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A super high rate straw drift chamber

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Abstract

We have devised a technique to read out a sense wire inside a straw tube in many independent sections without bulky plates between sections, thus reducing the occupancy considerably. Based on this technique, a prototype chamber is constructed, which is suitable for extremely high rate environments. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Drift chambers based on 2 mm radius straw tubes have been popular for high rate environment applications. Two good examples are the SDC barrel tracker [1], and the ATLAS transition radiation tracker (TRT) [2]. The innermost straw tubes of the SDC cylindrical barrel tracker were at the radius of ~ 80 cm from the beam and the straw tube length was ~ 200 cm. Each straw was read out from one end and the expected rate for these tubes was about 10 MHz at the SSC design luminosity of $L = 10^{33}/(\mathrm{cm}^2\,\mathrm{s})$. The ATLAS barrel TRT constructed with 150 cm long straw tubes occupies the radius from ~ 60 to ~ 100 cm from the beam. Although each straw tube is read out from both ends using 'wire-joint' technique (see Section 3) to reduce the occupancy by half, the expected highest rate is about 17 MHz at the design luminosity of $L = 10^{34}/(\mathrm{cm}^2\,\mathrm{s})$. With proper electronics, a hit efficiency of about 65% at 10 MHz rate can be easily obtained with 160 μm resolution [3,4]. The rate can be further reduced if one constructs two 75 cm long chambers and joins them back to back while still reading out each tube from both ends. This however introduces an undesirable large gap and material in the gap due to the end plates and associated wire fixation, gas supply and electronics.

We have devised a technique to readout a sense wire inside a straw in many independent sections without introducing bulky plates, thus reducing the rate considerably. The technique relies on a sense wire with several wire-joints, and wire supports made of conductive material.

Fig. 1 illustrates the concept. Fig. 1a shows a straw tube with a sense wire with one wire-joint (two wire sections) and Fig. 1b shows the same with two wire-joints (three wire sections). The wire-joint described in detail in the next section is made by cutting a sense wire and joining the ends with an insulating material (typically glass or plastic), thus creating two electrically independent sections. If there is only one joint (Fig. 1a), then the whole tube is sensitive by reading out from both ends of the

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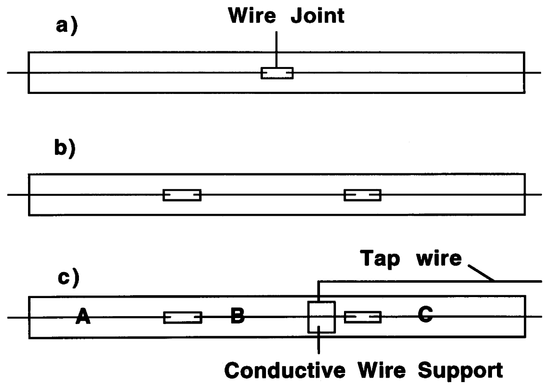

Fig. 1. (a) A straw tube with one wire-joint. The left and right sides of the wire-joint are independently read out. (b) A straw tube with two wire-joints. The two end sections can be read out, but the middle section is not sensitive. (c) A schematic of the technique of reading out the middle section. The signal on the middle sense wire is transferred out through a conductive wire support and the tap wire.

wire. If there is more than one joint, the sections other than the ends are dead regions. Our technique however allows readout of the dead regions without hampering wire tension, gas flow and wire replacement.

The technique to readout the middle section using a conductive wire support is shown schematically in Fig. 1c. The signal on the sense wire in the middle section is transferred to a conductive wire support which is in contact with the sense wire. (A description of the wire support is given in Section 3.) A wire connected to the wire support (hereafter called the tap wire) passes through the tube wall to bring the signal out. This wire runs along the outside of the tube and is fixed at an end plate for connection to the electronics.

Using this technique, a 80 cm long prototype chamber with 16 straw tubes has been constructed. There are two wire-joints per sense wire. The middle sections of the sense wires are brought out to one end of the chamber, resulting in 32 electronic channels at one end and 16 electronic channels at the other end. In the following sections, detailed descriptions of the technique, wire-joints, prototype construction and its performance are presented.

