Light mass window of lepton portal dark matter

Yuji Omura (Kindai Univ.)

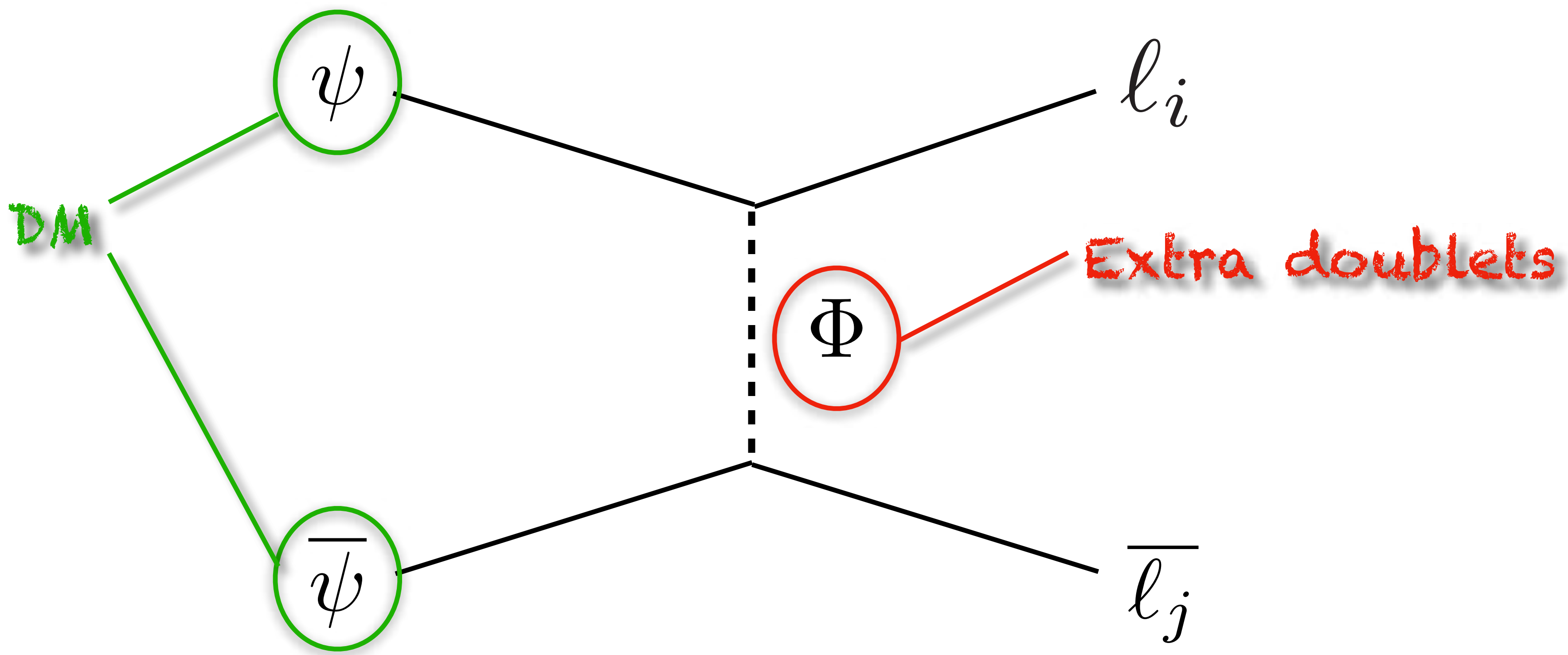
based on
JHEP03(2023)010 (arXiv: 2208.05487) with Syuhei Iguro (KIT) and Shohei Okawa (KEK);
JHEP02(2021)231 (arXiv: 2011.04788) with Shohei Okawa (KEK);
JHEP08(2020)042 (arXiv: 2002.12534) with Junichiro Kawamura (IBS) and Shohei Okawa (KEK)

Introduction

I am studying phenomenology in lepton portal DM models

Bai, Berger, JHEP08(2014)153;
J. Kawamura, S. Okawa, YO, JHEP08(2020)042;
PRD106(2022)1,015005

S. Okawa, YO, JHEP02(2021)231;
S. Iguro, S. Okawa, YO JHEP03(2023)010



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

  DM is scalar or fermion.

Interesting points of lepton portal DM models

- 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 …

- muon g-2 is enhanced in some setups.

J. Kawamura, S. Okawa, YO, JHEP08(2020)042 (arXiv:2002:12534)

- The mediator predicts characteristic signals at the LHC.

S. Iguro, S. Okawa, YO, JHEP03(2023)010 (arXiv:2208.05487)

In this talk,

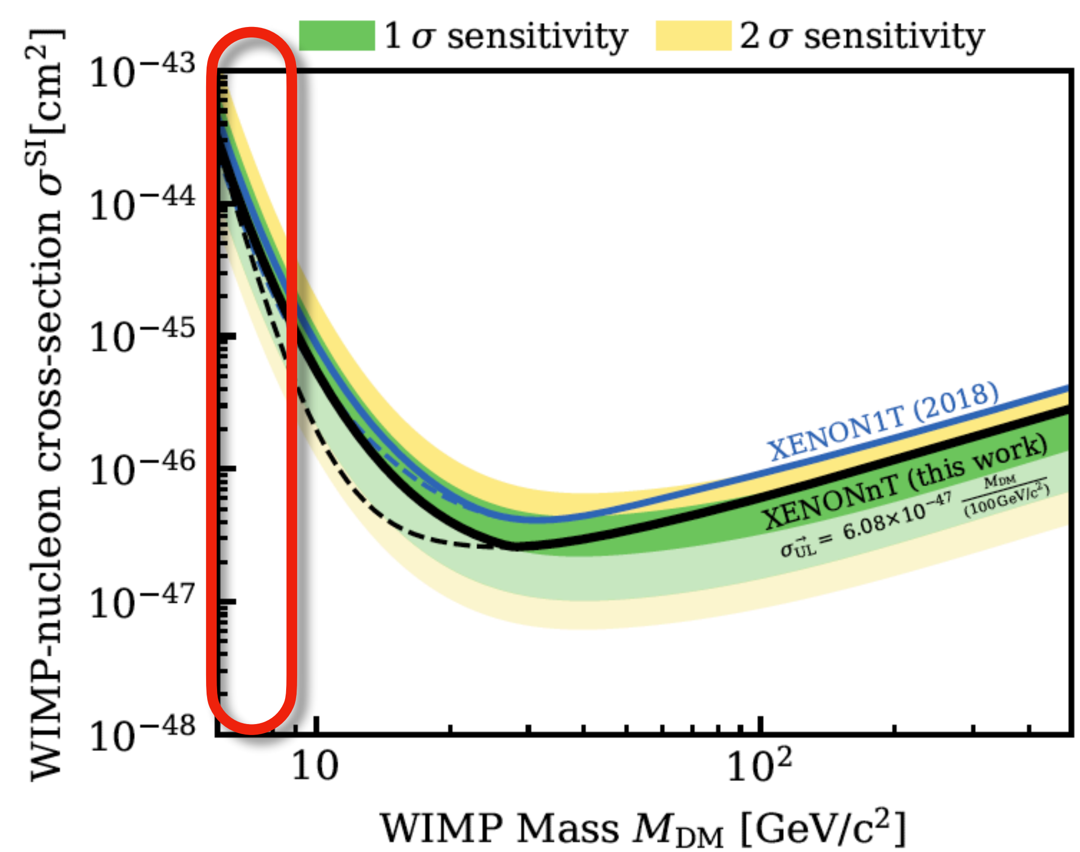
- DM is Dirac fermion

- DM mass is light:

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

  where the bound from the direct detection is not strong.

2303.14729, XENONnT



- I introduce our predictions for Higgs signals, collider signals, as well as DM signals.

Setup
of
lepton portal DM model

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

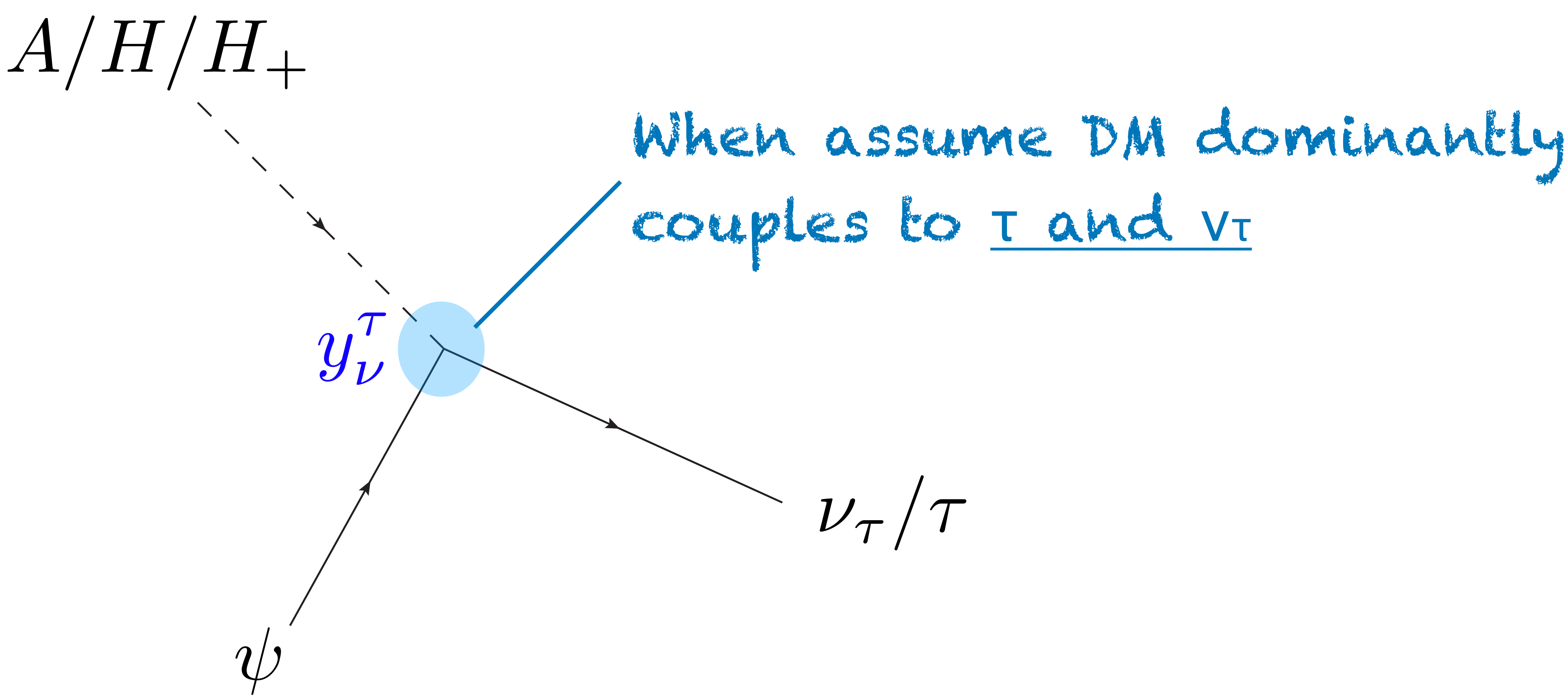
$$-\mathcal{L}_\ell = y_\nu^i \, \overline{\ell_L^i} \, \widetilde{\Phi}_\nu \, \psi_R + h.c.$$

