Data analysis for double beta decay processes in natural tin

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Introduction

In the recent past the terrestrial and extraterrestrial searches for neutrino mass, through the study of atmospheric, solar, reactor and supernova neutrino sources, have finally successfully established that neutrino has mass [1,2]. However, in oscillation experiments only the differences of squares of the neutrino masses, $\Delta m^2 \equiv |m^2_2 - m^2_1|$, can be measured, and the result does not predict the charge conjugation of neutrinos, i. e., whether they are Dirac or Majorana fermions [3]. The quest for physics beyond the standard model is gathering pace, with searches performed at accelerators such as the Tevatron, HERA, and CERN Large Hadron Collider (LHC), and also non-accelerator experiments, like the rare process of neutrinoless double beta decay (0υββ). The mass and nature of neutrinos play an important role in the theories beyond the Standard model. Double beta decay (2υββ) and nuclear (single) beta decay can provide the information on absolute effective mass of neutrinos [4]. 0υββ can also provide information about true nature of neutrino. 0υββ model also predicts that total lepton number, one of the fundamental conserved quantities of the standard model, is violated. It has been reported that the 2υββ decay allows investigating particle properties; in particular whether the Pauli Exclusion Principle is violated for neutrinos and thus neutrinos at least partially obey Bose–Einstein statistics [5].

In 2υββ, which is allowed by the standard model, two neutrons in the same nucleus decay simultaneously to emit two antineutrinos and two electrons? This was first discussed by M. Goeppert-Mayer in 1935 in the form of [6]

$$(Z,A) \rightarrow (Z+2,A) + 2e^- + 2\bar{\nu}_e \; (2\upsilon\beta\beta \text{ decay}) \quad ...(1)$$

Soon after the Geoppert-Mayer work, Majorana proposed a two-component neutrino [7]. Racah [8] and Furry [9] discussed another decay mode as

$$(Z, A) \rightarrow (Z+2,A) + 2e^- \; (0\upsilon\beta\beta \text{ decay}) \quad ...(2)$$

This mode violates total lepton number by two units and is forbidden in standard model.

Double beta decay processes in Tin isotopes

Double beta transitions of tin isotopes that emit γ rays are discussed here. There are three double beta isotopes of tin, like- ^{122}Sn and ^{124}Sn in the two-electron mode and ^{112}Sn for β+/EC and EC/EC decays. The Q values of the transition for ^{122}Sn, ^{124}Sn and ^{122}Sn isotopes are 366, 2287 and 1922 keV, and the natural abundances are 4.63%, 5.79%, and 0.97%, respectively. As there is no excited state of interest for ^{122}Sn decay, following decays are considered:

$$^{124}\text{Sn} \rightarrow {}^{124}\text{Te} + 2e^- + 2\bar{\nu}_e + \gamma \quad \dots (3)$$

$$2e^- + {}^{112}\text{Sn} \rightarrow {}^{112}\text{Cd} + (2\nu_e) + \gamma \quad \dots (4)$$

$$e^- + {}^{112}\text{Sn} \rightarrow {}^{112}\text{Cd} + e^+ + (2\nu_e) + \gamma \quad \dots (5)$$

Detailed double beta decay schemes of ^{124}Sn and ^{112}Sn have been reported in [10, 11]. From decay scheme of ^{124}Sn and ^{112}Sn, we find that primarily de-excitation take place via emission of 602.7 keV and 617 keV gamma rays, respectively.

The general expression used to calculate half-life for ββ decay is given by

$$T_{1/2} \sim \ln 2(Nt\varepsilon)/S \quad ... (6)$$

where N is number of ββ nuclei in the sample, ε is the detector efficiency, t is the duration of experiment and S is the maximum number of ββ events which can be extracted with a 90% confidence level.

Data analysis

Data analysis for double beta decay (DBD) processes is mainly done by three methods: (i) Bayesian method, (ii) maximum χ^2 method, (iii) maximum likelihood method. Klapdor, Dietz, and Krivosheina [12] have shown that the Bayesian method also predicts the existence of a peak for $0\upsilon\beta\beta$ mode. But this result leads to controversies. One main drawback with the later two methods is that at low counting rates observation of lines with negative values of parameters is possible. This is excluded in the Bayesian method. However in a separate work Arnaboldi et al [13] have justified their analysis with the later two methods for CUORICINO data.

In Bayesian method of data analysis one defines a distribution of different count rates in each bin of the spectrum for given parameters. Since DBD is a rare process therefore we expect the count rates to consider the Poisson distribution. Here we have chosen Poissonian for the individual bins. The distribution function is parameterized by the total intensity in the spectrum, and the relative intensity in the Gaussian line. Following the standard procedure we calculate the likelihood function and error interval for the peak. When the prior distribution is set constant the Bayesian method is roughly same as the maximum likelihood method.

Results and Discussion

Data for 13.3 g natural tin has been taken at Gran Sasso underground laboratory for ~100 days with low background Germanium detector facility. The data analysis is in the process of evaluating limits for half life of tin isotopes. The rough estimation for the half life with ε=0.5 and S=1.64σ gives value in the order of 10^{19} years. Exact calculations shall be reported in the symposium.

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