DEVELOPMENT AND APPLICATIONS OF a μ-PIC

Kentaro Miuchi*, Kaori Hattori, Shigeto Kabuki, Hidetoshi Kubo, Shunsuke Kurosawa, Hironobu Nishimura, Yoko Okada, Atsushi Takada, Toru Tanimori, Ken'ichi Tsuchiya, Kazuki Ueno [1]
Cosmic-Ray Group, Department of Physics, Graduate School of Science, Kyoto University Kitashirakawa-oiwakecho, Sakyo-ku, Kyoto, 606-8502, Japan [1]

Hiroyuki Sekiya, Atsushi Takeda [2]
Kamioka Observatory, ICRR, The University of Tokyo Higashi-Mozumi, Kamiokacho, Hida 506-1205 Japan [2]

1. INTRODUCTION

After the development of a micro strip gas chamber (MSGC) by Oed in 1987 (1), many types of micro-pattern gaseous detectors (MPGDs) have been developed so far. The Micromegas(2) and the GEM(3) (Gas Electron Multiplier) are the most widely-used MPGDs. They are used for the COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy) experiment (4), the CAST (Cern Axion Solar Telescope) experiment(5), and are studied to be used for the T2K project(6) and the ILC project(7).

We developed a two-dimensional MSGC(8) in 1990s and used for X-ray crystallography(9). The MSGC was found to be easily damaged by the discharges and was not used for other applications. We, thus, developed our original micro-pattern gaseous detector, named "μ-PIC" (micro pixel chamber) in order to overcome the weak properties of the MSGC. The μ-PIC is a simple printed circuit board, which makes the detector system simpler and more robust than other MPGD that have three-dimensional geometries. In this paper, the development of the μ-PIC and its applications are described.

* *Corresponding author,* (tel)+81(0)75-753-3867,(fax)+81(0)75-753-3799, (e-mail)miuchi@cr.scphys.kyoto-u.ac.jp

2. DEVELOPMENT OF THE μ-PIC

2.1 Structure and design concepts

The μ-PIC is a gaseous two-dimensional imaging device manufactured with the printed circuit board technology. Figure 1 shows the structure of the μ-PIC. The cathode electrodes are formed on the detection side of the substrate with a pitch of 400 μm. The substrate is polyimide of 100 μm thick. The cathode strips have circular openings of 260 μm diameter with a pitch of 400μm. Anode electrodes with a diameter of 50 μm are formed at the center of each opening and are connected through the substrate to the anode readout strips placed on the rear side. The gas multiplication occurs in the strong electric field near the anode electrode. Then the signal is read form the anode and the corresponding cathode readout strips and the two-dimensional position is known for each event. The pixel-shaped electrodes provide robustness against the discharges.

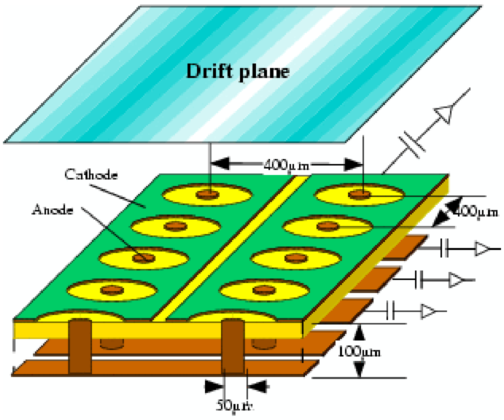

Figure 1. Structure of a μ-PIC.

2.2 Development history

We started the development with a small-sized μ-PIC which has a detection area of 3×3cm² in the year of 2000 (10). Then we made many pieces of practical-sized μ-PICs with a detection area of 10 × 10cm² (11) since 2002 and the performance reached the requirements for several applications. We consequently started the fabrications of large-sized (31 × 31 cm²) μ-PICs in the year 2004(12). Figure 2 is a picture of a large-sized μ-PIC. The fabrication process to form the anode electrodes of the large-sized μ-PIC is not optimized yet, therefore the operation gas gain is restricted to 5000, while that of the practical-sized one is more than 7000.

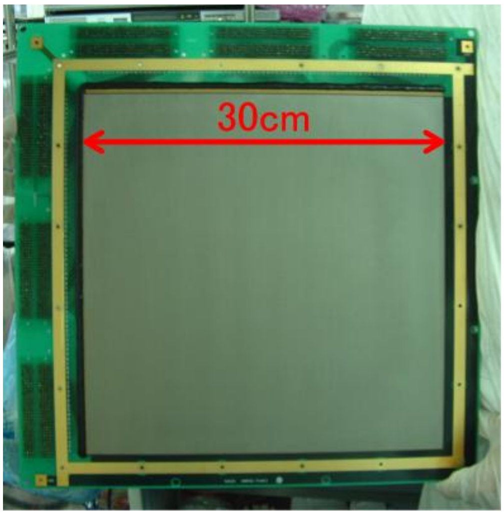

Figure 2. Picture of a large-sized μ-PIC.