2. Wire-joint

The wire-joint has been developed to read out the sense wire in a straw tube from both ends without bulky plates in the middle and is an integral part of the ATLAS barrel TRT. The wire-joint is made by cutting a sense wire and joining the two using an insulator which is typically a plastic or glass tube. The length of the tube should be as short as possible to reduce the dead region and the diameter should be small enough to go through the wire fixation holes and wire supports. The joint should also be as strong as the sense wire itself and radiation hard. It is also important to minimize the mass of the joint to reduce any wire sagging. For our application, we have chosen a glass tube with 7.0 mm length, 0.127 mm inner diameter and 0.254 mm outer diameter [5]. The mass of the glass tube is 0.0006 g. Compared to the 0.00013 g/cm of our sense wire (30 μm diameter gold plated tungsten wire), the contribution of the wire-joint to the wire sagging is negligible.

The joining of the wire to the tube can be accomplished either by glue or by melting the glass. We have tried both techniques and we have chosen the melting method because the glue injection into the glass tube is complicated by the small glass tube size and uncertainty of radiation hardness and strength of the glue joint. Unlike gluing, melting is actually wetting of the glass to the sense wire which results in bonding stronger than the sense wire itself when the melting is done properly.

There are two difficulties in making the joints. One is threading 30 μm diameter sense wire into a glass tube with 127 μm inner diameter and the other is the proper melting of the glass. The first difficulty is overcome by making a wire threading jig on x–y–z stages under a microscope (Fig. 2). The wire threading jig is made of a stainless block with a V grove to guide a wire to the glass. The end of the V grove is aligned with the glass tube using the x–y–z stage. The second difficulty is solved by using a micro-torch mounted on a stepping motor. The torch consists of two flames separated by 3 mm to melt left and right glass sections independently. The flame size and the speed of the torch passing under the glass tube are carefully calibrated in order to achieve the best melting conditions. The flame is

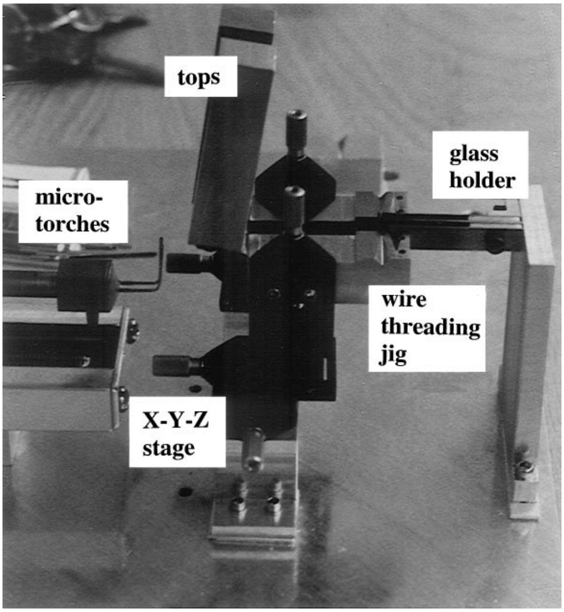

Fig. 2. The wire-joint production fixture. Shown here are wire threading jig, glass holding fixture and micro torches. There are two wire threading jigs located at the left and right side of the glass holder. Each is mounted on a x–y–z stage to align it with the glass tube. The V shape groves guide the wire and the tops are closed for threading operation. The wire-joint production operation is done under a microscope (not shown in the picture).

a mixture of methane and oxygen and passes the glass twice laterally. The mixture is controlled by two flow meters.

We have made several dozen joints with different melted length and found that the melted length has to be longer than 0.5 mm for the joint to be stronger than the wire itself, as measured by a tension test. As a quality control, we reject joints with melted length less than ~ 0.7 mm long. The tensile strength of 30 μm tungsten wire is about 2 N.

The middle of each glass tube is melted before usage for two reasons. One is to prevent the two sense wires from touching each other during the melting process and the other is to prevent arcing between the sense wires should a potential difference develop between wire segments.

