Performance study of 400 × 400 mm^2 and 600 × 600 mm^2 Micromegas track detectors using cosmic rays

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Abstract: The large area and high spatial resolution of particle detection are important aspects in the research and application of MPGD. Currently, there is no satisfactory technological solution to address these challenges, particularly in achieving long-term stable, high-resolution readout of large area detectors, and managing high irradiation background and counter rates. In this study, we utilized the thermal bonding method for manufacturing Micromegas detectors and conducted production and research on large area Micromegas detectors ranging from 400 × 400 mm^2 to 600 × 600 mm^2 in size. Several large area Micromegas detectors have been successfully developed, and a cosmic ray test system has been established. Using this system, we developed an alignment algorithm and investigated the position resolution, detection efficiency through performance testing, and μTPC reconstruction. A new alignment algorithm for plate detectors based on Millepede-II was developed using this system, effectively addressing the convergence issue of traditional algorithms in the rotation alignment of the x/y direction. The results of the cosmic ray test demonstrate that the detection efficiency of the 400 × 400 mm^2 thermal bonding Micromegas detector exceeds 95%, with a position resolution of approximately 130 μm. The position resolution of μTPC reconstruction is approximately 160 μm for particles with incident angles greater than 20 degrees. This paper covers the manufacturing of large area Micromegas detectors, cosmic ray testing, and data analysis methods.

1. Introduction

The large area and high spatial resolution of particle detection are important aspects in the research and application of micropattern gaseous detector (MPGD). For instance, in the upgrade of the ATLAS NSW [1], the large area Micromegas detector has been selected, with a single module covering an area of 2-3 m^2. Similarly, the CMS GEMs [2] also have opted the GEM detector, with a single module covering an area of 0.28-0.45 m^2.

In this study, we utilized the thermal bonding method (TBM) [3] to manufacture 400 × 400 mm^2 and 600 × 600 mm^2 Micromegas detectors and set up a cosmic ray test system to evaluate detector performance. Using this system, we have developed an alignment algorithm and investigated the position resolution, detection efficiency, and μTPC reconstruction.

2. Design and fabrication of Micromegas

Fig. 1 (a) shows the schematic of 400 × 400 mm^2 detectors. The 600 × 600 mm^2 detectors adopt a back-to-back structure design, as shown in Fig. 1 (b).

The TBM process is selected to manufacture the avalanche gap of the Micromegas detector. With the installation of the drift electrode, gas chamber, and readout connectors, a Micromegas detector is fabricated. The photo of 400 × 400 mm^2 detector and 600 × 600 mm^2 detector is shown in Fig. 2.

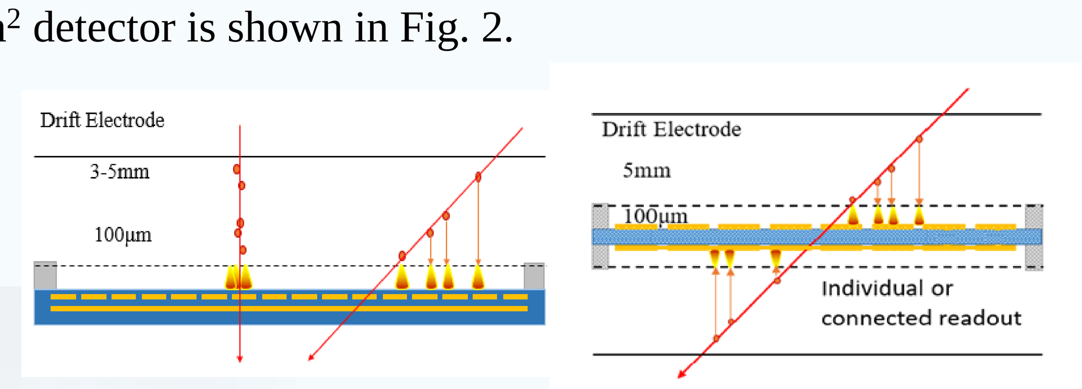

Fig. 1. (a) Schematic of the 400 × 400 mm^2 detector structure.
(b) Schematic of the 600 × 600 mm^2 back-to-back detector structure.

