Leptophilic DM model for LFV Higgs decay

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based on

SB, Zhaofeng Kang, arXiv:1510.00100

Outline

- LFV Higgs decay $h \to \tau\mu$
- Leptophilic model
- $h \to \tau\mu$
- $\tau \to \mu\gamma$, $h \to \gamma\gamma$ constraints,
  relic density and direct detection of DM
- Conclusions

LFV Higgs decay

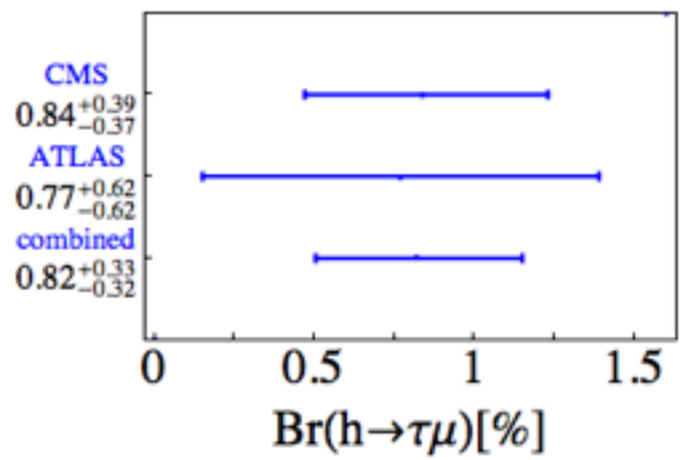
- Discovery of 125 GeV Higgs

- Measurement of Higgs couplings to the SM particles

- LF is accidental symmetry in the minimal SM. Neutrino oscillation experiments show it is broken. Although LFV Higgs decay is allowed in the SM, this loop-induced process is highly suppressed by the neutrino mass.

- Measurement of LFV Higgs decay → New Physics

LFV Higgs decay



- CMS reports 2.4σ excess from the SM, using $19.7 fb^{-1}$ at

  $\sqrt{s} = 8$ TeV, CMS cn, arXiv:1502.07400

  $$\mathcal{B}(h \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$$

- ATLAS result with similar dataset is consistent with CMS

  $$\mathcal{B}(h \to \mu\tau) = (0.77 \pm 0.62)\%,$$ ATLAS cn, arXiv:1508.03372

- LHC Run II can probe down to $\sim 10^{-3}$

Leptophilic DM

- N(1,1,0,-): Majorana fermion which we assume DM candidate

- φ_l(1,2,-1/2,-), φ_e(1,1,-1,-): Scalar doublets, and singlet

$$
\begin{aligned}
-\mathcal{L} = & -\mathcal{L}_{\rm SM} + m_{\phi_l}^2|\phi_\ell|^2 + m_{\phi_e}^2|\phi_e|^2 + \frac{1}{2}M\overline{N}N \\
& + \left(-y_{La}\bar{l}_a P_R N\widetilde{\phi}_\ell + y_{Ra}\bar{e}_a P_L N\phi_e + h.c.\right) \\
& + \left(-\mu\, H^\dagger\widetilde{\phi}_\ell\phi_e^* + h.c.\right) + \lambda_{-1}|\phi_e|^2|\phi_\ell|^2 + \lambda_0|H|^2|\phi_e|^2 + V_{\rm 2HDM},
\end{aligned}
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leptophilic DM portal

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leptophilic DM portal

H→τμ

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Neutrino masses

- The model has all the ingredients for radiative neutrino mass generation a la Ma model

$$m_\nu \sim \lambda_5 \frac{y_{La}^2}{16\pi^2} \left(\frac{v}{m_{\phi_\ell}} \right)^2 M.$$

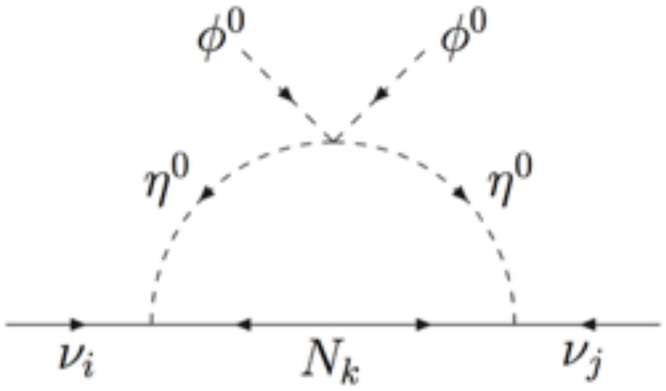


FIG. 5: One-loop scotogenic neutrino mass.

