Low background techniques from XMASS

Hiroshi Ogawa[a,b] , for the XMASS Collaboration

[a]*Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo*
[b]*Kavli Institute for the Particle Physics and Mathematics of Universe, the University of Tokyo*

Abstract. An 800kg liquid xenon detector (XMASS) was constructed at Kamioka Observatory, Japan in 2010, and a commissioning run was conducted from November 2010 to June 2012. Although we have achieved the design level of internal backgrounds, it was found that surface contamination is the major contribution of the remaining background. The origins of the surface background have been extensively investigated. In order to reduce these backgrounds and increase the sensitivity for Dark Mater search, refurbishment of the current detector and plans for a future ton-scale fiducial volume detector (XMASS-1.5) are presented.

Keywords: Dark Matter, liquid xenon, surface contamination
PACS: 95.35+d

INTRODUCTION

The XMASS is a multi-purpose detector using ultra pure liquid xenon. The XMASS project aims to detect dark matter, pp, and 7Be neutrinos and neutrino-less double beta decay. The detector is single phase and has ton scale fiducial volume[1].
Advantages of using liquid xenon as target material are its large amount of scintillation light (42,000 photons/MeV), and its “self-shielding” ability, i.e., owing to its large atomic mass (Z = 54) and high density (~2.9 g/cm3), gexternal ammas will be absorbed in a short distance from the detector surface, and hence liquid xenon itself acts as a shield against external gamma background.

The current XMASS-I detector has about 800kg liquid xenon mainly for dark matter search. As a second stage, we plan a 5ton xenon detector with a 1ton fiducial volume called XMASS-1.5.

DETECTOR DESIGN AND PERFORMANCE

The XMASS detector[2] was constructed underground at the Kamioka Laboratory with an overburden of with 2700 m.w.e. Figure 1 shows the detector layout. A cylindrical water tank of 10m diameter and 11m height contains 72 20-inch PMTs. It serves as a shield against fast neutrons and external gammas as well as an active muon veto. The detector itself contains 1085kg of liquid xenon, of which 835kg serve as an active scintillator target in its sensitive inner volume.

642 PMTs (Hamamatsu R10789) are mounted on the pentakis-dodecahedral inner surface of the detector at radii slightly larger but close to 40cm. The photo-cathode coverage of that inner surface is 62.4%. The quantum efficiency of the PMTs at the liquid xenon scintillation wavelength (~175nm) is ~30%. An interactions position and energy are reconstructed from the hit pattern on the inner detector surface.

Energy and position resolution were calibrated with several radioactive sources (57Co, 109Cd, 241Am and 55Fe). The scintillation yield was measured to be 14.7p.e./keVee by 122keV gammas from a 57Co source. At a detector center

LOW BACKGROUND TECHNIQUES FOR XMASS

We developed the new R10789 PMTs with Hamamatsu which are designed to have very low radioactivity (roughly a factor 100 better than traditional PMTs). We measured the parts of the PMT and selected the low radioactive materials. Table 1 summarizes these HPGe measurements.

The OFHC copper which is used for the detector frame and vessel were electro polished. All other materials (more than 250 samples) were checked by HPGe or ICP-MS. There total radioactivity are much lower than that of the PMTs.

The materials are selected too in term of low radon emanation by a pin-photo type radon detector. The radon concentration in the detector was measured to be 8.2+/-0.5 mBq for ^{222}Rn and to have an upper limit of 0.28mBq for ^{220}Rn. A radon removal system uses cooled charcoal was prepared in case we want to further reduce radon [3].

The xenon was distillated to reduce Kr which is present in commercial xenon[4]. 5 orders of magnitude reduction with 4.7kg/hr processing speed was achieved with the XMASS distillation system. The remaining Kr concentration in our xenon was measured to be less than 2.7ppt by atmospheric pressure ionization mass spectroscopy (API-MS).

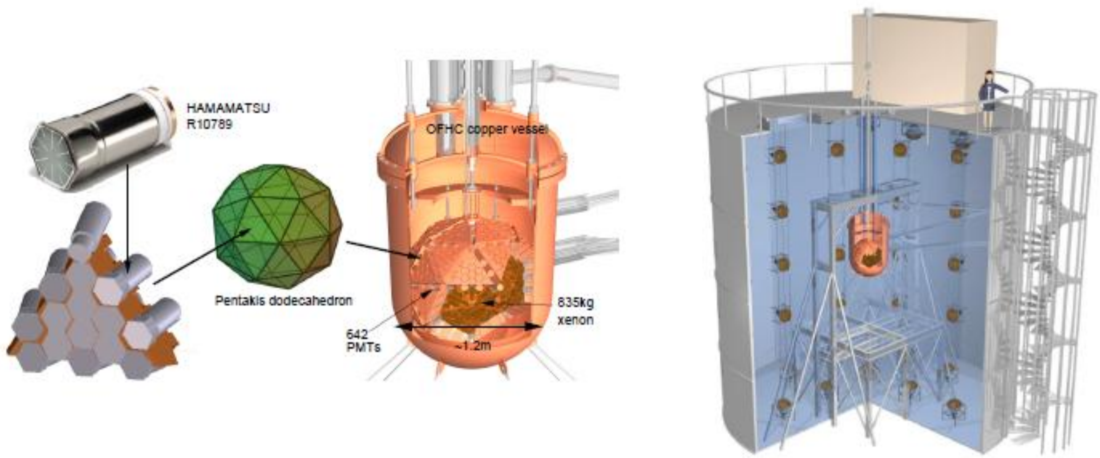

FIGURE 1. The view of XMASS detector.