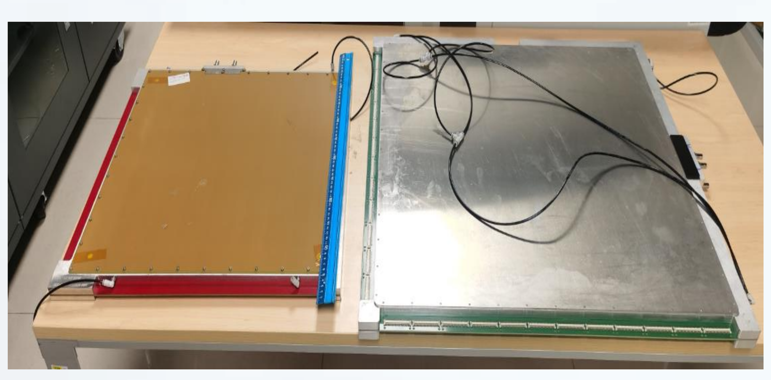

Fig. 2. Photo of 400 × 400 mm^2 detector on the left and 600 × 600 mm^2 detector on the right.

3. Experimental setup for cosmic ray test

To evaluate the performance of large-area detectors, a cosmic ray test platform was established, as shown in Fig. 3. Within this system, the 2 central 400 × 400 mm^2 detectors are designed for testing purposes. The remaining 8 150 × 150 mm^2 detectors are grouped in sets of 4, with each set placed above and below the test detectors, serving as reference tracks for muons from cosmic rays.

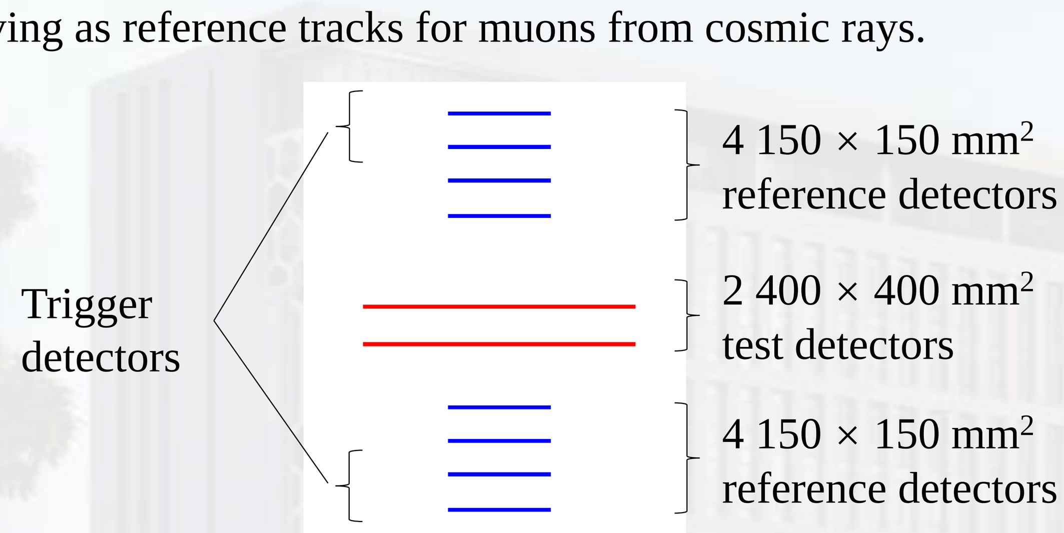

Fig. 3. Schematic of cosmic ray test platform.

4. Alignment algorithm

Using the cosmic ray platform, a new alignment algorithm for plate detectors based on Millepede-II [4] has been developed. The algorithm reconstructs particle trajectories using all detectors, calculates the intersection point p_g on the corrected detector plane, and converts it to detector local coordinates p_l based on alignment parameters. The goal is to minimize the residual between p_l and the actual hit point p_r.

