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Delay-line PPAC for Intermediate Energy Light Ions*

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Abstract: The gas detectors have the characteristics of low cost, easy preparation, reliable capability and convenient for use etc. A delay-line parallel-plate avalanche counter (PPAC) with five plates has been developed for the experiments at Radioactive Ion Beam Line in Lanzhou (RIBLL). The applicability of counter for high energy light ion has been tested with 57.6 MeV/u ^{6}He beam. A position resolution of ~1.8 mm (FWHM) and a timing resolution of ~2.6 ns are achieved. The detection efficiency is reasonable.

Key words: parallel-plate avalanche counter; intermediate energy light ion; detection efficiency; position resolution

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1 Introduction

The parallel plate avalanche counters (PPAC) has long been known as a position sensitive gas detector combining high efficiency and good transparency for charged particles[1]. The detection efficiency of PPAC depend on the nature and energy of the incident ion[2]. Therefore, most PPAC can reach high efficiency for light ions at low energy or for heavy ions. Since the intrinsic efficiency become much lower for light ions at intermediate energy, conventional PPAC has been mostly used for the detection of heavy ions in nuclear reaction experiment.

To measure the position of intermediate energy light ions precisely, a new PPAC has been designed and set up at the Radioactive Ion Beam Line in Lanzhou (RIBLL). The PPAC had five plates with symmetric structure and the charges were preamplified on both sides[3]. The advantage of such a structure was the wide region electron avalanches, which provided high total gain at low gas pressure. Conventional two-dimensional PPAC based on charge-division read-out has been used at the fragment separator facilities in RIKEN and NSCL for the position measurements[4]. However, piling up of signals becomes serious when the counting rate is higher than ~2×10^3 Hz. However, the signals of our PPAC were read out in delay-line method, which could achieve reasonable position and timing resolutions at ~10^6 Hz counting rates.

In this work, we placed PPAC in ^{6}He beam with energy ~60 MeV/u and α source, and evaluated the position and timing resolution. We also tested the long-time stability of PPAC in the light

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ion beam at accelerator.

2 Construction and Operation

The construction details of the PPAC are shown in Fig. 1. It consists of five electrodes, which are all kept in parallel to ensure a uniform electric field[2]. The gaps between the adjacent electrodes are 3 mm each, as can be adjusted by 8 screws.

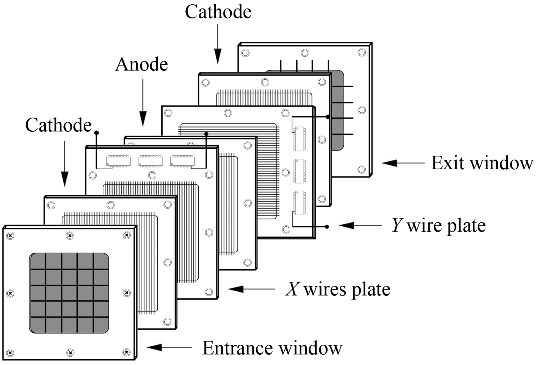

Fig. 1 Structure of the position sensitive PPAC with five plates.

The anode, made of 20 μm diameter gold-plated tungsten wires, is placed in the middle of the PPAC and held at a positive potential. The 75 μm diameter sense-wires are located symmetrically on both sides of the anode. In order to induce the horizontal (X) and vertical (Y) position information, the orientation of the wires on one of the sense-wire plate are perpendicular to those on the other[2]. The cathodes are composed of 20 μm diameter wires as the anode plane, but held at a negative potential.

The active area of PPAC is 60 mm × 60 mm. Both the entrance and exit windows are made of 7 μm/cm^2 thick Kapton films. The films are supported by a 10 mm mesh of nylon strings. All the wires are solidly and equidistantly assembled in parallel onto epoxy frames with non-conductive glue[2]. The productions of avalanche charges induce negative signals at the anode wires and positive signals at sense-wires. The wires on the same plate are 1 mm apart from each other and every two neighboring wires are welded onto one welding spot. Each delay-line(1520 series) has ten pins and a total delay time of 20 ns. In total there are 30 spots and therefore three delay-lines are used for each plate to provide 60 ns delay. The timing shift between two signals taken from both ends of the delay-line corresponds to the position of the incoming particle[6].

