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

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Abstract. CANDLES system had proposed for the study of double beta decay of ^{48}Ca by using of undoped CaF_2 scintillator. We have constructed CANDLES III detector at sea level. The result of first performance check is described.

1. Introduction

The study of neutrinoless double beta decay is of most importance for neutrino physics. We have been studying the double beta decay of ^{48}Ca. The most advantage of using ^{48}Ca isotope is background of natural radioactivities are strongly limited at the Q-value region. Because the Q-value which is the highest (4.27MeV) among double beta isotopes, is higher than natural radioactivities. we have developed the CaF_2(Eu) scintillation detector system (ELEGANT VI) which have being operated at the underground laboratory (Oto Cosmo Observatory). the most stringent limit on the half-life of $0\nu\beta\beta$ of ^{48}Ca has been obtained [1].

In order to enhance the sensitivity for the neutrino effective mass, we must scale up the detector. However, CaF_2(Eu) is not suitable for large detector because of the short attenuation length of scintillation lights, Then we proposed CANDLES (Calcium fluoride for the study of Neutrinos and Dark matters by Low Energy Spectrometer)

2. CANDLES system

CANDLES system is suitable for a large detector and powerful 4π active shielding system with use of updoped CaF_2 scintillators and liquid scintillator [2]. The large number of CaF_2s with a dimension of 10 cm cube are immersed in liquid scintillator. Scintillation lights from both CaF_2 and liquid scintillator are viewed by the large PMTs. The outside of the liquid scintillator vessel filled with pure water for the passive shield. The CaF_2 scintillator has a decay time of 1μ sec, on the other hand that of liquid scintillator is a few tens nsec. Thus by observing pulse shape the signals from liquid scintillator (external background) can be discriminated.

We constructed prototype detector CANDLES III in our laboratory at sea level, which consist of 40 PMTs (15inch×8, 13inch×32) and 60 CaF_2s with the total mass of 191kg. Twelve CaF_2s are located with the 20 cm distance from the center in a layer. Total five layers are supported by the wires inside a liquid scintillator vessel of 1 m in diameter and 1 m in height. These are contained in a water tank, which is 2.8 m in diameter and 2.6 m in height. The schematic view of the CANDLES III is shown by Figure 1.

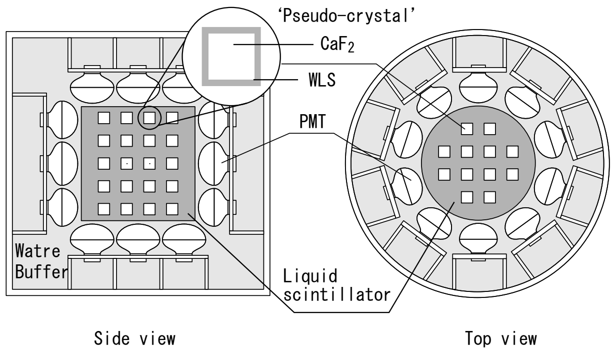

Figure 1. Schematic cross sectional view of the CANDLES-III detector. we constructed at sea level.

3. Performance test

The Data taking for the performance test started, and present result from the measurement of total live time of 30 hours. The total number of CaF_2s is 59 and the one of the crystals has much radioactive contamination. The contamination of the dirty one is equivalent to 46mBq/kg. The average of the other crystals contamination is about 42μBq/kg. 35 PMTs are used ,which correspond to 30% photo-coverage. In order to discriminate liquid scintillator pulse shape from CaF_2 scintillator pulse shape, different length of charge sensitive ADC gate (*total gate* and *prompt short gate*are introduced to each PMT. The demonstration of the pulse shape discrimination is shown in Figure 2. The ratio defined by ADC value of (*prompt short gate*)/(*total gate*),

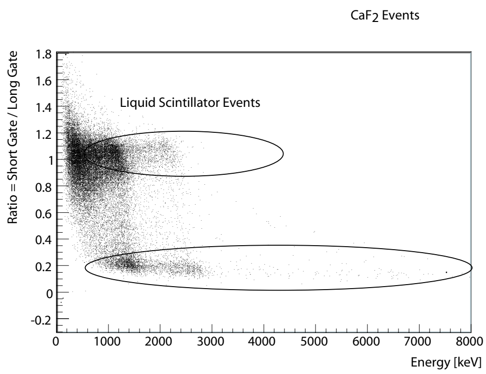

Figure 2. The pulse shape discrimination. the events distributed around 0.15 on vertical axis from CaF_2 scintillator, 1.0, from liquid scitillator, respectively. The events are selected around the CaF_2No.59

