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Results of a directional dark matter search from the NEWAGE experiment

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Results of a directional dark matter search from the NEWAGE experiment

T. Ikeda, K. Miuchi, T. Hashimoto, H. Ishiura, T. Nakamura, T. Shimada and K. Nakamura

Department of Physics, Kobe University, Rokkodaicho, Nada Hyogo 657-8501, Japan

E-mail: `tomonori@stu.kobe-u.ac.jp`

Abstract. In this study we present the results of a directional dark matter search from the NEWAGE experiment. A low-background gaseous detector, namely a low alpha-ray emitting μ-PIC (LAμ-PIC), was developed. The LAμ-PIC was installed in Kamioka Observatory and the NEWAGE-0.3" detector with a detection volume of 37 L was operated from June to November 2018. A total exposure of 1.1 kg·days was obtained and a reduction of background by 30 times comparing with a previous result was confirmed. The remaining backgrounds were studied using a Monte Carlo simulation. The main background in the energy region of $50 \leq E \leq 100$ keV was found to be alpha-rays emitted from the surface of the LAμ-PIC.

1. Introduction

Many cosmological observations indicate the existence of dark matter; however, no experiment has reached a widely agreed discovery. Most direct search experiments are designed to measure only the energy of the recoil nuclei and any annual modulation in these measurements [1, 2]. Since annual modulations are caused by the orbital motion of the Earth around the Sun, the signal amplitude is only a few %. Meanwhile the directional experiments are sensitive to the direction of the nuclear recoil. The forward-backward asymmetry of the recoil angular distribution, due to the circular motion of the solar system around the galaxy center, provides strong evidence for dark matter [3]. The recoil rates in the forward-backward direction can differ by an order of 10, depending on the recoil threshold.

NEWAGE is a directional experiment for the detection of dark matter using a low-pressure gas micro time projection chamber (μ-TPC) [4]. In 2015, the highest directional sensitivity was achieved [5], although a certain amount of radioactivity, which potentially contributed to the background, was later found inside a readout device, μ-PIC [6] which is one of the Micro-Pattern Gaseous Detector (MPGD). Hence a low-background μ-PIC, called LAμ-PIC, was developed and installed in the NEWAGE-0.3b" detector at Kamioka Observatory. In this paper, we report the first underground measurement results using this detector.

2. NEWAGE-0.3b" detector

The NEWAGE detector is comprised of a low-pressure gas μTPC that contains a LAμ-PIC, a gas electron multiplier (GEM) and a drift cage. A schematic of the NEWAGE-0.3b" detector is shown in Fig.1. The LAμ-PIC has a detection area of 30.7×30.7 cm^2 and the GEM with an effective area of 31.0×32.0 cm^2 was used as a preamplifier in order to support the gas gain.

In order to ensure a uniform electric field, wires with a spacing of 1 cm were placed on the side walls of the drift cage. The vacuum vessel was filled with CF_4 gas at a pressure of 76 Torr which enabled sensitivity to spin-dependent interactions and reduction of the diffusion effect during the electron-drift. In order to remove any ^{222}Rn present and maintain gas quality, a gas circulation system with cooled charcoal was installed.

The LAμ-PIC was developed in order to reduce alpha-ray emission from the detector surface. Although the structure of the pixel electrode is the same as in a conventional μ-PIC [6], the surface material that is exposed to the detection volume has been changed. The new surface material is a combination of polyimide and epoxy, which is a factor of hundred times less contaminated by isotopes of ^{238}U and ^{232}Th. Details are described in Ref. [7].

The anode and cathode signals of the LAμ-PIC were processed by an Amplifier-Shaper-Discriminator [8]. The cathode signals were grouped into four channels and their waveforms were recorded as the charge information. The addresses and time-over-threshold of all strips were recorded as tracking information.

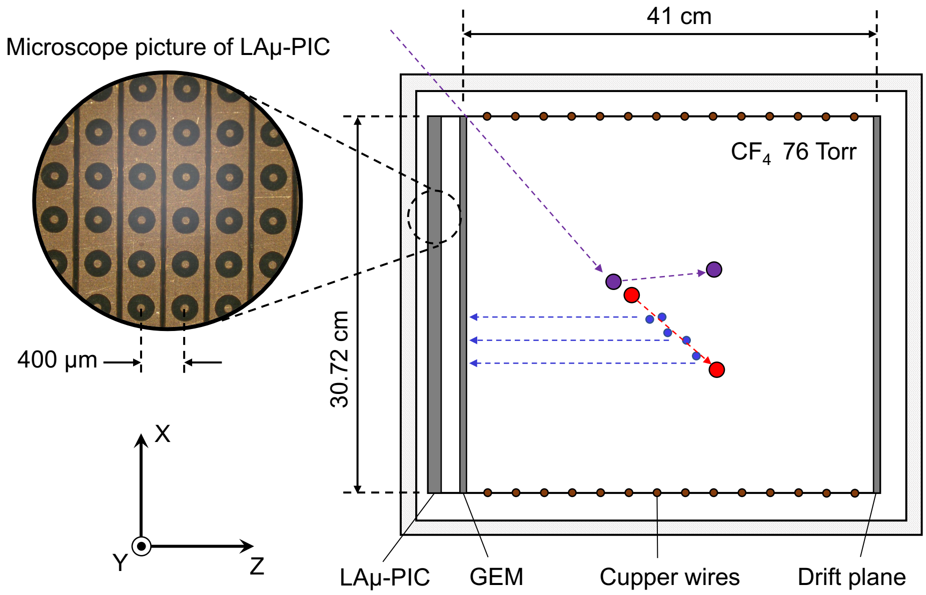

Figure 1. Schematic of the NEWAGE-0.3b" detector. A WIMP dark matter (purple) induces a nuclear recoil (red) which passes through the gas volume and ionizes electrons (blue). Ionized electrons are detected by the LAμ-PIC with tracking and energy information. The top-left images shows pixel electrode structure of the LA-μ-PIC, of which there are 768 $\times$ 768 pixels with a pitch of 400 μm.