The initial length of the glass tube is 7.0 mm, and the length of the final joint is about 5–6 mm after the melting. Although the glass tubes are not perfectly straight after melting, the sense wire from one end to the other end is straight under tension. With the help of the jigs, we were able to produce ~ 60 joints per 8 h shift with about 10% rejection. We have made about 1000 joints for various prototype chambers. It is important that the length of the final glass joint be less than $\sim 75\%$ of the length of the wire support in order for the joint to pass through the wire supports without breaking the glass.

One of the drawbacks of the joints is the dead region around the joints. Our measurement shows that the dead region extends less than 2 mm from the ends of the glass tube. The measurement was done using a collimated ^{55}Fe source. The charge amplified signal is put into a multi channel analyzer and counting rate and charge distribution are obtained. The width of the collimator slit is 0.5 mm and the source is 2 mm above the straw tube. The source is moved in 1 mm steps near the joint and 5 mm steps away from the joint. In Fig. 3, the charge distribution is plotted for several distances from the joints. In Fig. 4, the counting rate (above the pedestal) as a function of the distance from the joint is plotted from the left and right side of a joint. From the figures, it is estimated that the dead region extends less than 2 mm from the wire-joint. We note that all the measurements in this paper were performed with a 35:65 mixture of argon and ethane and the high voltage (HV) was set at 1650 V.

Although the wire-joint technique was developed for the straw tube based detectors, it can be applied to other typical drift chambers to reduce the occupancy by a factor of two. There should not be any complication since only sense wires are replaced and the mass of a glass joint is negligibly small.

3. Middle section readout

When there is more than one joint in a tube and the sense wire is read out from both ends, the middle segment is a dead region. In this section, a technique to read out this region is described. We have used two wire-joints (three wire sections) to demonstrate the technique and this technique can be expanded such that a sense wire can be divided into more than three sections and each section can be read out independently.

