Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 61 (2015) 737 – 741

Physics Procedia

13th International Conference on Topics in Astroparticle and Underground Physics, TAUP 2013

NEWAGE - direction-sensitive dark matter search experiment

Kiseki Nakamura[a], Kentaro Miuchi[b], Toru Tanimori[a], Hidetoshi Kubo[a], Hironobu Nishimura[a], Joseph D Parker[a], Atsushi Takada[a], Tetsuya Mizumoto[a], Tatsuya Sawano[a], Yoshihiro Matsuoka[a], Shotaro Komura[a], Yushiro Yamaguchi[b], Shota Nakaura[b], Hiroyuki Sekiya[c], Atsushi Takeda[c]

[a]*Department of Physics, Kyoto university, Oiwakecho, Sakyo-ku Kyoto-shi, Kyoto, 606-8502, Japan*
[b]*Department of Physics, Kobe university, Rokodai, Nada-ku Kobe-shi, Hyogo, 657-8501, Japan*
[c]*Kamioka Observatory, ICRR, The University of Tokyo, Gifu, 506-1205 Japan*

Abstract

NEWAGE is a direction-sensitive WIMP search experiment using micro pixel chamber. After our first underground measurement at Kamioka in 2009, we constructed a new detector, which was designed to have a twice larger target volume with low background material, a lowered threshold of 50 keV, an improved data acquisition system. In 2013, dark matter search in Kamioka underground laboratory was performed. We have succeeded to lower the background level by about one order of magnitude.

Keywords: dark matter, directionality, gaseous detector, MPGD

1. Introduction of direction-sensitive dark matter search

Non-baryonic dark matter is widely believed to account for a large fraction of the mass in the universe. The Weakly Interacting Massive Particle (WIMP) is one dark matter candidate which is well motivated by cosmology and supersymmetry. Direct detection of the dark matter is achieved via WIMP-nucleus elastic scattering. The expected event rate is very low because the cross section for a WIMP interacting with ordinal matter is very small. So, if we are to distinguish dark matter signals from background signals, an additional signal other than the simple energy spectrum is needed. An annual modulation of the event rate is one of the well studied distinct signals. Dark matter is considered to be distributed throughout our milky-way galaxy, and since the earth goes around the sun, the relative velocity of the dark matter with respect to the earth would have an annual variation. In this scenario, the event rate is expected to show an annual modulation of a few %[2]. The DAMA group reported that they detected dark matter by observing such an annual modulation[3]. Recently, CoGeNT group also reported the observation of the annual modulation[4]. But some other groups have reported negative results for the parameter region DAMA reported. From these

Email address: nakamura@cr.scphys.kyoto-u.ac.jp (Kiseki Nakamura)

doi:10.1016/j.phpro.2014.12.091

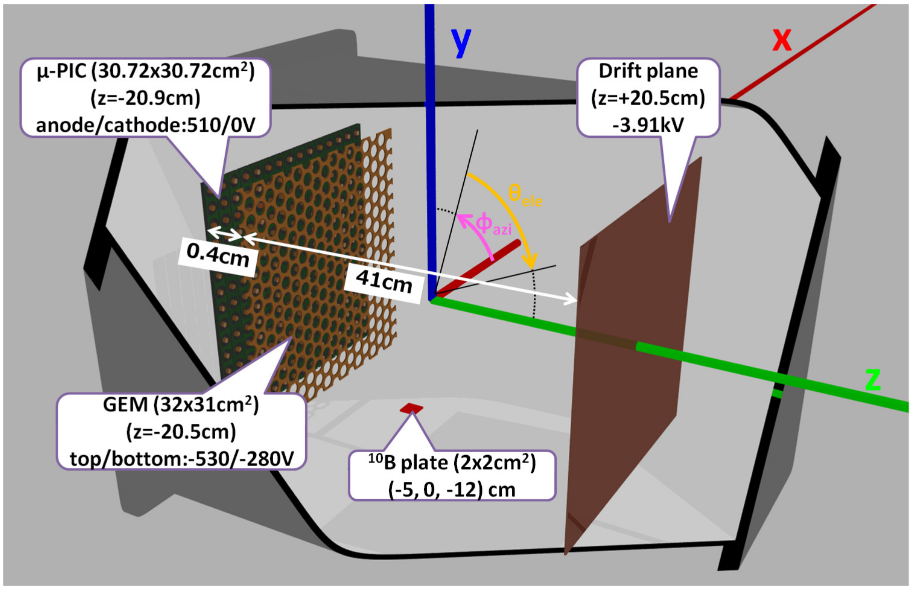

Fig. 1. The schematic image of the μ-TPC named NEWAGE-0.3b'. The coordinate system, with its origin at the center of the detection volume, is also shown. Red, blue and green lines shows the x, y and z axis. A glass plate with a thin layer of ^{10}B is set at $(-5, 0, -12)$ cm for the energy calibration.

