NEWAGE

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Abstract. NEWAGE (NEw generation WIMP search with an Advanced Gaseous tracking device Experiment) is one of the direction-sensitive dark matter search experiments with a gaseous timeprojection chamber. In this paper, we will report results of recent underground measurements, performances of our new detector, improvements of head-tail analysis.

1. Introduction

Directionality was said to provide a very strong evidence of direct dark matter detection\cite{1}\cite{2}. Since these ideas were proposed, several experimental and theoretical works on the possibility of detecting this distinct signal of dark matter have been performed\cite{3}.

NEWAGE is one of these direction-sensitive dark matter search experiments. In order to have directionality, we use a $\mu$-TPC with low pressure gas. We improved a WIMP-proton cross section of 5400 pb for 150 GeV/c$^2$ WIMPs by a direction-sensitive methods in 2010\cite{4}. However, we need to improve more than three orders of magnitude to set a competitive limits to other direction-insensitive searches. We plan to improve the sensitivity by reducing the internal radioactive background, lowering the energy threshold, discriminating head-tails of nuclear tracks and building large-volume detectors. In this paper, we report these efforts after our first underground run and new result using our latest detector.

2. NEWAGE detectors

We have three TPCs (time projection chamber) for several purpose (table 1). We have two large size detectors, named NEWAGE-0.3a' and NEWAGE-0.3b', in the underground laboratory. NEWAGE-0.3a' took the data for dark matter search in 2012 and improved dark matter limits. A large detector, NEWAGE-0.3b', was installed at Kamioka underground laboratory in March 2012, and the commissioning run is almost done. We have small size detector, NEWAGE-0.1a, in the surface laboratory for advanced test like head-tail R&D.

We use $\mu$-PIC\cite{5, 6}, one of the micro patterned gaseous detectors, as a main-multiplier and a readout of the $\mu$-TPC. The pitch of the $\mu$-PIC is 400 $\mu$m. We also use a gas electron multiplier
| name            | $\mu$-PIC | drift | location     | use                    |
|-----------------|-----------|-------|--------------|------------------------|
| NEWAGE-0.3a'    | $30 \times 30$ cm$^2$ | 30 cm | underground  | DM run, BG study       |
| NEWAGE-0.3b'    | $30 \times 30$ cm$^2$ | 40 cm | underground  | commissioning          |
| NEWAGE-0.1a     | $10 \times 10$ cm$^2$ | 10 cm | surface      | Head-tail R&D          |

**Table 1.** Specifications of NEWAGE TPCs.

![Figure 1](image_url)  

**Figure 1.** Obtained energy spectrum (left) and the $\cos\theta$ distribution (right) in RUN-13. We unfolded the energy spectrum with detection efficiency and thus this spectrum can be referred as an "effective" energy spectrum. The $\cos\theta$ distribution was made with 100-120 keV events.

3. **Underground measurments (NEWAGE-0.3a')**  
We performed underground measurements in 2012 at Kamioka underground laboratory with NEWAGE-0.3a. For this dark matter run, we had mainly three detector updates. First, we attached a mini-chamber containing about 100 gram of charcoal (TSURUMICOAL 2GS) at room temperature and circulated the TPC gas to reduce radon background. Second, we replaced glass-reinforced fluoroplastic used for the TPC cage with PTFE to reduce alpha-particles background. Third, we made a more precise gain map to reduce gamma-ray background. Details are described in ref [8].

This measurement, NEWAGE Kamioka RUN-13, started at Jan. 23, 2012 and continued until Jan. 24, 2013. The NEWAGE-0.3a' detector was filled with CF$_4$ at 152 Torr, and we had 11.48 g in the detection volume. The data acquisition live time was 217.1 days. During RUN-13, we changed the gas six times; once the gas was filled it was continuously circulated two months on average.

We set a fiducial volume of $5 \times 5 \times 31$ cm$^3$ to veto the background from the TPC wall. We eliminated the data with low gas gains and 134 live-days data remained. The gas gain after the live-time cut was stable in $\pm 10\%$. A total exposure used for the further analysis was 0.313 kg days.

We show the energy spectrum and the $\cos\theta$ distribution obtained in RUN-13 in Figure 1. The count rate at 100 keV$_{\text{a.e.}}$ was reduced by a factor of two. From obtained $\cos\theta$ distributions, we set a spin-dependent proton-WIMP cross section of 3130 pb for 150GeV WIMPs.
4. Detector upgrades (NEWAGE-0.3b’)

NEWAGE-0.3b’ is a new detector designed to improve sensitivities. We made three improvements for NEWAGE-0.3b’ construction. One is "large size", another is "radon elimination" and the third one is "low threshold". After the construction and performance test in the surface laboratory, we transferred NEWAGE-0.3b’ into Kamioka mine and started taking data. We explain each improvement and commissioning status.

