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Development of Gamma-Ray Direction Detector Based on MSGC

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Abstract

The Micro-Strip Gas Chamber (MSGC) has been developed as a real-time X-ray imaging detector. The MSGC with a long drift space has been operated well as a Time Projection Chamber (TPC), and detected fine tracks of charged particles with even less than 1mm, which we call this "Micro TPC". Here we consider the possibility of the imaging detector of MeV gamma-rays based on the Micro TPC having a wide solid angle. The direction of MeV gamma-rays, which interacts via Compton process with matter, can be obtained only by observation of both the recoiled electron and scattered gamma-ray. Full reconstruction of MeV gamma-rays would be enabled by the measurement of both recoiled electron tracks using the Micro TPC and scattered gamma-rays using another gamma-ray position detector such as a scintillator Angular camera combined with the Micro TPC.

Behaviors of electrons in the gas volume of the Micro TPC and scintillation photons in the scintillator were calculated using EGS4. Expected performances of this new gamma-ray detector were estimated.

1 Introduction

The Micro-Strip Gas Chamber (MSGC) was proposed by Oed in 1988 [1] as a new type of position sensitive proportional gas detector. Fine position resolution of 100μm is attained for MSGC, since electrode strips are printed on substrate at narrow intervals of 200μm. We have developed the large area MSGC with the fast data acquisition system for a real-time X-ray imaging. The fine position resolution of less than 100μm and excellent timing resolution of about 100nsec are attained for our MSGC. The schematic structure is shown in Fig. 1. In addition to anode and cathode, backstrip electrodes are printed orthogonally to anodes behind thin substrate. Signals from anode and backstrip enable us to obtain two-dimensional image. Stable operation is possible by a capillary plate installed in our MSGC as a intermediate gas multiplier [2].

Our MSGC has been used for a time-resolved X-ray imaging [3] and an X-ray polarization measurement [4]. Recently we have succeeded to observe images of fine tracks of charged particles using the MSGC X-ray imaging system like a cloud chamber. Using this feature observed in this system, a track of the electron recoiled by Compton scattering will be measured. In addition, if a scattered gamma-ray via Compton process is also detected by some detector behind the gas chamber, the incident direction of a gamma-ray could be fully determined from both the momentum vectors of the recoiled electron detected in MSGC and the detected scattered gamma-ray. This method needs no collimators, and furthermore provide a wide field of view ($\sim \pi$ str). This new detector would be very useful for a lot of application, e.g. gamma-ray astrophysics, medical diagnoses, radiation control, and so on.

Here we presents the simulated performances of this new gamma-ray detector using the Micro TPC and the scintillator Angular Camera.

2 Detection Principle

2.1 The Micro TPC based on MSGC

For the purpose of tracking charged particles, the MSGC having a deep gas volume has been developed, which works as a Time Projection Chamber (TPC). When a charged particle pass through the gas chamber, an electron cloud is generated along the track by the ionization. This electron cloud drifts toward electrodes of the MSGC along electric field formed by the drift electrode. Then a two-dimensional image of the track is projected as a sequence of hit points of electrodes on the MSGC (see Fig. 2). Three-dimensional track image is reconstructed from position information and time intervals of each hit point. Fig. 3 shows an example of three-dimensional track observed in the Micro TPC consisting of the 10cm $\times$ 10cm two-dimensional MSGC and the 8cm deep drift-gas volume. This track is considered due to α particles emitted from the radioactive isotope of lead contained in a glass capillary plate, which is set on the MSGC and used as a auxiliary gas multiplier. Here fine tracks of charged particles less than milli-meter were observed.

2.2 Determination of incident gamma-ray direction

When an incident MeV gamma-ray interact the gas in the drift volume, an electron is recoiled mainly by Compton process as following formula:

$$\cos\theta = 1 + \frac{m_e c^2}{E_k + E_{\gamma'}} - \frac{m_e c^2}{E_{\gamma'}},$$

where m_e is rest mass of an electron and c is light velocity, and also E_k, $E_{\gamma'}$, and θ is kinetic energy of recoiled electron, energy of scattered gamma-ray, and polar angle of scattering, respectively. In this process, all the momenta of incident gamma-ray, scattered gamma-ray, and recoiled electron lie on the same plane as shown in Fig. 4. If the azimuthal angle of the scattering plane, one of two polar angles and both the energies of the scattered gamma-ray and a recoiled electron are measured, the direction of the incident gamma-ray θ is fully determined from above equation. In addition, residual polar angle provide the good redanancy for the reconstruction, which enable us the good rejection power for the accidental background and the false reconstruction.