2.3 Performance

The performance of the practical-size μ-PIC was precisely studied [11]. The energy resolution was 23% FWHM at 5.9keV, the position resolution was 120μm (rms) and the inhomogeneity of the gas gain was 4% (rms). The maximum and operation gas gain is 16,000 and 7,000, respectively. The μ-PIC works stably for more than six mounts at the operation gain. Typical X-ray images taken with a μ-PIC are shown in Figure 3.

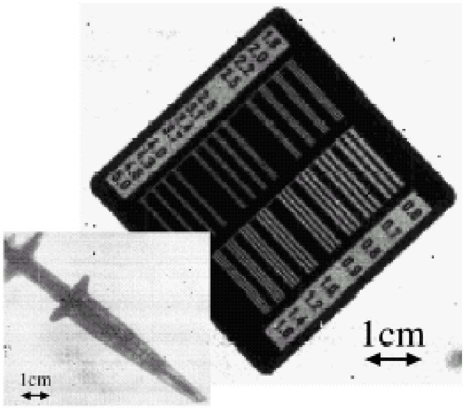

Figure 3. X-ray images taken with a μ-PIC.

3. APPLICATIONS OF THE μ-PIC

3.1 Overview

The□μ-PIC has a wide choice of applications. One of the simplest and best-studied applications is a time-resolved X-ray imaging detector for crystallography and small angle X-ray scattering[13]. High-rate X-ray diffraction experiments are performed at Synchrotron radiation facilities.

A fine-pitch three-dimensional tracking device, or a μ-TPC (micro time projection chamber), is developed as an application of the μ-PIC. The μ-TPC is subsequently studied for many applications.

A PS-TEPC (Position-sensitive tissue equivalent proportional counter), is a μ-TPC consisted of tissue-equivalent materials and is now being developed for a space dosimetory[14]. Figure 4 shows a schematic drawings of the PS-TEPC. The detection volume is filled with a tissue- equivalent gas (C_3H_8 55% + CO_2 39.6% + N_2 5.4%) and the wall of the gas chamber is made of tissue equivalent plastic. The size of the detection volume is 2.6 × 2.6 × 2.6 cm^3. We developed a test-model PS-TEPC and performed tracking test of heavy ion beams.

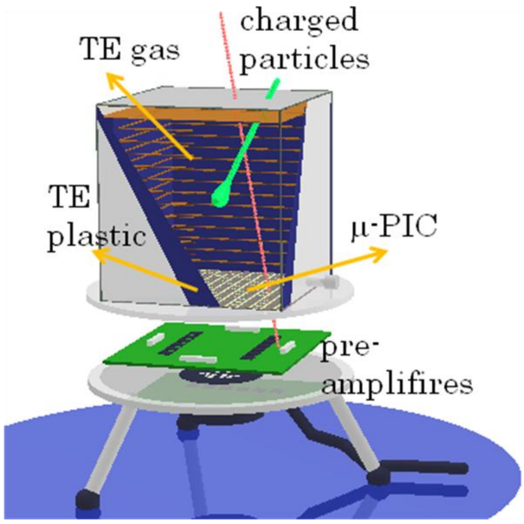

Figure 4. Design of the PS-TEPC.

An electron-tracking Compton camera, which is a hybrid detector of a μ-TPC and a position-sensitive scintillator, is intensely developed for gamma-ray astronomy and nuclear medicine [15].

NEWAGE project [16,17], which is a direction-sensitive dark mater search, has started its preliminary underground run at Kamioka observatory.

A time-resolved neutron imaging device for J-PARC neutron beam is also studied as an application of the μ-TPC[18]. Other applications of the μ-TPC such as a measurement of neutrino-nucleus scattering cross section, neutrinoless double beta decay search, KK-axion search, and a measurement of the magnetic moment of neutrinos are still in a very primitive phase, but could be realized in the future. We describe the R&D statuses of some of the applications in the following sections.

3.2 Micro time projection chamber

We developed a large volume μ-TPC based on a large-sized μ- PIC (TOSHIBA, S/N 20060222-3) and studied its fundamental performance[19]. A picture of the micro-TPC is shown in Figure 5. The detection volume of 23 × 28 × 31 cm^3 is filled with an argon-ethane gas mixture (9:1) of normal pressure. A total gas gain of 50,000 was achieved with a hybrid multiplication of the GEM and the μ-PIC. Measured energy resolution was 60% FWHM at 30 keV. We detected tracks of minimum ionizing particles and a three-dimensional position resolution of 0.51 mm was measured. These values are thought to be restricted by the inhomogeneity of the shapes of the anode electrodes, and improvements of the detector performance are expected for μ-PICs of the next fabrication.

