Invisible decay of a Higgs boson and dark matter

Osamu Seto

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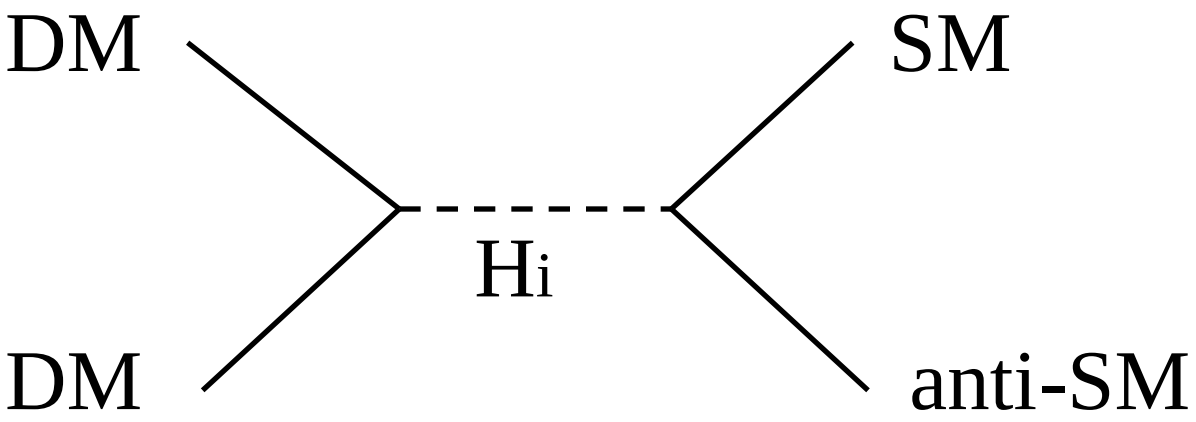
in prep.

§ Introduction

- Invisible decay of the SM-like Higgs boson is one typical collider signature of Higgs portal dark matter (HPDM).

§ Higgs portal dark matter

- A class of WIMP
- Annihilation is dominantly s-channel Higgs boson(s) exchange.



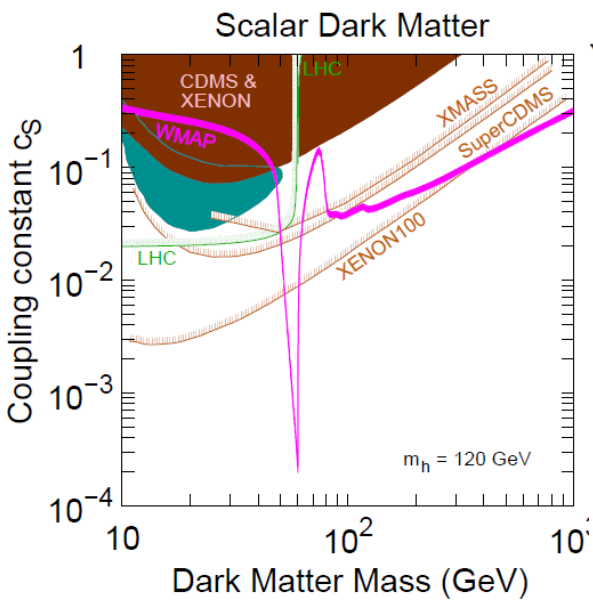
§ Higgs portal dark matter

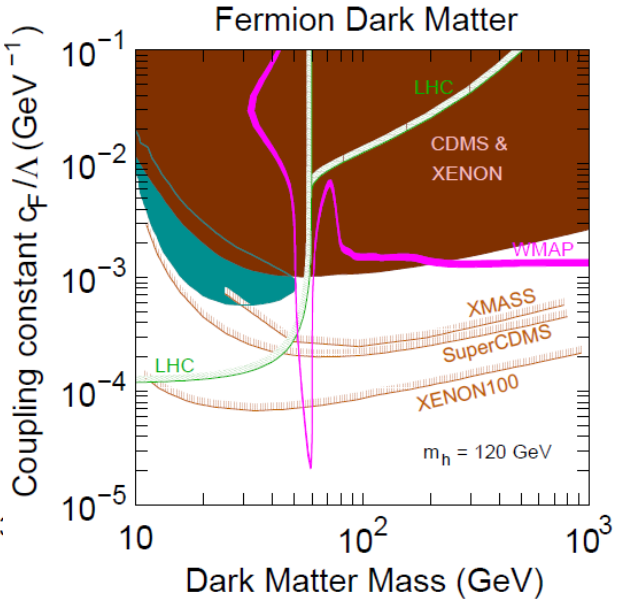
McDonald (1994),Burgess et al, ... [Kanemura et al (2010)]

