Status of the XMASS experiment

Katsuki Hiraide[1,2], *for the XMASS Collaboration*

[1]Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo, Higashi-Mozumi, Kamioka, Hida, Gifu, 506-1205, Japan
[2]Kavli Institute for the Physics and Matematics of the Universe, the University of Tokyo, Kashiwa, Chiba, 277-8582, Japan

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The XMASS project aims to detect dark matter, *pp* and ^{7}Be solar neutrinos, and neutrinoless double beta decay using ultra pure liquid xenon. The first phase of the XMASS experiment is dedicated to dark matter detection employing 835 kg of xenon as an active target. Current status of XMASS is presented.

1 Introduction

The XMASS project aims to detect dark matter, *pp* and ^{7}Be solar neutrinos, and neutrinoless double beta decay using ultra pure liquid xenon[1]. As the first phase, construction of the detector dedicated to dark matter detection was started in April 2007 and completed in September 2010. After installation of purified xenon, commissioning runs were conducted from December 2010 until June 2012. In this paper, preliminary results and future prospects of XMASS are presented.

2 Experimental setup

The XMASS detector is located underground (2,700 m water equivalent) in the Kamioka Observatory in Japan. It is a single phase liquid xenon scintillator detector containing 835 kg of liquid xenon in an active region. The volume is viewed by 630 hexagonal and 12 cylindrical Hamamatsu R10789 photomultiplier tubes (PMTs) arranged on an 80 cm diameter pentakis-dodecahedron support structure. A total photocathod coverage of 62.4% is achieved. In order to shield the liquid xenon detector from external gammas, neutrons, and muon-induced backgrounds, the copper vessel is placed at the center of a ϕ10 m$\times$ 11 m cylindrical tank filled with pure water. The water tank is equipped with 72 Hamamatsu R3600 20-inch PMTs to provide both an active muon veto and passive shielding against these backgrounds. The liquid xenon and water Cherenkov detectors are hence called an Inner Detector (ID) and an Outer Detector (OD), respectively.

PMT signals from ID are amplified by a factor of 11 using custom made preamplifiers and divided into Analog-Timing Module (ATM)[2] and Flash Analog-to-Digital Converter (FADC) inputs. ATM records both the integrated charge and arrival time of each PMT signal. For each ATM channel the discriminator threshold is set to -5 mV, which corresponds to 0.2 photoelectron (p.e.). Waveforms of each PMT signal are recorded using CAEN V1751 FADCs with

1 GHz sampling rate. In addition, every ∼10 PMTs are grouped together and the analog sum of their signals is output from ATM. Each sumed signal is digitized using CAEN V1721 FADCs with 500 MHz sampling rate. For OD, PMT signals are fed into ATMs with the discriminator threshold of 0.4 p.e.

When the number of hit PMTs in ID within a 200 ns window exceeds a certain threshold, an ID trigger is issued. In the same manner, an OD trigger is generated. A global trigger is asserted by either of them to initiate data acquisition for each event. Typical trigger rates for ID and OD are ∼4 Hz and ∼7 Hz, respectively.

Energy and position reconstruction calibrations are performed at several energies and positions along the central vertical axis ($z-$axis) using radioactive sources (^{55}Fe, ^{57}Co, ^{109}Cd, ^{137}Cs, and ^{241}Am). Using 122 keV gammas from the ^{57}Co calibration source placed at the center of the detector, the xenon light yield was found to be 14.7 p.e./keVee. In order to monitor the PMT stability and measure the trigger efficiency, eight blue LEDs with Teflon diffusers are mounted on the surface of the PMT support structure.

3 Light WIMP search

Weakly Interacting Massive Particles (WIMPs), the most possible dark matter candidates, can be detected directly through observation of nuclear recoils produced in their elastic scattering interactions with detector nuclei. Although many theories of physics beyond the Standard Model predict WIMPs with mass larger than 100 GeV, some experiments indicate a possible WIMP signal with a lighter mass of ∼10 GeV. The large light yield enables the analysis threshold to be lowered sufficiently to explore low mass WIMPs in XMASS. In order to achieve optimal sensitivity, the entire detector volume.

The data set used for this analysis, corresponding to 6.64 days of livetime, was taken in February 2012 with a low trigger threshold of four PMT hits in ID. A sequence of data reduction is applied to remove events caused by the tail of the scintillation light distribution after energetic events; (1) events triggered only with the liquid xenon detector are selected, (2) events that occurred within 10 ms of the previous event are rejected, and (3) events whose timing distribution has an RMS greater than 100 ns are removed. An additional cut is applied to remove Cherenkov events originated from ^{40}K contamination in the PMT photocathodes; events with more than 60% of their PMT hits occurring within the first 20 ns of the event window are removed as Cherenkov-like.

In order to set a conservative upper bound on the spin-independent WIMP-nucleon cross section, the cross section is adjusted until the expected event rate in XMASS does not exceed the observed one in any energy bin above the analysis threshold. The analysis threshold is chosen as the energy at which the trigger efficiency is greater than 50% for 5GeV WIMPs and corresponds to 0.3 keVee. The resulting 90% confidence level (C.L.) limit derived from this procedure is shown in Figure 1. Systematic uncertainties in the energy scale, and the trigger and selection efficiencies are taken into account. The impact of the uncertainty from the scintillation efficiency, $\mathcal{L}_{\rm eff}$, is large in this analysis, so its effect on the limit is shown separately in the figure. Without discriminating between nuclear-recoil and electronic events, XMASS sets an upper limit on the WIMP-nucleon cross section for WIMPs with masses below 20 GeV and excludes part of the parameter space allowed by other experiments. The updated result can be found in Ref. [3].

