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Lepton-flavored electroweak baryogenesis

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We explore lepton-flavored electroweak baryogenesis, driven by CP-violation in leptonic Yukawa sector, using the $\tau - \mu$ system in the two Higgs doublet model as an example. This setup generically yields, together with the flavor-changing decay $h \to \tau\mu$, a tree-level Jarlskog invariant that can drive dynamical generation of baryon asymmetry during a first-order electroweak phase transition and results in CP-violating effects in the decay $h \to \tau\tau$. We find that the observed baryon asymmetry can be generated in parameter space compatible with current experimental results for the decays $h \to \tau\mu$, $h \to \tau\tau$, and $\tau \to \mu\gamma$, as well as the present bound on the electric dipole moment of the electron. The baryon asymmetry generated is intrinsically correlated with the CP-violating decay $h \to \tau\tau$ and the flavor-changing decay $h \to \tau\mu$, which thus may serve as "smoking guns" to test lepton-flavored electroweak baryogenesis.

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I. INTRODUCTION

Explaining the origin of the baryon asymmetry of the Universe (BAU) is a forefront challenge for fundamental physics. The BAU is characterized by the baryon density n_B to entropy s ratio $Y_B = \frac{n_B}{s} = (8.61 \pm 0.09) \times 10^{-11}$ [1]. According to Sakharov [2], generation of a nonvanishing Y_B requires three ingredients in the particle physics of the early Universe: nonconservation of baryon number (B); C- and CP-violation (CPV); and out-of-equilibrium dynamics (assuming charge-parity-time CPT conservation). While the Standard Model (SM) of particle physics contains the first ingredient in the guise of electroweak sphalerons, it fails with regard to the remaining two. Physics beyond the SM is, thus, essential for successful baryogenesis.

Electroweak baryogenesis (EWBG) [3] is among the most theoretically well-motivated and experimentally testable scenarios, as it ties BAU generation to electroweak symmetry breaking (see [4] for a recent review). Extending the SM scalar sector can lead to a first order electroweak phase transition (EWPT), thereby satisfying the out-of-equilibrium condition. Addressing the second Sakharov criterion requires new sources of CPV, as the effect of CPV in the SM Yukawa sector is suppressed by the small magnitude of the Jarlskog invariant associated with the Cabibbo-Kobayashi-Maskawa (CKM) matrix and by the small quark mass differences relative to the electroweak temperature, $T_{\mathrm{EW}} \sim 100$ GeV.

An extended Yukawa sector, e.g., the one involving leptons, may remedy this SM shortcoming. Phenomenologically, the report by the CMS Collaboration of a signal for the charged lepton flavor violating (CLFV) Higgs boson decay $h \to \tau\mu$ (2.4σ significance) at $\sqrt{s} = 8$ TeV [5] hints at a possible richer leptonic Yukawa sector, despite no evidence for this decay mode having been observed in the ATLAS analysis at $\sqrt{s} = 8$ TeV [6] and in a preliminary CMS study at $\sqrt{s} = 14$ TeV [7]. Should an extended leptonic Yukawa sector exist, then the accompanying new CPV phases may provide sources for EWBG that do not suffer from the suppression associated with the SM quark Yukawa sector.

Motivated by these considerations, we study the viability of "lepton flavored EWBG", a scenario that relies on both CLFV and leptonic CPV. For concreteness, we use a variant of the type III two Higgs doublet model (2HDM) [8] with generic leptonic Yukawa textures [9] and focus on the $\tau - \mu$ families as an example. For a representative choice of Yukawa texture, we derive the CPV source for the EWBG quantum transport equations [10,11] in terms of the relevant Jarlskog invariant, ImJ_A. We then solve these equations, which encode the dynamics of CLFV scattering during the electroweak phase transition, and obtain the BAU as a function of the Yukawa matrix parameters. We also show that the same ImJ_A also generates a CPV coupling of the Higgs boson to τ leptons at $T = 0$, parametrized by a CPV phase ϕ_τ. Measurements of CPV asymmetries in $h \to \tau^+\tau^-$, as discussed in Ref. [12], would provide a test of this baryogenesis mechanism. Taking into account present constraints from measurements of $\Gamma(h \to \tau^+\tau^-)$ and limits on

$\Gamma(\tau \to \mu\gamma)$ we find that a $\mathcal{O}(10°)$ determination of ϕ_τ would probe this scenario at a significant level.

