Light lepton portal dark matter meets the LHC

Yuji Omura (Kindai Univ.)

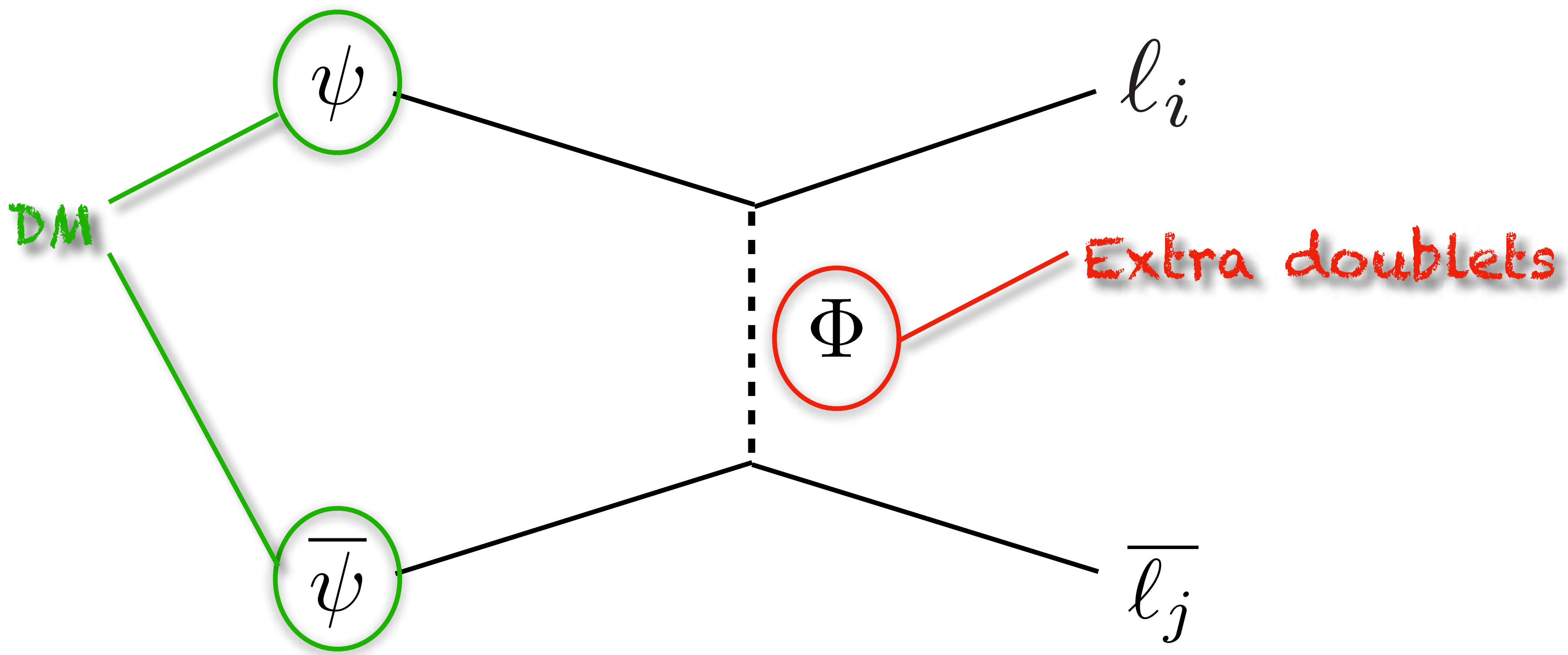
based on
JHEP03(2023)010 (arXiv: 2208.05487) with Syuhei Iguro (KIT) and Shohei Okawa (Barcelona U);
JHEP02(2021)231 (arXiv: 2011.04788) with Shohei Okawa (Barcelona U)

