PROCEEDINGS OF SCIENCE

Status of R&D of the ANKOK project: Low mass WIMP search using double phase argon detector

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The ANKOK project is a new dark matter search experiment in Japan using the double phase liquid argon detector which is specialized for the low mass ($\sim$ 10 GeV/c^2) WIMP detection. We are currently proceeding R&D efforts to establish its physics sensitivity, such as understanding of the liquid argon scintillation and ionization processes for very low energy deposition ($\sim$ 20 keV) and development of the new photo-sensor which has direct sensitivity for the 128 nm VUV light. In the next few years, we are targeting to construct a detector with fiducial mass of several tens of kg, and to collect the underground physics data to search for the low mass WIMP.

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1. The ANKOK Project

Liquid argon is known as an excellent target material for WIMP dark matter direct search experiment. Use of its ionization and scintillation signals, and scintillation pulse shape provides strong discrimination between the nuclear recoil (NR) events which are potential WIMP signal and the electron recoil (ER) events which are main source of the background. Relatively small atomic mass (A=40) gives higher nuclear recoil energy for WIMP-Ar nuclear scattering, thus it potentially has higher sensitivity for the low mass WIMP (~ 10 GeV/c^2).

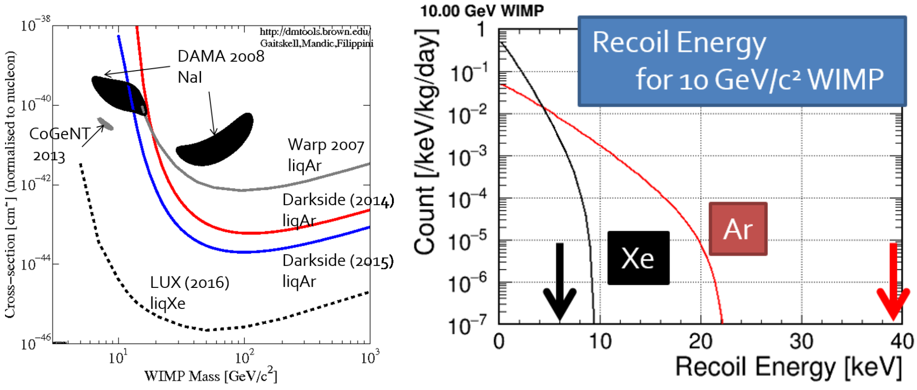

Figure 1: Left: Selected results of the WIMP direct search experiments which claim the observation (DAMA and CoGeNT) or with double phase noble gas detector (Warp, Darkside and LUX). Right: Nuclear recoil energy distributions of argon and xenon for 10 GeV/c^2 WIMP.

Left plot in Fig. 1 shows selected results from the recent WIMP search experiments. DAMA[1] and CoGeNT[2] claim observation of the signal in the low-mass and high-cross-section region, "DAMA region", and the same region is excluded by several liquid xenon experiments[3]. On the other hand, there are no liquid argon detectors which prove their sensitivities for the region [4, 5, 6]. Right plot in Fig. 1 shows the nuclear recoil energy distribution of the argon and xenon by 10 GeV/c^2 WIMP. Although end point of the recoil energy of the argon (20 keV) is about 2 times higher than that of xenon (10 keV), typical energy threshold for argon detector (40 keV) after the event selection to achieve the necessary background reduction is much higher compared to the threshold for the xenon detector (5 keV).

The primary target of the ANKOK project is to design and construct the double phase argon detector which is allowed to lower the energy threshold to 20 keV so that whole DAMA region can be explored. We identify crucial R&D components in the following:

- Improvement of the scintillation light detection yield
  We have achieved the highest level of the light yield of ~ 10 photo-electrons/keV$_{ee}$. It is noted that this light yield is already comparable to those of the xenon detectors.

- Understanding and reduction of the background sources (internal, external)
  Normal liquid argon contains about 1 Bq/kg of ^{39}Ar β-decay isotope, and this is usually the dominant source of the ER type background. However it is noted that the Darkside

result(2015) in Fig. 1 is based on the underground argon which reduces the ^{39}Ar by a factor of thousand, but the result still does not cover the DAMA region [6].

- Understanding and improvement of the background rejection
  We are currently concentrating our effort on this study by using a small size (0.5 kg fiducial mass) prototype detector. Better understanding of the liquid argon scintillation and ionization processes for very low energy deposition ($\sim$ 20 keV) would provide better rejection of ER background, and development of the new photo-sensor which has direct sensitivity for the 128 nm VUV light will lead better fiducialization of the detector.

In the next few years, we are targeting to construct a detector with fiducial mass of several tens of kg, and to collect the underground physics data at Kamioka Underground Observatory.

2. Status of R&D

Waseda liquid argon test stand is located at Nishi-Waseda campus of Waseda university in Tokyo, Japan. Details of the test stand which provide high purity liquid argon with respect to O_2, H_2O, and N_2 are described elsewhere[7].

