PROCEEDINGS OF SCIENCE

PoS(FPCP2015)054

Lepton-flavor-violating Higgs decay $h \to \mu\tau$ and muon anomalous magnetic moment in a general two Higgs double model

---

Kazuhiro Tobe[*][†]
Department of Physics and Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University
E-mail: `tobe@eken.phys.nagoya-u.ac.jp`

In a general two Higgs double model, flavor-changing phenomena mediated by neutral Higgs bosons are predicted. We find the $\mu-\tau$ flavor-violating Higgs interactions in a general Higgs doublet model can explain the excess event in a Higgs decay $h \to \mu\tau$ observed by the CMS collaboration as well as the anomaly of the muon anomalous magnetic moment, simultaneously. We also discuss that the predicition of $\tau \to \mu\gamma$ in the scenario can be within the reach of the future B-factory.

Flavor Physics & CP Violation 2015
May 25-29, 2015
Nagoya, Japan

---

[*] Speaker.

[†] This poster presentation is based on work in the collaboration with Yuji Omura and Eibun Senaha in Ref. [1].

1. Introduction

Since the standard model (SM) well-describes phenomena up to the electroweak scale, it is considered to be a very successful theory for elementary particles. The Higgs boson discovery further strengthens the success of the SM. On the other hand, there are a few phenomena which are not explained by the current understanding of the SM. One of them is the anomalous magnetic moment of muon (muon g-2). A discrepancy between the measured value ($a_\mu^{\rm Exp}$) and the SM prediction ($a_\mu^{\rm SM}$) of the muon g-2 has been reported [2]. For example, see [3], $\delta a_\mu = a_\mu^{\rm Exp} - a_\mu^{\rm SM} = (26.1 \pm 8.0) \times 10^{-10}$, and so far no clear understanding of this anomaly has been established. Another one is the event excess of the Higgs boson decay $h \to \mu\tau$, reported by the CMS collaboration at the Large Hadron Collider (LHC) experiment [4], ${\rm BR}(h \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$, which never occurs in the SM. These phenomena would be good hints for the physics beyond the SM. In this presentation, we show that these two anomalies in the muon g-2 and $h \to \mu\tau$ can be explained by the $\mu - \tau$ flavor-violating interactions in a general two Higgs doublet model (2HDM), and we also discuss the prediction of the scenario.

2. General two Higgs doublet model

In a general two Higgs doublet model (2HDM), both Higgs doublets can couple to all fermions and hence the Yukawa interactions are given by

$$\mathscr{L} = -\bar{L}_L^i H_1 y_e^i e_R^i - \bar{L}_L^i H_2 \rho_e^{ij} e_R^j + {\rm h.c.}, \tag{2.1}$$

where $L_L = (V_{\rm MNS} \nu_L, e_L)^{\rm T}$, where $V_{\rm MNS}$ is the Maki-Nakagawa-Sakata matrix. Here we take a basis where only Higgs doublet H_1 gets a vacuum expectation value (vev),

$$H_1 = \begin{pmatrix} G^+ \\ \frac{v+\phi_1+iG}{\sqrt{2}} \end{pmatrix},\ H_2 = \begin{pmatrix} H^+ \\ \frac{\phi_2+iA}{\sqrt{2}} \end{pmatrix},\ \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\beta\alpha} & \sin\theta_{\beta\alpha} \\ -\sin\theta_{\beta\alpha} & \cos\theta_{\beta\alpha} \end{pmatrix} \begin{pmatrix} H \\ h \end{pmatrix}, \tag{2.2}$$

where G^+ and G are Nambu-Goldstone bosons and $H^\pm$ and A are charged and CP-odd Higgs bosons, respectively. Thus the Yukawa interactions shown above are written in the fermion mass eigenstates.[1] The CP-even neutral Higgs bosons $\phi_{1,2}$ can mix and form the mass eigenstates h and H where h is a SM-like Higgs boson. For small $|c_{\beta\alpha}|$ ($c_{\beta\alpha} = \cos\theta_{\beta\alpha}$), $\phi_1 \simeq h$. Note that the Yukawa couplings ρ_e are flavor-violating interactions in general. The mass spectrum of neutral Higgs bosons in this model are expressed as

$$m_{H^+}^2 = m_A^2 + \frac{\lambda_5 - \lambda_4}{2} v^2,\ m_H^2 \simeq m_A^2 + \lambda_5 v^2, \tag{2.3}$$

where $\lambda_{4,5}$ are Higgs quartic couplings $(H_1^\dagger H_2)(H_2^\dagger H_1)$ and $(H_1^\dagger H_2)^2/2$, respectively, in the tree-level Higgs potential.

