THE RECENT RESULTS FROM KIMS EXPERIMENT

SeungCheon Kim for KIMS collaboration
Department of Physics and Astronomy, Seoul National University,
Seoul, 151-747, Korea

KIMS (Korea Invisible Mass Search) has been carrying out weakly interacting massive particle (WIMP) search experiment using CsI(Tl) scintillator at Yangyang underground laboratory (Y2L). The detector is composed of an array of 12 scintillators and its total mass is 103.4 kg. With almost one year of data, we estimated the nuclear recoil (NR) event-the candidate for WIMP events-rate based on the pulse shape discrimination (PSD) analysis and found there is no meaningful excess of NR events. The improved limit for WIMP-nucleon cross section are presented in the article.

1 Introduction

Thanks to various astronomical observations, the existence of the unknown, invisible (dark) matter as the major matter constituent of our universe becomes a compelling scenario [1]. We have plenty of dark matter candidates provided from the extension of the standard model of the particle physics, motivated independently from the dark matter problem. WIMP is one of the popular candidates since it can be introduced naturally in the theories such as the supersymmetry and explain the relic density of the dark matter very well [2]. Furthermore, if it exists, it will recoil the nucleus in the absorber, so that the recoil energy from the WIMP interaction directly can be detected. However, its recoil energy is expected to be less than around 10 keV and its event would happen very rarely. Therefore, the detector which has the lower energy threshold , larger detector mass, and better background suppression (or discrimination) will have more capability to observe the WIMP-nucleus interaction. KIMS experiment is WIMP search experiment based in Y2L using CsI (Tl) scintillators. CsI (Tl) scintillator is a widely used particle detector which is easy to handle. Since the constituent nuclei, iodine and cesium, have large atomic mass (A), 127 and 133 respectively, it can take advantage of A^2 scaling effect for the case of WIMP-nucleus spin-independent (SI) coherent scattering. For the case of WIMP-proton spin-dependent (SD) scattering, it can also have the good sensitivity because iodine and cesium have large proton spin expectation value. The PSD analysis method is also an additional good point of the CsI (Tl) scintillator. The nuclear recoil event-the candidate for WIMP-nucleus interaction- rate can be estimated in the statistical basis. However, the weak point of CsI (Tl) scintillator is its internal background such as ^{87}Rb, ^{134}Cs and ^{137}Cs. We had the intensive investigation for the background reduction, and now we have achieved 2-3 counts/day/kg/keV of backgroud level around 10 keV [3].

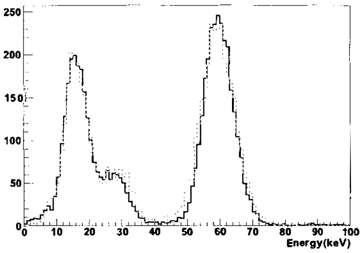
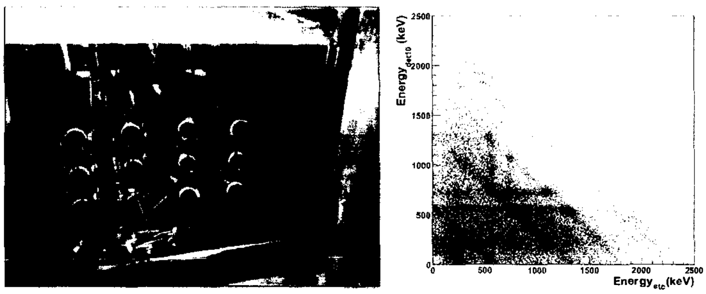


Figure 1: The energy spectrum with ^{241}Am source for one detector module. The black solid line is data. The red dashed line is simulation using GEANT4.9.5.