II. MODEL SETUP

We focus on CPV in the $\mu - \tau$ sector of type III 2HDM, assuming a CP-conserving scalar potential. The $SU(2)_L \times U(1)_Y$ invariant weak eigenbasis lepton Yukawa interaction is

$$\mathcal{L}^{\mathrm{Lepton}}_{\mathrm{Yukawa}} = -\overline{L^i}[Y_{1,ij}\Phi_1 + Y_{2,ij}\Phi_2]e^j_R + \mathrm{H.c.}, \qquad (1)$$

where $\Phi_{1,2}$ are the two Higgs doublets with the same hypercharge, L^i and e^j_R are the left-handed lepton doublet and right-handed lepton singlet in weak basis, with the family index i, $j = 2$, 3. Then we can uniquely define a Jarlskog invariant as the imaginary part of [13,14]:

$$J_A = \frac{1}{v^2\mu^{\mathrm{HB}}_{12}} \sum_{a,b,c=1}^{2} v_a v^*_b \mu_{bc} \mathrm{Tr}[Y_c Y^\dagger_a], \qquad (2)$$

with the power of Yukawa coupling (or mass parameter of fermions) product being two. Here $v_a = \sqrt{2}\langle\Phi^0_a\rangle$ is the vacuum expectation value (vev) of neutral Higgs fields, μ_{ab} is the coefficient of $\Phi^\dagger_a\Phi_b$ in the potential, and the trace is taken over flavor space. J_A is normalized to be a dimensionless quantity by dividing a factor $v^2\mu^{\mathrm{HB}}_{12}$, where $\mu^{\mathrm{HB}}_{12} = \frac{1}{2}(\mu_{22} - \mu_{11})\sin 2\beta + \mu_{12}\cos 2\beta$ is a quadratic Higgs coupling defined in "Higgs basis" [8,14]: $H_1 = \cos\beta\Phi_1 + \sin\beta\Phi_2$; $H_2 = -\sin\beta\Phi_1 + \cos\beta\Phi_2$; $\langle H^0_1\rangle = v/\sqrt{2} = 174$ GeV; and $\langle H^0_2\rangle = 0$.

The mass matrix for fermions is defined as $M = (v_1Y_1 + v_2Y_2)/\sqrt{2}$ in the weak basis, with a determinant of $M^\dagger M$ or M close to zero (since $m_\mu \approx 0$). For illustration, we choose a texture with $Y_{j,22} = Y_{j,23} \equiv 0$, with $j = 1, 2$. This immediately yields $\mathrm{Im}(J_A) = -\mathrm{Im}(Y_{1,32}Y^*_{2,32} + Y_{1,33}Y^*_{2,33})$ or

$$\mathrm{Im}(J_A) = -\mathrm{Im}(Y_{1,32}Y^*_{2,32}), \qquad (3)$$

with a further assumption $Y_{1,33} = Y_{2,33}$. The diagonalization condition $|M_{32}|^2 + |M_{33}|^2 = m^2_\tau$ immediately gives $|M_{32}| \le m_\tau$, and fixes the value of $|Y_{1,33}| = |Y_{2,33}|$. Since the proposed mass texture is not invariant under basis transformation of Φ_1 and Φ_2, $\tan\beta = v_2/v_1$ becomes an independent parameter (similar to what happens in type II 2HDM). Thus this setup contains five relevant and independent parameters: $\tan\beta$, α (the mixing angle in the CP-even Higgs sector), $|Y_{2,32}|$, $r_{32} = |Y_{1,32}|/|Y_{2,32}|$, and $\mathrm{Im}(J_A)$. Noticed that a strongly first order EWPT, necessary for successful EWBG, strongly favors $\tan\beta \sim 1$ in the Higgs alignment limit [15], where we choose to work below. This realization is less sensitive to the other three parameters, which contribute to the effective Higgs potential at finite temperature at quantum level only.

