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Abstract. The new limit on the electron lifetime is obtained from data of the Borexino experiment. The expected signal from the $e \to \gamma\nu$ decay mode is a 256 keV photon detected in liquid scintillator. Because of the extremely low radioactive background level in the Borexino detector it was possible to improve the previous measurement by two orders of magnitude.

1. Introduction

The electric charge conservation law is a fundamental physical principle. There are no hints for violation of this law neither in theory within the Standard model nor in any experiment. Since the electric charge non-conservation (CNC) is admitted in exotic theories such as extra-dimensional theories [1], investigation of such processes is an evident way to search for physics beyond the Standard model.

The most frequently searched for CNC processes are decays of the electron into neutral particles. Two decay modes are usually accounted for experimentally:

$$e \to \gamma\nu, \tag{1}$$

where a monoenergetic 256 keV photon is searched for, and

$$e \to \nu\nu\nu, \tag{2}$$

where only effects due to the electron disappearance would be observed. However, the impossibility of occurrence of such processes is presented in [2], where it is shown that such decays would be followed by a huge amount of low-energy bremsstrahlung photons. For the process (1) it would mean the absence of 256 keV photon while the electron disappearance is more model-independent and the corresponding atomic effects in the case (2) would remain the same. Thus one can see that observing the 256 keV photon from the electron decay would mean not only CNC but also going beyond the Standard model.

2. Overview of experiments

Study of the electron stability has long experimental history. The list of the experiments in which the electron decay was being searched for is presented in table 1. There are also plans for providing analogous studies at present and future experiments [18, 19, 20].

Table 1. Experimental tests for the electron stability.

year	material	limit for $e \to \gamma\nu$	limit for $e \to \nu\nu\nu$	CL	reference
1959	NaI	10^{19}	10^{17}	68%	[3]
1965	NaI	4×10^{22}	2×10^{21}	68%	[4]
1975	Ge	—	5.3×10^{21}	68%	[5]
1979	NaI	3.5×10^{23}	—	68%	[6]
1983	Ge	3×10^{23}	2×10^{22}	68%	[7]
1986	Ge	1.5×10^{25}	—	68%	[8]
1993	Ge	1.63×10^{25}	—	68%	[9]
1995	Ge	2.1×10^{25}	2.6×10^{23}	90%	[10]
1996	Xe	2×10^{25}	1.5×10^{23}	68%	[11]
1999	NaI	—	$(1.5 - 2.4) \times 10^{23}$	90%	[12]
1999	NaI	—	2.4×10^{24}	90%	[13]
2000	Xe	2×10^{26}	—	90%	[14]
2002	PXE	4.6×10^{26}	—	90%	[15]
2007	Ge	1.93×10^{26}	—	90%	[16]
2012	NaI	—	1.2×10^{24}	90%	[17]

2.1. NaI detectors

Experiments based on NaI detectors were the first to provide the limits on the electron stability [3, 4].The expected signal for the mode (2) is a photon with maximal energy of 33.2 keV emitted while filling the vacancy caused by the electron disappearance from the iodine K-shell. The decay to a photon and a neutrino is investigated by searching for the 256 keV photon. Various coincidence techniques are also applied in such detectors. First was the search of simultaneous 256 keV and 33.2 keV photons occurence [4]. Another approach based on the electron capture by a nucleus without the consequent atomic number change was considered recently in [17]. Simultaneous observation of the 33.2 keV photons and the nucleus deexcitation (417.9 keV) would mean the electron disappearance.

2.2. Ge detectors

The electron stability is widely studied using germanium detectors. The main advantage of such detectors is good energy resolution (about 1 keV). In addition, the background level in the region of interest is lower than that in NaI detectors. The expected signal is a photon of energy 11.1 keV for the mode (2) and a 256 keV photon for the mode (1), respectively.

2.3. Liquid scintillators

The strongest limits on the electron lifetime with respect to the decay mode (1) during the last fifteen years have been obtained with liquid scintillation detectors. Their main advantages are large mass and a possibility of purification from radioactive contaminations. The first one was