Ma, 0905.0221

Mass spectrum

- Charged scalars

  mixing between φ_l, φ_e after ew symmetry breaking

$$\phi_\ell \;=\; (\phi_\ell^+, (\phi_R + i\phi_I)/\sqrt{2})^T$$

$$\widetilde{e}_1 = \cos\theta(\phi_\ell^+)^* - \sin\theta\,\phi_e, \quad \widetilde{e}_2 = \sin\theta(\phi_\ell^+)^* + \cos\theta\,\phi_e,$$

$$m^2_{\widetilde{e}_{1,2}} = \frac{1}{2}\left[\left(m^2_{\phi_\ell} + m^2_{\phi_e}\right) \mp \sqrt{\left(m^2_{\phi_\ell} - m^2_{\phi_e}\right)^2 + 2\mu^2 v^2}\right]$$

- Neutral scalars

$$m^2_{\phi_R} \approx m^2_{\phi_\ell} + (\lambda_4 + \lambda_5)\,v^2/2, \quad m^2_{\phi_I} \approx m^2_{\phi_\ell} + (\lambda_4 - \lambda_5)\,v^2/2.$$

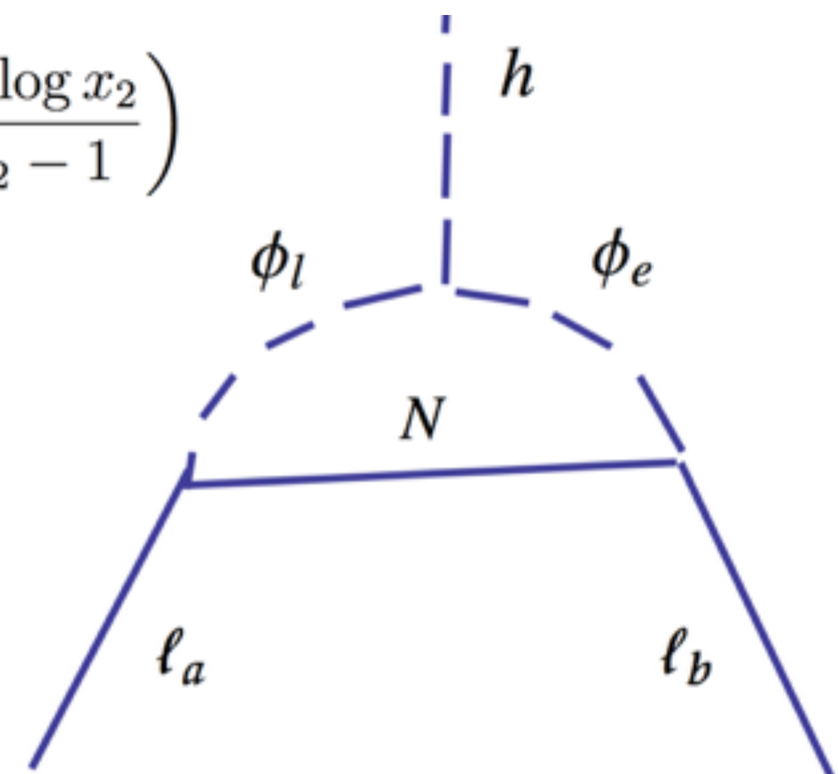
LFV Higgs decay, H→τμ

$$i\mathcal{M} = +i\bar{u}_b\left(F_L P_L + F_R P_R\right) v_a$$

$$F_L = \simeq \frac{1}{16\pi^2}\frac{\mu}{\sqrt{2}M} y_{Rb} y^*_{La}\left[\frac{1}{2}\sin^2 2\theta\left(G(x_1)+G(x_2)\right)+\cos^2 2\theta\, G(x_1,x_2)\right]$$

$$x_i \equiv m^2_{\tilde{e}_i}/M^2 \qquad G(x_1,x_2) \equiv \frac{1}{x_1-x_2}\left(\frac{x_1\log x_1}{x_1-1}-\frac{x_2\log x_2}{x_2-1}\right)$$

$$\Gamma(h\to\bar{\ell}_a\ell_b) = \frac{m_h}{16\pi}\left(|F_L|^2+|F_R|^2\right)$$



