Journal of Physics: Conference Series

The contribution of light Majorana neutrinos to neutrinoless double beta decay and cosmology

To cite this article: S Marcocci *et al* 2017 *J. Phys.: Conf. Ser.* **888** 012178

The contribution of light Majorana neutrinos to neutrinoless double beta decay and cosmology

S Marcocci[1], S Dell'Oro[1], M Viel[2,3] and F Vissani[4,1]

[1] INFN, Gran Sasso Science Institute, Viale F. Crispi 7, 67100 L'Aquila, Italy
[2] INAF, Osservatorio Astronomico di Trieste, Via G. B. Tiepolo 11, 34131 Trieste, Italy
[3] INFN, Sezione di Trieste, Via Valerio 2, 34127 Trieste, Italy
[4] INFN, Laboratori Nazionali del Gran Sasso, Via G. Acitelli 22, 67100 Assergi, L'Aquila, Italy

E-mail: simone.marcocci@gssi.infn.it, stefano.delloro@gssi.infn.it

Abstract. The current status of the neutrinoless double beta decay ($0\nu\beta\beta$) search is briefly summarized. The newest knowledge on oscillation parameters (2016 global analysis) and the recent theoretical developments allow us to infer updated expectations and uncertainties on the experimental investigations of $0\nu\beta\beta$. In addition, the very stringent bounds on the sum of the active neutrino masses Σ by post-Planck 2015 cosmological analyses have recently become very relevant for the $0\nu\beta\beta$ search. The values of the Majorana effective mass is smaller than 100 meV at 1σ C.L.. Such results motivate further cosmological investigations of neutrino masses and have a great impact for the interpretation of future generations of $0\nu\beta\beta$ experiments.

1. Introduction

Neutrinoless double beta decay ($0\nu\beta\beta$) [1] is a key tool to address some of the major outstanding issues in particle physics, such as lepton number conservation and the Majorana nature of neutrinos. Its discovery could also provide precious information on neutrino masses [2]. The $0\nu\beta\beta$ half-life can be factorized as:

$$\left[t_{1/2}^{0\nu}\right]^{-1} = G_{0\nu} \left|\mathcal{M}_{0\nu}\right|^2 \left|f\right|^2 , \tag{1}$$

where $G_{0\nu}$ is the phase-space factor (PSF), $M_{0\nu}$ is the nuclear matrix element (NME) and f is due to the physics beyond the Standard Model. Many different mechanisms could generate the $0\nu\beta\beta$ decay. If the ordinary neutrino exchange dominates, the "Majorana effective mass":

$$m_{\beta\beta} = m_{\rm e} \left|f\right| \equiv \left|\sum_{i=1}^{3} U_{{\rm e}i}^2 m_i\right| \tag{2}$$

is a convenient parameter to study the process. $U_{{\rm e}i}$ are the elements of the PMNS mixing matrix, m_i are the masses of the individual ν_i and $m_{\rm e}$ is the electron mass. The knowledge of the oscillation parameters [3] allows to constrain $m_{\beta\beta}$. However, Majorana phases are unknown and cannot be probed by oscillations, thus they must be left free to vary in a conservative analysis of $m_{\beta\beta}$.