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,

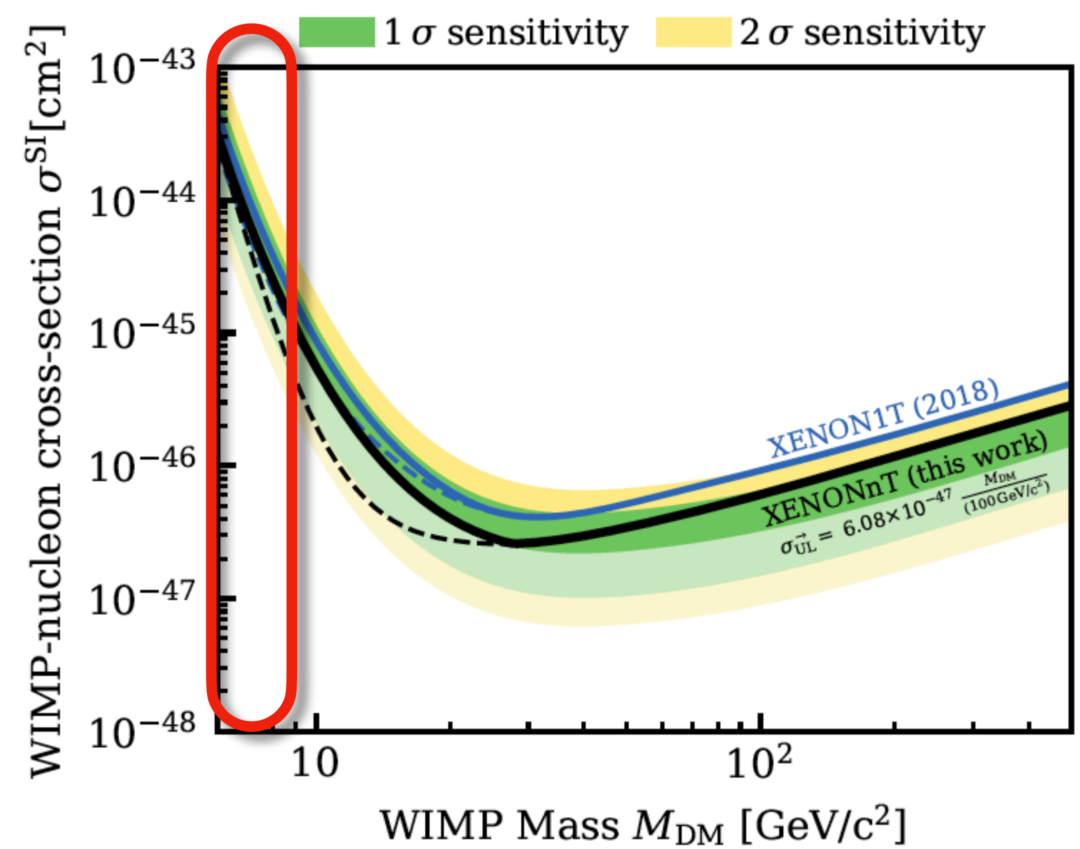
- DM is Dirac fermion

- 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

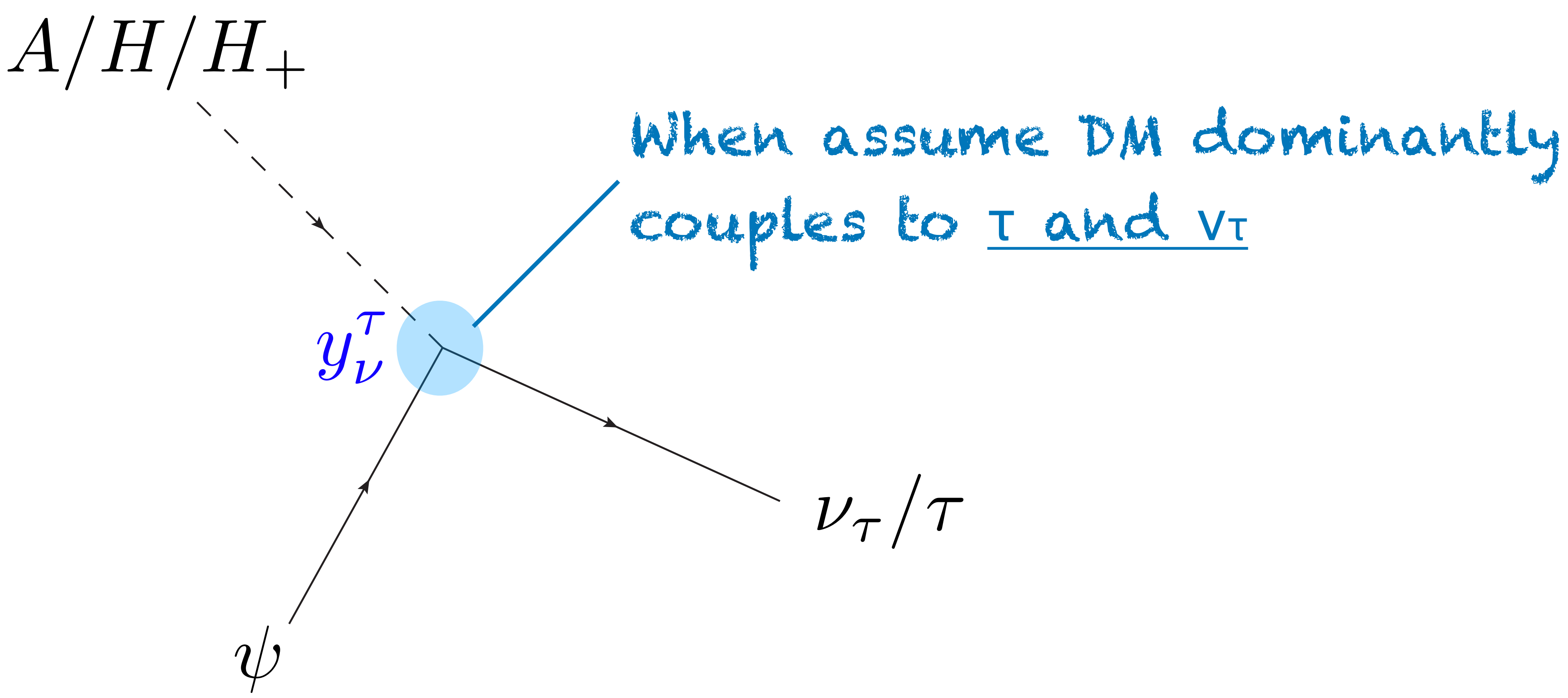
$$-\mathcal{L}_\ell = y_\nu^i\, \overline{\ell_L^i}\, \widetilde{\Phi}_\nu\, \psi_R + h.c.$$

