Correlations between lepton flavour violation at the LHC and type-I seesaw parameters in minimal supergravity

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The most general supersymmetric seesaw mechanism has too many parameters to be predictive and thus can not be excluded by any measurement of lepton flavour violating (LFV) processes. We focus on the simplest version of the type-I seesaw mechanism assuming minimal supergravity (mSugra) boundary conditions. We compute branching ratios for the LFV scalar tau decays, \( \sim \) (\( e; \)) \( ^{0}_1 \), as well as loop-induced LFV decays at low energy, such as \( \tau_i \rightarrow \tau_j + \) and \( \tau_i \rightarrow 3\tau_j \), exploring their sensitivity to the unknown seesaw parameters. We find some simple, extreme scenarios for the unknown right-handed parameters, where ratios of LFV branching ratios correlate with neutrino oscillation parameters. If the overall mass scale of the left neutrinos and the value of the reactor angle were known, the study of LFV allows, in principle, to extract information about the so far unknown right-handed neutrino parameters.

1. INTRODUCTION

Neutrino experiments have firmly established that neutrinos are massive and global neutrino oscillation data give precise values for the neutrino mass splittings and their mixing angles. The evidence of massive neutrinos provides the first experimental signal of physics beyond the Standard Model, being the so-called seesaw mechanism the most popular mechanism to generate a nonzero neutrino mass.

In this work, we study the correlation with neutrino parameters of the ratio of LFV decay of the stau, assuming mSugra boundary conditions and the simplest type-I seesaw mechanism as the origin of neutrino masses and mixings. In this theoretical framework, left-slepтон LFV decays are proportional to the square of the off-diagonal elements of the slepton mass matrix, due to the renormalization group equation (RGE) running of the soft breaking parameters.

2. ANALYSIS

For qualitative understanding, we consider the leading-log approximate solutions to the RGE's. The left-slepтон LFV decays are then proportional to

\[
\text{Br}(\tau_i \rightarrow \tau_j +) / \left( \frac{M^2}{Y} \right)_{ij}^2 \quad : \quad (1)
\]

where \( m \) and \( M \) are the diagonal matrices with the light neutrino mass eigenvalues \( m \) and the heavy neutrino mass eigenvalues \( M \), respectively; \( U \) is the lepton mixing matrix and \( R \) is a complex orthogonal matrix. This way, the left-slepтон LFV decays are correlated to neutrino parameters

\[
\text{Br}(\tau_i \rightarrow \tau_j +) / \left( U_i U_j \right) \left( m / m_i \right) \left( m / m_r \right) \left( R K \right) \left( R K \right) \left( \log \left( \frac{M}{M} \right) \right)^2 \quad : \quad (3)
\]

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In order to eliminate most of the dependence on the supersymmetry parameters, we work with ratios of LFV decays. Thus, for example, the ratio of stau LFV decays can be expressed in terms of the parameter \( r_{23}^{13} \),

\[
\frac{\text{Br}(\tau^- e^+ + \nu_{\ell}^\mu)}{\text{Br}(\tau^- e^+)} \approx \frac{M_{\nu_{\ell}^\mu}^2}{M_{\nu_{\ell}^\mu}^2 + M_{\nu_{\ell}^\mu}^2} r_{23}^{13} \,
\]

which only depends on neutrino parameters.

In the case of degenerate right-handed neutrinos and assuming \( R \) being real and tribimaximal (TBM) mixing \[5\],

\[
r_{23}^{13} = \frac{2 (m_2 - m_1)}{2 m_2} m_{\nu} \,.
\]

Table I shows the form of Eq. [5] and its numerical values, for different neutrino scenarios. For the case \( s_{13} \neq 0 \),

Table I: Parameter \( r_{23}^{13} \) for the case of degenerate right-handed neutrinos, assuming \( R \) being real and TBM mixing. Each column corresponds to a different neutrino scenario: strict normal hierarchical (SNH), strict inverse hierarchical (SIH), quasi-degenerate normal hierarchical (QD NH) and quasi-degenerate inverse hierarchical (QDIH) neutrinos. First row shows the analytical form of the parameter \( r_{23}^{13} \); second row (BFP) shows its value when including neutrino mass splittings to their best-fit point value and third row shows its value when considering the 3 allowed range for the neutrino mass-squared differences. Note that \( m_{\nu} \) is the ratio of the solar over the atmospheric mass splitting and \( s_{13} \) is the sign of the atmospheric mass splitting.