In the mass basis for both fermions and Higgs bosons, the τ Yukawa interaction is then parametrized as

$$-\frac{1}{v}\overline{\tau_L}\tau_R[h(m_\tau s_{\beta-\alpha} + N_{\tau\tau}c_{\beta-\alpha}) + H(m_\tau c_{\beta-\alpha} - N_{\tau\tau}s_{\beta-\alpha}) + iAN_{\tau\tau}] + \mathrm{H.c.}, \qquad (4)$$

where $\beta - \alpha$ is invariant under the basis transformation in Higgs family space [16]. The SM-like Higgs boson h receives two contributions to its coupling. The first one results from its H^0_1 component which is aligned with the τ mass. Another one is related to its H^0_2 component which is proportional to $N_{\tau\tau}$, the Yukawa coupling of H^0_2 with τ leptons, with

$$\mathrm{Re}(N_{\tau\tau}) = \frac{v^2\mu^{\mathrm{HB}}_{12}\mathrm{Re}(J_A) - 2\mu^{\mathrm{HB}}_{11}m^2_\tau}{2\mu^{\mathrm{HB}}_{12}m_\tau},$$
$$\mathrm{Im}(N_{\tau\tau}) = \frac{v^2\mathrm{Im}(J_A)}{2m_\tau}. \qquad (5)$$

The CLFV interactions are completely controlled by the Yukawa coupling of H^0_2, $N_{\tau\mu}$,

$$-\frac{N_{\tau\mu}}{v}\overline{\tau_L}\mu_R(c_{\beta-\alpha}h - s_{\beta-\alpha}H + iA) + \mathrm{H.c.}, \qquad (6)$$

with $\tan\beta = 1$, the expression in terms of weak basis parameters is given by

$$N_{\tau\mu} = e^{i\delta}\left|N_{\tau\tau}\frac{M_{33}}{M_{32}}\right|. \qquad (7)$$

Here δ is an unphysical phase undetermined in the diagonalization procedure which can be removed by field redefinition. For later convenience, we also have for $\tan\beta = 1$

$$\mathrm{Re}(J_A) = \frac{1}{2}(|Y_{2,32}|^2 - |Y_{1,32}|^2) + \frac{2m^2_\tau}{v^2}\frac{\mu^{\mathrm{HB}}_{11}}{\mu^{\mathrm{HB}}_{12}}. \qquad (8)$$

Finally, the charged Higgs-Yukawa interactions are governed by $-\sqrt{2}/vH^+\overline{\nu^i_L}N_{ij}e^j_R + \mathrm{H.c.}$

Given the four free parameters left for describing tree-level Yukawa interactions of the $\mu - \tau$ system, we present various phenomenological results (e.g., $h \to \tau\tau, \tau\mu$, and $\tau \to \mu\gamma$ constraints) and the BAU analysis in terms of the effective $h\bar{\tau}\tau$ coupling [17] (see Fig. 1)

$$-\frac{m_\tau}{v}[\mathrm{Re}(y_\tau)\bar{\tau}\tau + \mathrm{Im}(y_\tau)\bar{\tau}i\gamma_5\tau]h, \qquad (9)$$

with benchmark values assigned to r_{32} and $\beta - \alpha$. Here

$$\mathrm{Re}(y_\tau) = s_{\beta-\alpha} + \frac{c_{\beta-\alpha}}{m_\tau}\mathrm{Re}(N_{\tau\tau}),$$
$$\mathrm{Im}(y_\tau) = \frac{c_{\beta-\alpha}}{m_\tau}\mathrm{Im}(N_{\tau\tau}). \qquad (10)$$

