PROCEEDINGS OF SCIENCE

Status of ^{48}Ca double beta decay search with CANDLES

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We have studied the neutrino-less double beta decay($0\nu\beta\beta$) of ^{48}Ca with the CANDLES III system, which consists of CaF$_2$(pure) scintillators. The first result of ^{48}Ca double beta decay with the CANDLES III system was obtained by using 130.4 days of data. In this measurement, we achieved a background free measurement and a low background condition of 10^{-3} events/keV/yr/(kg of $^{\text{nat.}}$Ca). The sensitivity of this measurement, however, was limited by the small amount of ^{48}Ca. For a more sensitive measurement of ^{48}Ca $0\nu\beta\beta$, we have developed new techniques for ^{48}Ca enrichment and CaF$_2$ scintillating bolometer. In this paper, we will also show the current status of these techniques.

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1. Double beta decay of ^{48}Ca

The neutrino-less double beta decay ($0\nu\beta\beta$) is acquiring great interest after the confirmation of neutrino oscillation which demonstrated nonzero neutrino masses. Measurement of $0\nu\beta\beta$ provides a test for the Majorana nature of neutrinos and gives an absolute scale of the effective neutrino mass. Therefore many experiments have been carried out so far and many projects have been proposed.

The CANDLES project[1] has as main goal the discovery of ^{48}Ca $0\nu\beta\beta$. Among the double beta decay nuclei, ^{48}Ca has the advantage of having a $Q_{\beta\beta}$-value of 4.27 MeV. This large $Q_{\beta\beta}$-value gives a large phase-space factor to enhance the $0\nu\beta\beta$ rate and a reduced contribution from natural background radiations in the energy region of the $Q_{\beta\beta}$-value. Therefore a good signal to background ratio is ensured in a $0\nu\beta\beta$ measurement.

2. CANDLES III for double beta decay measurement

We have developed the detector system CANDLES III at the Kamioka underground laboratory (2700 m.w.e.), ICRR, the University of Tokyo. The CANDLES III system consists of 96 CaF_2(pure) scintillators with a total mass of 305 kg and a liquid scintillator with a total volume of 2 m^3. The CaF_2 scintillators, which are the main detectors, are immersed in the liquid scintillator. In this system, the liquid scintillator acts as veto counter for the CaF_2 scintillators by reducing the background events from the volume outside detector. In addition, the shielding system, which consists of boron sheets and lead bricks, is also installed. The shielding system reduces the γ-ray backgrounds from neutron capture reactions by the environmental neutrons. Performance of the shielding system was checked with/without a ^{252}Cf neutron source placed outside it. We found that background due to the neutron capture reactions was reduced to $\sim$ 1/100[2]. In addition to the low background conditions, the linearity of energy response is also an important performance of the system. For energy calibration, we use the ^{252}Cf neutron source and silicon and nickel bricks for capturing neutron, because γ-ray energy of standard γ-ray sources is lower than $Q_{\beta\beta}$ of ^{48}Ca. For this calibration, we used the γ peaks (3539 keV, 4934 keV, 7631 & 7645 keV and 8998 keV) from ^{28}Si, ^{76}Fe and ^{58}Ni(n, γ) reactions, and we were able to check that CANDLES III has good energy linearity below 9 MeV[3].

We performed a $0\nu\beta\beta$ measurement using 130.4 days of data after the shield installation. The criteria to select candidate events for $0\nu\beta\beta$ are given in reference [4]. New techniques for the background rejection were also reported in reference [5]. We observed no event in the $0\nu\beta\beta$ window of 4.17 - 4.48 MeV with 21 high purity CaF_2s as shown in fig. 1 a). As can be seen in the plot, the lack of statistics doesn't allow to conclude if the estimated background spectrum represents the observed data. Thus we show the observed spectrum with 93 CaF_2s including high contaminated CaF_2s in fig. 1 b). The observed events in fig. 1 b) were reproduced by background events from radioactive contaminations within CaF_2. By using the estimated background rate and experimental event rate with the 21 CaF_2s, we obtained a lower half-life limit of 5.6×10^{22} year (90 % C.L.) for $0\nu\beta\beta$. In addition to the result, we can find that a very low background event rate was achieved at the level of 10^{-3} events/keV/yr/(kg of $^{nat.}$Ca) for the 93 CaF_2s. This is comparable or less than those of other sensitive $0\nu\beta\beta$ experiments[4]. However, the sensitivity of this measurement was limited by the small amount of ^{48}Ca. To explore the mass region below 10 meV, we started to develop a new detector system by using new techniques.