As the detector gas, The iso-butane was used in the test of PPAC properties. However, we selected n-heptane as the circulating gas in the ^{6}He properties research at RIBLL. Compared to iso-butane, the usage of n-heptane helps to improve the efficiency of the detector due to its larger gas amplification. Moreover, PPAC can work stably at higher anode and cathode bias voltages with n-heptane, which also brings larger signals.

3 Test Experiments

3.1 Test experiments by α source

The measurements of the new PPAC were performed at RIBLL, and corresponding experimental results were illustrated below. The position resolution was tested with ^{239}Pu α source. The detectors were mounted in a chamber which had a vacuum better than 10^{-2} Pa.

In position resolution measurement, we placed a 1.4 mm thick diaphragm with matrix aperture closely before PPAC. The aperture was ϕ1 mm, and spacing between every two apertures was 3.3 mm. And α source was 14.5 cm away from the diaphragm, faced the centrality of PPAC. The voltage of anode was 680 V, while cathode was −260 V. Gas pressure inside PPAC was 600 Pa.

We achieved X and Y position of PPAC by the following equations:

$$X=\frac{x_1-x_2}{x_1+x_2},\ Y=\frac{y_1-y_2}{y_1+y_2},$$

where x_1, x_2, y_1, y_2 corresponded to the delay-times from each end of the delay-line in X(Y) direction, respectively. Two-dimensional position scatter plots were shown in Fig. 2.

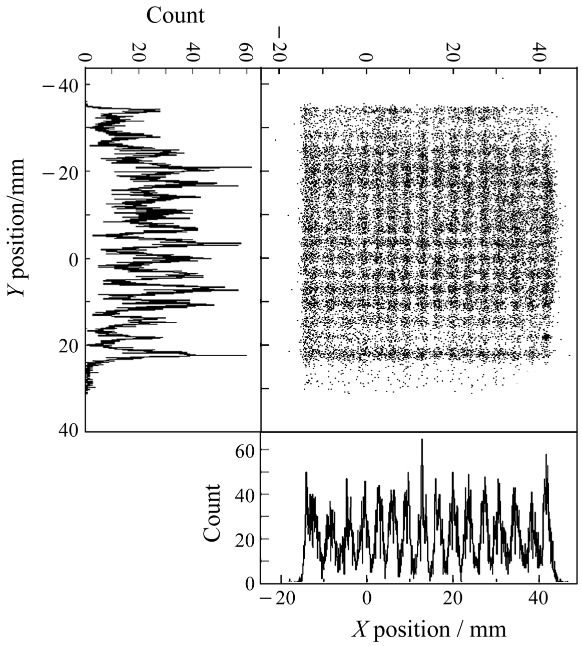

Fig. 2 2-dimension scatter of α source measured by PPAC.

For X position of PPAC, we got spectrum (X) along the apertures while $Y \sim -3$ mm[7]. Gaussian fitting calculated the FWHM was 2.35 mm. And we studied that the aperture correction was 1.52 mm(FWHM) using Monte Carlo method, which should be eliminated. Therefore, the position resolution of X, in the conditions above, was (1.80±0.05) mm. Equally, for Y position of PPAC, we got spectrum (Y) while $X \sim 1.5$ mm. With the same method we calculated the position resolution of Y was (1.64±0.38) mm.

By computing the difference between the means of the peak in Fig. 2 and the apertures' actual positions, we fitted the position linearity of PPAC. From the mean deflection, we knew the dispersion of PPAC was better than ±0.9 mm.

