# Study of a multi-wire proportional chamber with a cathode strip and delay-line readout *

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**Abstract** The design principle for a multi-wire proportional chamber with a cathode strip and delay-line readout is described. A prototype chamber of a size of 10 cm ×10 cm was made together with the readout electronics circuit. A very clean signal with very low background noise was obtained by applying a transformer between the delay-line and the pre-amplifier in order to match the resistance. Along the anode wire direction a position resolution of less than 0.5 mm was achieved with a $^{55}$Fe-5.9 keV X ray source. The simple structure, large effective area and high position resolution allow the application of a gas chamber of this kind to many purposes.

**Key words** multi-wire proportional chamber, delay-line readout, cathode strip, position resolution

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## 1 Introduction

The multi-wire proportional chamber (MWPC) has long been known as a position sensitive gas detector combining high efficiency and good transparency for charged particles[1]. Therefore it has been widely used to record particle tracks. Recently we have built a cosmic ray test station (CORTS)[2] at Peking University. One of the new requirements is to trigger the system with a precise track definition for the incoming particle. We choose the MWPC as the first option for its large size, simple structure, precise position resolution and high efficiency, but with some new design concepts applied.

Originally the signal from the MWPC is read out from its anode wire. Later on it was found that using an induced charge on the cathode may give even better position resolution[3]. In addition the design and manipulation of the cathode is generally much easier than those of the anode wire. Thereafter the cathode readout technique developed rapidly. There are basically two methods for cathode readout: strip-by-strip readout or interpolation readout. The former allows the best position resolution to be obtained and permits a high counting rate, but requires a very large number of readout channels which greatly complicate the electronics and data acquisition system. The latter needs only two readout channels for one dimension ($x$ or $y$) by applying the so-called charge-division or delay-line time difference technique, but can only bear a moderate or low counting rate. The delay-line technique has a further advantage of no-dissipative (low noise) signal propagation. For cosmic ray detection, the counting rate is generally very low and the application of the delay-line technique is appropriate.

We have designed firstly a small prototype of an MWPC with a two-dimensional delay-line readout. The chamber was tested using a $^{55}$Fe (5.9 keV X ray) radioactive source and the results are reported in this article.

## 2 Design and production of the chamber

### 2.1 Selection of the design parameters

The energy loss of a minimum ionization particle (MIP) in standard Ar gas is 2.4 keV/cm and the primary ion-electron pairs correspond to 25/cm on

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average. For a gas thickness of 2 mm the intrinsic detection efficiency may attain 99.3%[4]. We choose the distance between the anode layer and the cathode layer as $d = 3$ mm. The anode is composed of gold-plated tungsten wires with a diameter of 20 μm.

1) The anode wire spacing

The ratio of the amount of the induced charge on the cathode plane to the amount of the avalanched charge around the anode wire is related to the ratio of the wire spacing ($s$) to the plane distance ($d$). If $s/d < 1$ the induced charge on the cathode would be greatly reduced[5]. We therefore choose $s = d = 3$ mm in order to get a reasonably large signal.

2) The cathode-strip pitch ($w$)

The distribution of the induced charge on the cathode plane is as wide as 1.58 $d$ (FWHM)[6]. The width of the readout strip must be comparable to the width of the induced charge distribution in order to avoid differential non-linearity for the position interpolation. Theoretical and experimental studies show[7] that the non-linearity is negligible when $w \approx 0.8\,d$. We choose $w = 2.5$ mm for the present prototype.

### 2.2 The prototype detector

The sensitive area of this prototype MWPC is 10 cm ×10 cm. The distance between the upper and lower cathode planes is 6 mm; in between is the anode plane. The anode plane is composed of 34 parallel wires, 30 of which are normal gold-plated tungsten wires with a diameter of $\Phi = 20$ μm whereas 2 wires at each side of the plane are protection wires, with diameters of $\Phi = 50$ μm (gold-plated tungsten wire) and $\Phi = 100$ μm (stainless wire). The protection wires are used to reduce the grads of the electronic field at the side areas and in turn to reduce the probability of a spark in the chamber. The anode wires were fixed by 65 gram tensile force onto an epoxy frame of 2 mm thickness. All anode wires are connected together to give one output channel.

The strips on the lower cathode plane, which are perpendicular to the anode wires, are etched on an epoxy circuit board. The strip width is 2 mm and the spacing between adjacent strips is 0.5 mm. Four of the same lumped constant delay-line pieces, each of which is composed of 10 taps, are connected to the strip ends. In total 40 strips and therefore 40 delay taps are used for the lower cathode plane. The specifications of some delay lines are shown in Table 1. The upper cathode plane is composed of 200 gold-plated tungsten wires, which are parallel to the anode wires, with a wire diameter of $\Phi = 50$ μm and wire spacing of 0.5 mm. Every five wires are connected together at their ends to form one strip. Again there are 40 readout strips on the upper cathode plane, similar to that of the lower plane but in a perpendicular direction.

