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Falsifying Baryogenesis Mechanisms with Lepton Number and Flavour Violation

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Falsifying Baryogenesis Mechanisms with Lepton Number and Flavour Violation

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Abstract. Interactions that manifest themselves as lepton number violating processes at low energies in combination with sphaleron transitions typically erase any preexisting baryon asymmetry of the Universe. In this report, we discuss the constraints obtained from an observation of neutrinoless double beta decay in this context. If a new physics mechanism of neutrinoless double beta decay other than the standard light neutrino exchange is observed, typical scenarios of high-scale baryogenesis will be excluded unless the baryon asymmetry is stabilized via some new mechanism. We also sketch how this conclusion can be extended beyond the first lepton generation by incorporating lepton flavour violating processes.

1. Introduction

The observed baryon asymmetry of the Universe can be quantified as the baryon-to-photon number density ratio $\eta_B^{obs} = (n_b - n_{\bar{b}})/n_\gamma = (6.09 \pm 0.06) \times 10^{-10}$ [1] and various theories try to account for this value. One of the most popular scenarios of high-scale baryogenesis is leptogenesis, which involves lepton number violation and generates a $(B-L)$ number density asymmetry at some high scale. The created $(B-L)$ asymmetry is then rapidly translated into the baryon asymmetry by $(B+L)$ violating sphaleron processes above the electroweak scale.

Lepton number violation (LNV) is also closely related to the neutrino mass generation mechanism. If neutrinos have Majorana masses, lepton number is violated, implying the occurrence of neutrinoless double beta $(0\nu\beta\beta)$ decay. We highlight here the fact that a non-standard mechanism which contributes to $0\nu\beta\beta$ decay will also erase a pre-existing baryon asymmetry produced at high scales in the early Universe. In other words, the observation of non-standard $0\nu\beta\beta$ decay can falsify high-scale baryogenesis mechanisms [2].

2. Model Independent Description of $0\nu\beta\beta$ Decay

In order to be able to make a model independent conclusions, we describe $0\nu\beta\beta$ decay generically by $\Delta L = 2$ odd-dimensional effective operators. There are 129 such effective operators up to dimension 11 [3], for example

$$\begin{aligned}
\mathcal{O}_5 &= \Lambda_5^{-1}(L^i L^j)H^k H^l \varepsilon_{ik}\varepsilon_{jl}, \\
\mathcal{O}_7 &= \Lambda_7^{-3}(L^i d^c)(\bar{e^c}\bar{u^c})H^j \varepsilon_{ij}, \\
\mathcal{O}_9 &= \Lambda_9^{-5}(L^i L^j)(\bar{Q}_i \bar{u^c})(\bar{Q}_j \bar{u^c}), \\
\mathcal{O}_{11} &= \Lambda_{11}^{-7}(L^i L^j)(Q_k d^c)(Q_l d^c)H_m \bar{H}_i \varepsilon_{jk}\varepsilon_{lm}. \qquad (1)
\end{aligned}$$

In the above $\bar{e^c}, \bar{u^c}, \bar{d^c}$ stand for the charge conjugated $SU(2)_L$ singlets and $L = (\nu_L, e_L)^T$, $Q = (u_L, d_L)^T$, $H = (H^+, H^0)^T$ represent $SU(2)_L$ doublets. In Fig. 1 the contributions to $0\nu\beta\beta$ decay from the above four operators are diagrammatically depicted.

Assuming the dominance of a single operator, the $0\nu\beta\beta$ decay half-life can be expressed as

$$T_{1/2} = 2.1 \times 10^{25}\text{y} \cdot \left(\frac{\Lambda_D}{\Lambda_D^0}\right)^{2D-8}, \tag{2}$$

where Λ_D^0 is the scale corresponding to the current sensitivity, e.g. $\Lambda_7^0 \approx 3 \times 10^4$ GeV.

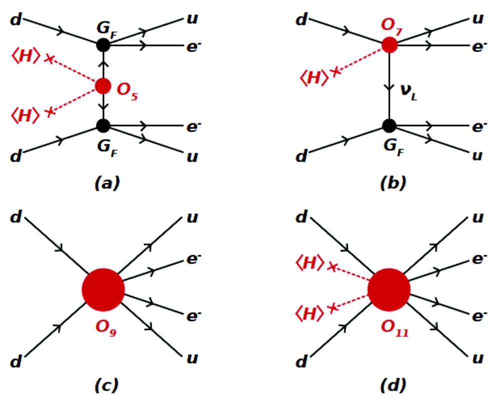

Figure 1. Diagrammatical description of the contributions to $0\nu\beta\beta$ decay triggered by the considered effective lepton number violating operators. (1)

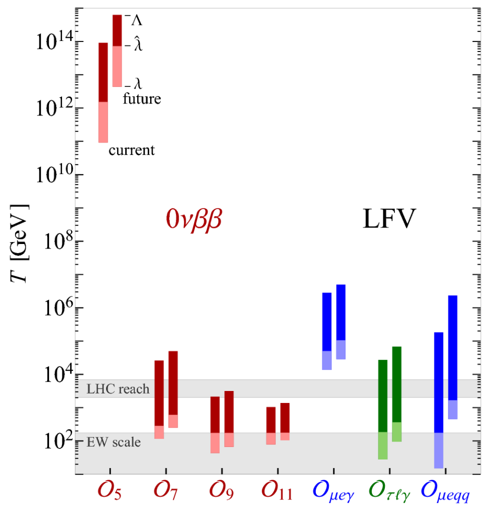

Figure 2. Equilibrium temperature ranges corresponding to particular operators employing current and future (left and right bars) sensitivity.