3.2 Test experiments at RIBLL

57.6 MeV/u ^{6}He beam was produced at RIBLL. Two new PPACs were mounted in the reaction chamber before the target, without diaphragm, to measure the position of the beam. The distance between two PPAC was 279 mm. Two PPAC used the same gas circuit, with n-heptane as the working gas. And gas flew from the prior PPAC1 to PPAC2. We placed a plastic scintillator in T2, the small chamber upstream of the reaction chamber, to count the number of ions.

We measured timing resolution in the preceding condition. The anode voltage was 675 V and cathode voltage was −260 V. Gas pressure was 600 Pa. We calculated the time difference between the plastic scintillator in T2 and the PPAC1's anode signals. As the result shown in Fig. 3, the timing resolution in this condition was (2.63±0.02) ns(FWHM). An intrinsic timing resolution for the scintillator was included. It was noted that a flow-rate of gas and bias voltages affected the timing resolution of PPAC anode signals, which improved slowly as the does increased. After 10 d irradiation with ^{6}He ions of ~10^{5} Hz, the timing resolution decreased less than 20%.

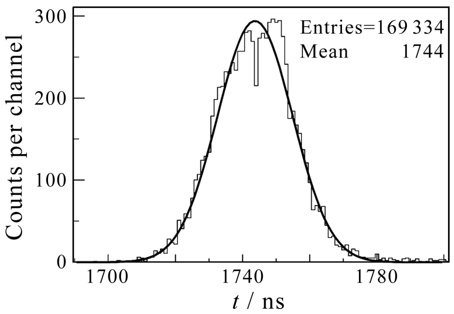

Fig. 3 Timing spectrum of anode signals coincident with a plastic scintillator for ^{6}He beam of 57.6 MeV/u.

In similar condition, we calculated the detection efficiency (η) by the following two equations[2]:

$$\eta_1 = \frac{N_1 \otimes N_2}{N_2}, \qquad \eta_2 = \frac{N_1 \otimes N_2}{N_1}$$

where N_1, N_2 means effective number of events in the PPAC1 and PPAC2.

In first days, we changed the voltages and gas pressure, and tried to get the best efficiencies. The efficiencies of two PPACs increased with the rise of anode voltage were shown in the Fig. 4. We could find out that anode voltage rising caused more marked effects in the positions detection efficiencies than anode. Considering the gas pressure in PPAC had a positive correlation to voltages, a pressure of 600 Pa was chosen.

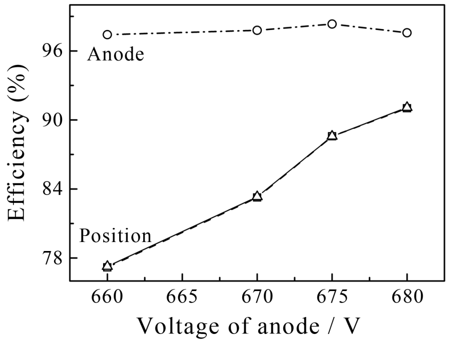

Fig. 4 Detection efficiencies of the PPAC1 with different anode voltage for ^{6}He beam of 57. 6 MeV/u, the gas pressure was 600 Pa.

In the measurements, we irradiated PPACs with ^{6}He ions of ～10^{5} Hz for ～10 d. The detection efficiency of PPAC1 achieved was more than 80% in 40 h, while the anode efficiency was more than 97%, as shown in Fig. 5. The detection efficiency of PPAC 2 was lower than that of PPAC1, which could achieve more than 64%, while the anode efficiency was more than 77%. The lower efficiency of PPAC2 resulted from the gas circuit, and gas flew from PPAC1 to PPAC2. Further, PPAC2 had a higher anode voltage threshold (254 mV) than PPAC1 (83 mV), which caused PPAC had a lower efficiency at anode. Therefore, in following experiment, we would use two separated gas circuit for different PPAC. After 34 h, we optimized the secondary beam and reduced the divergent emission. Typical two-dimensional position measured with PPACs after the optimization was shown in Fig. 6. The efficiencies had a marked rise while the effect of dispersion was minimized. The average detection efficiencies of the PPACs went down as the time increased after 40 h, because the thresholds of both PPACs' anodes were lifted up.

