The XMASS 800kg detector

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Abstract.
The XMASS 800kg detector, aiming primarily at the dark matter search, is currently under commissioning at the Kamioka Underground Observatory, Japan. The construction and performance of the detector are briefly reviewed.

1. Introduction
The XMASS experiment [1] is proposed to detect low energy solar neutrinos, neutrinoless double beta decay and dark matter particles using liquid xenon (LXe) scintillator. The scintillation lights generated by nuclear or electronic recoils in LXe are detected by surrounding photomultiplier tubes (PMTs). No electric field is applied to extract ionization signals from LXe. This makes it possible to realize a large scale experiment sensitive enough to the listed rare physic processes. Current XMASS detector contains 856 kg LXe in its active volume, hence named as XMASS 800kg detector. It is dedicated to dark matter search due to its limited size.

The experiment is located at the Kamioka Underground Observatory, Japan. The construction of experimental hall, 15 m wide, 15 m high and 21 m long, was completed in August 2008. The muon flux in the hall is down to $6 \times 10^{-8}$/cm$^2$/s/sr, thanks to a mean overburden of 2700 m.w.e. A cylindric water tank, 10 m in height, 10 m in diameter, was constructed in March 2009. It shields the inner detector from external neutron and $\gamma$ radiation. Its inner wall is equipped with 72 20-inch PMTs to detect Čerenkov light from cosmic ray muons. The water is constantly circulated and purified in order to keep the Rn concentration lower than 1 mBq/m$^3$.

The construction of inner detector was completed in October 2010. The performance of the detector and analysis methods are evaluated using commissioning data.

2. Inner detector
The inner detector is located in the center of the water tank. It contains 1080 kg of LXe in total, out of which, 856 kg is surrounded by 642 PMTs. The PMTs are supported by a copper frame shaped as a pentakis-dodecahedron with a diameter of about 1 meter, as shown in Fig.1. The photo-cathodes of PMTs cover 62% of the inner surface of the detector.

3. Calibration system
Low energy $\gamma$ sources can be inserted into the inner detector using a calibration system as shown in Fig. 2. A gate valve is used to isolate the inner detector when a source is mounted to the bottom end of a OFHC copper rod. The top end of the rod is connected to a step motor by
thin stainless steel wire. The z position of the source is controlled by the motor at < 1 mm accuracy. The gate valve is open after the top part of the system is vacuumed. The top PMT can be lifted up and rotated away, allowing the source to be lowered into LXe.

There is also an external γ calibration system. It consists of a “U” shaped soft hose mounted outside of the inner detector. A γ source can be moved around the detector through the hose. This makes it possible to study the detector response to external radiation. An external neutron calibration system is proposed. It will consist of a thin vertical pipe in the water tank, working as a collimator, and a plastic scintillator, working as a coincident detector.

4. Vertex reconstruction
The position and energy of an interaction point can be reconstructed using the number of photoelectrons (nPE) observed by each PMT. Assuming a position of the vertex, the expected nPE distribution in each PMT can be obtained by Geant4 [3] simulation. This distribution is normalized so that it can be used as a probability density function. The probability, \( p_i \), of PMT \( i \) recording nPE can be calculated afterwards. The likelihood of the vertex in the assumed

Figure 1. Structure of XMASS 800kg inner detector.

Figure 2. The low energy γ calibration system. The top PMT can be lifted up and rotated away, allowing a low energy γ source to be lowered into the active volume of the inner detector. The source can be fixed at different z positions. The precision is within 1 mm.
position $\vec{x}$ is the product of all $p_i$, $L(\vec{x}) = \prod_{i=0}^{641} p_i(n)$. The most likely position is obtained by maximizing $L$.

