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**New Results from the KIMS Experiment** 

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**Abstract**. The Korea Invisible Mass Search (KIMS) collaboration has performed experiments on dark matter searches and double beta decay searches at the Yangyang underground laboratory. Recent results of KIMS as well as the status of the R&D on various detectors are presented. For the WIMP search KIMS ruled out the recoil of <sup>127</sup>I of DAMA signal region unambiguously and set the most stringent limit on spin dependent WIMP interactions in the case of pure proton coupling. New limits on neutrino-less double beta decays of <sup>112</sup>Sn, <sup>124</sup>Sn, <sup>64</sup>Zn is also reported.

# 1. The KIMS experiment and Yangynag Undeground Laboratory

Yangyang Undeground Laboratory(Y2L) is located in a tunnel constructed for the Yangyang pumped storage power plant operated by Korea Midland Power Co. Ltd. The vertical rock overburden is 700m. The Korea Invisible Mass Search (KIMS) collaboration has carried out a dark matter search experiment using CsI(Tl) crystal and a development of detectors for the double beta decay search experiment. The temperature and humidity of the experimental hall and the detector chamber have been kept constant over the whole year. The radon level was measured to be 40-80 Bq/m<sup>3</sup>. Muon flux is measured using the muon detector, which was used for the neutron shielding as well. The measured muon flux,  $2.7 \times 10^{-3}$  m<sup>-2</sup>s<sup>-1</sup>, is consistent with the depth of the laboratory. Neutron flux in the experimental hall is measured with the 1 liter liquid scintillator (BC501A) to be  $8 \times 10^{-3}$  m<sup>-2</sup>s<sup>-1</sup> for 1.5 MeV <  $E_n$  < 6.0 MeV. The shielding structure for the WIMP search consists of 10 cm thick copper, 5 cm thick polyethylene, 15 cm thick lead and 30 cm thick mineral oil. The mineral oil contains 5% liquid scintillator and it works as a muon detector as well. Inside the innermost copper box, we flow the nitrogen gas continuously to get rid of radon contamination as well as to keep the low level of humidity.

# 2. WIMP searches using the CsI(Tl) crystal detectors

The KIMS group has developed CsI(Tl) crystals with high radio-purity[1]. The CsI(Tl) crystal is sensitive to both Spin Independent (SI) and Spin Dependent (SD) interaction of WIMP with nucleus. Especially the high sensitivity to the SD interaction in the case of pure proton coupling makes the KIMS experiment complementary to CDMS[2] and XENON[3] experiment who are the most sensitive experiments for the SI interactions and SD interactions in case of pure neutron coupling at the moment.

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The source of the major internal background in the crystal, <sup>137</sup>Cs has been successfully reduced to below 2mBq/kg by using the highly purified water in the Cs extraction process from the pollucite[1]. Rubidium contamination is reduced to the level of 1 ppb by re-crystallization technique. The contamination of U and Th is estimated to be at the level of 1 ppt. With this level of the impurity level, we expect the counting rate at about few counts/day/keV/kg(cpd) at 10 keV.

We have carried out a pilot experiment in 2004 with one crystal of 6 kg mass which is smaller than the final crystal. Using this data with amount of 237 kg days, we demonstrated that the CsI(Tl) crystal is highly competitive to other WIMP search experiment[4]. In 2005-2006, we have performed the engineering experiments using four full size CsI(Tl) crystals at the background level of 6 cpd, where we tested various running conditions to optimize the operation for WIMP search. Major part of the data was taken at the temperature  $T=0^{\circ}$ C. The amount of data was 3049 kg days. In order to understand the characteristics of background from photo multiplier tubes (PMT) we have taken data with acrylics boxes in the place of CsI(Tl) crystals mounted with the same PMTs used for WIMP search data. Using this data we developed highly efficient analysis cuts to reduce the PMT background at low energies without introducing bias on WIMP search data. Pulse shape discrimination method is used to extract the nuclear recoil event rates by WIMP interaction from the data where dominant



Figure 2 SD limits in case of purely proton coupling

contribution to the event rate came from the gamma ray background. Details of analysis method are described elsewhere[5]. The nuclear recoil event rates at 3 to 11 keV are consistent with null observation of WIMP interaction, we set the upper limit on WIMP-nucleon interaction cross sections as shown in Figures 1 and 2 for the SI interactions and SD interaction in the case of pure proton coupling respectively. DAMA signal region due to the recoil of <sup>127</sup>I, the dominant target SI interaction for the DAMA experiment[6], is ruled out. For the SD interactions, KIMS presents the most stringent limit in the case of pure proton coupling.