TABLE1. radioisotopes in the PMTs.

Isotopes	Activity[mBq/PMTs]
U-chain	0.70+/-0.28
Th-chain	1.51+/-0.31
K	9.10+/-2.15
Co	2.92+/-0.16

Unexpected background

Most of the background in XMASS was expected to be gammas from radioactive contaminations in the PMTs. However, our study of the origin of the background indicates that most of it originates on the inner surface of the detector. Figure 2 shows the observed energy spectrum with simulated background spectra. The backgrounds were identified to be 1) The upstream portion of ^{238}U decay chain and ^{210}Pb found in the aluminum used for sealing PMTs, and 2) ^{210}Pb on the inner surface of the detector. The concentration of ^{238}U and ^{210}Pb in the aluminum seal were confirmed by a HPGe measurement. ^{210}Pb on the inner surface were established by alpha event from ^{210}Po decay.

Above 5keV our background is reasonably well understood. The background below 5keV is not completely understood. But one likely candidate is a contamination with ^{14}C in GORE-TEX sheets between the PMTs and support structure.

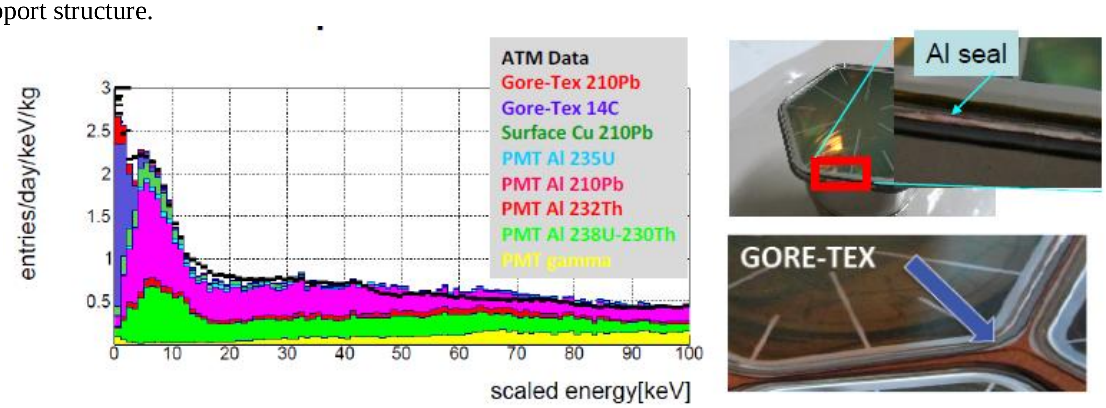

FIGURE 2. left figure is observed energy spectrum with simulated background spectrum below 100keV. Right top figure is picture of aluminum seal for PMTs. Right bottom figure is picture of GORE-TEX.

PHYSICS RESULT FROM XMASS-I

The overall background level in XMASS-I is still quite low, even with the unexpected surface background. And our large light yield allows for a very low analysis threshold of about 0.3keVee. This low energy threshold has sensitivity for low mass WIMPs and solar axion searches. No fiducialization is applied for these two analyses. The WIMP analysis with fiducialization is ongoing.

Weakly Interacting Massive Particles (WIMPs), the most probable dark matter candidate, can be detected directly through WIMPs-nucleon elastic scattering with target nuclei. Many theoretical models beyond the Standard Model predict that the mass of WIMPs is larger than 100GeV. But some experiments indicate a possible WIMPs signal with a lighter mass of ~10GeV[5,6,7].

The 5.6 ton day exposure of low threshold data which taken in February 2012 is analyzed[8]. Noise events, correlated events and Cherenkov events are rejected.

The observed spectrum does not have any prominent feature which could be interpreted as positive evidence of WIMP signals over background. Figure 3 (left) shows the resulting 90% C.L. limit with systematic uncertainties including energy scale, trigger and selection efficiency and uncertainty from the scintillation efficiency $L_{\rm eff}$. XMASS-I data excludes part of the region allowed by other experiments.

The axion is a hypothetical particle which is invented for solving the CP problem in the strong interaction. The particle would be produced in the sun. In the XMASS detector, axions can be detected through the axio-electric effect.

The same dataset is used as in the low mass WIMPs search[9]. No prominent feature suggests any positive evidence for an axion signal. Figure 3 (right) shows the resulting upper limit on the axion-electron coupling constant g_{aee}. We obtain the best direct experimental limit on g_{aee} below 1keV.

After the detector refurbishment, our sensitivity for these searches will be improved by an order of magnitude.

