Status of the COSINE-100 Experiment

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Presently a number of experiments are operating to search for the WIMP, a dark matter candidate. Among these experiments, DAMA/LIBRA claims to observe an annually modulated WIMP signal, while other experiments, using different technologies and target materials, exclude the DAMA/LIBRA signal region in the parameter space. The COSINE experiment aims at exploring these contradicting results by using NaI(Tl), the same target material as DAMA/LIBRA. The first phase detector with 106 kg of NaI(Tl), COSINE-100, was installed at the Yangyang underground laboratory in Korea. It consists of several shield structures, including a liquid scintillator veto system. The experiment has started physics data taking in late September 2016 and has been operating stably since then.

1 Introduction

Weakly Interacting Massive Particles(WIMPs) are well-supported dark matter candidates in the theory [1]. Numerous direct searches of WIMP have been carried out using different materials and techniques. Among these experiments, the DAMA/LIBRA experiment has reported the observation of an annual modulation signature of WIMPs [2]. However, the WIMP-nucleon cross sections inferred from this DAMA/LIBRA modulation signal are in conflict with other null observation from XENON100 [3], LUX [4] and SuperCDMS [5]. To resolve this confliction, several experiments have been performing a WIMP search using low-background NaI(Tl) crystals [6, 7, 8, 9, 10]. Using the same target material and techniques as DAMA/LIBRA, it is expected to confirm DAMA/LIBRA's observation without any ambiguity.

2 COSINE-100 experiment

COSINE-100 is a NaI(Tl) WIMP search experiment collaboration between KIMS and DM-Ice. The eight NaI(Tl) crystal array with a total mass of 106 kg was deployed at Yangyang underground laboratory in South Korea. Detectors are installed inside a substantial shield that consists, from the inside out, liquid scintillator, a copper box, lead blocks and plastic scintillator panels. Plastic scintillator panels also have a role to detect muon signals. The eight NaI(Tl) detectors are immersed into the liquid scintillator which acts as a veto system. Figure 1 shows the shield structure of COSINE-100 detector.

The room temperature and humidity are controlled by air conditioning system and the room air is circulated through a HEPA filter to maintain a clean environment. Detector room

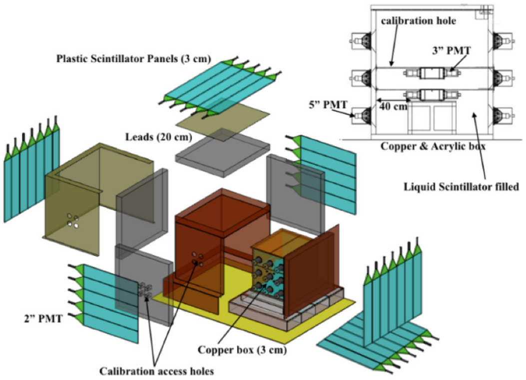

Figure 1: Shield structure of the COSINE-100 experiment. Encapsulated NaI detectors are placed inside the copper chamber which is surrounded by several shield materials for active shielding of various external backgrounds and liquid scintillator is filled in the copper chamber.

environmental parameters, the status of DAQ rate and electronics are monitored remotely online.

3 Performance of NaI detectors

Because of the low interaction rate between dark matter and ordinary matter, low background is crucial for WIMP search. We have studied backgrounds of NaI(Tl) crystals before the installation of COSINE-100 at the test setup which was in the CsI(Tl) crystals array used for KIMS-CsI experiment. Since the NaI detector is surrounded by CsI crystals, single NaI crystal hit events and multiple hit events crossing different crystal are separable using coincidence events of CsI detectors. One of the crystals installed in COSINE-100 has been studied in this setup and simulation was performed to understand backgrounds. From this study, we understand that the most stringent backgrounds in the NaI(Tl) crystal are associated to ^{40}K and ^{210}Pb [11]. The eight crystals were grown from four different types of powder, which have different levels of radioactive backgrounds.