After EWSB

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

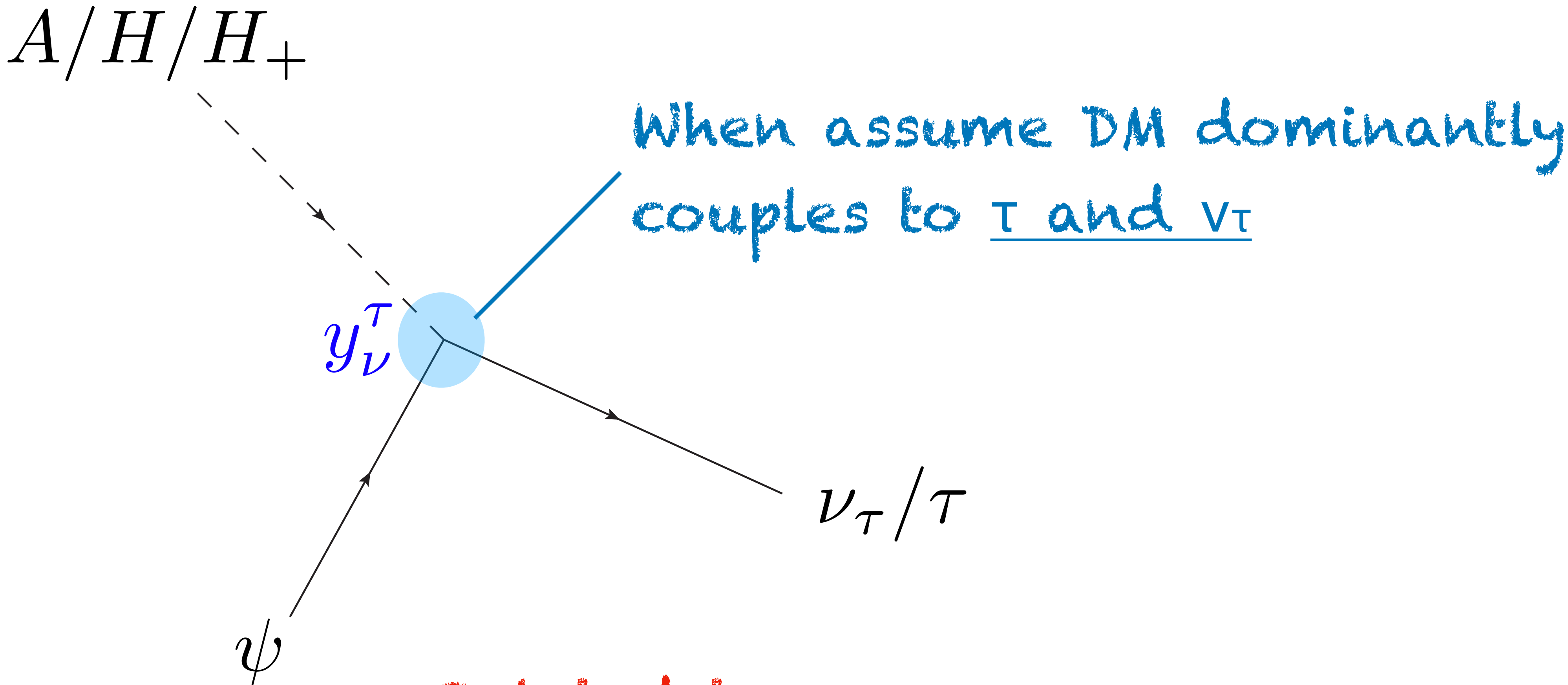
New particles and relevant couplings

DM couplings

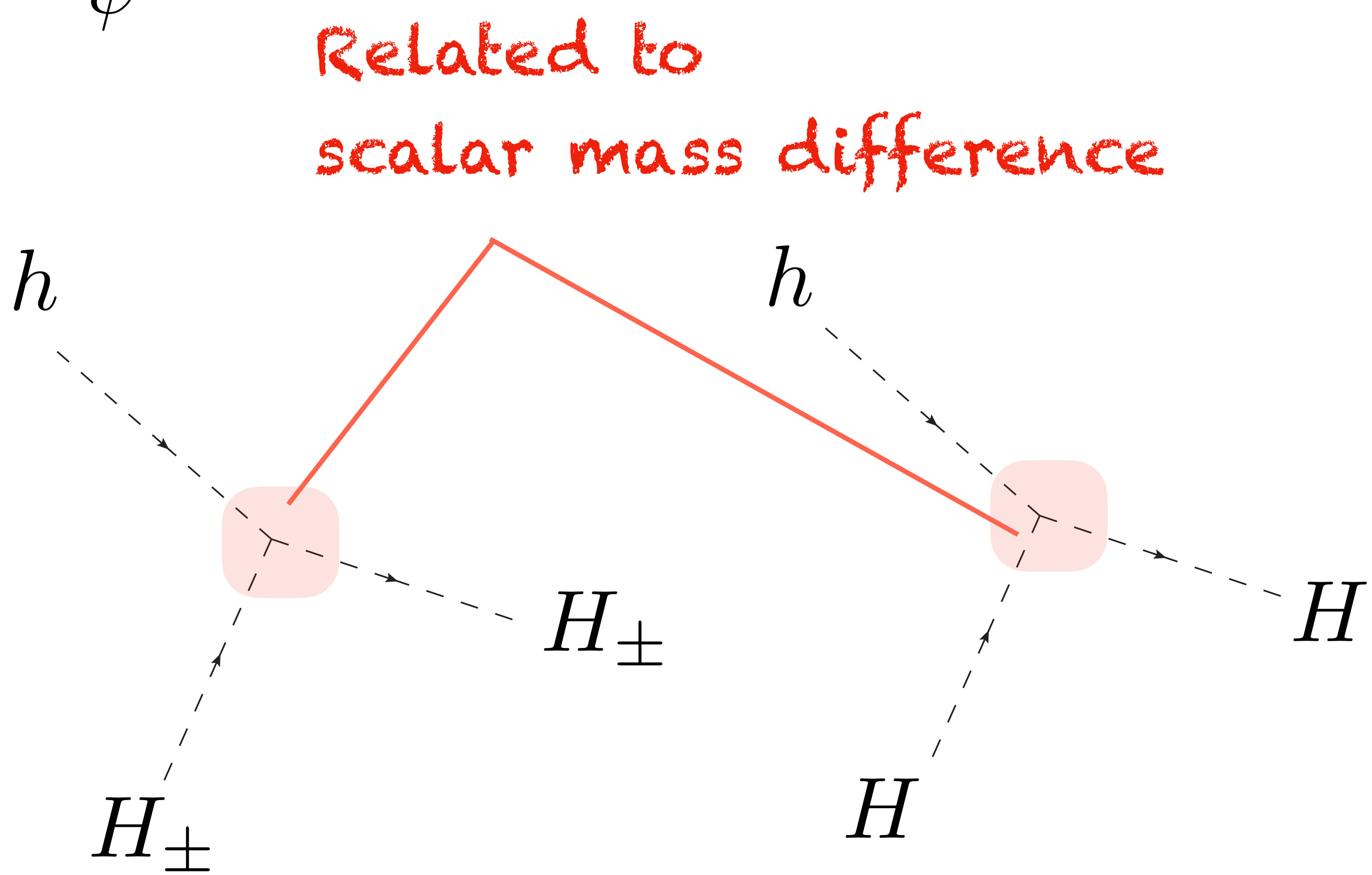


New particles and relevant couplings

DM couplings



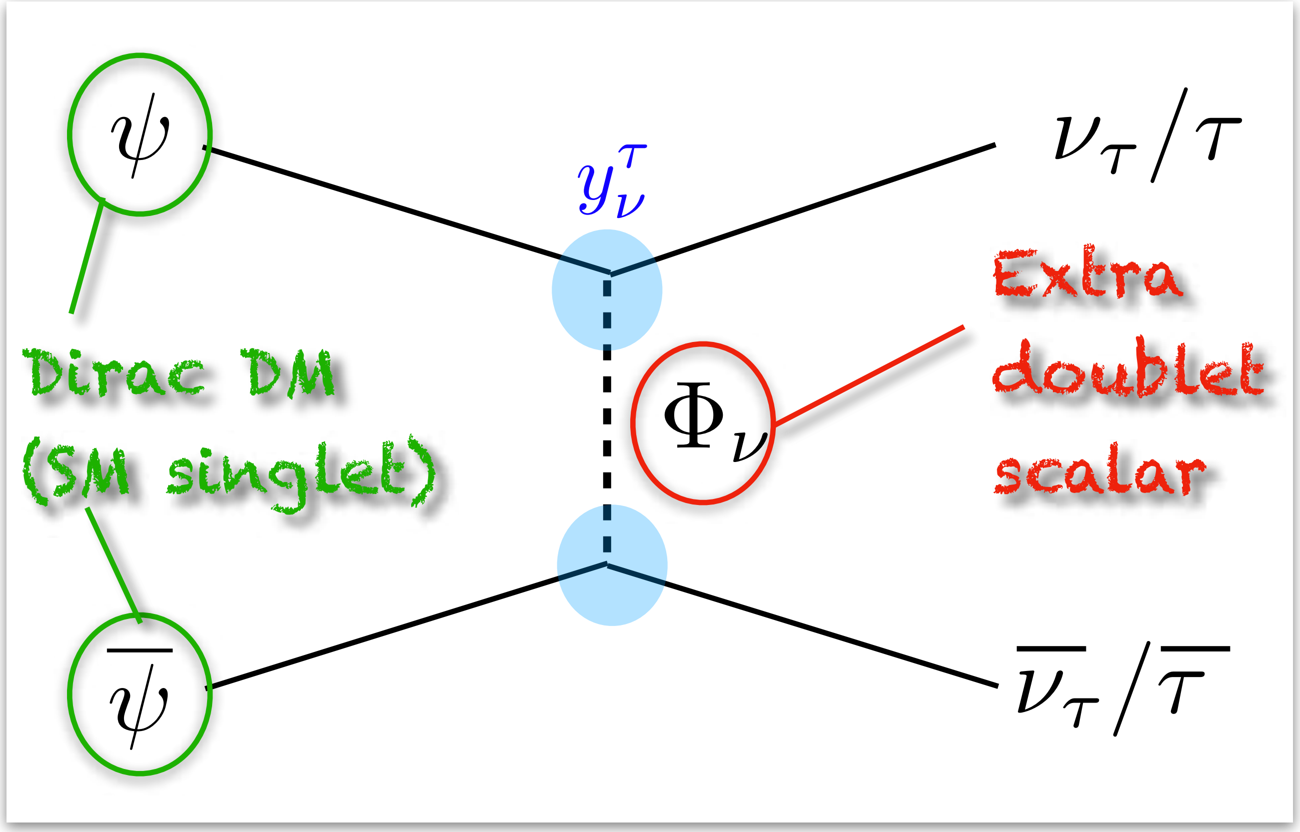
Extra scalar couplings



DM annihilate to leptons through scalar exchange

2002.12534 with Kawamura, Okawa

Assuming DM dominantly couples to τ and ν_τ



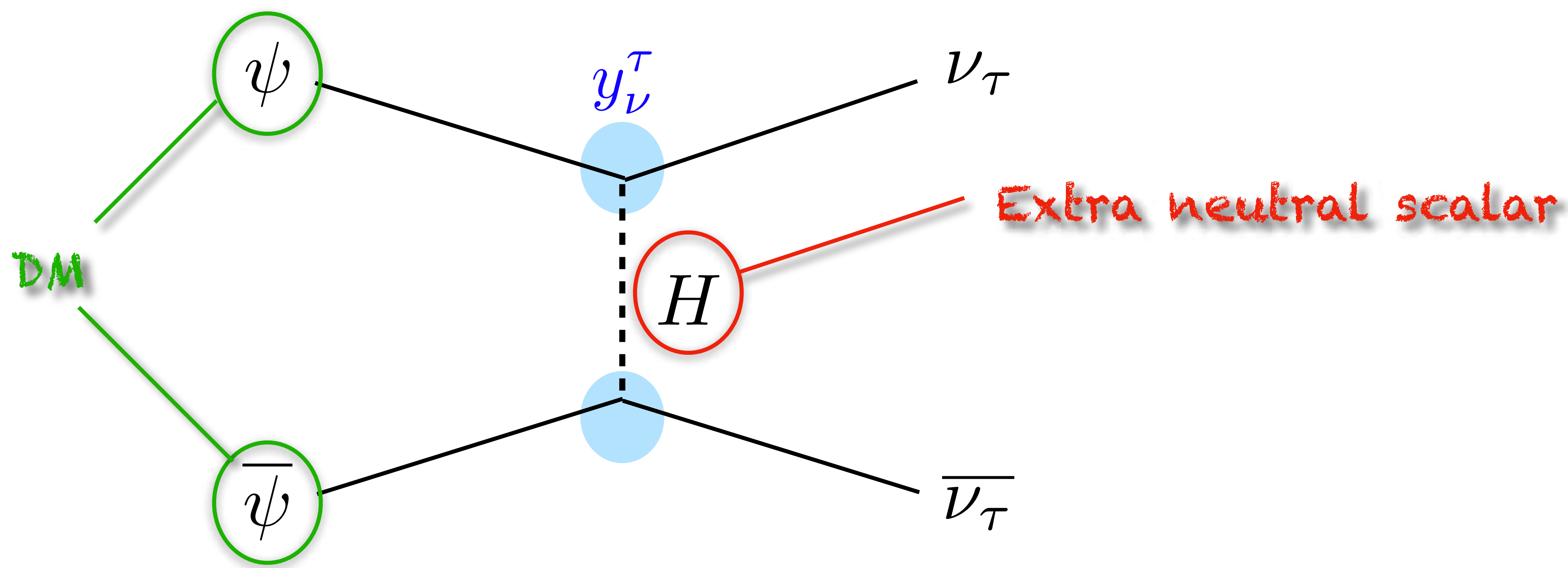
Note: The annihilation cross-section needs to be sizable to achieve correct relic density of DM.