After EWSB

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

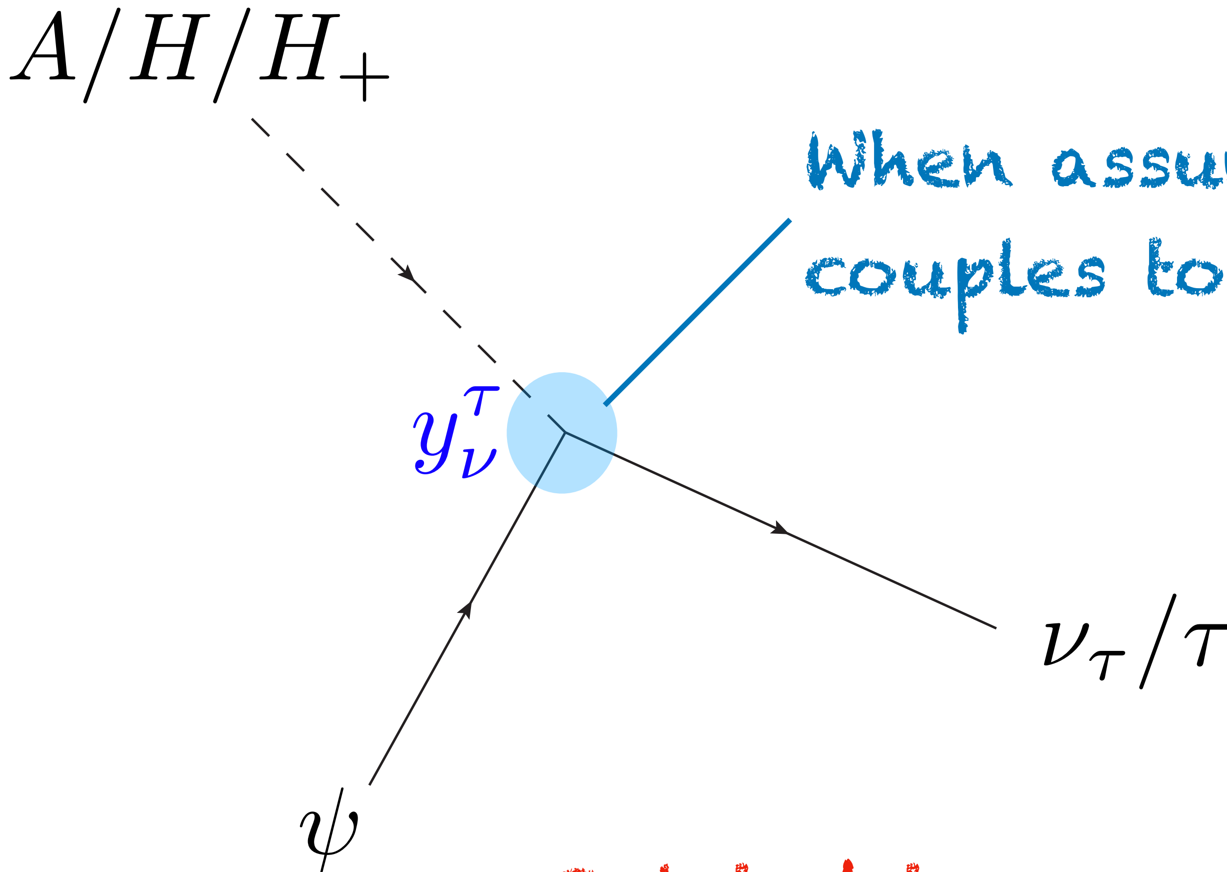
New particles and relevant couplings

DM couplings



New particles and relevant couplings

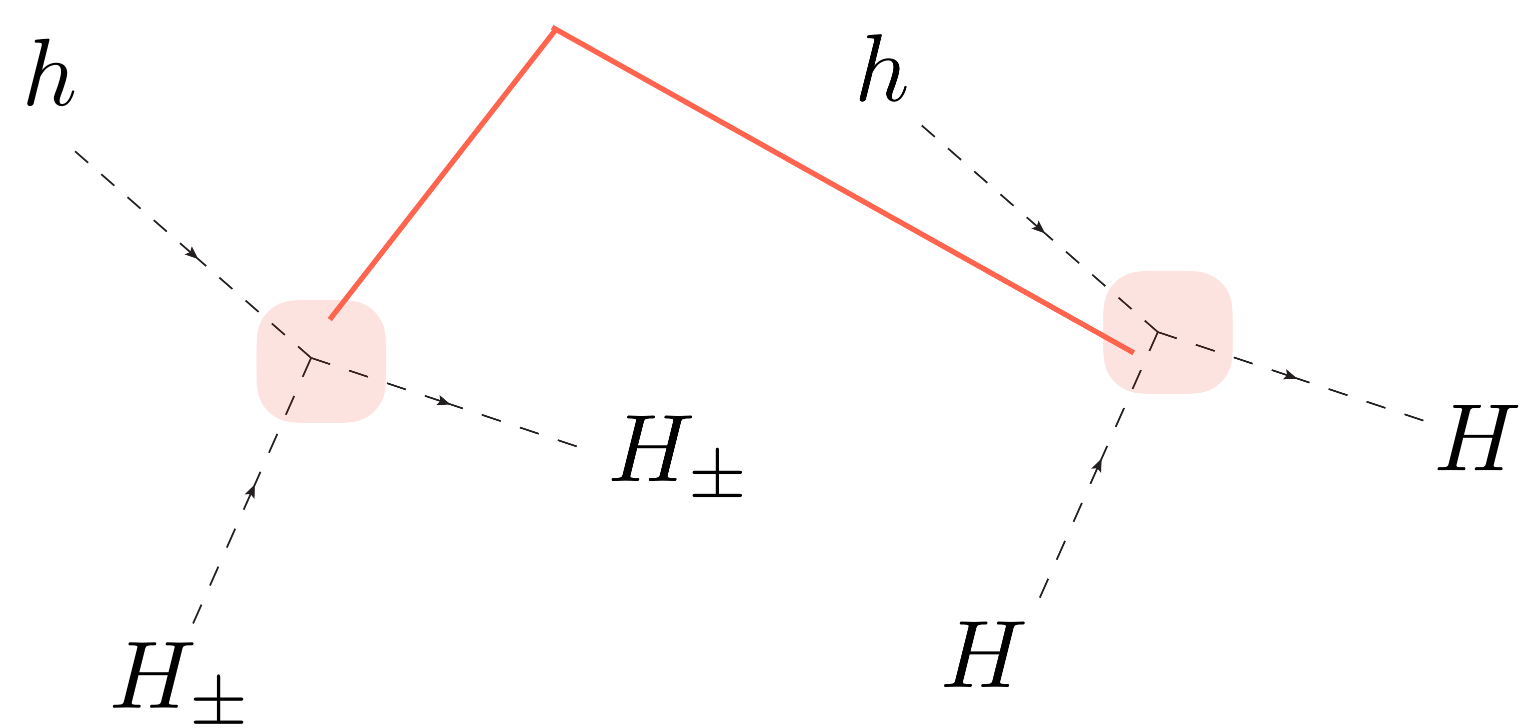
DM couplings



When assume DM dominantly couples to τ and ντ

Extra scalar couplings

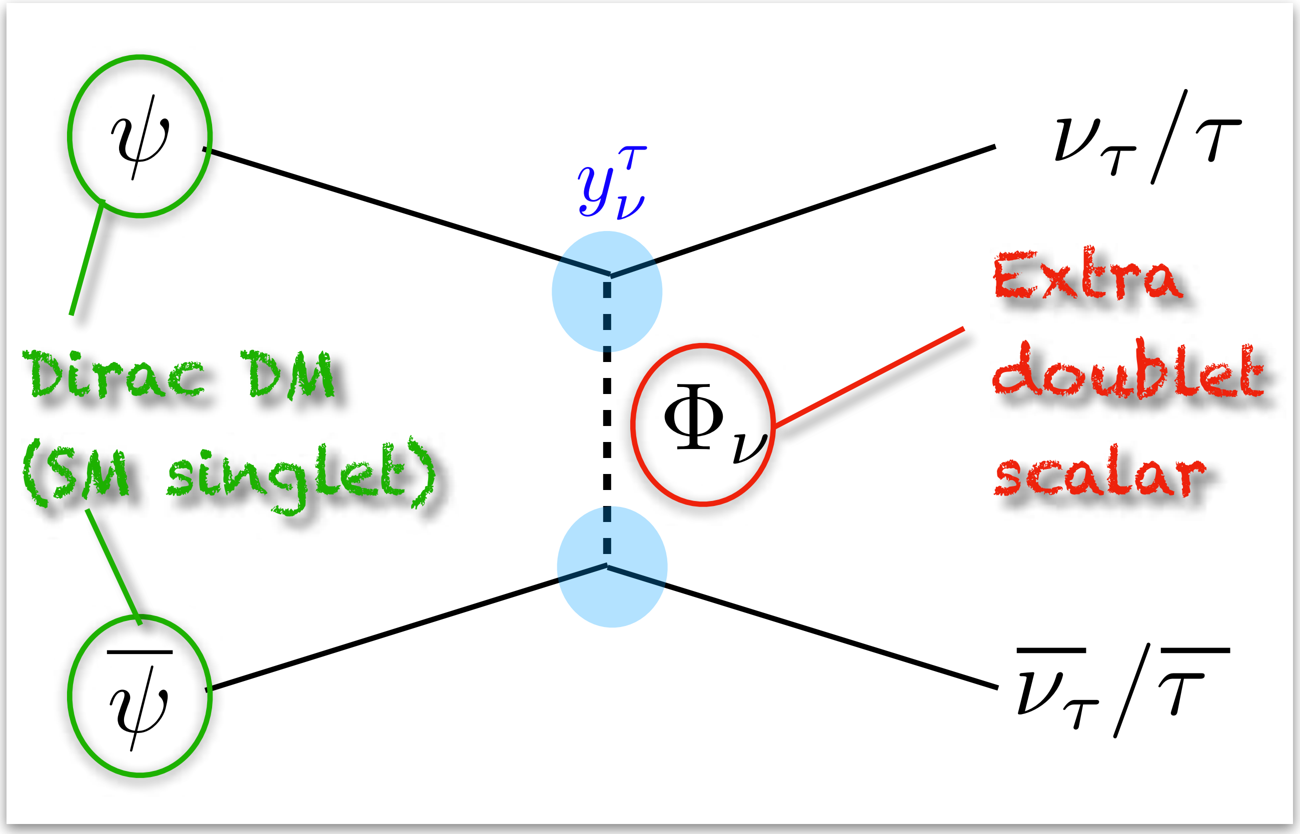
Related to scalar mass difference



DM annihilate to leptons through scalar exchange

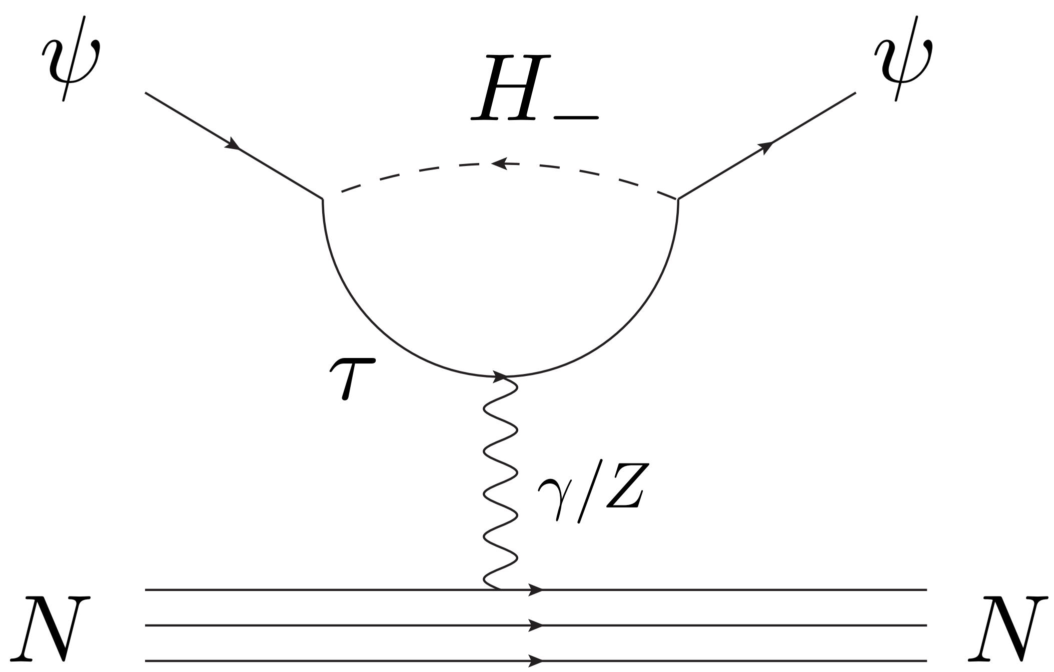
2002.12534 with Kawamura, Okawa

Assuming DM dominantly couples to <u>τ and ντ</u>

