Status of the KIMS experiment

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KIMS(Korea Invisible Mass Search) is the research project to search for the direct interaction of WIMPs (Weakly Interacting Massive Particles), one of the strongest candidates for the missing matter in the universe. The experiment has been carried out at the Yangyang underground laboratory in Korea using CsI(Tℓ) crystal scintillators whose total mass is 104.4kg. The status is reported here.

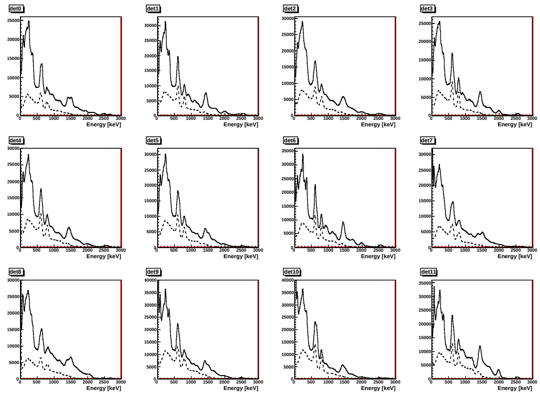
1 Introduction

The existence of dark matter is the prevailing hypothesis about the missing matter of our universe, which is supported by various cosmological observations, such as, galaxy velocity distribution [1], observations of X-rays from hot clusters [2], observation of the bullet cluster [3] and CMB anisotropy measurements [4].

The dark matter is very likely to be a WIMP(Weakly Interacting Massive Particle). And, candidates for WIMPs are very abundant, for example, the lightest supersymmetric particle, lightest kaluza-klein particle, massive sterile neutrino and axino, which are introduced from various motivations other than the dark matter problem. WIMPs are expected to recoil the nucleus and deposit a few tens keV of recoil energy. Since its interaction rate is known to be very rare, the detector material must be carefully chosen to avoid radioisotope background and proper passive and active shielding is required.

KIMS is a research project to search for this direct interaction of WIMPs using CsI(Tℓ) crystal scintillators, whose total mass is 104.4kg. The experiment has been carried out in the Yangyang underground laboratory(Y2L) which is at 2000 m water-equivalent-depth. CsI(Tℓ) crystal is a very popular scintillator well-known for its high scintillation yield. It is relatively easy to get large mass with an affordable cost. Also, it enables the pulse shape discrimination so that we can estimate nuclear recoil event rate. Furthermore, the spin expectation value of protons in Cs and I is relatively high compared to other target materials used for WIMP searches. Therefore, currently the most stringent limits on spin dependent WIMP interactions with pure protons is set with CsI(Tℓ) detector [6]. But, CsI crystal has intrinsic radioisotope backgrounds such as ^{137}Cs , ^{134}Cs and ^{87}Rb . We found that ^{137}Cs comes into the crystal through the processing water in manufactoring CsI powder. With ultra clean water, we obtained $\sim 2 counts/(keV \cdot kg \cdot day)$ level of background for CsI powder around 10keV region [5].

(a) Detector arrays



(b) Energy spectrum of Each detector

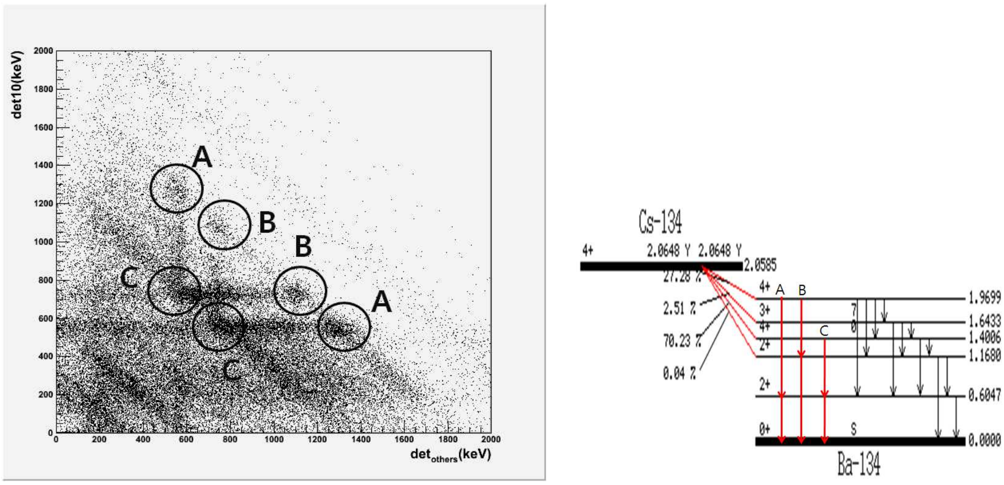
Figure 1: Detector arrays and their energy spectrum, at (b) dashed line represents multiple events.