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

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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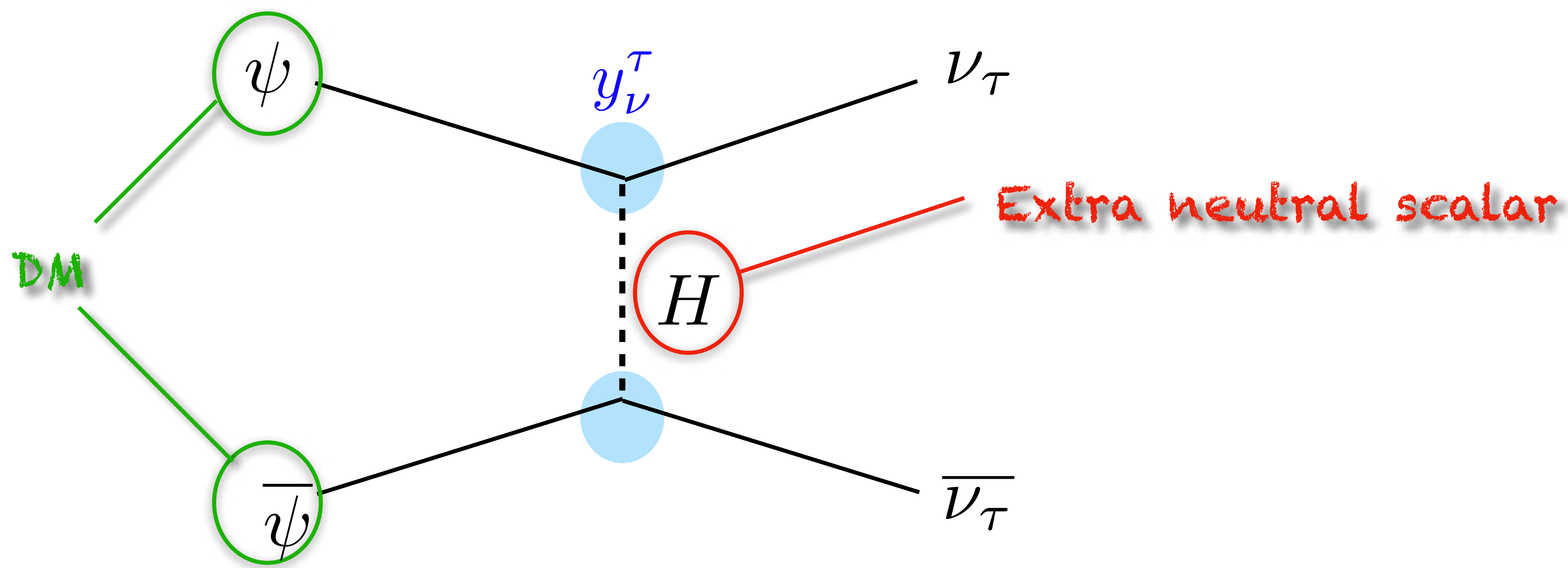

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Light DM requires a light neutral scalar

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 collider bounds

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From collider bounds

Mass differences
given by para. in scalar potential

Suppressed

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

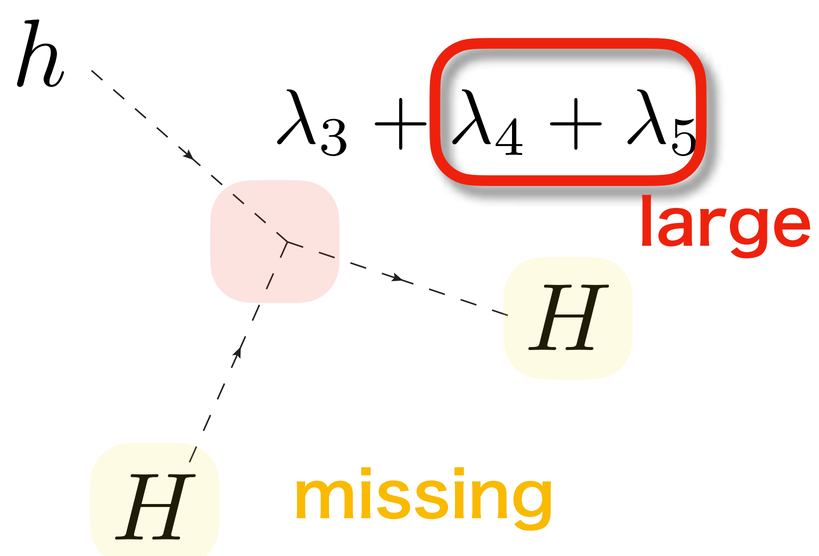
$$m_H^2 = m_{H+}^2 + \frac{(\lambda_4 + \lambda_5)v^2}{2}$$

Very large

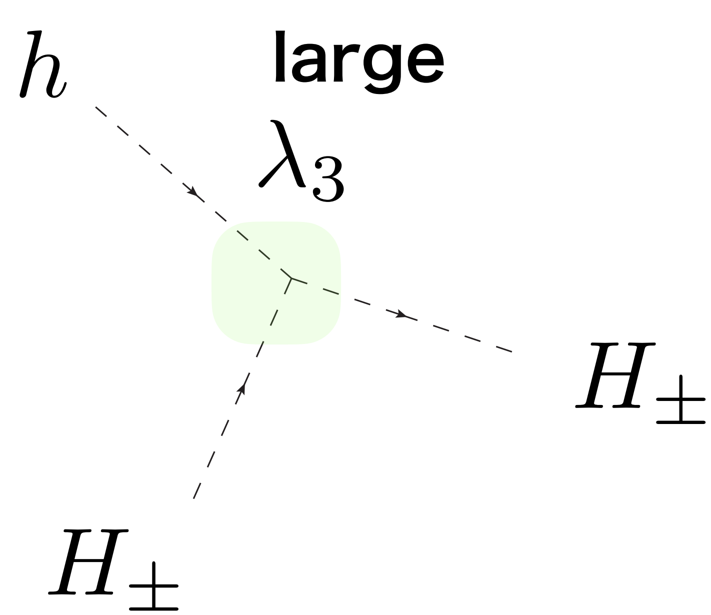
$$\lambda_4(\Phi^\dagger\Phi_\nu)(\Phi_\nu^\dagger\Phi) + \frac{1}{2}\lambda_5[(\Phi^\dagger\Phi_\nu)^2 + h.c.]$$

Light DM requires large couplings in scalar potential

Couplings between 125 GeV Higgs and extra scalars are large.



