XMASS experiment

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The XMASS experiment aims to detect pp and ^{7}Be solar neutrinos, and neutrinoless double beta decay using ultra pure liquid xenon. It requires low background and a low threshold which will also enable us to search for dark matter in the galactic halo.

The first stage of XMASS project is concentrated on dark matter searches utilizes 800 kg liquid xenon detector. The detector design and expected sensitivity for dark matter based on Monte Carlo simulations will be presented.

Keywords: Dark matter searches; liquid xenon; low background

1. Introduction

XMASS is a multi purpose low-background detector with pure liquid xenon in Kamioka mine (2,700 m.w.e.), Japan. The physics goals of XMASS project are real-time measurement of pp and ^{7}Be neutrinos, detecting neutrinoless double beta decays, and direct dark matter searches.

The first stage of XMASS project is concentrated on direct dark matter searches utilizes an 800 kg liquid xenon detector. It requires an ultralow background in the fiducial volume of the detector. The key idea to reduce background is to utilize the self-shielding effect of xenon. Since xenon has a large atomic number (Z=54), several tens of centimeters of outer layer of liquid xenon can absorb and shield low energy external gamma rays. In addition, it is easy to purify even after the experiment started because of liquid.

This self-shielding effect has been confirmed by using a prototype detector. Several experiments with the prototype detector which consists of a 31 cm cubic oxygen-free-highpurity-copper (OFHC) chamber, 54 photomultipliers (PMTs), and heavy shield have performed good position and energy reconstruction and low background environment as well as self-shielding effect [1].

Based on those encouraging experimental results, we are now designing the 800 kg detector. In this paper, the 800 kg detector design will be reported.

2. The XMASS 800 kg detector

The 800 kg detector consists of a spherical OFHC chamber with about 90 cm diameter filled with pure liquid xenon, and about 800 PMTs immersed in liquid xenon. Fig. 1 shows the schematic view of the detector and PMT arrangement defined in our Monte Carlo (MC) simulations.

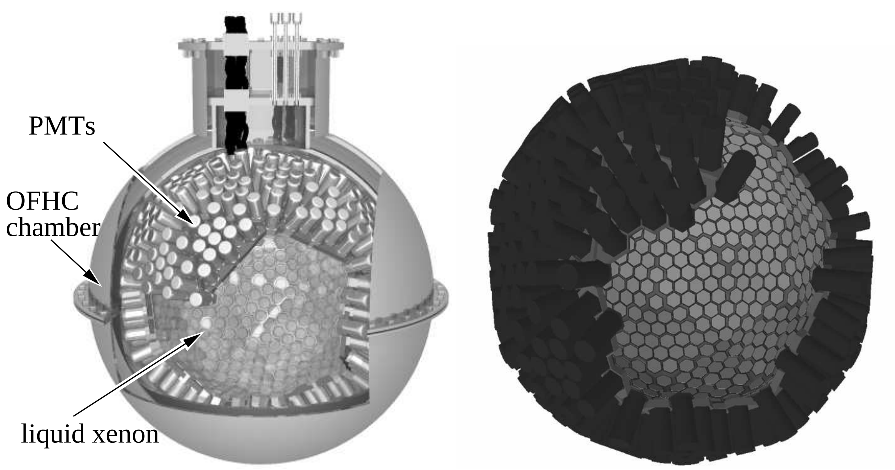

Fig. 1. The schematic view of the XMASS 800 kg detector consisting a spherical OFHC chamber with 90 cm diameter filled with pure liquid xenon, and about 800 PMTs immersed in liquid xenon (left), and PMT arrangement defined in MC simulations (right).

Physics performances of 800 kg detector have been studied by using MC simulations based on the geant4 simulation package. In order to set PMTs inside the detector as possible as dense, a shape of pentakisdodecahedron whose 60 triangle shape planes is chosen. A new PMT being developed for this project, Hamamatsu R8778 mod, whose hexagonal quarts window is set on a triangle shape plane. Since 10 PMTs per one plane are set, total 600 PMTs are set. In addition, other 212 PMTs are set on the gap between each triangle shape plane, therefore, total 812 PMTs are set. This arrangement achieves 67.0 % photo-coverage according to MC simulations. Averaged distance from the center of detector to photo-cathodes of PMTs is 44 cm. A volume of a sphere with 25 cm radius is used for fiducial.

The procedure of position and energy reconstruction is based on that of our prototype detector [1]. The position and energy are reconstructed from PMT charge patterns which are function of position and energy in the detector by using a likelihood method. Obtained position resolutions are 3.0 cm for 10 keV, and 4.8 cm for 5 keV at the boundary of fiducial volume. In general, the position resolution goes well far from the center because PMT is close to the position and number of detected photons increases.

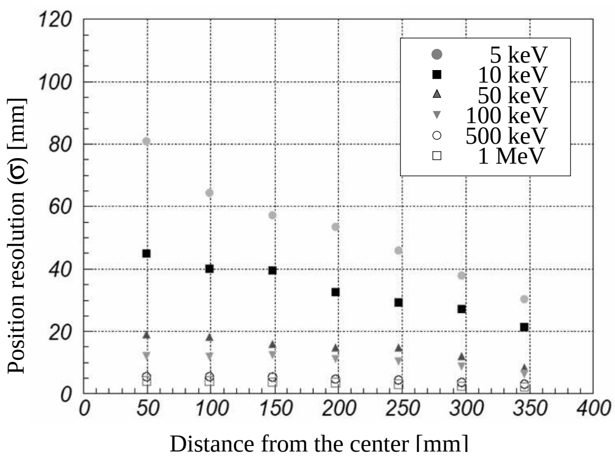

Fig. 2. Calculated position resolution. Gray closed circles, black closed squares, black closed triangles, gray closed triangles, open circles, and open squares are for 5 keV, 10 keV, 100 keV, 500 keV, and 1 MeV, respectively.

