論文内容の要旨

Study of pulse shape discrimination and low background techniques for liquid xenon dark matter detectors

（液体キセノン暗黒物質検出器のための波形識別
および低バックグラウンド技術の研究）

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The results of various astronomical observations show strong evidence for a large amount of dark matter in the universe. Weakly Interactive Massive Particles (WIMPs) are one of the well motivated dark matter candidates. WIMPs are predicted by Supersymmetry (SUSY), which is an extended theory beyond the Standard Model of the particle physics. Various dedicated dark matter search experiments are underway around the world.

As the first phase of the XMASS experiment, a 1 ton liquid xenon detector was developed to search for dark matter. The energy deposition by dark matter interactions in xenon is expected to be in the few keV to tens of keV range. The key idea behind the XMASS experiment is background (BG) reduction using the self-shielding of liquid xenon. The fiducial volume used to search for dark matter is within the center of the detector.

Radioactive impurities in PMT are the main BG source in the XMASS experiment. So we have developed a special low BG PMT. The radioactive impurities of all

materials used in these PMTs were measured using a Germanium detector and those with the lowest radioactive contamination were selected. Details of these developments for low background techniques are described in this thesis. The PMTs developed for XMASS have the lowest radioactivity among all other PMTs.

Typically xenon gas contains 0.1∼3 ppm krypton. Krypton has a long-lived radioactive isotope ^{85}Kr. To reach BG level of 10^{-4} counts/day/kg/keV, the goal of the XMASS experiment, krypton contamination in xenon has to be reduced by more than 5 orders of magnitude. The distillation system has been developed to remove krypton from xenon gas. This distillation system has achieved the lowest levels of krypton contamination ever. The design principle and the performance test of the distillation system are described in this thesis.

In order to further improve the sensitivity of XMASS, pulse shape discrimination (PSD) of liquid xenon was also studied in this thesis. A dedicated detector setup was constructed which has a high efficiency of collecting scintillation photons. In the first step of the PSD study, pulse shapes are measured with high light yield in order to evaluate the fundamental difference between nuclear recoils and electron recoils. From this study, a difference in the pulse shapes of nuclear and electron recoils is found even at the low energies relevant for dark matter detection. In the second step, the PSD performance was studied at the expected light yield for the XMASS detector (4.6 p.e./keV). Using a mask made from copper, the light yield was tuned to this value. The rejection power was $2.4 \pm 0.2(\mathrm{stat}) \pm^{0.3}_{0.2}(\mathrm{sys}) \times 10^{-1}$ for $4.8 \sim 7.2$ keV$_{ee}$ events.

Using the PSD technique developed in this thesis, improvement of the sensitivity of XMASS was estimated. The remaining BG caused by the radioactive impurities in the PMTs can be reduced more than one order of magnitude while keeping the detection efficiency of dark matter at 50%. The sensitivity at 90% C.L. is greatly improved to 5.6×10^{-45} cm^2 from 2.9×10^{-44} cm^2 using PSD at $M_\chi = 100$ GeV.