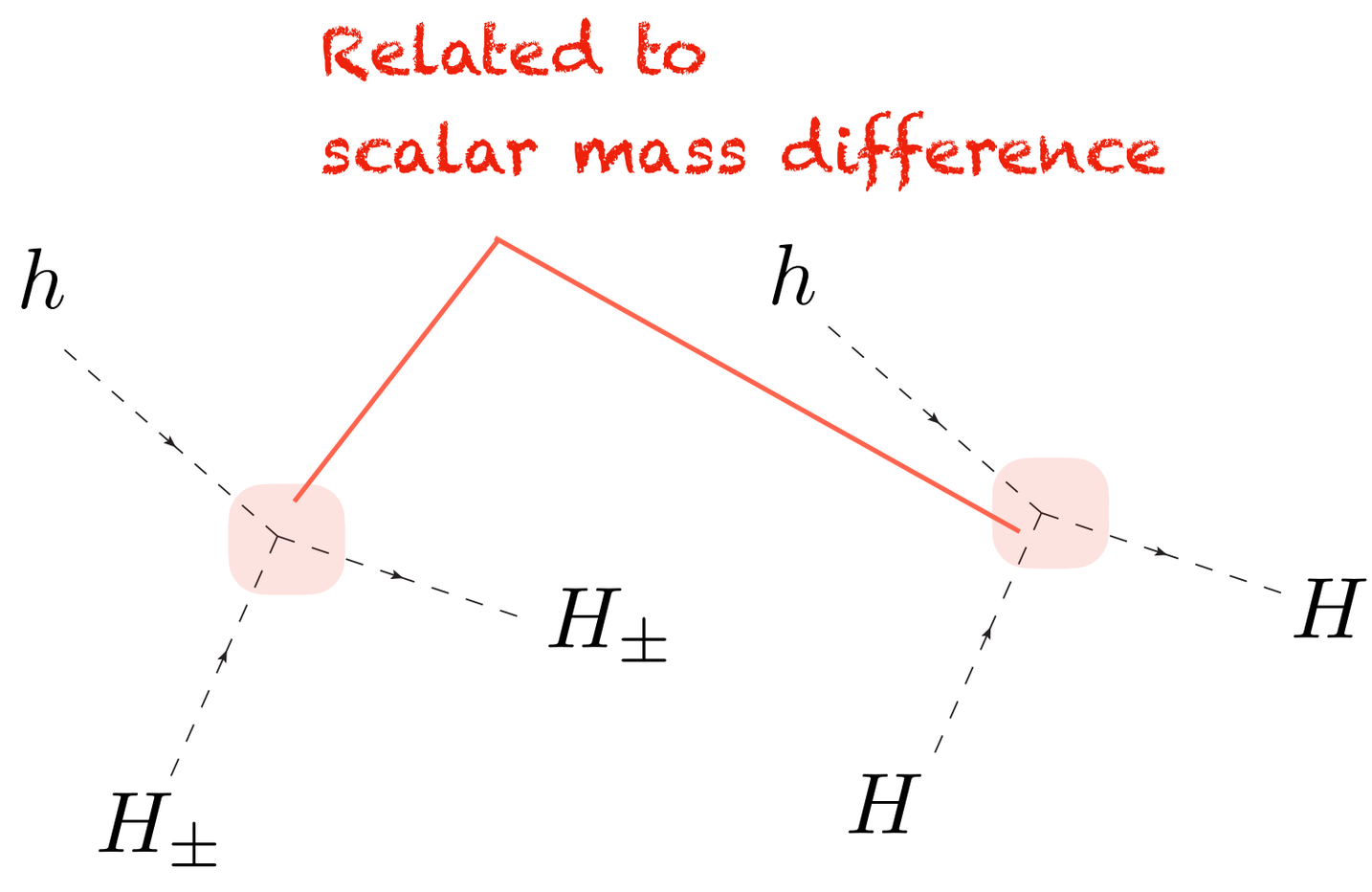
New particles and relevant couplings

DM couplings



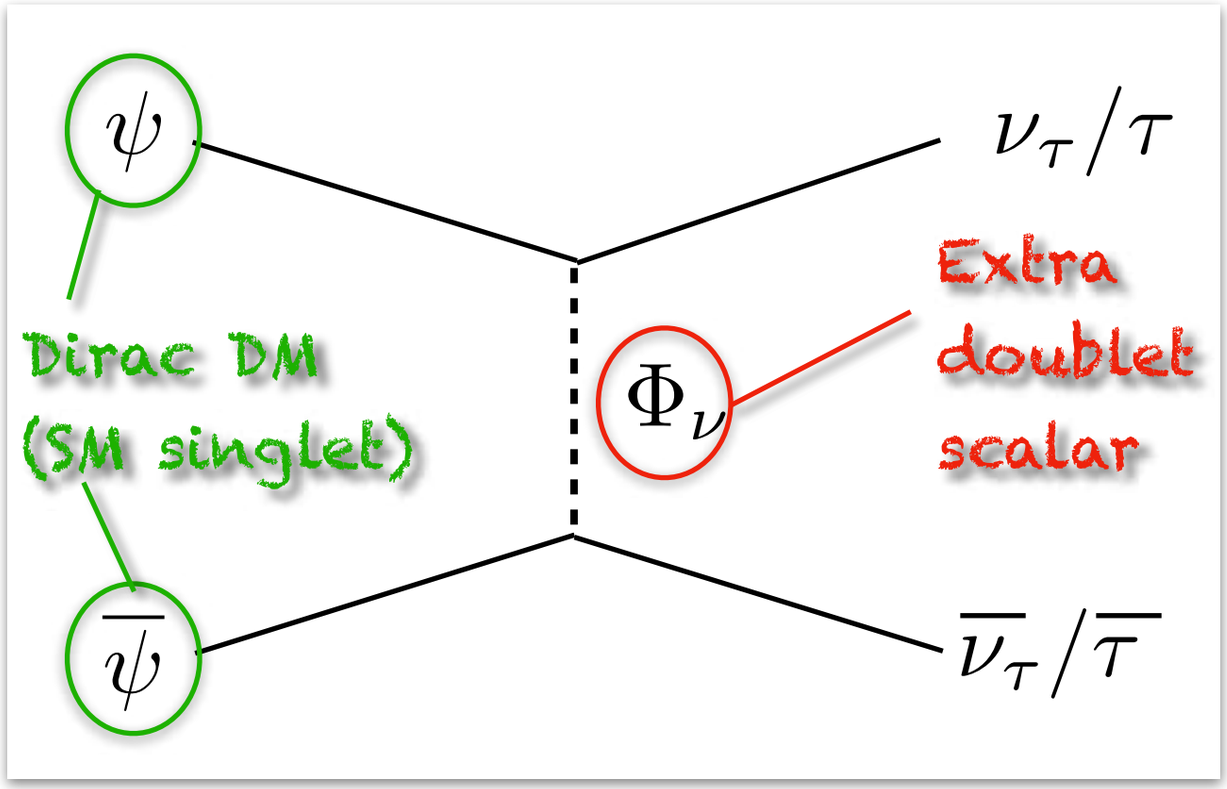
Extra scalar couplings





DM annihilate to leptons through scalar exchange

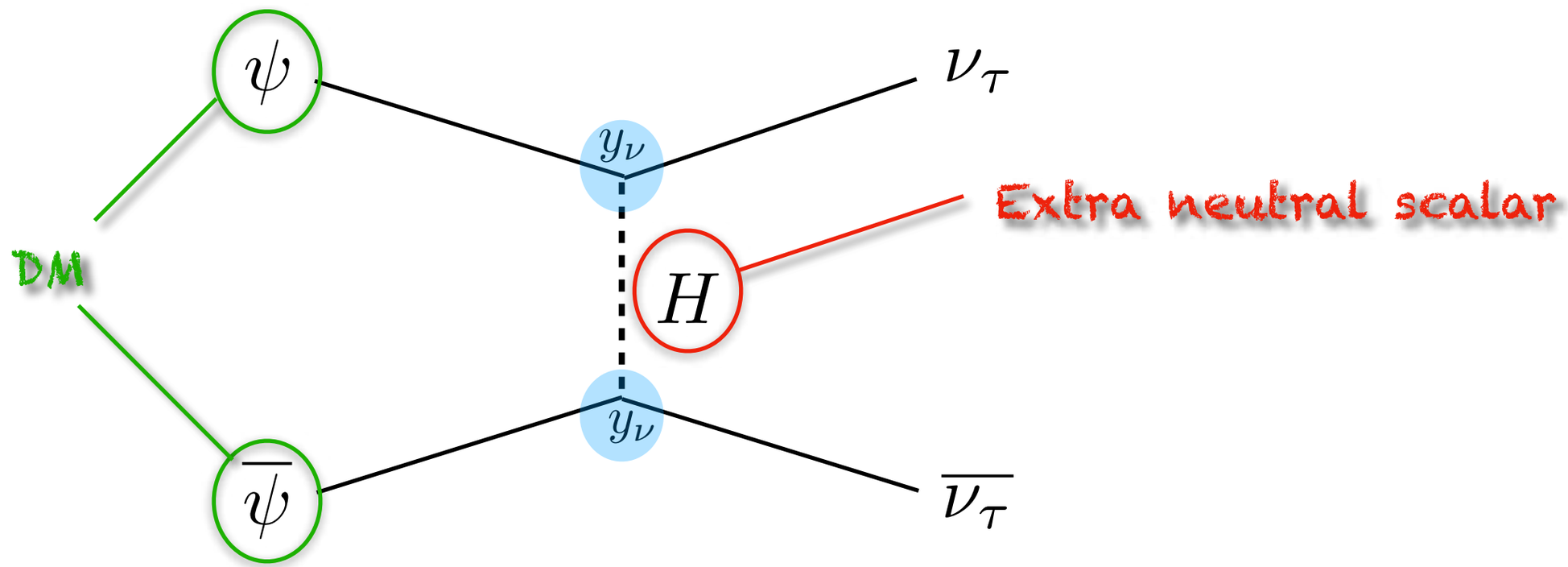
2002.12534 with Kawamura, Okawa



Note: The annihilation cross-section needs to be sizable to achieve correct relic density of DM.

DM annihilation

If DM is lighter than τ, DM annihilates to ν



$$(\sigma v_{\rm rel})_{\psi\bar{\psi}\to\nu\bar{\nu}} \simeq \frac{y_\nu^4 m_\psi^2}{128\pi(m_\psi^2 + m_H^2 - m_\nu^2)^2}\sqrt{1-\frac{m_\nu^2}{m_\psi^2}}$$