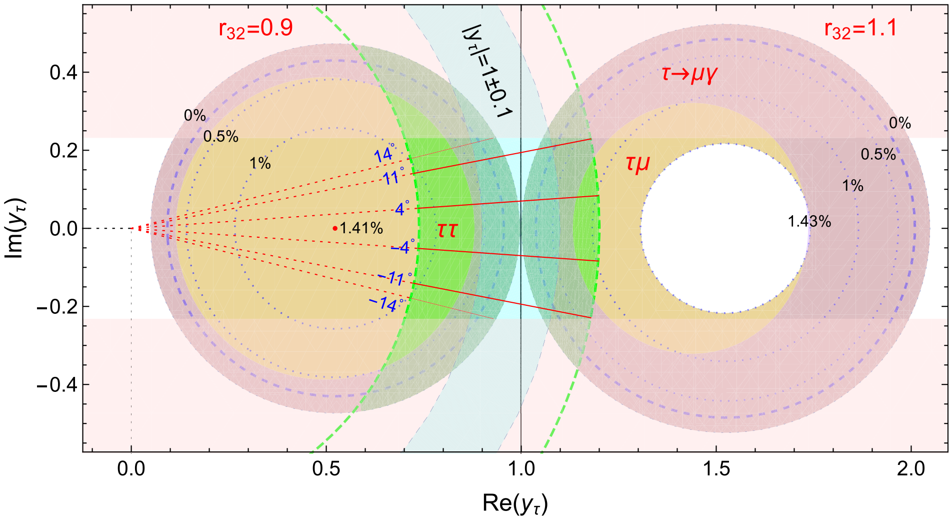

FIG. 1. Theoretical and phenomenological constraints on the Higgs-τ Yukawa couplings in Eq. (9). The inner parts of circular regions satisfy the diagonalization constraint $|M_{32}| \leq m_\tau$ for two representative choices of r_{32}, with the outer boundaries giving vanishing $\mathrm{Br}(\tau \to \mu\gamma)$ and $\Gamma(h \to \tau\mu)$. The $r_{32} = 0.9$ and $r_{32} = 1.1$ regions are separated by the vertical dashed line at $\mathrm{Re}(y_\tau) = \sin(0.05 + \frac{\pi}{2}) \approx 1$. Brown regions correspond to nonvanishing $\Gamma(h \to \tau\mu)$, with different representative values (1%, 0.5%, and 0%) denoted by circular dashed lines. For $r_{32} = 1.1$, the ATLAS 95% C.L. upper bound of 1.43% is shown, while for $r_{32} = 0.9$, a maximum BR of 1.41% can be achieved within the theoretically allowed region. The preliminary CMS upper limit 0.25% is indicated by a thick dashed blue circle in both cases. Upper limits on $\Gamma(h \to \tau\tau)$ (95% C.L.) and $\mathrm{Br}(\tau \to \mu\gamma)$(90% C.L.) are given by the green and grey regions, respectively. The region inside the green dashed lines gives the Higgs signal strength $\mu^{\tau\tau}$ allowed region at 95% C.L. without assuming a specific Yukawa texture. The inner light blue band labelled $|y_\tau| = 1 \pm 0.1$ corresponds to the region with a more SM-like $h\bar{\tau}\tau$ coupling. The region giving the observed BAU is indicated by the horizontal pink bands assuming $|\Delta\beta| \leq 0.4$ for $\beta - \alpha - \frac{\pi}{2} = 0.05$ as discussed in the text. The other relevant parameters are fixed to be $m_H = m_A = m_{H^\pm} = 500$ GeV, $v_w = 0.05$ [4,18,19], $L_W = 2/T$, $D_q = 6/T$, $D_{l_L} = 100/T$ [20], and $T = 100$ GeV. To guide the eye, the argument of y_τ is indicated with red-dotted lines. Note, the calculation of baryon asymmetry outside the circular regions could be unreliable due to the breaking of perturbative "mass insertion".

Then, the condition $|M_{32}| \leq m_\tau$ imposes a constraint at the ($\mathrm{Re}(y_\tau)$, $\mathrm{Im}(y_\tau)$) plane, allowing only a circular region centered at $(\mathrm{Re}(y_\tau) = s_{\beta-\alpha} + c_{\beta-\alpha}(1 + r_{32}^2)/(1 - r_{32}^2)$, $\mathrm{Im}(y_\tau) = 0)$ with a radius $2|c_{\beta-\alpha} r_{32}/(1 - r_{32}^2)|$. At its boundary, we have $M_{33} = 0$ and hence $N_{\tau\mu} = 0$. For $r_{32} = 1$, $N_{\tau\tau}$ is purely imaginary, yielding a vertical line at $\mathrm{Re}(y_\tau) = s_{\beta-\alpha}$. In Fig. 1, we present results in two representative cases: $r_{32} = 0.9$ and $r_{32} = 1.1$, with $\beta - \alpha - \frac{\pi}{2} = 0.05$.

