Measuring lepton flavor violation at LHC using a long-lived slepton in the constrained MSSM with right-handed neutrinos

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Minimal Supersymmetric Standard Model is an attractive theory. This theory gives a solution of "hierarchy problem", unification of gauge coupling constant, and dark matter candidate. In the MSSM, neutralino which is linear combination of bino, wino, and higgsinos is electorically neutral, and only weakly interacts with other particles. So, if the neutralino is the lightest SUSY particle (LSP) in the MSSM, it is an attractive candidate of the dark matter. If the neutralino is the dark matter, then mass difference (δm) between the neutralino and a next lightest SUSY particle (NLSP) have to be smaller than a few percent of the LSP mass in order to obtain relic abundance of the dark matter from coannihilation mechanism. We have considered a case where the LSP is the neutralino ($\tilde{\chi}_0$), the NLSP is the stau-like lightest slepton ($\tilde{l}_1$), and the δm is smaller than tau mass (m_τ) especially. In this case, lifetime of the NLSP becomes sensitive to effects of lepton flavor violation (LFV).

If $\delta m > m_\tau$, stau ($\tilde{\tau}_1$) can decay into a neutralino and a tau. Since this decay process is dominant and has large decay rate, lifetime of the stau is very short. However, this process is kinematically forbidden when $\delta m < m_\tau$. So, then the stau lifetime becomes long. If the LFV effects are exists in slepton sector, the stau can have new 2-body decay modes in which the stau decays into a neutralino and an electron or a muon even if $\delta m < m_\tau$. Partial decay widths of these decay modes are depends on the LFV effects strongly. So, the stau lifetime are sensitive to the LFV effects when $\delta m < m_\tau$. If the stau can be produced at LHC, LFV effects could be found by measuring the lifetime.

The LFV effects have been found from experiments of neutrino oscillation. One of the popular method to explain this effects is introducing right-handed neutrinos into a model. In our work, we calculate the LFV effects in the constrained MSSM (cMSSM) with right-handed neutrinos. In this model, new terms are added into a superpotential, because of including the right-handed neutrinos in MSSM. Then new 2 parameters are introduced. These are a neutrino Dirac Yukawa matrix $\mathbf{y}_\nu$, and a Majorana mass matrix of the right-handed neutrinos $\mathbf{M}_R$. In the cMSSM, other parameters don't have sizable off-diagonal elements at GUT scale, and one can take $\mathbf{M}_R$ diagonal by rotating base. So, only $\mathbf{y}_\nu$ has sizable off-diagonal elements at GUT scale. These off-diagonal elements induce the LFV effects in the slepton sector at lower scale.

Soft SUSY-breaking squared mass matrix of left-handed slepton ($\mathbf{m}^2_{\tilde{l}_L}$) can have sizable off-diagonal elements at lower scale. These off-diagonal elements are induced from $\mathbf{y}_\nu$ by renormalization equation

$$Q\frac{d(\mathbf{m}^2_{\tilde{l}_L})^\beta_\alpha}{dQ} = \frac{1}{16\pi^2}\left[\mathbf{m}^2_{\tilde{l}_L}\mathbf{y}^\dagger_\nu\mathbf{y}_\nu + \mathbf{y}^\dagger_\nu\mathbf{y}_\nu\mathbf{m}^2_{\tilde{l}_L} + 2(\mathbf{y}^\dagger_\nu\mathbf{m}^2_{\tilde{\nu}_R}\mathbf{y}_\nu + m^2_{H_u}\mathbf{y}^\dagger_\nu\mathbf{y}_\nu + \mathbf{A}^\dagger_\nu\mathbf{A}_\nu)\right]$$
$$+(\text{diagonal terms at one-loop})$$

where Q is renormalization scale, and α, β represent flavor e, μ, τ. On the other hand, squared mass matrix of right-handed slepton cannot have off-diagonale elements at one-loop order. Mass matrix of slepton on flavor base ($\tilde{e}_L, \tilde{\mu}_L, \tilde{\tau}_L, \tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_R$) includes $\mathbf{m}^2_{\tilde{l}_L}$. So, this matrix has sizable off-diagonal elements. When this matrix are diagonalized, the diagonalization matrix ($\mathbf{N}_{i\alpha}$) represents mixing of the slepton flavor states ($\tilde{l}_\alpha$ ($\alpha = e_L, \mu_L, \tau_L, e_R, \mu_R, \tau_R$)) in mass eigenstates

($\tilde{l}_i$ $(i=1,2,\cdots,6)$). We calculate this $\mathbf{N}_{i\alpha}$ by computer program. From this result, we calculate decay widths of the decay modes $\tilde{l}_1 \simeq \tilde{\tau}_1 \to \tilde{\chi}_0, e$ or $\tilde{\chi}_0, \mu$, and the lifetime of the lightest slepton.