3. Lepton Asymmetry Washout

For the washout driven by a single LNV $\Delta L = 2$ effective operator of dimension D the Boltzmann equation for η_L, the net lepton number in dependence on temperature T and normalized to the photon density n_γ, reads

$$n_\gamma H T \frac{\mathrm{d}\eta_L}{\mathrm{d}T} = c_D \frac{T^{2D-4}}{\Lambda_D^{2D-8}} \eta_L, \tag{3}$$

where $n_\gamma \approx 2T^3/\pi^2$ is the equilibrium photon density, $H \approx 1.66\sqrt{g_*}T^2/\Lambda_{Pl}$ denotes the Hubble parameter with the effective number of degrees of freedom g_* (≈ 107 in case of SM) and the Planck scale $\Lambda_{Pl} = 1.2 \times 10^{19}$ GeV. The constant c_D acquires the following values for the four operators of our interest: $c_{\{5,7,9,11\}} = \{8/\pi^5, 27/(2\pi^7), 3.2 \times 10^4/\pi^9, 3.9 \times 10^5/\pi^{13}\}$. The cosmological condition securing that the operator $\mathcal{O}_D$ is in equilibrium reads

$$\frac{\Gamma_W}{H} \equiv \frac{c_D}{n_\gamma H}\frac{T^{2D-4}}{\Lambda_D^{2D-8}} \approx 0.3 c_D \frac{\Lambda_{Pl}}{\Lambda_D}\left(\frac{T}{\Lambda_D}\right)^{2D-9} \gtrsim 1. \tag{4}$$

The above inequality is satisfied whenever the temperature T lies in the range

$$\Lambda_D \gtrsim T \gtrsim \lambda_D \equiv \Lambda_D \left(\frac{\Lambda_D}{0.3 c_D \Lambda_{Pl}}\right)^{\frac{1}{2D-9}}, \tag{5}$$

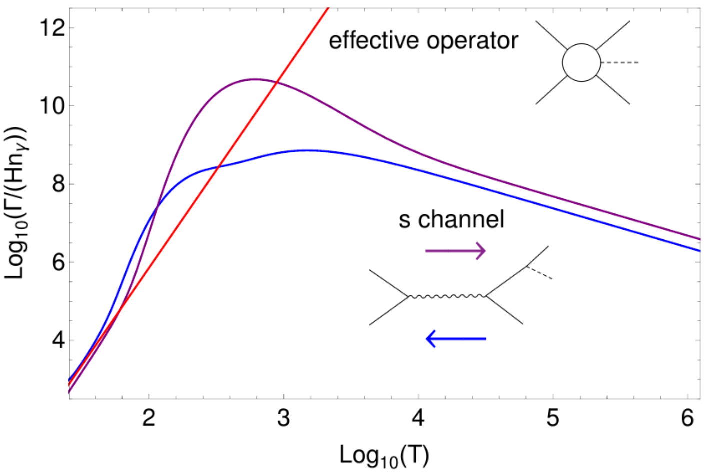

Figure 3. Comparison of washout calculated using the effective operator $\mathcal{O}_7$ (red) and the corresponding UV-completed model (blue and purple). The scale of the effective operator is set to the value $\Lambda_7 = (m_F m_B^2)^{\frac{1}{3}}$, where the heavy propagators are assigned the following masses: $m_B = 1$ TeV and $m_F = 2$ TeV.

which is shown for our four selected operators in Fig. 2. If $0\nu\beta\beta$ decay is observed and triggered by one of the non-standard mechanisms, high-scale baryogenesis scenarios above λ_D are excluded. The upper limit Λ_D is given by validity of the effective operator approach. From Fig. 2 one can see that there is a big difference between the temperature range corresponding to the Weinberg operator ($\approx 10^{14}$ GeV) and ranges for other LNV operators ($\approx 10^{3-4}$ GeV). This means that $0\nu\beta\beta$ decay can provide us with information about both low and high scales. However, it is very important to be able to distinguish non-standard mechanisms from the standard one, as they correspond to very different temperature ranges of efficient lepton asymmetry washout. This can be achieved by the observation of the decay from different isotopes or by the measurement of the angular and energy distribution of the outgoing electrons (SuperNEMO experiment). Observation of LNV at the LHC would also imply an exponential reduction of a primordial lepton asymmetry and an exclusion of highscale leptogenesis [4]. Obviously, only LNV in the electron sector can be examined using $0\nu\beta\beta$ decay. However, our conclusions can be generalised to the equilibration of other flavours, in case that lepton flavour violation occurs (see Fig. 2).

The validity of the model independent approach can be tested by comparison with fully UV-completed models containing low-energy LNV. Moreover, the interplay between LNV and LFV operators and related effects on washout can be studied in such an approach. In Fig., 3 the s-channel contribution to the washout produced by a generic model is shown and it is apparent that it is even higher than the rate of the effective operator. This further strengthens our argument that observation of $0\nu\beta\beta$ decay correspods to strong washout that would falsify many scenarios of high-scale baryogenesis.

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References

[1] P. A. R. Ade et al. [Planck Collaboration], Astron. Astrophys. **594** (2016) A13, arXiv: 1502.01589.
[2] F. F. Deppisch, J. Harz, M. Hirsch, H. Päs and W. Huang, Phys. Rev. D**92** (2015) 036005.
[3] A. de Gouvea and J. Jenkins, Phys. Rev. D **77** (2008), 013008.
[4] F. F. Deppisch, J. Harz and M. Hirsch, Phys. Rev. Lett. **112** (2014), 221601.