Light mass window of lepton portal dark matter

Yuji Omura (Kindai U.)

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with S. Iguro (Karlsruhe), S. Okawa (Barcelona U.)

Motivation

We propose a dark matter (DM) model, where DM mass is below 10 GeV and DM interacts with leptons.
We study the DM physics and the sensitivity of the LHC to this model.

Lepton portal DM model

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

Relevant terms

Yukawa coupling

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

After EWSB

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

Scalar couplings

$$V = m_1^2(\Phi^\dagger\Phi) + m_2^2(\Phi_\nu^\dagger\Phi_\nu) + \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2(\Phi_\nu^\dagger\Phi_\nu)^2 + \lambda_3(\Phi^\dagger\Phi)(\Phi_\nu^\dagger\Phi_\nu) + \lambda_4(\Phi^\dagger\Phi_\nu)(\Phi_\nu^\dagger\Phi) + \frac{1}{2}\lambda_5[(\Phi^\dagger\Phi_\nu)^2 + h.c.]$$

$$\Phi = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}(v + h + iG^0)\end{pmatrix}, \quad \Phi_\nu = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA)\end{pmatrix}$$

$$m_h^2 = 2\lambda_1 v^2, \quad m_A^2 = m_{H^+}^2 + \frac{(\lambda_4 - \lambda_5)v^2}{2},$$
$$m_{H^+}^2 = m_2^2 + \frac{\lambda_3 v^2}{2}, \quad m_H^2 = m_{H^+}^2 + \frac{(\lambda_4 + \lambda_5)v^2}{2}.$$

Parameters for light DM

- light DM requires light H
- STU parameters

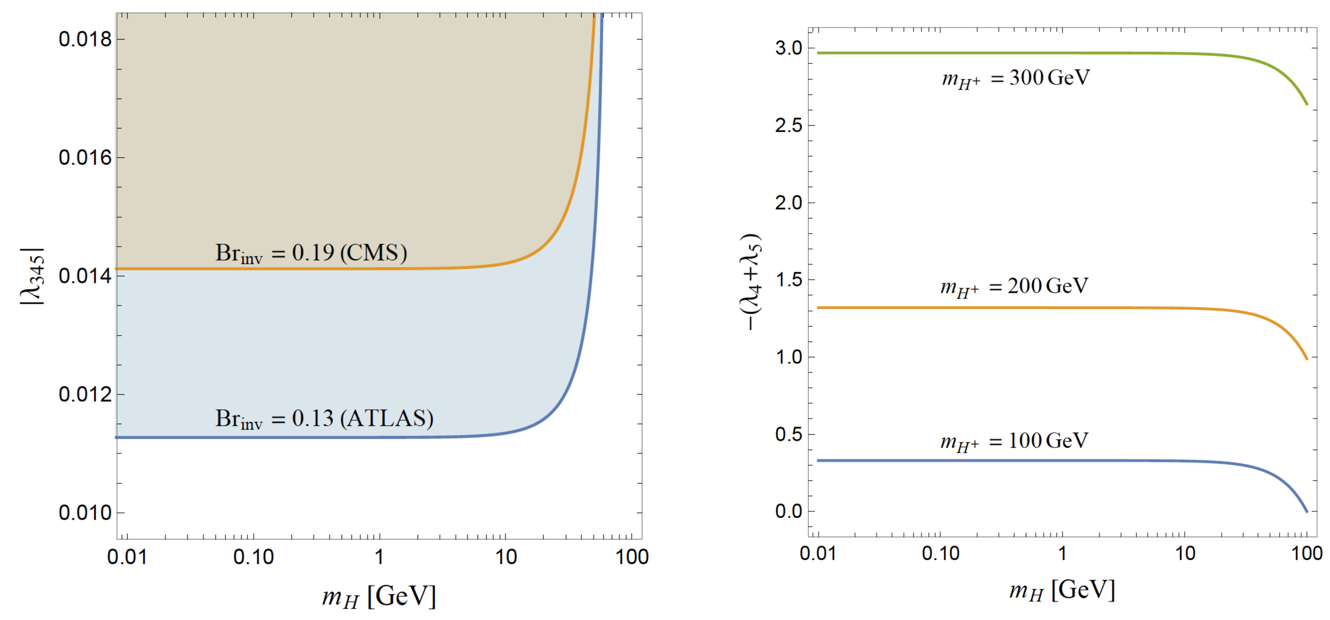
$$m_A \simeq m_{H_\pm} \gtrsim \mathcal{O}(100)\ \mathrm{GeV}$$

$$\lambda_4 \approx \lambda_5$$
$$\lambda_5 < 0, \quad |\lambda_5| = \mathcal{O}(1)$$