In these calculation, value of $\mathbf{y}_\nu$ is important. By see-saw mechanism, $\mathbf{y}_\nu$ is given as

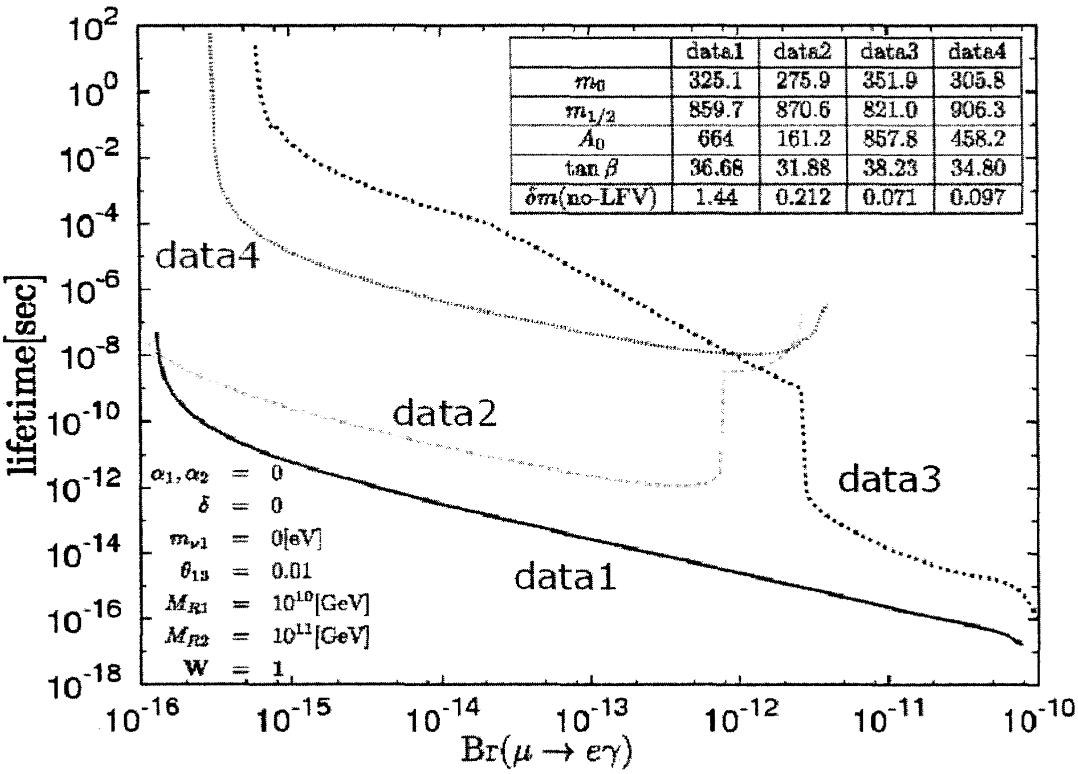
$$\mathbf{y}_\nu = \frac{1}{v_u}\sqrt{\mathbf{M}_R}\mathbf{W}\sqrt{\mathbf{m}_\nu}\mathbf{U}^\dagger_{\text{MNS}}$$

where $\mathbf{M}_R$ is diagonal right-handed neutrino Majorana mass matrix, $\mathbf{W}$ is complex orthogonal matrix, $\mathbf{m}_\nu$ is left-handed neutrino mass matrix, and $\mathbf{U}_{\text{MNS}}$ is MNS matrix. These parameters have total 18 degree of freedom. However mass differences of left-handed neutrinos ($\delta m^2_{12}, \delta m^2_{23}$), and two mixing angle in the MNS matrix (θ_{12}, θ_{23}) are determined by experiments. So, remaining free parameters are two Majorana CP phase of left-handed neutrinos, a Dirac CP phase in the MNS matrix, a 1-3mixing angle in the MNS matrix, a lightest left-handed neutrino mass, three right-handed neutrino masses, and six unobservable parameters in the $\mathbf{W}$. In these parameters, we have varied third right-handed neutrino mass M_{R3}. We fixed other prameters as

$$\alpha_1, \alpha_2 = \delta = 0,\ m_{\nu 1} = 0\,[\text{eV}],\ \theta_{13} = 0.01,\ M_{R1} = 10^{10}\,[GeV^2],\ M_{R2} = 10^{11}\,[GeV^2],$$

and $\mathbf{W}$ is identity matrix.

The lightest slepton lifetime depends on M_{R3}. Branching ratio of $\mu \to e\gamma$ also depends on M_{R3}. Figure shows correlation between the lightest slepton lifetime and the $\text{Br}(\mu \to e\gamma)$ as a numerical result. For calculation, we used 4 types of values of m_0, $m_{1/2}$, A_0, $\tan\beta$ as shown in the figure. These parameter sets gives δm smaller than m_τ when there is no-LFV. Stau lifetime is measurable within 10^{-5}-10^{-11}[sec] by ATLAS detector at LHC. If the lifetime and $\text{Br}(\mu \to e\gamma)$ can be measured, one can obtain limits on LFV parameters. $\text{Br}(\mu \to e\gamma)$ is constrained to be smaller than 1.2×10^{-11} by experiments. Even if $\text{Br}(\mu \to e\gamma)$ is too small to be measured by experiments, this could be determined by measuring the lightest slepton lifetime.



	data1	data2	data3	data4
m_0	325.1	275.9	351.9	305.8
$m_{1/2}$	859.7	870.6	821.0	906.3
A_0	664	161.2	857.8	458.2
$\tan\beta$	36.68	31.88	38.23	34.80
δm(no-LFV)	1.44	0.212	0.071	0.097

Figure 1: correlation between the lightest slepton lifetime and the $Br(\mu \to e\gamma)$