III. $h \to \tau\tau$ CONSTRAINTS

The decay width for $h \to \tau\tau$ is given by

$$\Gamma^{\tau\tau} = \frac{\sqrt{2} G_F m_h m_\tau^2}{8\pi} |y_\tau|^2. \tag{11}$$

Experimentally, the ATLAS signal strength is $\mu^{\tau\tau}_{\mathrm{ATLAS}} = 1.43^{+0.43}_{-0.37}$ [21] while CMS favors a smaller one $\mu^{\tau\tau}_{\mathrm{CMS}} = 0.78 \pm 0.27$ [22]. We take a χ^2 analysis at 95% C.L. for these two measurements, assuming a Gaussian distribution for both and neglecting their correlations. Apparently, the allowed parameter region should be a circular band at the ($\mathrm{Re}(y_\tau)$, $\mathrm{Im}(y_\tau)$) plane, as is indicated by two green dashed curves in Fig. 1. A future determination of this coupling that agrees with the SM value within ±10% is plotted as a curved blue band.

IV. $h \to \tau\mu$ CONSTRAINTS

The lepton flavor-changing decay width is given by

$$\Gamma^{\tau\mu} = \frac{\sqrt{2} c_{\beta-\alpha}^2 G_F m_h}{8\pi} |N_{\tau\mu}|^2. \tag{12}$$

Theoretically, a sizable $\mathrm{Br}(h \to \tau\mu)$ requires a small $|M_{32}|$ [see Eq. (7)]. At 8 TeV, ATLAS sets an upper limit on its branching ratio, $\mathrm{Br}(h \to \tau\mu) < 1.43\%$, at 95% C.L. [6], while CMS gives a best fit $\mathrm{Br}(h \to \tau\mu) = 0.84^{+0.39}_{-0.37}\%$ as well as an upper limit $\mathrm{Br}(h \to \tau\mu) < 1.51\%$ at 95% C.L. [5]. At 14 TeV, a preliminary CMS sets an upper limit of $\mathrm{Br}(h \to \tau\mu) < 0.25\%$ at 95% C.L. [7]. In Fig. 1, the current ATLAS limit 1.43% and the preliminary CMS limit 0.25% are both shown in the two cases with $r_{32} = 0.9$ and 1.1. The circular boundaries of the brown regions correspond to vanishing M_{33} or $N_{\tau\mu}$, yielding $\mathrm{Br}(h \to \tau\mu) = 0$.

V. $\tau \to \mu\gamma$ CONSTRAINTS

Nonvanishing $N_{\tau\mu}$ may also contribute to the rare decay $\tau \to \mu\gamma$, via one-loop neutral and charged Higgs-mediated

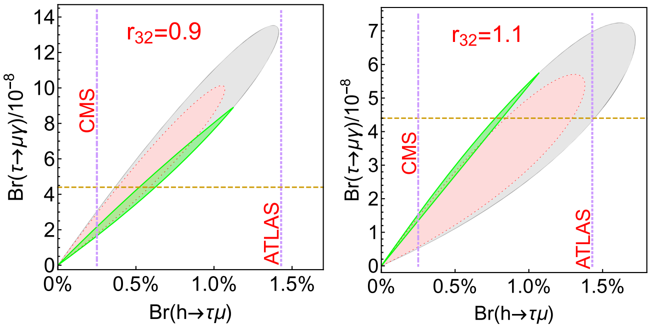

FIG. 2. Correlation between $\mathrm{Br}(h \to \tau\mu)$ and $\mathrm{Br}(\tau \to \mu\gamma)$ for $r_{32} = 0.9$ (left panel) and $r_{32} = 1.1$ (right panel) obtained by scanning $(\mathrm{Re}(y_\tau), \mathrm{Im}(y_\tau))$. The gray, pink, and green regions are allowed by the mass matrix diagonalization, the BAU observation, the current constraints for $h \to \tau\tau$ width, respectively. The experimental upper limit of $\mathrm{Br}(\tau \to \mu\gamma)$ is shown by horizontal brown lines and the current ATLAS and CMS upper limits of $\mathrm{Br}(h \to \tau\mu)$ are shown by vertical lines.

