Relation of CLFV to cosmological observables in the CMSSM coannihilation scenario with SeeSaw mechanism

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Abstract

We investigate the constrained minimal supersymmetric standard model with three right-handed Majorana neutrinos whether there still is a parameter region which is consistent with all existing experimental data/limits such as leptogenesis and the dark matter abundance and we also can solve the Lithium problem. We study three cases of the right-handed neutrino mass ratio (i) $M_2 = 2 \times M_1, M_3 = 40 \times M_1$, (ii) $M_2 = 4 \times M_1, M_3 = 40 \times M_1$, (iii) $M_2 = 10 \times M_1, M_3 = 40 \times M_1$. We obtain the mass range of the lightest right-handed neutrino mass that lies between 10^9 GeV and 10^{10} GeV. The important result is that its upper limit is derived by solving the Lithium problem and the lower limit comes from leptogenesis. Low-energy observables of these parameter sets such as BR($\mu \to e\gamma$) will be verified in the near future. This talk is based on Ref. [1].

1 Introduction

There are several phenomena which cannot be explained by the standard models (SMs) of particle physics and cosmology. Among such phenomena, the mass and mixing of neutrinos, the Baryon asymmetry of the universe (BAU), the existence of the dark matter (DM), so-called Lithium (Li) problems are compelling evidences that require new physics for explanations. The new physics should be incorporated in a unified picture beyond the SM of particle physics.

Supersymmetry (SUSY) with R parity is an attractive extension, where the lightest SUSY particle (LSP) become stable. In many SUSY models, the LSP is the lightest neutralino, and is a candidate for the DM. A most feasible parameter region where the neutralino relic density is consistent with the observed DM density is the so-called coannihilation region, in which the neutralino DM and the lighter stau, as the next-LSP (NLSP), are degenerate in mass [2].

When the mass difference of the neutralino and the stau is smaller than tau lepton mass, the stau becomes long-lived so that it can survive during the Big-Bang nucleosynthesis (BBN) proceeds [3]. Such a long-lived stau forms a bound state with light nuclei, and induces some kinds of exotic nuclear reactions. Disagreements between predicted and observed primordial abundances for ^{6}Li and ^{7}Li are so-called Li problems [4, 5], and could be solved via the exotic reactions [6, 7, 8].

How about the neutrino mass and the BAU? The neutralino-stau coannihilation scenario successfully accounts for the DM and solve the problems of BBN. If the scenario actually describes our universe, tiny neutrino masses and the observed baryon asymmetry also must be generated in this scenario. In this work, we consider the constrained minimal supersymmetric standard model (CMSSM) with the type I seesaw mechanism as a unified picture. We quantitatively search for the parameter space where all phenomena as we have mentioned above are successfully explained, and will show characteristic observables for this scenario.

2 Cosmological constraints

We take into account three cosmological observables; *(i)* DM abundance *(ii)* light element abundances *(iii)* baryon asymmetry. We show strategy to find favored parameter space. We

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consider the neutralino-slepton coannihilation scenario where the LSP is Bino-like neutralino $\widetilde{\chi}_1^0$ and NLSP is lightest slepton that almost consist of RH stau including tiny flavor mixing, $\widetilde{\ell}_1 = \sum_{f=e,\mu,\tau} C_f \widetilde{f}$. The interaction state is $\widetilde{f} = \cos\theta_f \widetilde{f}_L + \sin\theta_f \widetilde{f}_R$. The flavor mixing C_f and left-right mixing θ_f are determined by RG equations with neutrino Yukawa.

In a unique parameter space for the neutralino-slepton coannihilation, we focus on the space where the mass difference between $\widetilde{\chi}_1^0$ and $\widetilde{\ell}_1$ is smaller than tau mass. Assuming flavor conservation, open decay channels of $\widetilde{\ell}_1$ are $\widetilde{\ell}_1 \to \widetilde{\chi}_1^0 \nu_\tau \pi$, $\widetilde{\ell}_1 \to \widetilde{\chi}_1^0 \nu_\tau \ell \bar{\nu}_\ell$ $(\ell \ni e, \mu)$, and so on. Due to the phase space suppression and higher order coupling the $\widetilde{\ell}_1$ becomes a long-lived particle [9, 3]. If the lepton flavor is violated, the 2-body decays are allowed, $\widetilde{\ell}_1 \to \widetilde{\chi}_1^0 \ell$ $(\ell \ni e, \mu)$. Thus the longevity depends on the degeneracy in mass and also on the magnitude of LFV.

The long-lived $\widetilde{\ell}_1$ has significant effect on light element abundances through exotic nuclear processes. To quantitatively see this effect, we evaluate the $\widetilde{\ell}_1$ number density on the BBN era.

2.1 Dark matter relic density

After SUSY particles ($\widetilde{\chi}_1^0$ and $\widetilde{\ell}_1$) are chemically decoupled from SM sector, their total density, $n = n_{\widetilde{\chi}_1^0} + n_{\widetilde{\ell}_1^-} + n_{\widetilde{\ell}_1^+}$, will be frozen. Since all of SUSY particles eventually decays into the LSP, the DM relic density is indeed the total density. We search for favored parameters by numerically solving the equation to fit n to the observed DM density [10], $0.1133 \leq m_{\widetilde{\chi}_1^0} n h^2/\rho_c \leq 0.1265$ (3σ C.L.), where $h = 0.673$ is the Hubble constant normalized to $H_0 = 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, and $\rho_c = 1.054 \times 10^{-5}\,\mathrm{GeV\,cm^{-3}}$ is the critical density of the universe.