- invisible 125GeV Higgs decay

$$\Gamma(h \to HH) = \frac{|\lambda_{345}|^2 v^2}{32\pi m_h}\sqrt{1 - \frac{4m_H^2}{m_h^2}} \quad \text{with } \lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5.$$

large $\lambda_3 \approx -(\lambda_4 + \lambda_5)$

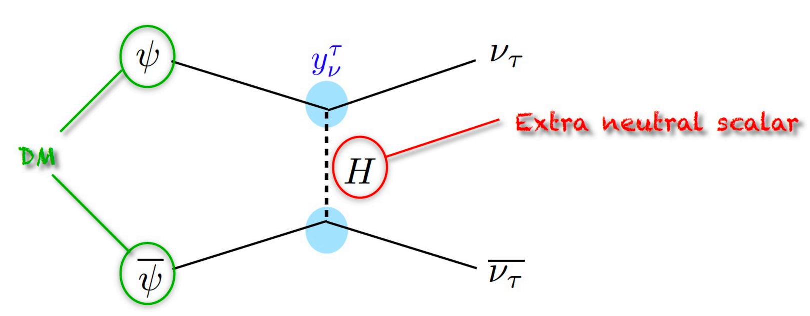


Phenomenology

- ***DM is produced thermally.***

Assuming DM dominantly couples to τ and ντ,

if DM is lighter than τ, DM annihilates to ν

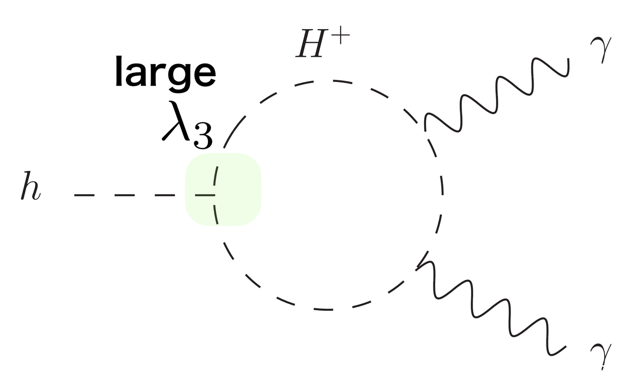


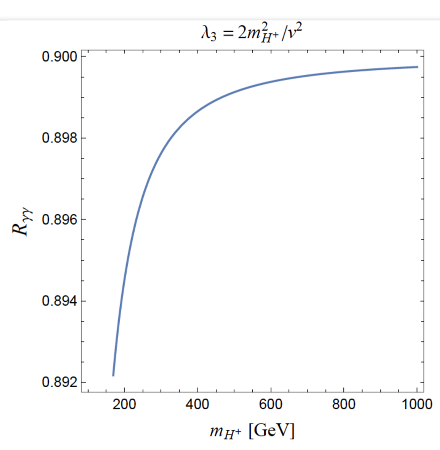
$$(\sigma v_{\rm rel})_{\psi\bar\psi \to \nu\bar\nu} \simeq \frac{y_\nu^4 m_\psi^2}{128\pi(m_\psi^2 + m_H^2 - m_\nu^2)^2}\sqrt{1 - \frac{m_\nu^2}{m_\psi^2}}$$

Light DM requires a light neutral scalar

- ***h→γγ is deviated from the SM because of large λ3.***

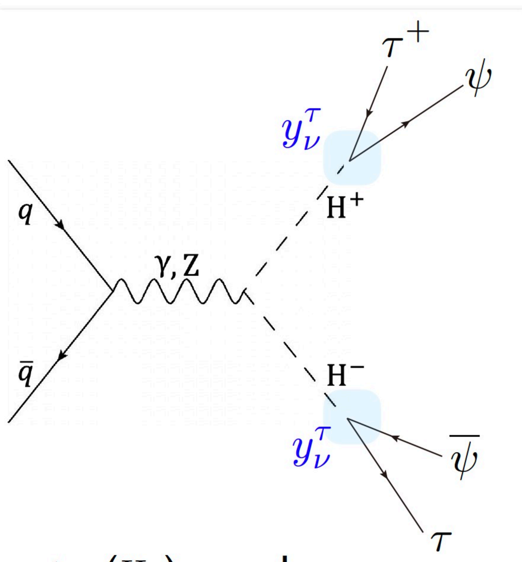
Deviation from the SM is about 10%.