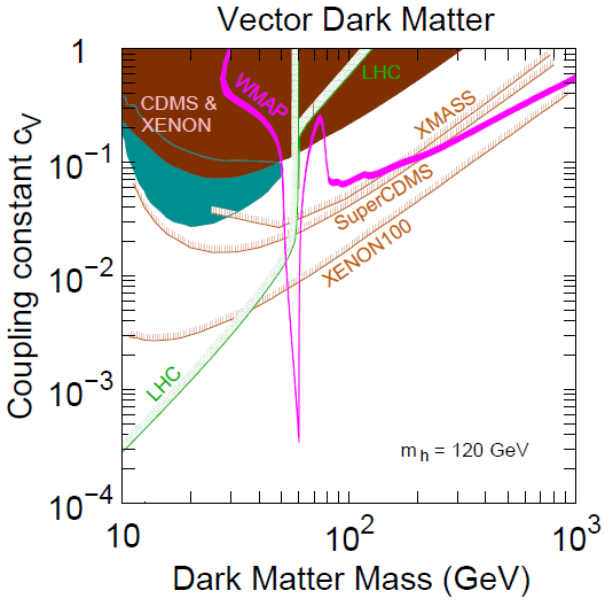
$$\mathcal{L}_S = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial\phi)^2 - \frac{M_S^2}{2}\phi^2 - \frac{c_S}{2}|H|^2\phi^2 - \frac{d_S}{4!}\phi^4,$$

$$\mathcal{L}_F = \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{\chi}\left(i\partial\!\!\!/ - M_F\right)\chi - \frac{c_F}{2\Lambda}|H|^2\bar{\chi}\chi - \frac{d_F}{2\Lambda}\bar{\chi}\sigma^{\mu\nu}\chi B_{\mu\nu},$$

$$\mathcal{L}_V = \mathcal{L}_{\rm SM} - \frac{1}{4}V^{\mu\nu}V_{\mu\nu} + \frac{M_V^2}{2}V_\mu V^\mu + \frac{c_V}{2}|H|^2 V_\mu V^\mu - \frac{d_V}{4!}(V_\mu V^\mu)^2,$$