Table 1. The type of delay line used in the prototype detector[10].

| part number | $T_D$/ ns | delay/ tap/ns | $T_R$/ ns | impedance/ Ω | $R_{DC}$/ Ω |
|---|---|---|---|---|---|
| 1507-50B | 50±2.5 | 5.0±1.5 | 9 | 100 | 2.0 |
| 1507-50C | 50±2.5 | 5.0±1.5 | 9 | 200 | 4.5 |
| 1507-50G | 50±2.5 | 5.0±1.5 | 9 | 500 | 6.0 |

## 3 Delay-line readout from the cathode plane

The movement of avalanched charge produced around an anode wire induces a negative signal at this wire and positive signals at the cathode plane and the neighboring anode wires. Due to the electronic field distribution the induced charge will be spread over several cathode strips, the average center of which is related to the position of the avalanche charge. A delay-line connected to the strips will transmit composite signals to both ends. The difference of time obtained from both ends of the delay-line is a measure of the position of the avalanche charge. Along the anode wire direction, the position of the avalanche charge is almost the same as the primary ionization position, whereas perpendicular to the anode wires the avalanche happens only at around the wire center position. Therefore position measurement along the anode wire can be continuous whereas that perpendicular to the anode wire is limited to the wire spacing[8].

The position resolution of the chamber is related not only to the structure and performance of the chamber, but also to the level of noise. Since the delay-line is, in principle, not a source of noise by itself, we need to consider only the outside noise. First of all a passive delay line must be terminated into its characteristic impedance to avoid signal reflection. Secondly the pre-amplifier attached to the delay-line should have very low noise.

Each cathode strip is directly sealed to a tap of the delay-line to reduce the distributed circuit capacity. The two ends of the delay line readout chain are terminated and matched by pulse transformers to a 50 ohm outside cable, similar to that described in Ref. [9]. Fig. 1 shows the readout circuit for the cathode strips. A consistently low noise pre-amplifier is needed to take advantage of the low noise readout circuit. We have chosen the ORTEC VT120B pre-amplifier and the timing filter main amplifier ORTEC 474. The former has an equivalent input noise of ⩽20 μV, an input resistance of 50 Ω and a rise time of ⩽1 ns.

We tested the performance of the readout circuit by applying the $^{55}$Fe-5.9 keV X ray. The delay-line type we used is 1507-50C (Table 1) which has 10 taps and a fixed delay of 5 ns per tap resulting in a total delay of 50 ns. 40 cathode strips require 4 pieces of delay-line and the total delay time is therefore 200 ns. The characteristic resistance of the delay-line is 200 Ω. The transformer* used between the delay-line and the outside cable of 50 Ω resistance is designed as primary coil $n_1 = 50$ windings (200 Ω) and secondary coil $n_2 = 25$ windings (50 Ω). The secondary coil is connected to the pre-amplifier VT120B via a 20 cm long cable of 50 Ω resistance. Signals taken from the pre-amplifier connected to the anode and the lower cathode plane are shown in Fig. 2, where $x1$ and $x2$ are the left and right ends of the delay-line readout, respectively. The timing shift between $x1$ and $x2$ exactly corresponds to the position of the incoming X ray, which is 3 cm off the center of the delay-line and close to the right side. There is no reflection signal following the primary signal, indicating very good resistance match via the transformer.

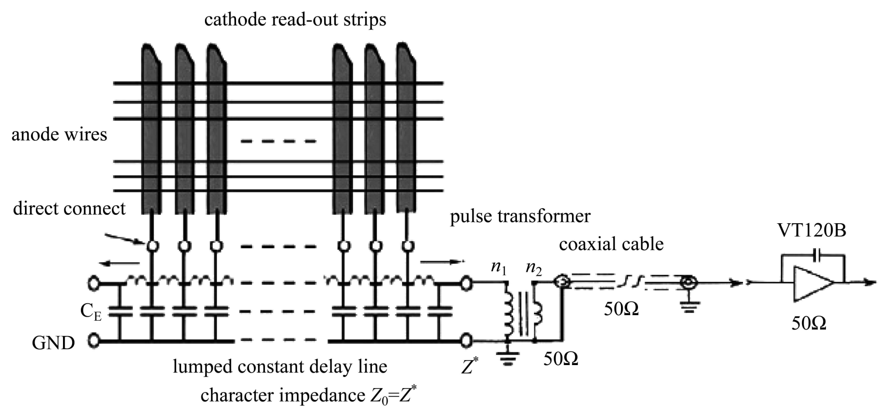


Fig. 1. The connection between the cathode strips and the pre-amplifier.

