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Development of negative-ion gaseous TPC using micro pattern readout for direction-sensitive dark matter search

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ABSTRACT: NEWAGE is the experiment of direction-sensitive dark matter search using low pressure gaseous TPC with micro pattern strip readout (μ -PIC). It allows to measure the distribution of angles of WIMP-nuclear recoil by track reconstruction, and it allows a positive signature of dark matter. In recent years, large size ($\sim 1 \text{ m}^3$) TPC filled with SF_6 gas, which is so called “negative-ion gas”, is under development. A TPC with negative ions is a novel technology for the measurement of absolute position of drift direction coordinates in a self-triggering system. The determination of the absolute track position allows to discriminate nuclear recoils in the target gas volume from alpha-rays from the detector surface, which is one of the background sources. Furthermore, diffusion of drifting negative ions is expected to be lower than that of nominal electron drift, which allows to improve angular resolution. This presentation reports the status of the development of negative-ion gaseous TPC with a prototype small chamber. In addition, we started to develop O(100) μm pitch gaseous TPC detector with pixel type readout system to achieve reconstruction of short track nuclear recoils with good angular resolution. It enables to explore lower mass region of direction-sensitive dark matter searches. We also report about the status of the pixel detector development.

KEYWORDS: Dark Matter detectors (WIMPs, axions, etc.); Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Time projection Chambers (TPC)

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1 Introduction

NEWAGE [1] is one of the direction-sensitive direct dark matter search experiments in the Kamioka underground observatory using a gaseous time projection chamber (TPC). Recently, large scale ($\sim 1 \text{ m}^3$) gaseous TPC filled with SF_6 gas, which is so called “negative-ion gas”, is under development. In the negative ion gaseous TPC, molecules capture ionized electrons right after their production and form negative ions [2]. It results that the negative ions, instead of ionized electrons, drift in the gas volume. It enables to reduce longitudinal and transverse diffusions. In addition, SF_6 gas forms two types of negative-ions: SF_6^- and SF_5^- with fractions of 97% and 3%, respectively [3]. The difference of their drift velocity allows to determine absolute track position of drift direction coordinates in self-triggering systems.

In this presentation, we reported two topics. Section 2 described the demonstration of the three-dimensional absolute position reconstruction of nuclear recoil events using our conventional micro pattern gaseous detector (μ -PIC [4]). Section 3 discussed about a development of next generation gaseous TPC which implements fine granularity and pixelized micro pattern readout. Finally, section 4 concluded the presentation.

2 Reconstruction of absolute three-dimensional position of nuclear recoils

We reported the demonstration of absolute three-dimensional position reconstruction of nuclear recoils using negative-ion gaseous TPC using μ -PIC readout system in this section. Figure 1 shows our detector, which is filled with SF_6 gas at 20 Torr. The μ -PIC has 256 anode strips and 256 cathode strips which cross orthogonal each other. The strip pitch is $400 \mu\text{m}$ for both electrodes. The μ -PIC has capability of gas amplification in each cross point of strips although the magnitude is not sufficient for the detection of nuclear recoil events. In order to compensate the gas gain, additional two GEM [5] layers are installed above the surface of μ -PIC electrodes.

In order to emulate dark matter-induced nuclear recoil events, a ^{252}Cf neutron source was placed nearby the detector. Figure 2 shows a typical waveform of a nuclear recoil event. Due to the difference of the drift velocities of negative ions, two peaks are visible around the time of $1020 \mu\text{s}$ and $1090 \mu\text{s}$, corresponding to SF_5^- and SF_6^- , respectively. The absolute position z is calculated to

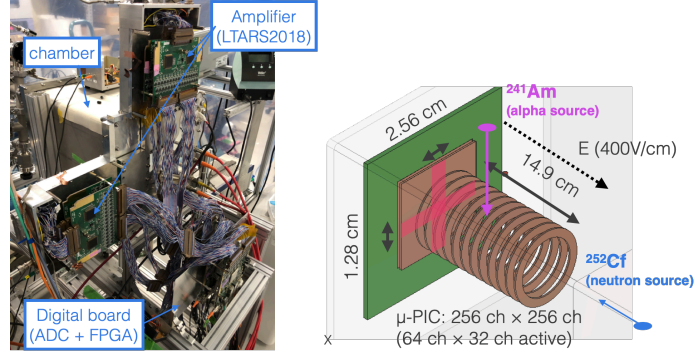


Figure 1. Picture (left) and schematics (right) of the negative-ion gaseous TPC.