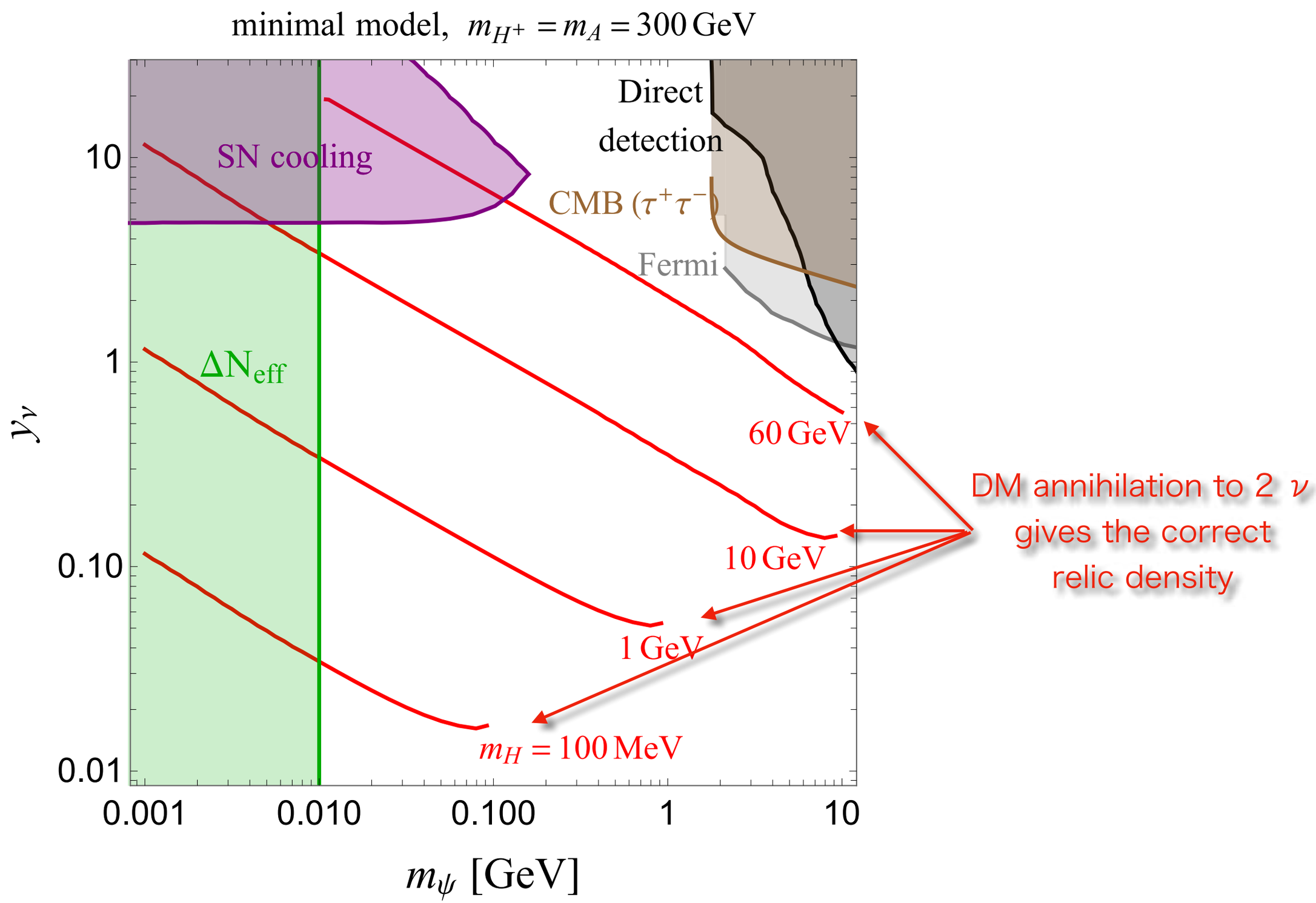
If H is also light, cross section is enough large to thermally produce DM.

Light DM predicts a light neutral scalar

Summary of results

Parameters to lead correct relic density of DM

2011.04788 with Okawa



It is difficult to test this mass region in the direct detection, but possible in the 125 GeV Higgs signal.

2011.04788 with Okawa

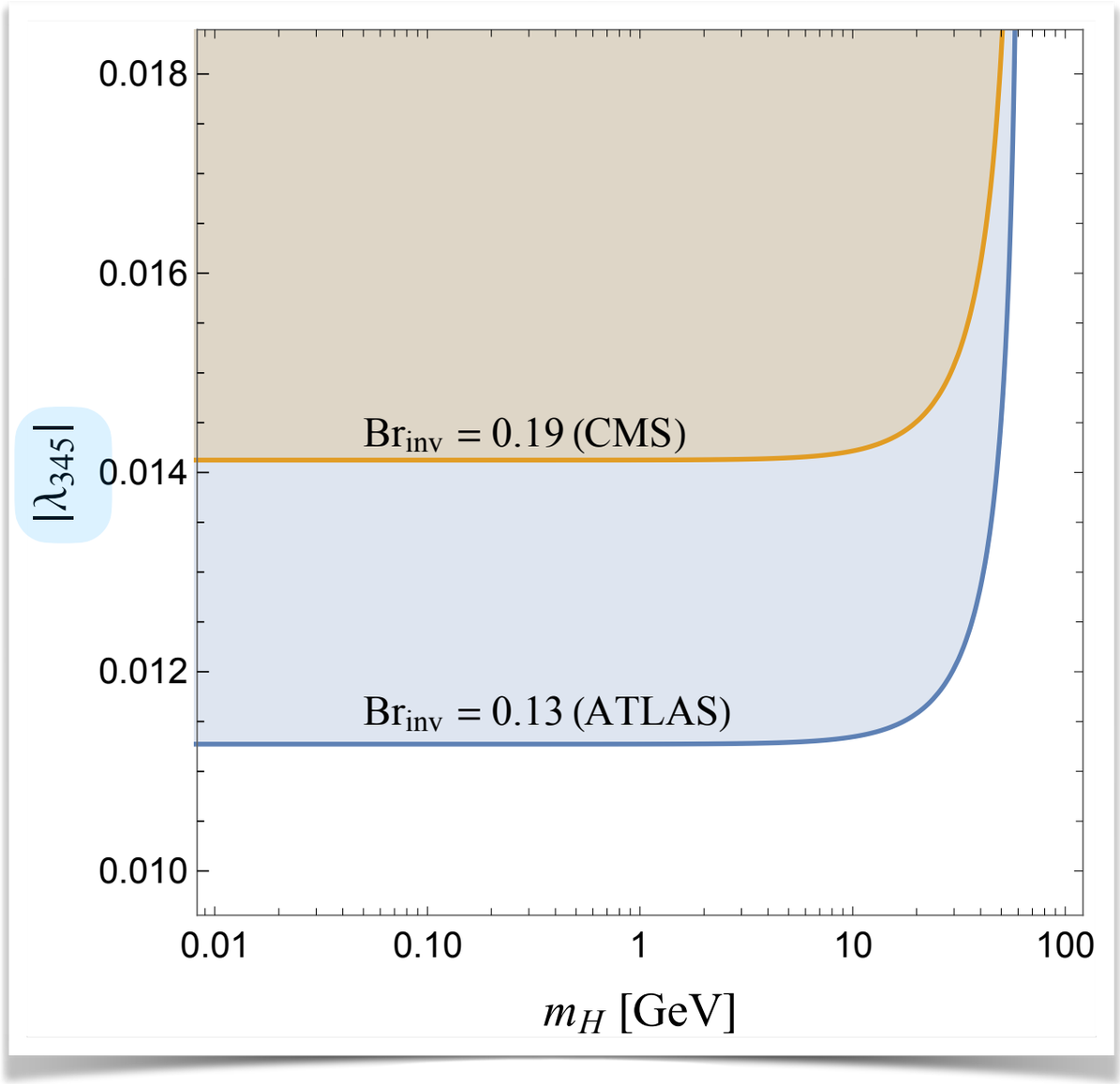
h decays to HH,
that is invisible decay of h.

