

# Digitization of Cylindrical GEM Detector

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**Abstract.** The BESIII inner drift chamber is suffering from aging effect. Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT) is considered as one of the upgrade candidates. A simulation study with Garfield++ program has been performed to understand the drift behaviour and to build a full digitization model. Parameters related to Lorentz angle, diffusion effect, drift time, multiplication and induction are obtained from the Garfield++ simulation. A preliminary digitization model is implemented in the BESIII Offline Software System (BOSS) based on those parameters.

## 1. Introduction

The Main Drift Chamber (MDC) is an important sub-detector of Beijing Spectrometer III (BESIII). It consists of an Inner Drift Chamber (IDC) and an Outer Drift Chamber (ODC) [1]. However, the gain and hit efficiency of the inner drift chamber is starting to decrease in recent years due to the aging effect.

A three-layer Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT) [2,3] is designed to replace the old inner drift chamber. The inner radii of each layer of the CGEM-IT is 76.9mm, 121.4mm and 161.9mm and the outer radii is 90.2mm, 134.7mm and 175.2mm, respectively. The length of each layer is 532mm, 690mm and 847mm, respectively. Figure 1 shows the structure of each CGEM-IT layer, which is composed of a cathode, 3 GEM foils, and a readout anode. The four gaps between those foils are Drift, Transfer1, Transfer2 and Induction gaps. Electric fields in those 4 gaps are 1.5kV/cm, 3kV/cm and 5kV/cm, respectively. A gas mixture of Ar/iC4H10 with a ratio of 90/10 is filled in CGEM-IT.

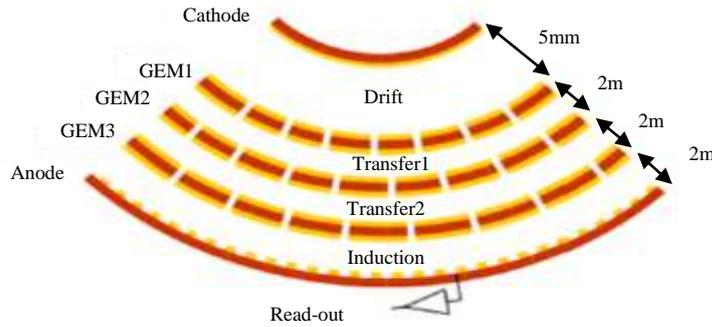
The structure of GEM foil is shown in Fig. 2, which consists of many double-cone shaped holes. A high voltage of 270V is applied on each GEM foil. The electrons generated from the ionization by an incident charged particle are multiplied in the holes of the GEM foil, and multiplied electrons are collected by the readout anode. The readout anode is segmented with 650  $\mu$ m pitch XV patterned strips. The stereo angle between X and V strips changes with the layer. The moving of the electrons in the induction gap can induce a current in a series of anode readout strips which will be reconstructed to be a cluster in the track reconstruction process. An analog readout is adopted for the CGEM-IT to measure both time (T) and charge (Q) of each firing strip. The position of the

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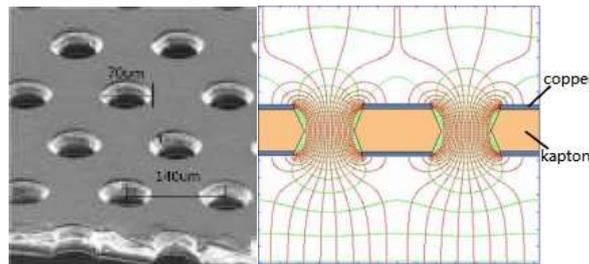
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incident track segment within the drift gap can be estimated from the cluster reconstruction with Q in a charge centroid method and with T in micro-TPC mode[4].

A full simulation software of CGEM-IT in the BOSS (BESIII offline software system) [5] has been developed based on Geant4 [6]. With the information obtained from the Geant4 simulation (such as the parameters of the incident particle including the particle type, charge, momentum and position in the drift gap), a digitization process is used to simulate the response of the detector, by which the information of the incident particle is converted to the index of firing strips, T and Q values of each firing strip.



