Light mass window of lepton portal dark matter

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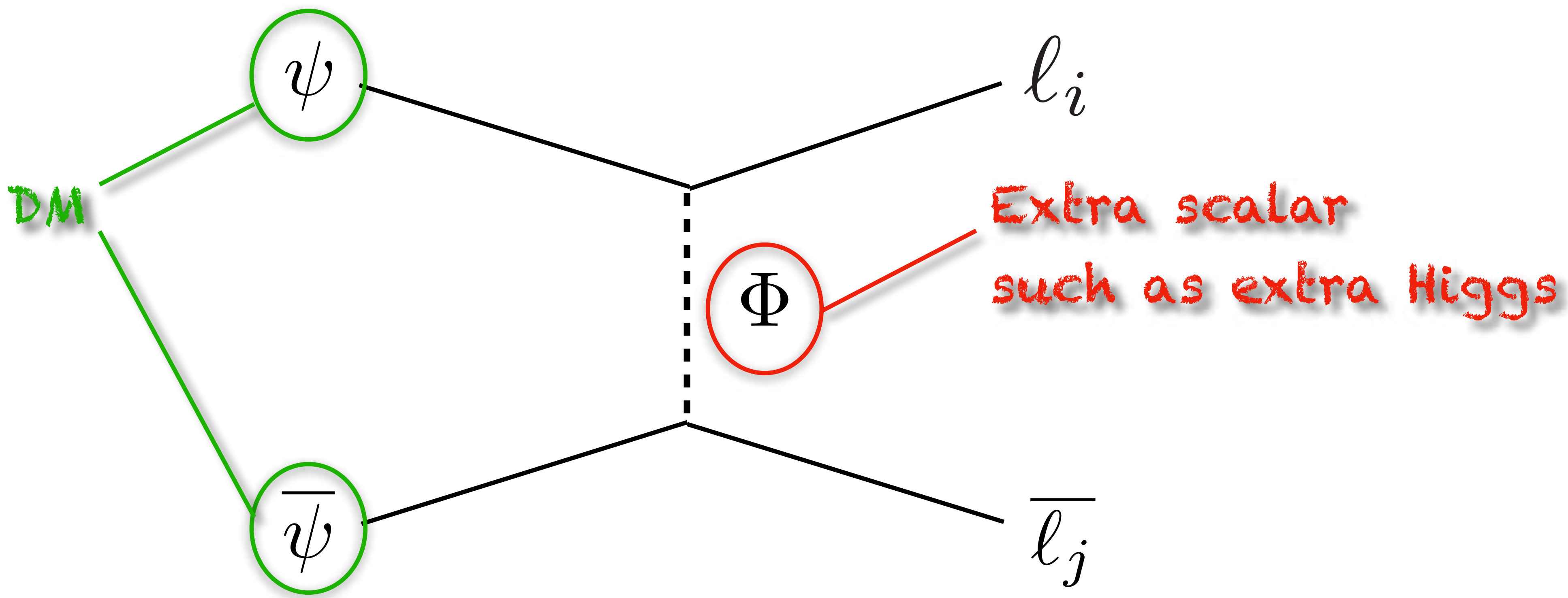
based on the collaboration with
J. Kawamura and S. Okawa
(arXiv: 2011.04788, 2002.12534)

Introduction

I am studying phenomenology in lepton portal DM models

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,

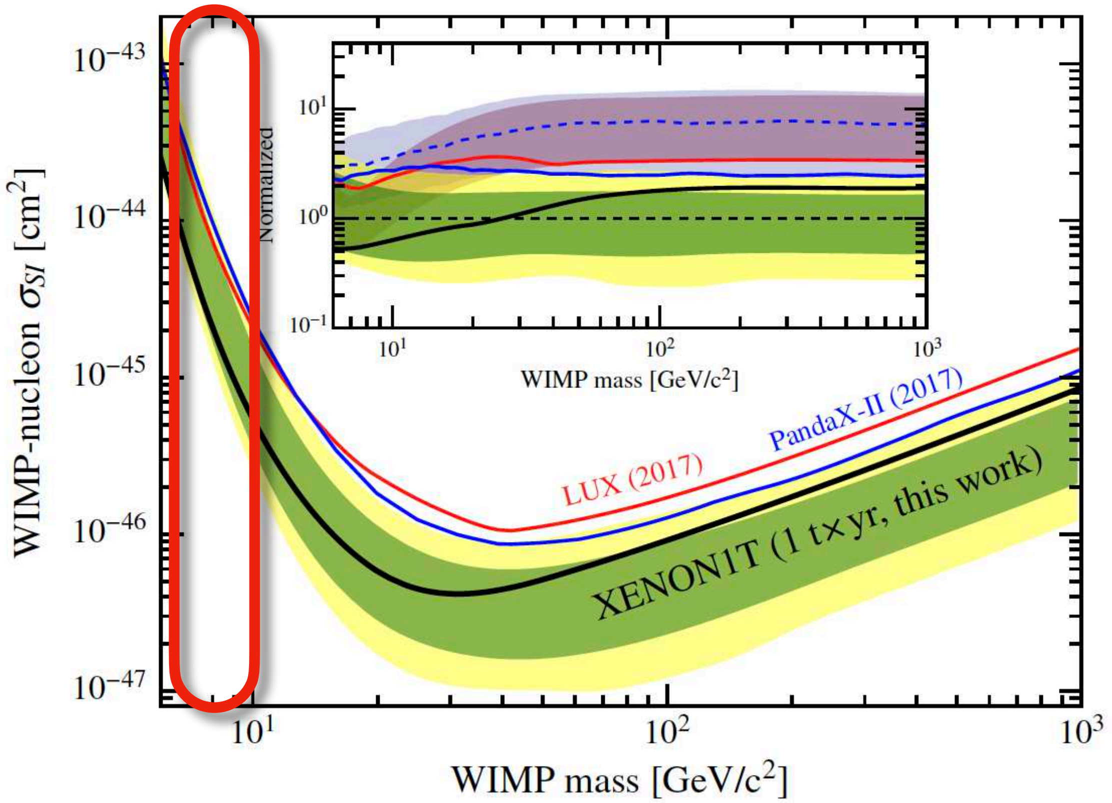
・introduce our recent results of Dirac DM case based on arXiv:2002.12534, 2011.04788 (collaboration with J. Kawamura, S.Okawa).

PRL121,111302

Focus on light DM region,

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

that can evade the strong bound from direct detection.