diagrams and two-loop Barr-Zee type diagrams [23,24]. Explicitly, one has

$$\mathrm{Br}(\tau \to \mu\gamma) = \frac{\tau_\tau \alpha G_F^2 m_\tau^5}{32\pi^4}(|C_{7L}|^2 + |C_{7R}^2|), \qquad (13)$$

where $\tau_\tau = (290.3 \pm 0.5) \times 10^{-15} s$ [25] is the τ lifetime, and $C_{7L/R}$ are the Wilson coefficients of the dipole operators $Q_7^{L/R} = e m_\tau \bar{\mu} \sigma^{\mu\nu}(1 \mp \gamma^5)\tau F_{\mu\nu}/8\pi^2$ in the Hamiltonian $-G_F[C_{7L}Q_7^L + C_{7R}Q_7^R]/\sqrt{2}$ [26]. In our setup, C_{7L} and C_{7R} are proportional to $N_{\tau\mu}^*$ and $N_{\mu\tau}$, respectively, yielding a vanishing C_{7R}. The current experimental limit is $\mathrm{Br}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$ (90% C.L.) [27]. The allowed parameter regions are denoted in gray in Fig. 1. There exists a positive correlation between new physics contributions to $\mathrm{Br}(h \to \tau\mu)$ and $\mathrm{Br}(\tau \to \mu\gamma)$. To make it more explicit, we project experimental constraints in Fig. 1 to the $\mathrm{Br}(h \to \tau\mu) - \mathrm{Br}(\tau \to \mu\gamma)$ plane (see Fig. 2). It is easy to see that the flavor-violating Higgs decay $\mathrm{Br}(h \to \tau\mu)$ of percent level is possible, without violating the experimental constraints for $\mathrm{Br}(\tau \to \mu\gamma)$. This is due to the fact that in type III 2HDM, new physics contributions to $\mathrm{Br}(h \to \tau\mu)$ and $\mathrm{Br}(\tau \to \mu\gamma)$ result from tree- and loop-levels respectively.

VI. ELECTRIC DIPOLE MOMENTS

Null results from experimental searches for the electric dipole moments (EDMs) of the neutron, neutral atoms, and molecules in general place stringent limits on new sources of CPV. In the present instance, the electron EDM (d_e) provides the most significant probe of $\mathrm{Im}(J_A)$ or $\mathrm{Im}y_\tau$, given the bound obtained by the ACME Collaboration using ThO [28]. In our setup, the dominant contribution to electron EDM results from the h–mediated Barr-Zee diagram with a τ lepton loop, because of nonvanishing $\mathrm{Im}y_\tau$. We find $|d_e/e| \approx 1.66 \times 10^{-29}|\mathrm{Im}y_\tau|$cm, yielding a bound of $|\mathrm{Im}y_\tau| < 5.2$. As indicated in Fig. 1, this bound is an order of magnitude larger than what is required to account for the observed BAU (see below). We also note in passing that CPV in the scalar potential will lead to mixing between the CP-even and CP-odd scalars. The resulting EDM can be considerably larger (see, e.g., [29–31]).

VII. ELECTROWEAK BARYOGENESIS

The CPV scattering from the bubble walls generates a left-handed fermion density n_L, which converts into a baryon number density n_B through the electroweak sphaleron transitions $\Gamma_{\rm ws}$ during a first order EWPT. As with earlier work, we will employ the "vev insertion approximation" to estimate the CPV sources [4], in the fermion weak basis, and compute n_L from quantum transport equations (see Ref. [11] for pedagogical discussions). Here we neglect bubble wall curvature [32], so that all relevant quantities depend only on the coordinate in the bubble wall rest frame $\bar{z} = z + v_w t$ with v_w being the wall velocity, $\bar{z} > 0$ (< 0) corresponding to (un)broken phase. Since nonzero densities for the first and second generation quarks as well as for the bottom quark are generated only by strong sphaleron processes, the following relations hold: $Q_1 = Q_2 = -2U = -2D = -2C = -2S = -2B$, where Q_k denotes the density of left-handed quarks of generation k and U, D, etc., denote the corresponding right-handed quark densities. In addition, $L_1 = L_2 = e_R \approx 0$ for negligible leptonic Yukawa interactions. Local baryon number density is also approximately conserved so $\sum_{i=1}^3 (Q_i + U_i + D_i) = 0$. The resulting transport equations are

