RECENT RESULTS FROM XMASS

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The XMASS project aims to detect dark matter, \textit{pp} and \textit{\textsuperscript{7}Be} solar neutrinos, and neutrino-less double beta decay using ultra pure liquid xenon. Recent results from the XMASS experiment which employs 835 kg of xenon as an active target are presented.

1 Introduction

The XMASS project\textsuperscript{1} aims to detect dark matter, \textit{pp} and \textit{\textsuperscript{7}Be} solar neutrinos, and neutrino-less double beta decay using ultra pure liquid xenon. Advantages of using liquid xenon as a 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 ($\sim 2.9 \text{ g/cm}^3$), incoming gammas can be absorbed in a short distance from the detector surface, and hence liquid xenon itself acts as a shield for external gamma backgrounds. As the first phase, construction of the detector pursuing 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, recent results and future prospects of XMASS are presented.

2 Experimental setup

The XMASS detector\textsuperscript{2} is located underground (2,700 m water equivalent) in the Kamioka Observatory in Japan. Figure 1 shows a schematic drawing of the detector. 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 $\phi 10 \text{ m} \times 11 \text{ m}$ 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.

Signals from each PMT are fed into ADCs and TDCs. For each PMT channel the discriminator threshold is set to 0.2 photoelectron (p.e.) equivalent. 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 \( \sim 4 \) Hz and \( \sim 7 \) Hz, respectively.

Energy and position reconstruction calibrations are performed at several energies and positions along the central vertical axis (z-axis) using radioactive sources (\(^{55}\text{Fe}, {^{57}}\text{Co}, {^{109}}\text{Cd}, {^{137}}\text{Cs},\) and \(^{241}\text{Am}\)). Using 122 keV gammas from the \(^{57}\text{Co}\) calibration source placed at the center of the detector, the xenon light yield was measured to be 14.7 p.e./keVee. Since the 5.9 keV X-ray from \(^{55}\text{Fe}\) is the lowest energy calibration point, the response at lower energies is extrapolated using a linear fit through all calibration energies.

### 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 \( \sim 10 \) GeV\(^3\)\(^4\)\(^5\).

The XMASS Collaboration has performed a search for low mass WIMPs\(^6\). The data set used for this analysis, corresponding to 6.70 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 \(^{40}\text{K}\) 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. The observed spectrum does not have any prominent feature which suggests positive evidence of WIMP signals over background. 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 5 GeV WIMPs and corresponds to 0.3 keVee. Figure 2 shows the resulting 90\% confidence level (C.L.) limit derived from this procedure. 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, \( \mathcal{L}_{\text{eff}} \), 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.

4 Axion search

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, $e + Z \rightarrow e + a + Z^\gamma$. In the liquid xenon detector, axions can be detected through the axio-electric effect, which is an analog of the photo-electric effect.

In order to search for solar axion 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 3 shows a summary of the upper limits on $g_{aee}$. The best direct 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.

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, studies 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 4 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.
6 Outlook

The XMASS Collaboration are working on modifications to the inner surface of XMASS, especially around the PMTs, to improve the detector performance. Data-taking will be resumed in summer 2013. By selecting fiducial volume events using an event reconstruction, more sensitive searches are expected to be done. Further discrimination of surface background using hits’ timing information is also underway. As a further next step, the XMASS detector will be upgraded to contain total liquid xenon mass of 5 tons (1 ton fiducial mass), which is called XMASS-1.5. The projected sensitivity to spin-independent WIMP-nucleon scattering is shown in Figure 5.

References

7. A. V. Derbin et al., JETP Lett. 95, 379 (2012).