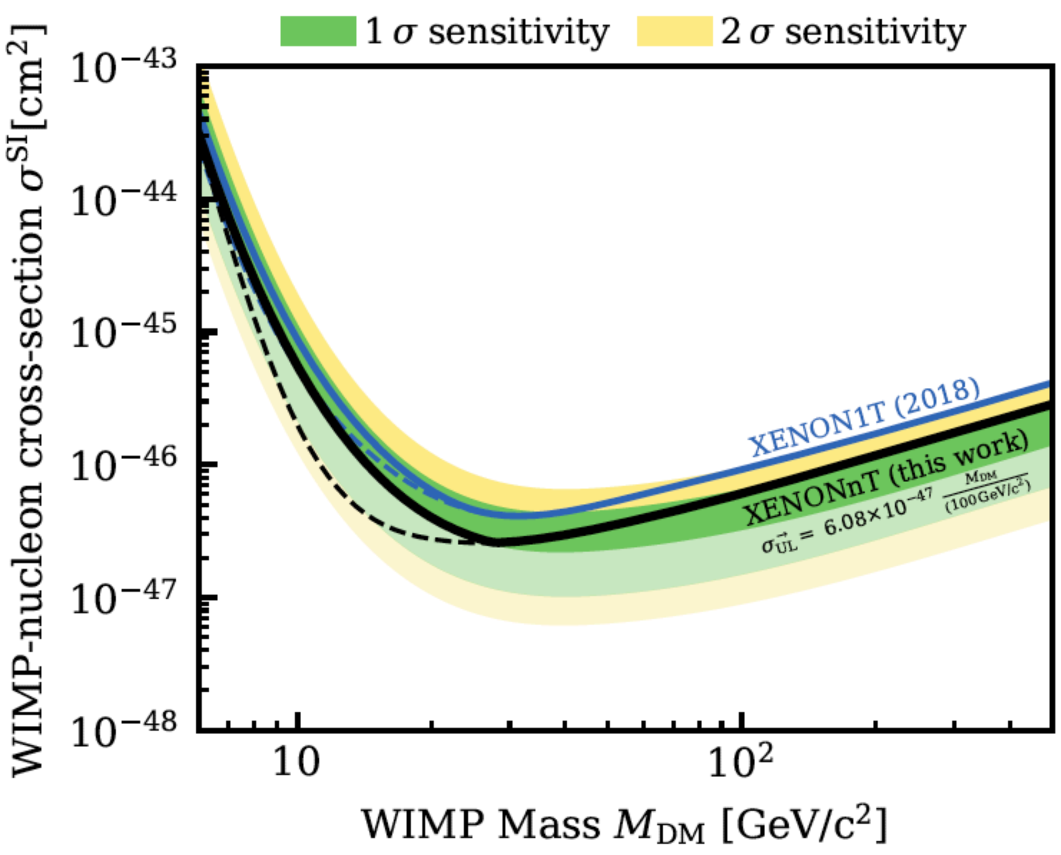


Direct detection

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



2303.14729, XENONnT



Please check the paper with J. Kawamura, S. Okawa,
(JHEP08(2020)042 (arXiv:2002:12534)).

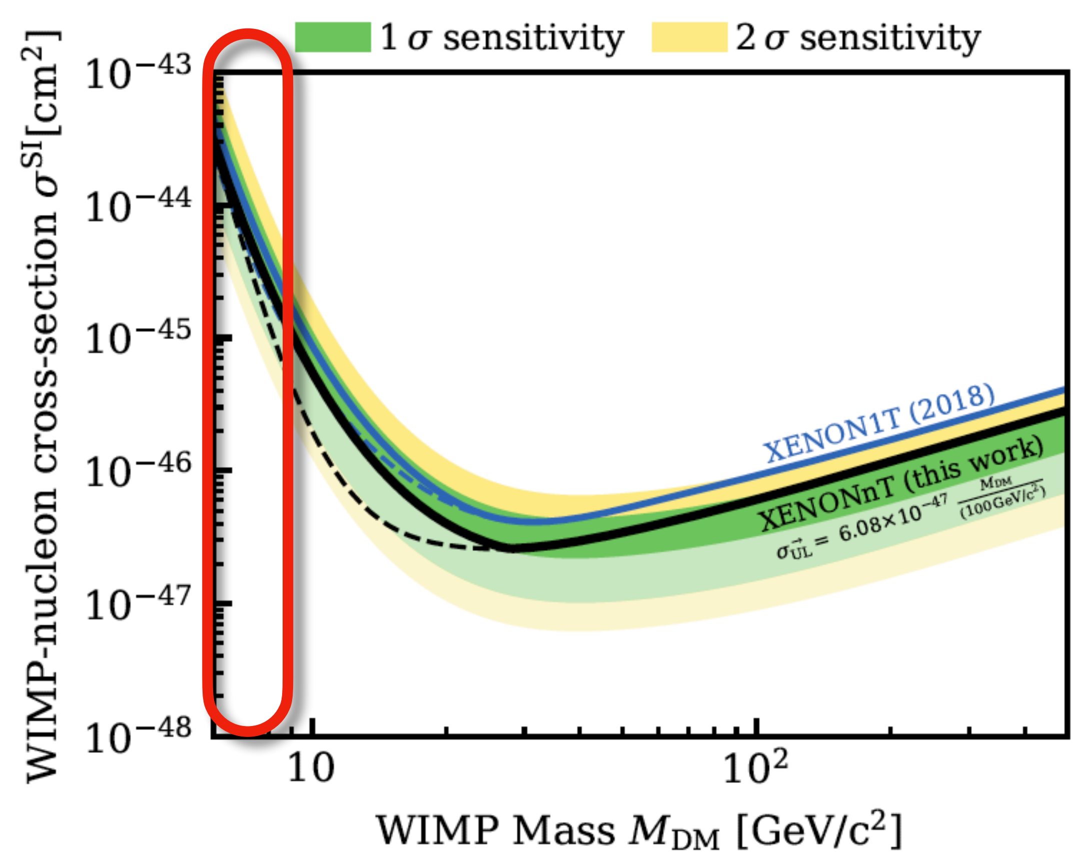
Let’s see vey light DM region !

Focus on light DM region,

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

that can evade the strong bound from direct detection.

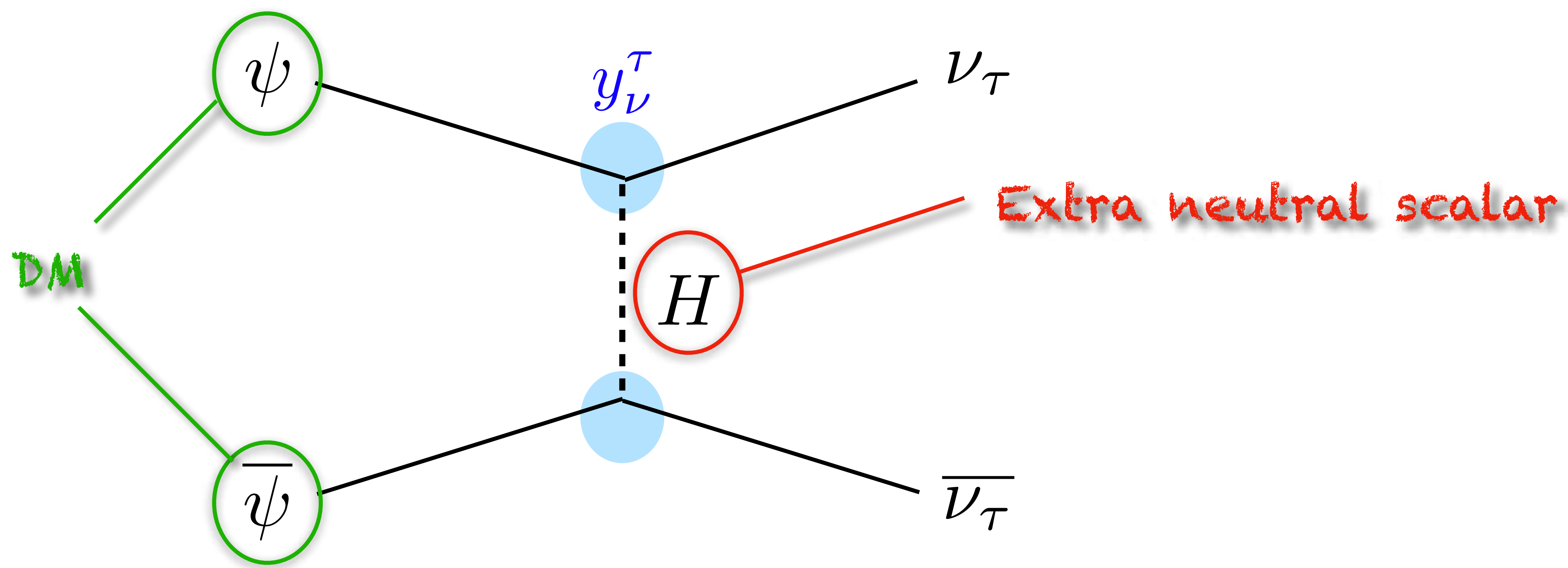
2303.14729, XENONnT



Let's see vey light DM region !

assuming DM dominantly couples to τ and ν_τ .