$$\begin{aligned}
\partial_\mu Q_3^\mu &= \Gamma_{mt}(\xi_T - \xi_{Q_3}) + \Gamma_t(\xi_T - \xi_H - \xi_{Q_3}) + 2\Gamma_{ss}\delta_{ss}, \\
\partial_\mu H^\mu &= \Gamma_t(\xi_T - \xi_H - \xi_{Q_3}) + \Gamma_\tau(\xi_{L_3} - \xi_{\tau_R} - \xi_H) - 2\Gamma_h \xi_H, \\
\partial_\mu L_3^\mu &= -\Gamma_{m\tau}(\xi_{L_3} - \xi_{\tau_R}) - \Gamma_\tau(\xi_{L_3} - \xi_{\tau_R} - \xi_H) + S_{\tau_L}^{CPV}, \\
\partial_\mu \tau_R{}^\mu &= -\Gamma_\tau(\xi_H + \xi_{\tau_R} - \xi_{L_3}) + \Gamma_{m\tau}(\xi_{L_3} - \xi_{\tau_R}), \\
\partial_\mu T^\mu &= -\Gamma_{mt}(\xi_T - \xi_{Q_3}) - \Gamma_t(\xi_T - \xi_H - \xi_{Q_3}) - \Gamma_{ss}\delta_{ss}, \\
\partial_\mu \mu_R^\mu &= S_{\mu_R}^{CPV}, \qquad (14)
\end{aligned}$$

where $\delta_{ss} = \xi_T + 9\xi_B - 2\xi_{Q_3}$, $\xi_a = n_a/k_a$, with k_a being the statistical weight [11] associated with the number density n_a of species "a"; and $\partial_\mu \approx v_w \frac{d}{d\bar{z}} - D_a \frac{\partial^2}{d\bar{z}^2}$ with D_a being the diffusion constant [20] from the diffusion approximation. The CPV source terms are

$$S_{\tau_L}^{CPV} = -S_{\mu_R}^{CPV} = \frac{v^2(\bar{z}) v_w \frac{d\beta(\bar{z})}{d\bar{z}} \mathrm{Im}(J_A)}{2\pi^2}\mathcal{I}, \qquad (15)$$

where $\mathcal{I}$ is a momentum-space integral that depends on the leptonic thermal masses (see Ref. [33]), and $d\beta/d\bar{z}$ characterizes the local variation of $\tan\beta(\bar{z})$ as one moves across the bubble wall. Furthermore $\Gamma_{ss} \approx 16\alpha_s^4 T$ is the strong sphaleron rate [34]; Γ_{mt} is the two body top relaxation rate [11]; and $\Gamma_{t/\tau}$ is the t/τ Yukawa induced three body rate [35]. After solving for the densities in Eq. (14), we obtain $n_L = \sum_i (Q_i + L_i)$ [36] and n_B, which is a constant in the broken phase:

$$n_B = \frac{3\Gamma_{\rm ws}}{D_q \lambda_+} \int_0^{-\infty} n_L(\bar{z}) e^{-\lambda_- \bar{z}} d\bar{z}, \tag{16}$$

where $\Gamma_{\rm ws} \approx 120\alpha_w^5 T$ [37] and $\lambda_\pm = (v_w \pm \sqrt{v_w^2 + 15\Gamma_{\rm ws} D_q})/(2D_q)$.

