Lepton flavor violation in two-body decays of quarkonia

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In this paper we first study various model-independent bounds on lepton flavor violation in processes of J/ψ, ψ', and Υ two-body decays, and then calculate their branching ratios in models of the leptoquark, the R violating minimally supersymmetric standard model, and top-color assisted technicolor models.

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I. INTRODUCTION

At present, the standard model (SM) not only has theoretical shortcomings but also must face experimental difficulties. The recent measurement of the muon anomalous magnetic moment by experiment E821 [1] disagrees with the SM expectations. Moreover, there is convincing evidence that neutrinos are massive and oscillate in flavor [2]. This seems to indicate that the presence of new physics will be detected first in the leptonic part. As probing new physics, lepton flavor violation (LFV) processes have as a natural consequence an increased interest experimentally and theoretically. Several experiments that may considerably improve our knowledge of lepton flavor violating processes, such as the two-body LFV of bosons and μ and τ LFV decays, are under consideration. For example, the DESY TeV-Energy Superconducting Linear Accelerator (TESLA) project will work at the Z resonance, reaching a Z production rate of 10^9 per year [3]. A number of theoretical studies are devoted to these LFV decays to investigate the new physics effects [4–7]. For the J/ψ meson, the BES Collaboration [8] has accumulated about 10^7–10^8 J/ψ events which are available to probe lepton flavor violation of J/ψ [9]. In this article, we study the LFV processes of the heavy vector bosons J/ψ, ψ', and Υ using some models beyond the SM.

The LFV decays of J/ψ, ψ', and Υ, such as $J/\psi,\psi',\Upsilon \to \mu e, \tau l$ ($l=\mu,\tau$), are absent in the SM at the tree level because of the strong Glaskow-Iliopoulos-Maiani (GIM) suppression. They are strongly suppressed by powers of small neutrino masses and have very small branching ratios. Experimentally, there are no clear bounds for these decays. Such decays therefore give room for the existence of new physics. Reference [9] discusses these flavor decays by using the simple "unitarity inspired" relations and get rather strong model-independent constraints on these two-body LFV processes:

$$\mathrm{Br}(J/\psi \to \mu e) \leqslant 4\times 10^{-13}, \tag{1}$$

$$\mathrm{Br}(J/\psi \to \tau l) \leqslant 6\times 10^{-7}, \tag{2}$$

$$\mathrm{Br}(\Upsilon \to \mu e) \leqslant 2\times 10^{-9}, \tag{3}$$

$$\mathrm{Br}(\Upsilon \to \tau l) \leqslant 10^{-2}. \tag{4}$$

From the above constraints, we can see that perhaps the BES experiment could observe some of these processes.

In fact, in many models beyond the SM, there exist many bosons (scalars or vectors), such as leptoquarks in grand unified theories (GUTs), sleptons in supersymmetry (SUSY), and Z' in technicolor models, which can induce LFV decays at the tree level and contribute large branching ratios. In many GUTs, the existence of leptoquarks is predicted, and these have been actively searched for in many collider experiments [10]. These new particles, which carry both the lepton and quark numbers, can couple to a current comprised of a lepton and a quark [11,12]. Thus, they can lead to the vertices $J/\psi\mu e$, $J/\psi\mu\tau$, and so on. Recently, Refs. [13,14] investigated the muon anomalous magnetic moment with the leptoquarks and got a restricted parameter space. Leptoquarks can induce quarkonium decay to ll' through the t channel.

There is a similar situation in SUSY models without lepton number conservation and R parity, where the squarks play the same role as leptoquarks in GUTs [15–18]. Although the present experiments constrain those couplings in various ways, the R-parity violating coupling may give a large contribution to $J/\psi\mu e$, $J/\psi\mu\tau$, and so on.

In top-color assisted technicolor (TC2) models [19], when the nonuniversal top-color interactions are written in the mass eigenstates, it may lead to flavor changing coupling vertices of the new gauge boson Z', such as $Z'\mu e$, $Z'\mu\tau$. Thus, the Z' has significant contributions to lepton flavor changing processes like $\mu\to 3e$, and may give a severe bound on the mass $M_{Z'}$ [7]. Z' can also, but differently from leptoquarks and sleptons, induce the decay of quarkonium to ll' through the s channel.