Large μ can enhance the LFV H decay both in the decoupling regime (eg. $\varphi_l \ll \varphi_e$ and $\theta \ll 1$) or in the large mixing regime ($\theta \approx \pi/4$)

LFV Higgs decay, H→τμ

- Decoupling limit

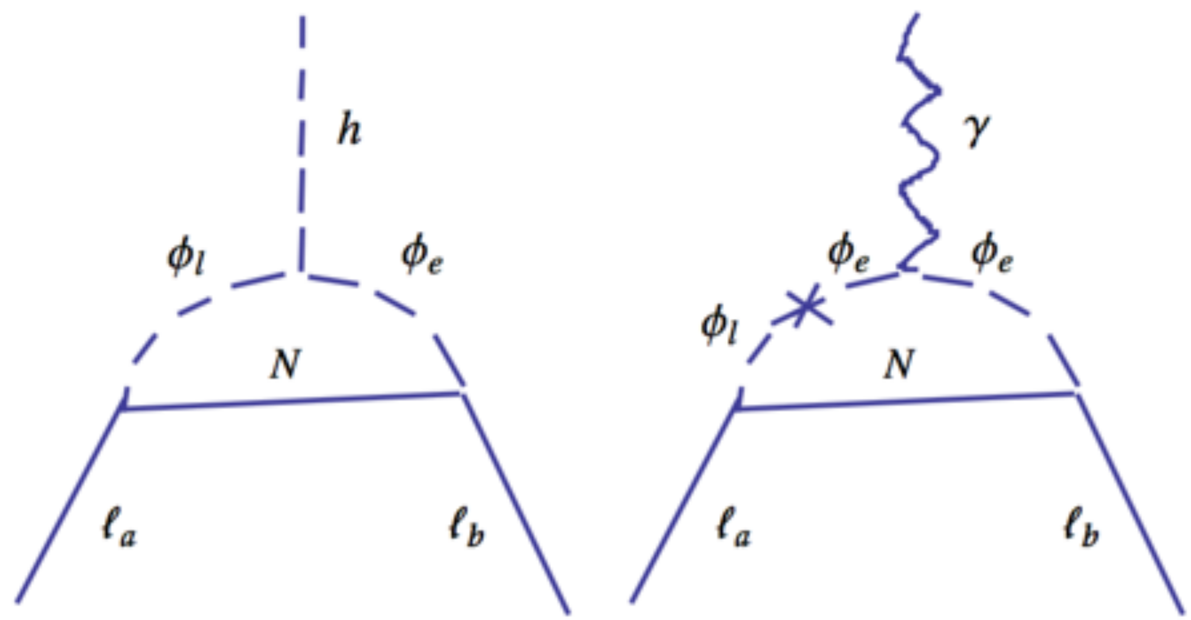
$$\mathrm{Br}(h \to \bar{\tau}\mu) = 1.2 \times 10^{-2} \left(\frac{\mu}{5\mathrm{TeV}}\right)^2 \left(\frac{1\mathrm{TeV}}{M}\right)^2 \left(\frac{G(x_1, x_2)}{0.2}\right)^2 \left(\frac{|y_{R\tau} y^*_{L\mu}|}{1}\right)^2$$

- Maximal mixing

$$\mathrm{Br}(h \to \bar{\tau}\mu) = 1.2 \times 10^{-2} \left(\frac{\mu}{10\mathrm{TeV}}\right)^2 \left(\frac{1\mathrm{TeV}}{M}\right)^2 \left(\frac{G(x_1) + G(x_2)}{0.4}\right)^2 \left(\frac{|y_{R\tau} y^*_{L\mu}|}{0.5}\right)^2$$