2 Experimental Description

The detector is an array of twelve CsI (Tl) scintillators, whose total weight is 103.4 kg. One detector consists one CsI (Tl) crystal and two photomultiplier tubes (PMTs) attached at each end of the crystal. The size of one crystal is $8 \times 8 \times 30$ cm^3 and its weight is around 8.6 kg. The photon yield is about 5 photoelectrons per keV. The energy spectrum obtained from energy calibration using ^{241}Am source is shown in Fig. 1, which is overlaid with the simulation from GEANT4.9.5. The energy spectrum shows 59.54 keV gamma-ray–main calibration point– and other gamma and x-rays expected from the decay of ^{241}Am and escape x-rays at the detector surface. The detector array is arranged as 3×4 as shown in Fig. 2 (a). The array enables the vetoing of the multiple hit events such as the compton scattering events. Since NR events occuring at one detector are the candidates for the signature which we are looking for, the multiple hit events are rejected in the WIMP search analysis. Figure 2 (b) shows the two dimensional scattering plot between the energy deposited in one detector and the others. The structure seen in this figure reflects the various decay mode of ^{134}Cs.



(a) (b)

Figure 2: The detector array (a) The detector array of 12 CsI (Tl) scintillators. (b) The two dimensional plot of the energy of one detector and the sum of the energy of the others.

The detector array is surrounded by the several shield layers consisting of 10 cm of copper, 5 cm of polyethylene, 15 cm of lead and 30 cm of liquid-scintillator-loaded mineral oil to stop external neutrons and gammas and veto the cosmic-ray muons. The muon flux at the experimental hall is about 2.7×10^{-7}/cm^2/s.

3 Data Analysis

The data presented in this article had been collected between September 2009 and August 2010. The total exposure of data is 24524.3 kg·days. An event is digitized by 400 MHz flash analog-to-digital converters (FADC) and its recorded time window is 40 μs, of which 25 μs duration is analyzed. As the PSD parameter, we used LMT10, which is the logarithm value of the mean time of each event estimated in 10 μs duration. As the quantity of data increased, we noticed the background which comes from the alpha decay which occurs at the surface of the crystal. The surface alpha (SA) background is shown in Fig. 3. One can see that the alpha events which did not deposit their full energy into the detector, escaping away from the surface are present even at the very low energy region, which is the energy range of the interest for the WIMP search. It is known that the adhesion of Rn progenies at the surface of the detector can cause this kind of events.

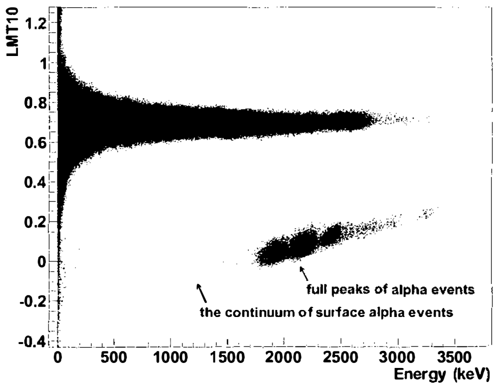


Figure 3: The energy versus the LMT10 (the logarithm of the mean time of each events estimated in 10 μs).

To understand the character of SA events, we contaminated the test CsI (Tl) crystal with Rn progenies by putting it in the Rn gas chamber. By tagging the out-going alpha events from the contaminated crystal, we collected the SA events[4]. The LMT10 of SA events are shown in Fig. 4 with that of NR events and electron recoil (ER) events for the comparison. The test crystals used for these calibration are the small crystal cut from the ingots from which the large crystals used for WIMP search were also cut. The probability density functions (PDFs) of LMT10 for each type of events obtained from the calibrations using test crystals and *in situ* compton events obtained from the detector array are used for the PSD analysis for the WIMP search.

4 Results

Assuming that there are only three components–NR, ER, SA–in the WIMP search data, we estimated the fraction of each component in the data with the bayesian analysis method[5]. The estimated NR event rate for twelve detectors are shown in Fig. 5. As the detector 0, 8 and 11 have large SA background level as about 3 times as high as the average of the remaining detectors, we excluded these crystal in drawing the combined results. The combined NR event rate is shown in Fig. 6. As seen in the figure, there is no meaningful excess of NR event.