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

Setup
of Dirac DM case

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	$-$
DM	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

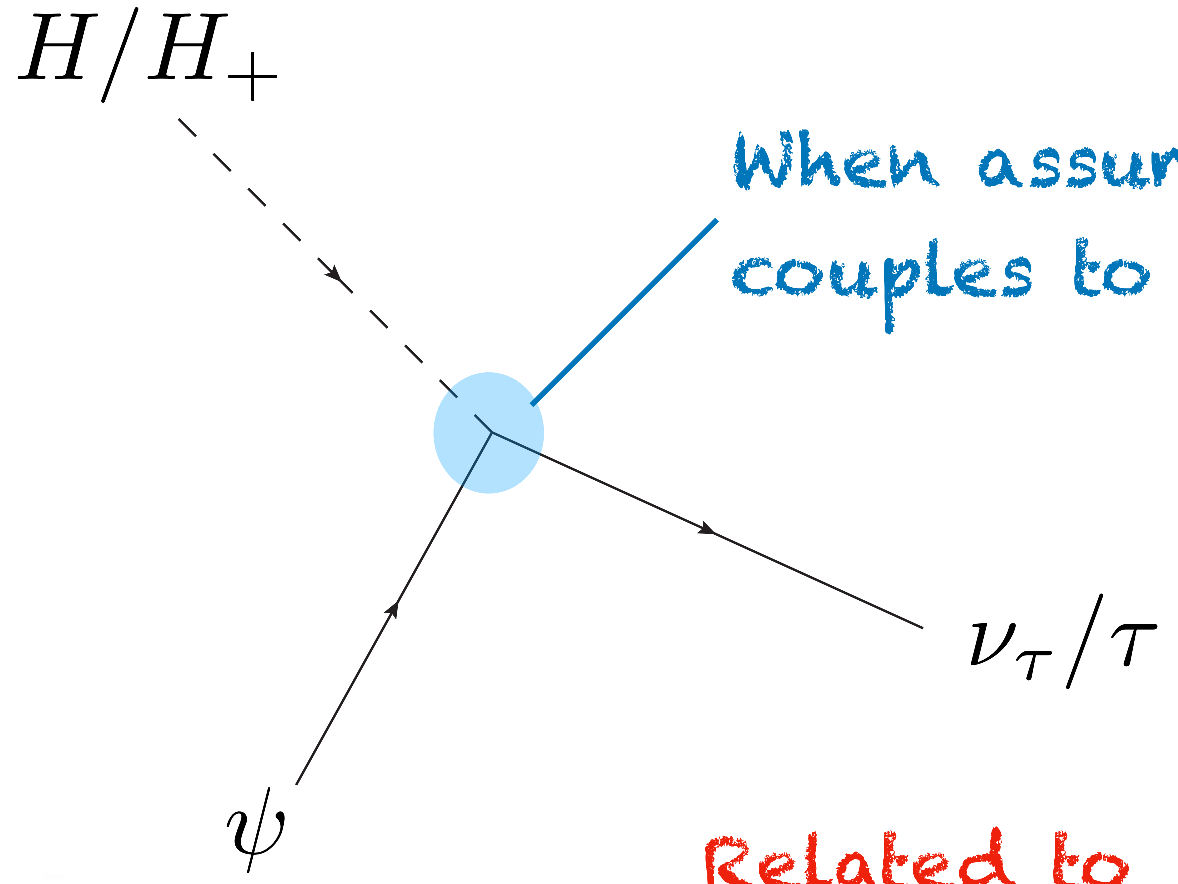
$$-\mathcal{L}_\ell = y_\nu^i \, \overline{\ell_L^i} \, \widetilde{\Phi}_\nu \, \psi_R + h.c.$$

