全国15TH重味物理和CP破坏研讨会，HFCPV-2017

Higgs Flavor-violating Decay Mediated by Flavored Dark Matter

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Outline

- SM: Higgs & flavor
- Beyond SM: Higgs flavor violating decay
- HLFV & lepton flavored DM
- Conclusion & outlook

SM: Higgs & flavor

- Higgs may be a key to understand new physics, it is

Related to neutrino mass origin

Related to baryon asymmetry

Related to dark matter

Related to neutrino mass origin

- In the extended theory to establish the above connections, Higgs properties are likely to deviate from the SM predictions

- Thus precision of Higgs is crucial to hunt for new physics hints

Flavor changing decays are of particular interest, considering their great suppression in SM

SM: Higgs & flavor

- Higgs (one doublet) & quarks (3 generations, chiral, 12 flavors)

Simultaneously diagonalizing the mass and Higgs Yukawa interactions → No flavor changing neutral current (FCNC) mediated by Higgs boson

- At loop level？ GIM-suppression in the charge flavor-violating loop!

In the SM one has for example $Br(h \to bs) \sim 10^{-7}$!

S. Bejar, F. Dilme, J. Guasch, and J. Sola, JHEP 08, 018 (2004)

SM: Higgs & flavor

- Higgs & leptons (3 generations, chiral, missing RHN)

Again, no Higgs mediated lepton flavor decay

- Neutrinos masses are strong evidence of new physics!!

Neutrino in the SM are massless, due to the absence of right-handed neutrinos

However, neutrinos are found to have tiny mass < 10^{-11} GeV!

- Higgs can still account for their masses, via the d=5 Weinberg operators:

Leading to Majorana neutrinos

Beyond SM: Higgs flavor violating decay

- Higgs violating decay: effective Lagarangian

- Higgs mediated FCNC in the quark sector ***VS*** $\Delta F=2$ bounds

Meson-antimeson mixing & CPV → $Br(h \to q_i q_j) < 10^{-3}$! Too small

G. Blankenburg, etc., PLB, 712 (2012) 386–390

Operator	Eff. couplings	95% C.L. Bound		Observables
		$\lvert c_{\text{eff}} \rvert$	$\lvert \text{Im}(c_{\text{eff}}) \rvert$	
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	$c_{sd} c^*_{ds}$	1.1×10^{-10}	4.1×10^{-13}	$\Delta m_K;\ \epsilon_K$
$(\bar{s}_R d_L)^2$, $(\bar{s}_L d_R)^2$	c^2_{ds}, c^2_{sd}	2.2×10^{-10}	0.8×10^{-12}	
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	$c_{cu} c^*_{uc}$	0.9×10^{-9}	1.7×10^{-10}	$\Delta m_D;\ \lvert q/p \rvert, \phi_D$
$(\bar{c}_R u_L)^2$, $(\bar{c}_L u_R)^2$	c^2_{uc}, c^2_{cu}	1.4×10^{-9}	2.5×10^{-10}	
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	$c_{bd} c^*_{db}$	0.9×10^{-8}	2.7×10^{-9}	$\Delta m_{B_d};\ S_{B_d \to \psi K}$
$(\bar{b}_R d_L)^2$, $(\bar{b}_L d_R)^2$	c^2_{db}, c^2_{bd}	1.0×10^{-8}	3.0×10^{-9}	
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	$c_{bs} c^*_{sb}$	2.0×10^{-7}	2.0×10^{-7}	Δm_{B_s}
$(\bar{b}_R s_L)^2$, $(\bar{b}_L s_R)^2$	c^2_{sb}, c^2_{bs}	2.2×10^{-7}	2.2×10^{-7}	

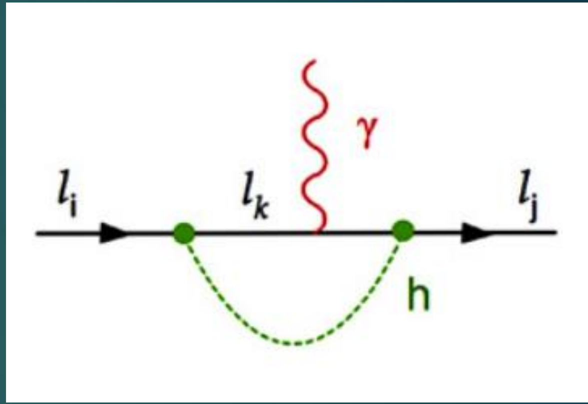
Beyond SM: Higgs flavor violating decay

- The left corner: Higgs lepton flavor violating (HLFV) decay

anomalous magnetic moments and electric dipole moments of charged leptons for i=j

Related to the (g-2)μ puzzle?