$\tau \to \mu\gamma$ constraint

- Generally very stringent in models with large $H \to \tau\mu$



- We can evade the $\tau \to \mu\gamma$ constraint in the decoupling regime without fine-tuning

$\tau \to \mu\gamma$ constraint

- $B(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

$$\mathcal{H}_{\rm eff} = C_L \overline{\mu_L} \sigma^{\mu\nu} \tau_R F_{\mu\nu} + C_R \overline{\mu_R} \sigma^{\mu\nu} \tau_L F_{\mu\nu}.$$

$$C_L = \frac{e}{32\pi^2 M} y_{L\mu} y^*_{R\tau} s_\theta c_\theta \left(F_2(x_1) - F_2(x_2)\right)$$

$$F_2(x) = \frac{-1 + x^2 - 2x \log x}{2x(1-x)^2}$$

- $\tau \to \mu\gamma$ is easily suppressed in the decoupling regime, $C_L \to 0$ if $\theta \to 0$.

- Fine-tuning is required in the maximal mixing case

h→γγ constraint

$$\mathcal{L}_{\rm eff} = c_\gamma \frac{\alpha}{\pi v} h F_{\mu\nu} F^{\mu\nu}$$

$$r_\gamma = r_{{\rm SM},\gamma} + \delta r_\gamma \approx -0.81 + \frac{1}{24}\frac{v\mu \sin 2\theta}{2m_{\tilde{e}_1}^2}$$

$$-0.05 \lesssim \delta r_\gamma / r_{{\rm SM},\gamma} \lesssim 0.20, \quad -2.20 \lesssim \delta r_\gamma / r_{{\rm SM},\gamma} \lesssim -1.95 \qquad \text{at 68.3\% C.L.}$$

$$-2.8 \times \left(\frac{m_{\tilde{e}_1}}{300{\rm GeV}}\right)^2 {\rm TeV} \lesssim \mu \sin 2\theta \lesssim 0.7 \times \left(\frac{m_{\tilde{e}_1}}{300{\rm GeV}}\right)^2 {\rm TeV},$$

$$28 \times \left(\frac{m_{\tilde{e}_1}}{300{\rm GeV}}\right)^2 {\rm TeV} \lesssim \mu \sin 2\theta \lesssim 31 \times \left(\frac{m_{\tilde{e}_1}}{300{\rm GeV}}\right)^2 {\rm TeV},$$

Relic density of DM

- The relic density is achieved by the annihilation of DM, N, into lepton pair via t-channel slepton exchange.

$$\sigma v_r \approx a + b v_r^2 \qquad \Omega h^2 \approx \frac{0.88 \times 10^{-10} x_f \mathrm{GeV}^{-2}}{g_*^{1/2}(a + 3b/x_f)}$$

$$a = \frac{1}{16\pi M^2}\frac{1}{(1+x_i)^2}\left(|\lambda_{ia}^L \lambda_{ib}^R|^2 + |\lambda_{ia}^R \lambda_{ib}^L|^2\right),$$

$$b = \frac{1}{192\pi M^2}\frac{1}{(1+x_i)^4}\left[|\lambda_{ia}^L \lambda_{ib}^L|^2(1 - 6x_i + x_i^2) + |\lambda_{ia}^L \lambda_{ib}^R|^2(1 - 2x_i) + (L \leftrightarrow R)\right]$$

$$\lambda_{1a}^L = -\sin\theta y_{Ra}, \quad \lambda_{2a}^L = \cos\theta y_{Ra}; \quad \lambda_{1a}^R = \cos\theta y_{La}, \quad \lambda_{2a}^R = \sin\theta y_{La}$$

Relic density of DM

- If y_L=0, a=0. M. Garny, A. Ibarra, S. Vogl, 1503.01500

The annihilation cross section is p-wave suppressed, and EW scale slepton is required to get the correct relic density.

- In our case, s-wave annihilation is allowed

$$a \approx \frac{1}{64\pi M^2} \sin^2 2\theta \left(|y_{La}y_{Rb}|^2 + |y_{Ra}y_{Lb}|^2\right) \sum_i \frac{1}{(1+x_i)^2}.$$

$$a \simeq 0.8 \times \left(\frac{400\,\mathrm{GeV}}{M}\right)^2 \left(\frac{\sin^2\theta}{0.1}\right) \frac{\left(|y_{La}y_{Rb}|^2 + |y_{Ra}y_{Lb}|^2\right)}{1.0} \mathrm{pb}$$

and the correct relic density is obtained in the decoupling regime

Direct DM detection

- DM-nucleon scattering is absent at tree-level.
- At one-loop, DM can interact with nucleon via Higgs or photon exchange.

