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THE GASEOUS PIXEL DEVICE

Proposal

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ABSTRACT

The Gaseous Pixel Chamber is a new device developed during the last year within the LAA project at CERN. Basically we print electrodes onto a flexible Kapton foil with standard printed circuit technology used in the CERN workshop. We have found a design which allows us to operate the foil as a particle detector operating in the gaseous limited streamer mode. This work has been previously reported [1,2,3]. We are well satisfied with the operational characteristics that this device has reached so far (efficiency, easy to build and operate). However, the demands imposed on any detector device at future hadron colliders are very stringent. There are still many possible improvements needed to meet the technical challenge for a device to work at the LHC, SSC or Eloisatron hadron collider (such as time response, space resolution, energy proportionality). Therefore we propose an R&D programme for studying the aspects that are relevant for application of this kind of detector within a hadron collider environment.

This device has been developed within the LAA Project, CERN

1. INTRODUCTION

It is well known that the proposed new multi-TeV high-luminosity *pp* colliders will require a large improvement of detectors currently in use in particle physics. The high radiation level, the high particle flux and the very short time interval between bunch crossings impose stringent requirements. Wire chambers that use gas amplification have been in use for the last 25 years or so. This amplification process is basically a high gain, low noise process, and devices which are somewhat radiation hard can be constructed. However, wire chambers need straight wires and these wires have to be held under mechanical tension. The finite length of the wire imposes a constraint to particle flux. If the 'occupancy' of an detector element is too high, a wire or something similar is no longer useful. To keep the wires tensioned requires a support structure. Straight wires impose a constraint on the geometry of the detector. What we need is a device that keeps the good properties of gas amplification (high gain, low noise and radiation hard) without having the constraint of straight stretched wires.

The Gaseous Pixel Chamber is a new device developed within the LAA project at CERN. Basically we print electrodes onto a flexible Kapton foil with standard printed circuit technology used in the CERN workshop. We have found a design which allows us to operate the foil as a particle detector operating in the gaseous limited streamer mode. With this device we can measure minimum ionizing particles. During our last beam test we reached an efficiency of 100 %.

2. EXPERIMENTAL RESULTS FROM THE GASEOUS PIXEL CHAMBER

This device is still being actively developed. We will only present some of the results here and concentrate on the results obtained with the device in a test beam. After studying the results presented here, it will be clear that we are working with a very promising new detector that can be adapted to fit various geometries and that is pixel in nature. In Section 3 we will consider where this type of detector could be used in a general type of experiment at a hadron collider.

2.1 The 'Standard' Gaseous Pixel Chamber

2.1.1 Description of Foil

Figure 1 shows the cross section of our 'standard' foil. Essentially it is a sheet of Kapton with various copper electrodes. These electrodes are a small anode spot (500 μm diameter) surrounded at some distance by a cathode plane. The voltage is applied to the anode spot by means of a small (200 μm diameter) plated through hole. We mount this foil in a gas tight box, through which we flow pure isobutane (recently we have performed some tests with additions of CF_4 and Ar). Electrons are liberated by a charged particle passing through the gas volume above the foil. These electrons undergo gas amplification as they approach the anode. Finally limited streamers are formed and therefore large signals appear on various electrodes. We show a picture of 3 successive pulses as measured on a digital oscilloscope in figure 2. We provide some field shaping with a 'roof' foil. The pattern of a roof foil and the cross section of a 'chamber' is shown in figure 3. The central spot of the roof foil is to provide field shaping but can also be 'read out' giving additional information as to which pixel fired.

We have various variations of this basic design. Recently we have had a substrate made from a double layer of Kapton i.e. a dielectric of 325 μm thickness compared to the standard 175 μm thickness. Results from this foil will be reported below. We have also constructed a chamber with two foils facing one another, but staggered. We call this the 'offset pixel chamber'. This will be elaborated upon below. One of the parameters that we want to reduce is the diameter of the through plated hole connecting the anode spot to the bus line below. This can be done by creating the holes with a laser. We should soon get an operational foil with laser ablated holes, but as a test we have tried simulating this small structure with a 50 μm diameter wire sticking up through a 200 μm unplated hole. These test results will be shown. We have also built a similar structure on a ceramic substrate which works, but not as well as the Kapton substrate. This will be discussed more fully later.