$$\frac{\lambda_{345}}{4}(2vh + h^2)H^2$$

should be tuned.

$$\lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5$$

gives large mass differences
between H+ and H



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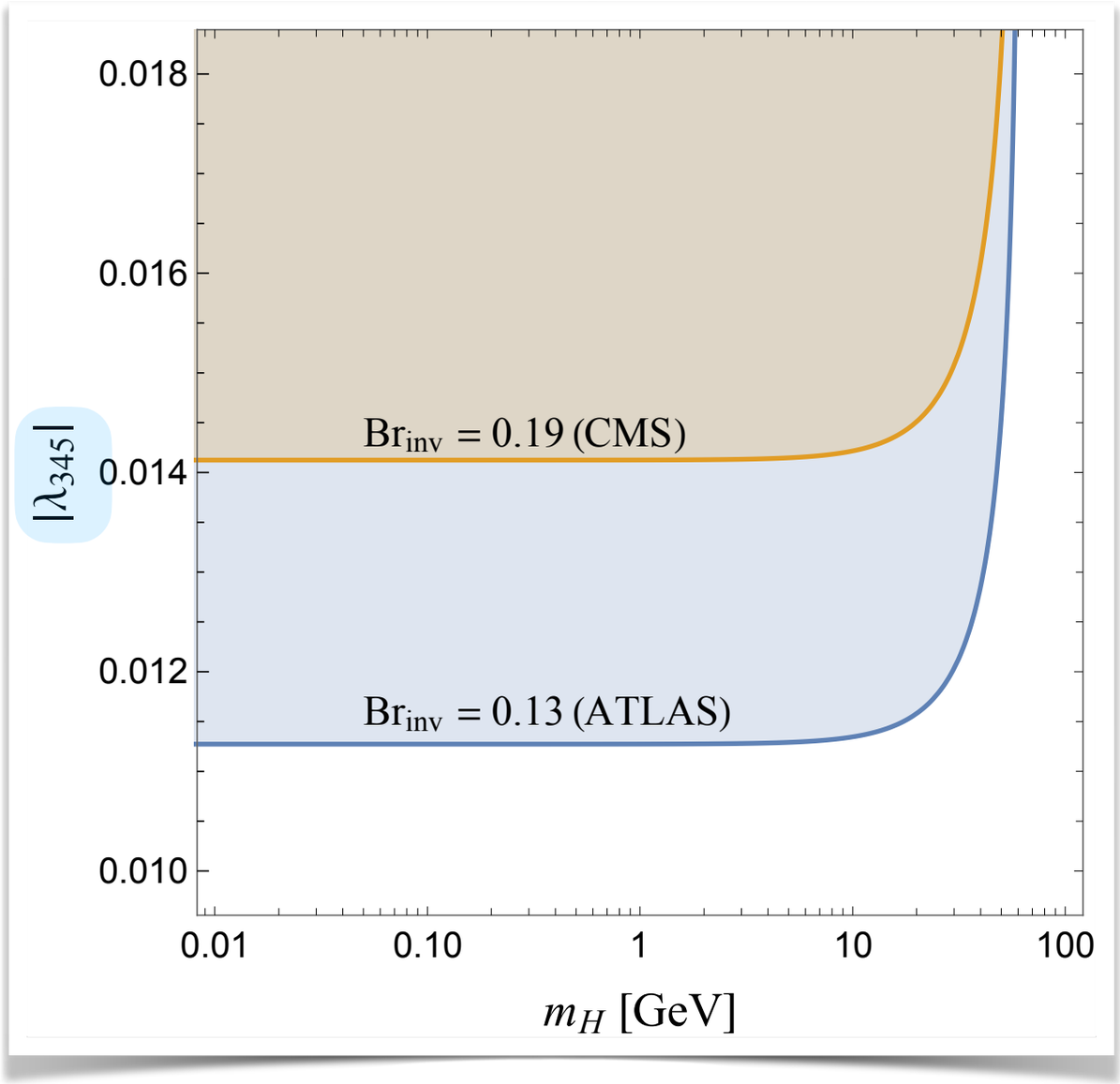