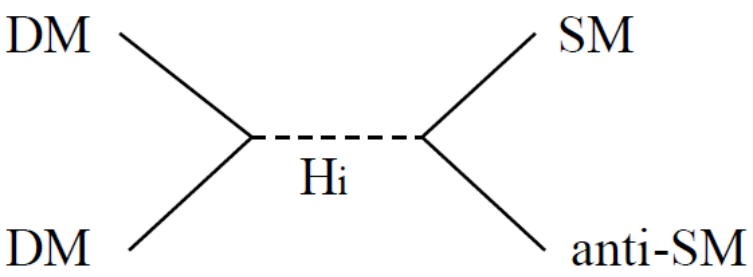


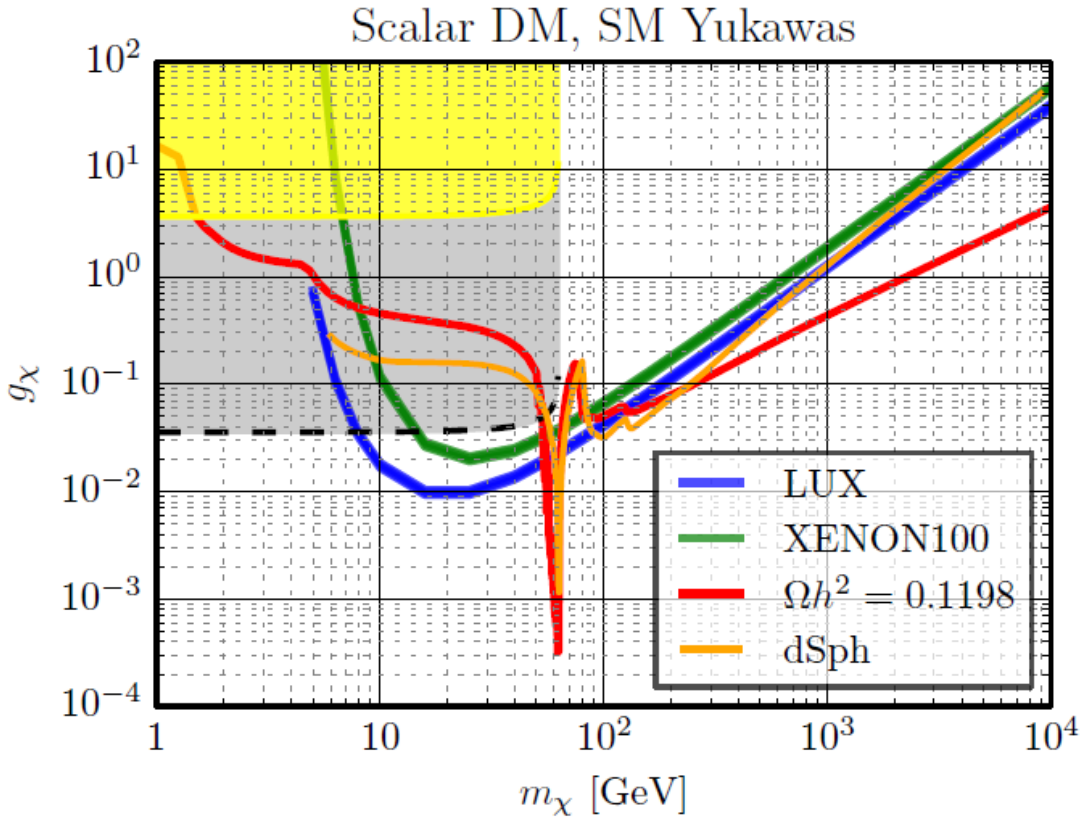




§ Higgs portal dark matter

McDonald (1994),Burgess et al, ...

