Activity at Kamioka Double-Beta Decay Facility

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RCNP has the double beta decay facility at the Kamioka underground laboratory, Institute for Cosmic Ray Research, the University of Tokyo, for underground science such as double beta decay search and low background measurements.

Study for Double Beta Decay of ^{48}Ca with CANDLES

Almost all substance of the universe is made of "matter", not "anti-matter". This is a mystery of "the matter dominated universe". The key point to solve the mystery is the lepton number non-conservation that means "anti-particle" and "particle" can convert to each other. CANDLES project aims at discovering neutrino-less double beta decay which does not conserve the lepton number. For the measurement of the neutrino-less double beta decay, we have developed the CANDLES III system using calcium fluoride (CaF_2) crystals that include double beta decay nuclei ^{48}Ca, at Kamioka Observatory.

In this paper, we briefly report the first result from CANDLES III system as published in ref.[1] and additional spectra. The CANDLES III system employs 96 CaF_2 scintillation crystals (305 kg) with natural Ca isotope which corresponds 350 g of ^{48}Ca. External backgrounds were rejected using a 4π active shield of a liquid scintillator surrounding the CaF_2 crystals. The internal backgrounds caused by the radioactive impurities within the CaF_2 crystals can be reduced effectively through analysis of the signal pulse shape. We analyzed the data obtained for a live-time of 130.4 days to evaluate the feasibility of the low background measurement with the CANDLES III detector. The major backgrounds in the $Q_{\beta\beta}$ value region of CANDLES III were the ^{208}Tl and ^{212}BiPo decays, which are decay in ^{232}Th series within the CaF_2 crystals. Therefore, the amount of ^{232}Th series impurities was used as an index for the high-purity crystal. According to fig. 1 (a), 21 CaF_2 crystals were selected as high purity crystals by using radioactive impurities of the ^{232}Th series that were less than 10 μBq/kg. On the other hand, fig. 1 (b) is obtained from 93 CaF_2 crystals whose radioactive impurities were including more than 10 μBq/kg.

We observed no events in the $0\nu\beta\beta$ window $4.17 - 4.48$ MeV for the selected 21 high purity CaF_2 crystals, whereas 6 events were observed for the 93 CaF_2 crystals. On the other hand, using Monte Carlo (MC) simulations, we estimated the background rate from the radioactive impurities in the CaF_2 crystals and the rate of high energy γ-rays caused by the (n, γ) reactions induced by environmental neutrons. According to the MC