3. Underground measurement results

The underground measurement, RUN22, was performed at Kamioka Observatory from June to November 2018. The total live time was 108 days, and the measurements were performed with a fiducial volume of 28 L and an exposure of 1.1 kg·days. During operation, energy calibrations and nuclear detection efficiency measurements were carried out every two weeks. At 50 keV, the measured detection efficiency for the nuclear recoil events after event selection is 14%. The obtained energy spectrum alongside previous results (RUN14) using a conventional μ-PIC, is shown in Fig.2. A 30 times background reduction in the $50 \leq E \leq 100$ keV energy region was confirmed.

In order to study any remaining background, the alpha-ray emission rate from the LAμ-PIC surface was measured by an alpha-ray counter (Ultra-Lo 1800 made by XIA LLC [9]). Background contributions due to ^{210}Po decay on the detector surface were observed with an emission rate of $(2.1 \pm 0.5)\times10^{-4}$ $\alpha/\mathrm{cm}^2/\mathrm{hr}$. A possible origin of the surface background is the embedding of daughter nuclei from radon-decay in the air into the detector surface [10]. A material placed in an atmosphere with a typical radon concentration for several days would give a level of radioactivity that is similar to what measured. In the high energy region of $2 \leq E \leq 10$ MeV, the underground spectrum measurement contained alpha-ray backgrounds from the decay chain of ^{220}Rn and ^{222}Rn. Using a Geant4 simulation, we estimated the amounts of ^{222}Rn and ^{220}Rn present to be 1.0 mBq/m^3 and 4.5 mBq/m^3 respectively.

The energy spectrum predicted by simulation from the two background sources mentioned above, alongside measured data, is shown in Fig.3. Since the alpha-ray backgrounds emitted from the LAμ-PIC stop upon hitting the GEM, the deposited energy becomes low and thus contributes to the low energy end of the spectrum (below 100 keV). The alpha-ray backgrounds due to radon decay in the gas also stop upon hitting the GEM and the drift plane. Although the short-track events pass through event selection and contribute to the spectrum above 100 keV, the long-track events can't pass through event selection. Thus a cut-off is seen at around 300 keV.

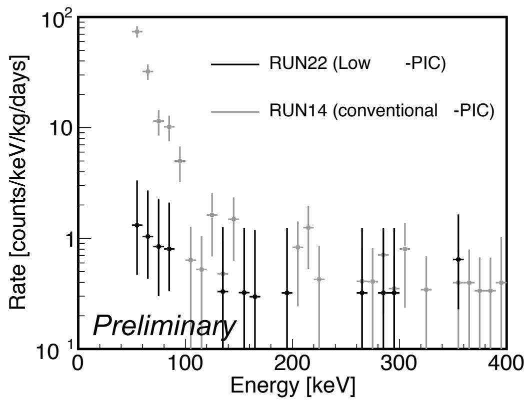

Figure 2. The underground measurement energy spectrum, where the detection efficiency is taken into account. The black dots with error bars are the results of RUN22 using the LAμ-PIC. The gray dots are the previous results of RUN14 using a conventional μ-PIC.

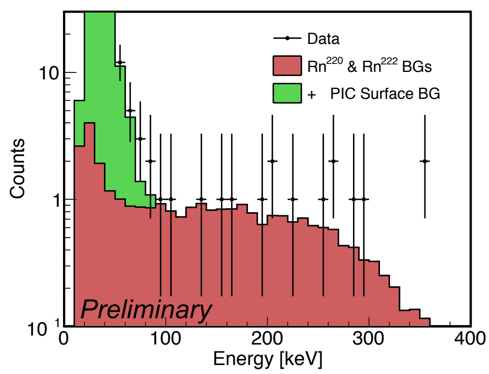

Figure 3. Comparison of the measured spectrum and the predicted background spectrum. The black dots are the measured data with error bars. The red histogram is the predicted alpha-ray background contributions from ^{220}Rn and ^{222}Rn and the green stacked histogram is the predicted alpha-ray background from the LAμ-PIC surface.

4. Discussion

The remaining backgrounds from the LAμ-PIC surface and radon are located around the GEM, LAμ-PIC and cathode plane. If we could determine the absolute z position with the self-trigger TPC system, the background can be removed. Recently, the discovery of minority carriers in CS_2 + O_2 gas mixtures by the DRIFT group opened the potential of an absolute z coordinate measurement in self-triggering TPCs [11]. Moreover, an SF_6 negative ion gas which can be handled easily while retaining the same advantage as a CS_2 + O_2 gas mixture, was found [12]. We have already studied a negative-ion μTPC using the μ-PIC+GEM system with CS_2 and SF_6 gases and have obtained a sufficient gas gain at low pressures [13]. The replacement of a gas mixture to a negative ion gas will enable us to extract any remaining backgrounds and improve sensitivity.

5. Conclusion

The NEWAGE-0.3b" detector was developed using the LAμ-PIC for a directional dark matter search and performed from June to November 2018 at Kamioka Observatory. Compared to our previous measurement, a 30 times background reduction in the $50 \leq E \leq 100$ keV energy region was confirmed. The simulation results indicates that the main background is the alpha-ray emission from the LAμ-PIC surface.

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