We investigate the bounds of $J/\psi,\psi',\Upsilon \to ll'$ using a model-independent analysis in Sec. II. Then, in Sec. III, we study these bounds using a model-dependent analysis in three models, leptoquarks, SUSY, and technicolor, respectively. We give our conclusion in the last section.

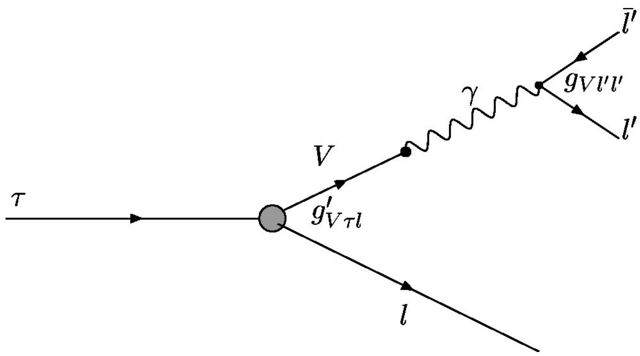

FIG. 1. Diagram of LFV decays $\tau\to l\overline{l'}l'$ through vector mesons J/ψ, Υ.

II. BOUNDS OF $V\to ll'$ USING MODEL INDEPENDENT ANALYSIS

Considering that a vector boson V, such as J/ψ, ψ', on Υ, couples to $\overline{l}l'$, the effective coupling between the vector boson V and $\overline{l}l'$ is

$$\mathcal{L}_{\rm eff}=g'_{Vll'}\overline{l}\Gamma_\alpha l' V^\alpha+\text{H.c.} \tag{5}$$

and [4]

$$\Gamma_\alpha=\left(\gamma_\alpha A_1^L+i\sigma_{\alpha\beta}\frac{q^\beta}{M}A_2^L+\frac{q_\beta}{M}A_3^L\right)P_L+(L\leftrightarrow R), \tag{6}$$

where the mass scale M is introduced to make the form factors $A_{2,3}^{L,R}$ dimensionless. For on-shell vector mesons, the $A_3^{L,R}$ form factors do not contribute. With this Lagrangian, we can calculate the decay $\tau\to ll'\overline{l'}$ (see Fig. 1). In the limit $m_e\to 0$, we obtain

$$\Gamma(\tau\to ll'\overline{l'})=\frac{g'^2_{V\tau l}g^2_{Vl'l'}m_\tau^5Q^2\alpha^2}{192\pi^3M_V^8}\left(\left|A_1^L-\frac{m_\tau A_2^R}{2M}\right|^2+\left|A_1^R-\frac{m_\tau A_2^L}{2M}\right|^2+\frac{3}{20}\left|\frac{m_\tau A_2^L}{M}\right|^2\right)+(L\leftrightarrow R), \tag{7}$$

where Q is the charge of the quark in the quarkonium, $Q=2/3$ for J/ψ and ψ' and $Q=-1/3$ for Υ. $g_{Vl'l'}$ is the vector meson decay constant and is not related to the effective coupling $g'_{V\tau l}$.

Similarly, we can get the LFV decay width

$$\Gamma(V\to\tau l)=\frac{g'^2_{V\tau l}}{24\pi}\frac{m_\tau^2}{M_V}\left(1+2\frac{M_V^2}{m_\tau^2}\right)\left(1-\frac{m_\tau^2}{M_V^2}\right)^2\times\left(\left|A_1^L\right|^2+\frac{1}{2}\left|\frac{m_VA_2^L}{M}\right|^2+(L\leftrightarrow R)\right). \tag{8}$$