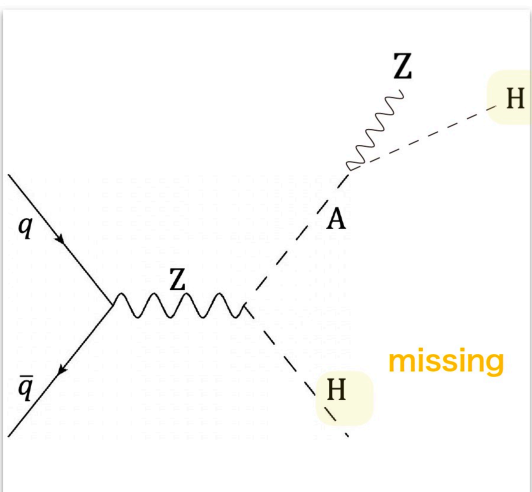


- ***The signals at the LHC***

The extra scalars can be produced at the LHC.



stau($H_\pm$) search



mono-Z

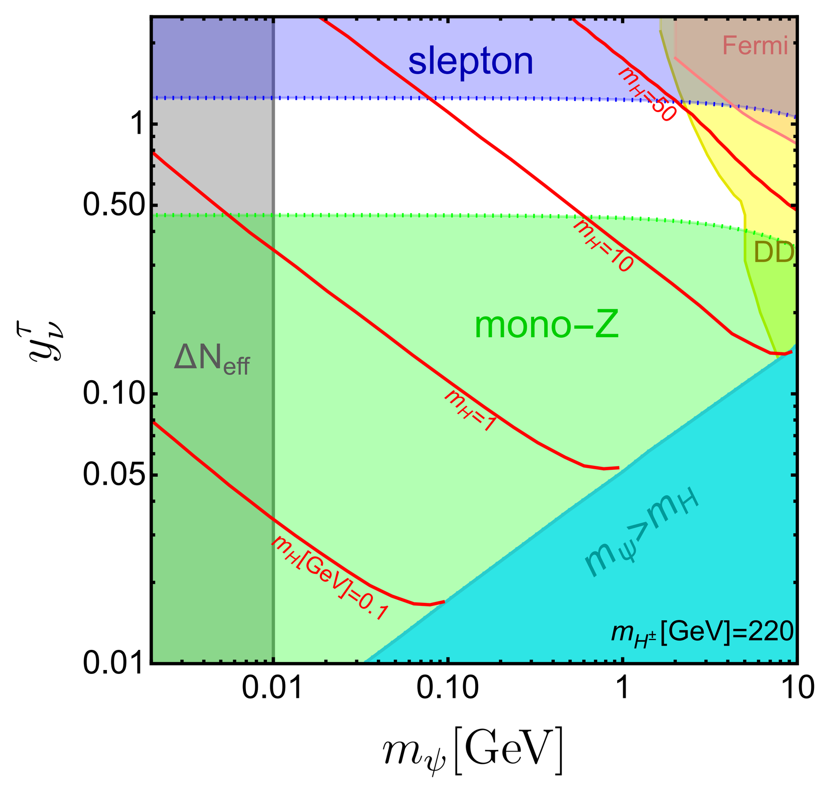
Mono-Z search is complementary to stau search.