**Fig. 1** Local structure of CGEM inner tracker



**Fig. 2** (a) Local structure and (b) electric field of GEM foil

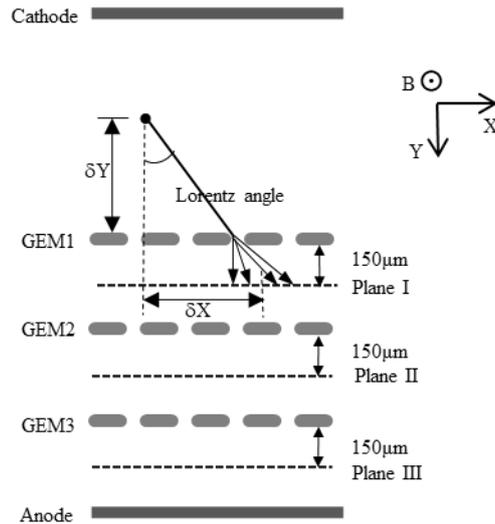
The digitization process could be divided into three steps. Firstly, simulation of ionization is implemented by calling the Heed package [7] through the interface provided by Garfield++ [8] program. Secondly, simulation of the drift and multiplication of the ionized and multiplied electrons is also based on Garfield++. But the complete simulation of the drift line and the multiplication is time consuming, so this step is simplified to be a sampling of the number, position and time of the multiplied electrons. The parameters describing the Lorentz angle, multiplication and diffusion are obtained by a prior simulation of different parts of CGEM with Garfield++. Finally, simulation of the signal induction which is also based on a prior simulation with Garfield++.

## 2. Methods of the Simulation Study

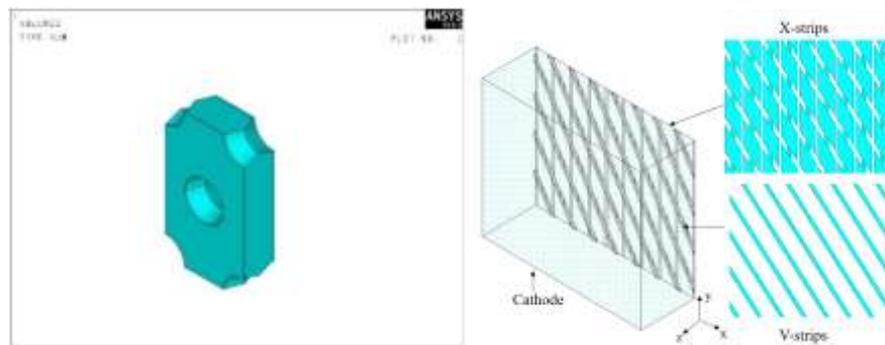
The construction of the geometry of the detector and the calculation of the electric field are based on ANSYS, which is a finite element analysis software [9]. The bending structure can be ignored in geometry construction, because the drift and the avalanche of an ionized electron usually occur within a few millimeters which is very small compared with the size of the whole detector. So a planar approximation instead of the cylindrical shape is adopted to simplify the construction of the detector with ANSYS. The definition of the coordinate is shown in Fig. 3, where the GEM foil is perpendicular to the Y axis and the magnetic field is parallel to the Z axis. Figure 4 shows an unit of GEM foil and anode plane constructed by ANSYS. The output of ANSYS is used as an input of the Garfield++ simulation. Due to the periodicity of the detector structure, the CGEM detector is realized in Garfield++ by extension of the unit structure in the X and Z axes.