Using the above equations and comparing to the standard decays $\tau\to\nu_\tau l\nu_l$

$$\Gamma(\tau\to\nu_\tau l\nu_l)=\frac{G_F^2m_\tau^5}{192\pi^3} \tag{9}$$

and

$$\Gamma(V\to l'l')=\frac{4\pi\alpha^2Q^2}{3}\frac{g^2_{Vl'l'}}{M_V^3}, \tag{10}$$

we obtain

$$\frac{\text{Br}(\tau\to ll'\overline{l'})}{\text{Br}(V\to\tau l)\cdot\text{Br}(V\to l'\overline{l'})}=\frac{\Gamma(\tau\to ll'\overline{l'})}{\Gamma(\tau\to\nu_\tau l'\overline{\nu_{l'}})}\cdot\frac{\Gamma_V^2}{\Gamma(V\to\tau l)\cdot\Gamma(V\to l'\overline{l'})}\times\text{Br}(\tau\to\nu_\tau l'\overline{\nu_{l'}})$$
$$=\frac{18\Gamma_V^2\cdot\text{Br}(\tau\to\nu_\tau l'\overline{\nu_{l'}})}{G_F^2m_\tau^2M_V^4(1+2M_V^2/m_\tau^2)(1-m_\tau^2/M_V^2)^2}\times\mathcal{A}, \tag{11}$$

where Γ_V is the total decay width of the vector bosons V and

$$\mathcal{A}=\frac{\left(|A_1^L-m_\tau A_2^R/2M|^2+|A_1^R-m_\tau A_2^L/2M|^2+\frac{3}{20}|m_\tau A_2^L/M|^2\right)+(L\leftrightarrow R)}{\left[|A_1^L|^2+\frac{1}{2}|m_VA_2^L/M|^2+(L\leftrightarrow R)\right]}. \tag{12}$$

By using the experimental bounds on $\text{Br}(\tau\to ll'\overline{l'})$ and the experimental values of $\text{Br}(V\to l'l')$ and $\text{Br}(\tau\to\nu_\tau l'\overline{\nu_{l'}})$ [20], we can obtain the bounds on $V\to\tau l$. To discuss the bounds, as in [4], we consider two limiting cases.

(1) When $|A_1^L|$ or $|A_1^R|\gg(m_\tau^2/M^2)|A_2^{L,R}|,\mathcal{A}\approx 1$. From Eq. (7), we get

$$\text{Br}(J/\psi\to\tau l)<1.0\times10^{-7}, \tag{13}$$

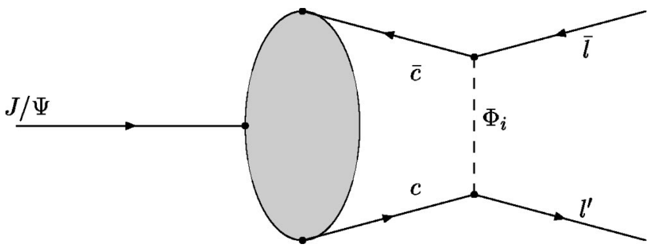

FIG. 2. Diagram of $J/\psi \to \mu\tau$ through leptoquarks or sleptons.

$$\mathrm{Br}(\psi' \to \tau l) \leqslant 0.7 \times 10^{-7}, \tag{14}$$

$$\mathrm{Br}(\Upsilon \to \tau l) < 8.0 \times 10^{-5}. \tag{15}$$

Similarly, by using $\mathrm{Br}(\mu \to e^- e^+ e^-) \leqslant 10^{-12}$ and the experimental values of $\mathrm{Br}(V \to e^- e^+)$ and $\mathrm{Br}(\mu \to \nu_\mu e \overline{\nu_e})$ [20],

$$\mathrm{Br}(J/\psi \to \mu e) < 2 \times 10^{-13}, \tag{16}$$

$$\mathrm{Br}(\psi' \to \mu e) \leqslant 1.2 \times 10^{-13}, \tag{17}$$

$$\mathrm{Br}(\Upsilon \to \mu e) < 1.7 \times 10^{-9}. \tag{18}$$

(2) When $|A_1^L|$ or $|A_1^R| \leqslant (m_\tau^2/M^2)|A_2^{L,R}|, \mathcal{A} \approx (13/10) m_\tau^2/M_V^2$. We get