If DM is lighter than τ, DM annihilates to ν



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

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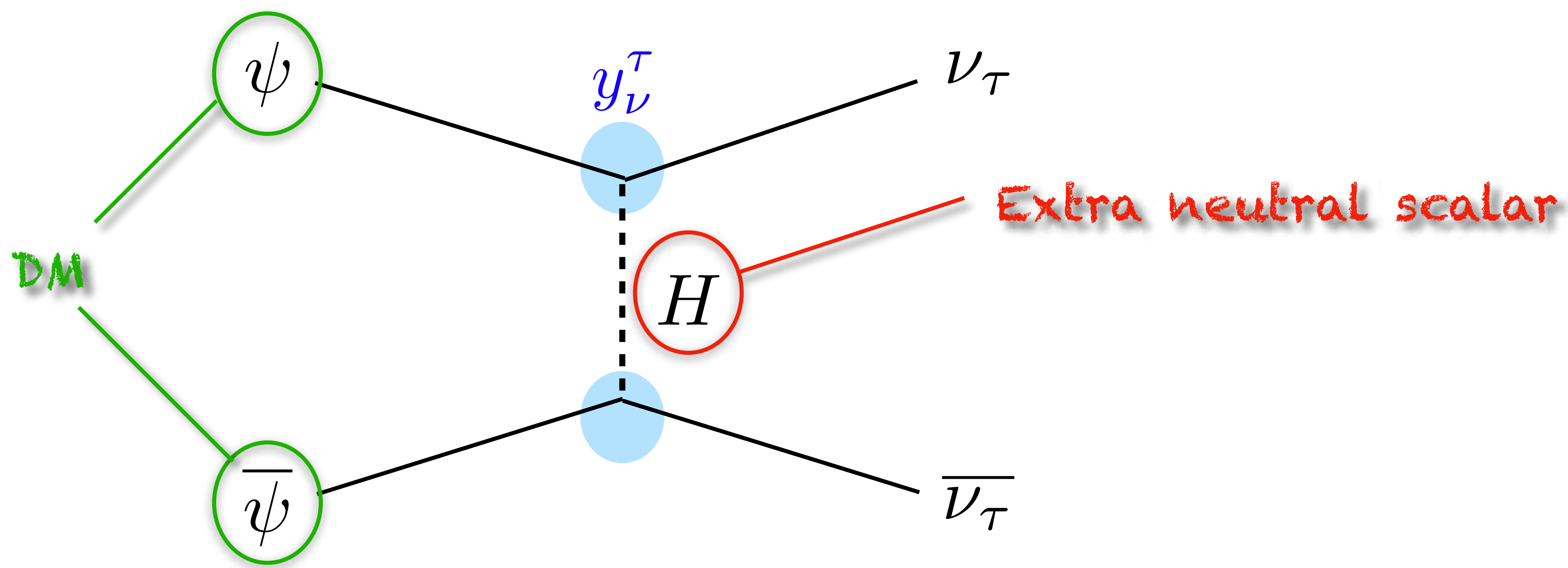

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Light DM requires a light neutral scalar

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

Parameters for light DM and light mediator

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

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

m_H close to m_ψ

Large mass hierarchy

$$m_A \simeq m_{H_\pm} \gtrsim \mathcal{O}(100)\,\mathrm{GeV}$$

From EWPOs and collider bounds

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From EWPOs and collider bounds

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

$$V = m_1^2(\Phi^\dagger\Phi) + m_2^2(\Phi_\nu^\dagger\Phi_\nu) + \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2(\Phi_\nu^\dagger\Phi_\nu)^2 + \lambda_3(\Phi^\dagger\Phi)(\Phi_\nu^\dagger\Phi_\nu) + \lambda_4(\Phi^\dagger\Phi_\nu)(\Phi_\nu^\dagger\Phi) + \frac{\lambda_5}{2}[(\Phi^\dagger\Phi_\nu)^2 + h.c.]$$

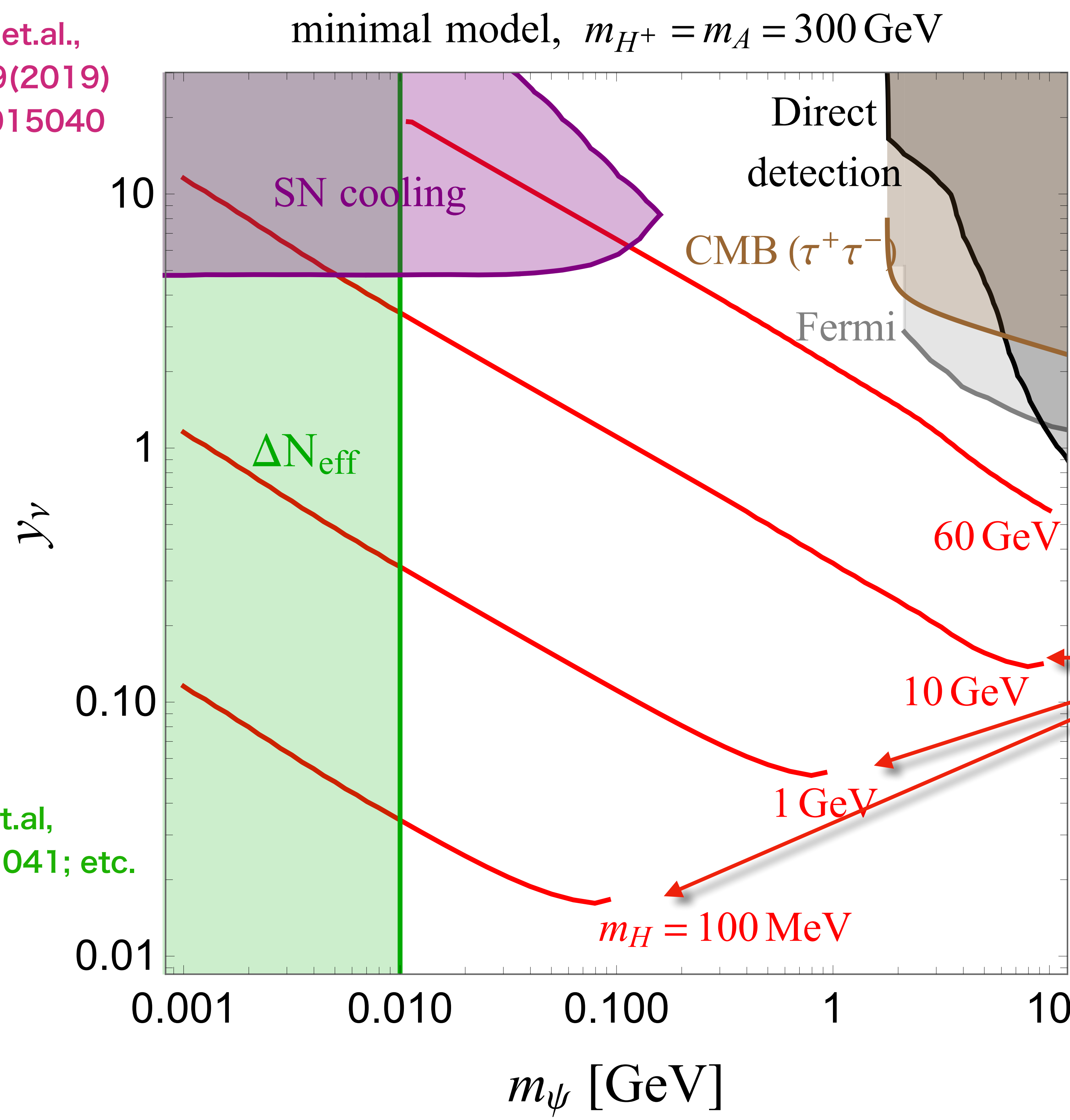
Phenomenology

Parameters to lead correct relic density of DM

(DM dominantly couples to τ and ν_τ)

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

Prediction deviates from the SM in the 125 GeV Higgs signal.

2011.04788 with Okawa

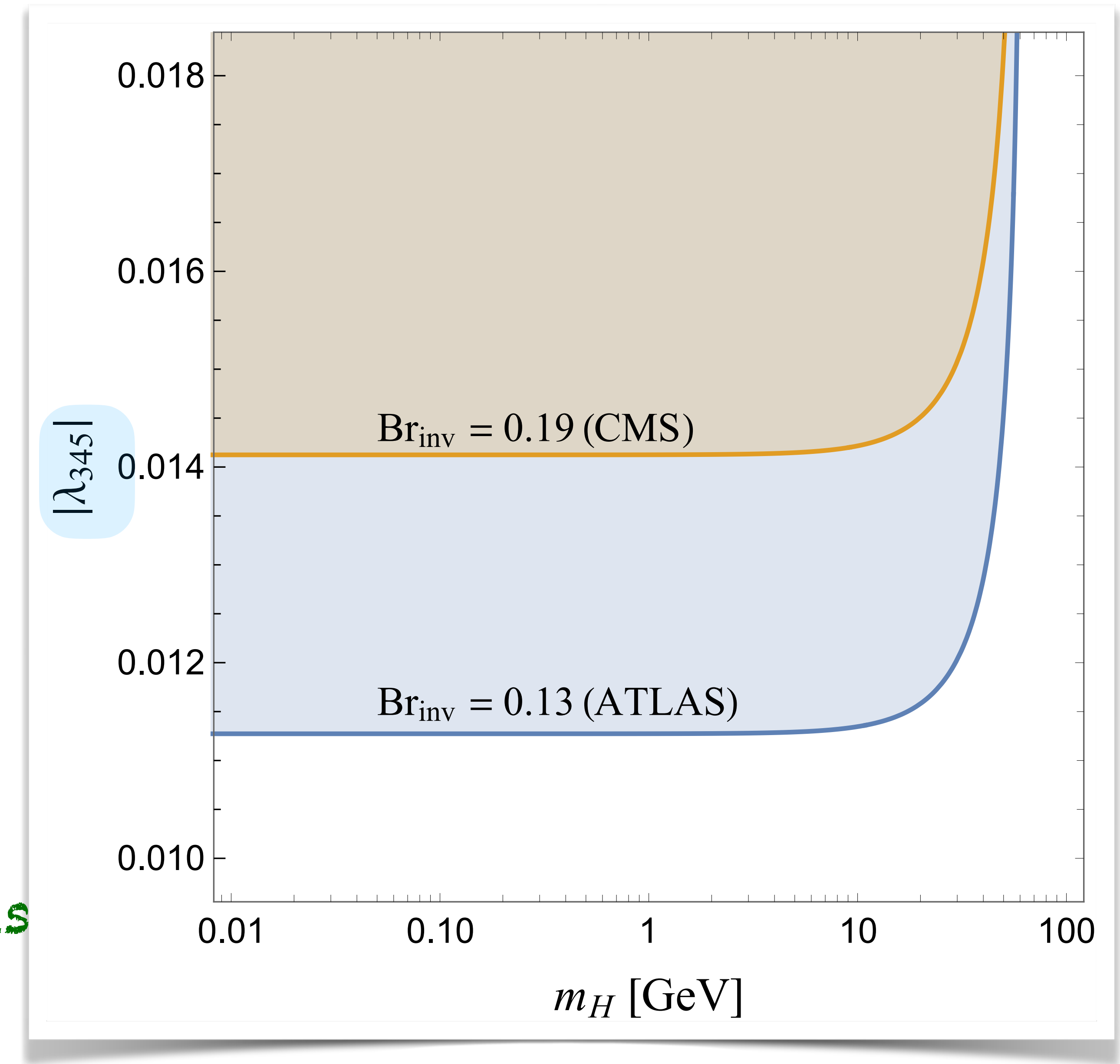
h decays to HH,
that is invisible decay of h.