2.2 Number density of long-lived slepton

Even after the chemical decoupling, although the total density remains the current DM density, each number density of $\widetilde{\chi}_1^0$, $\widetilde{\ell}_1^-$, and $\widetilde{\ell}_1^+$ continues to evolve. As long as the kinetic equilibrium with the SM sector is maintained, $\widetilde{\ell}_1$ and $\widetilde{\chi}_1^0$ follow the Boltzmann distribution. Processes maintaining the kinetic equilibrium are $\widetilde{\ell}_1^\pm \gamma \leftrightarrow \widetilde{\chi}_1^0 \tau^\pm$, $\widetilde{\ell}_1^\pm \tau^\mp \leftrightarrow \widetilde{\chi}_1^0 \gamma$, and so on. Even for a tiny LFV, flavor changing processes are relevant due to much larger densities of e and μ compared with of τ for the universe temperature smaller than m_τ. For example, for a reference universe temperature $T = 70\,\mathrm{MeV}$, reaction rates of these processes are

$$\frac{\langle \sigma' v \rangle_{\widetilde{\ell}_1 e \leftrightarrow \widetilde{\chi}_1^0 \gamma} n_e}{\langle \sigma' v \rangle_{\widetilde{\ell}_1 \tau \leftrightarrow \widetilde{\chi}_1^0 \gamma} n_\tau} \simeq \left(1.08 \times 10^9\right) C_e^2 \,, \quad \frac{\langle \sigma' v \rangle_{\widetilde{\ell}_1 \mu \leftrightarrow \widetilde{\chi}_1^0 \gamma} n_\mu}{\langle \sigma' v \rangle_{\widetilde{\ell}_1 \tau \leftrightarrow \widetilde{\chi}_1^0 \gamma} n_\tau} \simeq \left(9.93 \times 10^7\right) C_\mu^2 \,. \tag{1}$$

As long as $C_e \gtrsim 3.2 \times 10^{-5}$ and $C_\mu \gtrsim 1.0 \times 10^{-4}$, flavor changing processes maintain the kinetic equilibrium, and hence reduce $n_{\widetilde{\ell}_1^-}$.

2.3 Leptogenesis

We calculate the lepton asymmetry assuming the RH neutrinos being hierarchical in mass. Typical parameters for solving the Li problems are $M_1 \sim 10^{10}\,\mathrm{GeV}$ and $|\lambda_{\alpha 1}| \sim 10^{-3}$. Further, the decay parameter should be $K \equiv \Gamma_{N_1}/H(M_1) \sim \mathcal{O}(1)$ and $K_\alpha \equiv K \cdot \mathrm{BR}(N_1 \to \ell_\alpha \phi) \sim \mathcal{O}(0.1)$ $(\alpha \ni e, \mu, \tau)$. Here $H(M_1)$ is the Hubble parameter at $T = M_1$. Under such conditions, the lepton number of each flavor separately evolves, and it gives rise to $\mathcal{O}(1)$ corrections to the final lepton asymmetry with respect to where the flavor effects are ignored. The lepton and slepton asymmetry converts to the baryon asymmetry, and the conversion factor in MSSM scenarios is $Y_B = (8/23) Y_{B-L}$. The required lepton asymmetry in 3 sigma range is $2.414 \times 10^{-10} \lesssim |Y_{B-L}| \lesssim 2.561 \times 10^{-10}$ for the observed baryon number $\Omega_b h^2 = 0.0223 \pm 0.0002$ (1σ).

3 Analysis and Summary

Fig. 1 shows the correlation between M_1 and the branching ratio of $\mu \to e\gamma$ depending on M_2. The reaction rate displayed is basically proportional to the second lightest Majorana neutrino mass M_2. The enhancement comes from the elements of the Dirac neutrino Yukawa matrix λ_ν that have large absolute values for a fixed active neutrino parameter $|(\lambda_\nu)_{i2}| \propto M_2$. Each line possesses start and end point. The ^{7}Li problem is solved throughout each line. While the region wherein both ^{7}Li and ^{6}Li problems are solved is limited on the thick part in each line. It is easily understood. Too large M_1 gives rise to too large slepton mixing, and the long-lived slepton decays via the mixing before forming a bound state with ^{4}He.

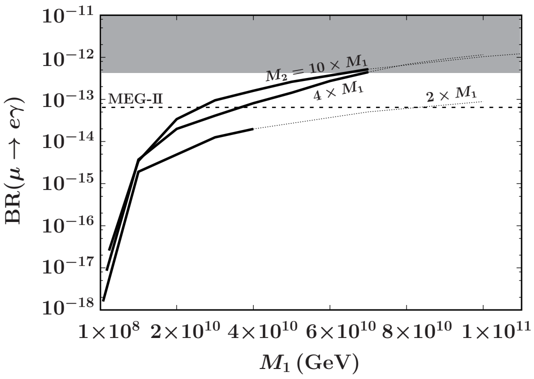

Figure 1: $\mathrm{BR}(\mu \to e\gamma)$ as a function of M_1 for $M_2 = 2 \times M_1$, $4 \times M_1$, and $10 \times M_1$. Both the ^{7}Li and ^{6}Li problems are solved with parameters for thick part, while only the ^{7}Li problem is solved for thin part. Gray region is excluded region, and the horizontal line show future sensitivity.

The parameter of RH neutrino is narrowed down to a small space through solving the ^{7}Li/^{6}Li problems and generating lepton asymmetry. This parameter leads to the clear correlation, which is therefore one of the characteristic prediction of this scenario. The prediction for $\mathrm{BR}(\mu \to e\gamma)$ lies in the range where the recent and near future experiment can probe. Our scenario can be precisely illuminated by combining LFV observables and unique collider signals.

Acknowledgement The author would like to thank organizers for financial support for traveling and local expenses.

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