$$\mathrm{Br}(J/\psi \to \tau l) < 3.6 \times 10^{-7}, \tag{19}$$

$$\mathrm{Br}(\psi' \to \tau l) \leqslant 2.5 \times 10^{-7}, \tag{20}$$

$$\mathrm{Br}(\Upsilon \to \tau l) < 2.9 \times 10^{-4}. \tag{21}$$

Similarly,

$$\mathrm{Br}(J/\psi \to \mu e) < 5.3 \times 10^{-13}, \tag{22}$$

$$\mathrm{Br}(\psi' \to \mu e) \leqslant 3.6 \times 10^{-13}, \tag{23}$$

$$\mathrm{Br}(\Upsilon \to \mu e) < 1.5 \times 10^{-8}. \tag{24}$$

From the above equations, we see that some of them [Eqs. (13) and (19)] can reach the current experimental level of BES.

III. BOUNDS OF $J/\psi \to ll'$ WITH MODEL-DEPENDENT ANALYSIS

A. Leptoquark model

Many models beyond the SM, like GUTs, naturally contain leptoquarks which can couple to a lepton-quark pair. This can induce the LFV two-body decays of J/ψ, ψ', and Υ through the t channel (see Fig. 2).

The leptoquarks contributing to these diagrams are Φ_1 and Φ_3 [14]. Their couplings are

$$\Phi_1 : [\lambda_{ij}^{(1)} \overline{Q}_{Lj} e_{Ri} + \tilde{\lambda}_{ij}^{(1)} \overline{u}_{Rj} L_{Li}] \Phi_1,$$

$$\Phi_3 : [\lambda_{ij}^{(3)} \overline{Q}_{Lj}^c L_{Li} + \tilde{\lambda}_{ij}^{(3)} \overline{u}_{Rj}^c e_{Ri}] \Phi_3.$$

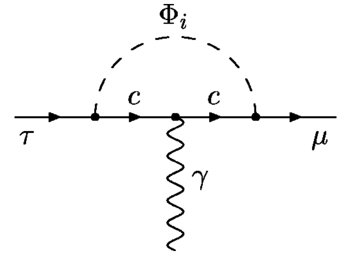

FIG. 3. Diagram of $\tau \to \mu\gamma$ through leptoquarks.

Confining ourselves to terms involving the μ τ and c quarks, and Φ_1, the relevant part of the interaction Lagrangian can be parametrized as

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{leptoquark}} = \overline{c}(\lambda_L^A P_L + \lambda_R^A P_R)\mu\Phi_A + \overline{c}(\lambda_L^A P_L + \lambda_R^A P_R)\tau\Phi_A + \mathrm{H.c.}, \tag{25}$$

where Φ is one of the above two leptoquarks, $\lambda_{L,R}$ is the structure of the chiral couplings, and $P_{L,R} = (1 \mp \gamma^5)/2$.

The decay width is

$$\Gamma(J/\psi \to \mu\tau) = \frac{|\mathbf{p}|}{32\pi^2 M_{J/\psi}} \int |\mathcal{M}|^2 d\Omega$$
$$= \frac{g_{J/\psi}^2}{96\pi} \frac{m_\tau^2}{M_{J/\psi}} \left(1 + 2\frac{M_{J/\psi}^2}{m_\tau^2}\right) \times \left(1 - \frac{m_\tau^2}{M_{J/\psi}^2}\right)^2 \cdot \frac{|\lambda_L^{c\mu}\lambda_L^{c\tau}|^2 + |\lambda_R^{c\mu}\lambda_R^{c\tau}|^2}{M_\Phi^4}, \tag{26}$$

where $g_{J/\psi}$ is the J/ψ decay constant. Comparing to the electromagnetic decay $J/\psi \to e^+ e^-$ through γ,