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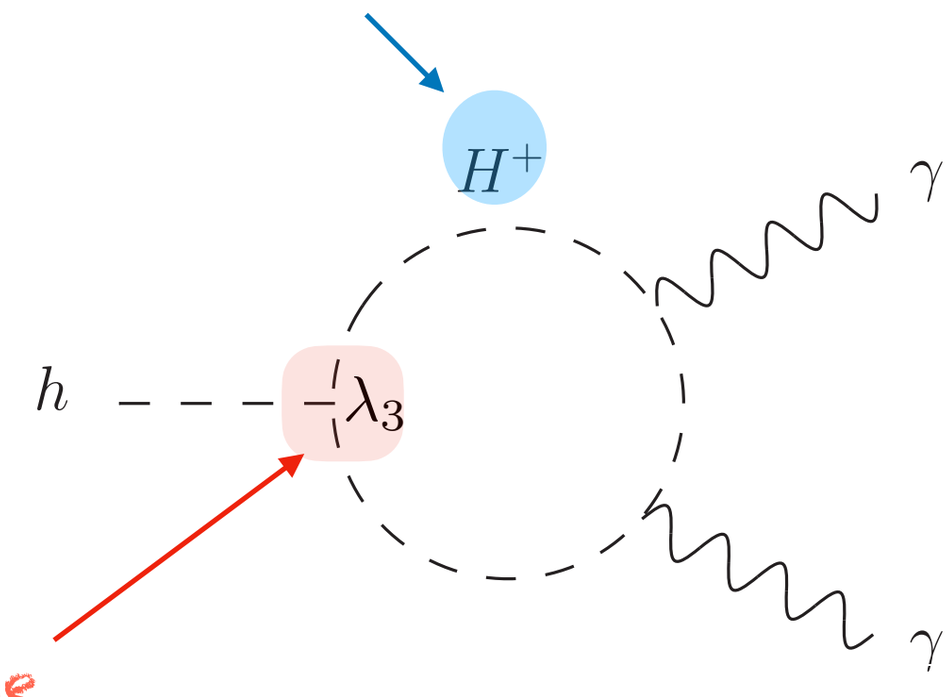
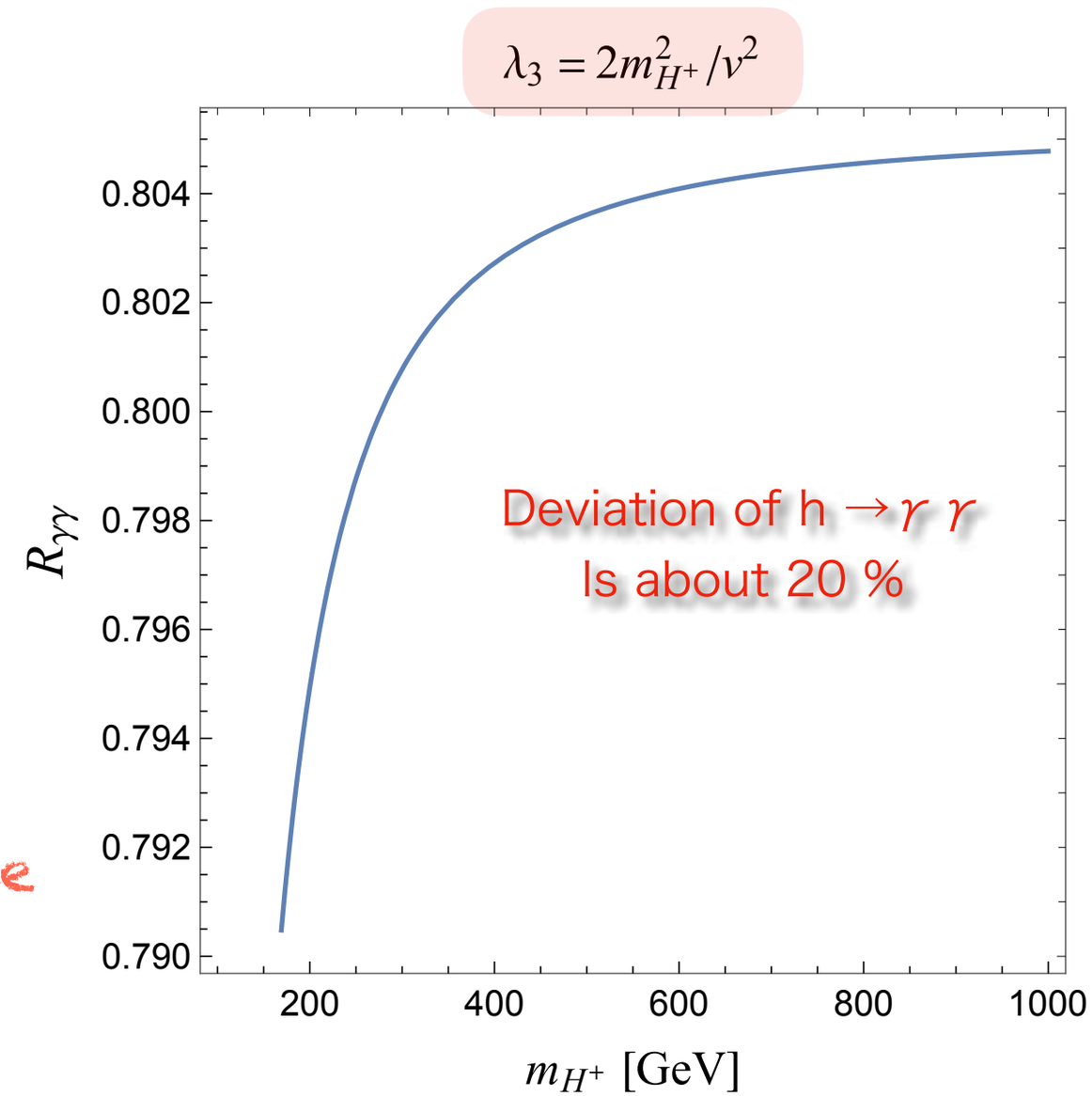
2011.04788 with Okawa

Heavier than ~250 GeV because of LHC



large
to make mass difference between
H and H+ large and suppress invisible
decay of h.



It is possible to test in the indirect detection.

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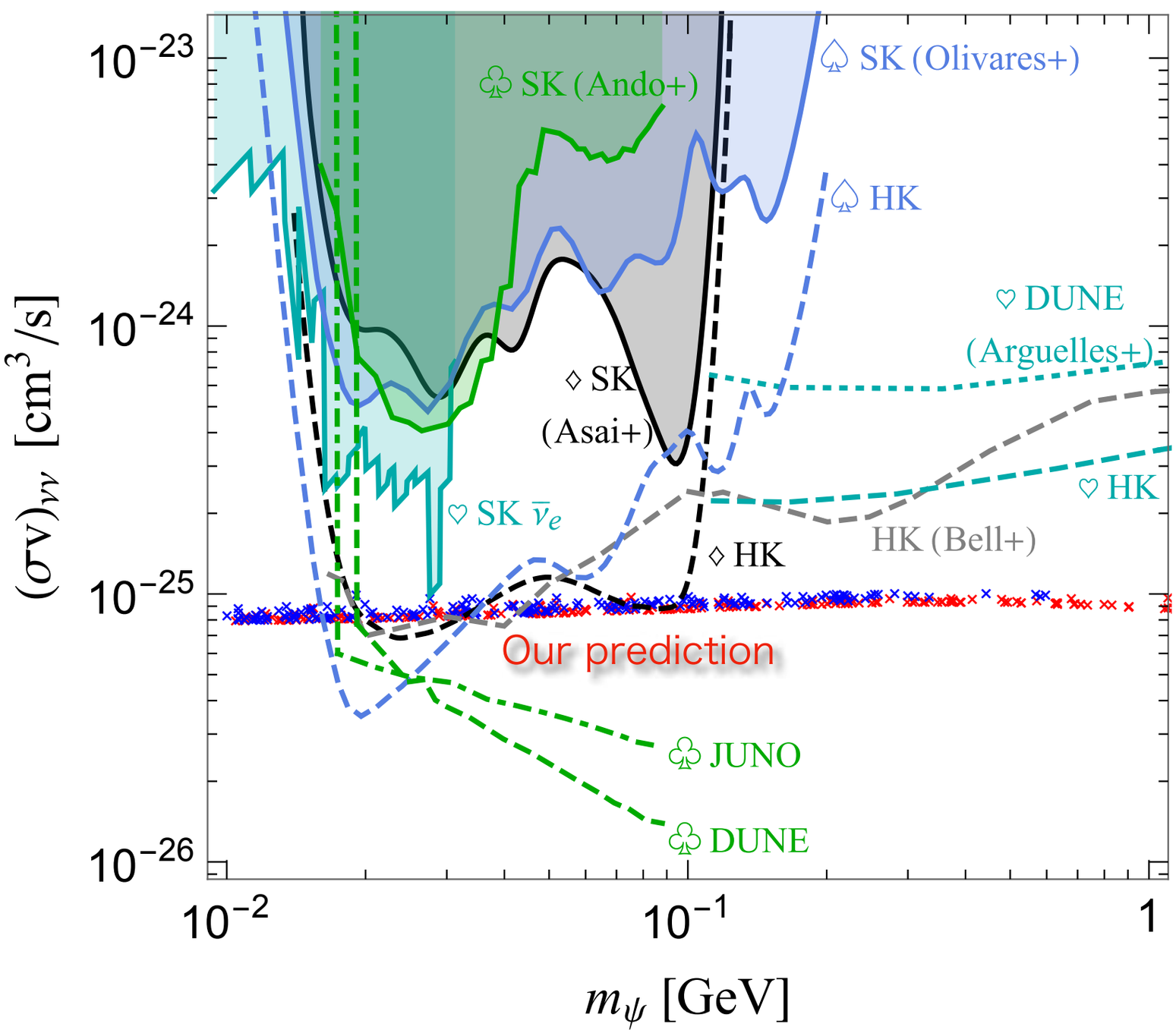
Our DM annihilates to ν_τ