The bound from invisible decay requires small coupling .
→large λ_3 cancels large $\lambda_4+\lambda_5$



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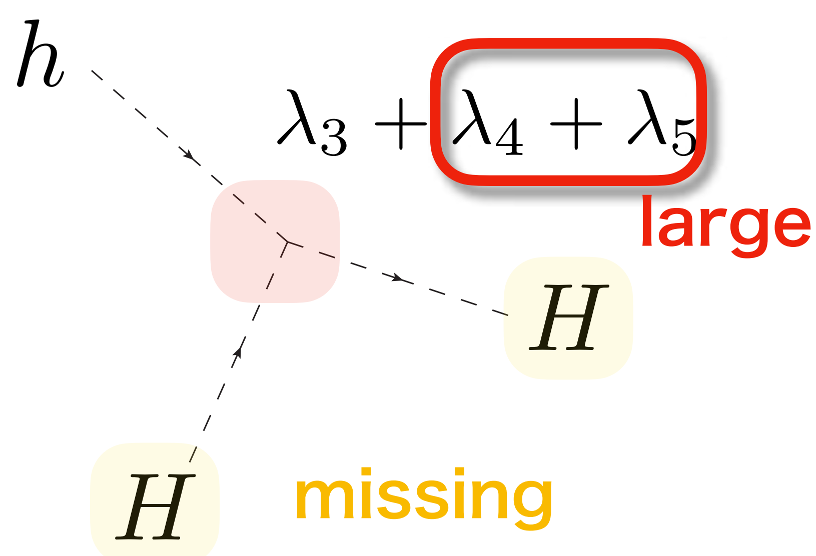

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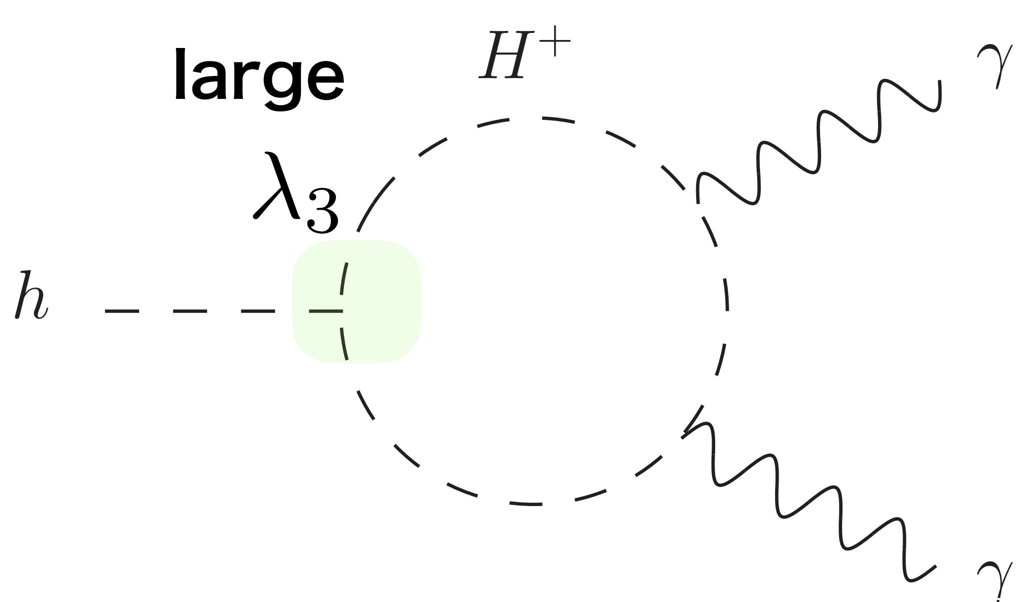
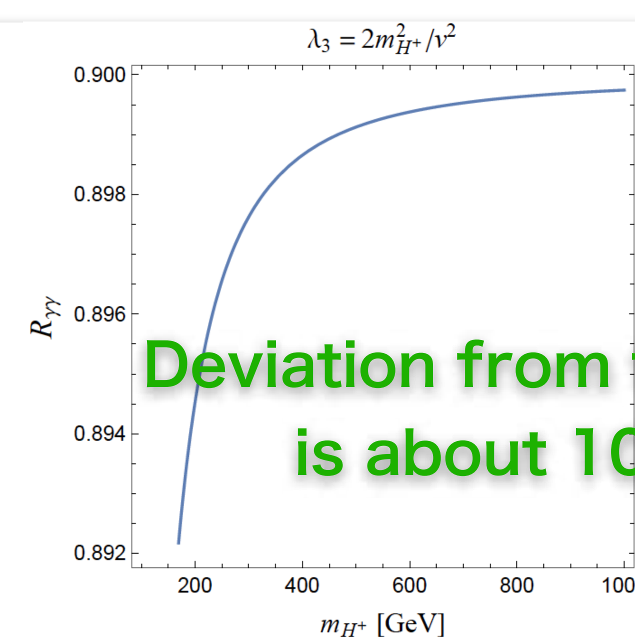
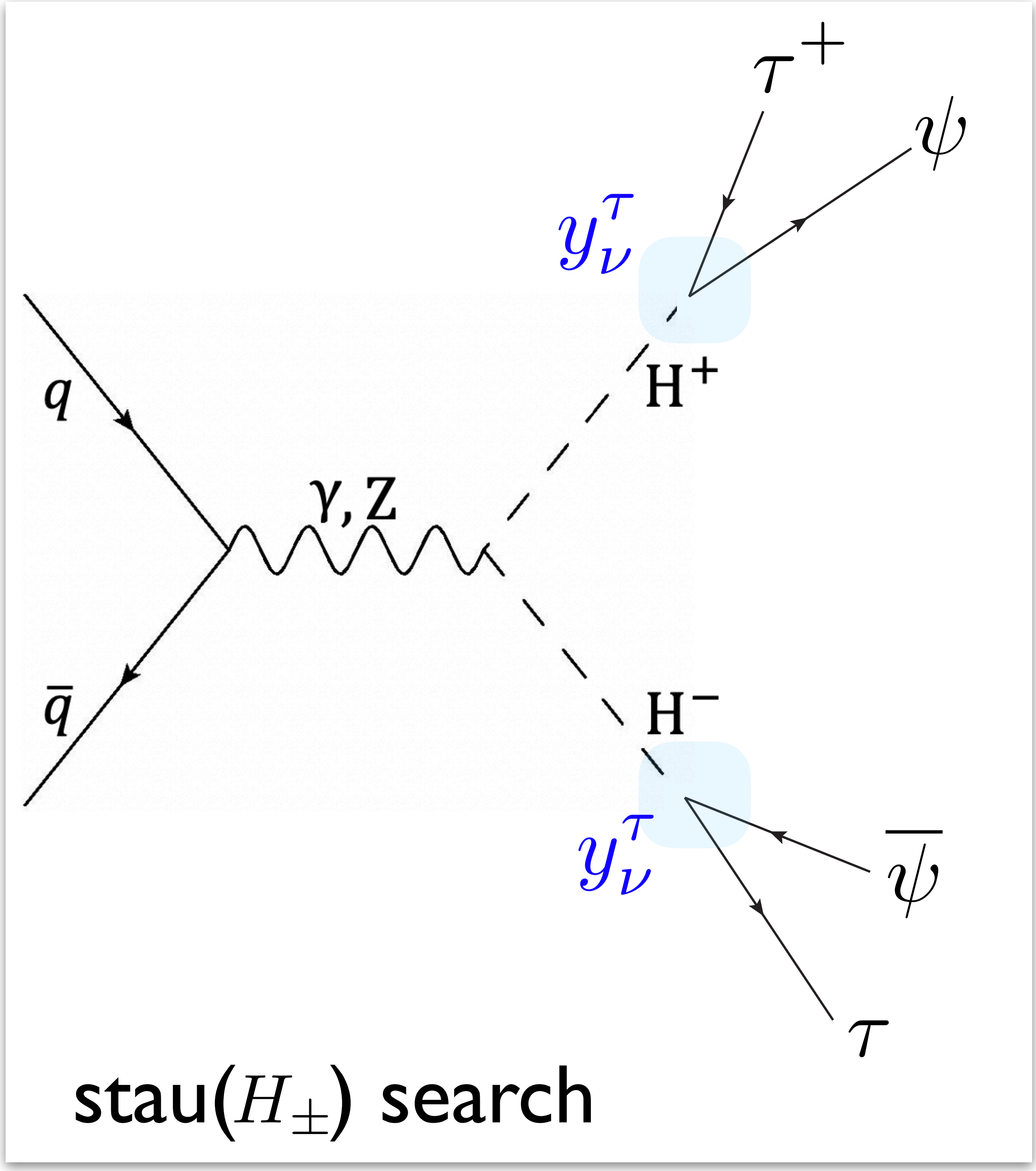
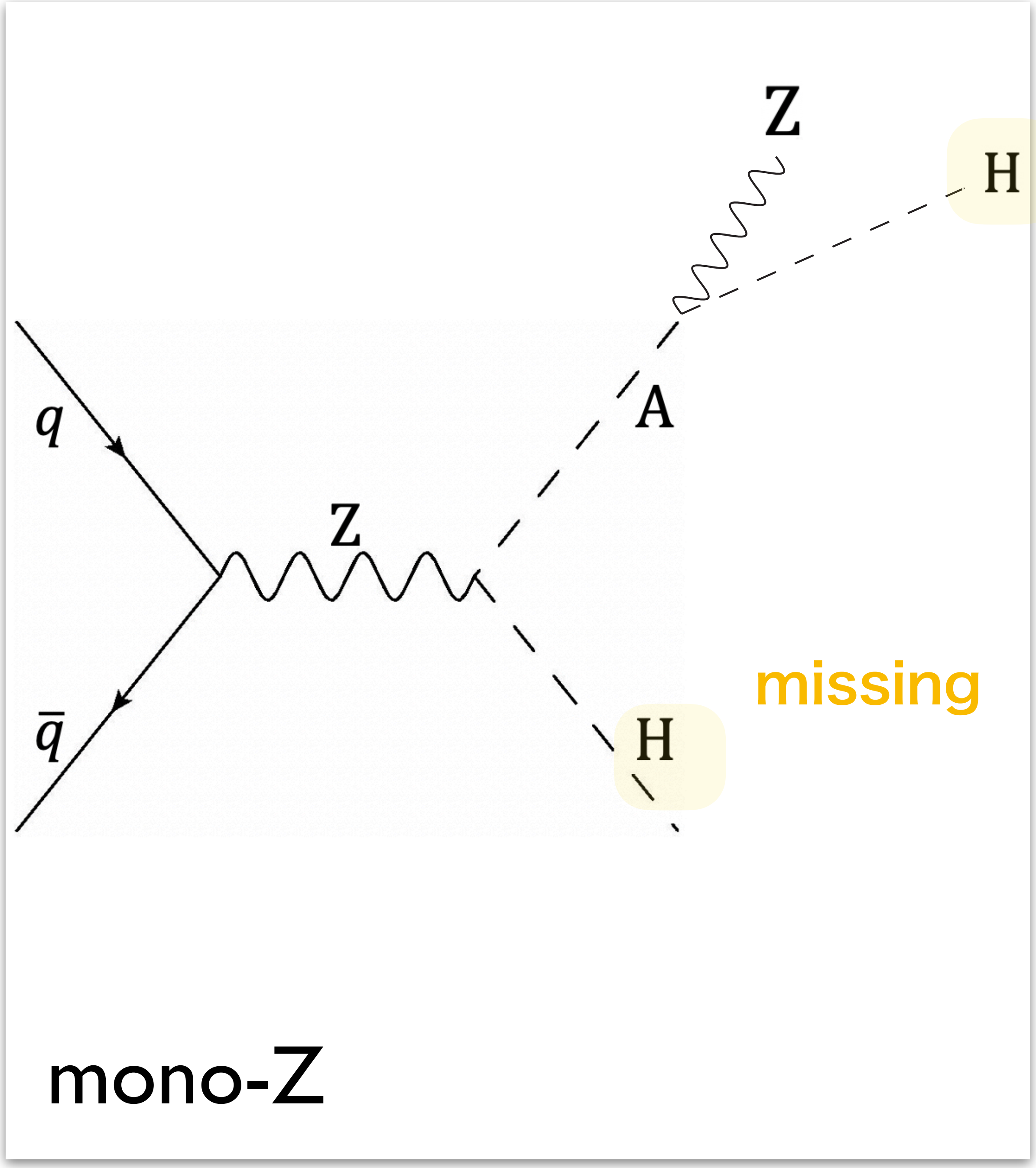