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

should be suppressed.

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

gives large mass differences
between H+ and H



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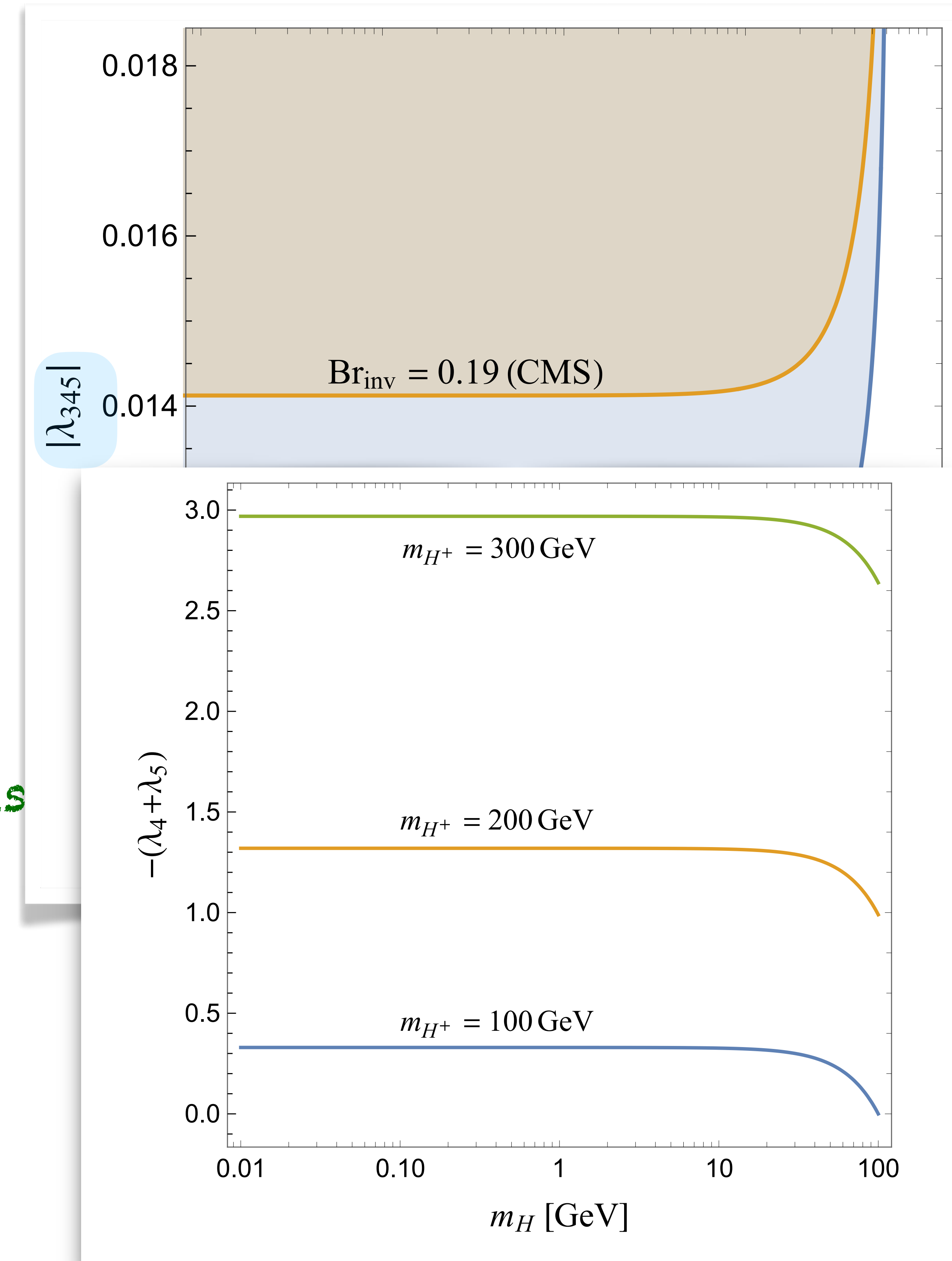

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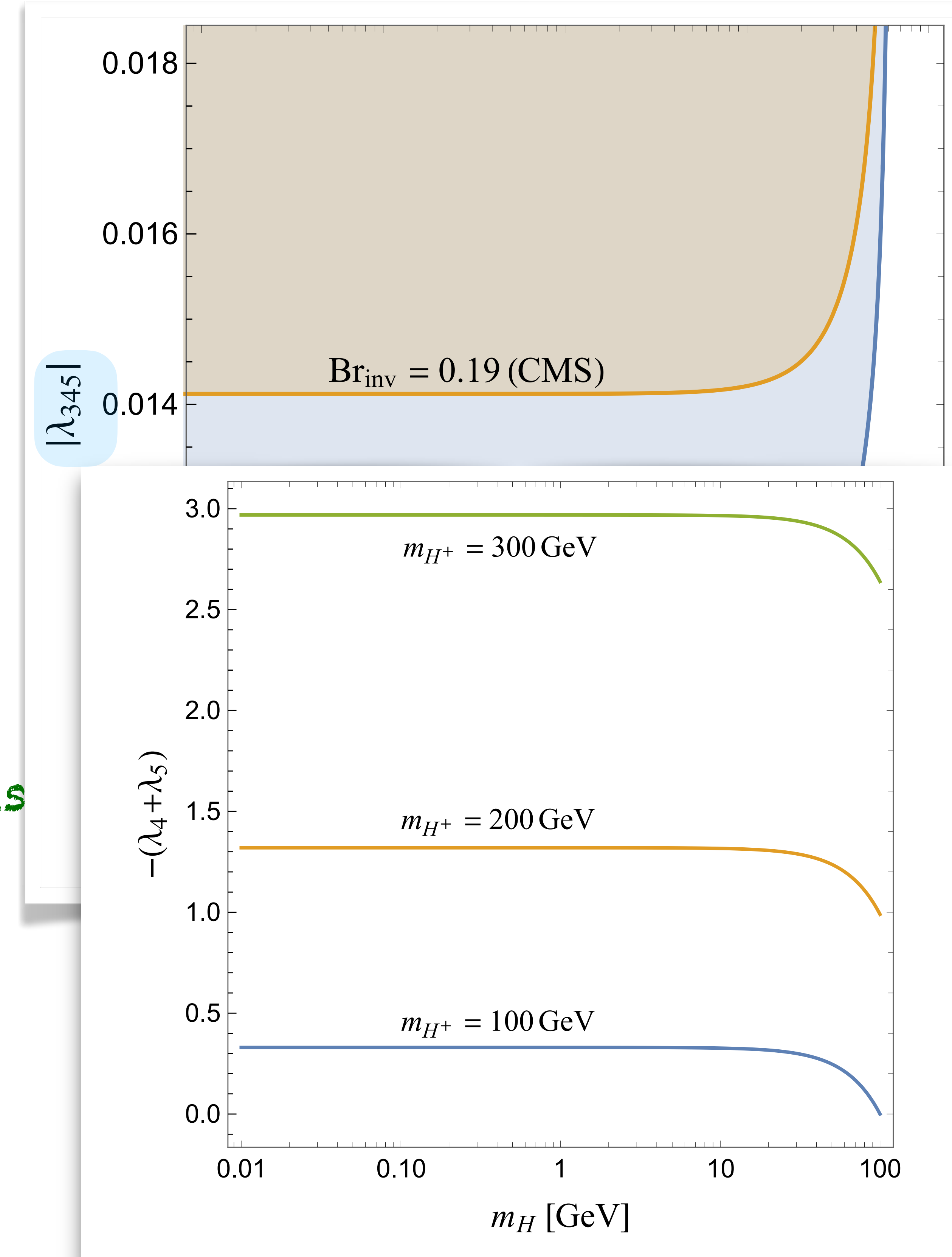
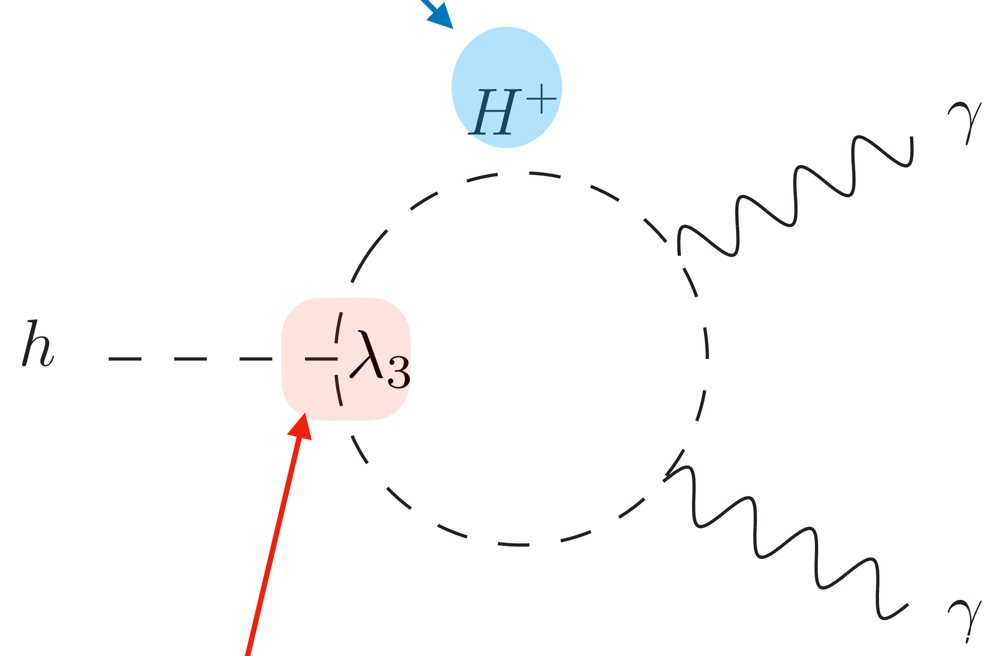
becomes large!