2.1. *Expected background level and sensitivity*

The main source of background achieved with the prototype detector is thought to be caused from the radio activities in R8778 PMTs. The measured radio activities of a R8778 PMT are $1.8 \pm 0.2 \times 10^{-2}$ Bq (U), $6.9 \pm 1.3 \times 10^{-3}$ Bq (Th), and $1.4 \pm 0.2 \times 10^{-1}$ Bq (^{40}K), and the expected background level from these activities is about 10^{-2} counts/day/kg/keV around 100 keV which explains the current background level of prototype detector. In the 800 kg detector, owing to much larger volume for self shielding further reduction is possible. In addition, we have a plan to develop one order of magnitude lower background PMTs.

We calculated gamma-ray background from the U chain radio activity in PMTs assuming that the activity is one order of magnitude lower (1.6×10^{-3} Bq) than that of current R8778 PMTs. Fig. 3 shows obtained energy spectra caused from U chain radio activity in PMTs. After fiducial volume cut of 20 cm from the wall, only one event was found below 100 keV with the statistic of 3.2 days which corresponds to $< 10^{-5}$ counts/day/kg/keV.

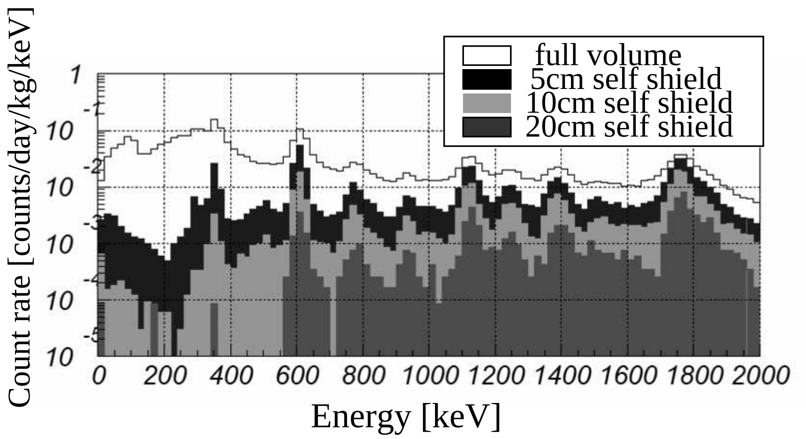

Fig. 3. Calculated background spectrum caused from U chain radio activity in PMTs. The open histogram shows the result obtained from the full volume. The black colored, light-gray colored, and gray colored histograms show the results after fiducial volume cuts of 5 cm, 10 cm, and 20 cm from the wall, respectively.

The background caused by external gamma rays and fast neutrons from the rock should be reduced below the PMT background level. Instead of a conventional lead and polyethylene shield, we selected a simple water shield against both gamma rays and fast neutrons. We estimated the required thickness of water shield surrounding the detector by using MC simulation. For external gamma rays, the initial energy spectrum from the rock calculated from the energy spectra measured by Ge detector without shield was used. As a result, more than 200 cm thickness is needed to reduce the background below the PMT background level. For fast neutrons generated by the (n, α) reaction from the radio activities in the rock, very conservative assumption was used, which is energies of all the fast neutrons are 10 MeV with measured flux of $1.15 \pm 0.12 \times 10^{-5}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ in Kamioka mine. As a result, more than 200 cm thickness is found to be sufficient.

Fig. 4 show the expected sensitivities for the spin-independent (SI) and

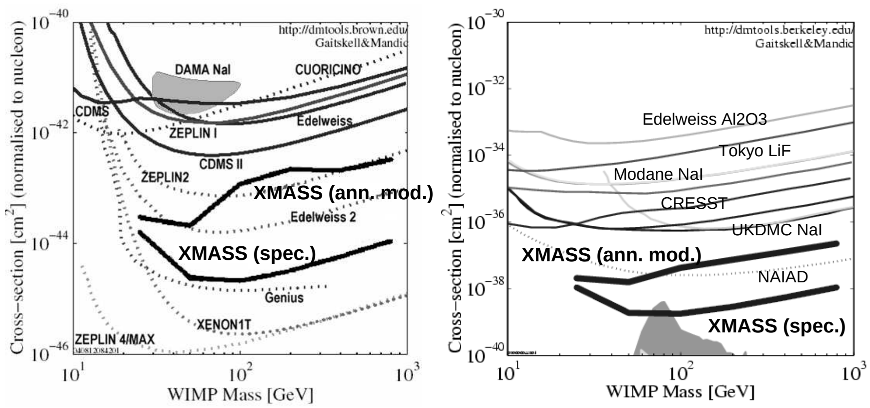

Fig. 4. Sensitivities for the spin-independent (left) and spin-dependent (right) cross sections of dark matter. Upper thick curves of each figure correspond to analyses to look for the annual modulation, and lower thick curves of each figure correspond to analyses to find an increase due to dark matter signal in the raw spectrum.

spin-dependent (SD) cross section of WIMPs, respectively, assuming that energy threshold of 5 keV ee and statistics of 0.5 ton · year and without any pulse shape discrimination.

3. Summary

XMASS experiment is a multi purpose low-background experiment with large mass liquid xenon. The first stage of XMASS project is constructing of 800 kg detector. We are now developing an 800 kg detector to detect dark matter and are going to start the dark matter search in the near future.

References

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