$$\Gamma(J/\psi \to e^+ e^-) = \frac{16\pi}{27} \alpha^2 \frac{g_{J/\psi}^2}{M_{J/\psi}^3}, \tag{27}$$

we get

$$\mathrm{Br}(J/\psi \to \mu\tau) = \frac{9}{2^9 \pi^2 \alpha^2} m_\tau^2 M_{J/\psi}^2 \left(1 + 2\frac{M_{J/\psi}^2}{m_\tau^2}\right) \times \left(1 - \frac{m_\tau^2}{M_{J/\psi}^2}\right)^2 \cdot \frac{|\lambda_L^{c\mu}\lambda_L^{c\tau}|^2 + \lambda_R^{c\mu}\lambda_R^{c\tau}|^2}{M_\Phi^4} \times \mathrm{Br}(J/\psi \to e^+ e^-). \tag{28}$$

We take the experimental value $\mathrm{Br}(J/\psi \to e^+ e^-) = (6.02 \mp 0.19)\%$ [20]. To get the constraints on $(|\lambda_L^{c\mu}\lambda_L^{c\tau}|^2 + |\lambda_R^{c\mu}\lambda_R^{c\tau}|^2)/M_\Phi^4$, we consider another lepton flavor decay $\tau \to \mu\gamma$ through leptoquarks (see Fig. 3). Comparing to the electroweak decay $\tau \to \mu\nu_\tau\overline{\nu_\mu}$, this gives a branching ratio of

$$\mathrm{Br}(\tau\to\mu\gamma)=\frac{3}{2^9\pi^2G_F^2}\cdot\frac{|\lambda_L^{c\mu}\lambda_L^{c\tau}|^2+\lambda_R^{c\mu}\lambda_R^{c\tau}|^2}{M_\Phi^4}\times\mathrm{Br}(\tau\to\mu\nu_\tau\overline{\nu_\mu}), \tag{29}$$

where G_F is the effective electroweak coupling. By using the experimental values $\mathrm{Br}(\tau\to\mu\gamma)<1.1\times10^{-6}$ and $\mathrm{Br}(\tau\to\mu\nu_\tau\overline{\nu_\mu})=(17.37\pm0.09)\times10^{-6}$, we can obtain

$$\frac{|\lambda_L^{c\mu}\lambda_L^{c\tau}|^2+|\lambda_R^{c\mu}\lambda_R^{c\tau}|^2}{M_\Phi^4}<1.5\times10^{-10}. \tag{30}$$

Thus, we obtain the bound of $\mathrm{Br}(J/\psi\to\mu\tau)$ with a scalar leptoquark as

$$\mathrm{Br}(J/\psi\to\mu\tau)<3.0\times10^{-8}. \tag{31}$$

Similarly, we get

$$\mathrm{Br}(J/\psi\to\mu e)<3.5\times10^{-15}, \tag{32}$$

$$\mathrm{Br}(\psi'\to\mu\tau)<9.3\times10^{-9}, \tag{33}$$

$$\mathrm{Br}(\psi'\to\mu e)<1.1\times10^{-15}, \tag{34}$$

$$\mathrm{Br}(\Upsilon\to\mu\tau)<1.3\times10^{-7}, \tag{35}$$

$$\mathrm{Br}(\Upsilon\to\mu e)<1.6\times10^{-14}. \tag{36}$$

B. SUSY model

In the supersymmetry model without R parity and lepton number conservation, rare processes $J/\psi,\psi',\Upsilon\to ll'$ are induced by squarks through the t channel (see Fig. 2).