The schematic view of the Micro TPC gamma-ray detector based on this idea is drawn in Fig. 5. Three-dimensional tracks of a recoiled electron is reconstructed by the MSGC on both sides of the gas chamber. In order to suppress the diffusion of the drifted electron in the gas volume, the drift volume is divided into two MSGCs. Also the scintillator Angular Camera consisting of the scintillator and the photomultiplier array covers the half of the gas volume in order to detect the recoiled gamma-rays. A trigger is generated from the signal of the Angular Camera.

3 EGS4 Simulation

In order to optimize the parameters of the detector and to estimate the performance of the Micro TPC gamma-ray detector, the very convenient program package EGS4 is used, which can simulate both the behaviors of Compton scattered gamma-ray photons and recoiled electrons. The EGS4 is a general purpose package for Monte Carlo simulation of high energy electrons and photons [5]. Here we consider the GSO as a scintillator of the Angular Camera, which has a better stopping power for gamma-rays than another scintillator. Properties of GSO scintillator can be also simulated using EGS4. In this simulation, a subroutine for the calculation of the behavior of scintillation photons is included.

The geometry of the Micro TPC in the calculation is a cubic shape, of which inside pure xenon is filled with an atmospheric pressure. Also $1 \sim 3$ cm thick GSO crystal covers around the cube (see Fig. 5). Incident gamma-rays are assumed to be perpendicular to the upper surface of the cube. There are four types of event patterns in the detector: (A) no interaction in the gas volume, (B) photoelectric effect (fluorescent X-ray is often absorbed in gas), (C) Compton scattering observed in the gas volume but scattered gamma-ray missing, (D) both scattered electron and gamma-ray observed in the gas volume and in the scintillator respectively. The available event is the last type in the four types. The detection efficiency satisfied with the requirement of (D) is shown in Fig. 6 as a function of the incident gamma-ray energy.

While electrons passing through gas the volume, the tracks are quite bent by multiple scattering. Averaged deflection angle of electron tracks determines the accuracy of a reconstructed direction of the gamma-ray. Here the deflection angle of the scattered electron is defined as an angular deviation from the initial direction of the scattered electron at the point on the track passing through the 3mm distance. Fig. 7 shows the distribution of the deflection angles of the recoiled electron track. Here the energy written in each figure is not electrons', but those of incident gamma-rays. The energy become higher, the deflection angles become smaller drastically. For high energy incident gamma-rays, most of recoiled electrons pass straight through the 3mm thick gas layer without multiple scattering. In this case, the electron track is determined within the accuracy of 1 degree.

While a ionized electron in the track drifts toward MSGC electrode, it gradually diffuses by thermal collision between electrons and gas molecules. In order to estimate the accuracy of direction of the recoiled electron, it is necessary to consider the diffusion of electron track as well as the deflection. However, it is not so easy to estimate diffusion properties, because it strongly depend on the electric field, gas pressure, and concentration of quencher gas [6]. Now we are developing the simulation by including above effects.

Scintillators are used for the detection of scattered gamma-rays. Dispersion of scintillation light is estimated quickly using the simplified simulation. In this simulation, the attenuation of scintillation light is ignored, and it is assumed that all photons, which reach surface of crystal, is absorbed. Soon we will use the full simulation including such effects. As a result, the dispersion of light is estimated to be about 1cm for 1cm thick GSO, and about 2cm for 2cm thick one (see Fig. 8).

4 Summary and Future Plan

Our MSGC is applied to Micro TPC, and three-dimensional tracks of charged particles (α particles) were observed. An imaging detector for the MeV gamma-ray based on the Micro TPC is proposed, which is expected to have a wide field of view and provide the full reconstruction of the direction of one gamma-ray. Expected performance of this gamma-ray detector was simulated using EGS4. Obtained detection efficiency is about 1%, and the accuracy of the direction of the gamma-ray is less than 1 degree for 1MeV gamma-ray. As a preliminary result, the dispersion of light in GSO crystal is about 1 to 2 cm.

In the next step, energy resolution of the Micro TPC will be taken into account. On the other hand, the estimation of position resolution of the scintillation detector combined with pixel type PMTs is now in progress.

References

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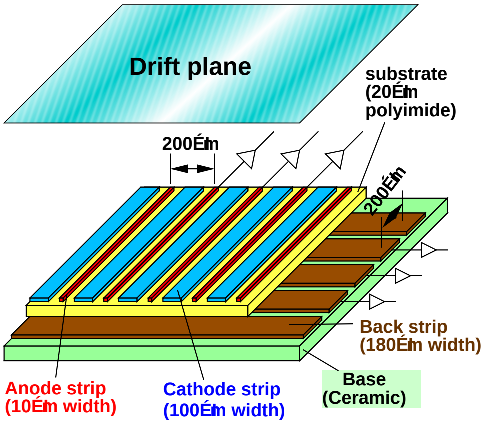

Figure 1: Schematic structure of 2D MSGC.