charged lepton flavor violating decay (CLFV) for i≠j, leading to individual upper bounds:



In 2012 with 4.7/fb of 7TeV ATLAS data gave Br($h\to\tau\boldsymbol{\mu}$/e)≲10%
In 2014 with 19.7/fb of 8 TeV CMS data gave upper bound & best fit (2.4σ excess) at 95% C.L:
Br($h\to\tau\boldsymbol{\mu}$)≲1.57% & Br($h\to\tau\boldsymbol{\mu}$)≈0.84%

Prospects 300/fb of 13 TeV LHC：Br($h\to\tau\boldsymbol{\mu}$)≲0.01%！

J. Kopp and M. Nardecchia, JHEP 1410, 156 (2014) ; Y. n. Mao and S. h. Zhu, arXiv:1505.07668

Beyond SM: Higgs flavor violating decay

- LFV: already observed in active neutrino oscillation such as $\nu_{\mu} \rightleftarrows \nu_{e}$
- Can LFV leave hints in other processes?

for example, LFV insertion in charged lepton-flavor-violating (CLFV) decay

JMarciano, W., and A. Sanda, PLB 67 (3), 303, 1977

- Very clear probe to new physics,

  in particular neutrino mass origin

Currently, the most stringent bounds: $Br(\mu \to e\gamma) < 10^{-13}$, $Br(\tau \to \mu\gamma) < 4.3 \times 10^{-8}$

J. Bjorken and S. Weinberg, Phys.Rev.Lett. 38, 622 (1977).

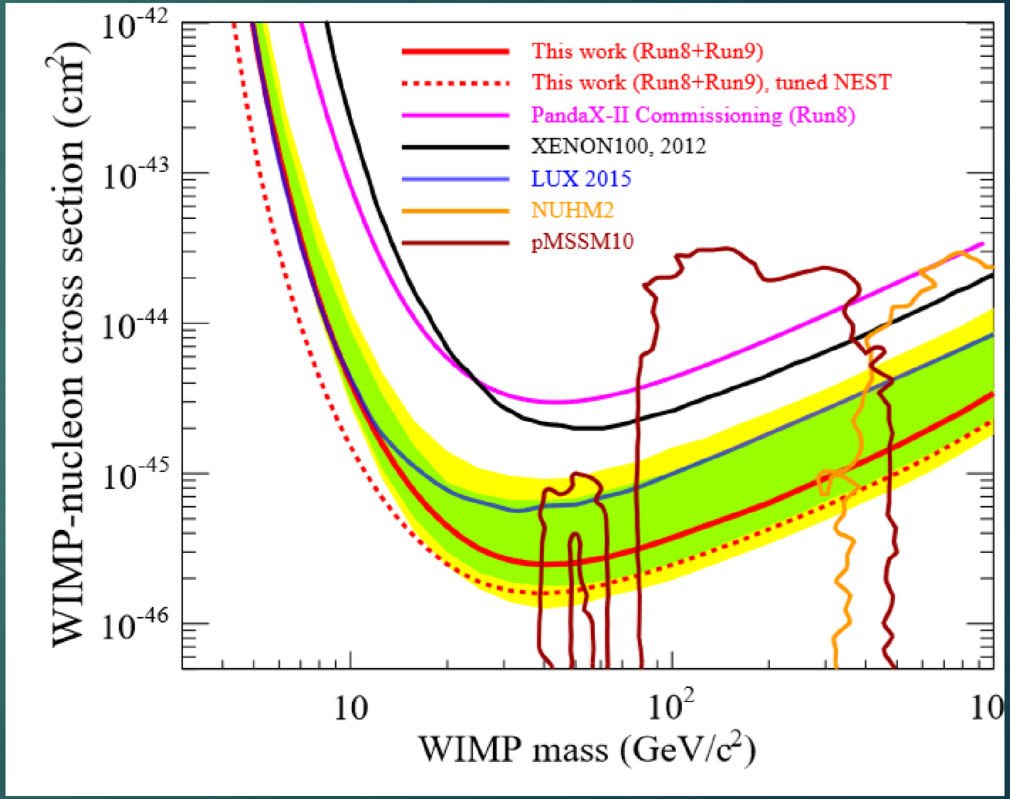
HLFV & lepton flavored DM

Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- Plights of weakly interacting massive particle (WIMP) dark matter

PandaX, LUX, XEON etc., are approaching the limit of DM direct detection, via DM-nucleon spin-independent (SI) scattering signals, from interactions: $(DM)^2(quark)^2$

Indirect detections from cosmic ray such as γ also begins to rule out typical WIMP with typical annihilation cross section(~1pb) today



Phys. Rev. Lett. 117 (2016) no. 12, 121303

HLFV & lepton flavored DM

Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- A way out the plight: leptonpllic dark matter