The superpotential for the lepton number violating supersymmetry can be written as

$$\mathcal{W}=\mathcal{W}_{\mathrm{MSSM}}+\mathcal{W}_{\not{L}}. \tag{37}$$

$\mathcal{W}_{\mathrm{MSSM}}$ represents the R-parity conservation sector supersymmetry and can be found in the literature [15]. The R-parity violation sector superpotential is

$$\mathcal{W}_{\not{L}}=\epsilon_{ij}\lambda_{IJK}\hat{L}_i^I\hat{L}_j^J\hat{R}^K+\epsilon_{ij}\lambda'_{IJK}\hat{L}_i^I\hat{Q}_j^J\hat{D}^K, \tag{38}$$

where $\hat{L}^I$ represents the Ith generation lepton superfields and $\hat{Q}^I$ represents the Ith generation quark superfields, which are all doublets of the $SU(2)$ group. $\hat{R}^I,\hat{D}^I$ are the Ith generation $SU(2)$ singlet lepton and quark superfields. Here, we have ignored the bilinear lepton number violation terms in the superpotential [16]. Although there are 36 trilinear R-parity couplings in the superpotential Eq. (38), our computation involves only two trilinear couplings λ'_{222} and λ'_{223}.

The calculation is similar to that for leptoquarks. The relative effective Lagrangian can be written as

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SUSY}}=\frac{\lambda'_{222}\lambda'_{223}}{4M_\Phi^2}(\overline{c}P_L\mu\overline{\tau}P_Rc+\overline{c}P_L\tau\overline{\mu}P_Rc), \tag{39}$$

where M_Φ^2 is the mass of the squark.

From this Lagrangian, we can get the decay width with a squark Φ is

$$\Gamma(J/\psi\to\mu\tau)=\left(\frac{(\lambda'_{222}\lambda'_{223})^2g^2}{3\times16^2\pi M_\Phi^4}\right)\frac{m_\tau^2}{M_{J/\psi}}\left(1+2\frac{M_{J/\psi}^2}{m_\tau^2}\right)\times\left(1-\frac{m_\tau^2}{M_{J/\psi}^2}\right)^2. \tag{40}$$

Comparing to the ordinary decay $J/\psi\to e^+e^-$ [Eq. (8)], we obtain

$$\mathrm{Br}(J/\psi\to\mu\tau)=\frac{9}{8\times16^2\pi^2\alpha^2}\left(\frac{(\lambda'_{222}\lambda'_{223})^2}{M_\Phi^4}\right)m_\tau^2M_{J/\psi}^2\times\left(1+2\frac{M_{J/\psi}^2}{m_\tau^2}\right)\left(1-\frac{m_\tau^2}{M_{J/\psi}^2}\right)^2\times\mathrm{Br}(J/\psi\to e^+e^-). \tag{41}$$

As for trilinear coupling constants, we adopt the single coupling hypothesis, where a single coupling constant is assumed to dominate over all the others, so that each of the coupling constants contributes one at a time [17]. The analysis of the tree level $\not{R}_p$ contributions to the D-meson three-body decays $D\to K+l+\nu, D\to K^*+l+\nu$ yields the bounds [18]

$$\lambda'_{22K}<0.18,\quad K=1,2,3.$$

If the supersymmetry is weak-scale theory with $M_\Phi=100$ GeV, we can obtain the bound of $\mathrm{Br}(J/\psi\to\mu\tau)$ with sleptons as

$$\mathrm{Br}(J/\psi\to\mu\tau)<5.0\times10^{-9}. \tag{42}$$

Similarly, we get

$$\mathrm{Br}(J/\psi\to\mu e)<5.7\times10^{-16}, \tag{43}$$

$$\mathrm{Br}(\psi'\to\mu\tau)<1.8\times10^{-9}, \tag{44}$$

$$\mathrm{Br}(\psi'\to\mu e)<1.9\times10^{-16}, \tag{45}$$

$$\mathrm{Br}(\Upsilon\to\mu\tau)<2.2\times10^{-8}, \tag{46}$$

$$\mathrm{Br}(\Upsilon\to\mu e)<2.5\times10^{-15}. \tag{47}$$

C. TC2 models

To solve the phenomenological difficulties of traditional technicolor theory, TC2 theory [19] was proposed by combining technicolor interactions with top-color interactions for the third generation at an energy scale of about 1 TeV. TC2 models predict the existence of a new gauge boson Z', which leads to LFV coupling vertices $Z'll'$ [7]. Thus, it can give a significant contribution to some LFV processes. In

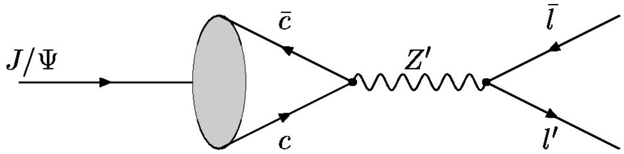

FIG. 4. Diagram of $J/\psi \to \mu\tau$ in TC2 models.