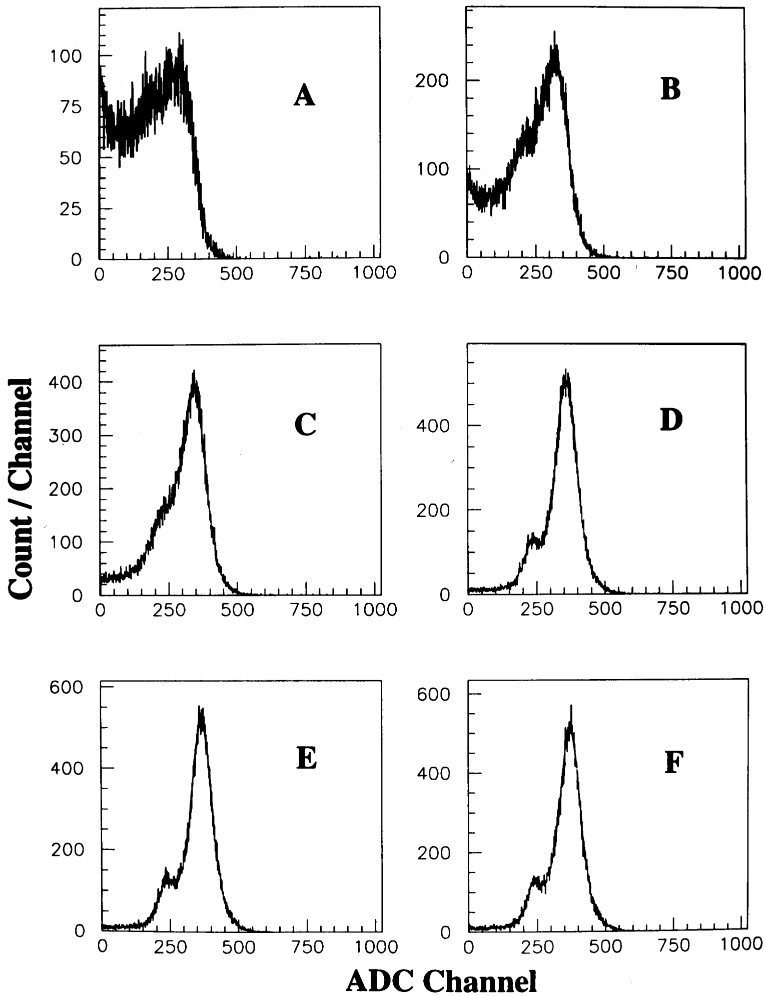

Fig. 3. ^{55}Fe spectrum measured using a multichannel analyzer for six different distances ((A)–(F): see Fig. 4 for the locations) from a joint. The signal from the chamber is amplified using a fast charge-sensitive amplifier (amplification of 100 and 1 GHz bandwidth). The 100 ns gate width is used for the multichannel analyzer.

Electrical connection of the middle section is achieved by a wire support made of conductive material. The helical wire support was originally developed to support sense wires inside straw tubes for electrostatic stability. Studies showed that a wire support is necessary if the sense wire span is longer than $\sim$ 100 cm for 2 mm radius straw tubes [6]. Normally the wire support is made of plastic material (typically $\sim$ 8 mm long) and the depth of the helical groove is the sum of the wire support radius and the sense wire radius as shown in Fig. 5. In the new application, the wire support is made of aluminum and the depth of the groove is only the radius of the wire support to insure a good contact between the wire support and the sense wire under tension.

The first step to readout the middle section is to cut out a rectangular slot (3 mm long along the tube $\times$ 2 mm wide) on the tube at the position where the wire support will be located. The slot should be large enough to prevent arcing between the tap wire and straw tube. The next step is to prepare the

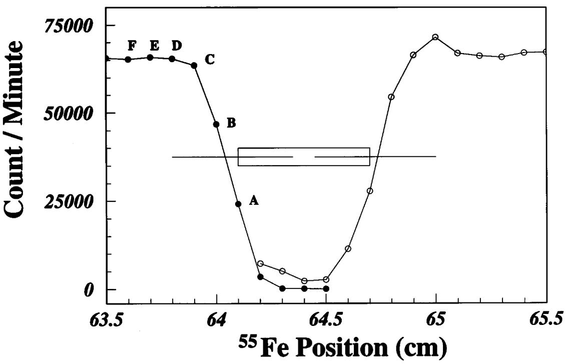

Fig. 4. Counting rate along the wire length as a function of distance from the joint. The plot with closed (open) circle is readout from the left (right) side of the joint. For a reference, the wire-joint is drawn in the figure, which is 6 mm long.

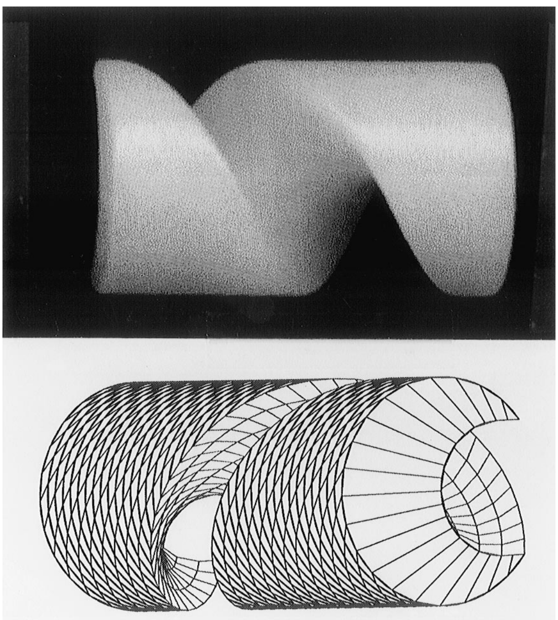

Fig. 5. Helical wire support. The top is a picture and the bottom is an autocad drawing.

wire support. Since the wire support is conductive, first it is inserted into a plastic sleeve. With the wire support inside the plastic sleeve, a hole with diameter 0.3 mm and depth of 1 mm is drilled from outside the sleeve to the wire support. This hole is to insert a tap wire to make a connection with the