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

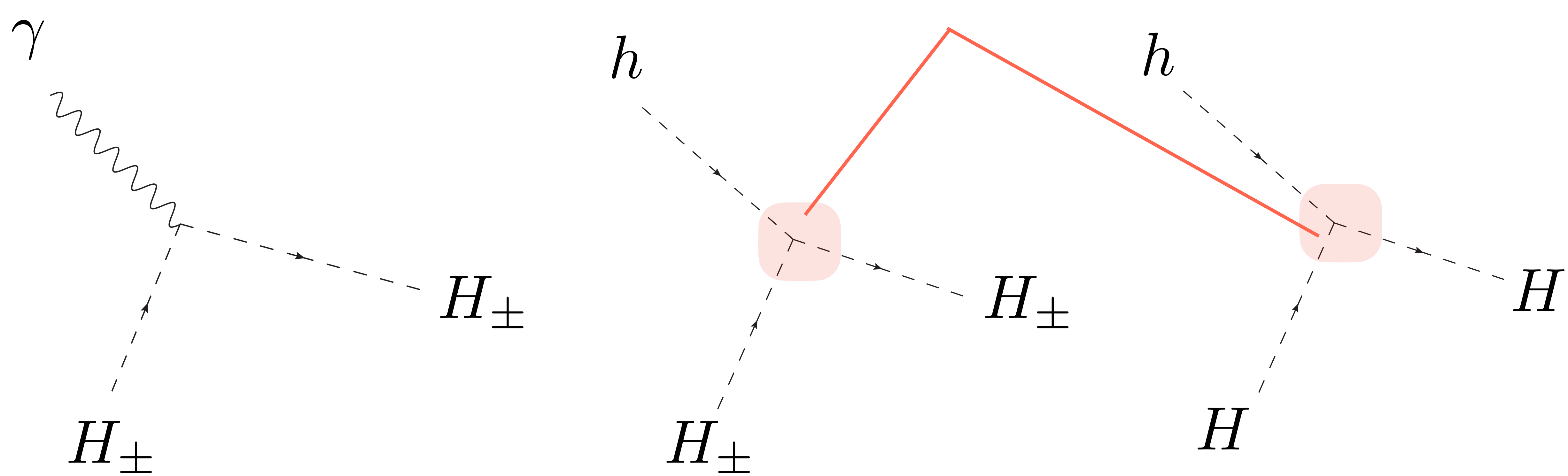
DM couplings



When assume DM dominantly couples to τ and ν_τ

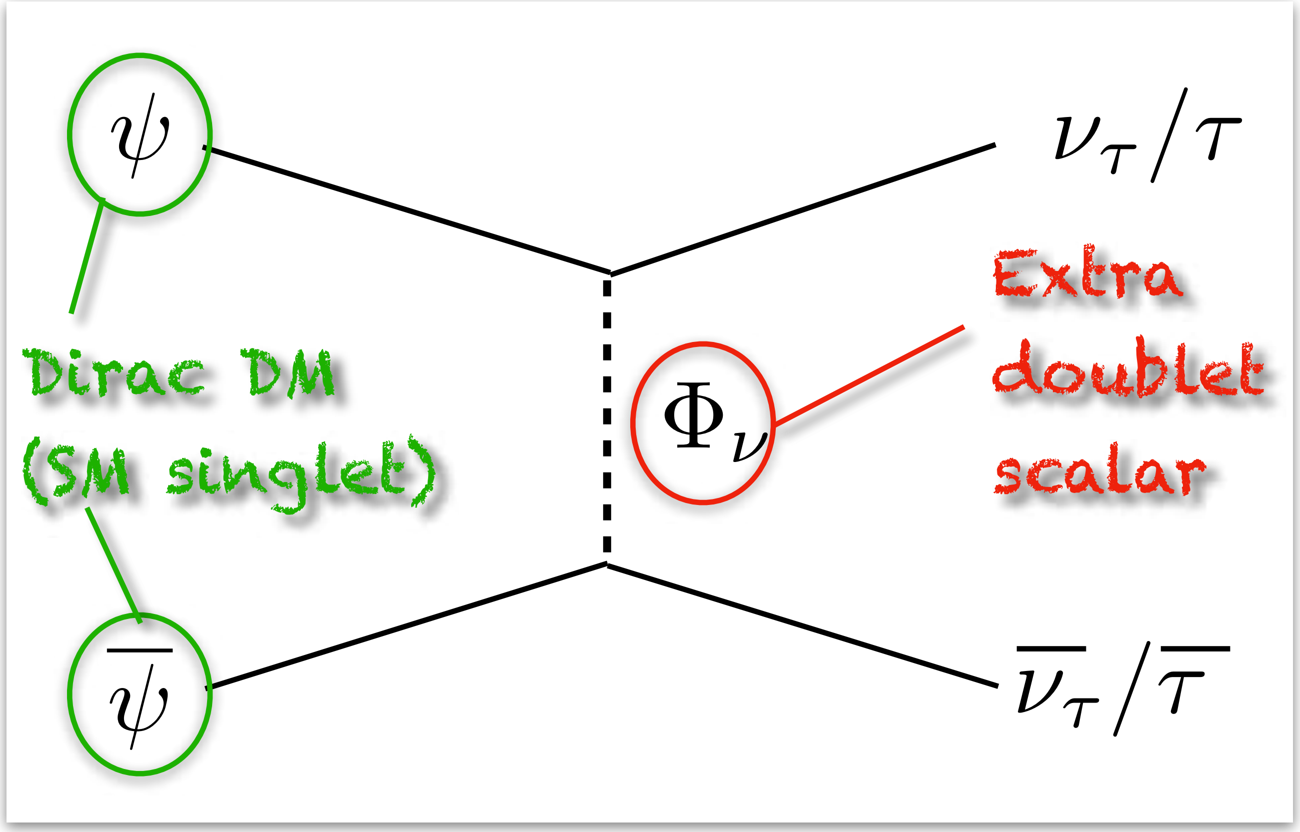
Extra scalar couplings

Related to scalar mass difference



DM annihilate to leptons through scalar exchange

2002.12534 with Kawamura, Okawa

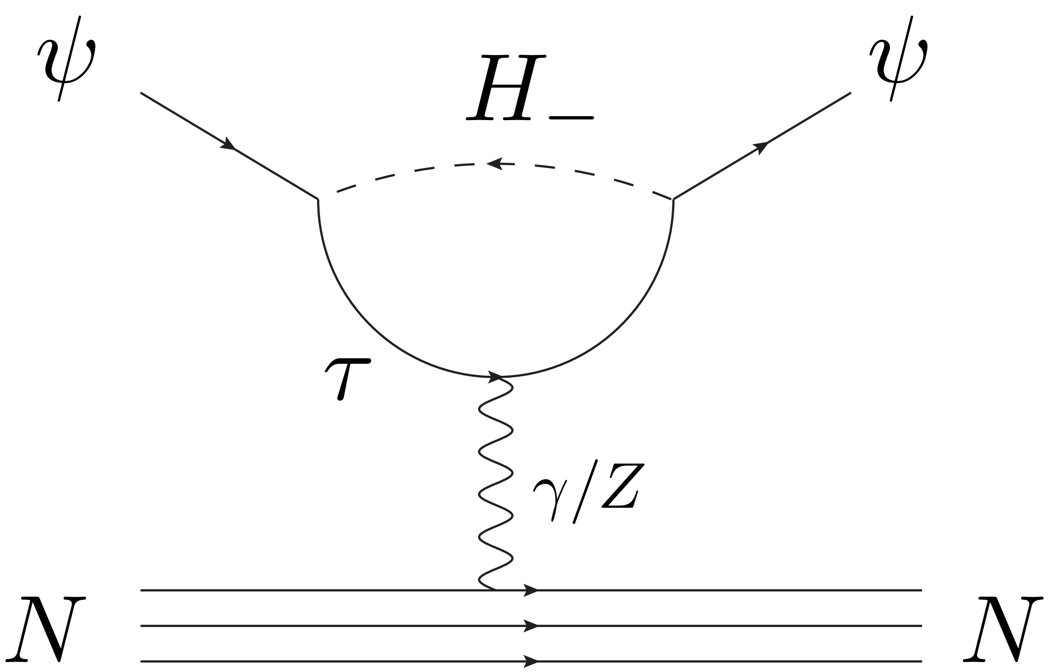


Note: The annihilation cross-section needs to be sizable to achieve correct relic density of DM.

$(\sigma v)_{\ell\ell'} \sim a$ (Dirac DM)