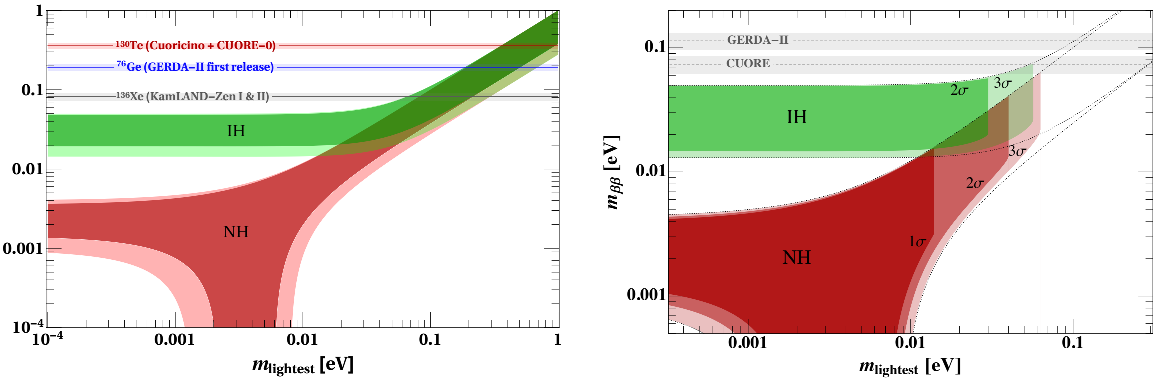

Figure 1. Constraints on $m_{\beta\beta}$ from oscillations as a function of the lightest neutrino mass with the corresponding 3σ uncertainty regions [10]. (Left) The horizontal lines show the current experimental limits for ^{76}Ge [6], ^{130}Te [7] and ^{136}Xe [8]. (Right) Constraints from cosmological surveys are added to those from oscillations. The shaded areas show the effect of the inclusion of cosmological constraints at different C. L.. The horizontal bands correspond to the expected sensitivity for two near future experiments [15].

2. Bounds on the Majorana mass

An experimental limit on the $0\nu\beta\beta$ half-life can be translated into a limit on $m_{\beta\beta}$ by reversing Eq. (1) and by using appropriate PSFs [4] and NMEs [12]. At present, the most recent and competitive bounds on $0\nu\beta\beta$ come from ^{130}Te, ^{76}Ge and ^{136}Xe ($t^{1/2}_{\mathrm{Ge}} > 5.3 \cdot 10^{25}$ yr [6], $t^{1/2}_{\mathrm{Te}} > 4.0 \cdot 10^{24}$ yr [7], $t^{1/2}_{\mathrm{Xe}} > 1.1 \cdot 10^{26}$ yr [8] at 90% C. L.).

A graphical representation of the current limits is shown in the left panel of Fig. 1, where the allowed regions for $m_{\beta\beta}$ are plotted as a function of the lightest neutrino mass for both the mass hierarchies [9, 10]. However, the theoretical uncertainty on NMEs is very large. Present and future scenarios could actually be worse than what is depicted by the horizontal bands in the plot. As it appears from Fig. 2, the main reasons for this fact are not the differences among the available theoretical models (QRPA [11], IBM-2 [12], ISM [13], . . .). Instead, the possible downward renormalization (i. e. reduction) of the value of the axial vector coupling constant g_A in the nuclear medium has (potentially) a much higher impact, as highlighted in right panel of Fig. 2. In particular, a few cases should be considered for the value of g_A, as shown in the figure and as discussed in Ref. [10].

3. Recent results from cosmology and implications for the $0\nu\beta\beta$ search

One of the most recent limits from cosmological surveys on the sum of the active neutrino masses (Σ) is so stringent, that it better agrees with the normal hierarchy ($\mathcal{NH}$) spectrum, rather than with inverted ($\mathcal{IH}$) one [14]. Similar results are obtained in newer and independent analyses (see Ref. [2] for further details). In particular, the limits reported in Ref. [14] imply:

$$\Sigma < 84\,\mathrm{meV}\ (1\sigma\,\mathrm{C.\,L.}) \qquad \Sigma < 146\,\mathrm{meV}\ (2\sigma\,\mathrm{C.\,L.}) \qquad \Sigma < 208\,\mathrm{meV}\ (3\sigma\,\mathrm{C.\,L.}). \qquad (3)$$

Results on Σ from cosmological surveys have been somewhat controversial in the past and thus they have to be taken with due caution. However, the recent developments show constant improvements in the systematics evaluation.

It is possible to combine the limit on Σ with the constraints on $m_{\beta\beta}$ coming from oscillations, according to the procedure outlined in Ref. [15]. The result is shown in the right panel of Fig. 1, where it can be seen that the oscillation parameters induce only minor uncertainties on the