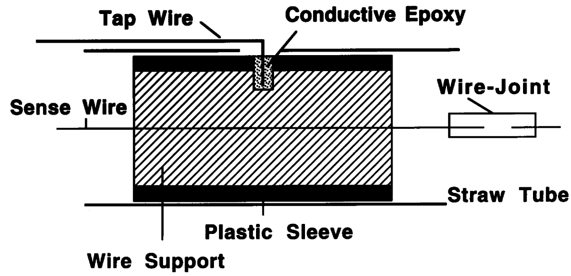

Fig. 6. A detailed drawing of the middle section readout scheme. The signal is transferred to the conductive wire support which is in contact with the tap wire. The tap wire brings the signal out from the tube to an end plate where electronics are connected. The tap wire runs along the outside tube surface.

conductive wire support. After a wire support is inserted into the position inside a straw tube, the tap wire is inserted into the drilled hole and conductive epoxy is injected into the hole for the electrical and mechanical connection. After the epoxy is cured, a thin layer of RTV is applied for a gas seal and to prevent arcing. The tap wire is 100 μm kapton coated copper wire, and is rated for 2000 V [7]. Fig. 6 shows a detailed drawing of the finished product. Before a finished straw is used, it is tested for conduction (from tap wire to the wire support), HV breakdown and gas leak.

4. Prototype chamber

In order to demonstrate the feasibility of using this technique, an 80 cm long prototype with 16 straws has been constructed. Each sense wire has two joints. The length of the three sections (called A, B and C in Fig. 1c) are 35, 15 and 30 cm, respectively. Since the basic design and components used in the prototype are similar to the ATLAS barrel TRT [2], a short description is given here.

The prototype was constructed using a carbon fiber shell for structural support and straw alignment as shown in Fig. 7. The carbon fiber shell is the same one used in the SDC barrel straw tracker [1]. Although each straw is reinforced using four carbon fiber strips along its length [2], it has to be supported every ~ 25 cm to reduce sagging. The support is provided by two partitions, also shown

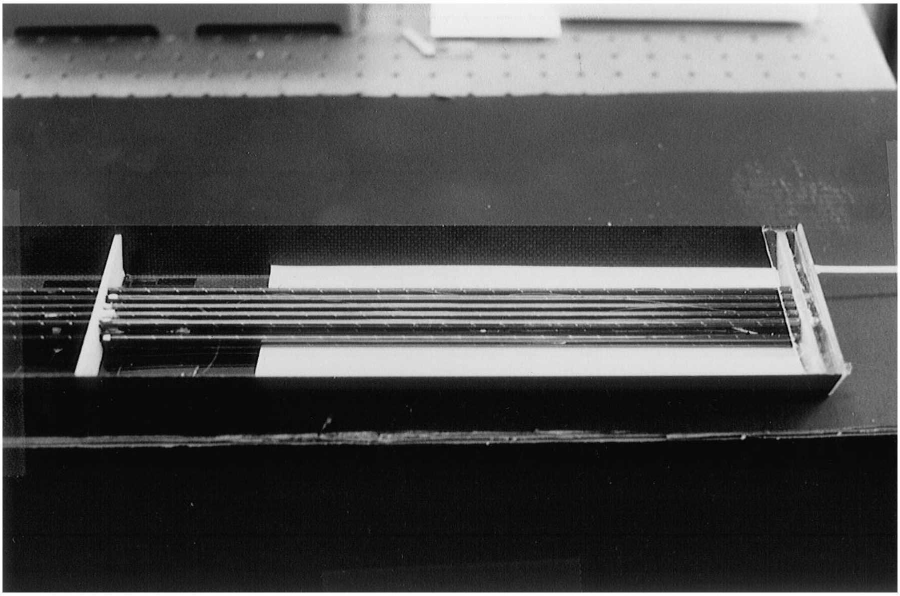

Fig. 7. A picture of the prototype chamber constructed with straws using the middle section readout scheme. The cover is opened. A part of the shell bottom is covered with a piece of paper for contrast. In the picture, a partition is seen at the left side of the picture and end plate (HV plate and tension plate) is seen at the right side of the picture.

in Fig. 7. The partitions made of G10 have holes such that straws are passed through and supported. These partitions are glued to the shell. In addition to the two partitions, there are end plates also made of G10 at each end of the shell as shown in Figs. 7 and 8. Each end plate consists of two plates. The inner plate is called the HV plate and the outer plate is called the tension plate.

