Journal of Physics: Conference Series

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To cite this article: A Vishneva *et al* 2017 *J. Phys.: Conf. Ser.* **888** 012193

Test of the electron stability with the Borexino detector

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Abstract. Despite the fact that the electric charge conservation law is confirmed by many experiments, search for its possible violation remains a way of searching for physics beyond the Standard Model. Experimental searches for the electric charge non-conservation mainly consider electron decays into neutral particles. The Borexino experiment is an excellent tool for the electron decay search due to the highest radiopurity among all the existing experiments, large detector mass, and good sensitivity at low energies. The process considered in this study is a decay into a photon and a neutrino, for which a new lower limit on the electron lifetime is obtained. This is the best electron lifetime limit up to date, exceeding the previous one obtained at the Borexino prototype at two orders of magnitude.

1. Introduction

Electron stability tests are the most common way of searching for possible electric charge conservation violation. Since the electric charge non-conservation (CNC) is incompatible with the Standard model [1], search for CNC processes is a way to discover new physics, or to validate the Standard model in case of their absence.

Processes usually considered in the electron stability tests are decays of electron to neutral particles: decay to 3 neutrinos (disappearance mode), and decay to a neutrino and a photon. Such tests were performed many times at various experiments (for recent review see [2]). Among these experiments Borexino has unique properties to improve the electron lifetime limit for the decay mode $e \to \gamma\nu$.

Borexino is a liquid scintillation neutrino detector located in Laboratori Nazionali del Gran Sasso, Italy [3]. Its active medium consists of 278 tons of pseudocumene (1,2,4-trimethylbenzene) with admixture of PPO (2,5-diphenyloxazole) at a concentration of 1.5 g/l. The energy threshold of Borexino is low enough to provide sensitivity to the electron decay mode $e \to \gamma\nu$ which is indicated by a monoenergetic photon of energy equal to half of the electron mass (256 keV). Radioactive background level in this region is 0.15 day^{-1}ton^{-1}keV^{-1}, which is the lowest one among all the existing experiments. This fact along with large statistics and well-studied background sources provides excellent sensitivity to the electron decay. The expected

IOP Conf. Series: Journal of Physics: Conf. Series **888** (2017) 012193 doi:10.1088/1742-6596/888/1/012193

improvement of the electron lifetime limit is at two orders at magnitude with respect to the previous best limit which is obtained at the prototype of Borexino [4].

2. Analysis approach

The 408 days livetime data set used in the analysis is acquired during the second phase of Borexino. The second phase started after an extensive purification campaign which has led to decrease of the event rates of several background components. The spectrum in the region of interest includes solar neutrinos (pp, ^{7}Be, pep, CNO), synthetic pile-up, and decays of radioactive elements (^{14}C, ^{210}Bi, ^{210}Po, ^{85}Kr and others). More thorough description of the spectrum composition can be found in [5].

The approach is to perform the spectral fit of the data with the fitting function modified by including the signal from the electron decay. The 256 keV photon emitted in the decay mode $e \to \gamma\nu$ is simulated using GEANT4, its rate is fixed at various values and added to the fitting function. Likelihood profile obtained from the corresponding set of spectral fits shows compatibility of the electron decay rate with zero within one standard deviation. The upper limit on the decay rate is 1.23 counts/day per 100 tons at 90% confidence level, which corresponds to the lifetime limit of $\tau \geqslant 7.2 \times 10^{28}$ years.

There are also several sources of systematic errors, namely, the uncertainty of the scintillator light yield determination, fiducial mass uncertainty, and the choice of an observable for energy reconstruction. These uncertainties lead to the additional smearing of the likelihood profile, which gives finally $\tau_{e\to\gamma\nu} \geqslant 6.6 \times 10^{28}$ years at 90% CL. Nowadays this result is the best electron lifetime limit for the considered decay mode. More detailed analysis description can be also found in [2], [6].

3. Theoretical implications

There is no any non-contradictory theory able to describe the electric charge conservation violation. However, there is an approach proposed by Bahcall [7] for estimating the magnitude of violation using the experimental limits. According to this approach, the CNC Lagrangian has a usual form and includes a small factor serving as a measure of charge non-conservation. For instance, the Lagrangian for the process considered in this study takes form

$$\mathcal{L}_{e\nu\gamma} = \frac{1}{2} e \varepsilon_{e\nu\gamma} \bar{\psi}_e \gamma_\mu (1 - \gamma_5) \psi_\nu A^\mu + \text{h. c.}, \tag{1}$$

where $\varepsilon_{e\nu\gamma}$ is the small CNC parameter. As was shown in [8], the transition probability for this decay is

$$\lambda_{e\nu\gamma} \simeq \varepsilon_{e\nu\gamma} \frac{\alpha}{32\pi} \frac{m_e c^2}{\hbar} \left(\frac{m_e}{m_\gamma} \right)^2. \tag{2}$$

Taking the best photon mass limit of 1×10^{-18} eV one can get $\varepsilon_{e\nu\gamma} \leq 3.3 \times 10^{-101}$ (90% CL), which is an almost five orders of magnitude stronger limit than the one obtained previously by DAMA collaboration [8].

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