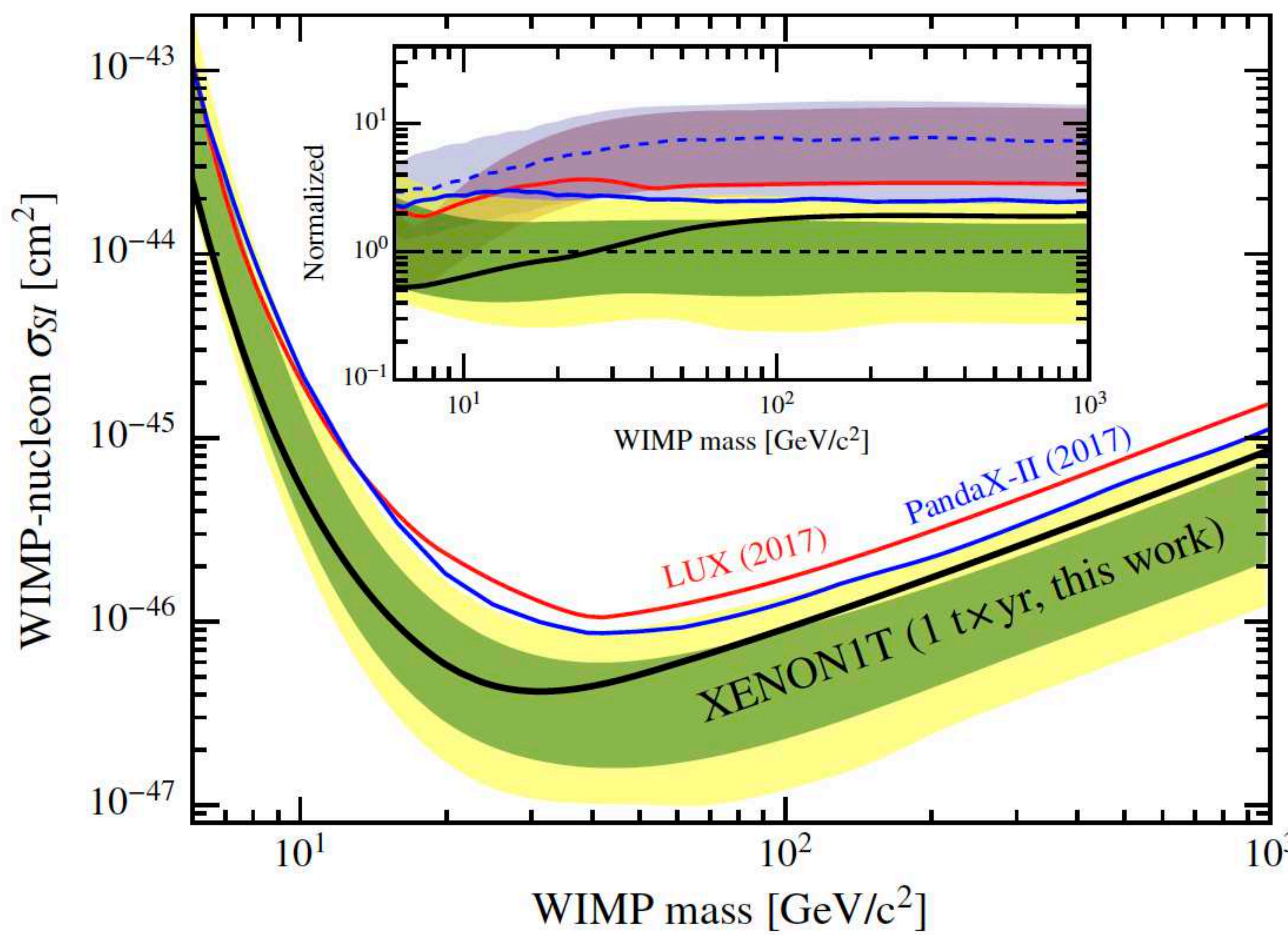
Direct detection

DM scatters with nuclei at the one-loop level,
and the cross section is enough large to be tested.