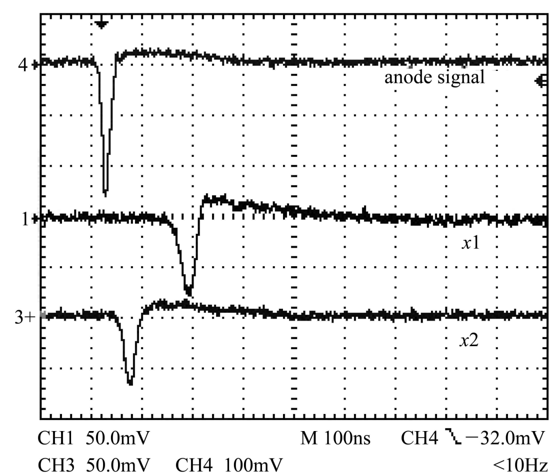


Fig. 2. Anode signal and cathode signals $x1$ and $x2$ taken from the pre-amplifier.

## 4 Measurement and results

The whole detector is placed in a gas chamber made of aluminum alloy. The gas composition is Ar(90%) + $CH_4$(10%) and the pressure is 500 Pa above atmospheric pressure. The X ray irradiation window is made of polyethylene foil 10 μm thick. A positive high voltage is applied to the anode plane and the cathode plane is linked to the ground via the delay line.

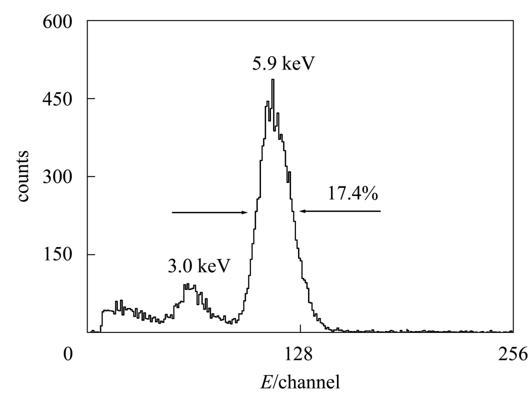


Fig. 3. Energy spectrum for the $^{55}$Fe X ray.

We have measured the counting rate plateau and the energy spectrum for the $^{55}$Fe X ray by the anode signal. The energy resolution is 17.4% (FWHM) at

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5.9 keV as shown in Fig. 3, where the full-energy peak stands clearly together with an escape peak from the Ar $K_\alpha$ - X ray.

The electronics and data acquisition system are schematically shown in Fig. 4. We denote the x-axis as the direction along the anode wires and the y-axis in a perpendicular direction. The signals from both ends of the delay-line are fed into the fast time preamplifier (FTP) via the transformer (T). The timing-filter amplifier (TFA) is used to amplify the signal and filter out the low frequency background. The signals are then discriminated and delay adjusted by the constant fraction discriminator (CFD) and the gate generator (GG), and then recorded by the time to digital converter (TDC) and a CAMAC data acquisition system.

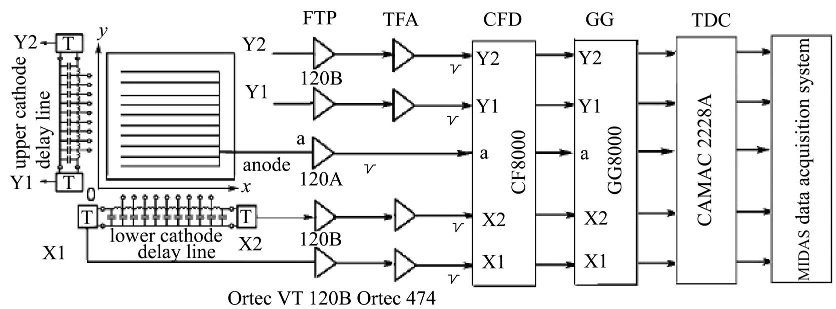


Fig. 4. The electronics and data acquisition system used in the test experiment.

We firstly position an X ray source without alignment at a distance of 30 cm above the MWPC, and give approximate uniform irradiation. A global linearity demonstration is shown in Fig. 5. A K-shaped copper foil and a wide cross window onto the MWPC are very clearly imaged. The position measurement in the $y$ direction is indeed limited to the anode wire spacing of 3 mm as described in Section 3 and shown in Fig. 6(b). The position response in the $x$ direction is continuous, which implies a high position resolution and linearity.