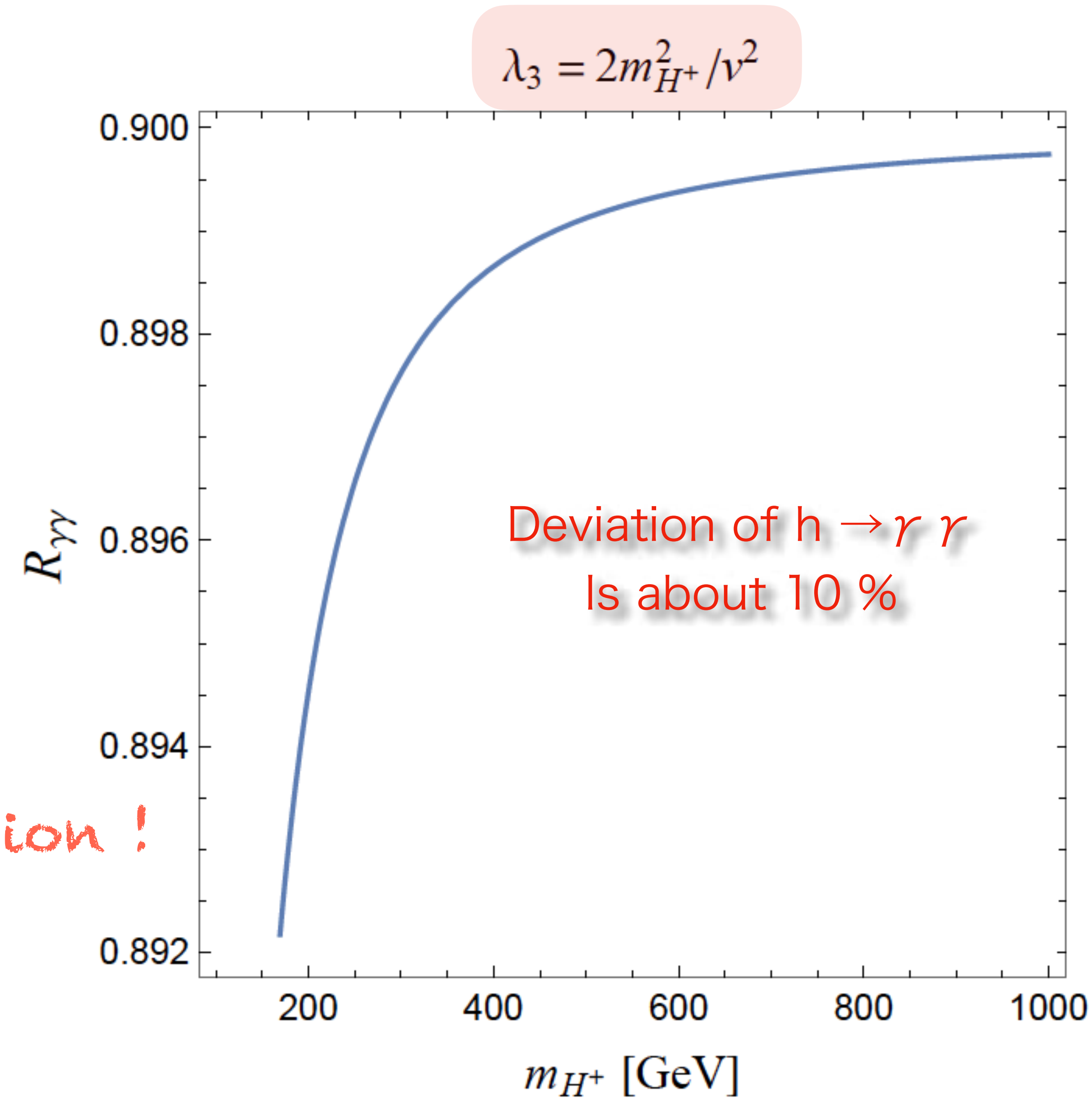
h→γγ deviates from the SM prediction!

2011.04788 with Okawa

Heavier than ~250 GeV because of LHC

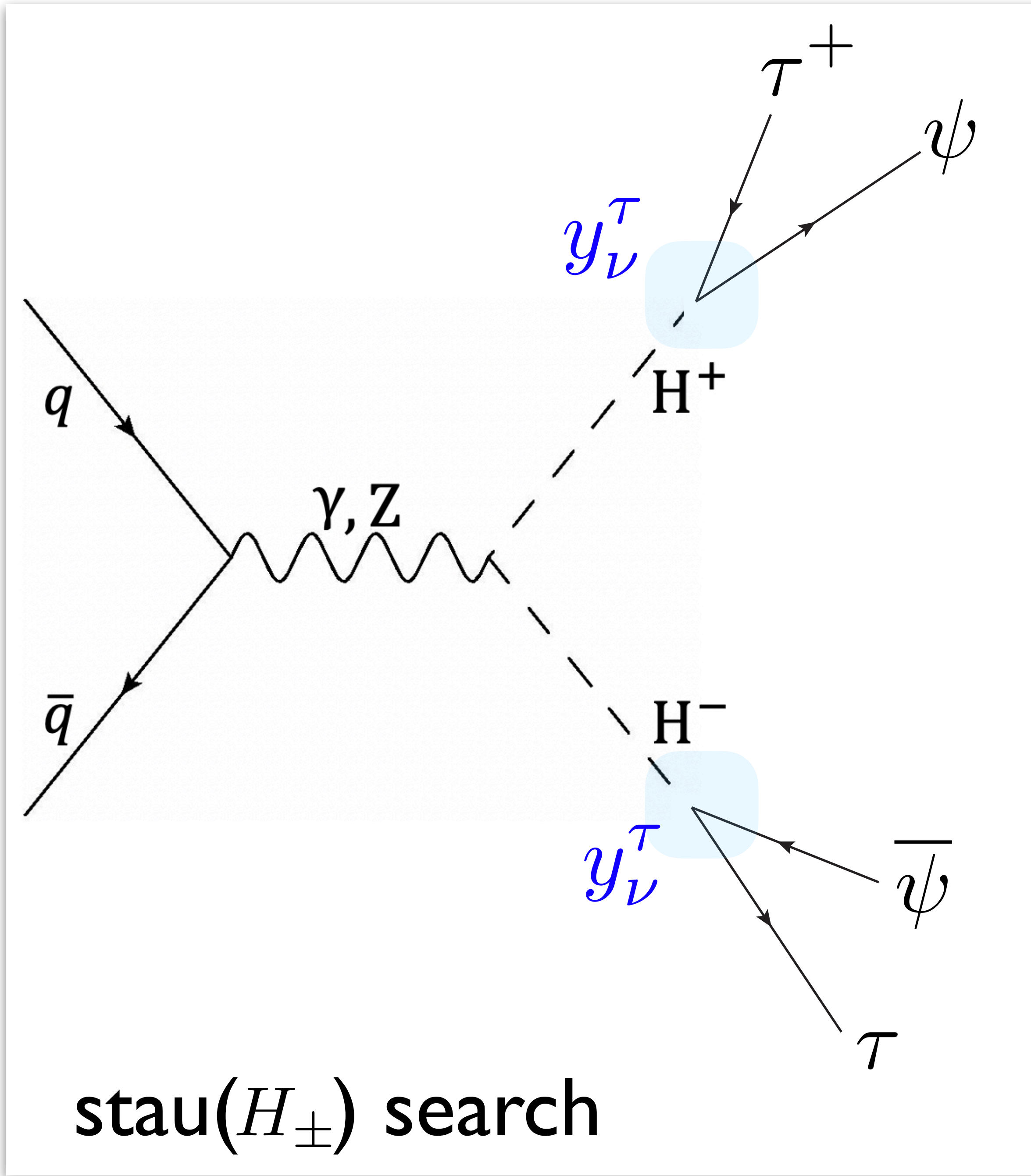


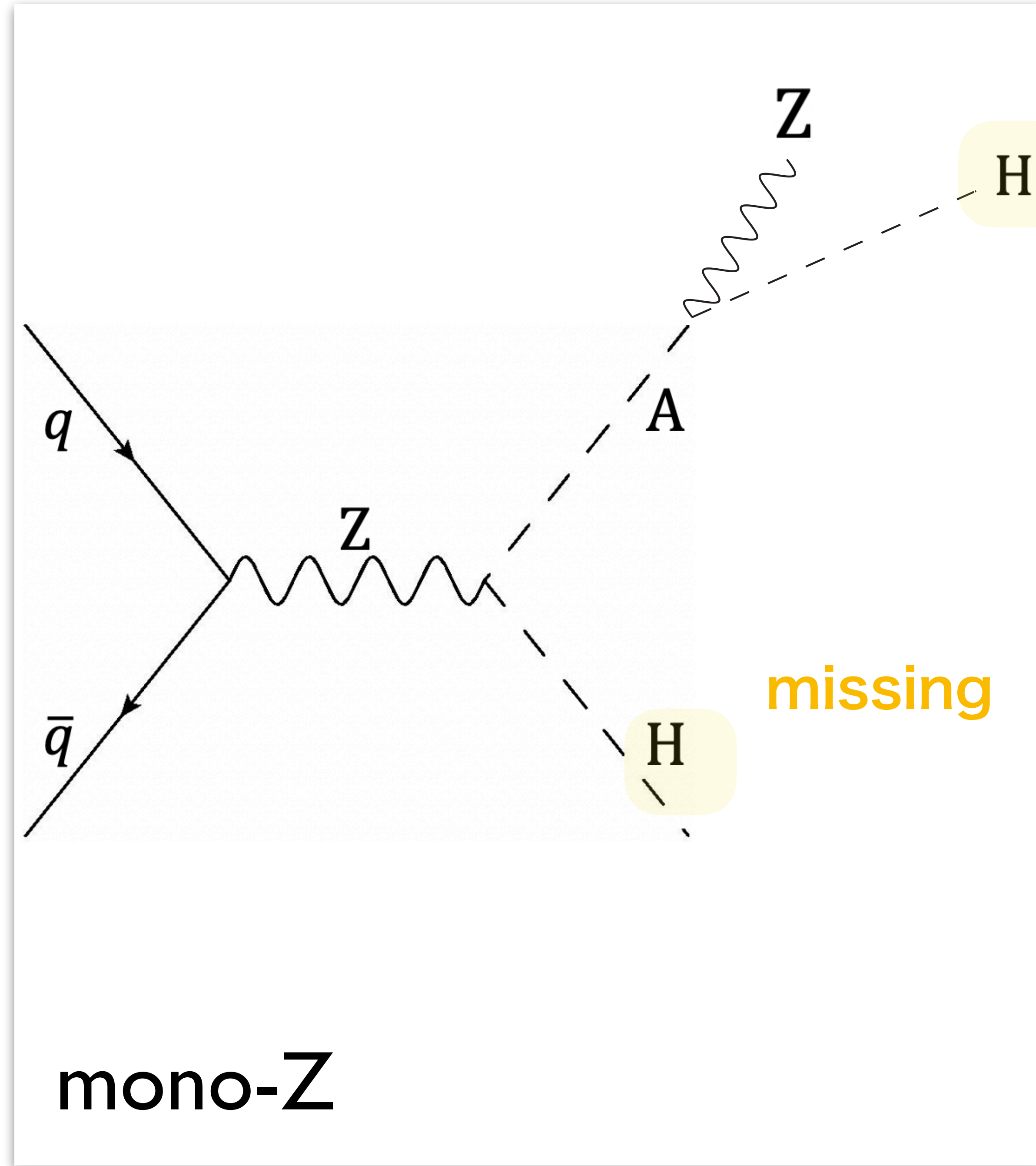
large λ3 enhance this loop contribution !