2.1.2 Efficiency and Rate Effects (Standard Pixel)

The first results from the 'basic foil' have been more extensively discussed in a previous publication [1]. We will present here the results from testing this chamber in a 6 GeV/c pion beam. The chamber consisted of the standard foil and roof as described in the previous section. The spacing between the foil and the roof was 8 mm. We mounted this chamber in a test beam in the East Hall at CERN. We could vary the intensity of the core of the beam spot from 5,000 particles/cm^2/sec to 100,000 particles/cm^2/sec. The efficiency versus the voltage for various fluxes is shown in figure 4. It is clear that at the highest flux we are becoming dominated by space charge effects. Also at this high flux we have rate induced sparking above 6.4 kV. However at 50,000 particles/cm^2/sec the onset of rate induced sparking is 6.8 kV although we are seeing a drop in efficiency due to space charge effects. However it should be noted that this chamber already is operating at a relatively high rate in a very stable manner. We have been working in a pulsed environment (one 0.4 sec spill every 30 seconds) so it appears that worries regarding the stability of having an insulator close to the anode are unfounded. The pixel size in this case is 1 cm^2 so the rate effects will be less if we can reduce the pixel size. We are also operating at very high gain in limited streamer mode, again the rate effects will be reduced if we find a way of working at lower gain. We will show later that a chamber built with a thick Kapton substrate has an extended plateau.

2.1.3 Position Resolution

We have taken some data with the standard pixel chamber to determine the position resolution. The chamber was mounted in a test beam in the CERN East hall. The position of the incoming particle was measured with 2 sets of drift chambers. In figure 5 we show a scatter plot for radial distance of the particle from the anode versus the drift time recorded from the pixel chamber. A clear band is seen. We fitted a curve to this band and used this to calculate a radial distance from the drift time measurement. A histogram of the residuals is shown in figure 6. The FWHM is 760 μm, this corresponds to a sigma of 320 μm. We think the contribution to this width from the measurement error made by the external drift chambers to be small. We hope to improve this result when we start working with smaller hole, smaller anode chambers.

2.2 Thick Substrate Foil

2.2.1 Description of Substrate

We have two types of foil which have thicker substrates. The first is one which has a layer of extra dielectric 'printed' onto the surface (mask chamber). This is actually solder mask material used in printed circuit board manufacturing. It is 75 µm thick. The pattern printed is shown in figure 7. Another foil had a substrate of two layers of Kapton, which had been glued together by the manufacturer of the copper clad Kapton material (thick Kapton chamber). Both foils have been tested in the beam, but during the thick Kapton chamber test we were parasitic users of the test beam, thus the foil was only tested at high rates.

2.2.2 Efficiency (Thick Kapton)

Figure 8 shows the plateau curve for the standard chamber and the mask chamber at a low beam flux (1 kHz/cm^2). We find the detection efficiency for the mask pixel chamber to be higher than the standard pixel (100% versus 98%). We think that this is due to having the dielectric thicker above the high voltage bus line, thus fewer electrons are needed to charge the surface (and also fewer needed to keep the surface charged). We show the plateau curve for the thick Kapton chamber for various mixtures of Argon and isobutane in figure 9 and for mixtures of CF_4 and isobutane in figure 10. The beam was at a higher intensity (20 kHz/cm^2). The efficiency was measured using the first 1000 particles of each spill. If we integrated over three spills the measured efficiency was lower (90% compared to 96%). We are not sure if this is due to a space charge effect or simply the lowering of the anode voltage when current is drawn through the 10 MΩ limiting resistor. This will be investigated further. The point to note is the excellent behaviour of the chamber at these high rates.

2.3 Small Anode Chamber

2.3.1 Need for New Technologies

As previously mentioned we want to test the effect of reducing the diameter of the plated through hole. At present the hole is mechanically drilled. 200 µm is the smallest hole that the CERN workshop can drill (we are about to try with 150 µm). There are techniques to produce holes in Kapton with lasers. Holes can be 'burned' through the Kapton foil with a single laser pulse, with the laser being pulsed at 50 Hz. Diameters of 75 µm can be produced through 300 µm glass epoxy, one expects this technique to be easier with Kapton. We have been investigating another technique known as laser ablation. UV-light from an excimer laser of 193 nm wavelength is used to illuminate a mask which defines the structure to be ablated. This mask pattern is optically projected onto the surface. The high energy photons (6.4 eV) of these lasers break up the chemical bonds rather than evaporate the material by heating. By exciting the electronic states of the molecule the atoms no longer feel attracted to each other but feel a repulsive force. The physics of this process is still under investigation by the experts. However, this technique is already in use for large scale fabrication of high density multilayer computer boards, so we are quite convinced that this technique could also be used for a possible large scale fabrication of our detector, once the R&D phase is over. We have had some foils with laser ablated holes prepared by Siemens. These foils are now in the final stage of preparation in the CERN workshop. We have been contacted by various people from the