Deviation from the SM is about 10%.

The extra scalars can be produced at the LHC.



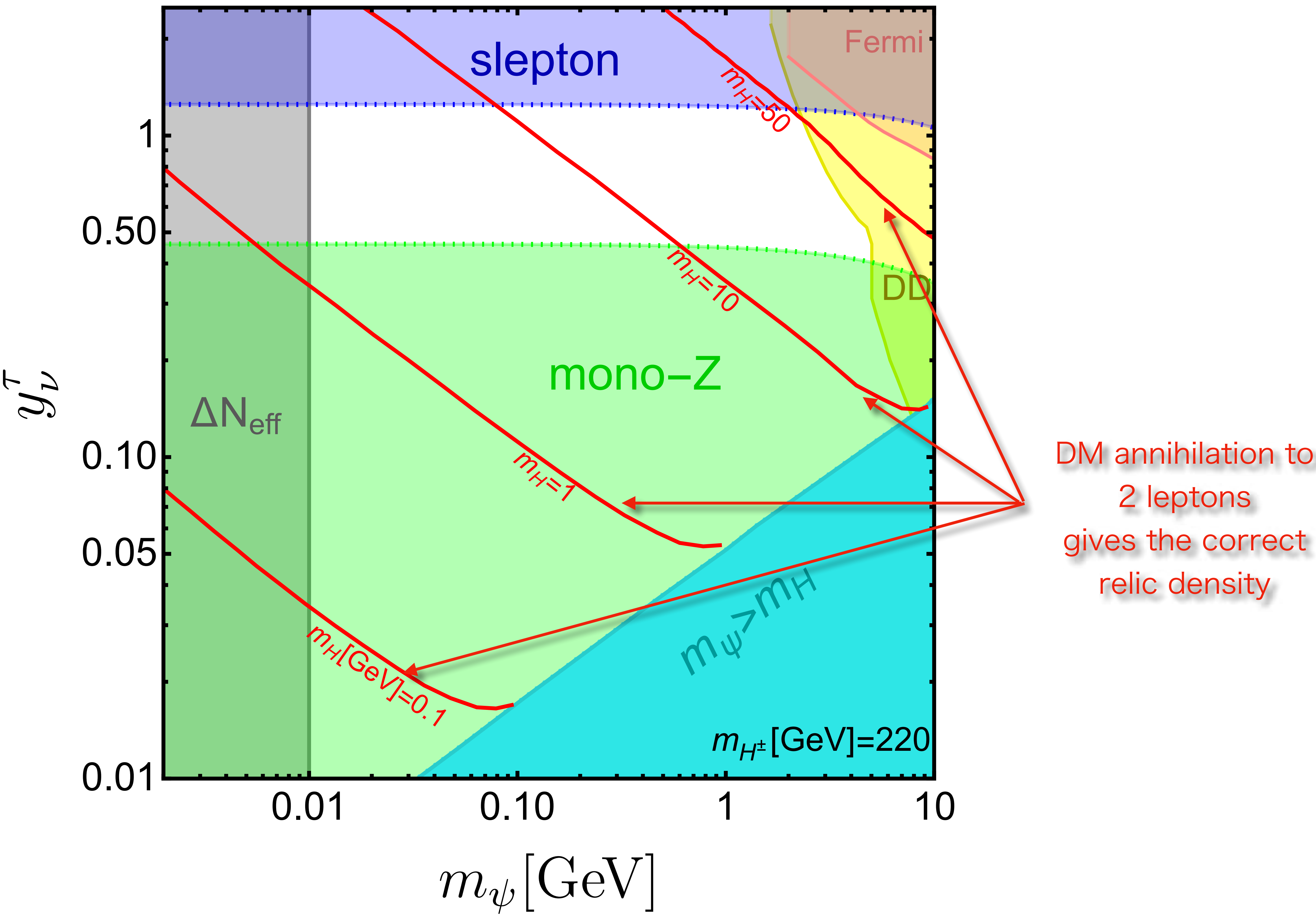


Mono-Z search is complementary to stau search.

Allowed parameter region

(DM dominantly couples to τ and ν_τ)

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



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, $h \to \gamma\gamma$ is largely deviated (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.