DM mainly interacts with SM through the lepton sector, thus no (tree-level) DM-nucleon scattering, e.g., **via a leptonic Z' or Higgs portal or,**

- A natural realization: lepton flavored DM (Majorana χ with Z_2)

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

G. Blankenburg, etc., PLB, 712 (2012) 386–390

mediator quantum numbers specify interactions of the Majorana DM dominantly with leptons

Ma's radiative neutrino model (RHN+Higgs doublet) is a "derivation" of lepton-flavored DM

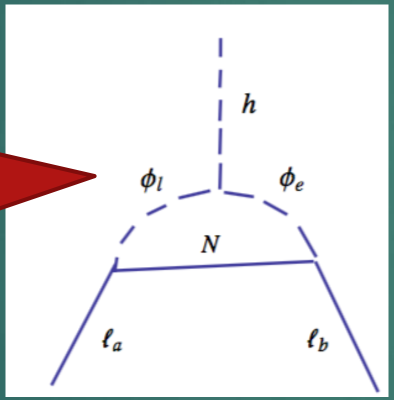
HLFV & lepton flavored DM

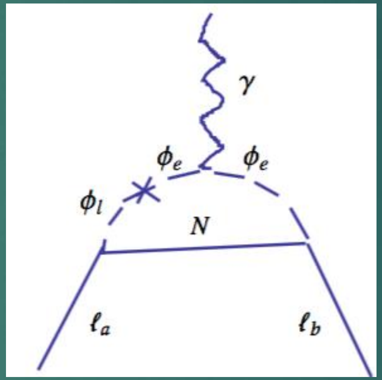
Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- The singlet mediator ϕ_e: **new and crucial**

Admits a large HLFV without giving a too large CLFV, without significant tuning

HLFV is enhanced by μ and survives in the decoupling limit $\theta \to 0$





CLFV is not proportional to μ and goes to zero if the singlet-doublet mediator mixing angle vanishes

$$\Gamma(\tau \to \mu\gamma) = \frac{(m_\tau^2 - m_\mu^2)^3}{4\pi m_\tau^3}\left[|C_L|^2 + |C_R|^2\right]$$

in the decoupling limit: F_L is not suppressed while $C_L \to 0$

HLFV & lepton flavored DM

Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- The singlet mediator $\boldsymbol{\phi}_e$: **new and crucial**

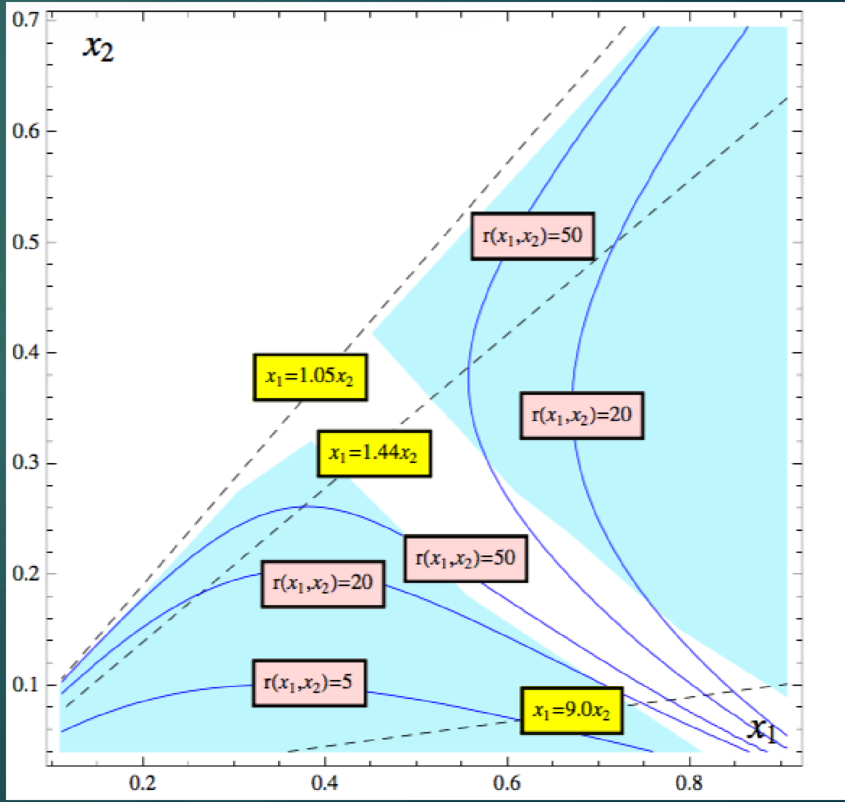
Estimation of ratio $R\tau$=Br($h\to\tau\boldsymbol{\mu}$)/Br($\tau\to\boldsymbol{\mu}\gamma$) in the decoupling limit

$$R_\tau \approx 2.5\times 10^5 \left(\frac{\mu}{10\,\mathrm{TeV}}\right)^2 \left(\frac{0.1}{\sin\theta}\right)^2 \left(\frac{G(x_1,x_2)/(F_2(x_2)-F_2(x_1))}{20}\right)^2.$$