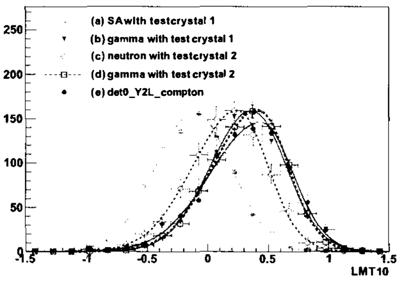


Figure 4: LMT10 distributions at 3 keV (a) SA with test crystal 1,(b) gammas with test crystal 1, (c) neutrons with test crystal 2, (d) gammas with test crystal 2 (e) Compton scattering events in detector 0 used in the WIMP search.

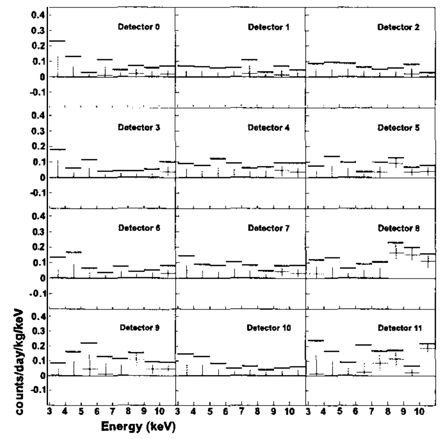


Figure 5: Nuclear recoil event rates for twelve detectors. The black horizontal bar indicate 90% C.L. upper limits, the red vertical lines denote the 68% C.L. interval, and the red horizontal bars the most probable values.

This results have the important implication for the interpretation of DAMA annual modulation signal. The annual modulation amplitude of DAMA is reported as 0.0183 ± 0.0022 counts/day/kg/keV in the 2-4 keV energy range in NaI (Tl) scintillators [7]. Considering the different quenching factors for NaI (Tl) and CsI (Tl) [8,9], the corresponding energy range in KIMS is 3.6–5.8 keV. The 90% confidence level (C.L.) upper limit of NR event rate in this range is 0.0098 counts/day/kg/keV, which is well below the DAMA modulation amplitude disfavoring the any WIMP-iodine interaction scenario such as inelastic dark matter model (iDM). The allowed iDM parameter space for DAMA and our exclusion limit for the WIMP of 70 GeV mass are presented in Fig. 7.

From the combined NR event rate limit, we derived the WIMP-nucleon cross-section limits for SI interaction and SD proton interaction based on the standard halo model [6]. Our new limits are presented in Fig. 8. Especially, for SD proton interaction we set the most stringent limit around 70 GeV WIMP mass.

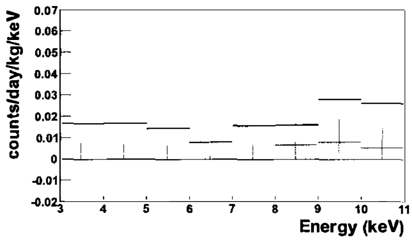


Figure 6: Total nuclear recoil event rates from the combined results from nine detectors (without detector 0, 8 and 11). The details are same with Fig. 5.

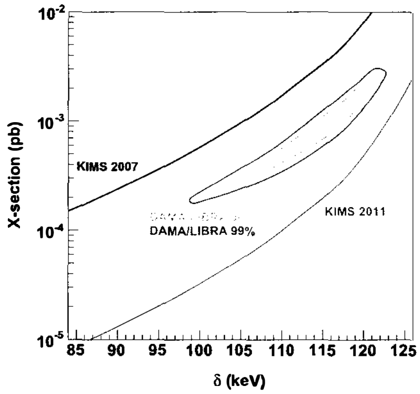


Figure 7: The allowed parameter space for DAMA and the limits reported here for a 70 GeV WIMP mass in iDM model. δ is the mass split between the ground and excited states of the WIMP. The astronomical parameters from Ref. [10] are used.