1 example

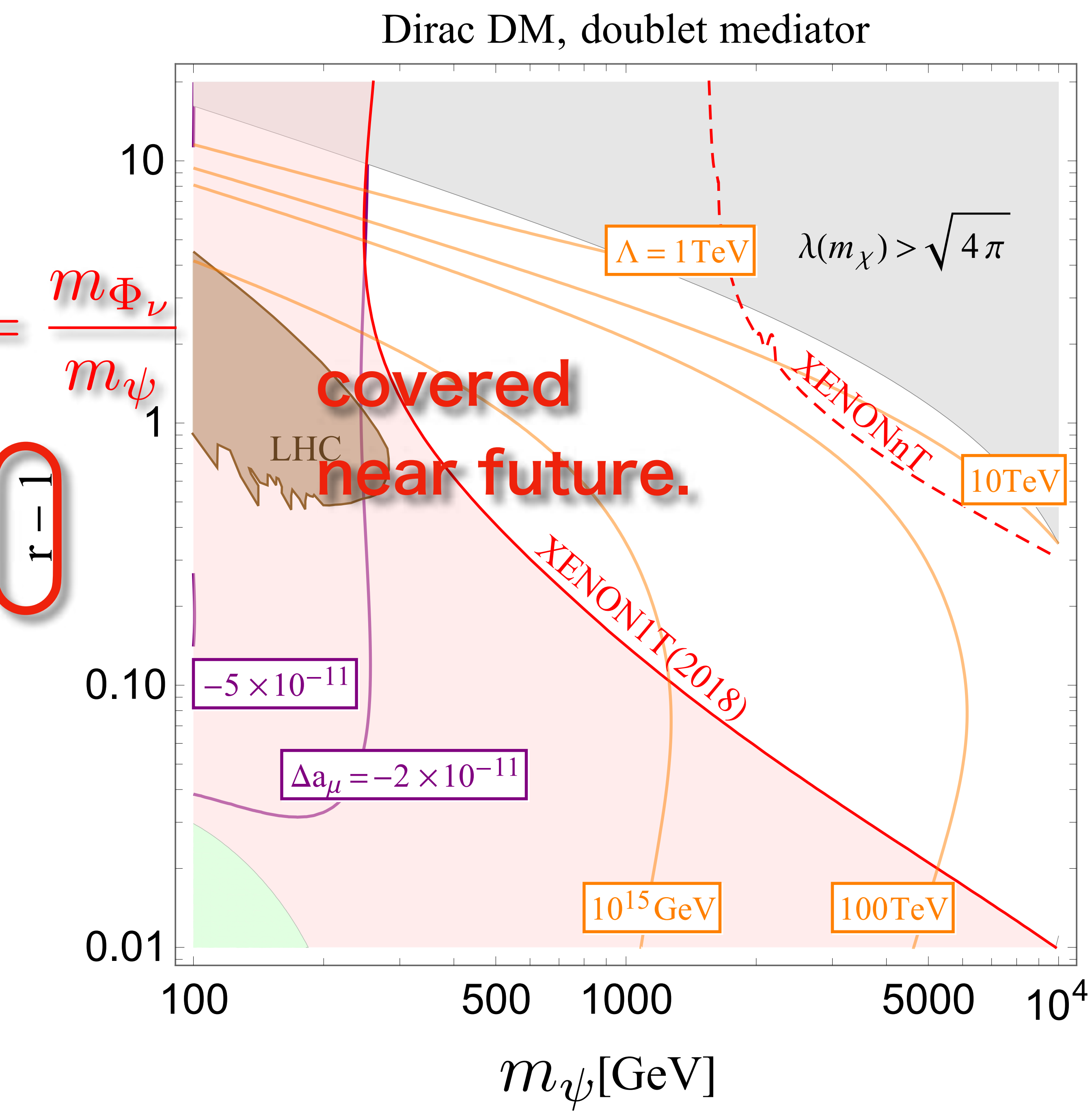
PRL121,111302

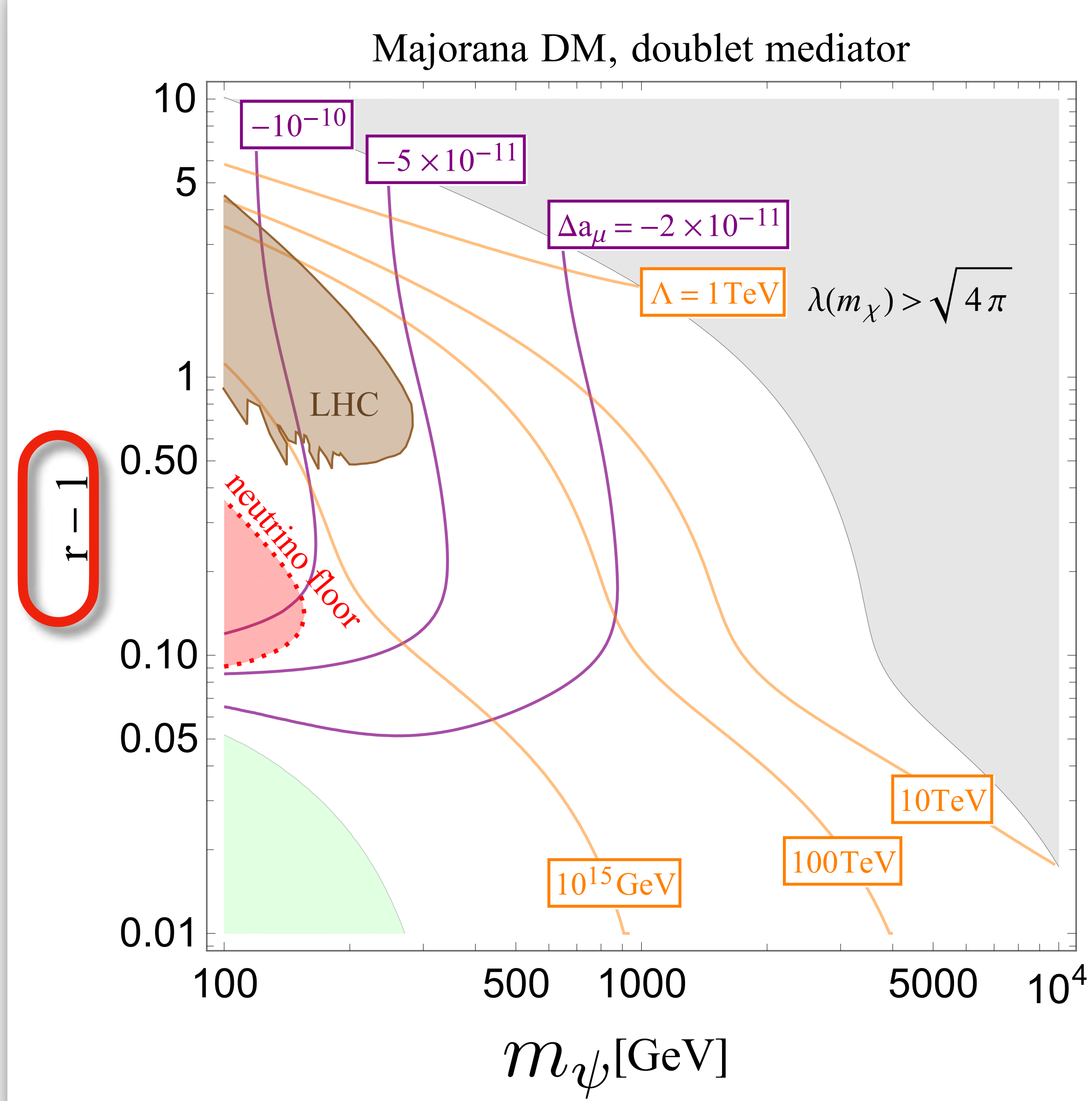


Fermion DM case

2002.12534 with Kawamura, Okawa

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



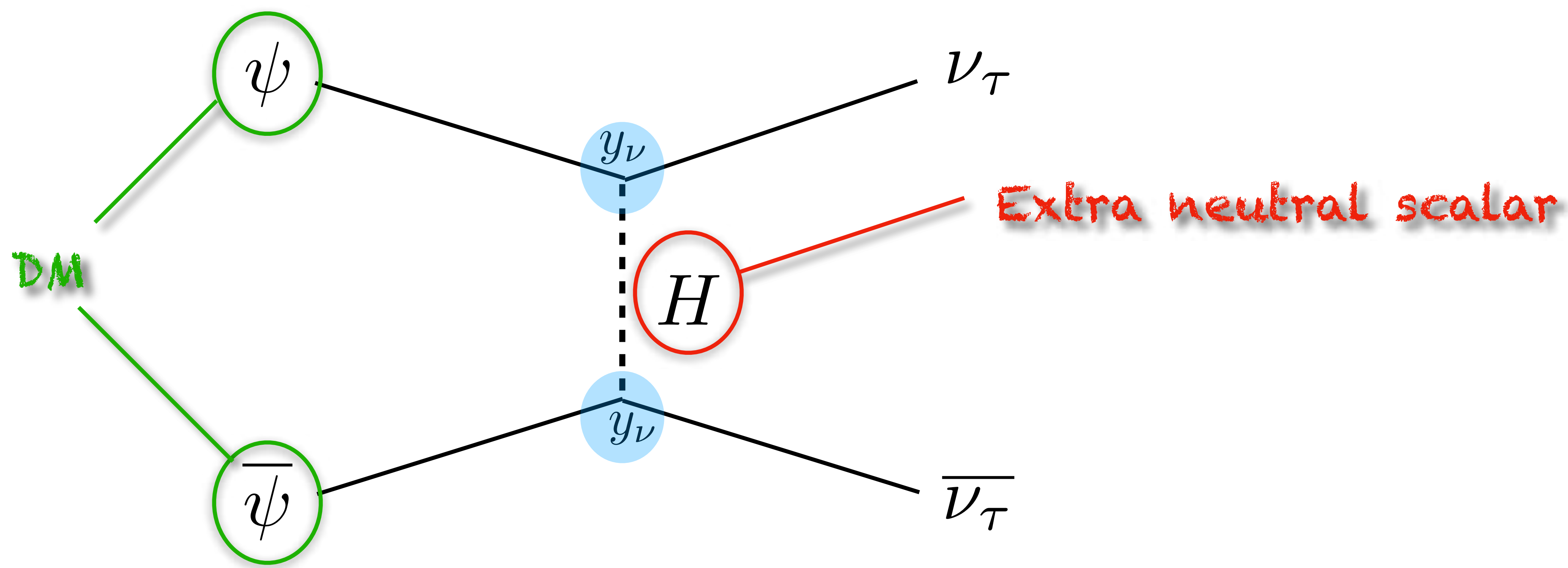


In Majora DM,
the allowed region becomes wider,
See 2002.12534 for more detail.

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

Let's see vey light DM region !

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 requires a light neutral scalar

