Double Beta Decays of ^{116}Cd Studied by ELEGANT V

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Double beta decays ($\beta\beta$) are currently of interest from nuclear and astrophysical viewpoints[1, 2, 3]. Neutrinoless double beta decays ($0\nu\beta\beta$), which violate the lepton number (L) conservation law, provide evidence for physics beyond the electroweak standard theory, including the Majorana neutrino mass $\langle m_\nu \rangle$. Two-neutrino double beta decays ($2\nu\beta\beta$) conserve L, and are thus within the framework of the standard theory. In this letter we aim to report the final result for the observation of the $2\nu\beta\beta$ half-life and the search for $0\nu\beta\beta$ in ^{116}Cd by means of the direct counting method, following to our previous result[4].

Experimental methods and data analysis for the present ^{116}Cd $\beta\beta$ study are similar as in the previous ^{100}Mo and ^{116}Cd studies[4, 5]. The measurement was made by means of ELEGANT V (ELEctron GAmma-ray Neutrino Telescope V: ELV) at the Kamioka underground (2,700 m w.e.) laboratory. Details of EL V are given elsewhere[6]. Totally the 2447hours experiment was carried out using 93.13g of the ^{116}Cd source and 88.52g of $^{\rm n}$Cd one for the comparison. The measured sum energy ($E_\beta + E_{\beta\prime}$) spectrum for ^{116}Cd source is shown in Fig.1(a).

Since background effects are crucial at this kind of the ultra rare nuclear processes, various analyzes were examined to reveal the effects from the residual radioactivities on the data taken at this experiment. The radioactive nuclei considered at this work are of U-series($^{234\rm m}$Pa, ^{214}Pb, ^{214}Bi and ^{210}Pb), of Th-series(^{212}Pb, ^{212}Bi and ^{208}Tl), ^{40}K and ^{90}Sr. Other nuclei (of primordial, of cosmic ray origin and of manmade) do not make apparent contributions. Note that radioactive equilibrium is not considered at all in this work. The obtained background amounts are reported in the Ref.[7] in detail with the statistical error up to $\sim$20%. All the background events regenerated using Monte Carlo simulations(MC) are shown in the Fig.1.

One can obtain the $2\nu\beta\beta$ halflife ($T^{2\nu}_{1/2}$) by the subtraction of estimated events caused by background fake events from the observed spectra, provided that the background reconstruction is sufficient to describe events survived at the $^{\rm n}$Cd side. As one can notice that the present background model described above occupies more than 90% of events observed at the $^{\rm n}$Cd side especially between 1.0 and 2.0 MeV while there exists a broad peak below 1.0MeV which is due to the remained effect of ^{210}Bi in Cd source, the number of events caused by both of the true $\beta\beta$ and the residual ^{210}Bi was simultaneously obtained by the χ^2 fitting procedure in which the numbers of events of both procedures were set as the fitting parameters between 0.7 and 2.0 MeV. The $T^{2\nu}_{1/2}$ can be derived as $T^{2\nu}_{1/2} = [2.6^{+0.7}_{-0.5}(stat.) \pm 0.5(syst.)] \cdot 10^{19}$yr with $\chi^2/NDF = 1.33$ where $NDF = 12$. The result of χ^2-fitting procedure is shown in Fig.1(b).

The above obtained value of $T^{2\nu}_{1/2}$ can be compared with some other recent recalled results. The previous value by the ELEGANT group[4] was the first observed value and was a preliminary result since only a part of data set was used for the analysis. The result is consistent with the present value which is given as the result of the analysis of the full data set. Using an enriched crystal $CdWO_4$ scintillator[8], they obtained a close value to the present value but there is a possibility that ^{90}Sr impurities imitating the effect cannot be excluded.

Another results from NEMO II detector[9] gives another value which has some discrepancy with the present value. The background study does not cover whole of their data set in their analysis.

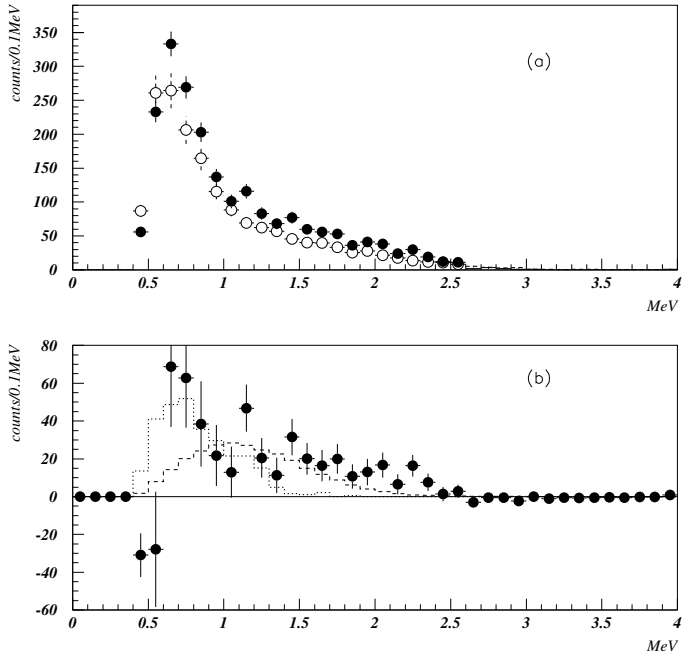

Figure 1: Sum energy spectra of two PL's after θ-cut of events with their vertex points at ^{116}Cd . (a)Black circle with solid error bar : the experimental data, white circle with dashed error bar : the estimated background events reconstructed by MC. (b)The difference of the experimental and the estimated background spectra together with the $2\nu\beta\beta$ MC calculation for $T^{2\nu}_{1/2} = 2.6 \cdot 10^{19}$yr (dash) and the contribution from the residual ^{210}Bi in ^{116}Cd (dot).

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