Results from KIMS


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Abstract. KIMS is a dark matter search experiment using low background CsI(Tl) crystals at Yangyang Underground Laboratory in Korea. With a total exposure of 3409 kg-d data, we set a new limit on WIMP-nucleon cross section. We achieved the most stringent limit on the spin-dependent interaction for a pure proton case. We were able to exclude the DAMA signal region for both spin-dependent and spin-independent interaction for the WIMP mass greater than 20 GeV/c². KIMS experiment is upgraded with 12 CsI(Tl) crystals corresponding to a total mass of 104 kg and accumulating data since Jan. 2008.

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INTRODUCTION

Results from cosmological and astronomical observations [1, 2] favors matter density of universe of ~ 30%. Among these, amount of known matter is only ~ 4% and the rest is believed to be Dark Matter, yet unidentified form of matter. Weakly Interacting Massive Particles (WIMPs) are the most widely searched candidates of particle dark matter and their typical mass range is between 10 GeV to a few TeV.

The Korea Invisible Mass Search (KIMS) experiment is located at Yangyang Underground Laboratory, which is about 700m vertical depth underground. KIMS uses CsI(Tl) crystals for WIMP search. The shielding structure of KIMS consists of mineral oil for neutron shielding and muon veto, lead, copper for gamma shielding. Details of KIMS detector can be found in the previous publications [3, 4]. We have accumulated a total exposure of 3409 kg-d data with 4 low background CsI(Tl) crystals operated at T=0°C. Dimension of each crystal is 8 x 8 x 30 cm³ and its weight is 8.7 kg. Green-enhanced Rb-Cs photo multiplier tubes with Quartz windows are mounted on both sides of each crystal. Data from each PMT is amplified and recorded by a home-made 500MHz flash analog-to-digital converter. Each event is recorded for a duration of 32 μs when the event satisfied the trigger condition: at least two photoelectrons within 2 μs on both PMTs.

Average light yield of CsI(Tl) crystals is about 5 photoelectrons/keV. Energy resolution measured with ²⁴¹Am source is 7.3% at 59.5 keV.

We have reduced internal background of CsI(Tl) crystal by orders of magnitude through various processes those were reported in Reference [5, 6]. For the crystals used for the current analysis, contamination of ¹³⁷Cs is about 1.7 mBq/kg, ⁸⁷Rb less than 1ppb. Background from ¹³⁴Cs could be removed by off-line analysis by requiring one and only fired crystal.

ANALYSIS

We adapted mean time(MT) as a Pulse Shape Discrimination (PSD) variable to distinguish nuclear recoil signals from electron recoil signals in the CsI(Tl) crystal [7, 8].

For the calibration of nuclear recoil, we obtained reference distribution of nuclear recoil events using the Am-Be neutron source. This calibration was done with smaller size test crystal. We have prepared test crystals for each type of crystal we used for WIMP search and their size were 3 x 3 x 3 cm³. We also collected electron recoil samples using ¹³⁷Cs with test crystals for the comparison with the electron recoil calibration data obtained from WIMP search setup with ¹³⁷Cs source.

As one can see in Figure 1, mean time distributions of nuclear recoil events are faster than electron recoil. Fig-
FIGURE 1. Mean time(MT) distribution of nuclear recoil events for the test crystal(open squares), electron recoil events for the test crystal(tilled triangles) and a full size crystal(open circles) in the 6-7 keV range.

Figure 1 also shows that mean time distributions of electron recoil events for the two different size crystals are in a good agreement. This assures that we can use nuclear recoil data from test crystals as a reference for the WIMP search analysis.

Since PMT noise is the most significant background at low energy in our experiment, we took 350 kg-day data with the same-sized clear acrylic boxes in the place of CsI(Tl) crystals using the same PMTs in place. In this data, we used the same system and trigger condition as WIMP search data. With this data we developed cuts which removed PMT noise events from WIMP search data.

Every event is fitted to a double exponential function given by

$$PDF(t) = \frac{1}{\tau_f} e^{-(t-t_0)/\tau_f} + \frac{R}{\tau_s} e^{-(t-t_0)/\tau_s},$$

where $\tau_f$ and $\tau_s$ are decay time constants of fast and slow components, and $R$ is the ratio between two components.

While signals from CsI(Tl) crystal have two components, PMT noise signal does not have long component. Therefore we also fit each event with one exponential function. In order to remove PMT related background we applied series of cuts, such as

- $\log(\tau_f)$
- the ratio of the maximum likelihood values of two component fit to one component fit
- charge asymmetry between signals from two PMTs on one crystal

Since WIMP scattering event would not cause multiple scattering in our detector volume, we require only one fired crystal. This cut also removes background from $^{134}$Cs. Those rejected events with signals in more than one crystal are mainly from Compton scattering of gammas and they are used to check the validity of gamma calibration as well as efficiency estimation. After applying all cuts, event selection efficiency becomes 30% (3 keV) to 60% (above 6 keV) depends on measured energy.

Nuclear Recoil event rate is extracted in each keV bin from 3 to 11 keV range. Mean time distribution of each calibration data is fitted to an asymmetric gaussian function, and finally log(MT) distribution of WIMP search data are fitted to the sum of two reference distributions. Details of this analysis is given in [9].

Our result on Spin-Independent interaction(SI) is shown in Figure 2 together with 3$\sigma$ signal region of DAMA [11]. This is the first time that this region is ruled out by a crystal detector which contains the same $^{127}$I as a dominant nucleus for SI interactions of WIMP.

Our limit on Spin-Dependent interaction for pure proton coupling is given in Figure 3 together with results from CDMS [12], PICASSO [15], NAIAD [13], SIM- PLE [14] and DAMA [11]. Our result shows the most stringent limit.

KIMS UPGRADE

Since Jan. 2008, we started taking data with a total mass of about 100 kg. This represents a three-fold increase in mass over that used for the published result. Figure 4 shows the photo of 12 crystals inside of Cu box at the Yangyang underground laboratory.

Preliminary analysis shows background rates of those crystals ranges from 2 to 4 counts/kg/day. We are also studying muon coincidence events to develop new cuts to remove the tail events caused by afterglow of the crystal when a large energy is deposited in the crystal by

FIGURE 2. Exclusion plot for the SI interaction at the 90% confidence level.

534
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References