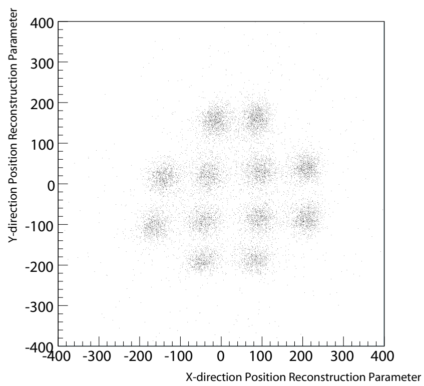

Figure 3. Two dimensional plots of position reconstruction parameters at the third layer. The events are higher than 2MeV and CaF_2-like events from the value of the ratio.

One of the important subject of the detector performance is to identify the crystals where scintillation lights are emitted. This performance useful to the rejection of background origin of decay of ^{208}Tl, which can be rejected by identifying preceding α decay in the same crystal. For the preliminarily analysis, We use the position reconstruction parameter defined by as follows; R=$\sum_{i=1}^{npmt}$ADC(i)$\times$PMT(i)/$\sum_{i=1}^{nmpt}$ADC(i), where *npmt* is ID of PMT, ADC(i) is observed pulse hight in i-th PMT, and PMT(i) is the coordinates of i-th PMT. The Result of position reconstruction is showd by Figure 3. The events are higher than 2MeV and CaF_2-like events from the result of the pulse shape discrimination. The identification of each crystal was found to be possible, though this algorithm for the reconstruction will be improved.

The Energy resolution influences the rejection of $2\nu\beta\beta$ decay events. In order to estimate the energy resolution of the detector system, we used α events cased by decay of ^{214}Po (U-Chain). Considering the quenching factor, the peak energy of the α events is 2.3MeV. The obtained resolution is 9%, which is correspond to 6.6% at Q-value region.

The obtained energy spectra of crystal number 59 and 60 are shown in Figure 4. No.60 is a dirty crystal. These are located at bottom layer and next to each other. In the Q-Value region (4.0$\sim$4.5MeV) of the dirty crystal spectrum, 8.6 events/hour was obtained. Since the contamination of clean crystals are three order of magnitude less than the dirty one, $\sim 8\times10^{-3}$ events/hour is expected for each clean crystal. However 3 events were remained in the Q-value region of the clean crystal No.59. At the current understanding, these events attribute to cosmic rays. muons which are most part of cosmic rays are almost rejected by active shield. However μ^{-}s lost the kinetic energy and captured by a nucleus, there can be emitting high energy gammas. In addition, an inelastic scattering process by environmental fast neutrons or a bremsstrahlung process by muons, these process have possibility of the background. we are investigating the influences of cosmic rays by using of the simulation or same experiments. In case that these remaining several events in the clear crystal are cased by the cosmic rays, these events will be negligible moving to the underground laboratory.

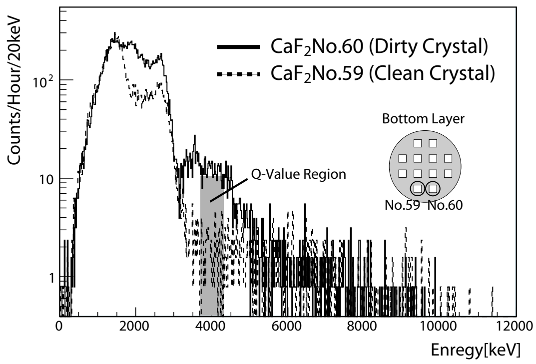

Figure 4. Energy Spectra of CaF_2No.59 and No.60. These are located at the bottom layer.

4. Discussion

We evaluated the performance of the CANDLES III at sea level. We obtained clear separation of generation source of the CaF_2 scintillation lights. Comparing the spectrum of the dirty crystal to that of clean crystal, $\sim10^{-3}$ events/hour to each crystal is expected. Moreover pulse shape discrimination by use of the FADC, internal background can be rejected. The rejection efficiency is expected about 99%. The performance check is under the investigation using the 500MHz FADC. We have plan to move CANDLES III, which will be somewhat improved to the underground laboratory next summer (2008). Introducing the 500MHz FADC and moving to the underground laboratory, almost all zero background measurement is expected.

References

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[2] S.Yoshida *et al*, 2005 *Nucl. Phys. (Proc.Suppl.)* B **138** 214-216