Status of the KIMS Experiment

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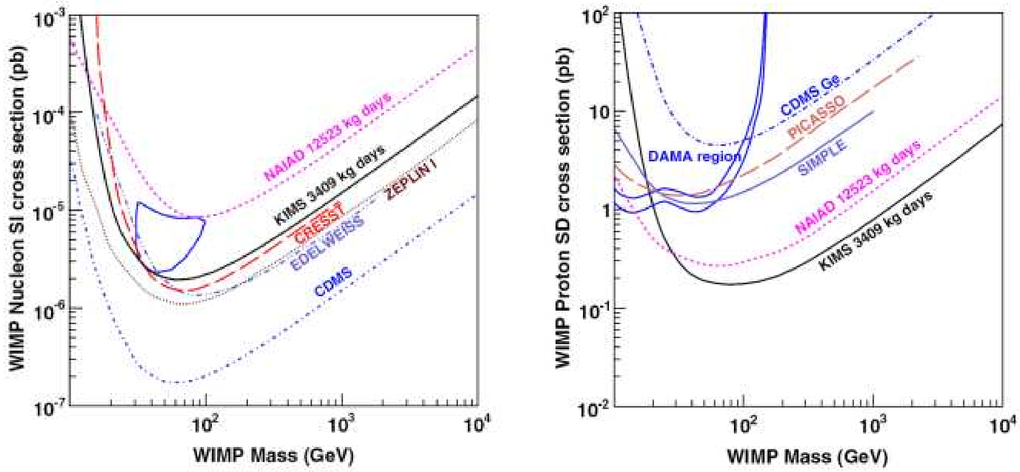
KIMS (Korea Invisible Mass Search) Collaboration has carried out WIMP search using CsI(Tℓ) crystal scintillators. The experiment was conducted in YangYang underground laboratory(Y2L), of which the water equivalent depth is about 2000m. Besides CsI main detectors, we are operating neutron detector and muon detector to understand the background events other than WIMP. Recently the CsI main detector was upgraded to 104.4 kg. The current status of KIMS project is reported.

1 Introduction

Dark matter problem is a long-standing, open question about the missing mass which isn't identified yet, but whose gravitational effect is evident [1]. Furthermore, it is supposed to occupy most part of the matter component in the universe. By recent astronomical observation, like bullet cluster [2], the existence of exotic dark matter, not ordinary like atom or other known particle, is supported more than before. WIMP (Weakly Interacting Massive Particle) is one of strong candidates of the dark matter since it is introduced naturally from the supersymmetry theory. LSP (lightest supersymmetric particle) can be the stable, massive and weakly interacting particle so that it can explain the relic dark matter density for present large scale structure of the universe [3]. WIMP is expected to recoil the nucleus and deposit a few tens keV of recoil energy. All over the world, many experiments to detect WIMP are going on. KIMS(Korea Invisible Mass Search) is one of these projects, using CsI(Tℓ) crystal scintillator, which has been carried out in Yangyang underground laboratory (Y2L) in Korea.

Atomic mass number	$Cs = 133,\ I = 127$
Density(g/cm^3)	4.53
Decay constant(ns)	~ 1000
Peak emission(nm)	550
Light yield($photon/MeV$)	~ 60000
Hygroscopicity	Slight
Spin expectation value(Cs)	$< Sp >= -0.370,\ < Sn >= 0.003$
Spin expectation value(I)	$< Sp >= 0.309,\ < Sn >= 0.075$

Table 1: Properties of CsI(Tℓ) crystal.



(a) (b)

Figure 1: SI exclusion limit (a). SD exclusion limit for pure proton (b).

CsI(Tℓ) is a very popular scintillator, which has high light yield and weak hygroscopicity. Table 1 shows the some properties of CsI(Tℓ) crystal. CsI(Tℓ) crystal enables pulse shape discrimination so that we can statistically separate the electron recoil background from nuclear recoil signals. Since CsI(Tℓ) has high spin expectation value, especially for proton, it is quite sensitive to the Spin Dependent(SD) interaction of WIMP with nucleus, which makes this project distinguished. But, because of internal radio-isotopes, ^{137}Cs , ^{134}Cs , ^{87}Rb , we have made serious efforts to reduce these impurities, and now we can obtain $\sim$ 2cpd level of crystal [4]. Using these crystal, we have performed the experiment in Y2L, whose water-equivalent-depth is 2000m, with proper passive and active shieldings, and neutron monitoring detector. The full description about the detector system can be found in other documents [5].