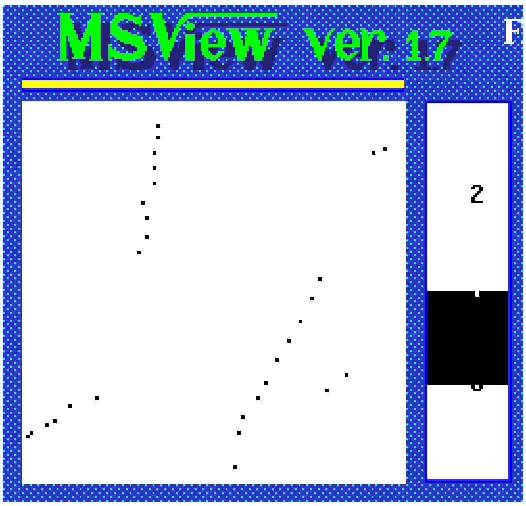

Figure 2: Two-dimensional track image projected on 2cm $\times$ 2cm area of MSGC. Each sequence of dots represents a track image projected on electrode plane.

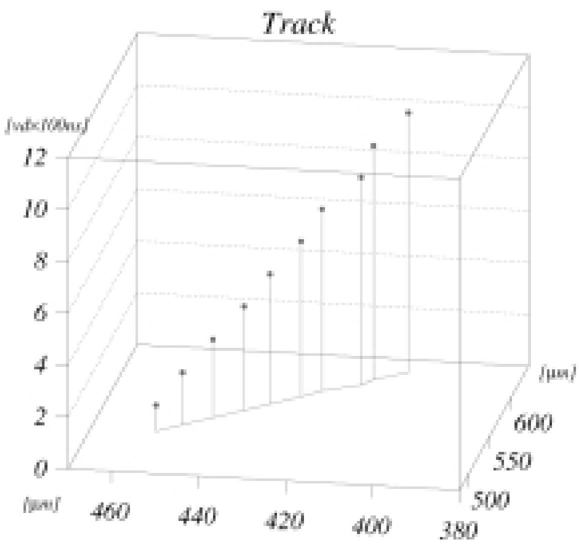

Figure 3: A three-dimensional track image of an α particle. A track is reconstructed from position and timing data of each dot.

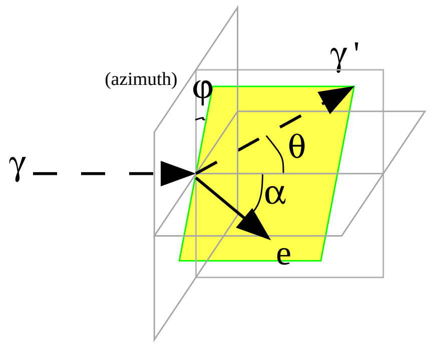

Figure 4: Direction of scattered gamma-ray and recoiled electron.

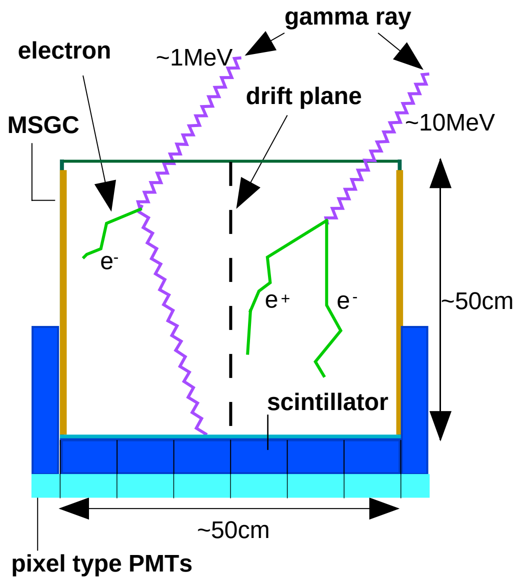

Figure 5: Schematic illustration of the Micro TPC gamma-ray detector. Recoiled electron tracks are detected the Micro TPC based on MSGC, and scattered gamma-rays are absorbed in scintillators behind the gas chamber.