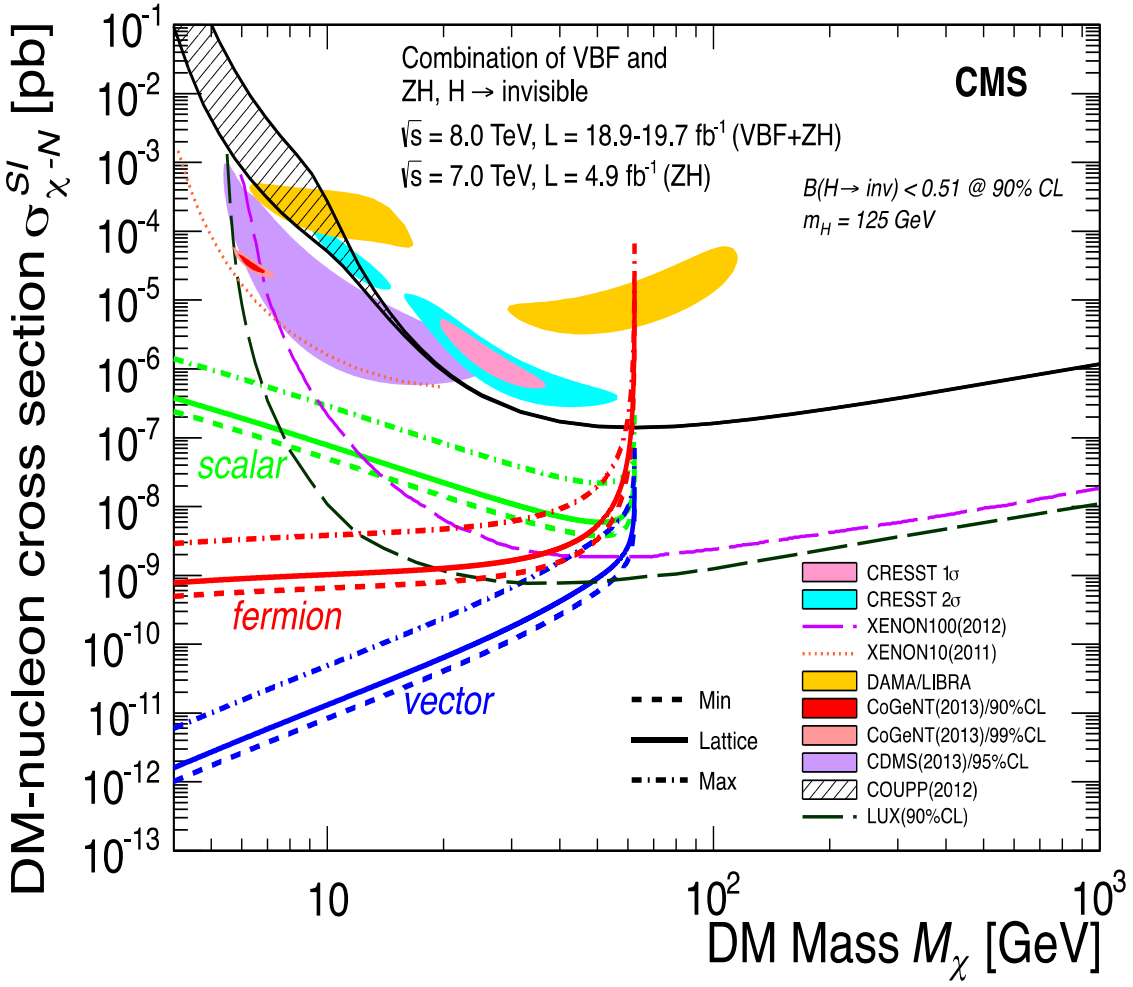




[Bishara et al 1504.04022]

§ Higgs portal dark matter

Collider constraints [CMS (2014)] (similar at ATLAS)



Invisible decay of a Higgs boson and dark matter

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[Meta title]

Invisible decay of a Higgs boson and dark matter

[Actual title]

When a Higgs boson invisible decay is measured, does it indicate Higgs portal dark matter?

§ Higgs boson invisible decay

- In the SM, $h \rightarrow Z^*Z^* \rightarrow 4\nu$
- BSM, e.g.,

  $h \rightarrow 2\,\chi$ in SUSY [Griest and Haber (1988)]

  $h \rightarrow 2$ Majoron [Joshipura and Rindani (1992)]

  $h \rightarrow 2$ graviscalar in ADD [Giudice et al (2001)]

  $h \rightarrow 2\ 4^{th}\nu$ [Belotsky et al (2003)]

  $h \rightarrow 2$ DM in HPDM [Bento et al (2000)]

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  $h \rightarrow 4\nu$ in THDM

§ Higgs boson invisible decay in neutrinophilic THDM

§ § Concept of neutrinophilic Higgs

- If neutrino mass is given by $m_\nu = y_\nu v_\nu$

v_ν ↓ y_ν ↑

- If neutrino mass is given by $\frac{y^\nu_{ik} v_\nu y^{\nu T}_{kj} v_\nu}{M_k}$, the smallness is at least partially due to smallness of Higgs VEV

v_ν ↓ y^ν ↑ and/or M_k ↓

§ § Neutrinophilic Higgs doublet models [Ma (2001), Gabriel and Nandi (2006),…]

- Yukawa couplings

$$\mathcal{L}_Y = -y_{\ell_\alpha}\overline{L}_\alpha\Phi_1\ell_{R_\alpha} - y_{u_\alpha}\overline{Q}_\alpha\tilde{\Phi}_1 u_{R_\alpha} - y_{d_\alpha}\overline{Q}_\alpha\Phi_1 d_{R_\alpha} - y_{\alpha i}\overline{L_\alpha}\tilde{\Phi}_2\nu_{R_i}$$

- Dirac or Majorana

$$\mathcal{L}_M = -\frac{1}{2}\overline{\nu^c_{R_i}}M_i\nu_{R_i}$$

- Higgs potential

$$\begin{aligned} V &= \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 - (\mu_{12}^2\Phi_1^\dagger\Phi_2 + \text{H.c.}) \\ &\quad +\lambda_1|\Phi_1|^4 + \lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \left\{\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)^2 + \text{H.c.}\right\} \end{aligned}$$

§§ Neutrinophilic Higgs doublet models [Ma (2001), Gabriel and Nandi (2006),…]

- Yukawa couplings

$$\mathcal{L}_Y \supset -\frac{y_{\alpha i}}{\sqrt{2}}\overline{\nu_\alpha} H P_R \nu_i + i\frac{y_{\alpha i}}{\sqrt{2}}\overline{\nu_\alpha} A P_R \nu_i + y_{\alpha i}\overline{\ell_\alpha} H^- P_R \nu_i$$

- Higgs boson decay

$h \to HH / AA \to \nu\,\nu\,\nu\,\nu$ **Invisible!!**

- If H or A is on-shell, Br($h \to$ inv) can be large.

