Double Beta Decay of ^{48}Ca with CaF_2(Eu) Scintillators

S. Umehara, T. Kishimoto, I. Ogawa, K. Matsuoka, R. Hazama, H. Miyawaki, S. Yoshida, K. Kishimoto, K. Mukaida, K. Ichihara, Y. Tatewaki and T.Kobayashi

Faculty of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan

The measurement of double beta($\beta\beta$) decays is of interest from nuclear and astrophysical viewpoints. We have studied $\beta\beta$ decays of ^{48}Ca[2][3] by means of ELEGANT VI[1] with CaF_2(Eu) scintillators. ^{48}Ca has the largest $Q_{\beta\beta}$-value 4.27MeV among $\beta\beta$ decay nuclei. The least background rate is expected around the $Q_{\beta\beta}$-value because the $Q_{\beta\beta}$-value is larger than the end point of natural background γ-ray energy.

In the ELEGANT VI system, the backgrounds from external origins can be strongly suppressed because of the 4π active shield and the large $Q_{\beta\beta}$-value of ^{48}Ca. The remaining backgrounds are the events due to radioactive contaminations within CaF_2(Eu) detector[2] as shown in figure 1. The expected background origins are mainly composed of the following components, (a) $^{212}\mathrm{Bi}\xrightarrow[\beta]{}{}^{212}\mathrm{Po}\xrightarrow[\alpha]{}{}^{208}\mathrm{Pb}$ (Th-chain) and (b) $^{214}\mathrm{Bi}\xrightarrow[\beta]{}{}^{214}\mathrm{Po}\xrightarrow[\alpha]{}{}^{210}\mathrm{Pb}$ (U-chain). Since ^{212,214}Po nuclei in (a) and (b) have half-lives(0.299μsec,164μsec) comparable with the duration of the pulse signal of CaF_2(Eu) (τ=1μsec), the consecutive pulse is measured as one event in the ADC gate(4μsec). Recently we installed a system for a measurement of the pulse shape in order to reject the events. figure 2 shows the typical pulse shape of the consecutive pulse obtained by the system. Performing the pulse shape analyses(PSD), we can reduce the background events down to 2.8% for ^{212}Bi and 0.002% for ^{214}Bi above 3MeV.

The energy calibration is one of the most important tasks for neutrino-less double beta $0\nu\beta\beta$ decay study, since variation of energy scale in the long measurement deteriorates the energy resolution, which has a great influence on the identification between true($0\nu\beta\beta$) and background events. The stabilities of PMT gain and electronics were monitored by the peak position of γ-ray(^{137}Cs source:662keV) and α-rays(contamination in CaF_2(Eu)), which were contained in the observed background spectra, on every month. In addition to the routine calibrations, we have checked peak positions obtained by analysis with coincidence between scintillators and using LED. The details of analysis are given in Ref.[3].

The detection efficiency for $0\nu\beta\beta$ events depends on the energy resolution and the analyses for the event selection. The efficiency was calculated by Monte Carlo simulation(GEANT 3) and estimated to be 67% in the energy window from 4.07 to 4.47MeV.

The obtained spectra are shown in figure 3. Experimental measurement to search for the decay had been carried out from January of 2003 to December[3]. Total live time was 204.3 $\times$ 6.1 days $\cdot$ kg. In figure 3, the solid(dotted) line shows the spectrum with(without) PSD of the consecutive events. There is no events in the energy window for $0\nu\beta\beta$.

Following the procedure of Ref.[4], we derived the half-life limit on $0\nu\beta\beta$ decay of ^{48}Ca as,

$$T_{1/2}^{0\nu\beta\beta} > 3.5 \times 10^{22}\mathrm{years}(68\% C.L.), \tag{1}$$

$$> 1.3 \times 10^{22}\mathrm{years}(90\% C.L.), \tag{2}$$

The effective Majorana neutrino mass $\langle m_\nu \rangle$ was limited from obtained lower limit of the $T_{1/2}^{0\nu\beta\beta}$ with the theoretical nuclear matrix elements[5] as,

$$\langle m_\nu \rangle < (6.3 - 39.4) eV (90\% C.L.). \tag{3}$$

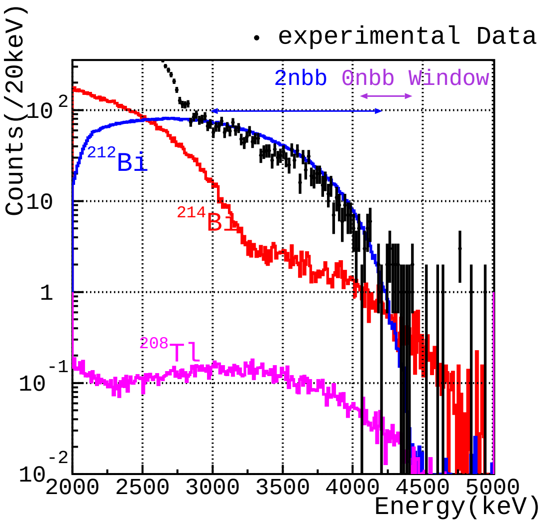

Figure 1 : Simulated spectra of backgrounds from the internal radioactivities and experimental spectrum. The measured spectrum was well reproduced by the simulated one in $\beta\beta$ window[2][3].

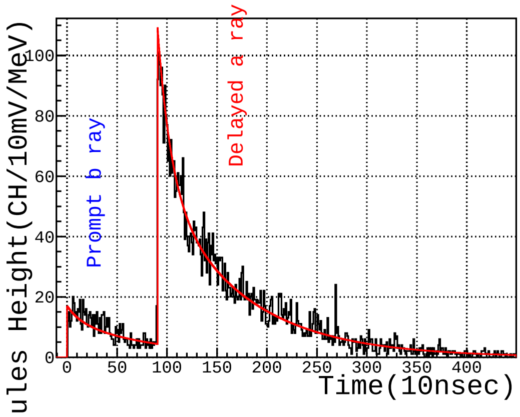

Figure 2 : Typical consecutive pulse obtained by 100MHz FADC.

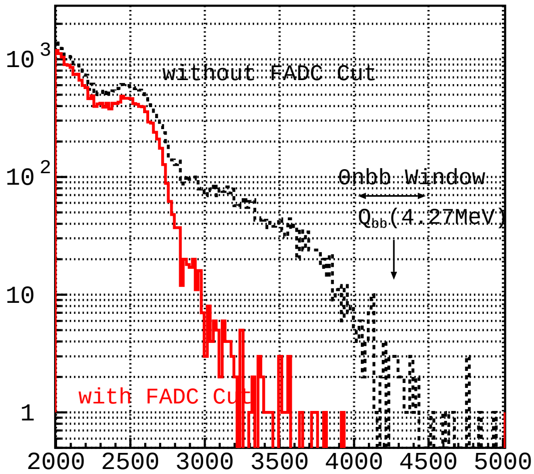

Figure 3 : The obtained energy spectra by event selections. A bump around 2.6 MeV is due to 2.6MeV γ-rays from ^{208}Tl. There is no events in the $0\nu\beta\beta$ energy window.

References

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