Signals at the LHC

The extra scalars can be produced at the LHC.



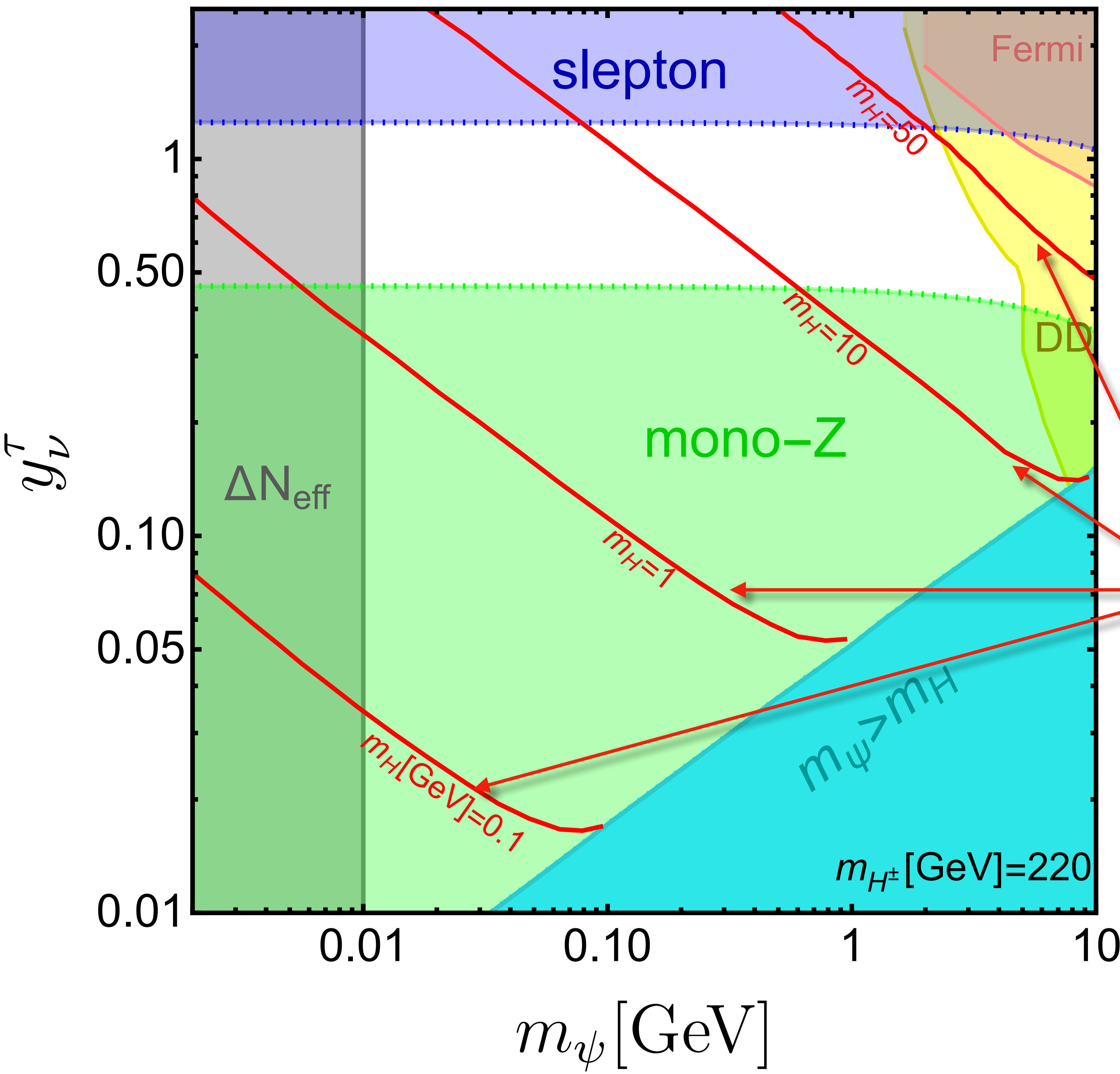


Mono-Z search is complementary to stau search.

Allowed parameter region

(DM dominantly couples to τ and ν_τ)

S. Iguro, S. Okawa, YO JHEP03(2023)010
(arXiv: 2208.05487)

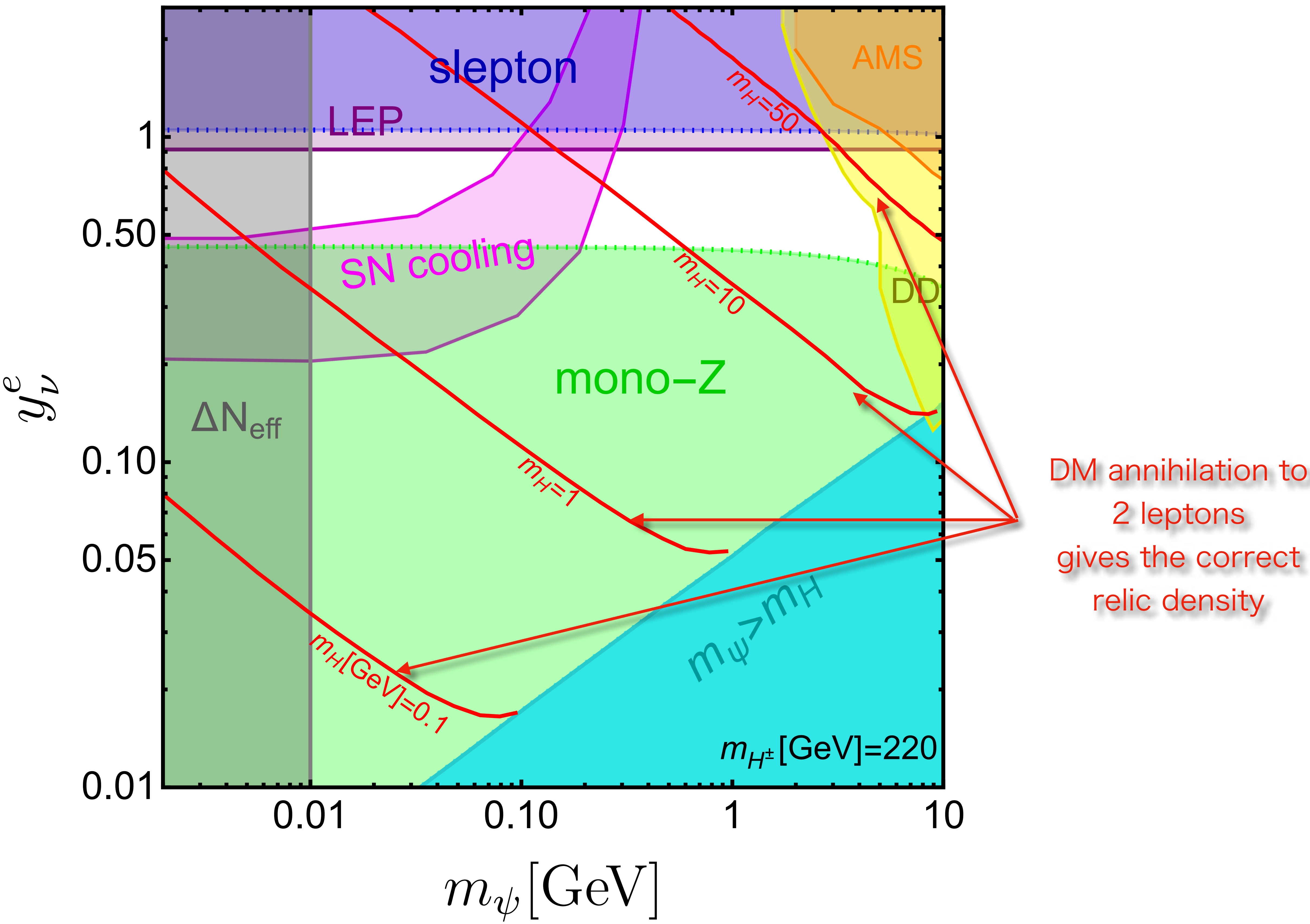


DM annihilation to 2 leptons gives the correct relic density

Allowed parameter region in the light lepton case

(DM dominantly couples to e and ν_e)

S. Iguro, S. Okawa, YO JHEP03(2023)010
(arXiv: 2208.05487)



Summary

- 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 one issue: large couplings required in the scalar potential. → A solution is to add one more scalar (See arXiv: 2011.04788, S.Okawa and YO).
- In Higgs physics, deviation of $h \to \gamma\gamma$ is about 10 % and invisible decay is also large, because of the large couplings.
- We can search for the scalars at LHC: Mono-Z search is complementary to stau search.
- Please check our recent paper on scalar, H, DM scenario.