§ § Invisible decay

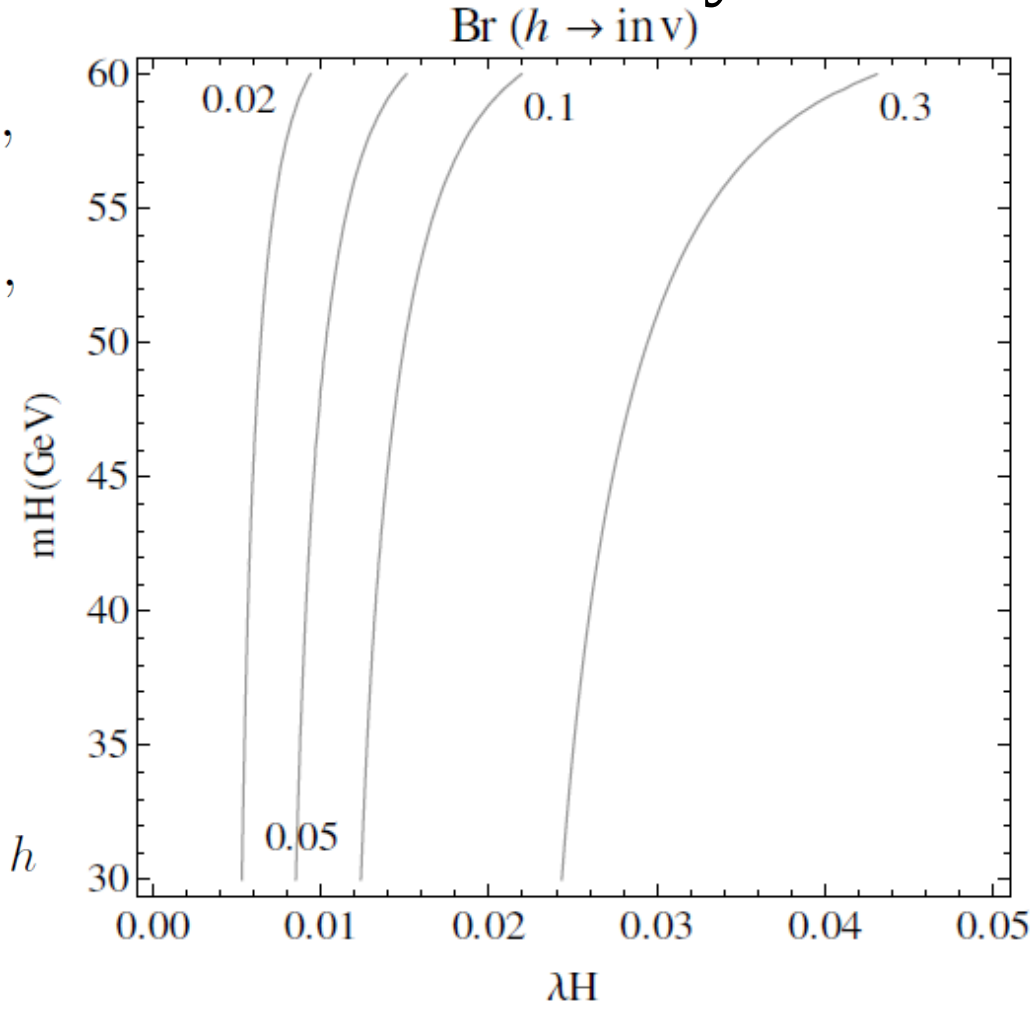
- Higgs bosons masses

$$m_H^2 = \mu_2^2 + \frac{\lambda_3+\lambda_4+\lambda_5}{2}v^2,$$
$$m_A^2 = \mu_2^2 + \frac{\lambda_3+\lambda_4-\lambda_5}{2}v^2,$$
$$m_{H^\pm}^2 = \mu_2^2 + \frac{\lambda_3}{2}v^2.$$