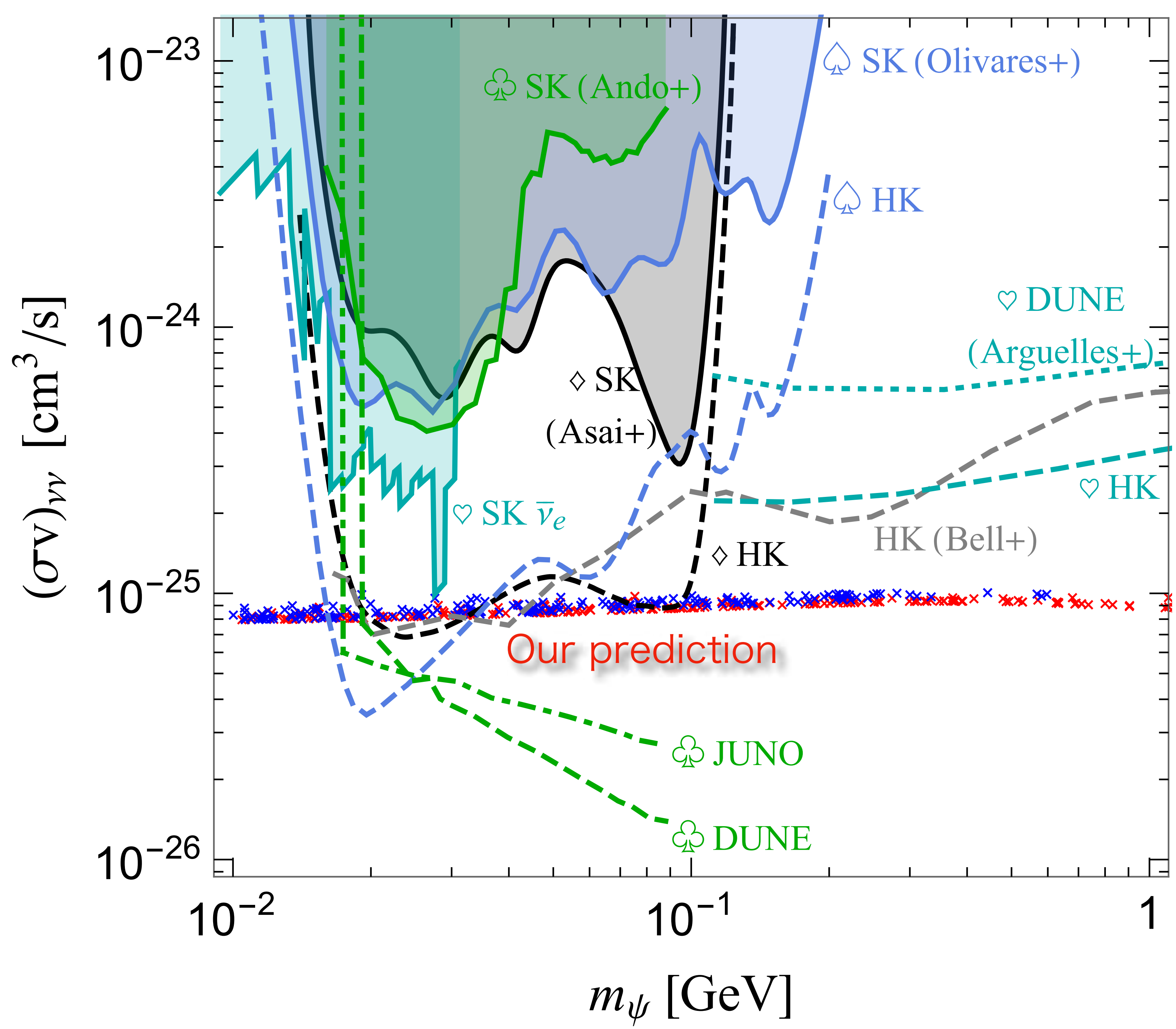
END

Backup

It is possible to test in the indirect detection.

2011.04788 with Okawa

Our DM annihilates to ν_τ



About the invisible decay of 125 GeV Higgs

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

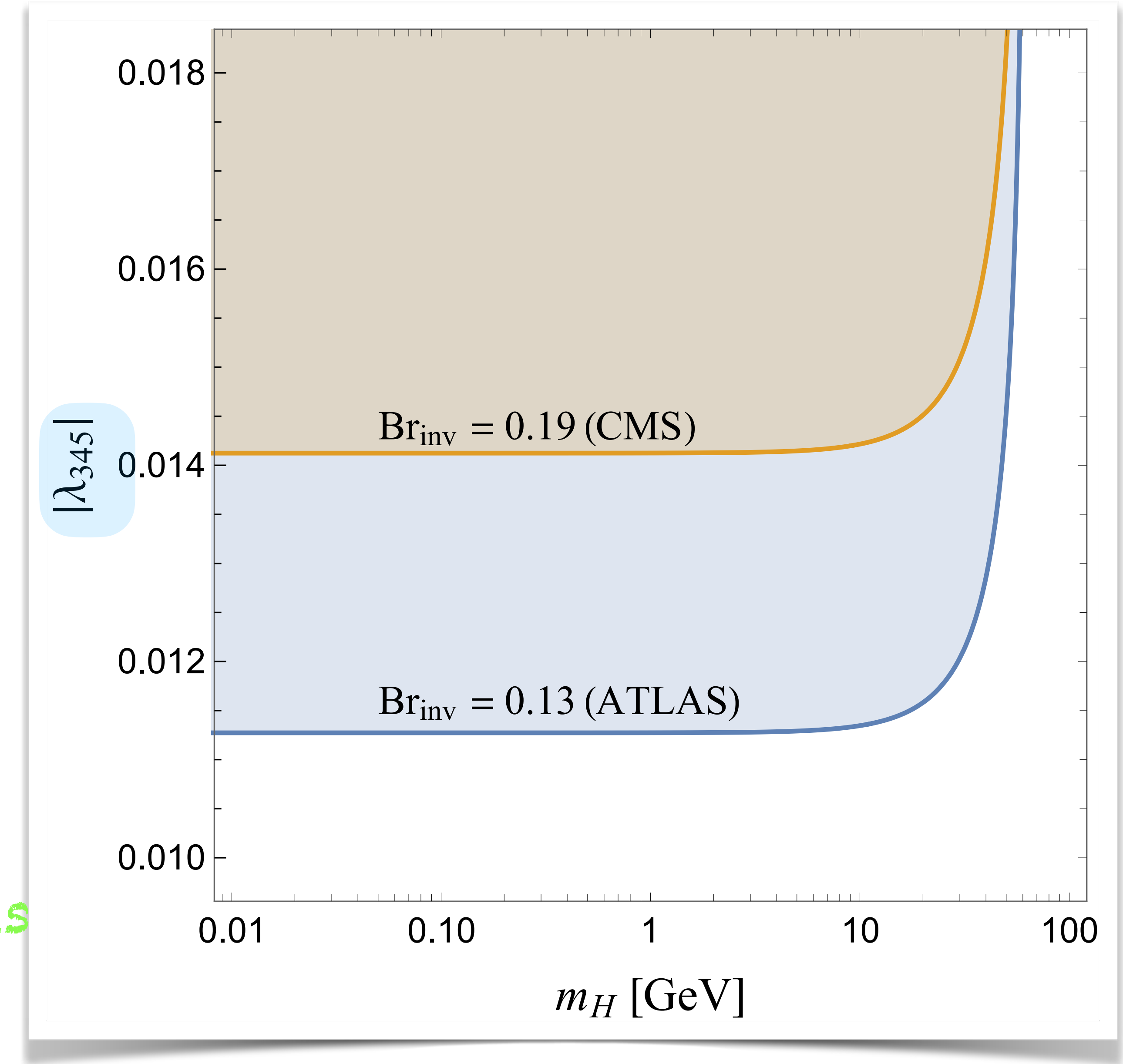
$$\frac{\lambda_{345}}{4}(2vh + h^2)H^2$$

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.