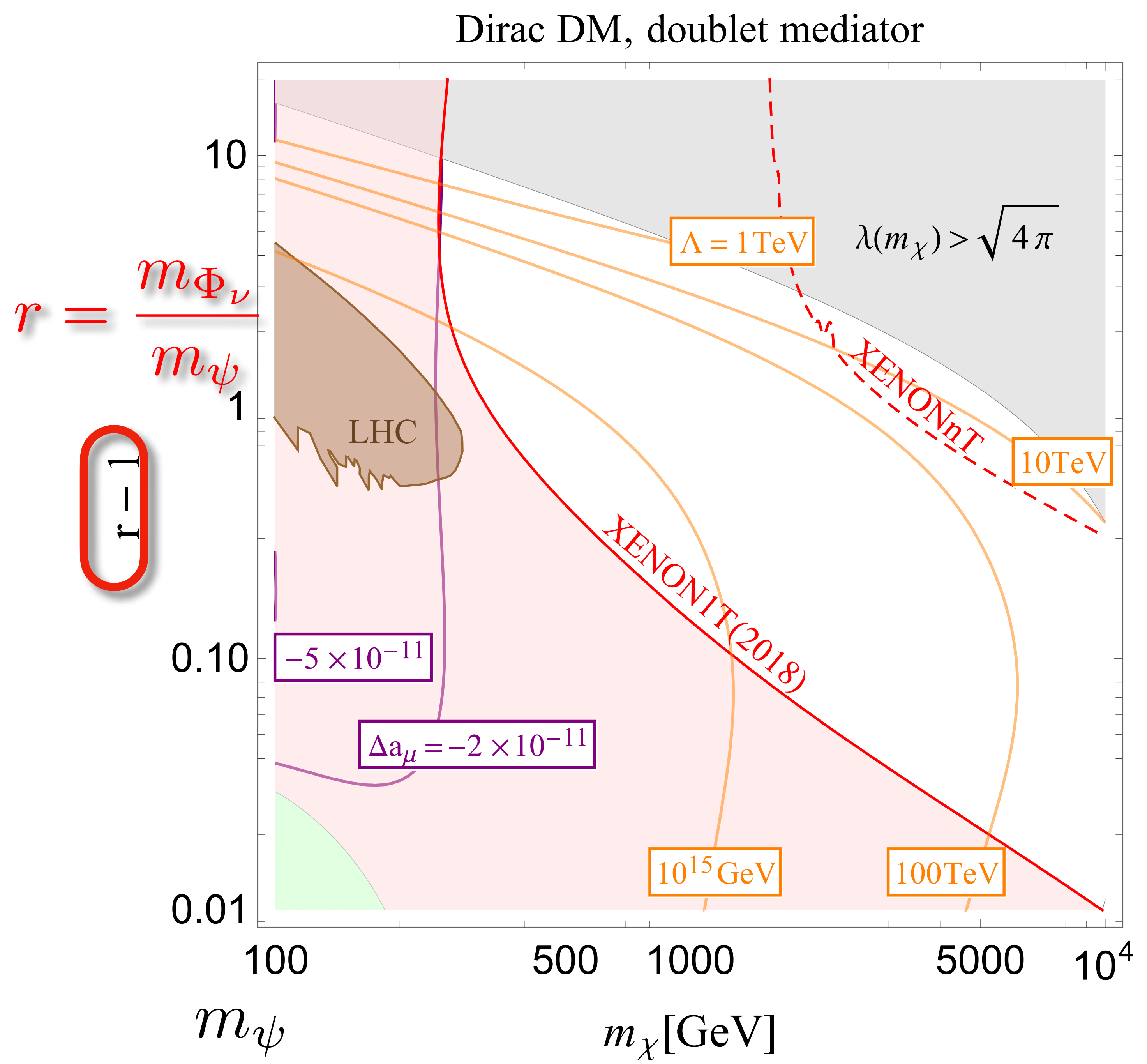
(arXiv: 2310.13685, Higuchi, Iguro, Okawa, YO)

END

Backup

Heavy region

2002.12534 with Kawamura, Okawa

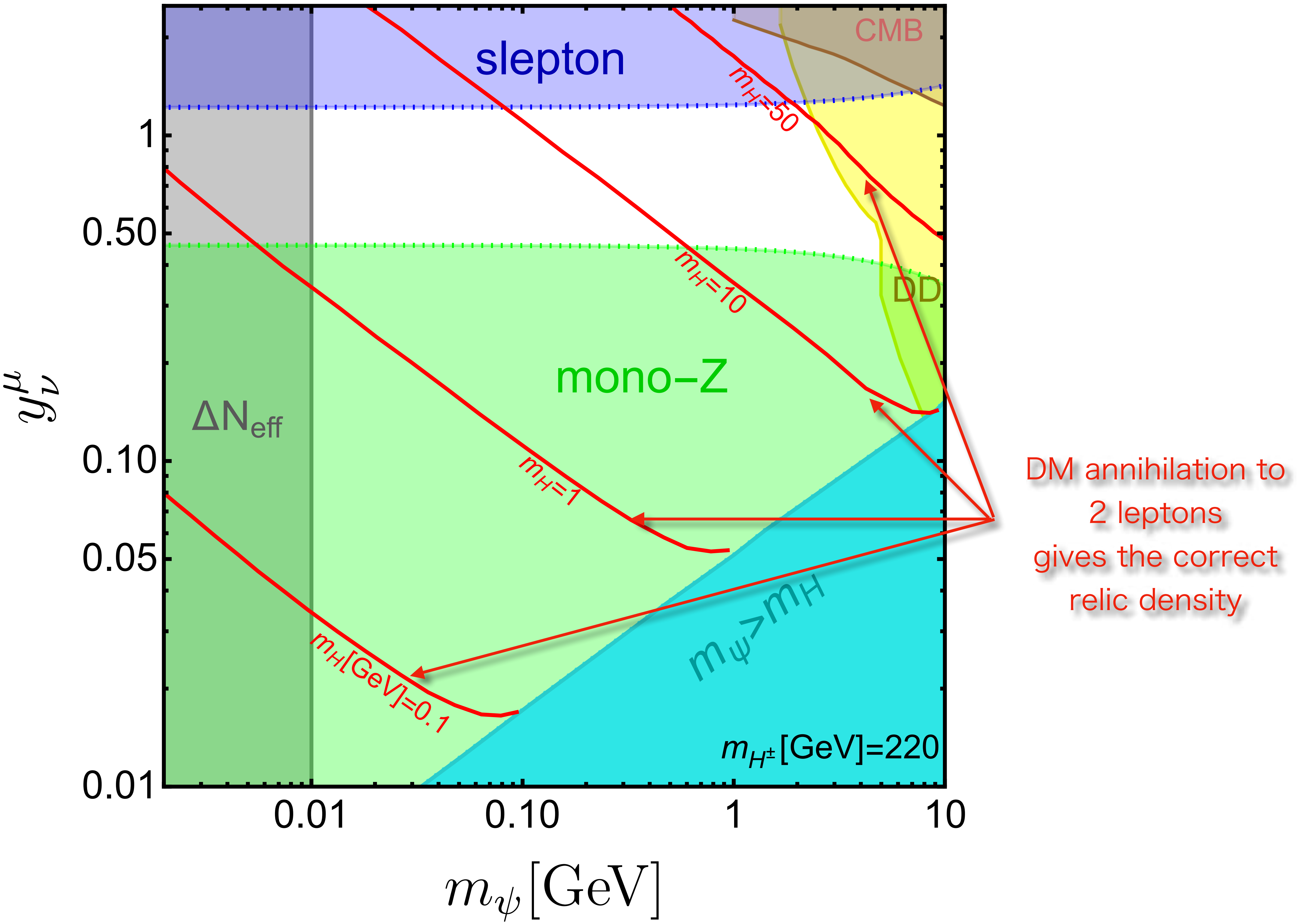


In this study, we assume DM dominantly couples to μ.

Allowed parameter region

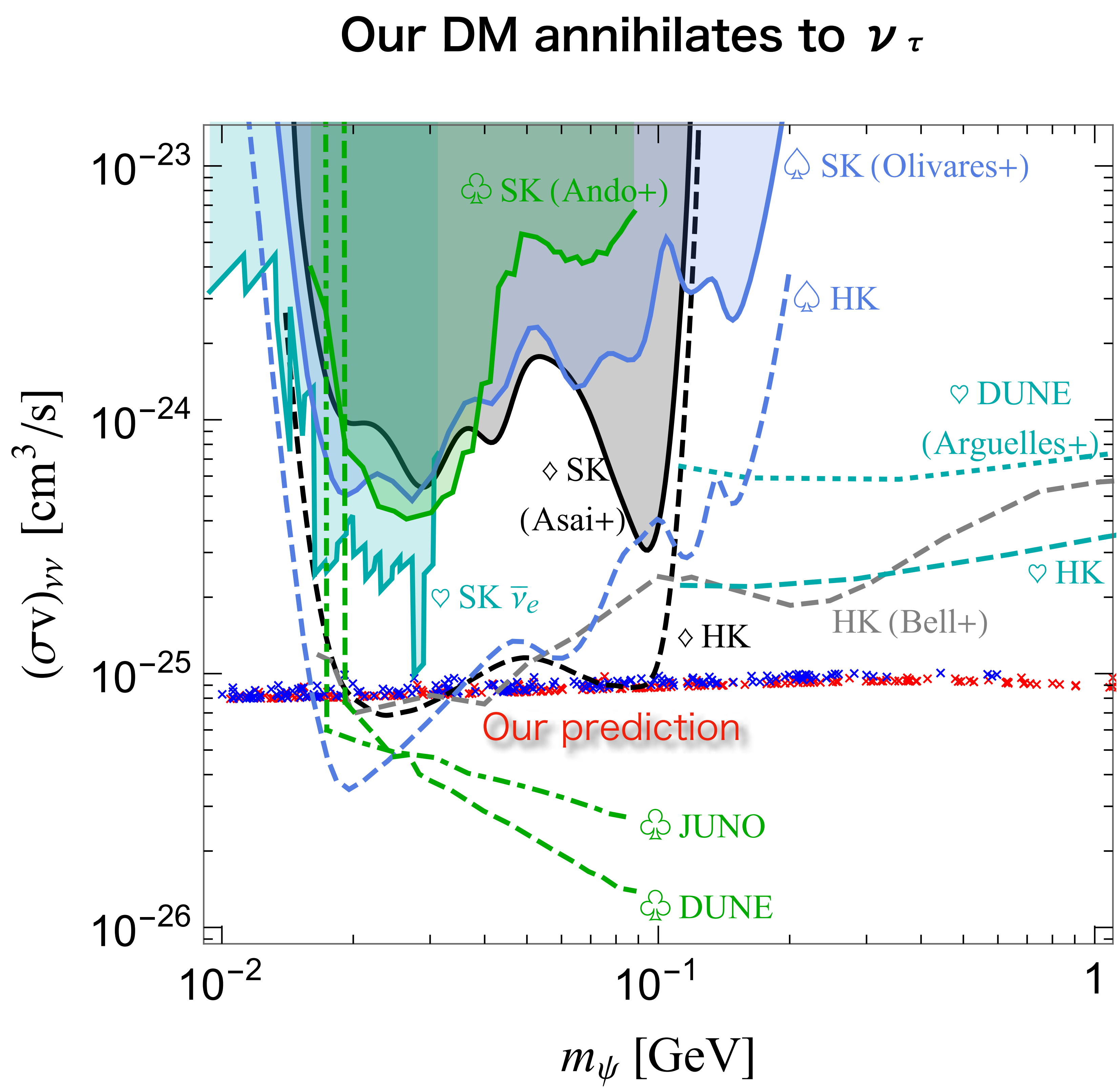
(DM dominantly couples to μ and ν_μ)

S. Iguro, S. Okawa, YO JHEP03(2023)010
(arXiv: 2208.05487)



It is possible to test in the indirect detection.

2011.04788 with Okawa



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

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