2 Latest WIMP search results

Each detector module is composed of a crystal and two PMTs which are mounted at both ends of the crystal. The crystal weighs 8.7kg, and its size is 8cm $\times$ 8cm $\times$ 30cm. The PMT is green-enhanced and the light yield is around 5 photoelectron per keV. Each event was recorded for a period of 32 μs with 500 MHz FADC. We required 2 photoelectrons in 2 μs in each PMT for an event condition. With 4 detector modules, we obtained 3409 kg·days of data.

At the energy range of interest, 3–11 keV, PMT noise events significantly limits the sensitivity. So, to understand the PMT background events, we took some data after replacing CsI(Tℓ) crystals with clean acrylic boxes. With this experiment, we found following facts. Firstly, PMT background event decays faster than scintillation signals from the crystal. Secondly, it decays as one exponential function rather than two components of exponential. Thirdly, it is asymmetric across 2 PMTs. According to the cuts developed by PMT-only-test, we could reject all the PMT background events. And, we selected only single hit events, which fire only one detector module, since WIMP doesn't do the multiple scattering.

We applied pulse shape discrimination method to the selected events to calculate the nuclear recoil event rate, using the mean time calibration with ^{137}Cs Compton scattering γ and neutron from Am-Be source. In determining the nuclear recoil event rate, we considered various factors for systematic error, i.e, variation according to different crystals and temperature. From this careful estimation, we concluded that our nuclear recoil event rates are consistent with zero and we set the limit of WIMP-Nucleon cross section at 90% confidential level [6].

Through this result, we can cross-check DAMA experiment which claims the observation of WIMP by annual modulation technique with NaI(Tℓ) crystals. As shown in Figure 1(a), our result is not compatible with DAMA signal region. At least, we can say that we ruled out the DAMA signal region contributed from ^{127}I , the dominant target of SI interaction for DAMA experiment. And, as shown in Figure 1(b), for SD interaction in the case of pure proton coupling, we could set the most stringent limit around 100GeV WIMP mass. However, DAMA / LIBRA recently confirmed their annual modulation signature with higher statistics. Therefore the annual modulation remains to be checked independently by other experiments. KIMS with higher mass may be able to check annual modulation directly.

3 Study of background event which mimics WIMP

Because neutrons also make nuclear recoil, it's very hard to distinguish neutron signals from WIMP signal. So, neutron background must be suppressed as much as possible. Main sources of neutron are spontaneous fission of ^{238}U, (α, n) reactions and neutrons induced by cosmic muons. Neutrons from these natural radioactivity except cosmic muon, can be blocked through proper passive shield sufficiently. But, high energy cosmic ray can produce the neutron inside of the shield structure. Furthermore, since when high energy muon hits the crystal, it produces an event with very long tail like a few tens of millisecond for CsI(Tℓ) , this tail event can be detected as the low energy signal (Figure 2). A detailed study for the rejection of these tail events is in progress.

To understand the neutron and cosmic muon background, we installed neutron monitoring detector made of BC501A scintillator inside and outside of the detector shield. And,we made detector's outmost layer which covers the detector shield in 4π direction with the mineral oil mixed with liquid scintillator for the muon veto. The measured muon flux in our experimental hall is 2.7×10^{-7} /cm^2/s . The neutron flux at the experimental hall is measured as 8×10^{-7}/cm^2/s for 1.5MeV–6MeV neutron. We measured the muon induced neutron rate inside of the shield from the coincidence between neutron detector and muon detector. The measurement is $(3.8 \pm 0.7) \times 10^{-2}$ counts/day/liter for 0.4MeV–2.75MeV neutron. This is more or less consistent with our GEANT4 simulation result, $(2.0 \pm 0.2) \times 10^{-2}$ counts/day/liter. The neutrons induced by cosmic muons are thereby not affecting our WIMP search at the level of the current sensitivity.

4 Current status

Recently, The total detector mass is increased to 104.4kg, which consists of 12 modules. A preliminary study shows the background levels are 2–4 cpd depending on the crystal. We have took the data from the end of 2007, and some minor optimization has been done. After one year, we expect to see some important messages about the annual modulation.

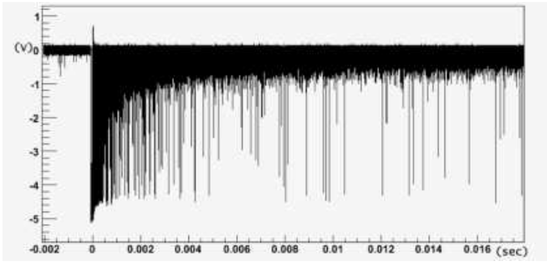


Figure 2: High energy muon event with long tail observed by CsI(Tℓ) detector. The time scale shown in the figure is up to 17ms and one can still see the photoelectrons.

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