Development and performance evaluation of a GEM-TPC for the experiment of highly excited state of nuclei with high rate and high energy unstable nuclear beam


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1. Introduction

A giant resonance, which is a highly excited state of nucleus with nuclear collective motion, is one of the interesting subjects in the nuclear physics. The properties of nuclear matter and nuclear force can be studied from it. Studies for the giant resonances of stable nuclei were performed with missing mass spectroscopy in forward scattering by measuring a recoil in previous researches [1]. In order to extend our understanding to isospin asymmetric region, experiments in inverse kinematics using neutron-rich unstable nuclear beam are planned. Since the beam decays with particle emission immediately after a reaction, an ejectile has to be detected. However, it is difficult to measure the ejectile in forward scattering due to its very low energy. In the case of \((\alpha, \alpha')\) using \(^{68}\text{Ni}\) with 200 MeV/u as a beam, the energy of the scattered \(\alpha\) is less than 1.5 MeV/u with both the scattering angle of less than 5° in center of mass frame and the excitation energy of 20 MeV. Therefore, an active target gas detector, which is a combined device of gas target and gas detector, can be a powerful tool to detect the ejecta with very low energy due to its small material budget.

A Time Projection Chamber using Gas Electron Multiplier (GEM-TPC) as an active target has been developed and a performance test was carried out. Requirements of the GEM-TPC for the above example are as follows:

- The GEM-TPC can be operated with a high intensity beam (> 10^6 pps) since the cross section is small, about 0.1 mb;
- The angular resolution of the track of the ejectile in the center of mass frame and the resolution for the excitation energy are required to be less than 3.5 mrad and 1 MeV, respectively. Thus, the angular and energy resolutions in the laboratory frame are required to be less than 7.5 mrad and 1 MeV, respectively.

2. Design of Active Target GEM-TPC

The rate of the ejecta by elastic scatterings is about 10^3 pps with a beam rate of 10^6 pps. Under the condition, GEMs [2], which are one of Micro-Pattern Gaseous Detectors (MPGDs), are suitable since they can suppress ion feedback and performance degradation of electron multiplication. The thickness, hole diameter, and hole pitch of the GEM used for the GEM-TPC are 100 µm, 70 µm, and 140 µm, respectively.

A gas mixture of He (95 %) + CO\(_2\) (5 %) at about 760 Torr is used. The mixture proportion is optimized by taking account of the material budget and the gas gain of the GEM. A field cage was designed using Garfield [3] by taking account of the field distortion from ground and the beam. The beam profile is 10 \(\times\) 50 (the z direction) mm\(^2\) in RMS. The electric field is created by double-layered metallic wires (the distance between the layers is 15 mm) with a pitch of 2.5 mm. The length of the field cage for the z direction is 250 mm. The field distortion by electron-ion pairs created by the beam was evaluated with two configurations, with and without a 40 mm-gap at beam injection area. The right panel of Fig.1 shows the field cage with the gap. Figure 2 shows the position difference in the x direction during drift from the top to the bottom of the field cage as a function of the distance from the center of the field cage in the x direction where the beam was injected. The solid circles show the results with both beam and the gap, the solid squares show those with beam and without the gap, and the open circles show those without beam (a Ni beam with 200 MeV/u and an intensity of 10^2 pps). From the results, the gap is necessary for the track dispersion in the x direction to be less than 7.5 mrad. In the case with the gap, the dispersion for the track with a flight length of 100 mm is less than 5 mrad. Readout pads with Backgammon geometry are used in order to reduce the number of the pads (right of Fig.3). Hit positions are determined from charge proportion of the neighboring pads. The pad size was optimized by a simulation [4] with consideration for the angular resolution in the xy-plane and the number of pads. In the simulation, the statistical fluctuation of the energy loss was assumed as the energy resolution. The pads with 16.45 \(\times\) 16.45 mm\(^2\) are used.

3. Performance Test

A performance test of the GEM-TPC was carried out using a \(^{3}\text{He}^{2+}\) beam with 7.5 MeV/u accelerated by the 12UD Pelletron tandem accelerator at the University of Tsukuba Tandem Accelerator Complex (UTTAC) [5]. At the performance test, the position, angular, and energy resolutions

\(^1\text{In this article, x, y, and z directions are defined as shown in Fig.1.}\)
Figure 1. Left: A picture of the field cage. Right: A typical reaction with the field cage with the gap for beam injection. A beam scatters with the nucleus of the gas atom inside the TPC.

Figure 2. The simulation result of field distortion. The solid circles show the result with both beam and the gap, the solid squares show those with beam and without the gap, and the open circles show the result without beam. The beam passes at $x = 0$ and the active area of readout pad is $2.5 \text{ cm} < x < 12.5 \text{ cm}$.

The position resolutions in the $y$ and $z$ directions are less than $700 \mu\text{m}$ and about $80 \mu\text{m}$, which lead to the angular resolution of less than $8.3 \text{ mrad}$ and about $1.2 \text{ mrad}$, respectively, when effects due to straggling and the particles which stop inside the field cage are not considered. The energy resolution is $3.9 \%$ in RMS.

The position resolution in the $z$ direction and the energy resolution satisfy our requirements though the position resolution in the $y$ direction is slightly larger than the requirement since the energy resolution is larger than the statistical fluctuation of the energy loss.

Figure 3. Left: A typical event at the performance test. Right: A schematic view of the readout pads.

Figure 4. The top left and top right panels show the position resolutions in the $y$ and $z$ directions as a function of incident position, respectively. The bottom left panel shows the distribution of the induced charge summed for all pads. The bottom right panel shows the geometry of the beam incident position.

4. Result

The results are shown in Fig.4. The top left and top right panels show the results of the position resolutions in the $y$ and $z$ directions as a function of the incident position, respectively. The bottom left figure shows the distribution of the induced charge summed for all pads. The geometry of the beam incident position is shown in the bottom right in Fig.4. The position resolutions in the $y$ and $z$ directions are less than $700 \mu\text{m}$ and about $80 \mu\text{m}$, which lead to the angular resolution of less than $8.3 \text{ mrad}$ and about $1.2 \text{ mrad}$, respectively, when effects due to straggling and the particles which stop inside the field cage are not considered. The energy resolution is $3.9 \%$ in RMS.

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5. Conclusion and Outlook

A GEM-TPC for use as an active target has been developed for nuclear experiments using unstable nuclear beams. It is intended to measure the ejectile in forward scattering. A performance test was carried out using $^4\text{He}^{2+}$ with 7.5 MeV/u. From the test result, the position resolutions in the $y$ and $z$ directions are less than $700 \mu\text{m}$ and about $80 \mu\text{m}$, respectively. The energy resolution is $3.9 \%$ in RMS.

In the future, following items will be studied:

- Performances for incline incident particles;
- Effect of the field distortion and $\delta$-ray from a high intensity and high energy beam.

References