be $z = v_{\text{SF}_5^-} \cdot v_{\text{SF}_6^-} / (v_{\text{SF}_5^-} - v_{\text{SF}_6^-}) \cdot \Delta t$, where Δt is the time difference of two peaks, and $v_{\text{SF}_6^-}$ and $v_{\text{SF}_5^-}$ are the drift velocities measured to be 8.3 cm/ms and 8.9 cm/ms, respectively. Therefore the absolute position z is 8.6 cm far from the detector surface. The detection efficiency of SF_5^- peaks was evaluated to be $85 \pm 3\%$ in this study. This result marks an important step for the development of negative ion gaseous TPC towards the practical use for directional dark matter searches.

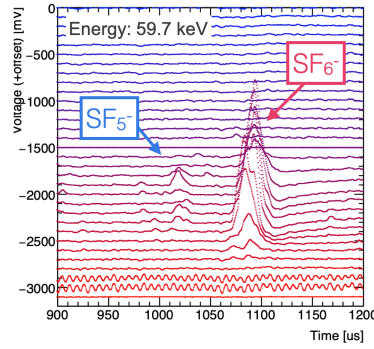


Figure 2. Waveform of a typical nuclear recoil event in anode strips.

3 Development of fine granularity pixel readout detector

One of the remarkable characteristics of negative ion gases is its small diffusion. It allows the precise reconstruction of charged particle tracks. However, since the current detector, μ -PIC, has 400 μm pitch strip readout, it is difficult to reconstruct tracks which have less than ~ 1 mm length although the diffusion of negative ions is small enough. In order to achieve shorter track reconstruction, we need a new detector with fine granularity readout structure. Moreover, the replacement from strip electrodes to pixel electrodes allows to reduce reconstruction of ghost tracks. Therefore we had started to develop a ~ 100 μm pitch two-dimensional pixel detector.

The development of pixel readout gaseous TPC was started from the design and production of a readout ASIC, named “QPIX NEO v1”, which is originate from QPIX [6]. The QPIX NEO v1 has 8×8 pixel channels. Each pixel size is $155 \mu\text{m} \times 155 \mu\text{m}$. Figure 3 shows the microscope picture of a QPIX NEO v1 and the illustration of its function specification. Since the QPIX NEO v1

is the prototype version, it has two output format for each channel as functionality tests; one is the ADC waveform format and the other is the time over threshold (ToT) format, allowing to record four hits for each channel. The test of the functionality is ongoing. The development of fine granularity readout electronics will be a portal to the low mass dark matter search with its directionality.

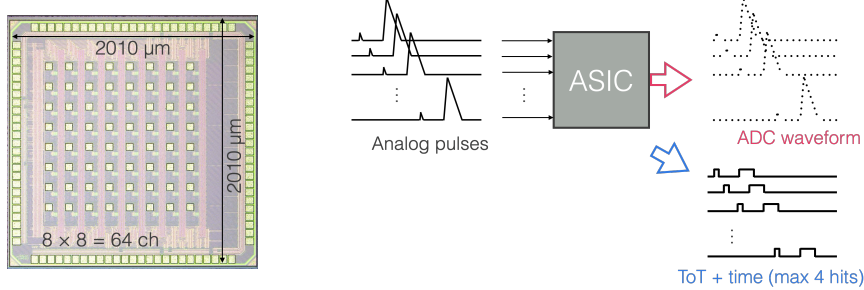


Figure 3. (Left) Microscope picture of QPIX NEO v1. (Right) Illustration of basic function.

4 Conclusion

We reported the capability to improve sensitivity for direction-sensitive dark matter search using negative-ion gaseous TPC with micro pattern readout. The first absolute three-dimensional position reconstruction of nuclear recoil events was successfully working using μ -PIC. Furthermore, we started the development of high granularity readout electronics: QPIX NEO v1 as a pixelized micro pattern TPC. These works will provide higher sensitivity directional dark matter search.

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