2 Detector description

The whole detector system is composed of 3 × 4 CsI(Tℓ) detector arrays shielded adequately with Cu, Polyethylene, lead and Muon veto layer made of liquid scintillator covering the whole system with 4π coverage, which also acts as a neutron moderator. Details of the KIMS detector can be found in other documents [7]. Each detector module consists of a crystal and two PMTs mounted at both ends of the crystal. The crystal weighs 8.7kg, and its size is 8 cm × 8 cm × 30 cm. The PMT has green-enhanced photocathodes and their photoelectron yields are about 5 per keV. At present, events are recorded for a period of 40 μs and digitized with 400MHz FADC. We required 2 photoelectrons within 2 μs in each PMT for an event trigger condition. We applied 8ms dead time after high energy event trigger. The efficiency of this dead time application is more than 99% .

Figure 1 shows the detector array and their energy spectrum. The dashed line is the energy spectrum of multiple hit events. Here one can see the two dominat peaks correspond to ^{134}Cs , 604 and 795keV. The Compton scattered and full-peak events of these gammas are very useful in various calibration. As seen in Figure 2 (a), a plot of the energy spectrum of one detector versus that of the others, one can see various decay modes of ^{134}Cs . Each circle in the plot (a) represents the decay mode of same letter in (b).

Since neutron events mimic WIMPs, we measured the neutron background inside the detector shield using BC501A liquid detectors. Though the passive shield blocks neutron background sufficiently, there can be neutron background inside the shield due to high energy muon interactions with the shield structure. From the coincidence between Muon detector and neutron detector, we measured the muon induced neutron rate, $(3.8 \pm 0.7) \times 10^{-2}$ counts/day/liter for 0.4 MeV - 2.75 MeV neutron. It is roughly consistent with our GEANT4 simulation results, $(2.0 \pm 0.2) \times 10^{-2}$ counts/day/liter.



(a) Energy of det10 and others

(b) Decay mode of ^{134}Cs

Figure 2: Identification of decay mode of ^{134}Cs with detector arrays.

3 PMT noise background study

In a rare phenomena search experiment with low energy threshold using PMTs, the background from PMT noise limits the sensitivity seriously. There are several main sources for PMT noise background. These are thermionic emission, afterpulse, Cerenkov radiation from Cosmic rays or background radioisotopes. Scintillation from the glass envelope also can cause PMT noise. For thermionic emission, since it is seen as one single photo electron(SPE) and its typical rate is a few kHz, the probability of several thermionic emissions in the $40\mu s$ event window for both PMTs contributing to energy range higher than 2keV is negligible. Afterpulse is produced by the collision of the residual gas ion in the PMT with the photocathode. After collision, several SPEs are released at the same time. Therefore, it forms big cluster signals compared to the normal SPE. Figure 3 shows the 2-dimensional scatter plot between the size of a cluster and the time from the previous cluster. The cluster size is indicated by the number of SPEs. Usually, the cluster size is one SPE. But, one can find clusters whose size are equivalent to several SPEs and which show up in a fixed time span from the previous cluster. These time spans depend on ion colliding with a photocathode. Cerenkov radiation also produces several SPEs in a very short time, less than a few ns, it also shows big clusters in its signal.

For PMT background study, We took about 2 month data putting clean acrylic boxes in place of crystals. We call it PMT-only-detector. From these data, we found PMT noise event has big clusters in it, and it can be understandable with above explanation. Since it is almost random coincident between two PMTs, the event is asymmetric in signal size and time distribution along two PMTs. Based on these facts, we developed the event selection cuts to reject the PMT noise event. We applied these cuts to 25 days of PMT-only-detector data and for most of detectors, less than 10 events survived equivalent to $\sim$ 0.05 count/kg/day. After applying PMT noise rejection cut and other cuts (e.g multiple hit rejection), our preliminary background level is 2–4 $counts/(keV \cdot kg \cdot day)$ after efficiency correction.

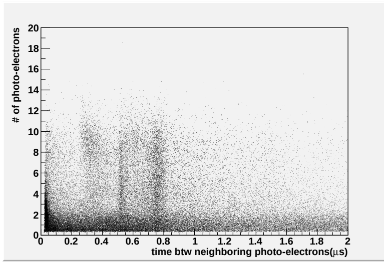


Figure 3: Signal size and time distribution of afterpulse.

4 Status and plan

We have collected about one year data with 104.4kg of detector. Based on better understanding of PMT noise background, we have developed more efficient cuts. Background level is 2–4 $counts/(keV \cdot kg \cdot day)$. Now, various analysis is going on for the accumulated data. More time is required to analyze the annual modulation to cover the whole time bins of a year. Currently, we are testing new PMT known for higher quantum efficiency in metal packaging. If it shows better performances, it will be adopted in the future upgrade.

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