|          | SNH          | SIH          | QD NH        | QDIH        |
|----------|--------------|--------------|--------------|-------------|
| \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) |
| BFP      | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) |
| 3        | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) | \( r_{23}^{13} \) |

Figure 1 shows the squared ratios as a function of \( s_{13}^2 \), for different neutrino scenarios and for two choices of the Dirac phase \( \text{Di} \). For strongly hierarchical right-handed neutrinos and assuming \( R \) being the identity, the parameter \( r_{23}^{13} \) does not depend on the light neutrino mass, any more, but on their mixing angles and Dirac phase. For the specific case in which \( s_{13} = 0 \), Table II shows the analytical form of \( r_{23}^{13} \) and its numerical values, for different right-handed neutrino mass scenarios. For the case of nonzero values of \( s_{13} \), Fig. 2 shows the squared ratios as a function
Table II: Parameter $r_{23}^3$ for the case of strongly hierarchical right-handed neutrinos, assuming $R$ being the identity and $s_{13} = 0$. Each column corresponds to a different heavy neutrino scenario: if $M_1$ is the heaviest mass eigenvalue (Dominant $M_1$), if $M_2$ is the heaviest mass eigenvalue (Dominant $M_2$) and if $M_3$ is the heaviest mass eigenvalue (Dominant $M_3$). First row shows the analytical form of the parameter $r_{23}^3$; second row (BFP) shows its value when fixing neutrino mixing angles to their best point value and third row shows its value considering the 3 allowed range for the neutrino mixing angles.

|                | Dominant $M_1$ | Dominant $M_2$ | Dominant $M_3$ |
|----------------|----------------|----------------|----------------|
| **BFP**       | $(r_{23}^3)^2 = 4$ | $(r_{23}^3)^2 = 1$ | $(r_{23}^3)^2 = 0$ |
| **3**          | $(r_{23}^3)^2$ [2;3;85] | $(r_{23}^3)^2$ [0.53;20] | $(r_{23}^3)^2 = 0$ |

of $s_{13}^2$, for different right-handed neutrino mass scenarios. Note that for the scenario of dominant $M_3$, the parameter $r_{23}^3$ is proportional to $s_{13}^2$.

Figure 2: Square ratios $(r_{23}^3)^2$ (blue line, dotted line), $(r_{23}^3)^2$ (red line, dashed line) and $(r_{23}^3)^2$ (green line, full line) versus $s_{13}^2$ for the case of strongly hierarchical heavy neutrinos, $R$ being the identity and the rest of the neutrino parameters fixed to their best point values. First and second panel correspond to $= 0$ and $= 0$, respectively, in the case of dominant $M_1$, while third and fourth panel correspond to $= 0$ and $= 0$, respectively, in the case of dominant $M_2$.

3. RESULTS

In order to check the validity of our analytical estimate of ratios of stau LFV decays, we have performed a numerical calculation of such LFV decays making use of the program package spheno[6]. More details can be found in Ref. [7].

For degenerate right-handed neutrinos, the panel in Fig. 3 shows the stau LFV decays as a function of the heavy neutrino mass $M_3$, for $M$ SUGRA benchmark point SPS3[8], SNH ($m_3 = 0$) and TBM mixing.

For strongly hierarchical right-handed neutrinos, the other panels in Fig. 3 show the stau LFV decays as a function of the heavy neutrino dominant mass, which is $M_1$ in the second panel, $M_2$ in the third panel and $M_3$ in the fourth panel. Again, NH and TBM have been assumed.

Note that the ratio of the stau LFV decays follows very accurately the analytical estimate in the region allowed by the upper limit on $B R(\tau e)$.

4. CONCLUSION

Neutrino experimental data show that neutrinos are massive and mix. If its origin is the simplest supersymmetric mechanism and $m$ SUGRA boundary conditions hold, then LFV decays are related to neutrino parameters. In particular, we have studied the relation of the ratio of the stau LFV decays with neutrino parameters for different neutrino scenarios.
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