Results

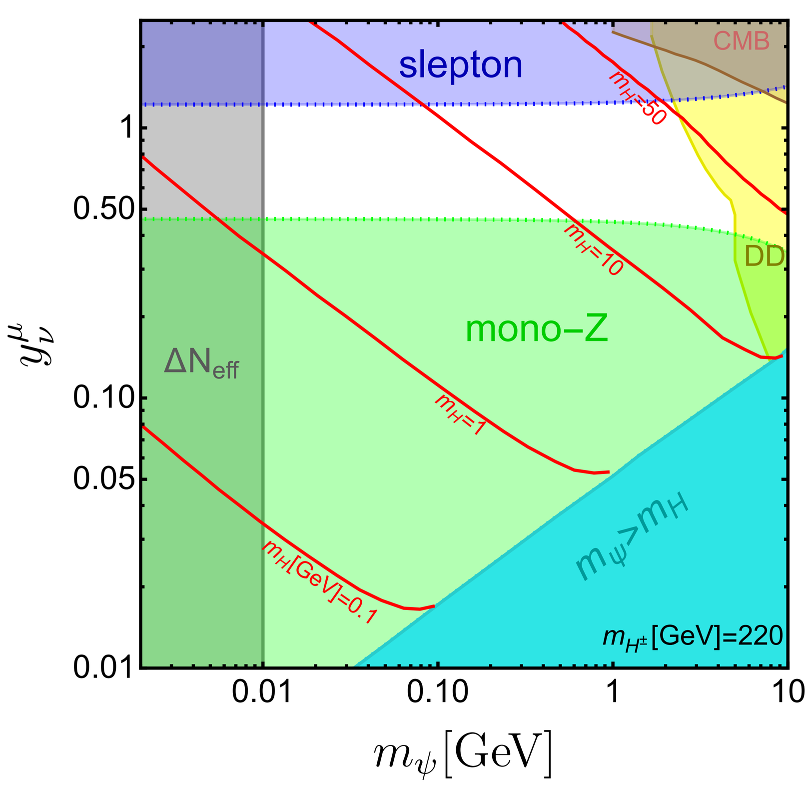
(i) τ-philic ($|y_\nu^\tau| \gg |y_\nu^{e,\mu}|$)

On the red lines, DM annihilations to 2 leptons give the correct density when m_H =0.1, 1, 10, 50 GeV.

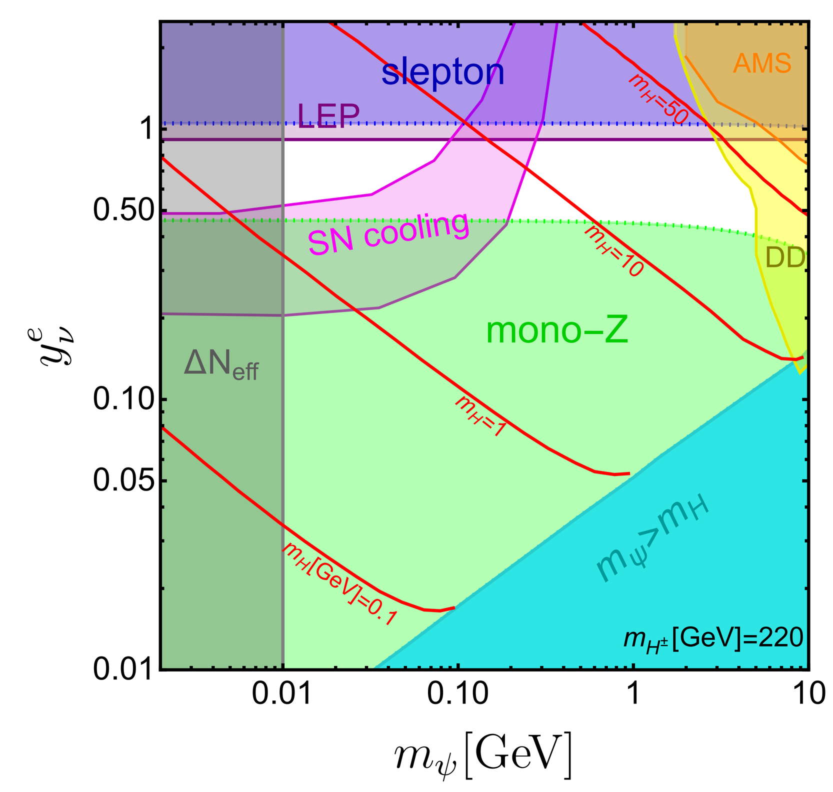
The colored regions are excluded by the direct detection (DD), the LHC searches, Neff and so on.



(ii) μ-philic ($|y_\nu^\mu| \gg |y_\nu^{e,\tau}|$)



(iii) e-philic ($|y_\nu^e| \gg |y_\nu^{\mu,\tau}|$)



Summary

- DM can be lighter than 10 GeV, if DMs annihilate to 2 neutrinos. The light DM can evade the strong bounds from the direct search.
- The mono-Z search at the LHC is complementary to the stau search.
- Large couplings lead Landau poles.
  → Introducing a singlet scalar can relax this bound (2208.05487).