The usual matrix rotation form has been replaced by the quaternion rotation form, as shown in Fig. 4, effectively addressing the convergence issues in traditional x/y rotation alignment algorithms. The comparison results of the two alignment algorithms are shown in Fig. 5, using simulation data generated by geant4.

$$\vec{p}_{il} = \Delta R_i^{-1} R_i^{-1} \left[\vec{k} \frac{(\vec{p}_{i0} + \Delta \vec{p}_i - \vec{b})^{\intercal} R_i \Delta R_i \vec{Z}^{\intercal}}{\vec{k}^{\intercal} R_i \Delta R_i \vec{Z}^{\intercal}} + \vec{b} - \vec{p}_{i0} - \Delta \vec{p}_i \right]$$

$$R\vec{p} \rightarrow QpQ^{-1}$$

$$p_{il} = q_i^{-1} Q_i^{-1} \left\{ k \frac{Re[(p_{i0} + \Delta p_i - b) Q_i q_i Z q_i^{-1} Q_i^{-1}]}{Re(k Q_i q_i Z q_i^{-1} Q_i^{-1})} + b - p_{i0} - \Delta p_i \right\} Qq$$

Fig. 4. The alignment algorithm equations in matrix and quaternion rotation forms.

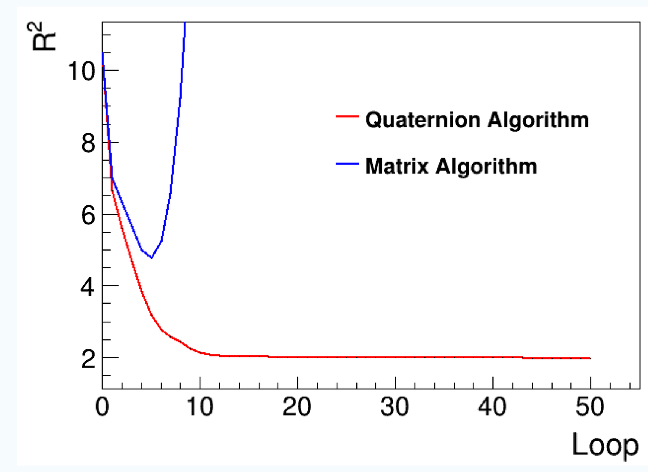

Fig. 5. The comparison results of matrix and quaternion algorithms.

5. Performance of Micromegas

- Fig. 6 displays the amplitude distribution of hits, with the horizontal axis already converted to collected charge based on the electronics characteristics.
- In Fig. 7, the scan results on detector efficiency indicate that for both x and y dimensions, an efficiency exceeding 95% is achieved when the mesh voltage is greater than 560V.
- Residual distributions of 400 × 400 mm^2 and 600 × 600 mm^2 detectors are shown in Fig. 8 and 9, fitted with double Gaussian distributions. Due to platform size limitations, only 4 track detectors are used in the 600 × 600 mm^2 detector testing, resulting in a wider residual distribution due to errors in the reference trajectory.
- The scan results on detector resolution are shown in Fig. 10, including charge center method, μTPC method and weighted average results.

