Leptogenesis with exclusively low-energy CP Violation in the Context of Minimal Lepton Flavour Violation

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Abstract. We analyze lepton flavour violation (LFV) and the generation of the observed baryon-antibaryon asymmetry of the Universe (BAU) within a generalized minimal lepton flavour violation framework with three quasi-degenerate heavy Majorana neutrinos. The BAU which is obtained through radiative resonant leptogenesis can successfully be generated widely independent of the Majorana scale in this scenario and flavour effects are found to be relevant. Then we discuss the specific case in which CP violation is exclusively present at low-energies (a real R matrix) in the flavour sensitive temperature regime. Successful leptogenesis in this case leads to strong constraints on low-energy neutrino parameters.

1. Introduction

Since the discovery of neutrino masses it is known that lepton flavour is not conserved. However, from non-observation of LFV processes such as $\mu \to e\gamma$ we know that those interactions have to be highly suppressed. Extensions of the Standard Model that implement LFV should keep such processes automatically small and allow for new-physics particles with moderate masses. In the quark sector, these issues can nicely be accommodated with the Minimal Flavour Violation (MFV) hypothesis [1]. Analogously to the quark sector, Minimal Lepton Flavour Violation (MLFV) can be formulated as an effective field theory in which the lepton Yukawa couplings are the only sources of flavour violation [2]. In order to additionally explain the smallness of neutrino masses with the help of the see-saw mechanism and estabishing the requirements for leptogenesis, the MFV hypothesis in the lepton sector includes also lepton number violation at some high scale. Avoiding additional flavour violation, the three heavy right-handed Majorana neutrinos introduced are degenerate in mass.

2. General Picture

Since radiative corrections spoil the degeneracy of the Majorana masses [3, 4], it is appropriate to combine the MLFV hypothesis with a choice of a scale at which the Majorana masses are exactly degenerate [4]. A natural choice for the degeneracy scale is the GUT scale. Then the mass splittings of the Majorana neutrinos at the Majorana scale required for resonant leptogenesis [5] are induced radiatively. This mechanism to obtain the BAU is called radiative resonant leptogenesis (RRL) [6].

3. CP Violation at high and low Energies

Considering first the case with CP violation in the neutrino Yukawa couplings present at high and low energies the situation is as follows [4]:

- The baryon asymmetry of the universe can be generated of the right order of magnitude with RRL independent of the Majorana scale. The inclusion of flavour effects [7, 8] in the Boltzmann equations below a certain Majorana scale is relevant.
- Correlations between the generation of the BAU and LFV decays such as $\mu \to e\gamma$ or ratios of such processes are very weak. Therefore MLFV is not as predictive as the corresponding framework in the quark sector.
- A flavour specific treatment allows for successful leptogenesis in the special case of no high-energy CP violation which is in accordance with the findings of [8, 9].

4. Special Case of exclusively low-energy CP Violation

We study then the implications of a successful leptogenesis in the case of exclusively low-energy CP violation with the PMNS matrix being the only source of CP violation (the R matrix in Y_ν of the Casas-Ibarra Parametrization [10] is real), which can be obtained provided flavour effects are taken into account ($M \lesssim 10^9 - 10^{12}$ GeV) [4]. We find that the right amount of the baryon asymmetry of the universe can be generated in the flavour sensitive regime (see figure 1) under the following conditions [11]:

- The light neutrino masses have a normal hierarchy,
- there is at least one non-vanishing Majorana phase,
- $\sin(\theta_{13}) \gtrsim 0.13$,
- $m_{\nu,\mathrm{lightest}} \lesssim 0.04$ eV.

If these constraints are fulfilled, we find strong correlations among ratios of charged LFV processes. For example the ratio of $B(\mu \to e\gamma)/B(\tau \to \mu\gamma)$ which varies over many orders of magnitude when high-energy CP violation is present, is found then to be clearly below one (see figure 2).
Therefore the specific case of exclusively low-energy CP violation turns out to be much more predictive than the general one and offers constraints that are testable in low-energy experiments.

Acknowledgments

I would like to thank G.C.Branco, A.J.Buras and M.N.Rebelo for discussions. This research was partially supported by the German Bundesministerium für Bildung und Forschung under contract 05HT6WOA and by the Graduiertenkolleg München.

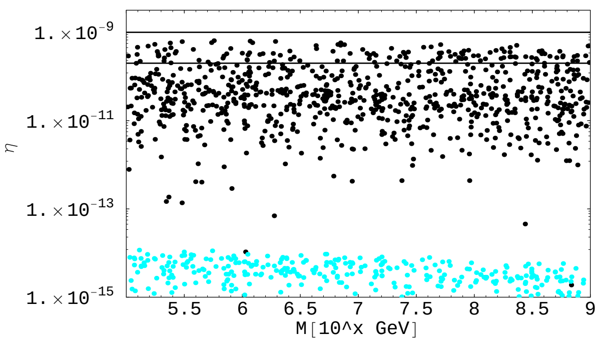

Figure 1. The BAU versus the Majorana scale up to 10^9 GeV in the case of exclusively low-energy CP violation present [11]. The *black points* correspond to the three-flavour estimate, the *light-blue points* to the single-flavour solution [5]. The two black lines mark where the BAU is of the right order of magnitude.

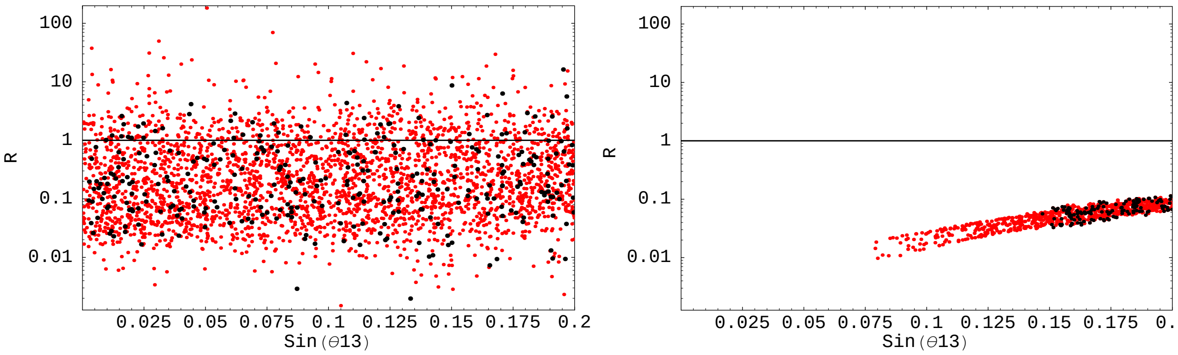

Figure 2. R $= B(\mu \to e\gamma)/B(\tau \to \mu\gamma)$ versus $\sin(\theta_{13})$ for the general analysis [4] including high-energy CP violation (left plot) and with exclusively high-energy CP violation (right plot) [11] where R is clearly below 1. The *black points* fulfill the leptogenesis constraint, the constraint on $\sin(\theta_{13})$ in the lower case can be read off.

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