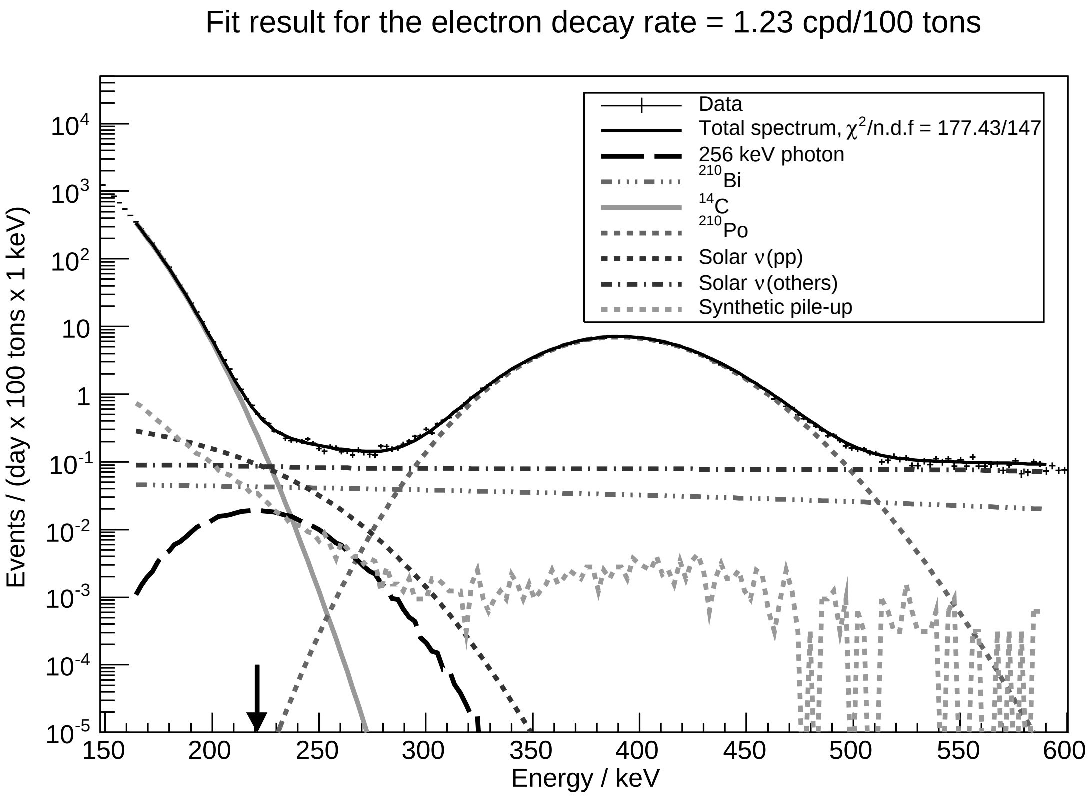

Figure 1. Borexino spectrum composition.

DAMA/LXe experiment [11, 14]. This detector contains 6.5 kg ($\sim$ 2 litres) of liquid xenon. This apparatus has rather low energy threshold and is sensitive to both electron decay modes.

The second one is the prototype of the Borexino detector, CTF-II [21]. Its main goal was to test the purification techniques developed for Borexino. During the tests various scintillators were used. CTF-II was filled with 4 tons of PXE (phenylxylylethane) which has less ionization quenching in comparison with PC (pseudocumene) used in Borexino. Large mass and extremely low background level made it possible to obtain a stronger limit of 4.6×10^{26} years (90% confidence level) on the electron lifetime in shorter exposure time. This result remained the best until the same study was performed in Borexino.

3. The Borexino detector

Borexino is a large volume scintillation detector located deep underground in the Laboratori Nazionali del Gran Sasso [22]. Its active media contains 278 tons of organic liquid scintillator, namely, pseudocumene (1,2,4-trimethylbenzene) with admixture of PPO (2,5-diphenyloxazole) at a concentration of 1.5 g/l. Borexino has extremely low background level in the region of interest, namely 0.15 day^{-1}ton^{-1}keV^{-1}. The energy threshold is above 50 keV so Borexino is not sensitive to the disappearance mode. By comparing sensitivity of CTF and Borexino the expected electron lifetime limit is estimated, which exceeds the previous one at two orders of magnitude.

4. The electron decay search

4.1. Analysis approach

The data set used in the analysis were acquired from January 2012 to May 2013 (Borexino Phase 2). This data set was obtained after the purification campaign [23] which reduced in particular the contamination of ^{85}Kr and ^{210}Bi which give a significant contribution in the low-energy region.

The same 408 days data set is successfully used in the measurement of solar pp-neutrino flux [24]. In this analysis the same energy range (150–600 keV) and parameters used in the fitting procedure are considered. The only difference is the addition of the 256 keV photon line in the fitting function. The sample of spectral fit is shown on Fig. 4.1. One can see that the sought-for peak (marked by arrow) is shifted to the lower energies due to ionization quenching.

4.2. Constraint on the pp-neutrino event rate

The 256 keV photon occurrence is strongly correlated with pp-neutrino event rate. Therefore treating the pp-neutrino rate as a free parameter in the fit leads to non-physical values at the limit. Indeed, the 256 keV photon event rate corresponding to the 90% confidence level ($\simeq$ 12 cpd/100 tons) corresponds to zero pp-neutrino rate which is not consistent with observations by radiochemical experiments [25]. As far as the latter ones are not sensitive to the electron decay it is reasonable to use their results to constrain the pp-neutrino event rate. This constraint gives the limit on the event rate of 1.23 cpd/100 tons. The lifetime limit is expressed as $\tau \geqslant \epsilon \mathrm{N}_e \mathrm{T}/\mathrm{S}_{\mathrm{lim}}$, where N_e is the total number of electrons in the detector, ϵ is the fraction of electrons survived after the fiducial volume cut, T is the exposure time, and $\mathrm{S}_{\mathrm{lim}}$ is the event rate limit. It gives the electron lifetime of $\tau \geqslant 7.2 \times 10^{28}$ years.

4.3. Systematic errors study and final results

The main sources of the systematic errors in this study are the following. The most important is the precision of the scintillator light yield measurement ($\sim$ 1%). It strongly influences the peak position and therefore affects the sensitivity. Another source of systematic errors is the fiducial mass measurement precision, which gives negligible effect. Choice of the energy estimator can also affect the result. In the present study two variables are used as energy estimators, namely, number of PMTs hit in the time intervals of 230 ns and 400 ns. After having accounted for all these effects the lifetime limit has become weaker and the final result for the electron lifetime limit is $\tau_{e\rightarrow\gamma\nu} \geqslant 6.6 \times 10^{28}$ years at the 90% confidence level. This study is described in more details in [26].

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