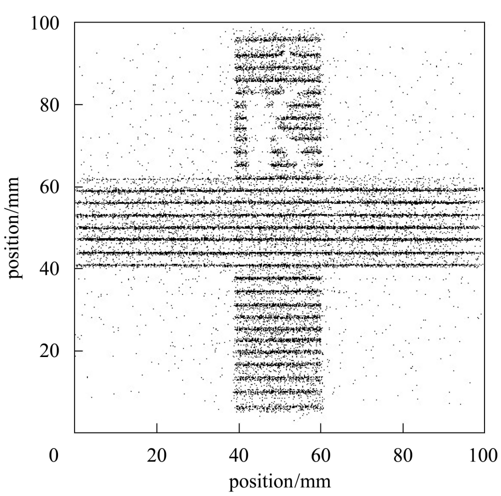


Fig. 5. The 2D position spectra for uniform irradiation.

To demonstrate the position resolution and linearity along the $x$ direction, we place a 210 μm-wide collimating slit between the $^{55}Fe$ X ray source and the MWPC, moving the slit along the $x$ axis from 41 mm to 59 mm in equal steps of 0.8 mm which is only 32% of the cathode strip pitch. The acquired position spectrum is shown in Fig. 7(a). The measured position and the position resolution (FWHM) as a function of the slit position are illustrated in Fig. 7(b). The linear coefficient is 0.99983 which shows excellent linearity, while the position resolution is only about 0.5 mm. Subtracting the 0.4 mm effective size of the X ray source, the intrinsic position resolution along the $x$ direction of the MWPC should be about 0.3 mm.

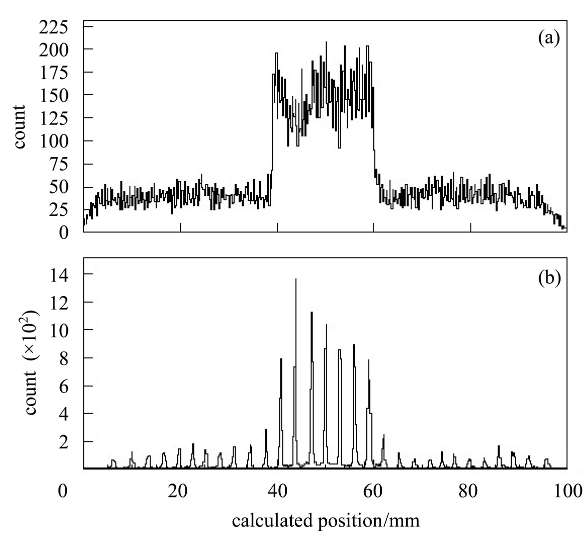


Fig. 6. Projection of the spectra in Fig. 5 to (a) $x$ direction and (b) $y$ direction.

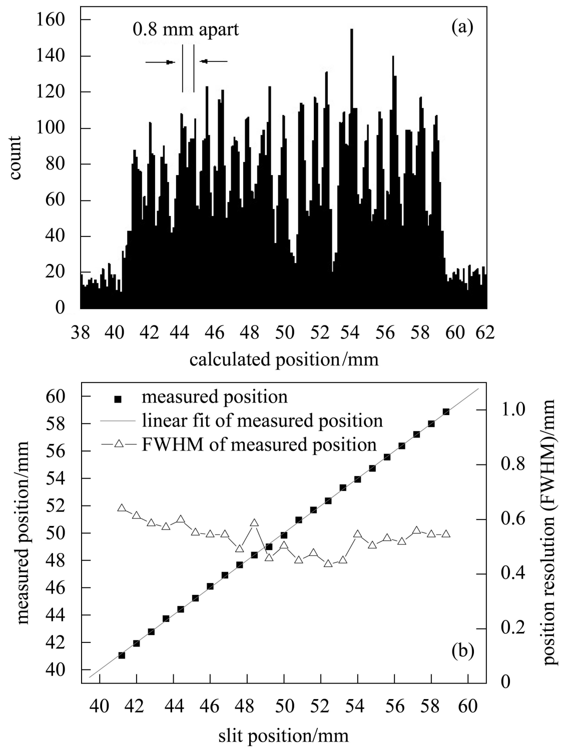


Fig. 7. (a) The 1D position spectra in the $x$-axis and (b) as a function of the slit position.

As described in Ref. [11] the position resolution is dependent on the effective noise level, the amount of charge contained in a signal, the width of signal, the characteristic resistance of the delay-line and its total delay time, etc. We have studied the influence of the delay-line property on the time resolution and found that the type 1507-50C (Table 1) is most appropriate for the current MWPC.

## 5 Conclusion

We have described the design principle for a MWPC with a cathode strip and delay-line readout. A prototype chamber of 10 cm × 10 cm was made together with the readout electronics circuit. A very clean signal with very low background noise is obtained by applying a transformer between the delay-line and the pre-amplifier to make the impedance match. A position resolution of less than 0.5 mm is achieved along the anode wire direction with the irradiation of a $^{55}$Fe 5.9 keV X ray source. The simple structure, large effective area and high position resolution allow the application of this kind of gas chamber to many purposes.

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