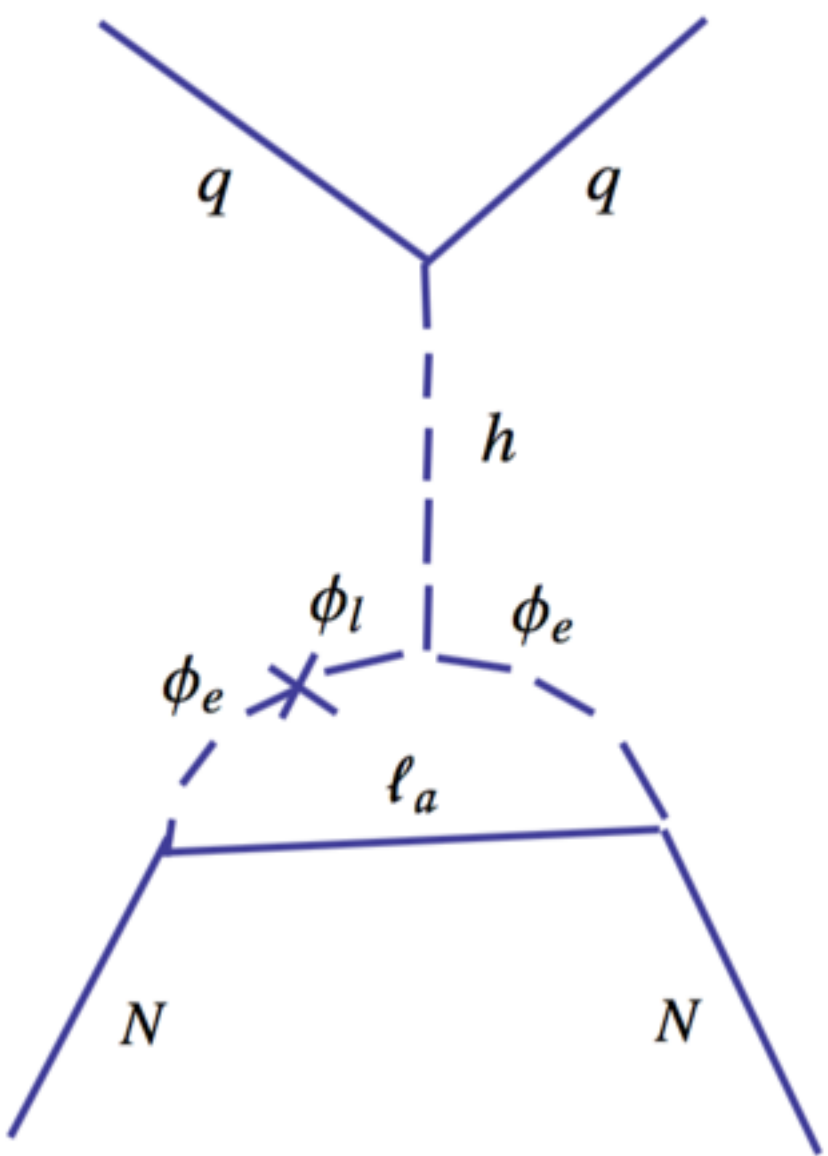
$$\boxed{\mathcal{O}_h = \lambda_{hN}(0) h\bar{N}N} \qquad \mathcal{O}_A = \mathcal{A}\bar{N}\gamma^\mu\gamma^5 N\partial^\nu F_{\mu\nu}$$