Light DM case

Focus on light DM region,

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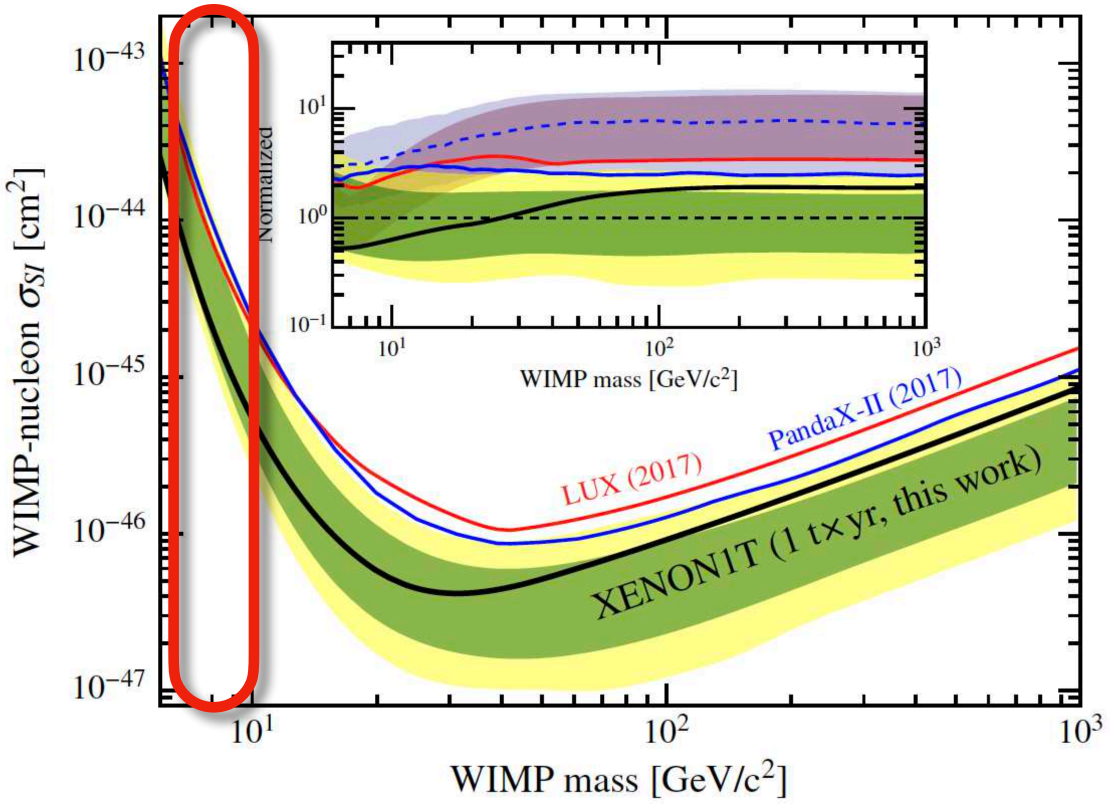
PRL121,111302



Our parameter space

DM mass: $m_\psi \leq 10\,\mathrm{GeV}$

$$m_h = 125\,\mathrm{GeV}$$

m_H **close to** m_ψ

Large mass hierarchy

$$m_A = m_{H_\pm} \gtrsim 250\,\mathrm{GeV}$$

From LHC
(work in progress)

Mass differences
given by para. in scalar potential

Suppressed

$$m_A^2 = m_{H+}^2 + \frac{(\lambda_4 - \lambda_5)v^2}{2}$$

$$m_H^2 = m_{H+}^2 + \frac{(\lambda_4 + \lambda_5)v^2}{2}$$

Very large

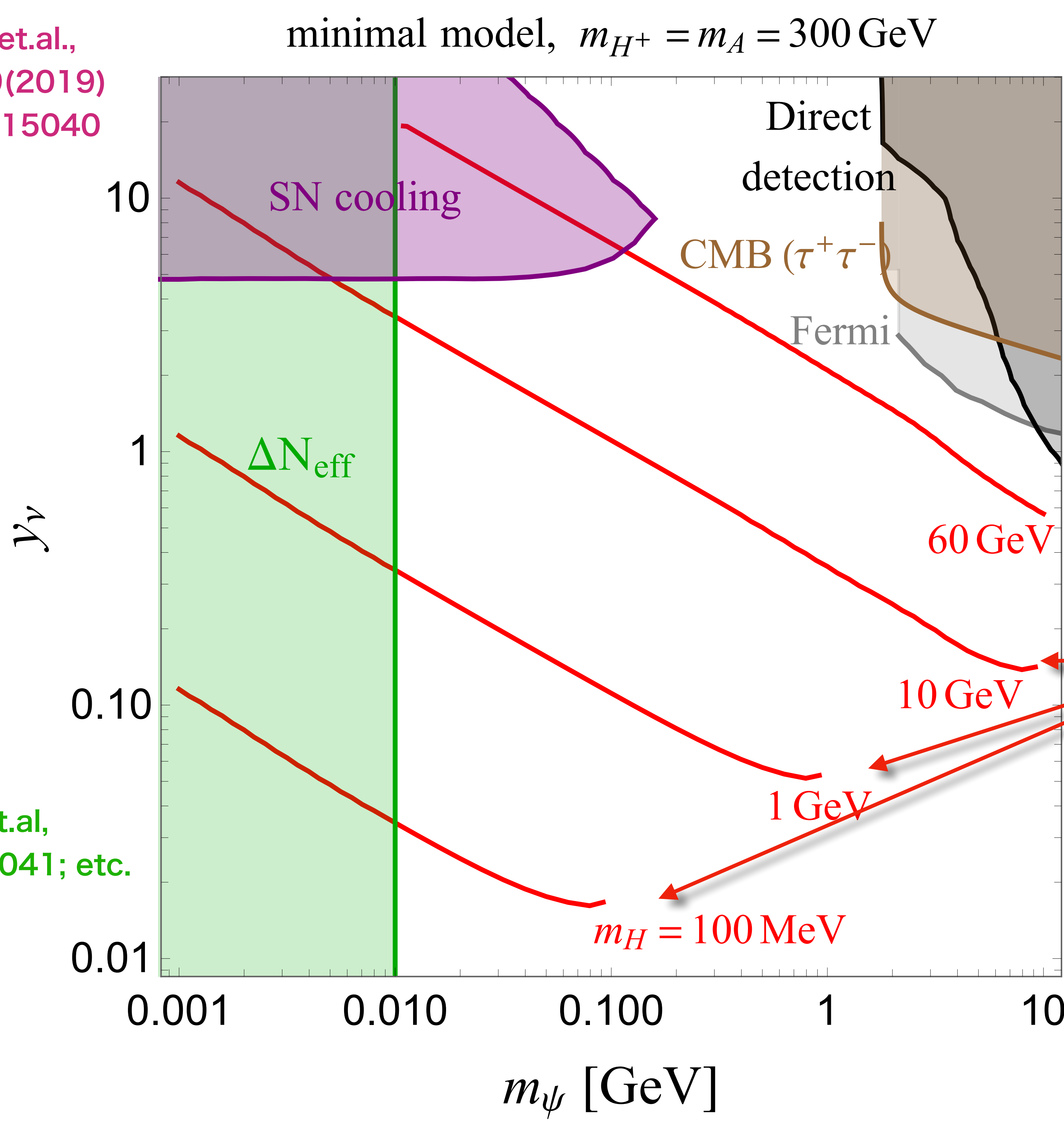
$$\lambda_4(\Phi^\dagger\Phi_\nu)(\Phi_\nu^\dagger\Phi) + \frac{1}{2}\lambda_5[(\Phi^\dagger\Phi_\nu)^2 + h.c.]$$

Parameters to lead correct relic density of DM

2011.04788 with Okawa

Chu,et.al., PRD99(2019) no.1 015040

Boehm, et.al, JCAP08(2013)041; etc.



DM annihilation to 2 ν gives the correct relic density

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.