Figure 5. Picture of a large volume μ-TPC system.

3.3 Dark matter search

Revealing the nature of dark matter is receiving much more attention after the successive results of the WMAP cosmic microwave background all-sky observation[20] and the results of the Hubble Cosmic Evolution Survey group[21]. We proposed a direction-sensitive dark matter direct search experiment with a μ-TPC[17]. In our experiment, we use the motion of the solar system relative to the galactic halo where dark matter WIMPs (weekly interacting massive particles) are thought to be moving in random directions. This relative motion is expected to be observed as a "wind of WIMPs" blowing to the earth. The WIMPs scatter the target nuclei and WIMP-wind is observed by detecting the tracks of the recoil nuclei. A large forward-backward asymmetry of the recoil angle distribution is thought to provide a distinct signal of the WIMPs. In addition, the direction of the WIMP-wind has a diurnal modulation due to the rotation of the earth. Therefore, the direction-sensitive method is a very reliable one compared to the conventional method which relies on the annual modulation signals.

We studied the performance of the μ-TPC describe in the previous section as the WIMP-wind detector.[22] We studied the performance with a 0.2 bar CF_4 gas and performed a preliminary dark matter search experiment in a surface laboratory. We set the first direction-sensitive limits on the WIMP-proton elastic scattering cross section.[23] We started a measurement in Kamioka underground laboratory to improve the sensitivity.

In most of the dark matter experiments performed in the world, the sensitivity is restricted by the gamma-ray background. The background with the μ-TPC, in contrast, will be dominated by ambient neutrons generated in the surrounding rocks, because the μ-TPC can discriminate the gamma-ray background events (electron tracks) from the neutron and

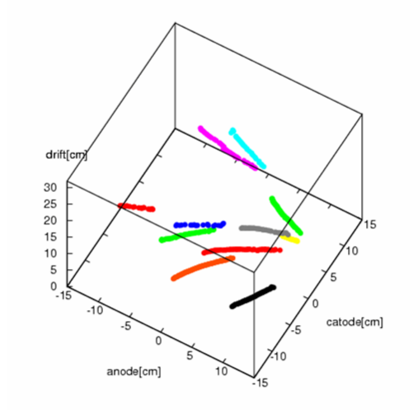

Figure 6. Proton tracks detected by a large-sized μ-TPC.

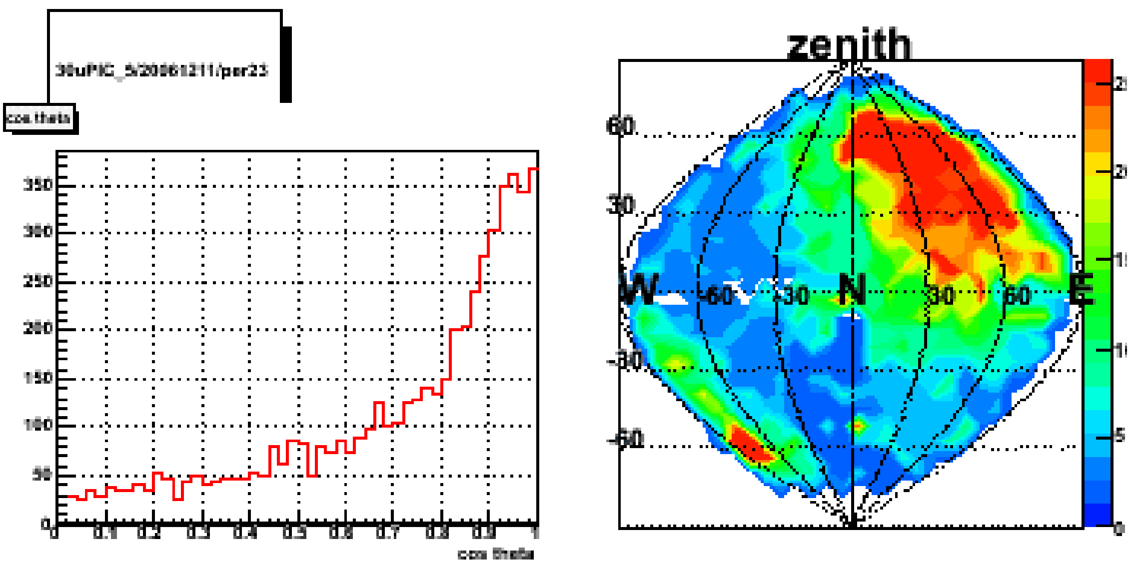

Figure 7. Measure cos θ distribution (left) and the neutron image drawn with the tracks of the recoil protons (right). Neutron source is set in the direction of 45 degrees from north to east and elevation of 35 degrees.