- Couplings

$$\mathcal{L} \supset -v\left(\frac{1}{2}(\lambda_3+\lambda_4-\lambda_5)A^2 + \frac{1}{2}(\lambda_3+\lambda_4+\lambda_5)H^2 + \lambda_3|H^+|^2\right)h$$

- Invisible decay of *h*



§ § Invisible decay

- Higgs bosons masses

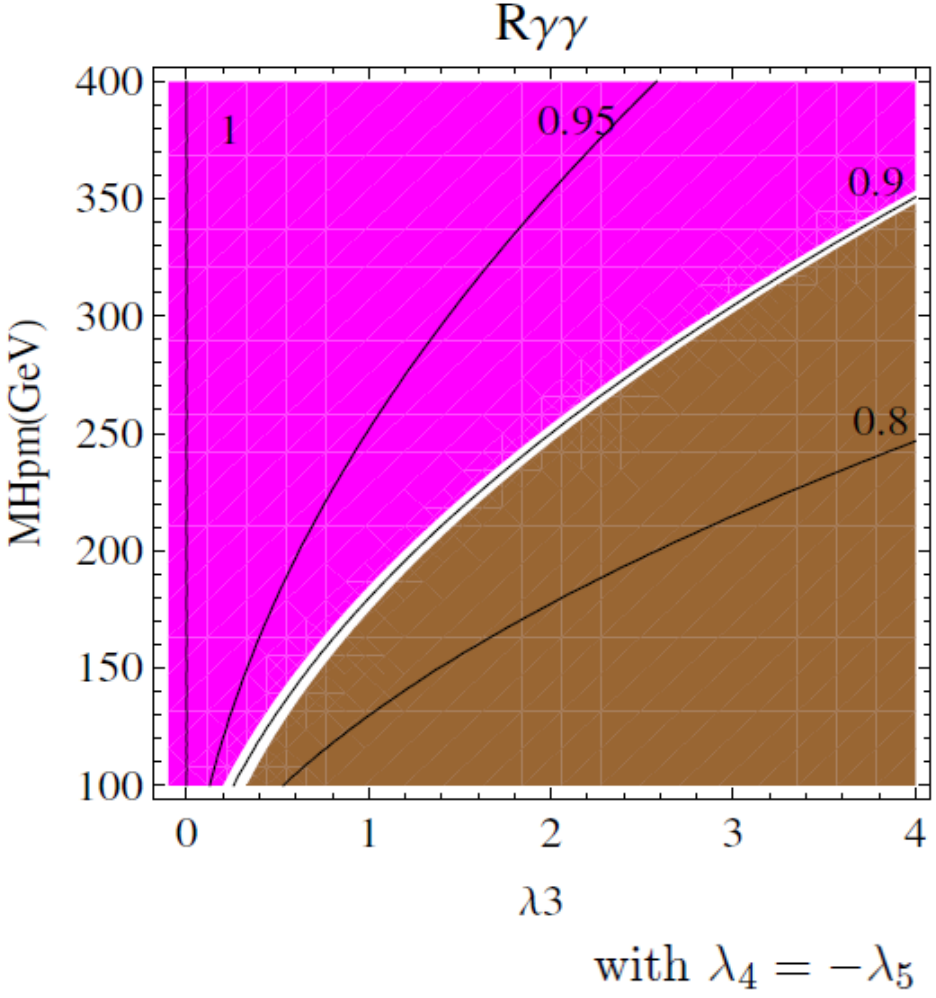
$$m_H^2 = \mu_2^2 + \frac{\lambda_3+\lambda_4+\lambda_5}{2}v^2,$$
$$m_A^2 = \mu_2^2 + \frac{\lambda_3+\lambda_4-\lambda_5}{2}v^2,$$
$$m_{H^\pm}^2 = \mu_2^2 + \frac{\lambda_3}{2}v^2.$$

- Strength

1.17 +0.27 [ATLAS (2014)]

1.14 +0.26/-0.23 [CMS (2014)]