recent results, a new method is required to obtain more robust evidence. A direction-sensitive method is capable of providing another distinct signal[5, 6]. Owing to the Cygnus constellation is seen in the forward direction of the Solar system's motion, dark matters would seem to come from the Cygnus direction like "WIMP-wind". The direction-sensitive method detects this incoming direction by measuring the recoil nuclear tracks. The recoil angle relative to the expected wind direction is expected to have a large asymmetry between the forward scattering and back scattering more than 10 times. In addition, since the Cygnus direction is varying per day and per year, the systematic error due to the daily and seasonal environmental variation will be canceled. A low pressure gaseous detector with a good position resolution is suitable for the direction-sensitive dark matter search to detect a shorter track than 1 mm in atmospheric pressure gas.

2. NEWAGE detector

We have developed a direction-sensitive dark matter detector, NEWAGE-0.3b' to improve the sensitivity by one order of magnitude from previous measurement performed by NEWAGE-0.3a[1]. NEWAGE-0.3b' was designed to have a twice larger target volume with low background material, a lowered threshold, and an improved data acquisition system.

2.1. system

A schematic view of the μ-TPC and the internal structure are shown in Figure 1. μ-TPC consists of a micro pixel chamber (μ-PIC) which is a two-dimensional fine-pitch imaging device[7], a gas electron multiplier (GEM)[8], and $30 \times 30 \times 41\,\mathrm{cm}^3$ of detection volume filled with 0.1 atm of CF_4 gas. x, y and z axis are defined in Figure 1, and the unit is cm in this paper unless otherwise mentioned. A μ-PIC[7] is an imaging detector and works as a main gas-amplifier and as readout electrodes. The $30.72 \times 30.72\,\mathrm{cm}^2$-sized μ-PIC has 768×768 pixels with a pitch of $400\,\mu$m, which are connected by 768 anode strips and 768 cathode strips. The anode and cathode strips are orthogonally formed and thus we obtain the two-dimensional position of a hit pixel. In addition, z-position is obtained by using timing information. In order to obtain a sufficient gas gain, a GEM is settled 4 mm above the μ-PIC as a sub-amplifier. The effective area of the GEM is $31 \times 32\mathrm{cm}^2$ covering the whole area of the μ-PIC. The GEM area is segmented into

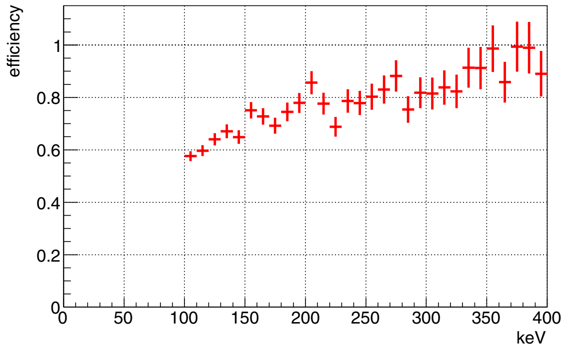

Fig. 2. The detection efficiency of nuclear events.

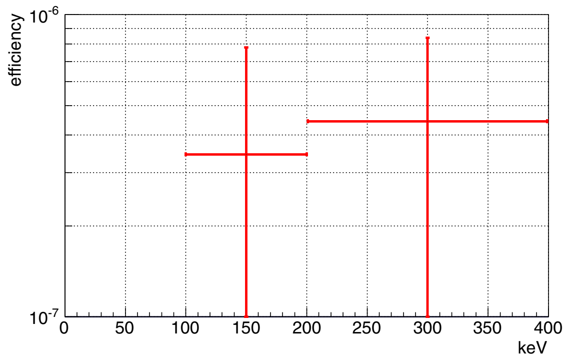

Fig. 3. The detection efficiency of the electron event, or gamma-ray rejection power.