Assuming a fast τ_R diffusion [38], we solve the transport equations perturbatively at the leading order of Γ_t^{-1}, Γ_y^{-1}, Γ_τ^{-1}, and Γ_{ss}^{-1}. We have further neglected $\Gamma_{m\tau}$ in the final result as it is generally small compared with Γ_{mt}; then n_B is proportional to $\mathrm{Im}(y_\tau)$ with no dependence on $\mathrm{Re}(y_\tau)$. One important remaining parametric uncertainty is the difference of $\beta(\bar{z})$ in the broken and symmetric phases ($\equiv \Delta\beta$) since the CPV source term and thus n_B are both directly proportional to it. Here we take its maximum magnitude to be 0.4 and vary it to obtain the bands in Fig. 1, where the upper and lower bands give opposite signs of BAU resulting from the unknown sign of $\Delta\beta$. Imposing the condition $|M_{32}| < m_\tau$ as discussed above then restricts $\mathrm{Re}(y_\tau)$ to the region of overlap between the pink bands and the two circular regions.

VIII. RESULTS AND COLLIDER PROBES

Combining the analyses above, we find that there exist parameter regions in Fig. 1 where the observed BAU can be explained without violating current experimental bounds. These regions are characterized by $|\mathrm{Im}(y_\tau)| \gtrsim \mathcal{O}(0.1)$, corresponding to $|\mathrm{Im}(J_A)| \gtrsim \mathcal{O}(10^{-5})$ or $|\phi_\tau| > \mathcal{O}(10°)$. As indicated above, the present EDM upper bounds on these CPV parameters are roughly an order of magnitude larger than the BAU requirements. The next generation searches for neutron, atomic, and molecular EDMs that plan for order of magnitude or better improvements in sensitivities may, thus, begin to probe the BAU-viable parameter space.

Alternatively, collider measurements of the *CP* properties of the $h\bar{\tau}\tau$ coupling may also test this scenario. For example, a recent study shows that use of the ρ-meson decay plane method or impact parameter method at the LHC may allow a determination of ϕ_τ with an uncertainty of 15°(9°) with an integrated luminosity of 150 fb^{-1} (500 fb^{-1}), or $\sim$4° with 3 ab^{-1} [17]. At Higgs factories, ϕ_τ could be measured with an accuracy $\sim$4.4°(2.9°), with a 250 GeV run and 1 ab^{-1}(5 ab^{-1}) luminosity [39,40]. Therefore, the collider measurements of the *CP*-properties of the $h\bar{\tau}\tau$ coupling complement the measurements of $h \to \tau\mu$ or $\tau \to \mu\gamma$, which constrain more the parameter regions with relatively small $|\mathrm{Im} y_\tau|$ or $|\phi_\tau|$.

IX. CONCLUSION

In this letter, we explored EWBG in a simplified $\tau - \mu$ Yukawa texture in type III 2HDM. We show that three phenomena in particle physics and cosmology are strongly coherent in this context:

(i) flavor-violating Higgs decay at colliders,
(ii) cosmic baryon asymmetry (CBA),
(iii) nontrivial *CP*-properties of Higgs coupling with $\tau\tau$ leptons at colliders.

That is, a nonzero Higgs coupling with $\tau\mu$, if deciphered in type III 2HDM [41–46], generically implies the existence of a new Jarlskog invariant in the Yukawa sector which can be orders of magnitude larger than the CKM one, thus explaining the CBA, and meanwhile yields a *CP*-violating Higgs coupling with $\tau\tau$ as "smoking guns" at colliders. Compared to the existent studies on EWBG and leptogenesis in 2HDM in literatures, the new study quantitatively correlates the generation of CBA with flavor-conserving and flavor-violating Higgs measurements, both of which are being actively taken at the LHC. Interestingly, the phenomenology study in this setup can be extended to neutrino and quark sectors. For example, this setup does yield a *CP*-violating coupling between neutrinos and charged Higgs bosons which is proportional to $\mathrm{Im}(N_{\tau\tau})$. This effect could be probed in the decay of charged Higgs boson to τ and neutrinos at LHC. Extending a similar flavor structure to the quark sector, the anomalies in the measurements of $B \to D\tau\nu$ and $B \to D^*\tau\nu$ can be well explained [47]. Here the misaligned Yukawa textures can lead to CLFV interactions via the mediator $H^\pm$. We hope that our study can trigger more interests on the potential roles of Higgs bosons in flavor physics and cosmology, as well as their intrinsic correlation.

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