Since a full simulation of all processes for a particle passing the CGEM with Garfield++ is very time-consuming and hard to be parameterized for digitization model, the whole process is divided into four parts by the three reference planes, which is shown in Fig. 3. In first three parts, the simulation of a single electron is performed from the generated position to the reference plane after the next GEM foil, which contains the drift in one gap and the multiplication in one layer of foil. Since some of the multiplied electrons may be captured by the electrode on the foil under the influence of the electric field in the region near the foil, the distance between the reference plane and the GEM foil cannot be too small. For the first part, the generated position is the location of

ionization in the drift region. The electron is generated uniformly in X-Z plane with a zero initial velocity. So in the other two parts, the electron starts from 150 microns after the previous foil and is also generated uniformly in X-Z plane with a zero initial velocity. After all the sampling in the three parts, the distributions of all the multiplied electrons which pass through the third GEM foil can be obtained. In Garfield++ simulation, the R value of the Penning coefficient parameter is set to be 0.44 [10]. In the fourth part, to accelerate the induction simulation, we build an induction model by dividing the basic unit into several grids. For each grid, we simulate the induced signal for electrons with center initial position, and use this as the induced signal for all electrons in this grid. Finally, we sum up all signal shapes from each multiplied electron to get the final result for each strip.



**Fig. 3** Four parts for Garfield++ simulation with electric field in Y direction, magnetic field in Z direction

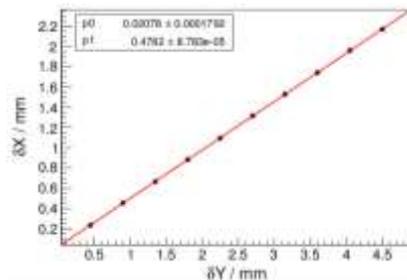


**Fig. 4** The unit of GEM foil (left) and anode plane (right) constructed by ANSYS

### 3. Results of Garfield++ Simulation

The drift and multiplication behaviour of a single electron, including the Lorentz angle, transverse diffusion, drift time and electron multiplication distribution is obtained from Garfield++ simulation.

#### 3.1. Lorentz Angle

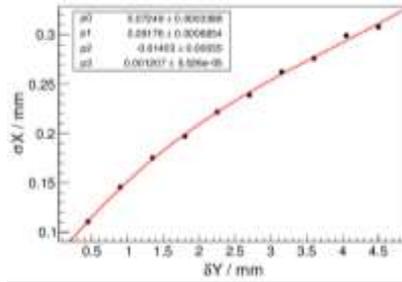


**Fig. 5** For ionized electrons in drift region, the mean displacement of multiplied electrons in X direction as a function of  $\delta Y$

As shown in Fig. 3, a displacement of the electron in X direction ( $\delta X$ ) is induced by the Lorentz force. Electrons with different Y are generated to determine the Lorentz angle. The distance between the electron and the top surface of the GEM foil is defined as  $\delta Y$ . From the line fit to the graph of  $\delta X$  versus  $\delta Y$ , the Lorentz angle can be obtained. Figure 5 shows the result from the drift region. The Lorentz angle in the drift region is bigger because of the lower electric field in this region.

### 3.1.1. Transverse Diffusion.

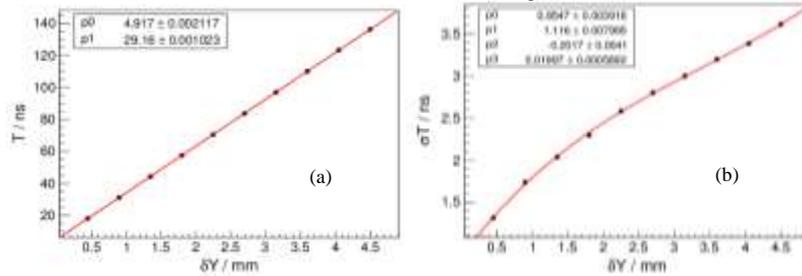
The cluster size of multiplied electrons is affected by transverse diffusion, which can be extracted from fitting the displacement distribution of the multiplied electrons. For Transfer1 and Transfer2, the diffusion effect can be described with a sigma of Gaussian distribution since the drift distance is almost constant. In the drift region, the diffusion effect is a function of  $\delta Y$ , as shown in Fig. 6. The diffusion in the X direction is a little bigger than that in the Z direction because the drift line is not perpendicular to the X direction due to the Lorentz force.