TC2 models, the contributions of Z' to the LFV process $J/\psi \to \mu\tau$ can be induced through the s channel (see Fig. 4).

The couplings of the new gauge boson Z' to ordinary fermions, which are related to the LFV process $J/\psi \to \mu\tau$, can be written as

$$\mathcal{L}_{\rm eff}^{Z'} = -\frac{g_1 \tan\theta'}{6} Z'_\mu [\overline{c_L}\gamma^\mu c_L + 2\overline{c_R}\gamma^\mu c_R + \cdots] - \frac{g_1}{2} Z'_\mu [k_{\tau\mu}(\overline{\mu_L}\gamma^\mu \tau_L + 2\overline{\mu_R}\gamma^\mu \tau_R) + \cdots], \quad (48)$$

where g_1 is the $U(1)_y$ coupling constant at the scale Λ_{TC}, $k_{\tau\mu}$ is the flavor mixing factor, and θ' is the mixing angle. With the above Lagrangian, we can obtain the decay width contributed by the new gauge boson Z':

$$\Gamma(J/\psi \to \mu\tau) = \left(\frac{\pi k_1 \tan^4\theta'}{12 M_{Z'}^2}\right)^2 \frac{g^2(k_L^2 + 4k_R^2) m_\tau^2}{12\pi M_{J/\psi}} \times \left(1 + 2\frac{M_{J/\psi}^2}{m_\tau^2}\right)\left(1 - \frac{m_\tau^2}{M_{J/\psi}^2}\right)^2. \quad (49)$$

Comparing to the ordinary decay $J/\psi \to e^+e^-$, we obtain

$$\mathrm{Br}(J/\psi \to \mu\tau) = \frac{9}{32 \times 12^2 \alpha^2}\left(\frac{k_1 \tan^4\theta'}{M_{Z'}^2}\right)^2 \times (k_L^2 + 4k_R^2) m_\tau^2 M_{J/\psi}^2 \left(1 + 2\frac{M_{J/\psi}^2}{m_\tau^2}\right) \times \left(1 - \frac{m_\tau^2}{M_{J/\psi}^2}\right)^2 \mathrm{Br}(J/\psi \to e^+e^-). \quad (50)$$

Using the results of Ref. [7], we can obtain the bound on $\mathrm{Br}(J/\psi \to \mu\tau)$ with Z' as

$$\mathrm{Br}(J/\psi \to \mu\tau) < 3.3 \times 10^{-8}. \quad (51)$$

Similarly, we get

$$\mathrm{Br}(J/\psi \to \mu e) < 3.8 \times 10^{-15}, \quad (52)$$

$$\mathrm{Br}(\psi' \to \mu\tau) < 1.0 \times 10^{-8}, \quad (53)$$

$$\mathrm{Br}(\psi' \to \mu e) < 1.2 \times 10^{-15}, \quad (54)$$

$$\mathrm{Br}(\Upsilon \to \mu\tau) < 1.3 \times 10^{-7}, \quad (55)$$

$$\mathrm{Br}(\Upsilon \to \mu e) < 1.6 \times 10^{-14}. \quad (56)$$

IV. CONCLUSIONS

We have investigated the bounds of lepton flavor violation processes of J/ψ, ψ', and Υ two-body decays in leptoquark, SUSY, and TC2 models. We used the constraints on couplings obtained in other ways to obtain the indirect bounds on $\mathrm{Br}(J/\psi, \psi', \Upsilon \to l l')$ in a model-independent way. It is interesting that some results reach the experimental level. It was also shown that these new particles perhaps can be seen or ruled out by near future experiments.

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