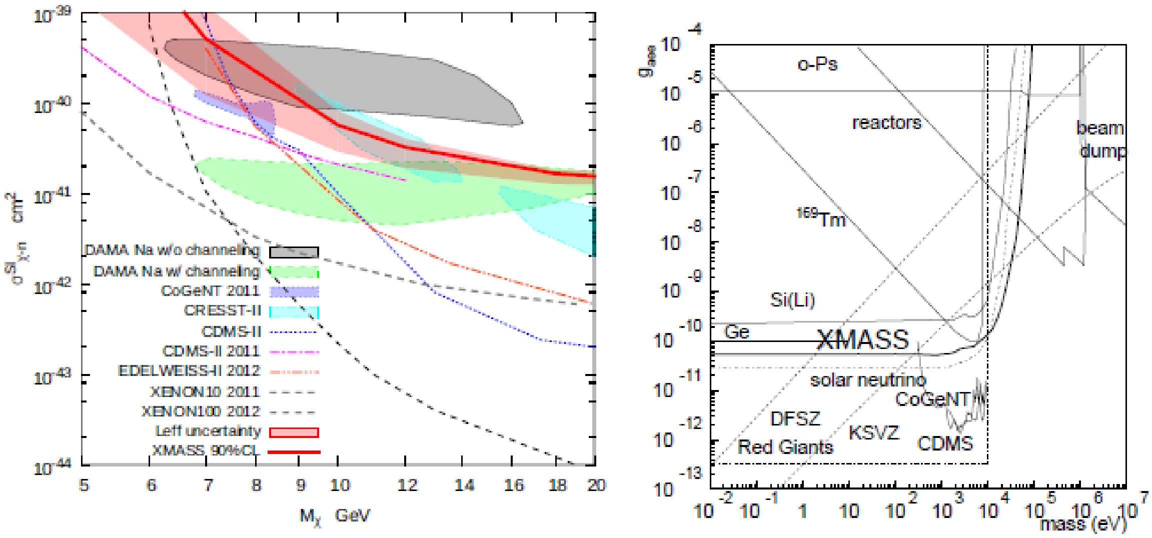

FIGURE 3. (left) Spin-independent WIMPs-nucleon cross section as a function of WIMPs mass. (right) Limits on the axion-electron coupling constant g_{aee} as a function of axion mass.

NEXT STEP FOR XMASS

Refurbishment of detector

The scintillation light from the upstream portion of ^{238}U decay chain and ^{210}Pb in the PMT aluminum produce the majority of the background events in the energy range relevant for Dark Matter search. Our refurbishment effort specifically addresses this background.

The efforts of refurbishment are :

1) A copper ring covering the aluminum seals on the PMTs will prevent light from the α, β and low energy gammas emerging from the seal from entering the detector's sensitive volume.

2) Surface structure improvement to simplify surface and to cover the gap between ring and ring to reduce the leakage events.
3) GORE-TEX is removed.
4) All copper materials used in the detector is now electro-polished to remove surface ^{210}Pb.
5) PMT surface are cleaned to reduce their surface ^{210}Pb.

During the refurbishment work, the environment will be tightly controlled to reduce surface contamination. The radon level is reduced about 0.1Bq/m^3. Detector materials are sealed against radon exposure before assembly. Dust is controlled below class 10 by High Efficiency Particulate Air (HEPA) filter.

The experiment will resume after refurbishment in autumn, 2013.

XMASS-1.5

A ton scale fiducial volume detector (5ton xenon for full volume) is planned as XMASS-1.5. New PMTs will be developed using cleaner material (including aluminum seals). The shape of the photocathode side of the PMT entrance window will become dome shaped. This will help to detect light emitter to the side of the entrance window.

We hope to start the constructing this detector within 2014. The sensitivity for spin independent WIMPs-nucleon scattering will reach to 10^{-46} cm^2 @ 5keV.

OUTLOOK

Data from XMASS-I commissioning run were analyzed and background sources identified. Physics results are reported for a low mass WIMPs search and a solar axion search. Analysis efforts for a WIMP search with fiducialization are ongoing. The background level is not as low as original expected, but the background sources are well understood above 5keV. The refurbishment of XMASS detector is ongoing. Also ton scale fiducial volume detector (5ton xenon for full volume) is planned as XMASS-1.5.

REFERENCES

1. Y.Suzuki, arXiv:hep-ph/0008296
2. K.Abe *et al.*, Nucl. Instrum. Meth. A 716, (2013) 78
3. K.Abe *et al*., Nucl. Instrum. Meth. A 661, (2012) 50
4. K.Abe *et al.*, Astroparticle Phys. 31 (2009) 290
5. R.Bernabei *et al.*, Eur. Phys. J. C56 (2008) 333
   R.Bernabei *et al.*, Eur. Phys. J. C67 (2010) 39
6. C.E.Aalseth *et al.*, Phys. Rev. Lett. 106 (2011) 131301
7. G.Angloher *et al.*, Eur. Phys. J.C 72 (2012) 1971
8. K.Abe *et al.*, Phys. Lett. B 719 (2013) 78
9. K.Abe *et al.*, arXiv:1212.6153, accepted for publication in PLB