---

[1] The Yukawa couplings in quark sector can also be written similarly.

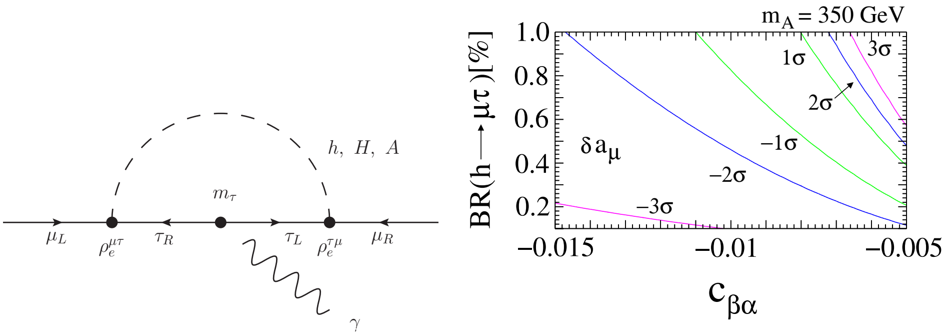

Figure 1: (Left) A Feynman diagram for neutral Higgs boson contributions to the muon g-2 via the $\mu - \tau$ flavor-violating Yukawa couplings $\rho_e^{\mu\tau\,(\tau\mu)}$. A photon is attached somewhere in the charged lepton line. (Right) Neutral Higgs contributions to the muon g-2 (δ_μ) as a function of BR($h \to \mu\tau$) [%] and $c_{\beta\alpha}$ ($= \cos\theta_{\beta\alpha}$). The lines where the muon g-2 anomaly is explained within $\pm 1\sigma$, $\pm 2\sigma$ and $\pm 3\sigma$ are shown. Here we have assumed that $m_A = 350$ GeV, $\lambda_4 = \lambda_5 = 1$ and $\rho_e^{\tau\mu} = -\rho_e^{\mu\tau}$.

3. $h \to \mu\tau$ and muon g-2

The flavor-violating Yukawa couplings $\rho_e^{\mu\tau\,(\tau\mu)}$ can easily explain the CMS event excess in $h \to \mu\tau$ if the size of the Yukawa couplings satisfies the following condition,

$$\bar{\rho}^{\mu\tau} \equiv \sqrt{\frac{|\rho_e^{\mu\tau}|^2 + |\rho_e^{\tau\mu}|^2}{2}} \simeq 0.26 \left(\frac{0.01}{|c_{\beta\alpha}|}\right) \sqrt{\frac{\mathrm{BR}(h \to \mu\tau)}{0.84 \times 10^{-2}}}. \tag{3.1}$$

These $\mu - \tau$ flavor-violating Yukawa couplings $\rho_e^{\mu\tau\,(\tau\mu)}$ can induce extra contributions to the muon g-2, mediated by neutral Higgs bosons, as shown in Fig. 1 (Left). Note that the extra-contributions to the muon g-2 are proportional to the τ mass, which is necessary to flip the chirality of the muon and induces the $O(m_\tau/m_\mu)$ enhancement in the muon g-2, compared to one induced by the flavor diagonal Yukawa coupling. Therefore, the $\mu - \tau$ flavor violation is essential to have the large extra-contributions to the muon g-2. Assuming that $m_A = 350$ GeV, $\lambda_4 = \lambda_5 = 1$ and $\rho_e^{\tau\mu} = -\rho_e^{\mu\tau}$, the numerical values of extra contributions to muon g-2 (δa_μ) are shown as a function of BR($h \to \mu\tau$) [%] and $c_{\beta\alpha}$ ($= \cos\theta_{\beta\alpha}$) in Fig. 1(Right). The lines where the muon g-2 anomaly is explained within $\pm 1\sigma$, $\pm 2\sigma$ and $\pm 3\sigma$ are displayed. One can see that the both anomalies in $h \to \mu\tau$ and the muon g-2 can be explained by the $\mu - \tau$ flavor-violating interactions in the general 2HDM when $|c_{\beta\alpha}|$ is small.