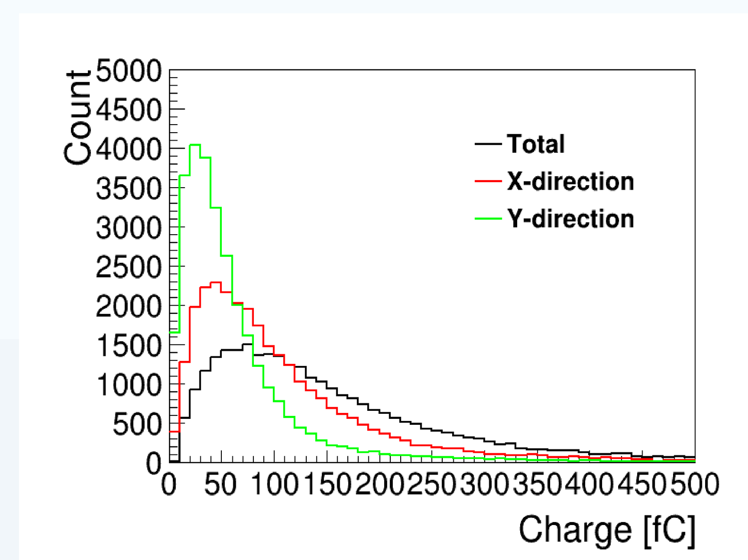

Fig. 6. Distribution of the amplitude of hits.

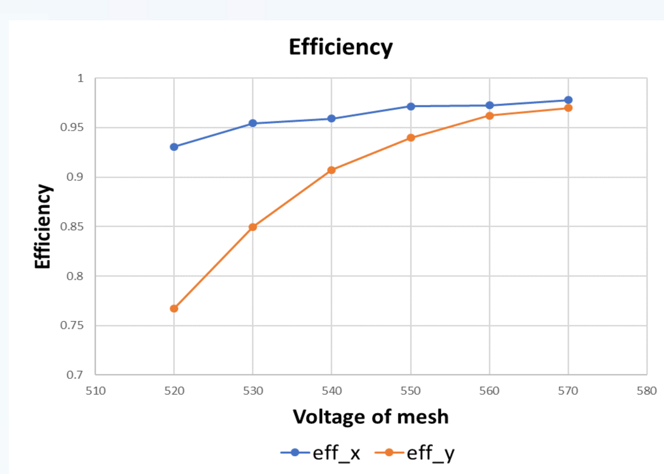

Fig. 7. Variation of detector efficiency with voltage of mesh.

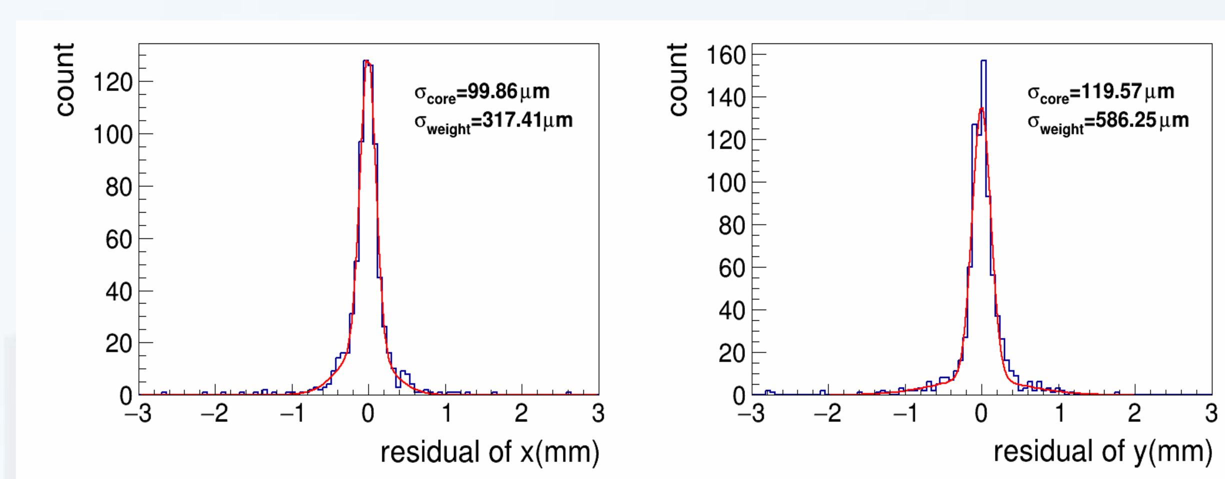

Fig. 8. Residual distributions of x/y dimensions of 400 × 400 mm^2 detectors.