Rutherford Appleton Laboratory (R.A.L.) because they have been excited about our Gaseous Pixel Chamber. They have a lot of these up-to-date technologies, such as laser ablation, in-house. We are trying to form some kind of collaboration to give us access to their facilities.

2.3.2 Preliminary Results from Small Anode Chamber

As a test of the possible effect of having a small anode, we have fabricated a foil where a small diameter wire (50 μm) is used instead of a through plated hole. The hole in the Kapton foil is 200 μm, the wire sticks up above the surface by 300 μm (the chamber operated in a similar way when we cut the wires level to the surface). In figure 11 we show the efficiency for detecting 6 GeV/c pions for a variety of Argon and isobutane mixtures. For pure isobutane the knee of the plateau is at 4 kV. This should be compared with 6 kV for a standard pixel chamber. The voltage where sparking occurs (~7 kV) should be the same (we did observe a spark at 6 kV with the small anode chamber but think that this may be due to the 'home-made' nature of the device). The remarkable thing we found was that it worked with very little quensher in the gas mixture. With the standard pixel chamber we found that with more than 20% Argon added to isobutane, the chamber had voltage breakdown before it reached full efficiency for minimum ionising particles.

In figure 12 we show the charge spectrum for the chamber with 96% Ar 4% isobutane at its operational voltage of 1000 volts. There is a very clean peak separated from the pedestal. There are also peaks at twice, x3, x4 and x5 the charge of the first primary peak. After some investigation we conclude that these are due to more than one pixel firing when more than one particle traverses the chamber.

2.4 The Offset Pixel Chamber

2.4.1 Construction of Offset Pixel Chamber

There are many advantages in having a highest possible pixel density, for example faster time response for through going particles and better position resolution. However, depending on the manufacturing techniques, there will be a lower limit of pixel size due to the finite size of the anode. We have investigated the possibility of increasing this density by a factor two by having two foils facing one another (sharing the same gas volume) but staggered by half a cell width in the x and y direction. Thus the anode of one foil faces the cathode plane of the other. We constructed a chamber to test this possibility. The gap between the foils was 8 mm.

2.4.2 Test Beam Results from Offset Pixel Chamber

In the test beam we derived a signal from the logical 'OR' of the two foils. The efficiency for detecting 6 GeV/c pions is shown in figure 13. In figure 14 we show the drift time spectrum of a single foil of this chamber, for comparison we show the drift time spectrum of the standard pixel chamber. A scatter plot of the position of the particles that do not fire either foil is shown in figure 15. It is easy to see the structure of inefficient hits follows the boundaries between the pixel cells. We expect that we can reduce this inefficiency by changing the gap between the foils. We are also investigating whether the shape of the cathode plane plays a role. Further work is in progress.

2.5 The Ceramic Chamber

2.5.1 Construction of the Ceramic Plate

We have built a pixel device using a ceramic substrate[3]. Ceramic circuits are made by 'printing' layers of conducting or insulating paste onto a ceramic plate. The plate is then 'fired' at about 900°C. Initially the layer of paste is 40 µm thick, this reduces to 12 µm during the firing. Then another layer of paste can be printed which can be subsequentially fired. With this technique one can fabricate a multilayer circuit board without the necessity of drilling holes. The printing is by serigraphic techniques using stainless steel meshes. The ceramic plate has to be flat, otherwise the screen has to stretch to accommodate the different levels, and this introduces distortions. Lines of 100 µm width can be successfully printed. To generate an anode spot we first print a narrow ridge of dielectric material and then print a 100 µm conductive line at right angles to this ridge. Thus the conductive line goes up one side of the ridge and down the other. We then fill each side of this ridge with dielectric material. This results in having a thin anode line buried under dielectric material except at certain spots where it comes to the surface. The size of the exposed anode spot is defined by the width of the conductive line and by the width of the top of the ridge. In our case the anode is a square spot of 100 by 100 µm. We need to have the layer of dielectric covering the anode bus line as thick as possible. We thus make the dielectric ridge by printing three layers of widths 350, 275 and 100 µm successively. The anode lines can be successfully printed over this ridge. At some distance we need the cathode plane. Since the anode bus line has to run beneath it we need a certain thickness of dielectric to hold off the applied high voltage. The figure supplied by the manufacturer is > 28 volts/µm. Thus 15 layers of dielectric should hold off more than 5460 volts. At a radius of 2 mm from the anode spot we start building these layers of dielectric. The cross section of a pixel is shown in fig. 16.

