Sensitivity of $\beta\beta$ decay experiment of natural tin using HPGe

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1. Introduction

Double beta decay is a second order weak and rare process. A highly sensitive double beta decay experiment requires the best possible energy resolution and lowest possible background at energies near the $\beta\beta(0\nu)$ Q-value.The sensitivity of double beta decay experiment scales with the product of source mass and exposure time, M.t, as long as no background events are observed around the peak search for. If there would be any background events are observed around the peak, sensitivity will scales with the square root of the product M.t divided by the background index (BI) expressed in cts/(keV.kg.yr) and the energy window defining the signal region Δ E, i. e. $(\frac{M.t}{BI\Delta E})^{\frac{1}{2}}$ [1].

2. Experimental set-up and Background sources Simulation

A uniform distribution of the radioactive isotopes in the sample was assumed. Background originating from the detector system as well as γ-rays produced in the vicinity of the detector system which then propagate into the detector volume were included in simulation. The ^{238}U and ^{232}Th decay chains were assumed to be in secular equilibrium in the simulation of radioactive decays. The probability distribution functions of each component have been generated by Geant4 [2] Monte Carlo simulations assuming specific source locations. The goodness of the fit was then performed to the aforementioned background components to check how accurately describe the data set with the present statistics.

A search for double β-decay modes in a sample of natural tin was performed at Gran Sasso National Laboratory (LNGS) of the INFN (Italy) with a coaxial n-type ultra low background HPGe detector (GeBer) with volume of 244 cm^3. The data were accumulated over 2367 h for sample and over 6109 h for background (without sample).

3. Background model and Half-life measurement

TABLE I: Major contributions of the radioactive sources to the background model.

Source	Counts	Source	Counts
^{228}Ac	32416	^{212}Bi	7989
^{214}Bi	9399	^{60}Co	2200
^{137}Cs	171	^{40}K	31277
^{212}Pb	9189	^{214}Pb	10813
^{208}Tl	3455		
Experimental	100268		

Spectral shapes included in the model matrix to produce background model are: ^{228}Ac and ^{208}Tl, measured on the surface of the detector and in the sample, ^{214}Bi, ^{214}Pb and ^{212}Pb, measured around the detector set-up and in the sample, ^{212}Bi, measured around the detector set-up, ^{40}K, ^{60}Co and ^{137}Cs, measured on the surface of the detector and in the sample and muons and neutrons contributions from the environment. All the contributions are then added to the background model. The total counts from each contribu-

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tion in the model are summarized in Table I which are in agreement with experiment. In Table II and Table III, the intensity of the major peaks in the simulated model are compared with that of the major peaks found in experimental spectrum. The comparision of simulated and experimental spectra are shown in fig 1 which are well agreement except below 400 keV. The difference might occur due to the intrinsic radioactivity of the HPGe detector material.

TABLE II: Comparision of the major peaks in the model spectrum with that in the background spectrum

Isotopes	Energy (keV)	model	spectrum
^{212}Pb	238.6	475±50	453±43
^{214}Pb	351.9	478±28	412±33
^{137}Cs	661.7	254±25	253±19
^{212}Bi	727.3	40±16	39±18
^{228}Ac	911.2	100±19	119±14
^{60}Co	1173.2	162±18	157±14
^{40}K	1460.7	584±25	802±26
^{214}Bi	1764.5	85±10	74±9
^{208}Tl	2614.5	107±9	98±10

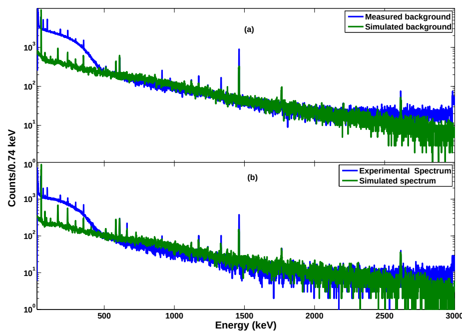

FIG. 1: Comparision of (a) measured background and simulated background spectrum and (b) measured spectrum with natural tin sample and simulated contribution to the measured spectrum of the radioactive decays.

The $\beta^-\beta^-$ decay from ^{124}Sn to 2_1^+ state of ^{124}Te occurs through emission of 602.7 keV γ ray from the 2_1^+ to the ground state of ^{124}Te. A total of (19±23) events have been observed for the above transition in a spectrum obtained with the tin sample. With a detection efficiency of 7.10%, a half-life limit $T_{1/2} > 0.97\times10^{18}$ years is calculated for $\beta^-\beta^-$ decay from ^{124}Sn to 2_1^+ state of ^{124}Te. Similarly,for the $(0\nu + 2\nu)\beta^+$/EC decay processes in ^{112}Sn to the first excited state, 2_1^+, of ^{112}Cd, a γ ray of 617.5 keV is emitted. The total number of events observed under the photo peak of 617.5 keV is (-10±18). With a detection efficiency of 4.67%, a half-life limit $T_{1/2} > 3.00 \times 10^{17}$ years is calculated for the decay from ^{112}Sn.

TABLE III: Counting rate of gamma rays measured in GeBer detector

Isotope	Energy KeV	counts per hour
^{238}U	295.2	0.059±0.007
	351.9	0.120±0.007
	609.3	0.102±0.005
	1764.5	0.025±0.002
^{232}Th	238.6	0.171±0.010
	583.1	0.055±0.004
	2614.5	0.029±0.002
^{40}K	1460.7	0.313±0.007
^{60}Co	1173.2	0.042±0.003
	1332.2	0.043±0.003
^{137}Cs	661.7	0.012±0.002

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