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Title	Development of Energy Calibration System of CANDLES with Triggerable Gamma Ray Source for Study of 48Ca Double Beta Decay
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Abstract of Thesis

Name (VAN THI THU TRANG)	
Title	Development of Energy Calibration System of CANDLES with Triggerable Gamma Ray Source for Study of ^{48}Ca Double Beta Decay (^{48}Caの二重ベータ崩壊の研究のためのトリガー可能なγ線源によるエネルギー較正システムの開発)

Abstract of Thesis

CANDLES experiment is a project to search for neutrinoless double beta decay ($0\nu\beta\beta$) of ^{48}Ca by using CaF_2 scintillators. $0\nu\beta\beta$ violation of lepton number conservation which is a key principle to realize matter dominate universe. It is an extremely rare phenomenon. CANDLES detects scintillation light by which electron energy can be measured. Energy of two electrons from the $0\nu\beta\beta$ corresponds its Q-value (4.3 MeV). Therefore, a precise energy calibration at the Q-value region is crucial for its identification. CANDLES has been using a radioactive source of ^{88}Y (1.8 MeV) to calibrate 96 CaF_2 scintillators. Although ^{88}Y gives almost highest energy gamma ray, it is still much lower than Q-value. We, thus, have been using linear extrapolation of the calibration to the Q-value region. Later we acquired data of peak positions for several other gamma rays for the calibration. They are ^{40}K (1.4MeV), ^{208}Tl (2.6 MeV), gamma energies from (n,γ) reaction at ^{1}H (2.2 MeV), ^{28}Si (3.5 MeV and 5.0 MeV), ^{56}Fe (7.6 MeV) and ^{58}Ni (9 MeV). The observed peak positions showed deviation from the linear extrapolation of the ^{88}Y calibration. The deviation appeared to be 0.4% at Q-value region and has energy dependence. Since realistic estimation of region of interest (ROI) is crucial for the estimation of $0\nu\beta\beta$ decay rate, we have to confirm the deviation. We know statistical error of each data, however, estimation of systematic error is vital for the confirmation of the deviation. We studied systematic errors, in particular, energy leak into liquid scintillation (LS) which acts as 4π active veto in detail. Since some fraction of gamma rays energy leaks into liquid scintillation, total energy appears to be different. For this purpose, we developed a new energy calibration system by using ^{24}Na source (1.37 MeV and 2.75 MeV). ^{24}Na becomes ^{24}Mg by emitting beta rays and then ^{24}Mg emits two gamma rays. We can tag the two gamma rays by detection of beta rays by NaI(Tl). In order to obtain enough ^{24}Na intensity for the calibration, size of NaI(Tl) detector and configuration of neutron activation are optimized by Monte Carlo (MC) simulation and confirmed by the experiment. With new calibration system, we observed not only two gamma rays of ^{24}Na but also gamma rays from backgrounds of ^{40}K and ^{208}Tl. This simultaneous measurement of 4 gamma rays is crucial for the evaluation of systematic errors. We confirmed the deviation from the linear extrapolation of ^{88}Y calibration. The deviation may be attributed to genuine property of CaF_2 scintillator. Background free spectrum obtaincd by the ^{24}Na clearly shows that the MC simulation reproduces the experimental data. We studied deviation for $0\nu\beta\beta$ peak by MC simulation since electrons give less energy leak into liquid scintillation than that of gamma rays. We found the energy deviation at Q-value is 0.96 ± 0.04% at maximum. Genuine property of CaF_2 crystal may reduce the deviation which we leave for future study.

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論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

CANDLES is a project to search for neutrinoless double beta decay (0νββ) of 48Ca by using 96 CaF2 scintillators. 0νββ demonstrates violation of lepton number conservation which is a key principle to realize matter dominate universe. It is an extremely rare phenomenon. CANDLES detects scintillation light by which electron energy can be measured. Energy of two electrons from the 0νββ corresponds its Q-value (4.3 MeV). Therefore, a precise energy calibration at the Q-value region is crucial for its identification. CANDLES has been using a radioactive source of 88Y (1.8 MeV) to calibrate 96 CaF2 scintillators. Although 88Y gives almost highest energy gamma ray, it is still much lower than the Q-value. We have been using linear extrapolation of the calibration to the Q-value region. Later we acquired data of peak positions for several other gamma rays for the calibration. They are 40K (1.4MeV), 208Tl (2.6 MeV), gamma energies from (n,γ) reaction on 1H (2.2 MeV), 28Si (3.5 MeV and 5.0MeV), 56Fe (7.6 MeV) and 58Ni (9 MeV). The observed peak positons showed deviation from the linear extrapolation of the 88Y calibration. The deviation appeared to be 0.4% at Q-value region and has energy dependence. Since realistic estimation of region of interest (ROI) is crucial for the estimation of 0νββ decay rate, we have to confirm the deviation. We studied systematic errors, in particular, energy leak into liquid scintillation (LS) in detail. Since some fraction of gamma ray energy leaks into liquid scintillator, total energy appears to be different. For this purpose, we developed a new energy calibration system by using 24Na source (1.37 MeV and 2.75 MeV). 24Na is produced by neutron activation of 23Na inside NaI(Tl) scintillator. 24Na becomes 24Mg by emitting beta ray and then 24Mg emits two gamma rays. We can tag the two gamma rays by detection of beta rays by NaI(Tl). Thus background free gamma ray spectrum is obtained which is new and important development of this research. In order to obtain enough 24Na intensity for the calibration, size of NaI(Tl) detector and configuration of neutron activation system are optimized by Monte Carlo (MC) simulation and confirmed by experiments. With new calibration system, we observed not only two gamma rays of 24Na but also gamma rays from backgrounds of 40K and 208Tl. This simultaneous measurement of 4 gamma rays is crucial for the evaluation of systematic errors. We confirmed the deviation from linear extrapolation of the 88Y calibration. The deviation may be attributed to genuine property of CaF2 scintillator. Background free spectrum obtained by the 24Na clearly shows that the MC simulation reproduces the experimental data. We studied deviation of 0νββpeak by MC simulation since electrons give less energy leak into liquid scintillator than that of gamma rays. We found the energy deviation at Q value is 0.96 ± 0.04% at maximum. Genuine property of CaF2 crystal may reduce the deviation which we leave for future study. The author plays a central role for this study, in particular, for the development of triggerable 24Na source.

新しいエネルギー較正法を開発し、Q値でのズレを明確にした本結果は48Caの二重ベータ崩壊を研究する上で大きな一歩と言える。本論文は博士（理学）の学位論文として十分価値のあるものと認める。