2011.04788 with Okawa

Allowed parameter region

(DM dominantly couples to μ and ν_μ)

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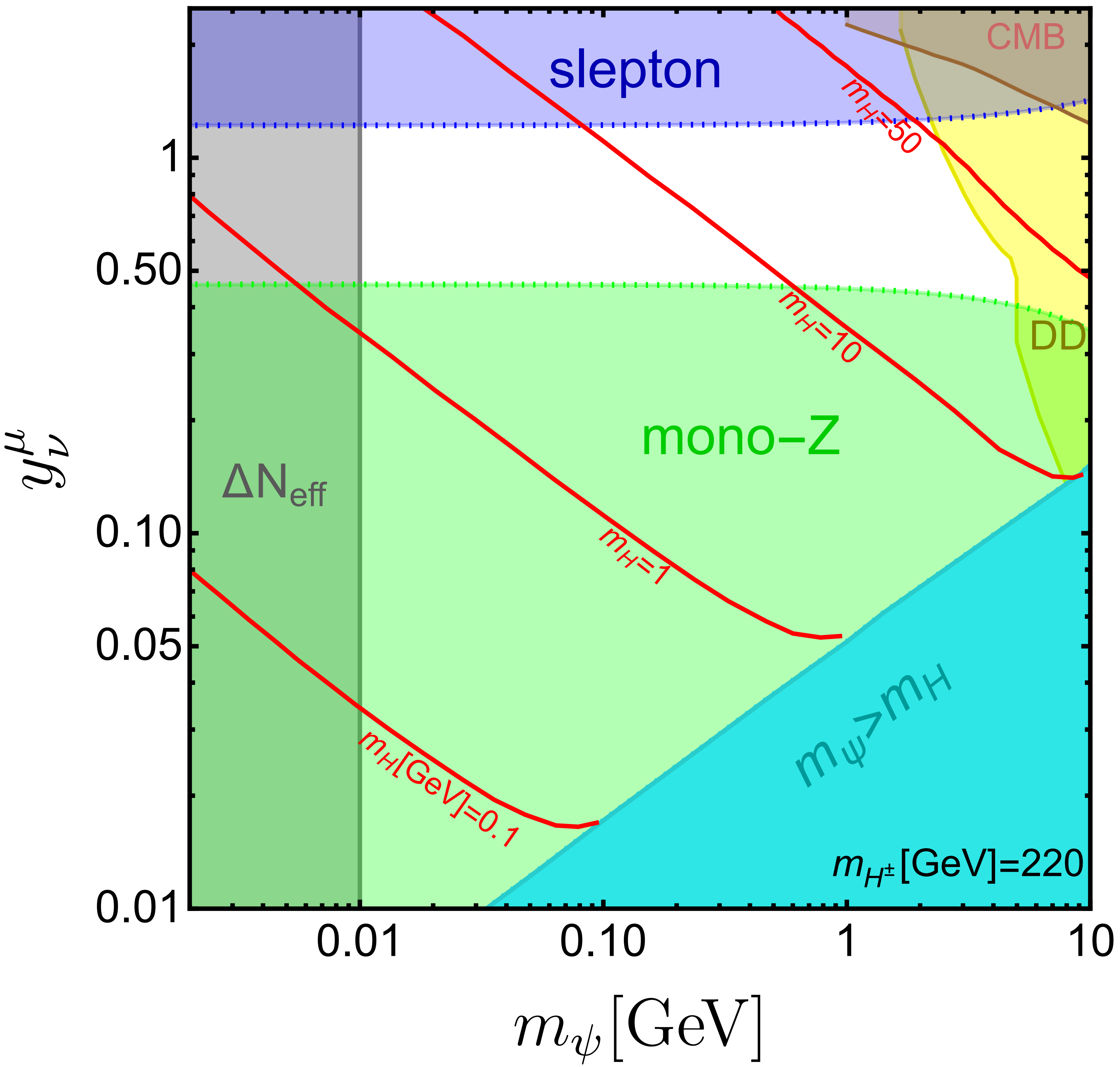
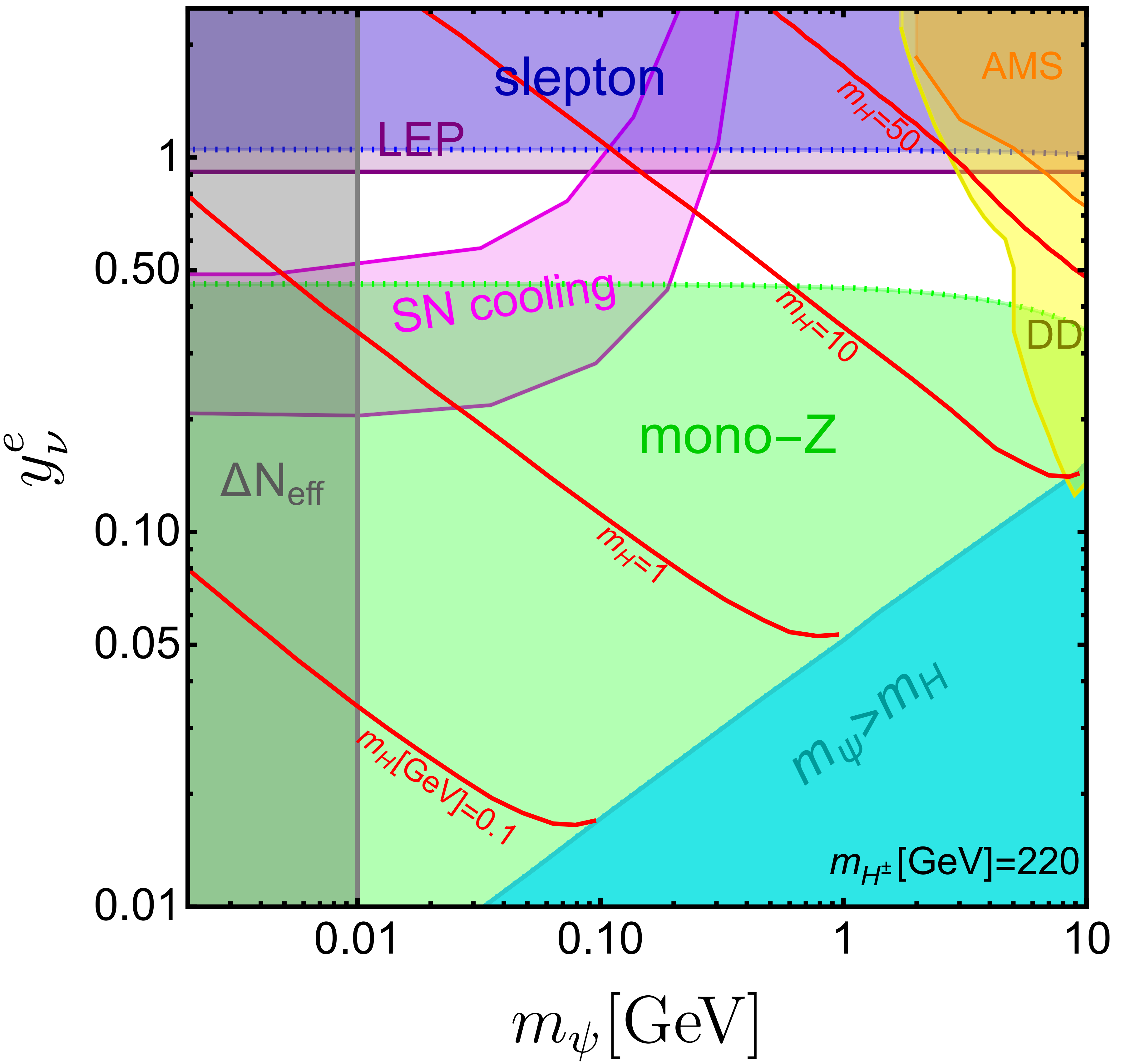


Allowed parameter region

(DM dominantly couples to e and ν_e)

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



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

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