A group of eight straw tubes is electrically connected to a copper pad on the top of the HV plate using end plugs. For the connection, a small amount of conductive epoxy is applied outside each end plug before being inserted into a straw tube. Additional conductive epoxy is applied to complete the connection to a pad. After the epoxy is cured, a generous amount of non conducting epoxy is applied for the gas seal. HV is supplied to the pads through 100 kΩ resistors in series using the copper traces on the bottom of the HV plate. A filter capacitor (1000 pF) is connected between each group of eight straws and ground to reduce ringing and cross talk.

The tension plate is where the sense wires and tap wires are fixed. The sense wires are tensioned with 60 g of weight and the tap wires are pulled slightly before fixation. A simple modification of doubling the wire fixation holes on the tension plate is made in order to accomodate the tap wires.

The tap wires from the middle section run along the outer surface of the straw tubes. They pass through the HV plate and are fixed at the tension plate. Although the tap wire is coated with 50 μm Kapton, and is rated for 2000 V, handling causes micro cracks in the Kapton and results in occasional arcing between the tap wire and the straws. (High voltage is applied to both the inner and outer surfaces of straws.) In order to prevent arcing, 1 mm wide 50 μm thick Kapton tape is laid on the straw tube below the tap wire. Even though the wire density is doubled compared to the ATLAS barrel TRT at one end plate, no high voltage breakdowns were observed.

5. Performance

The performance of chambers based on 2 mm radius straw tubes has been extensively studied,

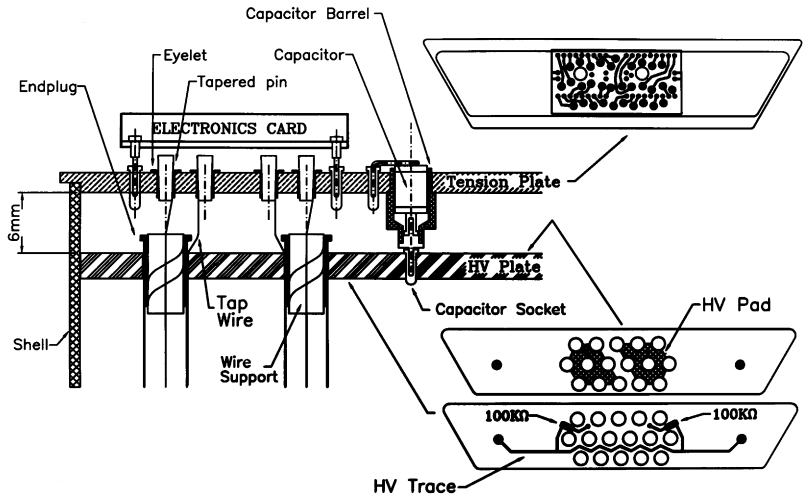

Fig. 8. A detailed end plate drawing. An end plate consists of two plates, inner (or HV plate) and outer (or tension) plate. HV to straws is provided through the pads and traces on the HV plate. The traces on tension plate are to route signals from sense wires and tap wires to electronics.

including high rate performance [3,4]. In this paper, we report on the performance of the middle section with regard to pulse shape and cross talk.

Unlike the end sections, the signal from the middle section goes through two interfaces before it reaches the read out electronics. The first is the connection between the sense wire and the wire support. The second interface is the connection between the wire support and the tap wire. Each section has a different impedance. The impedance of the straw tube with a sense wire at the center is about 300 Ω, the impedance of the section where the conductive wire support is located is 15 Ω, and the impedance of the tap wire running on the tube surface is about 10–100 Ω depending on the distance between the wire and straw tube.