For Br($h\to\tau\boldsymbol{\mu}$)~1%, this value is constrained to be $>10^5$,

- Natural enhancement

$$\Delta = \max\{|\Delta_i|\}|_{i=1,2,3} \quad \text{with} \quad \Delta_i \equiv \frac{\partial \log(F_2(x_2)-F_2(x_1))}{\partial \log \mu_i}$$



HLFV & lepton flavored DM

Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- The singlet mediator ϕ_e: **new and crucial**

Admits a singlet fermionic & leptophlic dark matter candidate

Annihilation without p-wave suppression: $\sigma v = a + b v^2$

difficult in the Ma's model because of the strong tension between DM annihilation & CLFV

Chiral flipping

1. If $a \to 0$, DM annihilation today will be greatly suppressed and thus hard to detect indirectly
2. Generically $a \neq 0$ (in particular for a large HLFV), leading to distinguishable signals

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

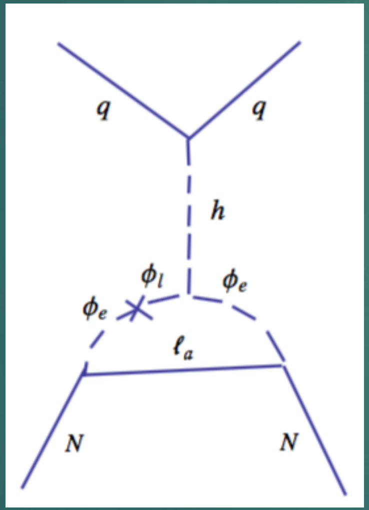
$$b = \frac{1}{96\pi M^2}\frac{1}{(1+x_i^{-1})^4}\left[2|\lambda_{ia}^L|^2|\lambda_{ib}^L|^2(1+x_i^{-2}) - |\lambda_{ia}^L|^2|\lambda_{ib}^R|^2\left(1+4x_i^{-1}-3x_i^{-2}\right) + (L \leftrightarrow R)\right].$$

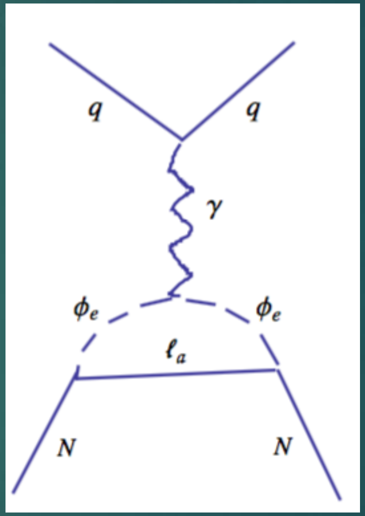
HLFV & lepton flavored DM

Seungwon Baek and ZF Kang, JHEP, 1603 (2016) 106

- DM direct detection at radiation

Higgs mediated & photon mediated: NOT completely undetectable





$$\sigma_{\rm SI}^{p} \approx 4.0 \times 10^{-8} \left(\lambda_{hN}(0)/0.1\right)^2 \,{\rm pb}$$

$$\lambda_{hN}(0) \approx 0.01 \times \left(\frac{\sin\theta}{0.2}\right)\left(\frac{|y_{La}|^2+|y_{Ra}|^2}{1}\right)\left(\frac{\mu}{5{\rm TeV}}\right)\left(\frac{0.3{\rm TeV}}{M}\right)$$

$$\mathcal{O}_A = \mathcal{A}\bar{N}\gamma^\mu\gamma^5 N\partial^\nu F_{\mu\nu},$$

$$\mathcal{A} \approx -\frac{e\left(|\lambda_{ia}^L|^2+|\lambda_{ia}^R|^2\right)}{192\pi^2 M^2}\left(-3\log(x_i\epsilon_a) - \frac{x_i+3}{1-x_i}\log\frac{x_i^{-1}-1}{\sqrt{\epsilon_a}}\right)$$

$$\mathcal{A}/\left(|\lambda_{ia}^L|^2+|\lambda_{ia}^R|^2\right) \sim \mathcal{O}(10^{-7}){\rm GeV}^{-2}.$$

Conclusion & outlook

- Higgs flavor violating decay is a good probe to new physics
- HLVF is the left playground
- We establish a connection between HLFV and lepton-flavored dark matter
- The other playground: top flavor violating decay to Higgs & top flavored DM…..