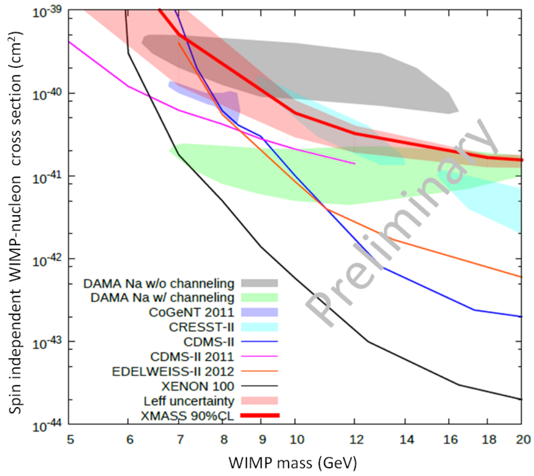

Figure 1: Spin-independent WIMP-nucleon cross section as a function of WIMP mass.

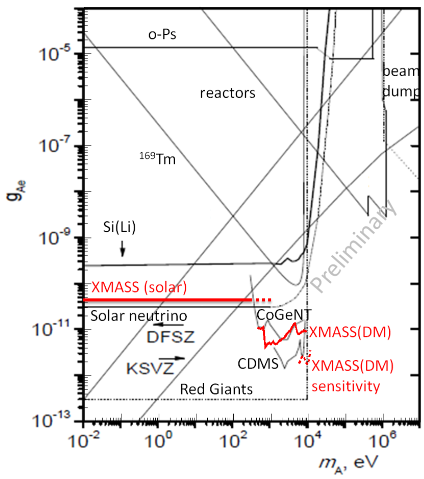

Figure 2: Limits on g_{aee} as a function of axion mass. The original figure is from Ref. [4].

4 Axion searches

Axion is a hypothetical particle which is invented for solving the CP problem in the strong interactions. The particle would be produced in the sun through various mechanisms; in this paper, we focus on Compton scattering of photons on electrons, $e + \gamma \rightarrow e + a$, and bremsstrahlung of axions from electrons, $e + Z \rightarrow e + a + Z$[4]. There is also an argument that axions would be a dark matter which can explain DAMA signals[5]. These axions can be detected through the axio-electric effect, which is an analog of the photo-electric effect, in the liquid xenon detector.

In order to search for solar and dark matter axions in XMASS, the same data set as used for light WIMPs search is analyzed. No prominent feature which suggests a positive evidence of axion signals over background is observed. Hence, by adopting a criteria that the expected signal cannot be larger than the observed spectrum at 90% C.L., upper limits on the axion-electron coupling constant, g_{aee}, are derived. Figure 2 shows a summary of the upper limits on g_{aee}. In the solar axion search, the best experimental limit on g_{aee} is obtained, and the limit is close to the one obtained theoretically based on the consistency between the observed and expected solar neutrino fluxes. For the dark matter axion search, a comparable result with other experiments is obtained. The result can be further improved for axions with masses above 5 keV by fitting the observed spectrum with the signal and background spectra, which is shown as the sensitivity in the figure.

5 Understanding backgrounds

It is important to understand background contamination in order to look for positive evidences of signals. The most backgrounds after the standard selection mentioned above were originally considered to be gammas emitted from radioactive contaminations in PMTs. However, stud-

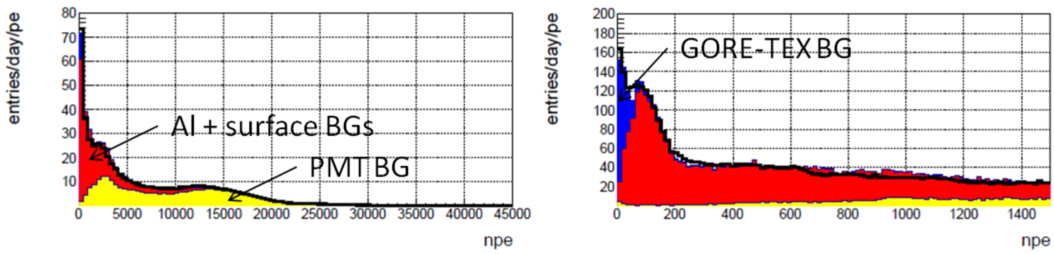

Figure 3: Observed energy spectrum overlaid with simulated background spectrum.

ies of the origin of the background reveals that most of it originates from the inner surface of the detector. Aluminum sealing parts for the PMT, which are faced to liquid xenon, have contaminations of ^{238}U and ^{210}Pb, confirmed by a measurement with a high purity germanium detector. The inner surface of the PMT support structure is contaminated by ^{210}Pb, indicated by a measurement of alphas in the detector. Figure 3 shows the observed energy spectrum overlaid with simulated spectrum based on the measured activities. Though backgrounds are identified above 5 keV, origins of events below 5 keV are not completely understood. Contamination of ^{14}C in the GORE-TEX® sheets between the PMTs and the support structure may explain a fraction of the events. Light leaks through this material are also suspect. Finally, the XMASS Collaboration are working on modifications to the inner surface of XMASS, especially around the PMTs, to improve the detector performance.

6 Conclusion and outlook

The XMASS Collaboration has conducted commissioning runs using 835 kg liquid xenon. With an exposure of 5.54 ton days, light WIMP and axion searches were performed. XMASS sets an upper limit on the WIMP-nucleon cross section for WIMPs with masses below 20 GeV and excludes part of the parameter space allowed by other experiments. For solar axions, the best experimental limit on g_{aee} is obtained. In the dark matter axion search, the result is comparable to other experiments. Intensive studies on background contamination reveals that most of events remaining after the standard selection originate from the inner surface of the detector. By selecting fiducial volume events using an event reconstruction, more sensitive searches are expected to be done. Furthermore, modifications to the inner surface of the detector are under way.

References

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