Fig. 9 shows the signals from ^{55}Fe and ^{90}Sr sources measured with a digital scope from an end section and the middle section. One thousand signals were averaged. In order to match the typical electronic input impedance of 300 Ω (corresponds to the impedance of a straw tube with a wire at the center), a 50 Ω input impedance pre-amplifier (amplification of 100 and 1 GHz bandwidth) was connected to the sense wire through a 250 Ω resistor.

There are some differences between the signals from an end and from the middle. The signal from the middle section is smaller in amplitude and wider in width (FWHM). The difference of the amplitude is due to the interfaces. For the end sections, the signal reflected from the wire joint is the same polarity (negative going) as the original signal. Thus the amplitudes add together (note that the maximum propagation time is about 2 ns, and it can be ignored). Although the same is true for the signal in the middle section reflected from the wire-joint, there is another reflection at the conductive wire support due to the impedance mismatch. However this reflected signal is the opposite polarity (because the signal travels from high impedance to low impedance region), which reduces the overall amplitude. The difference in width can be explained in a similar manner.

Since the shape of the signal is basically the sum of the original and the reflected signals and the difference in the propagation time between the two is negligibly small, there is little change in the signal shape as a source moves along the length of the middle section. However, very near the conductive wire support (<2 mm), the signal shape is distorted and the efficiency drops because of the non uniform electric field. This effect disappears ~ 3–4 mm away from the wire support. We also note that the background noise from the middle section is not any different from the end sections.

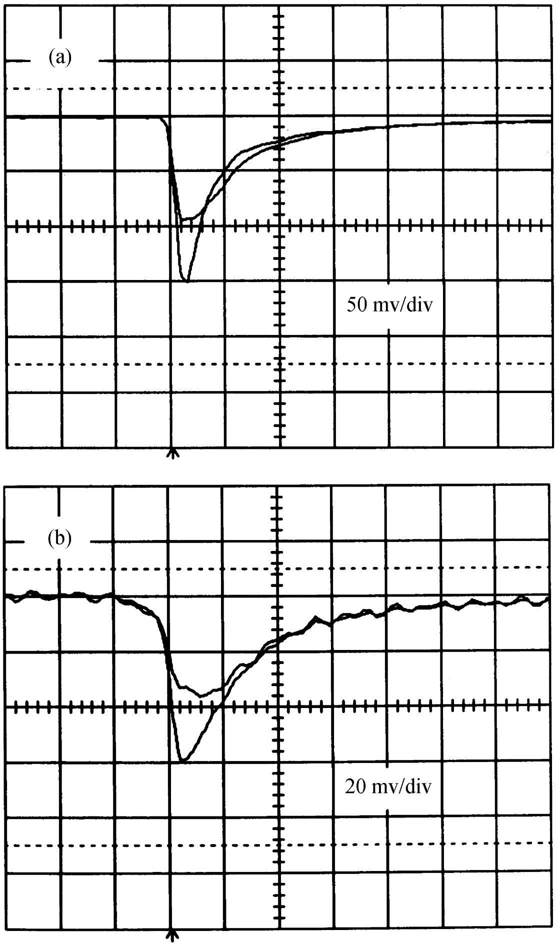

Fig. 9. (a) Averaged ^{55}Fe signal from the end section of a wire (higher amplitude) and from the middle section of a wire. The vertical axis is 50 mv/division and the horizontal axis is 20 ns/division. (b) Same as (a) except the source is ^{90}Sr and the vertical axis is 20 mv/division.

The main concern in using this technique is the cross talk because the tap wire runs on the outside of the straw, traversing other sections of the sense wire. Fig. 10 shows the cross talk between different wire sections. There are 6 possible combinations from the three wire sections (A, B, and C sections, see Fig. 1c). The largest cross talk shown in Fig. 10a is observed from section C to B, i.e, when a ^{55}Fe source is positioned on section C (trigger signal) and the cross talk is observed in section B. In Fig. 10, signals from 1000 triggers are averaged. The polarity of the cross talk is opposite to the signal and its amplitude is about 5% of the trigger signal. About 50% of the cross talk is due to the tap wire (from the measurement made with short tap wire) and the rest is due to the conductive wire support and end plates (from the measurement made with a straw tube without the conductive wire support). Although the opposite sign of the cross talk is tolerable since discriminators can be designed to ignore positive pulses, too large cross talk could distort the signal in other sections and result in decreased resolution and efficiency.