Summary and comments

- DM lighter than 10 GeV can evade the strong bound from the direct DM search. Mediator should be also light.

- Making mass difference among scalars is a big issue: large couplings required in the scalar potential. → A solution is to add one more scalar (See our paper, arXiv: 2011.04788, S.Okawa and YO).

- In Higgs physics, h $\to \gamma\gamma$ is largely deviated (about 20 %) and invisible decay is also large, because of the large couplings.

- We can also test our model in the neutrino observation.

- We can search for the scalars at LHC, ILC, etc. (Work in progress).

END

Backup

Extended model with a scalar

2011.04788 with Okawa

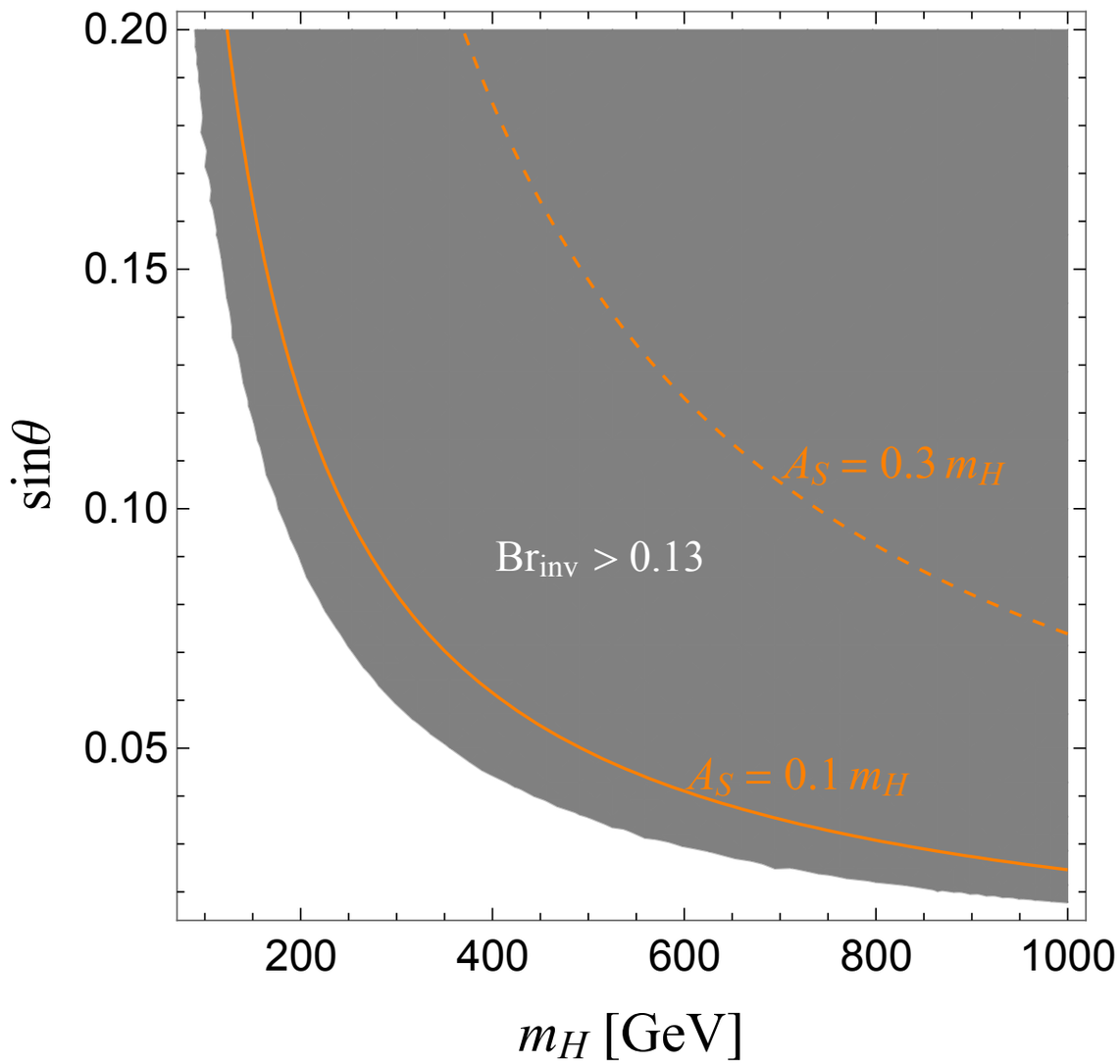
	Fields	spin	$SU(3)$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$	Z_2
	Q_L^i	$1/2$	$\mathbf{3}$	$\mathbf{2}$	$\frac{1}{6}$	0	$+$
	u_R^i	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$\frac{2}{3}$	0	$+$
	d_R^i	$1/2$	$\mathbf{3}$	$\mathbf{1}$	$-\frac{2}{3}$	0	$+$
	ℓ_L^i	$1/2$	$\mathbf{1}$	$\mathbf{2}$	$-\frac{1}{2}$	1	$+$
	e_R^i	$1/2$	$\mathbf{1}$	$\mathbf{1}$	-1	1	$+$
	ψ_L	$1/2$	$\mathbf{1}$	$\mathbf{1}$	0	1	$-$
	ψ_R	$1/2$	$\mathbf{1}$	$\mathbf{1}$	0	1	$-$
	Φ	1	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{2}$	0	$+$
	Φ_ν	1	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{2}$	0	$-$
extra	S	1	$\mathbf{1}$	$\mathbf{1}$	0	0	$-$