8 sub-areas to reduce discharge damages. The substrate of the GEM is LCP of 100 μm thick and the hole size and pitch are 70 μm and 140 μm, respectively. The drift length is 41cm, which was determined by the optimization between the target-increase advantage and the angular-resolution determination with a longer drift length. The electric field is formed by the drift plane and wires on the side walls of the drift region with a spacing of 1 cm. Applied voltages for the μ-PIC, the GEM and the drift plane are written in Figure 1, where a stable operation with a combined (μ-PIC×GEM) gas gain of 2500 was obtained. A glass plate with a thin layer of ^{10}B is installed at the position of $(-5, -12, 0)$ cm for the energy calibration. The μ-TPC is placed on a 2.5 cm thick stainless-steel vacuum vessel filled with CF_4 gas at 0.1 atm. Since the diffusion of drifting electron is small in CF_4 gas and fluorine have a large spin-dependent WIMP-proton cross-section, CF_4 gas is suitable for a direction-sensitive spin dependent dark matter search.

A data acquisition system (DAQ) with a dedicated electronics for the μ-PIC readout was adopted for the NEWAGE-0.3b' detector[9]. Two types data, namely "track" by the memory board and "charge" by the flashADC, are mainly recorded by the DAQ system. For "charge" information, analog signal of 768 cathodes are amplified and grouped down to 4 channels, then these waveforms are recorded by a 100 MHz flash ADC. From the summed waveforms (FADC-sum), the energy deposition of a charged particle is evaluated. For "track" information, there are two types of DAQ-mode for "track" data with a different measured parameters ; DAQ-mode1 and DAQ-mode5. DAQ-mode1 records by reducing the size of data by taking *x*-*y* coincidence and limiting the number of output addressed for the "track" information, and it is used for previous measurement with NEWAGE-0.3a. DAQ-mode5 records the addresses and time-over-threshold (TOT) of all hit strips. TOT is the time duration of the waveform corresponding to the energy deposit. DAQ-mode5 is applied for NEWAGE-0.3b' by upgrading the farmware of electronics, and its enables to obtain the additional inforation of the energy-loss of charged particles.

2.2. *performance*

In this subsection, we discuss the important detector performances for dark matter search : nuclear detection efficiency, electron detection efficiency (or gamma-ray rejection power), direction-dependent efficiency, and angular resolution.

Since the energy loss of an electron is much smaller than that of a nuclei, electron events should be long and scratched. By using the difference of track length and energy-loss density, we defines the gamma-ray-cuts to remove gamma-rays keeping the nuclear events. With the gamma-ray-cuts, we measured the detection efficiency for the nuclear events and the rejection power for gamma-ray events. The measured detection efficiency of the nuclear recoil events is shown in Figure 2. We defined the efficiency by dividing the measured energy spectrum after all cuts by the simulated one. An ideal simulation results, not including the detector responses was used as the denominator. In order to cancel the position dependence and measure an overall response of the detector, an averaged spectrum of 6 measurements by placing a ^{252}Cf to 6 places; (25.5 cm, 0 cm, 0 cm), (−25.5 cm, 0 cm, 0 cm), (0 cm, 25.5 cm, 0 cm),

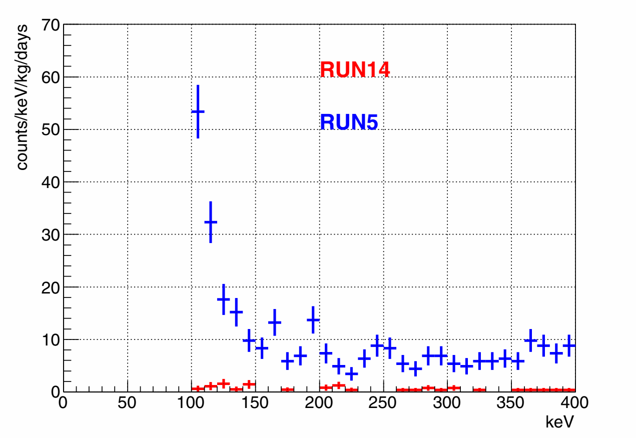

Fig. 4. Obtained energy spectrum in Kamioka RUN-14 (red points). Blue points are the results of previous measurements RUN-5[1]. Detection efficiency was taken into account.

(0 cm, −25.5 cm, 0 cm), (0 cm, 0 cm, 47.5 cm) and (0 cm, 0 cm, −47.5 cm) were used. Since the energy deposition of nuclear events (^{19}F and ^{12}C) are sufficiently large , an intrinsic detection efficiency of nuclear recoil events should basically be 100%. The discrimination of the threshold and the cut efficiency decrease the detection efficiency for low energy range. The detection efficiency does not reaches the intrinsic one in the high energy due to the z-fiducialization. We obtained the detection efficiency of nuclear events as 60% at 100 keV.