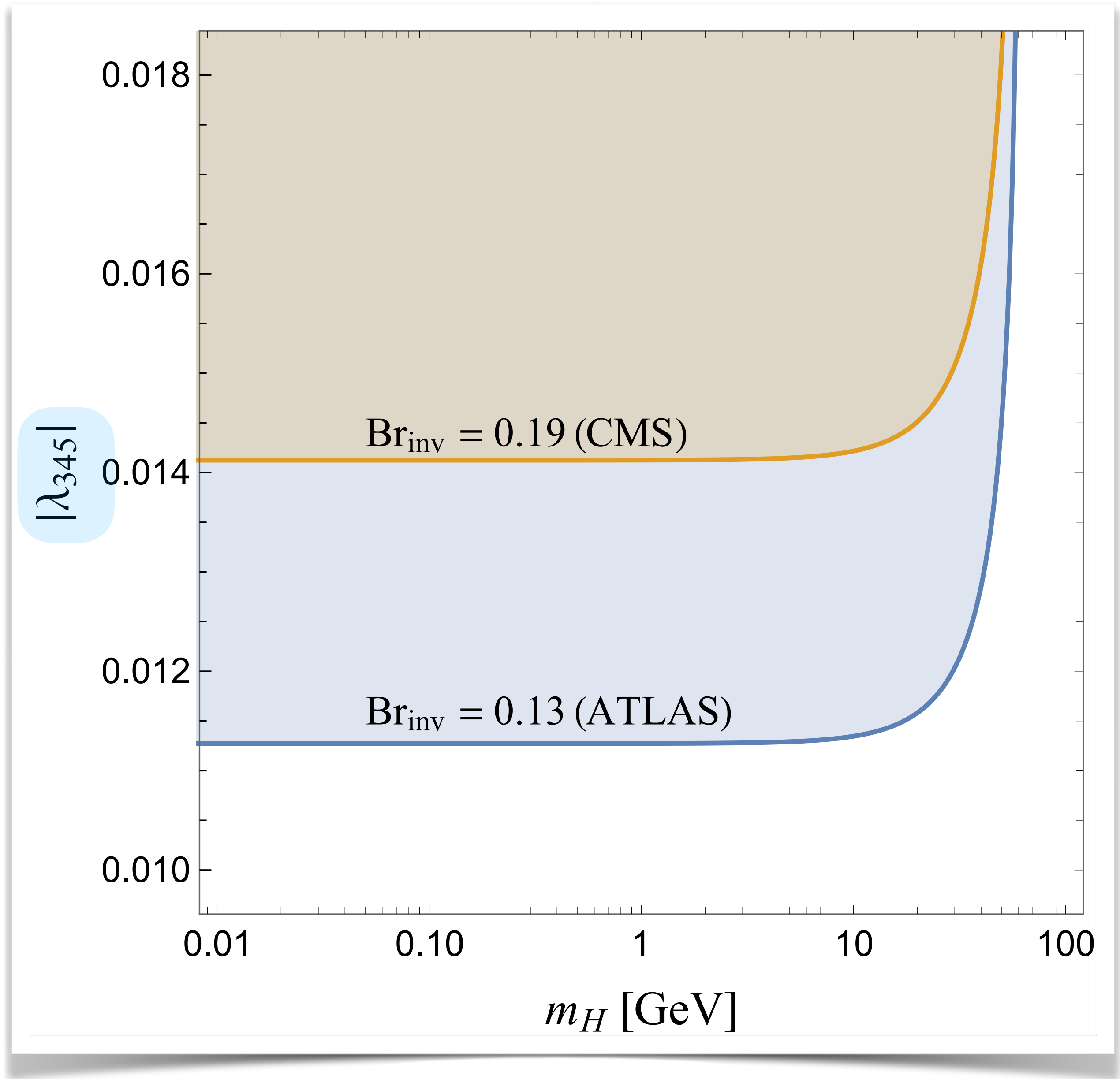
$$\frac{\lambda_{345}}{4}(2vh + h^2)H^2$$

should be tuned.

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

gives large mass differences between H+ and H

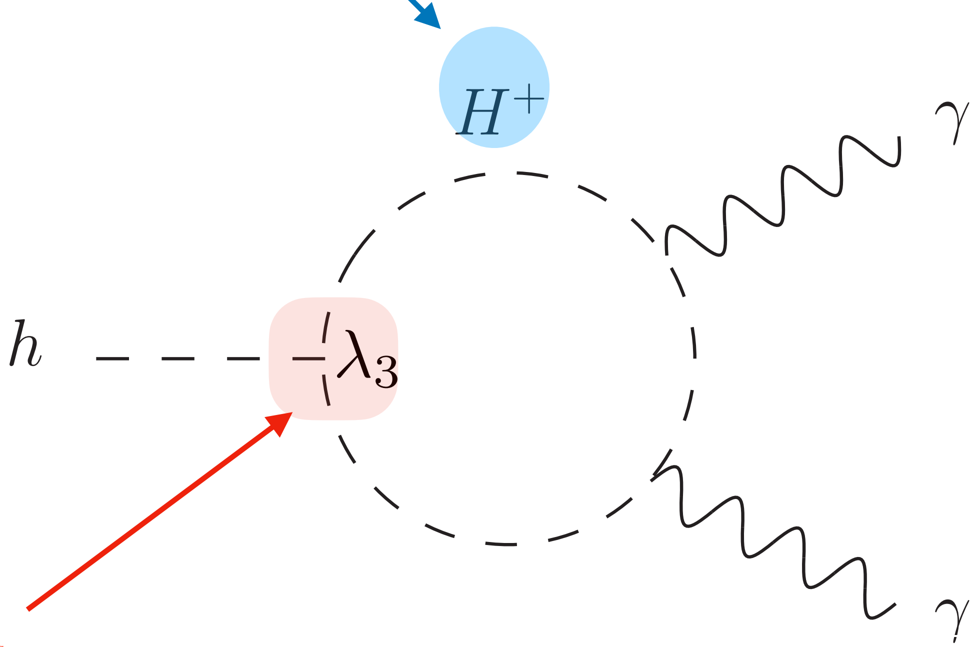
becomes large and
λ3 gives hH+H- coupling.