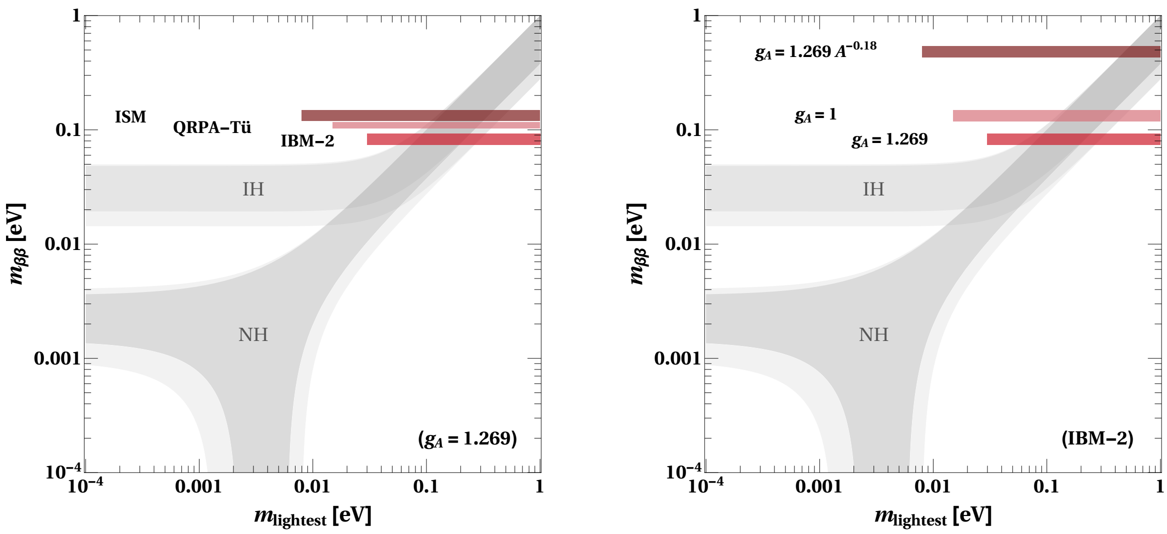

Figure 2. Uncertainty of the current $m_{\beta\beta}$ bound from ^{136}Xe [8]. (Left) Dependence on the NME (QRPA [11], IBM-2 [12], ISM [13]). (Right) Dependence on the value of the axial vector coupling constant. See Ref. [2] for an extensive discussion.

expected value of $m_{\beta\beta}$. They are responsible for the widening of the allowed contours in the upper, lower and left sides of the picture. The boundaries in the rightmost regions are due to the information from cosmology and are cut at various confidence levels. It is notable that at 1σ, due to the exclusion of the $\mathcal{IH}$, the set of plausible values of $m_{\beta\beta}$ is highly restricted.
The next generation of $0\nu\beta\beta$ experiments is expected to probe the upper values of the predicted $\mathcal{IH}$ region, with sensitivities for $m_{\beta\beta}$ of a few tens of meV (assuming no quenching on g_A) [10]. In order to probe $m_{\beta\beta}$ values compatible with the current tight bounds on Σ, assuming the correctness of the new cosmological analyses, multi-ton scale detectors are needed [15, 16].
Nevertheless, a signal from the next generation of experiments will either imply a mechanism different from the light Majorana neutrino exchange as mediator for the $0\nu\beta\beta$ process, or it will disprove some assumptions of present cosmological models.

References

[1] Furry W H, *Phys. Rev.* **56**, 1184 (1939).
[2] Dell'Oro S, Marcocci S, Viel M and Vissani F, *Adv. High Energy Phys.* **2016**, 2162659 (2016).
[3] Capozzi F, Lisi E, Marrone A, Montanino D and Palazzo A, *Nucl. Phys.* B **908**, 218 (2016).
[4] Kotila J and Iachello F, *Phys. Rev.* C **85**, 034316 (2012).
[5] Barea J, Kotila J and Iachello F, *Phys. Rev.* C **91**, 034304 (2015).
[6] B. Schwingenheuer, seminar at LNGS (June, 29th 2016).
[7] Alfonso K *et al.* (CUORE Collaboration), *Phys. Rev Lett.* **115**, 102502 (2015).
[8] Gando A *et al.* (KamLAND-Zen Collaboration), *Phys. Rev Lett.* **117**, 082503 (2016).
[9] Vissani F, *J. High Energy Phys.* **9906**, 022 (1999).
[10] Dell'Oro S, Marcocci S and Vissani F, *Phys. Rev.* D **90**, 033005 (2014).
[11] Šimkovic F, Rodin V, Faessler A and Vogel P, *Phys. Rev. C* **87**, 045501 (2013).
[12] Barea J, Kotila J and Iachello F, *Phys. Rev. C* **91**, 034304 (2015).
[13] Menéndez J, Poves A, Caurier E and Nowacki F, *Nucl. Phys. A* **818**, 139 (2009).
[14] Palanque-Delabrouille N *et al.*, *J. Cosm. Astropart. Phys.* **1502**, 045 (2015).
[15] Dell'Oro S, Marcocci S, Viel M and Vissani F, *J. Cosm. Astropart. Phys.* **1512**, 023 (2015).
[16] Viel M, talk at Neutrino 2016. [Proceedings under publication]