5 Conclusion

KIMS experiment has been running an array of CsI (Tl) scintillators whose total mass is 103.4 kg. From the exposure of 24524.3 kg·days of data, we estimated the NR event rate with the PSD analysis. As we identified the surface alpha background in the low energy region, we also incorporated this background in the PSD analysis. As no meaningful excess of NR event is found, we set the 90 % C.L. limit of NR event rate. This is inconsistent with the interpretation of WIMP-iodine interaction for DAMA results. We presented the new improved limit for WIMP-nucleon interaction in the case of SI and SD proton interactions. Especially for SD proton interactions, we set the most stringent limit around 70 GeV WIMP mass.

Acknowledgments

This research was supported by the WCU program (R32-10155) and Basic Science Research Grant (KRF-2007-313-c00155) through the National Research Foundatation funded by the Ministry of Education, Science and Technology of Korea.

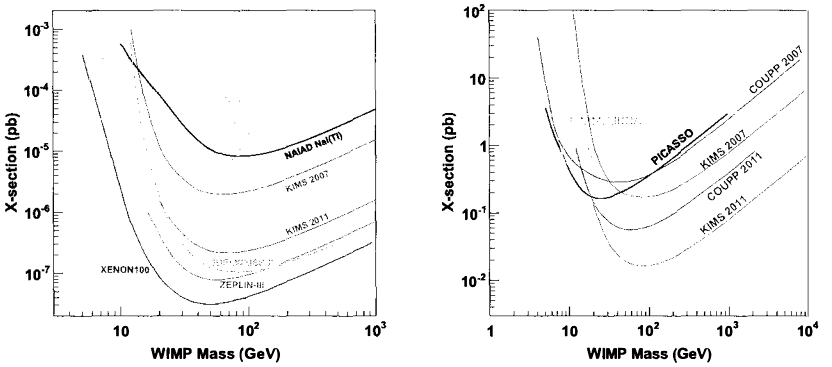


Figure 8: The 90 % exclusion limits on **(Left)** SI WIMP-nucleon and **(Right)** SD WIMP-proton cross sections. In both plots DAMA results interpreted by Savage *et al.* [19] are used (3σ contours are drawn). The SI plot includes NAIAD [11], CRESST-II [12], EDELWEISS-II [13], ZEPLIN-III [14], XENON100 [15] and CDMS [16] limits. The SD plot includes PICASSO [17] and COUPP [18] limits.

References

1. E. Komatsu *et al.*, ApJS **192**, 18 (2011).
2. G. Jungman, M. Kamionkowski and K. Griest, Phys. Rep. **267**, 195 (1996).
3. H. S. Lee *et al.*, *Nucl. Instrum. Methods* **571**, 644 (2007).
4. S. C. Kim *et al.*, *Astropart. Phys.* **35**, 781 (2012).
5. A. Caldwell *et al.*, Comp. Phys. Comm **180**, 2197 (2009).
6. J.D. Lewin and P.F. Smith, *Astropart. Phys.* **6**, 87 (1996).
7. R. Bernabei, *et al.*Eur. Phys. J. C **67**, 39 (2010).
8. S. K. Kim *et al.*, *New J. Phys.* **12**, 075003 (2010).
9. H. S. Park *et al.*, *Nucl. Instrum. Methods* **491**, 460 (2002).
10. S. Chang *et al.*, *Phys. Rev.* D **79**, 043513 (2009).
11. G. J. Alner *et al.*,*Phys. Lett.* B **624**, 186 (2005).
12. G. Angloher *et al.*, *Astropart. Phys.* **31**, 270 (2009).
13. E. Armengaud *et al.*, *Phys. Lett.* B **687**, 294 (2010).
14. V. N. Lebedenko *et al.*, *Phys. Rev.* D **80**, 052010 (2009).
15. E. Aprile *et al.*, *Phys. Rev. Lett.* **105**, 131302 (2010).
16. Z. Ahmed *et al.*, science **327**, 1619 (2010).
17. S. Archambault *et al.*, *Phys. Lett.* B **682**, 185 (2009).
18. E. Behnke *et al.*, *Phys. Rev. Lett.* **106**, 021303 (2011).
19. C. Savage *et al.*, JCAP **04**, 010 (2009).