The XMASS experiment

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The XMASS project is a multi purpose low background experiment with large volume of liquid xenon (LXe) scintillator. The current stage with a 835 kg LXe detector was started in 2010. After the commissioning data taking, we have refurbished the detector to reduce PMT related background and resumed data taking. The physics results obtained with commissioning run and the current status of the XMASS are reported.

1 Introduction

The XMASS project [1] was proposed to observe rare events such as elastic scattering of electron by *pp* solar neutrinos, neutrino-less double beta decay, and elastic scattering of nuclei by dark matter particles with a single phase LXe detector. In the XMASS detector, scintillation lights from LXe are observed by photo-multiplier tubes (PMTs) arranged around the LXe volume. LXe is suitable for the rare event search since LXe has high atomic number and density, so it is worked as shield material against external radiation. XMASS-I, the first stage of the XMASS project aims at the search for the dark matter. The XMASS-I detector was constructed in 2010 with 835 kg of LXe in the pentakis-dodecahedral copper vessel, and commissioning runs were conducted from 2010 to 2012. The performance of XMASS-I detector is summarized in Ref. [2].

2 Physics results from XMASS-I commissioning run

2.1 Search for light WIMPs

Since deposit energy by WIMPs is small, the lower energy threshold of XMASS is advantageous for detecting them. In some of the commissioning runs were taken in a low threshold setting. The analysis threshold was set to four hits of PMTs which correspond to 0.3 keV_{ee}. We used 6.7 days with 835 kg entire LXe volume with applying simple cut to reduce Cherenkov background events that occur in quartz windows of PMTs. To constrain light WIMPs, we compare each expected energy spectrum of a certain mass of light WIMPs with the observed data. XMASS excludes part of the parameter space favored by other experiments [3].

2.2 Search for solar axions

The axion is a hypothetical particle introduced by Pecci and Quinn for solving the CP problem in strong interaction. The search for axion as well as axion-like particles (ALPs) focuses on coupling to photons, nucleons and electrons. The signals XMASS searched for are produced by the Compton scattering of photons on electrons and the bremsstrahlung of axions from electrons in the Sun. They can couple to electrons and cause the axio-electric effect to deposit their total energy in the XMASS-I detector. With the same data set of search for light WIMPs, the model independent limit on the coupling for mass $\ll 1$ keV is $\mid g_{aee} \mid < 5.4 \times 10^{-11}$ (90 % C.L.) was obtained. The obtained bounds on the axion mass for the DFSZ and KSVZ axion models are 1.9 and 250 eV, respectively [4].

2.3 Search for inelastic WIMP nucleus scattering on ^{129}Xe

Inelastic scattering that excites low-lying nuclear states in suitable target nuclei provides another avenue to probe for WIMP dark matter. ^{129}Xe is suitable for search for inelastic scattering since it has the lowest-lying excited nuclear state at 39.58 keV among the xenon isotopes. The lifetime of its excited state is short (τ = 1ns), so we searched for a peak at 39.58 keV γ-ray with high energy tail due to the recoil of the ^{129}Xe nucleus. We applied various cuts to reduce the background events as shown in the Figure 1 (left) for sensitive search. We apply a cut based on reconstructed vertex positions, timing information and PMT hit pattern information to reject surface events which are misidentified as inner events. We achieved a low background $\sim 3{\times}10^{-4}$/day/kg/keV$_{ee}$ with 41 kg of LXe fiducial volume. The dominant contribution to the remained events is ^{214}Pb from ^{222}Rn. We observed no significant excess in 165.9 live days data and derived upper limit of inelastic cross section on ^{129}Xe nuclei. We also obtained an upper limit for spin dependent WIMP-nucleus cross section shown in Figure 1 (right). This limit is the first derived exclusively from data on inelastic scattering [5].

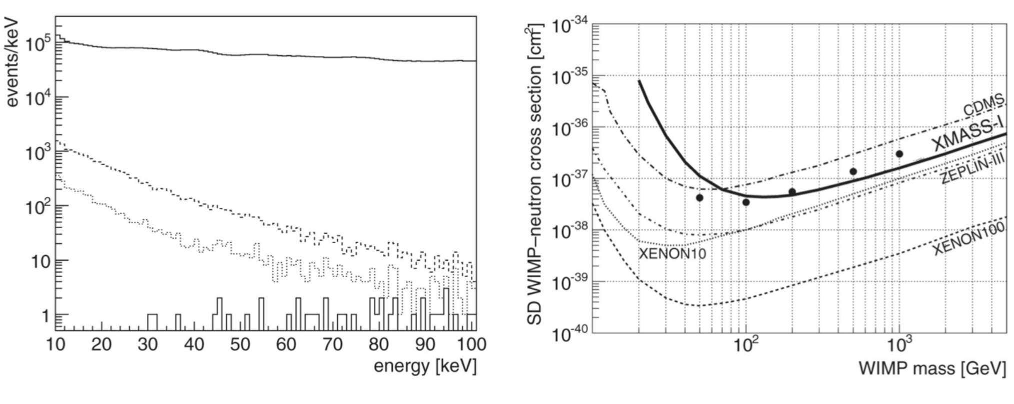

Figure 1: (Left)Energy spectra of the observed events after each reduction step. From top to bottom, the observed energy spectrum after pre-selection (solid), radius cut (dashed), timing cut (dotted) and hit pattern cut (solid), respectively. (Right) The upper limit on the spin-dependent WIMP-neutron cross section from our search for inelastic scattering of WIMPs on ^{129}Xe. The thick line with its gray shaded systematic uncertainty band represents our limit using the form factors of Ref. [7], and the dots represent our limits following Ref. [8] .