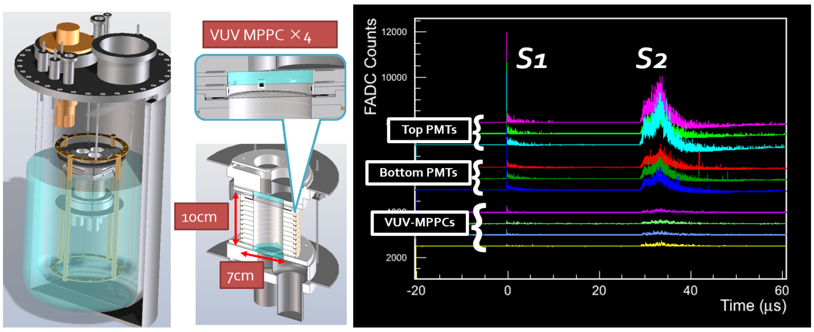

Figure 2: Drawings of the 0.5 kg prototype detector (left), and typical waveform (right).

Figure 2 shows schematic view of the 0.5 kg prototype detector. The 0.5 kg detector has radius of 7 cm and drift length of 10 cm mainly composed by PTFE. Quartz plates of 1 cm thickness with transparent ITO electrode are mounted on top and bottom of the detector, and a wire grid plane (4 mm pitch, 100 μs stainless steel wire) is inserted 1 cm bellow the surface of the top quartz plate. The liquid argon surface is kept at the center of the top quarts plate and wire grid so that the high electric filed up to 4.5 kV/cm which is sufficiently extracting the drift electron from liquid to gas phase is imposed. Maximum -10 kV (1 kV/cm) of high voltage is generated by using 10-stage Cockcroft-Walton (CW) generator located inside the liquid argon, and each stage of CW generator is connected to copper field shaping ring.

Argon scintillation light is detected by using 3 PMTs (HAMAMATSU R11065, 3", QE$\sim$ 30%@430 nm) located bottom and 3 PMTs (HAMAMATSU R6041-506, 2", QE$\sim$ 25% @430 nm) located top of the detector. These PMTs do not have quantum efficiency for 128 nm argon scintillation light, so surface of quarts plates is coated by TPB wavelength shifter (128 nm to 430 nm). For further improvement of the light yield, 3M ESR reflector coated by TPB is placed at the side wall of the detector.

A new multi-pixel photon counter (MPPC) sensitive to vacuum ultra-violet (VUV) light (wavelength $\lambda < 150$ nm) has recently been developed and produced by Hamamatsu Photonics K.K. Details of the performance of this new photo-device for detecting the argon scintillation light and the idea for using this to improve the spatial resolution for the double phase detector are described elsewhere [8]. 4 VUV MPPCs are mounted on side wall of the detector around the liquid surface to provide the better spatial resolution near the detector wall. Right plot in Fig. 2 shows waveform of the 6 PMTs and 4 MPPCs for a typical ER event obtained by ^{60}Co γ source. Total S1 Light yield of the prototype detector is about 5 photo-electrons/keV$_{ee}$.

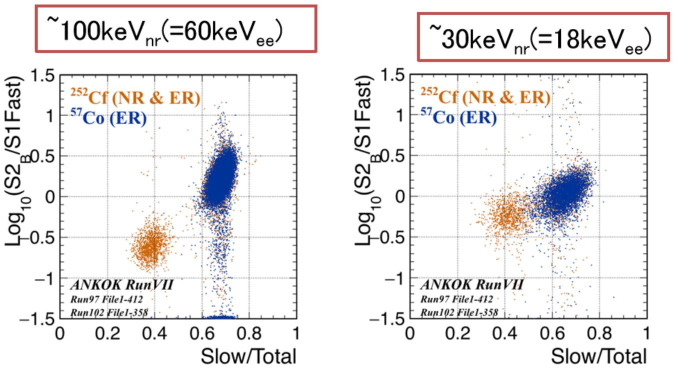

Figure 3: Particle ID performance of the 0.5 kg prototype detector with two different energy deposition (left: 100 keV$_{nr}$, right:30 keV$_{nr}$).

Figure 3 shows performance of the NR/ER reduction for the prototype detector using S1 pulse shape discrimination and S2/S1 light yield ratio with 200 V/cm of drift field. NR and ER events are obtained by ^{252}Cf neutron source and ^{57}Co gamma source, respectively. Left plot is for the recoil energy of 100 keV$_{nr}$ which provides excellent ER reduction, and the reduction is still marginal for 30 keV$_{nr}$ in the right plot.

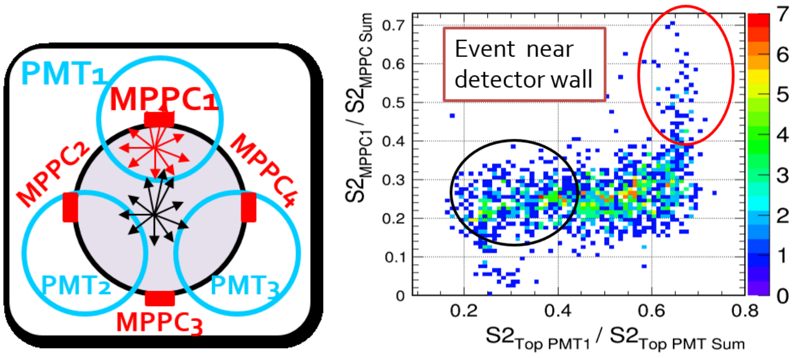

Figure 4: Schematic view of geometrical arrangement of PMTs and MPPCs (left), and correlation between fractions of the S2 light yield in MPPC1 and PMT1.