2.5.2 The Ceramic Chamber in a Test Beam

We constructed a chamber using a 'roof' board of similar design to that used for the standard pixel chamber. We installed this chamber in a 6 GeV/c pion beam in the CERN East hall. We flowed pure isobutane through the chamber (some argon was added to the mixture later). We applied 500 volts to the central roof spot. Figure 17 shows the increase of efficiency for detecting through going particles as a function of the voltage across the pixel. Unfortunately we had some voltage breakdowns for voltages above 6.2 kV so that we could not reach full efficiency. Figure 18 shows the charge distribution of the cathode pulse for 3 different gas mixtures but with the same applied high voltage. It is interesting to note that there is a slow increase in pulse height for increasing argon concentration, but a much more dramatic change in the shape of the charge distribution. The distribution of large pulses on the right of the peak is due to two (or more) pixels firing when more than one particle traverses the chamber. The efficiency for detecting particles also increases slightly with increasing argon concentration.

We believe that the inefficiency for detecting minimum ionising particles is caused by having the anode bus line covered by only 35 µm of insulator. We are fabricating a new ceramic board with a thicker layer of dielectric. We also expect that the gain will increase by having thicker dielectric around the anode spot. Using this technique one has an anode spot of 100 µm in size compared to 500 µm for the standard pixel device. Maybe this defines more precisely the position of the high electric field needed for gas amplification, and thus could lead to better spatial resolution.

3. GASEOUS PIXEL CHAMBERS WITHIN A HADRON COLLIDER EXPERIMENT

There are many advantages of using detectors with gas amplification. They can be made relatively radiation hard. Gas amplification is intrinsically a high-gain, low-noise process. Wire chambers have been in use in particle physics for the last 25 years, therefore they are known devices. However there are disadvantages related to constraints imposed by having straight stretched wires. By having a device that keeps the advantages of gas amplification without having this constraint opens up many possible areas of use.

3.1 Muon Detection

For the barrel muon detection one needs to cover a large area with cheap, easy to build and reliable detector. One also needs good position resolution and x and y readout for triggering purposes. The gaseous pixel detector may be the ideal device for this application. Most designs use toroidal magnets in the forward direction. Therefore for muon detection it would be ideal to have a detector that has circular geometry. It is very easy to arrange the pixels to follow a curve and thus have a device with r,ϕ readout. We have already shown [1] that the gaseous pixel chamber has no problems with rates up to 2×10^4 particles/pixel/sec (it is quite clear that we can work at higher rates than this when the device is fully developed). Thus again the gaseous pixel chamber appears to be a good candidate.

3.2 Instrumented Iron

Various detector designs call for the instrumentation of the iron between the hadron calorimeter and the muon detection system. This system is to measure the hadronic shower leakage, detect catastrophic energy loss of muons and also to track muons. The detectors used for this purpose have to fit in many awkward places. The gaseous pixel device is good for this application as it can easier be made in any geometry to fit into a certain space. More importantly the gas gain is defined by the anode-cathode spacing (which is defined by the surface of the foil) rather than by a distance between two surfaces. Thus the chamber will operate even if it is severely distorted.

3.3 Pre-Shower Device

There are various schemes to have a pre-shower device in front of the electromagnetic calorimeter. It is possible to consider layers of lead followed by gaseous pixel chambers. The pixel readout is ideal for this purpose. It is also possible to imagine using a gaseous pixel chamber with a photocathode and use it to read out BaF crystals. Again the pixel nature is highly desirable. Again the gain is set by the anode-cathode spacing so mechanically it would be an easy device to build. It should be pointed out that there may be problems with poisoning of the chamber with these photosensitive gases, so it is not clear that the gaseous pixel chamber can be used for this. For both these devices it may be necessary to work in proportional mode. As yet we have only observed limited streamer mode of operation, however we expect to work in proportional mode when we have devices with smaller anode structures.