4. $\tau \to \mu\gamma$

The large $\mu - \tau$ flavor violation also generates $\tau \to \mu\gamma$. Feynman diagrams of the dominant one-loop and (Barr-Zee type) two-loop contributions are depicted in Fig. 2. It is known that the Barr-Zee type two-loop contribution can be dominant because of the large top Yukawa coupling [5]. We find that even if unknown Yukawa couplings ρ_f ($f = e, u, d$) other than $\rho_e^{\mu\tau\,(\tau\mu)}$ are negligibly small, the predicted branching ratio of $\tau \to \mu\gamma$ can be as large as 10^{-9}, which might be within the reach of the future B-factory. If extra-Yukawa couplings, such as ρ_u^{tt} and $\rho_e^{\tau\tau}$, are non-zero,

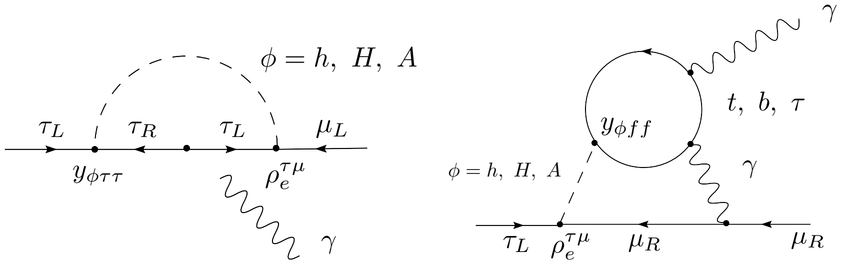

Figure 2: Feynman diagrams for the dominant one-loop and (Barr-Zee type) two-loop contributions to $\tau \to \mu\gamma$.

they can enhance the rate of $\tau \to \mu\gamma$. In Fig. 3, the branching ratio of $\tau \to \mu\gamma$ is shown as a function of $\rho_e^{\tau\tau}$ and ρ_u^{tt}. Here, we have assumed that $m_A = 350$ GeV, $\lambda_4 = \lambda_5 = 1$, $c_{\beta\alpha} = -0.008$ and $\mathrm{BR}(h \to \mu\tau) = 0.84\%$ with $\rho_e^{\tau\mu} = -\rho_e^{\mu\tau}$. For this parameter set, δa_μ is 2.9×10^{-9}, which explains the muon g-2 anomaly within 1σ. In Fig. 3, lines of $\mathrm{BR}(\tau \to \mu\gamma)$ for 4.4×10^{-8} (current experimental limit) and 10^{-9} are shown. As one can see from Fig. 3, the future improvement of the branching ratio at the 10^{-9} level would have the great impact on proving this scenario. For further detail of the phenomenological analysis for this model, see Ref. [6].

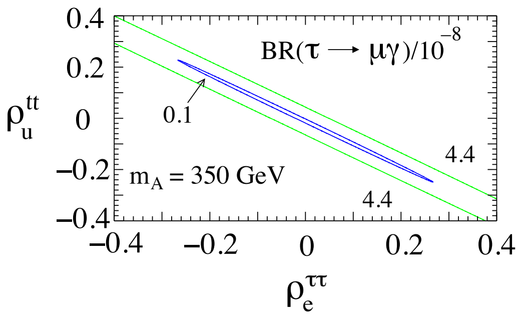

Figure 3: Branching ratio of $\tau \to \mu\gamma$ is shown as a function of $\rho_e^{\tau\tau}$ and ρ_u^{tt}. Here lines of $\mathrm{BR}(\tau \to \mu\gamma)$ for 4.4×10^{-8} (current limit) and 10^{-9} are depicted. We have assumed that $m_A = 350$ GeV and $\lambda_4 = \lambda_5 = 1$, $c_{\beta\alpha} = -0.008$ and $\mathrm{BR}(h \to \mu\tau) = 0.84\%$ with $\rho_e^{\tau\mu} = -\rho_e^{\mu\tau}$. We note that for this parameter set, $\delta a_\mu = 2.9 \times 10^{-9}$, which can explain the muon g-2 anomaly within 1σ.

References

[1] Y. Omura, E. Senaha and K. Tobe, JHEP **1505** (2015) 028 [arXiv:1502.07824 [hep-ph]].

[2] K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38** (2014) 090001.

[3] K. Hagiwara *et al.*, J. Phys. G **38** (2011) 085003 [arXiv:1105.3149 [hep-ph]].

[4] V. Khachatryan *et al.* [CMS Collaboration], arXiv:1502.07400 [hep-ex].

[5] D. Chang, W. S. Hou and W. Y. Keung, Phys. Rev. D **48**, 217 (1993) [hep-ph/9302267].

[6] Y. Omura, E. Senaha and K. Tobe, work in progress.