Several criteria to reject PMT noise are required to select events. PMT noise and scintillation signal have different time characteristics of fast and relatively slow component. By using the characteristics, PMT noise is well separated from scintillation signal [10]. Noise signals produced by PMTs usually make large asymmetries in total charge between two PMTs. The charge asymmetry parameter is also used for rejection of noise events. Event selection efficiencies estimated using Compton scattering events from ^{60}Co radioactive source reach about 90% at 1 keV and 94% at 2 keV energy range in Crystal 7. It shows that event selection cuts work well for discriminating signal from noise. To reduce the events around 3 keV from ^{40}K decay, one of main backgrounds, coincidence of 1460 keV events with the liquid scintillator is required [12].

Figure 2 shows single hit events energy spectra for four crystals grown from different types of powder after all event selection criteria described above are applied. Due to high light yield around 13 p.e./keV on average, the energy threshold reaches to 2 keV. The peak near 46 keV (Figure 2, left) and slowly decreasing distribution at low energy region (Figure 2, right) reflect

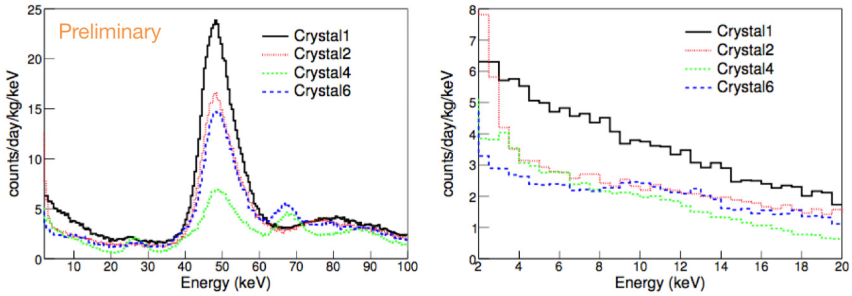

Figure 2: Energy spectrum comparisons for four crystals grown from different types of powder after event selection criteria applied. The peak near 46 keV (left) and slowly decreasing distribution (right) reflect contamination level of ^{210}Pb in a crystal.

contamination level of ^{210}Pb in a crystal. The simulation is ongoing to understand backgrounds of crystals more deeply [13]. For muon induced events rejection, data from the plastic scintillator array is under study [14].

4 Prospects of COSINE-100

We have an experience on the analysis using pulse shape discrimination (PSD) method for the NaI(Tl) crystal [15]. Based on it, it is possible to search a WIMP with a few months data using PSD analysis which allows to extract WIMP candidate events by discriminating nuclear recoil from electron recoil backgrounds. The study of WIMPs annual modulation signature is going to be performed once we have more than one year of data. Assuming 4.3 counts/day/kg/keV flat background with no modulation signal, two years of data with 1 keV threshold will give comparable sensitivity with DAMA's 90% C.L. allowed region as shown in Figure 3.

For the next phase of COSINE-100, several efforts to lower background level of the crystals are ongoing. Low energy events induced by Pb decay are measured to understand characteristics of ^{206}Pb nuclear recoil deposition on the surface of the NaI(Tl) crystals, which can mimic WIMP induced events. NaI(Tl) crystal encapsulation R&D is also ongoing by immersing the crystal in the liquid scintillator or coating plastic scintillator on the crystal to tag backgrounds more effectively.

5 Summary

The first phase of the COSINE-100 experiment deployed 106 kg of NaI(Tl) crystals at Yangyang underground laboratory. COSINE-100 has been operated stably since it started taking data at the end of September 2016. We have capability to directly test DAMA annual modulation results within two years. Through various R&D efforts, we expect to achieve a background reduction.

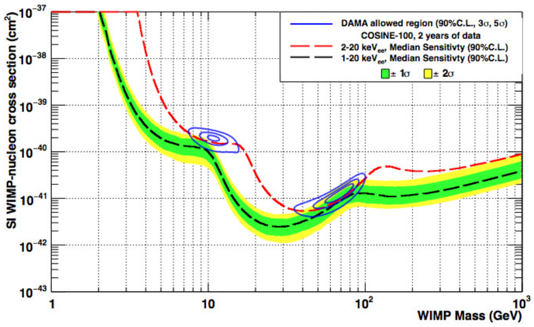

Figure 3: The median expected (black dotted line) 90% CL upper limit on the WIMP-nucleon spin-independent cross-section from the COSINE-100 experiment assuming the background only hypothesis, shown together with WIMP induced DAMA/LIBRA allowed region.

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