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

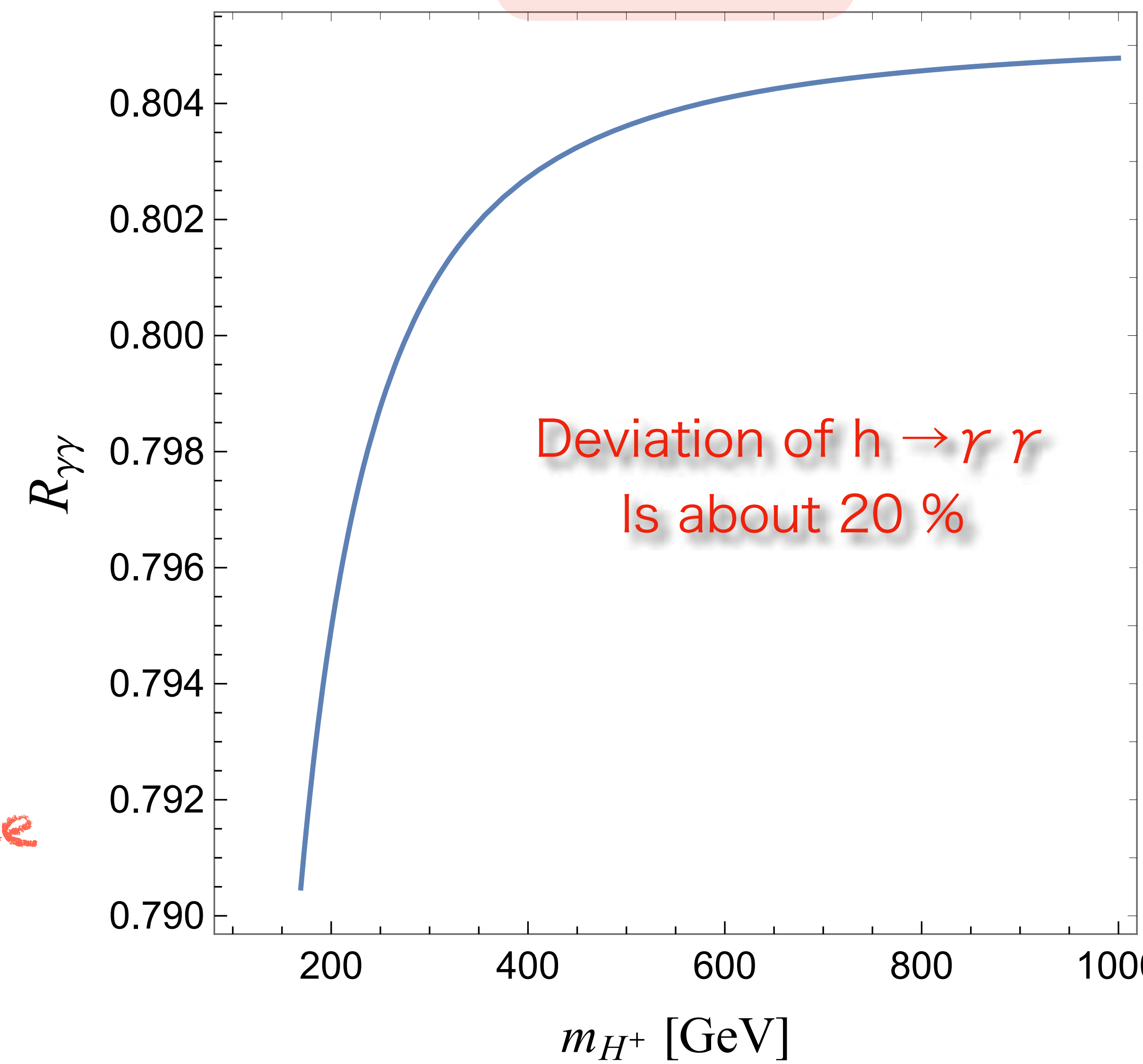
2011.04788 with Okawa

Heavier than ~250 GeV because of LHC



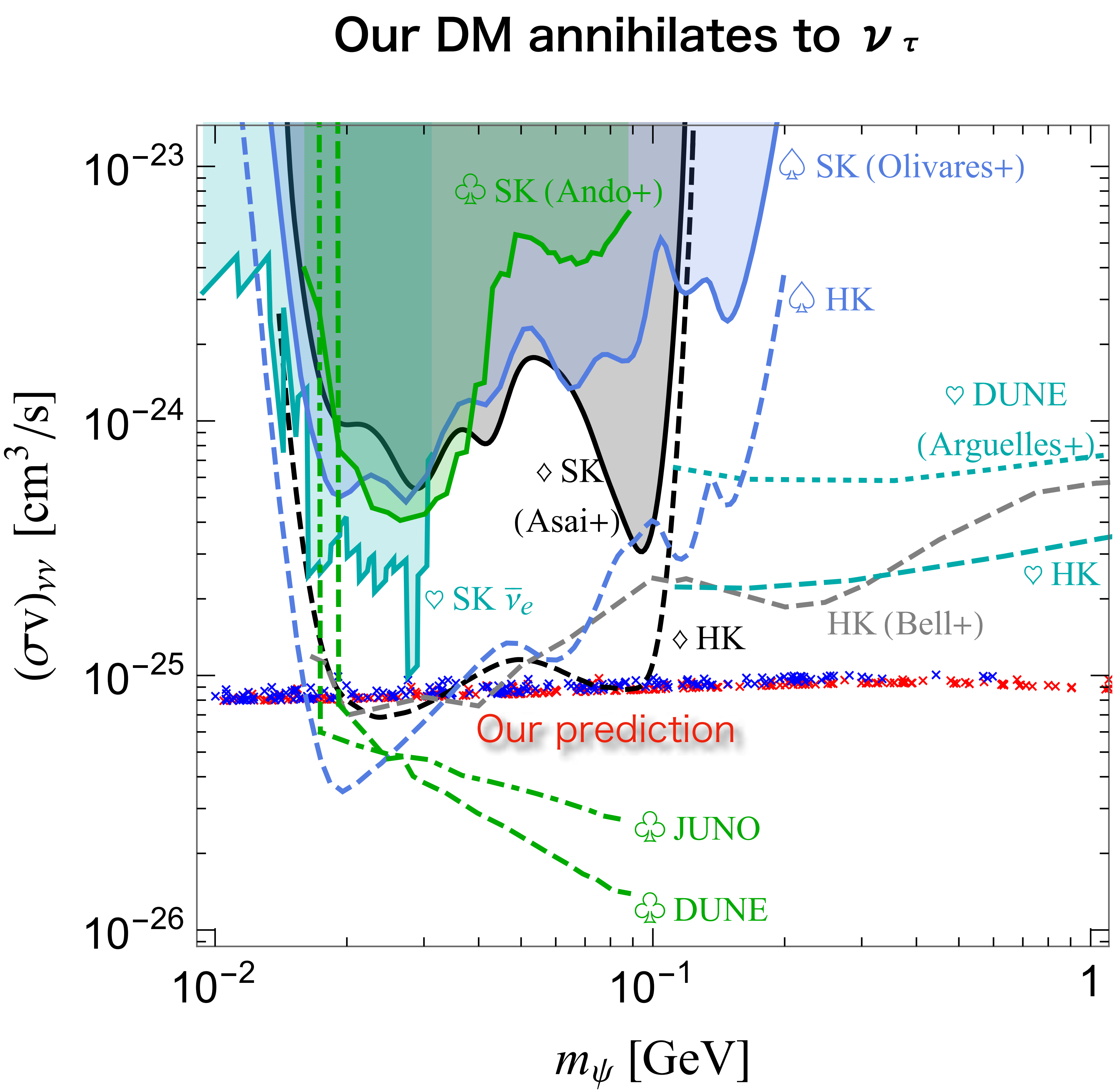
large
to make mass difference between H and H+ large and suppress invisible decay of h.

$\lambda_3 = 2m_{H^+}^2/v^2$



It is possible to test in the indirect detection.

2011.04788 with Okawa



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