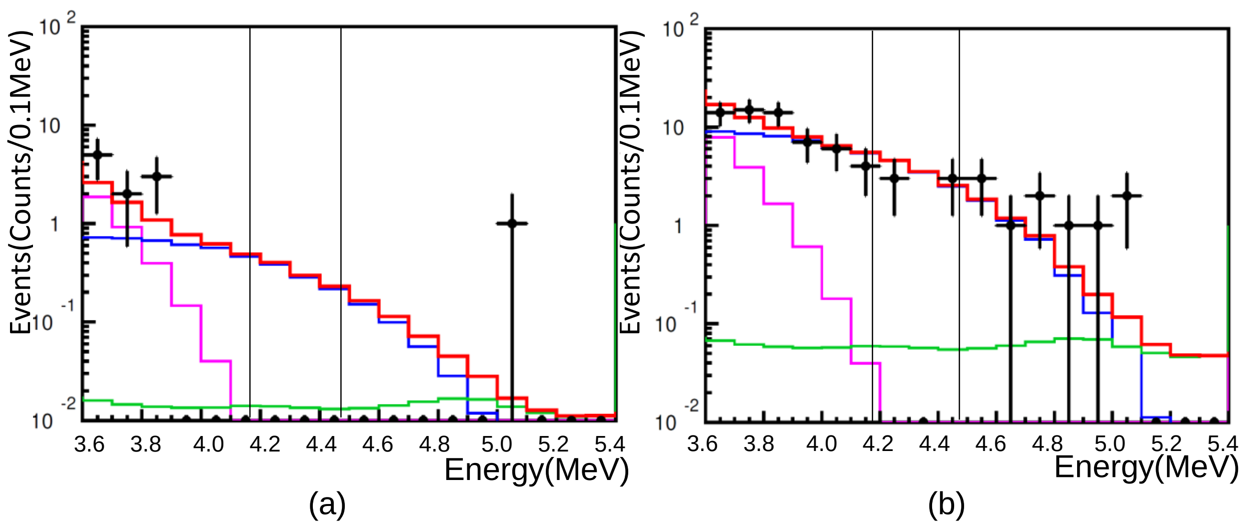

Figure 1: Obtained energy spectra (plots) and simulated background spectra (lines) obtained using 21/93 CaF_2 crystals in (a)/(b). Blue, magenta, and green lines correspond to simulated background spectra of ^{208}Tl and ^{212}BiPo, $2\nu\beta\beta$ decay, and (n,γ) events, respectively. Red line represents summed up spectrum of all three simulated spectra. The experimental energy spectrum around the $Q_{\beta\beta}$ value region is well reproduced by the simulated one.

simulation, the expected background rate was estimated to be 1.0 counts in the $0\nu\beta\beta$ window for the 21 CaF_2 crystals, considering the position of the crystals and the impurities contained therein.

By using experimental data and the MC simulation, We can set a lower limit and experimental sensitivity on the half-life of $0\nu\beta\beta$ decay. The half-life limit with 90% C.L. obtained by selecting 21 high purity CaF_2 crystals was 5.6×10^{22} year. This limit was comparable to the most stringent value obtained via measurement for over two years using the ELEGANT VI detector [3]. We also obtained an experimental sensitivity of 2.7×10^{22} year (90% C.L.). Based on the obtained half-life limit, the upper limit on the effective Majorana neutrino mass $\langle m_\nu \rangle \leq 2.9 - 16$ eV (90% C.L.) was derived using the nuclear matrix elements obtained from ref. [4] and the reference therein.

The present limits on the half-life and effective Majorana mass were obtained using $^{\mathrm{nat.}}$Ca instead of enriched ^{48}Ca crystals. The limit on $\langle m_\nu \rangle$ did not reach sufficient sensitivity compared with those in experiments using other enriched $\beta\beta$ isotopes, such as ^{76}Ge and ^{136}Xe, because of the lack in ^{48}Ca isotope. The natural abundance of ^{48}Ca is approximately 0.2%, which is the smallest among the $\beta\beta$ decaying nuclei used in other experiments. On the other hand, this result exhibits a large potential of approximately 500 enhancement in case enrichment could be achieved. The highest enrichment achieved thus far is 96.6%, which leads to approximately 540 enhancement[5]. Several approaches to ^{48}Ca enrichment, such as electromagnetic/optical separators, laser isotope separation, chemical separation, and electrophoresis, each with the aim of producing large amounts of ^{48}Ca, are under development [6].

The observed energy spectrum around the $Q_{\beta\beta}$ value region was well reproduced by the simulated one, estimated with the three background candidates considered. In other words, there were likely no additional high-impact backgrounds. The observed event rate in the $0\nu\beta\beta$ window was approximately 10^{-3} events/keV/yr/(kg of $^{\mathrm{nat.}}$Ca), which was comparable or less than those of other sensitive $0\nu\beta\beta$ experiments. The present result is useful for the development of a more advanced detector and shows that ^{48}Ca is a promising target nucleus for the $0\nu\beta\beta$ decay search using CaF_2 crystals.

Detector system for measurement of radioactive contaminations(Ge detector)

The materials used for construction of the detectors which aim to detect the rare processes such as double beta decays and dark matter, should be carefully selected by the measurement of long-lived radioactive impurities, because the impurities might be main source of backgrounds. Especially for $0\nu\beta\beta$ decay search, the main sources of backgrounds are due to the radiative decays of ^{214}Bi, ^{208}Tl and ^{212}Bi nuclei in U- and Th-series. Thus the amounts of U and Th contaminations largely influence on the sensitivity of the detectors.

RCNP offers detector systems for measurement of radioactive contaminations as the joint usage/research. The one is the system to measure radiative decays within scintillating crystals. Details are shown in the 2019 RCNP annual report. The other one is a low-background γ-ray detector system, which consists of a high purity Ge detector. The system was used to measure radioactivities in various kind of materials. The system has been installed in the Kamioka underground laboratory. The sensitivities of the system for U- and Th-chains are ~ 1 mBq/kg for CaF_2 powder. In this year the system used to select low background materials for a dilution refrigerator, which will be used for dark matter search. Details are shown in report of the RCNP joint usage/research. The system will be applied for such material selection.

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