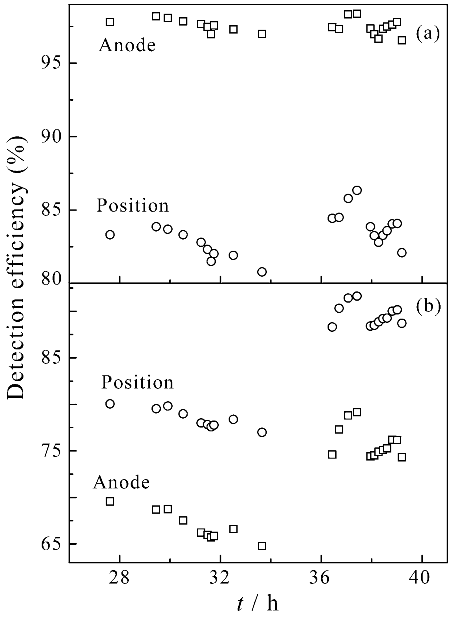

Fig. 5 (a) Detection efficiencies of PPAC1 in ^{6}He beam of 57. 6 MeV/u in the 40th hour. (b) Same of PPAC2 in the beam.

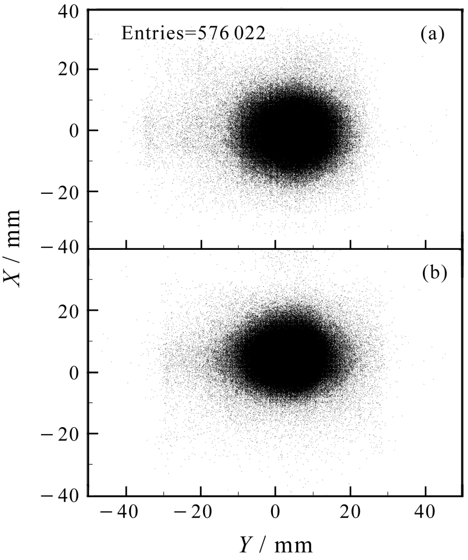

Fig. 6 Two-dimensional scatter plots of two PPACs in ^{6}He beam of 57. 6 MeV/u during the 40th hour.

4 Conclusion

We have developed the five plates delay-line PPAC that could have a high-efficiency for intermediate energy light ion. The PPAC was tested at RIBLL with ^{6}He beam of 57. 6 MeV/u and the α source. Typically, a position resolution better than 1. 8 mm (FWHM) and a timing resolution better than 2. 7 ns (FWHM) were achieved. Furthermore, we achieved more than 80% detection efficiency for 57. 6 MeV/u ^{6}He beam at the first 40 h.

However, it decreased with the increase of irradiation time. Since the efficiency of the PPAC was strongly dependent on the voltage applied and the gas pressure filled in the counter, it was necessary to evaluate the optimum conditions for operation in the in-beam experiment.

Some results show that at very low pressures, gas gain on thick wires is higher than that on thin wires at the same applied voltage[8]. To improve the efficiency of PPAC, we will do more tests with larger diameters wires (ϕ75 μm or ϕ100 μm) in anode, which could bring a higher electric field and gas gain. We also will separate gas circuit of different PPAC in later experiment.

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用于高能轻粒子探测的延迟线 PPAC*

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摘　要：气体探测器有成本低廉、制备简单、性能可靠和方便使用等特点。研制了一种5层板结构的延迟线平行板雪崩电离室(PPAC)，用于兰州放射性束流线(RIBLL)上开展的实验。在57.6 MeV/u的^{6}He束流条件下测试了这种探测器对高能轻粒子的适用性，得到了位置分辨为1.8 mm (FWHM)，时间分辨为2.6 ns，以及可靠的探测效率。

关键词：平行板雪崩电离室；中能轻粒子；探测效率；位置分辨

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