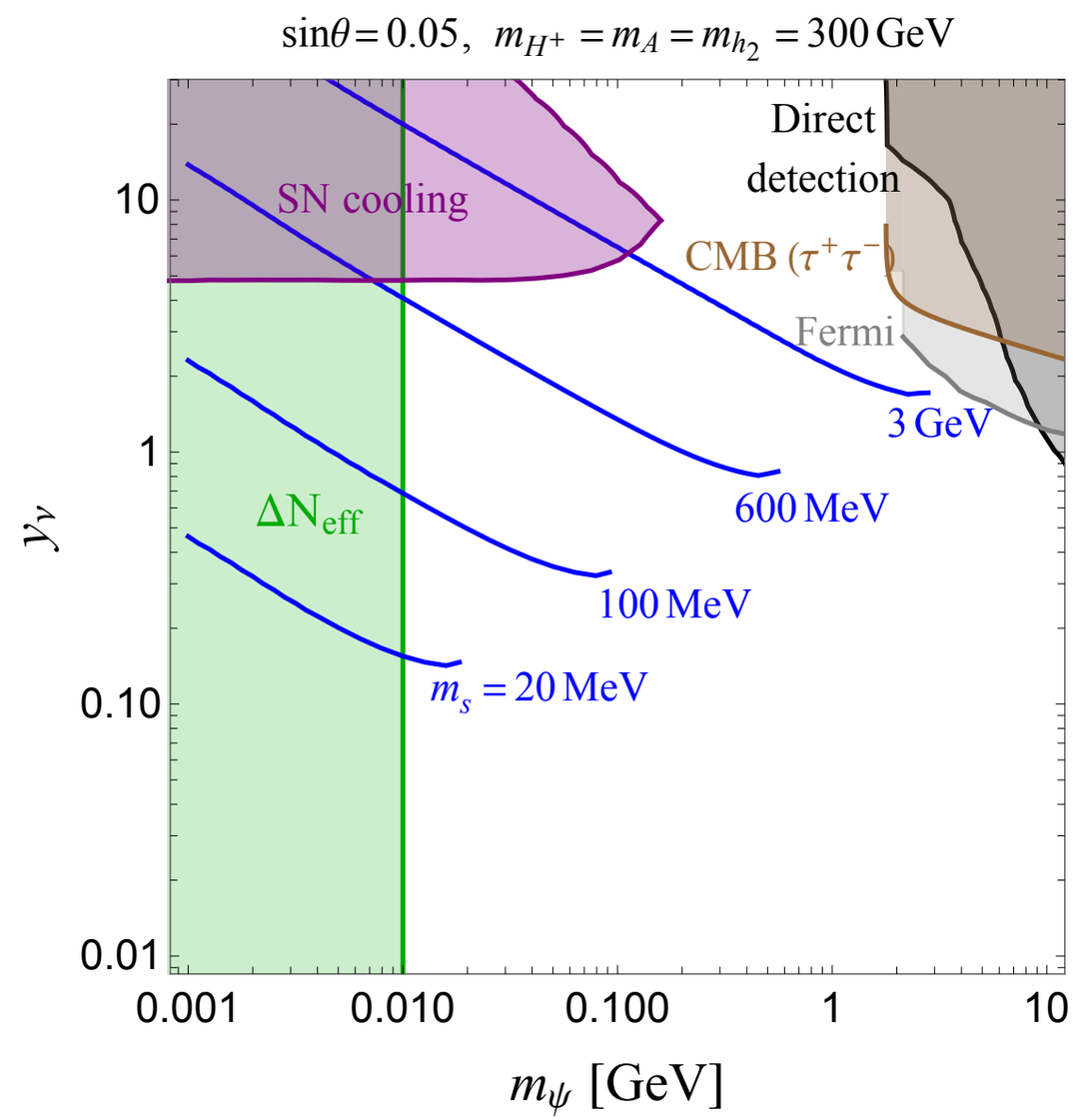
Additional coupling involving S

$$-\Delta\mathcal{L} = A_S\,\Phi^\dagger\Phi_\nu S + h.c.$$

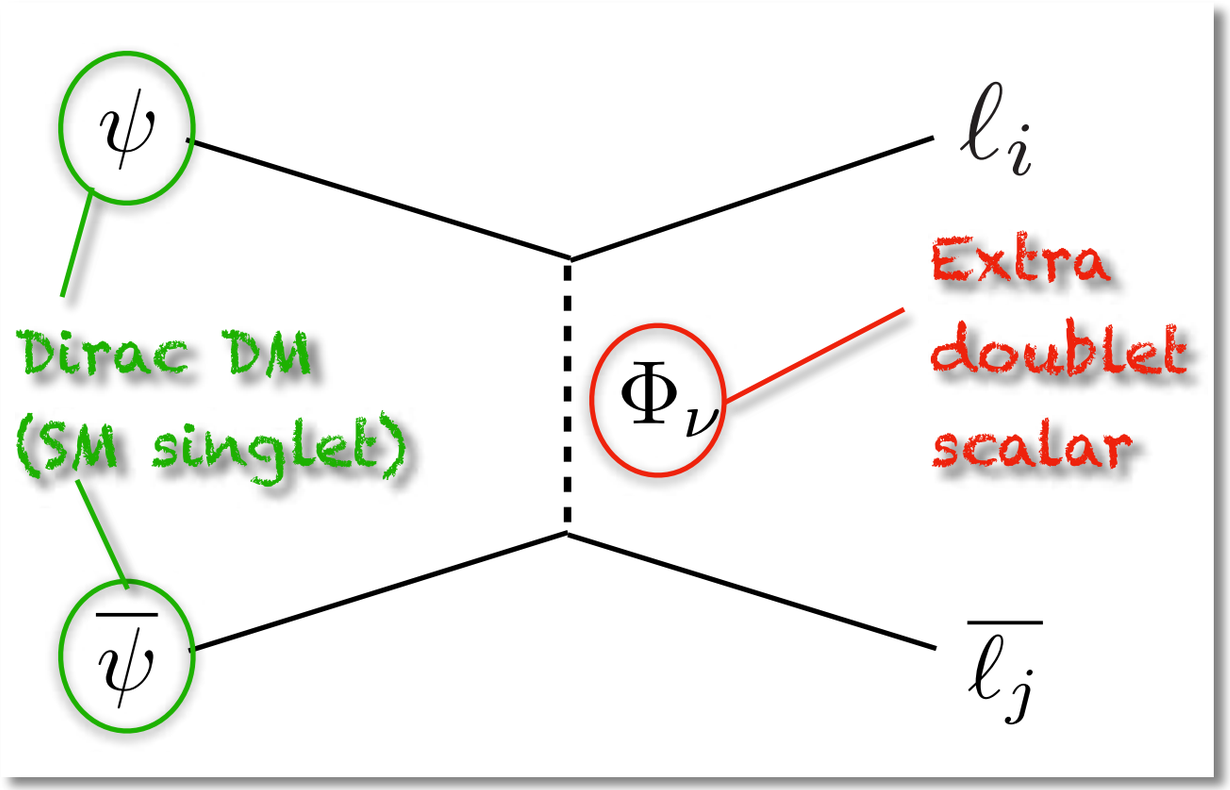
Result in extended model with a scalar

2011.04788 with Okawa