Left plot in Fig. 4 shows geometrical arrangement of the 3 PMTs and 4 MPPCs in the view from the top. The S2 light yield which is ensured to be emitted near the liquid argon surface detected by MPPCs rapidly increases around the wall of the detector. Right plot in Fig. 4 shows correlation between fraction of the S2 light yield in MPPC1 and PMT1. The fraction is about 1/4 for MPPC1 and 1/3 for PMT1 at the center of the detector (black lines) as expected, but the fraction of MPPC1 rapidly increase at the edge of the detector (red lines). This feature is useful information to improve the fiducialization in detector radius direction.

For detailed understanding of the detector performance and the background components, we have developed a GEANT4-based simulation [9]. Details of the simulation are described elsewhere [10]. Left plot in Fig. 5 shows energy spectrum measured by 2.5" NaI detector at the Waseda test stand. The distribution is fitted into the spectrum model of several environmental γ components such as ^{238}U, ^{232}Th, ^{40}K, cosmic, and so on, and the flux of each component is determined. The spectrum model is evaluated using the PHITS simulation package[11]. Right plot in Fig. 5 shows energy spectrum measured by the 0.5 kg prototype argon detector, overlaid with simulated spectrum by using the flux obtained by the NaI detector. Measured data is in reasonable agreement with the simulation, it means we have established reasonable understanding of the prototype argon detector performance as well as the proper handling of the ER background. The orange histogram shown in right plot of Fig. 5 corresponds to the expected energy spectrum for ^{39}Ar with fixed rate of 1 Bq/kg. Currently it is about 100 times lower than observed environmental γ events.

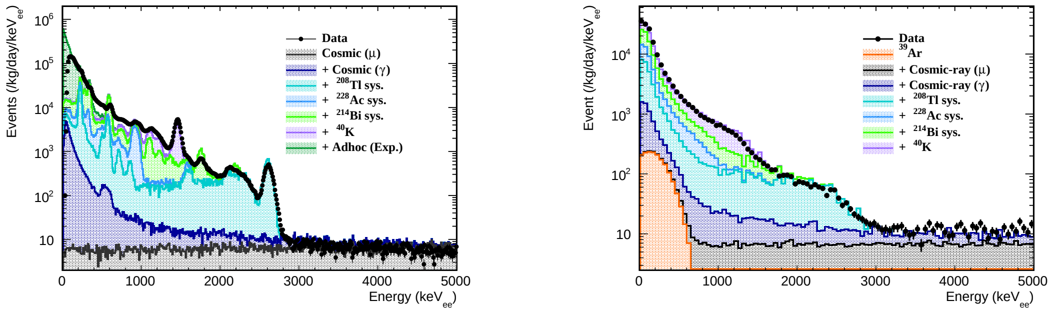

Figure 5: Energy spectrum measured by the 3" NaI detector (left) and the 0.5 kg prototype detector (right) compare with simulated distributions.

3. Summary and Outlook

The primary target of the ANKOK project is to design and construct the double phase argon detector which is allowed to lower the energy threshold to 20 keV so that whole DAMA region can be explored. We are currently proceeding R&D efforts using the 0.5 kg prototype detector. In the next few years, we are targeting to construct a detector with fiducial mass of about 30 kg and to collect calibration data at Waseda test stand first, then to collect the underground physics data at Kamioka Underground Observatory. Preliminary design of the 30 kg detector is shown in Figure 3.

Although flux of the environmental neutron background is expected to be significantly ($\mathcal{O}(10^3)$) reduced at the underground laboratory, the environmental γ which mainly comes form the rocks around the test stand (building concrete, ground surface, etc), is expected to be similar at the underground laboratory. Thus we plant to establish the ^{39}Ar signal at Waseda test stand by constructing the radiation shield (lead and copper) to reduce the environmental γ. After such reduction, we expect to start observing the ER backgrounds from other sources such as radiation from the material inside the detector. It is important to identify the high radioactive material, and establish the procedure to reduce the background (physically replace the material or analytically reject such event). We consider this is a crucial step to improve the physics sensitivity of the experiment.

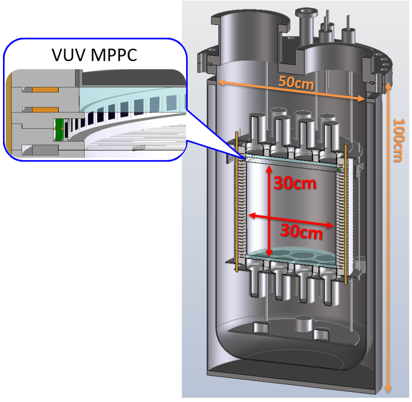

Figure 6: Current design plan of the 30 kg detector.

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