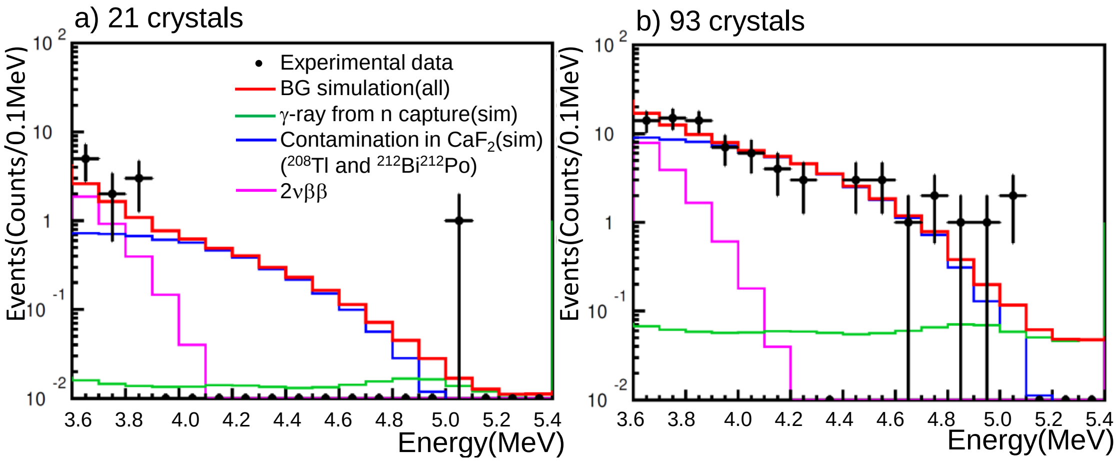

Figure 1: a) Energy spectra by using 21 high purity CaF_2 crystals. There is no events in $Q_{\beta\beta}$ region. b) Energy spectra by using 93 CaF_2 crystals including relatively high contaminated ones. The observed events were mainly represented by the background events from the radioactive contaminations within the CaF_2 crystals.

3. Development of a new detector system

The requirements for the high sensitive measurement of the ^{48}Ca $0\nu\beta\beta$ are (1) a large quantity of ^{48}Ca and (2) a detector system with high energy resolution at $Q_{\beta\beta}$. The current CANDLES system has a total ^{48}Ca mass of 350 g due to its small natural abundance (0.187%) of ^{48}Ca, although total mass of the CaF_2 scintillators in the system is 305 kg. Therefore the enrichment of ^{48}Ca is a better solution for improvement of the sensitivity. On the other hand, requirement (2) comes from view point of background reduction for the measurement. Expected background events for a measurement with enriched ^{48}Ca are from two neutrino double beta decay ($2\nu\beta\beta$), because the background rate per (mass of ^{48}Ca) from $2\nu\beta\beta$ does not decrease while the background rate from the other sources decreases. The $2\nu\beta\beta$ events can be reduced by using a detector system with high energy resolution. Details of the required energy resolution will be described later.

3.1 Enrichment of ^{48}Ca

In general, enriched stable isotopes are produced at electromagnetic separators and gas centrifuges. However, production of enriched ^{48}Ca is very difficult. One of the methods for ^{48}Ca enrichment is chemical isotope separation using condensed phases of a solution and an adsorption material. Calcium isotope fractionations have been observed in several chemical exchange processes by using crown-ether. Enrichment by using electrophoresis technique was also reported. These references are shown in reference [6].

Another promising technique is laser isotope separation, which has been developed by Prof. H. Niki group of Fukui University as reported in reference [7]. They succeeded ^{48}Ca enrichment by laser separation and obtained the results of maximum ^{48}Ca isotope ratio of ~ 80 %, although amount of ^{48}Ca is very small. Now we started development of the mass production of enriched ^{48}Ca as reported in reference [8]. The cost estimation for the production will be presented in a further work.

3.2 Scintillating bolometer with CaF_2(pure) crystal

Scintillating bolometer is a good candidate for high sensitive measurement for double beta decay. As mentioned above, the main background candidates will be the $2\nu\beta\beta$ events. Required energy resolution for a measurement to explore below 10 meV is 0.5 % at $Q_{\beta\beta}$-value region. Now we started to develop a scintillating bolometer with a large CaF_2 crystal with a Korean group[9]. In this study, we have succeeded signal read-out of scintillation and thermal signals from CaF_2 at the same time. Currently, we obtained an energy resolution of 1.8 % (σ) at 4.9 MeV. This resolution is better than the one of the current CANDLES system. However we expect to be able to improve the energy resolution. Details of the study were also reported in references [6][9]. In future, we will construct the new detector system using the CaF_2 scintillating bolometer to explore the mass region below 10 meV.

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