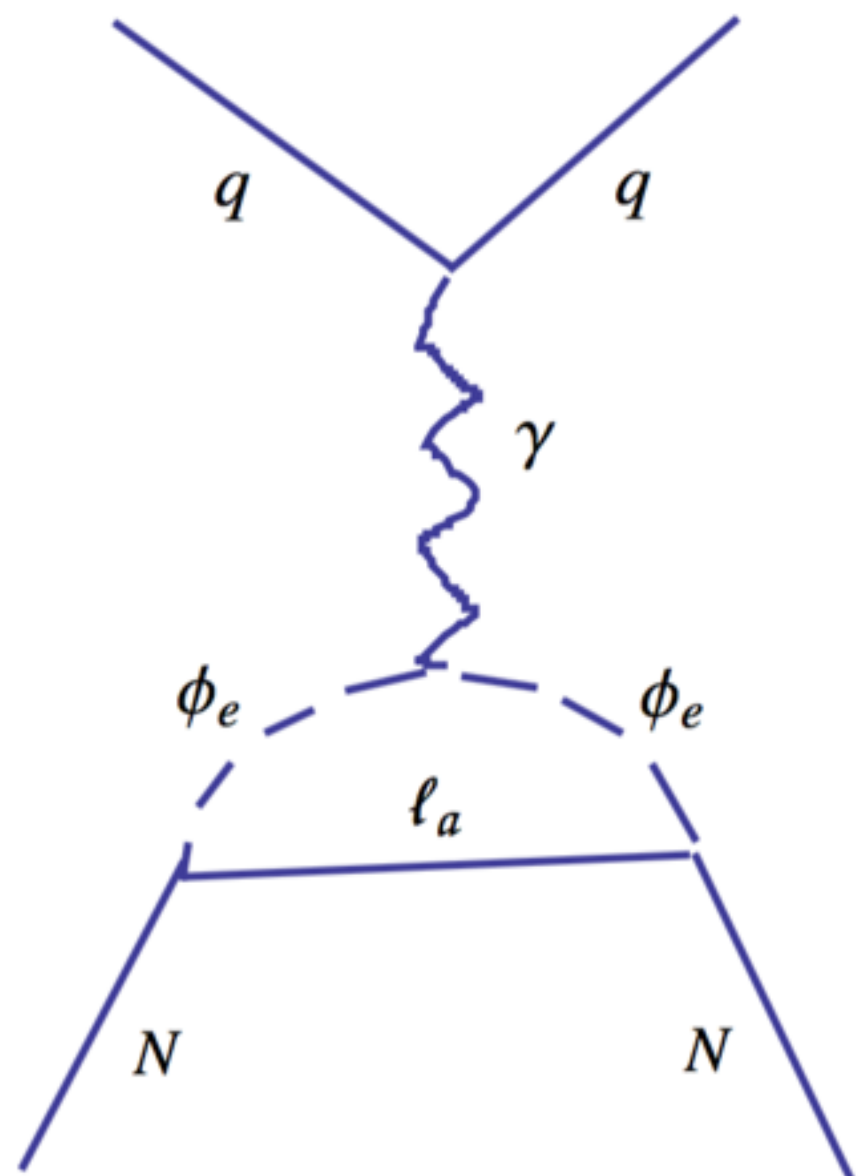
$$\lambda_{hN}(0) \approx 0.01 \times \left(\frac{\sin\theta}{0.2}\right)\left(\frac{|y_{La}|^2 + |y_{Ra}|^2}{1}\right)\left(\frac{\mu}{5\mathrm{TeV}}\right)\left(\frac{0.3\mathrm{TeV}}{M}\right) \qquad \mathcal{A}/\left(|\lambda^L_{ia}|^2 + |\lambda^R_{ia}|^2\right) \sim \mathcal{O}(10^{-7})\mathrm{GeV}^{-2}$$

$$O(10^{-2}) \qquad O(10^{-4})$$

of current LUX bound $\qquad \sigma^p_{\mathrm{SI}} \approx 4.0 \times 10^{-8}\mathrm{pb}$

Direct DM detection





Conclusions

- Leptophilic dark matter model with coupling to both $SU(2)_L$ doublet and singlet scalars can explain the large $h \to \tau\mu$ signal
- $\tau \to \mu\gamma$, $h \to \gamma\gamma$ constraints can be evaded easily in the decoupling regime
- The correct relic density can be obtained. Direct detection cross section is typically two-orders of magnitude smaller than the current LUX bound

Thank you very much!