**Fig. 6** In drift region, the sigma of multiplied electrons' displacement in X direction as a function of  $\delta Y$

### 3.1.2. Drift Time

As shown in Fig. 7 the drift time and its resolution are functions of drift distance in drift region. In Transfer1 and Transfer2, the mean of the drift time and the time resolution are very close due to the same electric field.



**Fig. 7** In drift region, (a) drift time as a function of  $\delta Y$  and (b) sigma of drift time as a function of  $\delta Y$

### 3.1.3. Multiplication

The gain of electrons can be described by Polya distribution [11]:

$$P(G) = C_0 \frac{(1+\theta)^{(1+\theta)}}{\Gamma(1+\theta)} \left(\frac{G}{G_0}\right)^\theta \exp\left[-(1+\theta)\frac{G}{G_0}\right], \quad (1)$$

where  $C_0$  is a constant,  $G$  is the number of multiplied electrons reaching the reference plane,  $G_0$  is the average effective gain of a single electron and  $\theta$  is the parameter determining the variance of Polya distribution. The value of  $\theta$  is related to the electronic proportion of energy exceeding the ionization threshold.

### 3.1.4. Signal Induction

Signal induction process is also studied by the simulation with Garfield++. Figure 8 shows the induced current on the central X and V strip (with the most induced charge) of Layer 1 for a charged track.

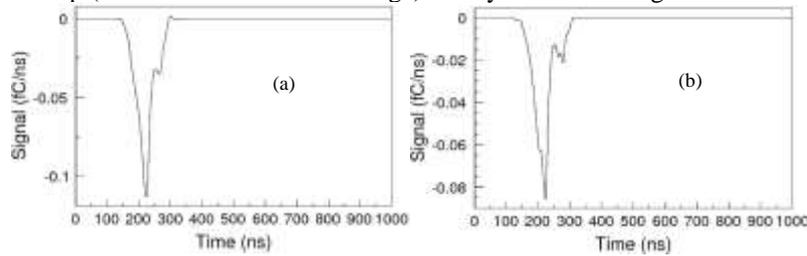


Fig. 8 Induced current on (a) the central X strips and (b) the central V strips

#### 4. Digitization Model

Based on the results of the Garfield++ simulation described in the previous section, a preliminary full digitization algorithm has been implemented. Figure 9 shows the cluster size of Layer 1 obtained from the digitization algorithm, from which we see that the mean value of the cluster size is 4.1 and 3.4 for X and V respectively.

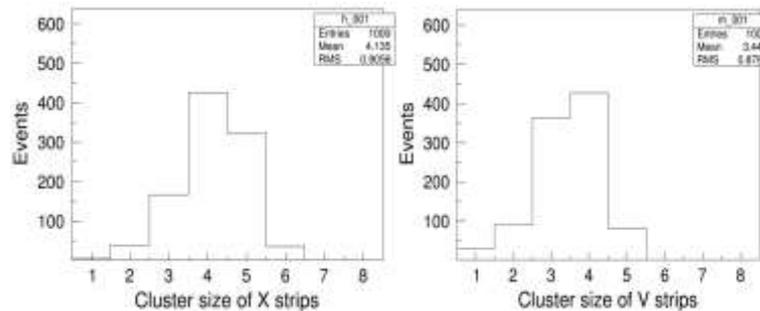


Fig. 9 Cluster size of (a) X strips and (b) V strips

#### 5. Conclusion

A Garfield++ simulation on the CGEM inner tracker has been performed according to the needs of the digitization model. Preliminary results including Lorentz angle, diffusion, drift time, multiplication and induction are obtained from the Garfield++ simulation and used in the digitization algorithm. The digitization model will be improved in the next step. The effect of electronics will be considered. The samplings in the process of drift and multiplication may be optimized. Currently, a simple threshold was applied in the digitization model. However, the actual case of the detector should be complicated. The thresholds could be different layer by layer, even channel by channel. All of these will be considered in the future when the experiment data is available. In addition, a MC tuning will be applied for further reducing the difference between data and simulation.

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