- Mass and couplings

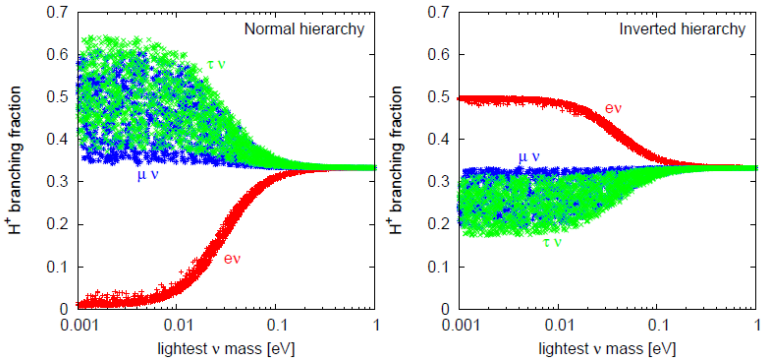


§§ Constraints on H+

- Similar to slepton for Dirac neutrino

$m_{\tilde{l}} \gtrsim$ 300GeV[ATLAS(2014)]

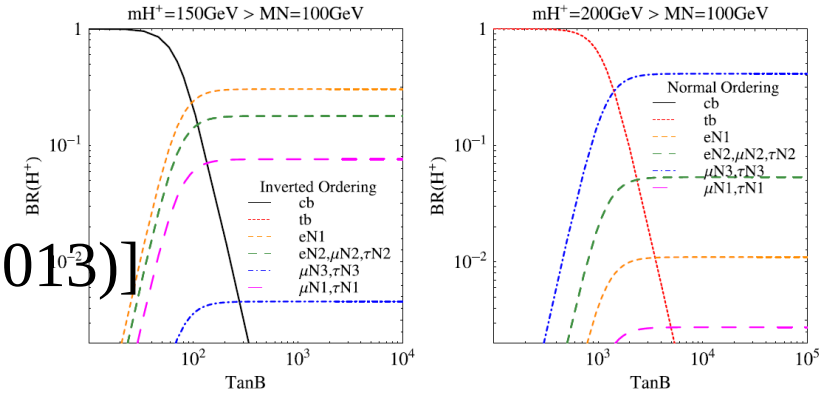
260GeV[CMS(2014)]



[Davidson and Logan (2009)]

- For Majorana neutrino
- ν mass → $y \lesssim \mathcal{O}(10^{-5})$

H+→cs, 90-150GeV[ATLAS(2013)]



[Haba and Tsumura (2011)]

§ § More on Majorana case

1. For $m_{N_R} > m_{H/A}$

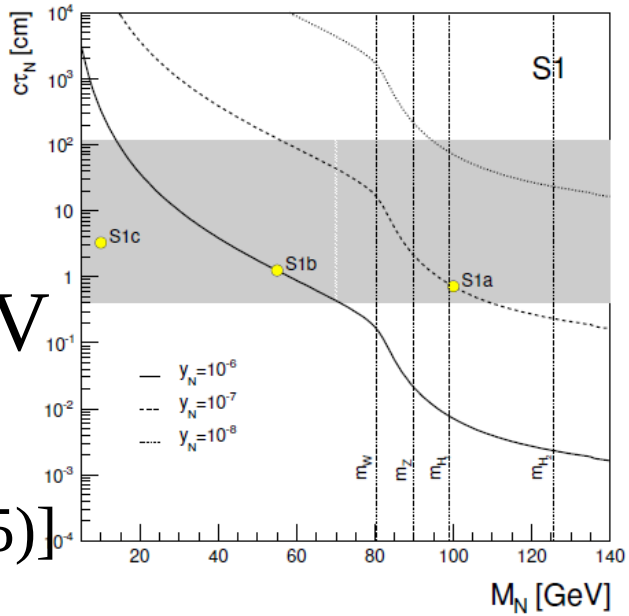
$$H/A \longrightarrow \nu\bar{\nu}$$

2. For $m_{N_R} < m_{H/A}$

- Displaced vertex of N_R decay

$$N_R \longrightarrow Z^*\nu, h^*\nu\ , W^*\ell$$

$c\tau \gtrsim 1$ cm for $m_{NR} = \mathcal{O}(10)$ GeV



[Cerdeno et al (2015)]

§ Summary

- If Br($h \to$ inv) $\gtrsim \mathcal{O}(0.01)$ is measured, decay final states would be DM, ν or more exotics.

- A Higgs invisible decay may and may not be due to DM.

- Simple THDM offers a ``may not'' example.
- Even when Br($h \to$ inv) $\gtrsim \mathcal{O}(0.01)$, we can consider, e.g., axion DM.