2.4 Search for Bosonic Superweakly Interacting Massive Dark Matter Particles

Bosonic super weakly interacting massive particles (super-WIMPs) are a candidate for lukewarm dark matter. For vector boson case, it is called as dark photon, hidden photon and so on. With the absorption of such a boson by a xenon atom, these dark matter candidate would deposit their total energy equivalent to their rest mass in the detector. We search for super-WIMPs in the mass range between 40 and 120 keV. The data set and the reduction method is same as the search for inelastic scattering from ^{129}Xe. We optimized the cut parameters in the reduction steps for each rest mass of super-WIMPs to obtain the best sensitivity. Figure 2 (left) shows the energy spectra of the observed events and simulated events. No significant excess above background, which mostly comes from the radon daughter ^{214}Pb, was observed. Figure 2 (right) shows the limits on coupling constant for pseudoscalar bosons and vector bosons at 90 % C.L. This is the first direct detection experiment exploring the vector super-WIMPs and the obtained limit for the vector super-WIMPs excludes the possibility that such particles constitute all of the dark matter [6].

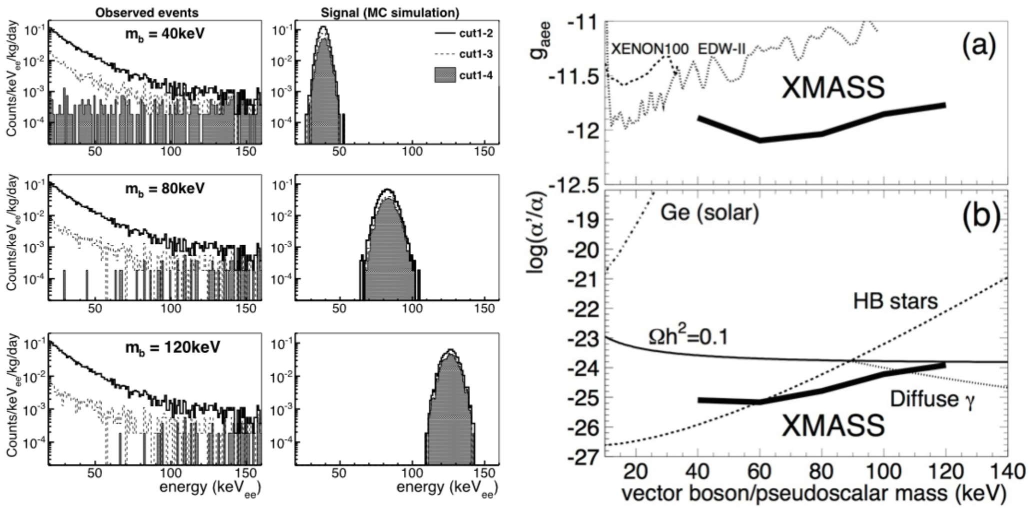

Figure 2: (Left)Energy spectra of the observed events and simulated events after each reduction step for each vector boson mass. Hatched histogram shows remaining events after applying radius cut, timing cut and hit pattern cut. (Right)Limits on coupling constants for (a)electrons and pseudoscalar bosons and (b) electrons and vector bosons at 90% C.L. (thick solid line)

3 Refurbishment of XMASS-I detector and the current status

During the commissioning run we conducted detailed studies on XMASS-I and found that the radioisotopes of ^{210}Pb and ^{238}U in the aluminum seal of the PMT windows is the majority of observed events. To reduce these background, we covered the PMTs with copper ring and high purity aluminum is evaporated on the side of PMT quartz window to minimize the scintillation lights from the aluminum seal. The other issue is background events at blind corners of PMTs are frequently mimic events within the fiducial volume. Thin copper plates were installed to minimize the gaps between the PMT rings. After the refurbishment work was accomplished in November 2013, DAQ was resumed and now we already accumulated about 200 days data. Figure 3 shows the photographs of PMT before and after refurbishment. Now we are working on the detailed analysis of data for deeper understanding of remained backgrounds and for better sensitivities. A result of a quick check are shown in Figure 3. One order of magnitude reduction above 5 keV for entire volume is achieved.

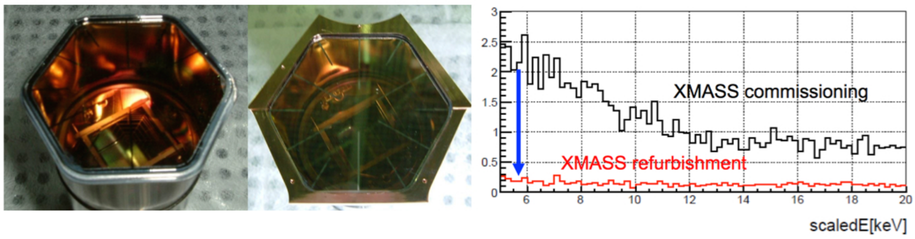

Figure 3: (Left and Middle)The photographs of PMT before and after refurbishment. The aluminum seal of the PMT window is covered with the copper ring to prevent scintillation photon from radioisotopes. (Right)Energy spectrum for entire volume before and after refurbishment. The vertical axis is counts/day/kg/keV$_{ee}$. One order of magnitude reduction is achieved.

4 Summary

The goal of the XMASS project is to observe the various rare events with a large volume of LXe. The current XMASS-I detector has the largest target mass (835 kg) and achieve the very low energy threshold (0.3 keV$_{ee}$). We discussed the physics results of the XMASS-I from the commissioning runs. The refurbishment work for the XMASS-I detector and the current status of the XMASS experiment are also reported.

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