The detection efficiency of electron events, or the gamma-ray rejection power, was evaluated by irradiating the detector with gamma-rays from a ^{137}Cs source and comparing the data with the simulation results. The detection efficiency for a given energy bin was calculated by dividing the measured event rate with the simulated event rate of the electron with that energy. Evaluated detection efficiency in the energy bin 100 – 400 keV was less than 10^{-6}. The energy dependence of the electron detection efficiency is shown in Figure 3.

The overall direction-dependent efficiency is measured by irradiating neutrons from a ^{252}Cf source placed at (25.5 cm, 0 cm, 0 cm), (−25.5 cm, 0 cm, 0 cm), (0 cm, 25.5 cm, 0 cm), (0 cm, −25.5 cm, 0 cm), (0 cm, 0 cm, 47.5 cm) and (0 cm, 0 cm, −47.5 cm). We confirmed that we can emulate isotropic recoil (standard deviation is 23%) with a weighted sum of these six measurements by Geant4 simulations. Measured direction-dependent efficiency is used for weighting the expected direction distribution of recoil nuclear track scattered by the dark matter for the direction analysis.

Angular resolution is evaluated by using neutron-nuclear elastic scattering. Comparing measured $|\cos\theta|$ distributions to simulated ones, where θ is the angle between nuclear direction to a ^{252}Cf neutron source direction, angular resolution is measured. By a detector study prior to the dark matter search experiment, the energy threshold with an angular resolution of 40° was confirmed to be lowered from 100 keV to 50 keV[10]. Because of comparing the previous measurement, we discuss 100 – 400 keV energy range in this paper.

3. Underground measurement

A direction-sensitive dark matter search experiment was performed with the NEWAGE-0.3b' detector in an underground laboratory in Kamioka mine (RUN-14). The NEWAGE-0.3b' detector was placed in Laboratory B, Kamioka Observatory located at 2700 m water equivalent (w.e.) underground (36.25 ' N, 137.18 ' E). The μ-PIC plane of the μ-TPC was placed vertically and the z-axis is aligned to the direction of S30°E. Any radiation shield was not set mainly for an easy access to the detector. The target gas was

CF_4 at 0.1 atm in the fiducial volume of $275\,\mathrm{cm}^3$. Thus exposure of the sub-runs are $0.177\,\mathrm{kg}\cdot\mathrm{days}$ and $0.150\,\mathrm{kg}\cdot\mathrm{days}$, making a total exposure of $0.327\,\mathrm{kg}\cdot\mathrm{days}$.

By taking into account the detection efficiency (Figure 2), we obtained the ”final” energy spectrum of RUN14(2013) shown in Figure 4 together with the result from previous measurement, RUN5(2009). Compared to the RUN5, the background rate of RUN14 is reduced by $\sim 1/10$ in the energy range of $100-400\,\mathrm{keV}$.

4. Conclusion

Directionality of nuclear recoils is the strong signal for direct detection of the dark matter. NEWAGE is aiming at detecting the signature using a gaseous micro time projection chamaber. Underground dark matter search was performed with newly developed lower-threshold and lower-gamma-level detector, and it turned out that the background was reduced by about one order of magnitude. Since the background level was reduced, the expected limit will improve about one order of magnitude. Now, directional analysis and limit calculation is undergoing.

References

[1] K. Miuchi, et al., Phys. Lett. B 686 (2010) 11.
[2] J. D. Lewin and P. F. Smith, Astropart. Phys. 6 (1996) 87.
[3] R. Bernabei et al., J. Phys. Conf. Ser. 375 (2012) 012002.
[4] C. E. Aalseth et al., Phys. Rev. D 88 (2013) 012002.
[5] G. Masek et al., Proceedings of the Workshop on Particle Astrophysics (1989) 43.
[6] G. Gerbier et al., Nuclear Phys. B Proc. Sup. 13 (1990) 207.
[7] A. Takada, et al., Nucl. Instrm. Methods Phys. Res. Sect. A 573 (2007) 195.
[8] F. Sauli, A. Sharma, Annu. Rev. Nucl. Part. Sci 49 (1999) 341.
[9] H. K. et al., IEEE Nucl. Sci. Symp. Conf. Rec. 1 (2005) 371.
[10] K. Nakamura, et al., JINST. 7 (2011) C02023.
[11] H. Nishimura, Doctor Thesis Kyoto University.