The performance of the vertex reconstruction program is evaluated using a $^{57}$Co source fixed at $z = -40, -30, ..., 40$ cm in the active volume of the inner detector. The results are shown in Fig. 3. The left plot shows the distribution of reconstructed vertices on the $z$-$y$ plain. The top right plot shows the same distribution along $z$ axis. The achieved position resolution in terms of RMS is 1.4 cm at $z = 0$ cm and 1.0 cm at $z = 20$ cm for the 122 keV $\gamma$-rays from $^{57}$Co. The bottom right plot shows the energy spectrum of the $^{57}$Co source at the center of the detector ($z = 0$ cm). The light yield calculated from the 122 keV peak is $15.1 \pm 1.2$ PE/keV. The energy resolution in terms of RMS is 4% at 122 keV. Both position and energy distributions can be well produced by Geant4 simulation as shown by the blue histograms overlaid on the right plots.

Figure 3. Results of the vertex reconstruction. The left and top right plots show the position distribution of reconstructed vertices of events collected with a $^{57}$Co source at different $z$ positions. The bottom right plot shows the energy distribution of the same source in the center of the detector.

5. Evaluation of background
The external background is expected to be dominated by $\gamma$-rays from PMTs. The average radioactivity in each PMT is measured to be 0.7 mBq for uranium chain, 1.5 mBq for thorium chain, 2.9 mBq for $^{60}$Co and less than 5.1 mBq for $^{40}$K. Simulation shows that the background events induced by the PMTs are less than $10^{-4}$ count/day/kg/keV in the inner most volume with a radius of 20 cm.

Possible internal background includes $^{222}$Rn, $^{220}$Rn and $^{85}$Kr. Krypton can be distilled out of LXe due to its lower boiling point. This was done using a distillation tower purification system developed locally. [2] The remaining krypton contamination is measured to be less than 2.7 ppt at 90% confidence level with a gas chromatography followed by an atmospheric pressure ionization mass spectrometer. In order to remove radon, gaseous xenon was purified by SAES getters with a flow rate of 30 L/min before being filled into the inner detector. Xenon circulation
systems in both gaseous and liquid phases for removing radon by filters are under preparation. The contamination of $^{222}\text{Rn}$ can be identified by the time coincidence between the two consecutive decays of its daughter nuclei: 1. $^{214}\text{Bi}$ β-decays into $^{214}\text{Po}$, and 2. $^{214}\text{Po}$ α-decays into $^{210}\text{Pb}$ with a half life of 164 µs. The measured value is $8.2 \pm 0.5$ mBq in total. Similarly, the contamination of $^{220}\text{Rn}$ can be identified by the time coincidence between $^{220}\text{Rn}$ α-decay into $^{216}\text{Po}$ and $^{216}\text{Po}$ α-decay into $^{212}\text{Pb}$ with a half life of 140 ms. The measured value in total is less than 0.28 mBq at 90% confidence level.

6. Sensitivity
The right plot in Fig. 4 shows the expected energy spectrum assuming 1 year of exposure, flat background at a level of $10^{-4}$ count/day/kg/keV, WIMP-nucleon spin independent cross section of $10^{-44}$ cm$^2$, 50 GeV WIMP and the relative scintillation efficiency of 0.2. The sensitivity of WIMP-nucleon cross section as a function of WIMP mass is shown in the left plot.

![Figure 4](image)

**Figure 4.** Left: Expected sensitivity of WIMP-nucleon spin independent cross section as a function of WIMP mass. Right: Expected energy spectrum after 1 year of measurement.

7. Conclusion
The construction of XMASS 800 kg detector was completed in October 2010 and commissioning runs are ongoing. The measured light yield is $15.1 \pm 1.2$ photoelectron/keV. The expected external and internal background is confirmed to be under control. The position resolution of the vertex reconstruction program is about 1.0 cm for the 122 keV γ-rays from $^{57}\text{Co}$.

References
[1] Y. Suzuki et al., hep-ph/0008296.
[2] K. Abe et al., Astropart. Phys. 31 (2009) 290.
[3] S. Agostinelli et al., Nucl. Instr. and Meth. A 506 (2003) 250.