The first improvement is "large size". Not being angular resolution worse significantly, we expanded the drift length from 30 cm to 40 cm. Also, we decided to adopt a larger size GEM to cover whole area of μ-PIC. Due to these improvements, the sensitive volume of NEWAGE-0.3b’ is about twice larger than that of NEWAGE-0.3a’. Furthermore, drift cage is made of PEEK, emits less radon gas than our previous material, glass-reinforced plastic.

The second improvement is "radon reduction". Almost all metal slightly contain U-chain or Th-chain isotopes. Since radon background from these isotopes reach secular radioactive equilibrium, radon emanates with a time constant of radon after gas change. Gas circulation is expected to reduce U-chain radon ($^{222}_{\text{Rn}}$) because time constant of such radon is slow as 5.5 days. We constructed a gas circulation system with cooled charcoal in order to reduce U-chain radon. We use a dry-pump to circulate gas and the gas flow is 500 ml/min. We use a refrigerator to cool charcoal, and a heater to control temperature. The temperature in stable operation is 230K. In order to check radon reduction, we measured the time dependence of high energy background. Figure 3 shows time dependence of high energy event rate ($3 - 10\text{ MeV}$). Seeing time dependence without gas circulation, we can see the 5 days time constant which indicates existence of U-chain radon in NEWAGE-0.3b detector. Using our gas circulation system, we succeed to reduce radon by 1/10.

The third improvement is "low threshold". In our case, the energy threshold is limited by the track length, because we need a certain length to keep the direction sensitivity. By using the lower pressure gas, we were able to measure the angular resolution in the $50 - 100\text{ keV}$ energy range in addition to other energy ranges. Thus we lowered the energy threshold to $50\text{ keV}$ keeping direction sensitivity[9].

In March 2013, we transferred NEWAGE-0.3b’ to underground laboratory and started commissioning run. First, we measured fundamental detector performances (calibration, drift velocity, flatness), and obtained consistent results compared to the surface measurements. Then, we measured the high energy background without the gas circulation system (Figure
5). NEWAGE-0.3b’ obtained less than 1/4 lower event rate. By replacing material of drift cage from glass-reinforced fluoro-plastic to PEEK, we reduced radon emanation. After these commissioning run, we started DM run from 17 July 2013.

5. R&D for head-tail recognition (NEWAGE-0.1a)
Head-tail recognition of the nuclear track is important to improve the sensitivity of a direction-sensitive dark matter search experiment[10]. DM-TPC group has shown the possibility of head-tail recognition of high energy nuclear tracks[11] followed by the DRIFT group’s work in the energy range relevant to the dark matter search for one dimension[12]. We started the head-tail study just before the last CYGNUS workshop[8]. We used NEWAGE-0.1a with CF$_4$ gas at 152 Torr. We doubled the statistics and obtained better significances.

When we calculated the skewnesses of the direction parallel to the incoming neutron irradiation, statically significant $\gamma$ with 4.1$\sigma$, 5.1$\sigma$, and 7.1 $\sigma$ are observed for the energy range of 70-100keV, 100-200keV, and 200-400keV, respectively.

When we calculated the skewnesses of the direction orthogonal to the incoming neutron irradiation, the $\gamma$ were consistent with zero in the all energy ranges.

These results shows that we can recognize head-tail with a sufficient statistics down to 70
Figure 6. Energy dependence of the measured skewness. The points with errorbars (red online) and asterisks (blue) show the skewness parallel and orthogonal to the incoming neutrons.

keV. We plan to measure the skewness with lower pressure gases to lower the threshold. We also plan to evaluate the skewness from the waveform which contains timing information so that a real three-dimensional head-tail analysis can be carried out.

6. Conclusions
We are proceeding NEWAGE project toward the dark matter detection. From recent measurement taken by NEWAGE-0.3a’, we updated WIMP-proton spin-dependent cross section limit and obtained value was 3130 pb for 150 GeV/$c^2$ WIMP mass. Aiming to DAMA region as our next step, NEWAGE-0.3b’ was constructed, which is low background, low threshold and large volume detector. Now, a commissioning run started at underground laboratory. In future, head-tail recognition is necessary to improve the sensitivity. So we started head-tail analysis with NEWAGE-0.1a and recognized head-tail statistically as for over 70keV.

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