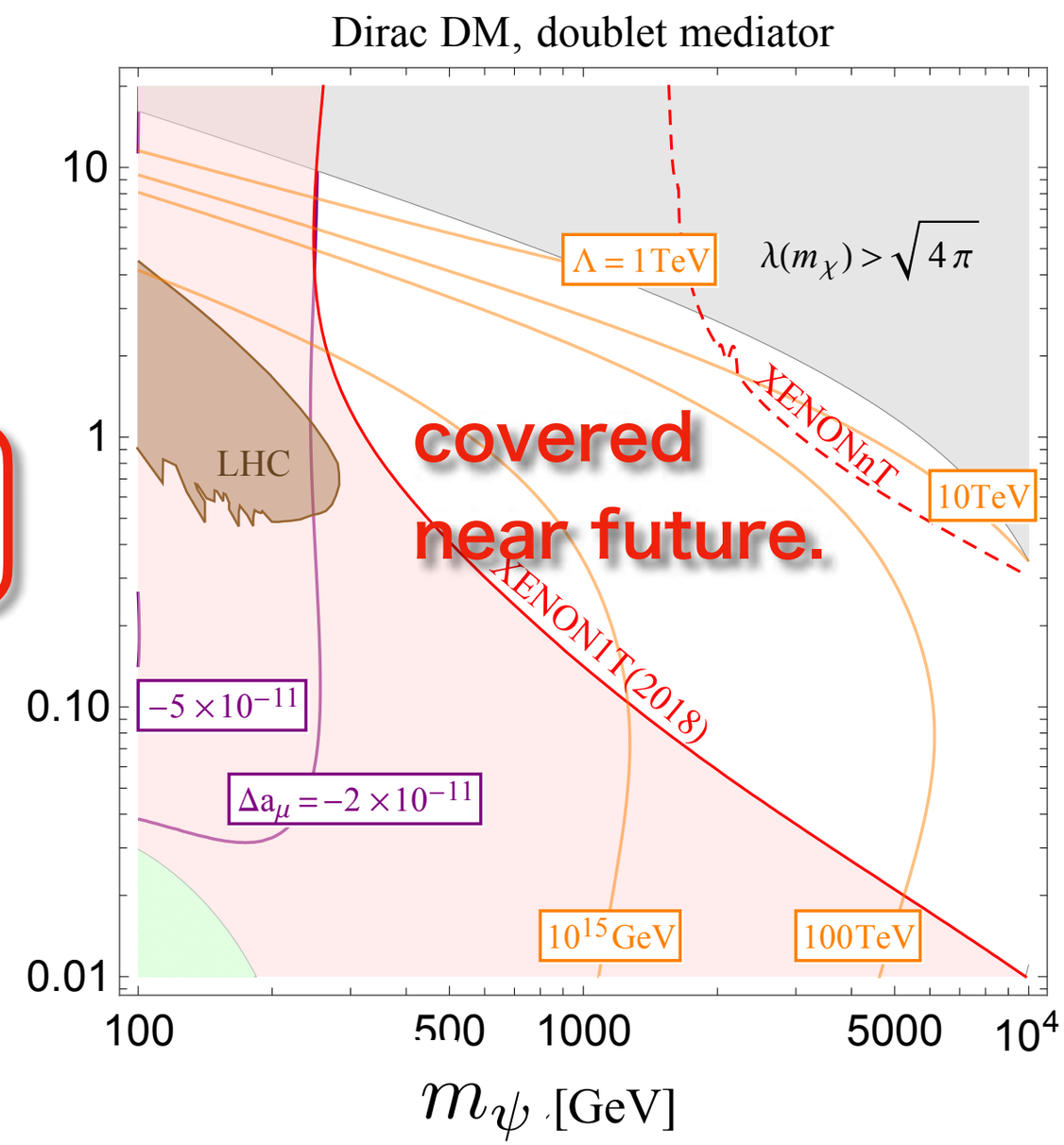
current status of Dirac Fermion DM model



2002.12534 with Kawamura, Okawa

$$r = \frac{m_{\Phi_\nu}}{m_\psi}$$

r − 1



Assuming DM is heavier than 100 GeV, all regions will be covered by XENONnT.

See 2002.12534 for more detail.