WIMP events (nuclear tracks) by the dE/dx information. Measured discrimination factor is better than 2×10^{-4}.

In addition to the conventional passive water shield against neutrons, we plan to monitor the neutron background with the μ-TPC operated with a gas different from that for a dark matter run. Measurement of the signal (WIMP) and background (neutron) with the same type of the detectors would increase the sensitivity to the WIMPs and decrease the systematic errors. We plan to add small amount of hydrocarbon to the CF_4 gas to increase the sensitivity to the neutrons and improve the angular resolution. Neutrons effectively deposit energy on protons and protons have longer tracks than carbon and fluorine nuclei with a same kinetic energy do. We performed a proof of principle test with a gas mixture of CF_4 and isobutane (8:2) of 0.2bar. We irradiated the μ-TPC with fast neutrons from a ^{252}Cf source and typical proton tracks are shown in Figure 6. We plotted the $\cos\theta$ distribution in the left panel of Figure 7, where θ is the angle between the direction of the incoming neutron and that of the recoil proton. In the right panel of the Figure 5, a neutron image drawn by the proton tracks is shown. The neutron source is set in the direction of 45 degrees from north to east and elevation of 35 degrees. Although we need more quantitative study before a background measurement in the underground laboratory, a proof of principle of a direction-sensitive neutron background measurement was shown.

5.Conclusions

We developed a micro-pixel chamber (μ-PIC), which is one of the variations of the micro pattern gaseous detectors. A large-volume μ-TPC with a detection volume of $23 \times 38 \times 30$ cm^3 based on a large-sized μ-PIC with a detection area of 31×31 cm^2 was developed. A study for a direction-sensitive dark matter direct search experiment is carried out. A proof of principle test of direction-sensitive neutron background measurement was performed and we obtained the direction distribution of the recoil protons and the image of the fast neutron.

ACKNOWLEDGEMENT

This work was supported by a Grant-in-Aid in Scientific Research of the Japan Ministry of Education, Culture, Science, Sports and Technology, SENTAN of Japan Science and Technology Agency, and a Grant-in-Aid for the 21st Century COE "Center for Diversity and Universality in Physics". This work is partially supported by a research-aid program of Toray Science Foundation.

REFERENCE

(1) A. Oed, Nucl. Instr. Meth., **A263** (1988) 351.

(2) Y. Giomataris, *et.al.*, Nucl. Instr. Meth., **A376** (1996) 29.

(3) F. Sauli, Nucl. Instr. Meth., **A386** (1997) 531.

(4) http://wwwcompass.cern.ch/

(5) http://cast.web.cern.ch/CAST/

(6) http://jnusrv01.kek.jp/public/t2k/

(7) http://www.linear-collider.org/

(8) T. Tanimori, *et.al.*, Nucl. Instr. Meth., **A381** (1996) 280.

(9) A. Ochi, *et.al.*, Nucl. Instr. Meth., **A477** (2002) 48.

(10) A. Ochi, *et al.*, Nucl. Instr. Meth., **A471** (2001) 264.

(11) T. Nagayoshi et al., Nucl. Instr. Meth. **A 525** (2004) 20.

(12) A. Takada *et. al*, Nucl. Instr. Meth., **A573** (2007) 195.

(13) A. Takeda *et. al*, Journal of Synchrotron Radiation, **12**, (2005) 820.

(14) K. Terasawa *et al.*, Radiat. Detect. and Their Uses, KEK (2005) 63

(15) A. Takada *et. al*, Nucl. Instr. Meth., **A 546** (2005) 258.

(16) H. Sekiya *et. al.*, Nucl. Instr. Meth., **A573** (2007) 204.

(17) T. Tanimori *et. al.* Phys. Lett. B, **578** (2004) 241.

(18) T. Tanimori, *et. al*, Nucl. Instr. Meth., **A529** (2004) 373.

(19) K. Miuchi *et. al*, Nucl. Instr. Meth., in press; physics/0701085)

(20)D. N. Spergel, *et. al*, Astrophys. J. Suppl. **148** (2003) 175; D. N. Spergel, *et. al*, astro-ph/0603449

(21)R Massey, *et. al*, Nature **7125** (2007) 445.

(22) K. Miuchi *et. al,* proceedings of the Identification of Dark Matter (IDM 2006); physics/0701118.

(23) K. Miuchi *et. al,* submitted for Phys. Lett. B.