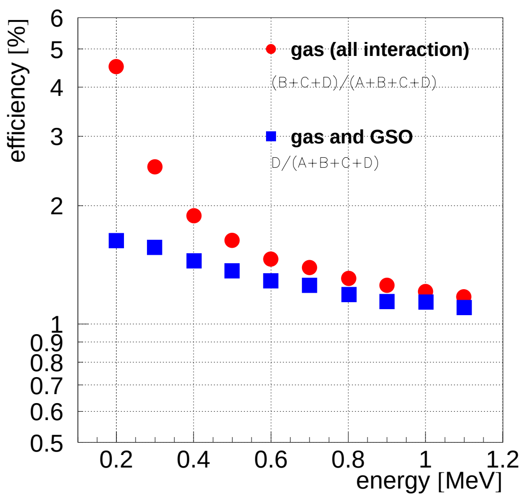

Figure 6: Detection efficiency of Micro TPC gamma-ray detector. Round markers mean efficiency of interaction only in gas region. Efficiency shown as square marker is due to the effective events.

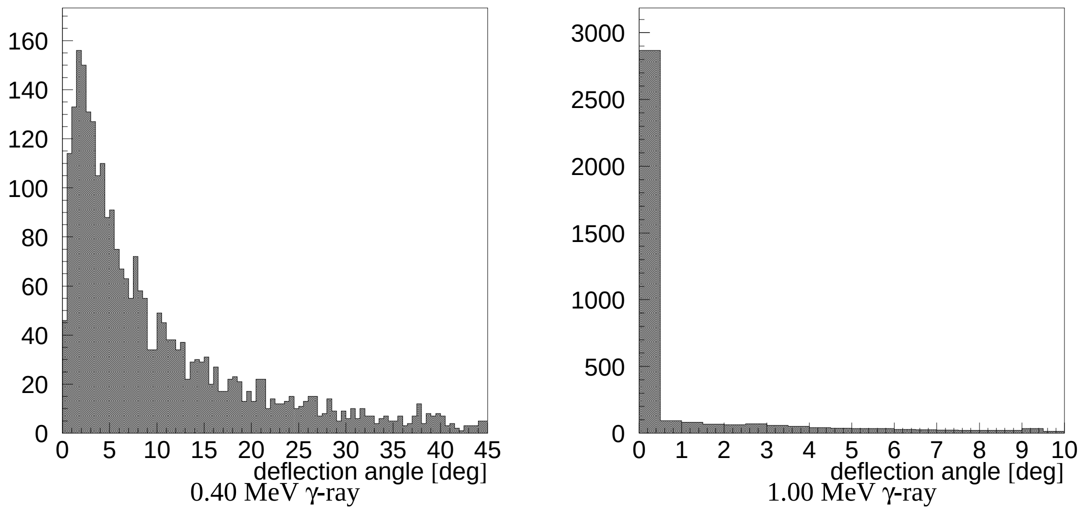

Figure 7: Distribution of deflection angle.

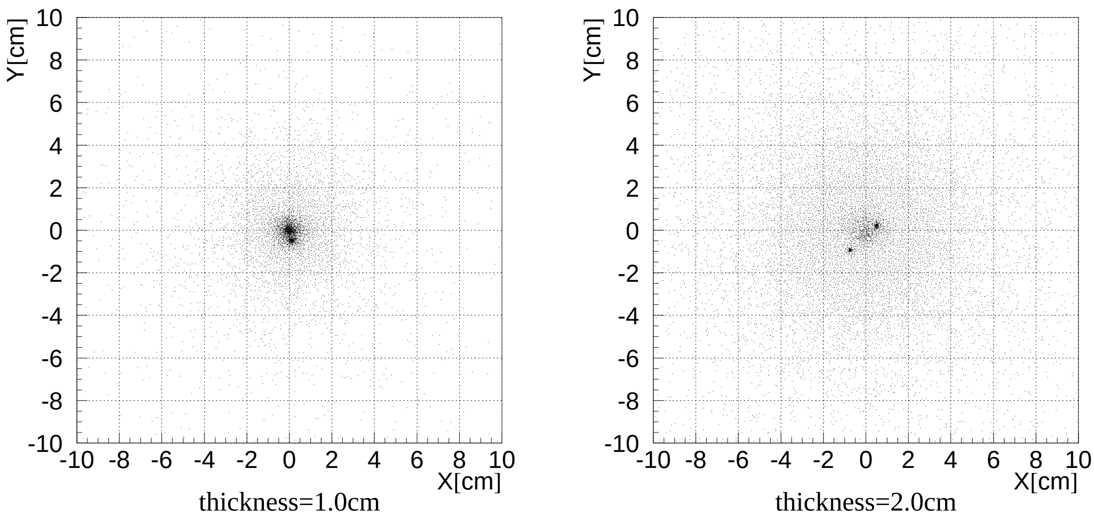

Figure 8: Distribution of scintillation photons. Energy of incident gamma-ray is 700keV. Total event number is 20.