The next largest cross talk is observed from B to C, and the averaged cross talk signal is shown in Fig. 10b. Like the cross talk from C to B, the polarity is opposite and the amplitude is about 2% of the triggered signal. In general, the characteristics of the cross talk are (1, 2, and 3 below are within the same straw tube and 4 and 5 are between different straw tubes)

1. Most of the cross talk shows up with opposite polarity to the trigger signal.
2. The maximum cross talk with opposite polarity observed is about 5% for the worst case and $\sim$ 1–2% for other combinations.
3. The maximum cross talk with the same polarity is less than 1%.
4. The cross talk between the straw tubes within the group of eight (sharing the same HV and filter capacitor) is $\sim$ 1%.
5. The cross talk between different groups of eight straws is less than 1%.

6. Conclusions

In this paper, a technique to read out a sense wire inside a straw tube in several independent sections without additional bulky plates is presented. Using this technique, we have constructed a prototype chamber for a feasibility study. The chamber did not exhibit any special problems of noise, gas leaks or HV instability. With the prototype, we have shown that the signal from the middle section is easily transferred out and is not very different compared to the ones from the end sections. We have also measured the cross talk between different

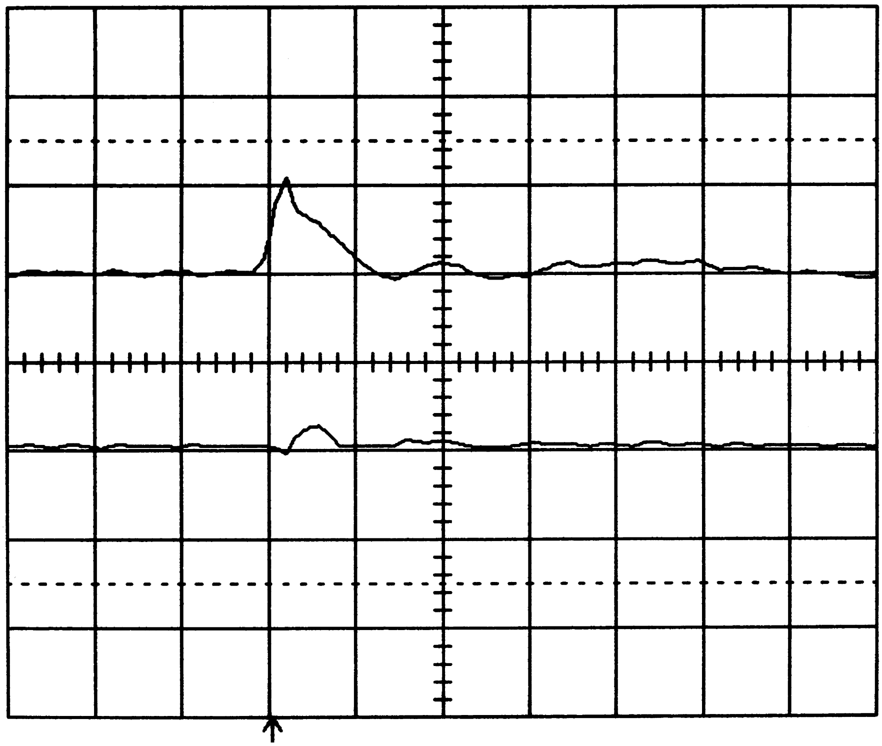

Fig. 10. The averaged cross talk signal from C to B (top trace) and the cross talk from B to C (bottom trace). Please see Fig. 1c for the location of the section A, B and C. ^{55}Fe source is used for the study. The vertical axis is 5 mv/division and the horizontal axis is 20 ns/division.

wire sections. The polarity of the main cross talk is the opposite (i.e., positive) to the signal and the magnitude is small enough not to raise concerns.

Although there should be more R& D for a large scale application of this technique in the areas of manufacturing, we do not believe that there are any fundamental problems. This technique could be suited for the next generation collider detectors.

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