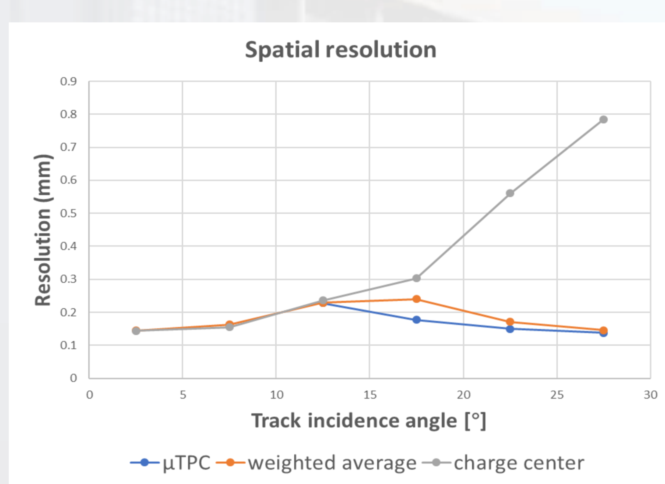

Fig. 10. Variation of charge center method, μTPC method and weighted average result with incident angle.

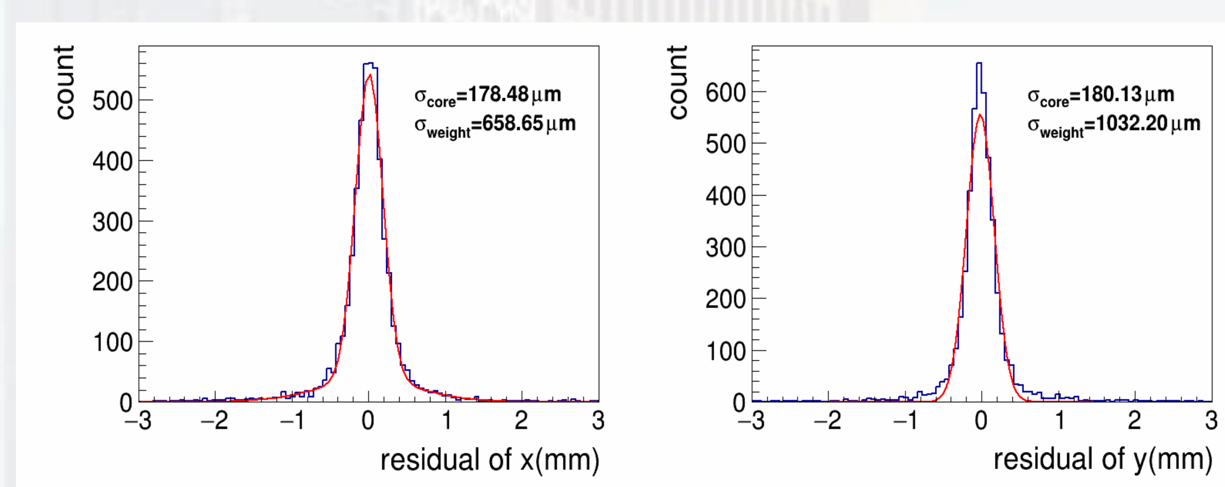

Fig. 9. Residual distributions of x/y dimensions of 600 × 600 mm^2 detectors. The wider residual distribution is due to errors in the reference trajectory.

6. Conclusion

This paper introduces large area Micromegas detectors fabricated using the TBM method, and investigates their performance. Through cosmic ray testing of 400 × 400 mm^2 detectors, the efficiency is better than 95%, the position resolution by the charge center method is 100-120 μm, and the μTPC reconstruction achieves a position resolution of approximately 160 μm at angles greater than 20°. A preliminary study of 600 × 600 mm^2 detectors has been conducted. Additionally, a new algorithm for alignment of planar detectors is proposed in this study, effectively addressing the divergence issue during rotation alignment in the x/y dimensions.

Reference

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