#### 3. Double beta decay searches

KIMS has developed the experimental techniques for neutrino-less double beta decay search.  $CaMoO_4$  crystal can be a good detector candidate for the double beta decay search of <sup>100</sup>Mo, once the large sized high efficient scintillation crystals with low background are available. The scintillation properties and background for small crystals and large crystals have been studied in collaboration with Russia and Ukraine groups and the feasibility of the experiment is investigated[7]. One large size crystal was installed in a shield surrounded by CsI(Tl) crystals and lead shielding at Y2L and a long term data taking for the internal background measurement has started.

Metal loaded liquid scintillator is another potential candidate for the double beta decay search. Tin loading to the pseudocumene(PC) based liquid scintillator in terms of the tetramethyltin (TMSN) has been tested. Up to 50% of TMSN (32.6% tin in weight) was successfully loaded into the liquid scintillator. At the 50% TMSN loading, the light yield was about 57% of that of the liquid scintillator without TMSN loading[8].

While developing the new techniques, we have performed an experiment using a setup consisting of a 100% efficiency HPGe detector and a low background CsI(Tl) crystal. We located a sample of one liter tetrabuthyltin (TBSN), which contained 34% by mass of Sn, between the HPGe detector and

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the CsI(Tl) crystal detectors and measured gamma rays for 140 hours. From the analysis of this data after subtracting background, we did not observe any excess counts over the background. We looked for signals from the double beta decay of <sup>124</sup>Sn to the excited states 602.7(2+), 1156.0(0+), and 1325.5(2+) keV and set the 90% CL level lower limits on the half life time of  $2.3 \times 10^{18}$ ,  $6.7 \times 10^{18}$ ,  $7.9 \times 10^{18}$  years, respectively[9]. Using the same data but by looking for 511 keV gamma ray siganls in HPGe detector and Csi(Tl) crystal detector in coincidence, we searched for the  $\beta$  +/EC of <sup>112</sup>Sn. After subtracting background measured with the same amount of de-ionized water sample, we set the 90% CL lower limit of the half life time for  $\beta$  +/EC of <sup>112</sup>Sn to be 9.1×10<sup>17</sup> years[9]. This is five orders of magnitude improvement over the previous limit[10].

A 8.0cm×8cm×1.0cm sample of Zn metal with 99.8 % purity was measured for the period of 332 hours using the same setup used for TBSN measurement. Again applying the same analysis technique that was used for  $\beta$  +/EC of <sup>112</sup>Sn search, and subtracting the background measured by the same size oxygen free high conductivity(OFHC) copper sample, we set the 90% CL lower limit of the half life time for  $\beta$  +/EC of <sup>64</sup>Zn to be 1.3×10<sup>20</sup> years[9]. This result is inconsistent with the previous claim of a positive signal with half life of 1.1±0.9×10<sup>19</sup> years[11] and is two order improvement over the previous limit by ZnWO<sub>4</sub> crystal[12].

# 4. Conclusion

The KIMS group reported new limits on WIMP search using the CsI(Tl) crystal detectors. The most stringent limit on SD WIMP interactions for the case of pure proton coupling is obtained. The DAMA signal region is ruled out for both SI and SD WIMP interaction for the WIMP mass greater than 20  $\text{GeV/c}^2$ . KIMS has installed 12 crystals (about 100 kg mass) this year and expects to take data more than a year with a stable condition. KIMS is also carrying out detector development for the double beta decay search. A significant progress is made on the improvement of the scintillation properties and of the growth of large size crystals of CaMoO<sub>4</sub>. Tin loading to the liquid scintillator was successfully done with a reasonable light yield and energy resolution. Measurements of TBSN and Zn samples using an experimental setup of HPGe detector and CsI(Tl) crystal, new lower limits on the half life time of neutrinoless double beta decays of <sup>124</sup>Sn, <sup>112</sup>Sn and <sup>64</sup>Zn is established, which are significant improvements over the previous experimental results.

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