3.4 Tracking

For tracking at a super collider there have been many elegant solutions suggested. However it may be possible to supplement this central tracking either for trigger purposes or maybe to provide extra z information. Since this device is pixel in conception it does not suffer from the occupancy problems usually found with gaseous detectors in the central region. For example a simple jet trigger could be built that just demands a certain track density in given ranges of ϕ and pseudo-rapidity. The clear separate peaks shown in figure 12 for different number of pixels firing indicates that this would be a very simple device to build and instrument.

4. GOALS, MILESTONES AND OTHER THINGS IN THE FUTURE

4.1 Standard Pixel Chamber

The first goal is to optimise the chamber continuing to use the technology that we have been using for this last year. That is to use the standard technology of the printed circuit workshop here at CERN. This is to have 200 μm diameter holes in a 325 μm Kapton substrate. We do not know how small the anode-cathode spacing can be made and still have reliable operation. We do not know if the anode size is important (for the thinner Kapton substrate we did not improve the operation to reduce the anode below 500 μm in diameter). We also need to further study the offset pixel geometry to see if we can apply this trick to effectively double the pixel density. We have also seen that the streamer direction can be measured by the difference of induced charges on different electrodes. This will be needed to solve the equivalence of the left-right ambiguities of conventional drift chambers. We have to study how the cathode and/or the roof can be divided to provide this information.

4.2 Ceramic Chamber

The second goal is to investigate the ceramic device. We have ordered a device that has a thicker layer of dielectric over the anode bus line. We expect that this device will work as well as (hopefully better than) the Kapton based device. If so, then again we will need to optimise the anode-cathode spacing for this device. We can investigate whether the smaller anode size does give us an improved spatial resolution. It is possible to get 50 μm object size in ceramic, so it may be possible to decrease this device in size using the same technology.

4.3 Laser Ablation

The third goal is to investigate the devices with smaller holes produced with lasers. If we simply scale our device linearly with the size of the hole, then at present as we have 1 cm^2 pixels with 200 μm holes, we should be able to produce 2.5 x 2.5 mm^2 pixels with 50 μm hole diameter. In reality a gaseous device with 1 mm^2 pixels is not that far off. Structures with these small anodes should also work in proportional mode which opens up many possible applications for this device.

4.4 Microdot Chamber

The developments in the field of vacuum microelectronics of field emission cathodes [5] opens a very interesting possibility. Here they are building structures similar to vacuum valves, except that they are scaled down by many orders of magnitude. The thermionic cathode is replaced by field emission cathodes to provide a source of electrons. A cross section of such a device is shown in figure 19. One can see that the geometry is similar to the gaseous pixel chamber, however their cathode (the tips) are equivalent to our anodes. Thus by reversing the voltage applied to this device and by adding a gas, maybe it would work as a particle detector. We are about to study the feasibility of using such devices as gaseous detectors.

The similarity between these field emission structures and our gaseous pixel chamber looks like the similarity between the Multiwire proportional chamber and the gaseous microstrip detectors of Oed and others [6]. We hope to see the same kind of improvements due to the reduction of cell size.

4.5 Read Out

There are many ongoing efforts by various groups working on schemes to read out pixel detectors. They usually have some solid state device in mind. We should make use of these developments for our device. One hopes that it will be easier as our signals are much larger. One should not forget that even though our device is a pixel type detector, there is nothing stopping us bussing the anodes together in a line, or even in other types of groups

5. REQUEST

It seems that some of these projects submitted to this R&D committee are in a stage 2 phase of development. This is because a first stage prototype has been successfully built and now the problem is to study how a large scale prototype behaves, and/or how to integrate it with other detectors making up the whole of a hadron collider experiment. On this scale, we are still in the stage 1 phase of development. We still can and need to learn a lot with small prototypes. So far the largest device we have operated is 16 x 16 cm (but there is no apparent problem to make larger devices). Up till now we have been supported totally (and expect to continue to be supported) by the LAA project at CERN. Our budget is modest, at the peak of our activities we were spending 3,500.- S.F./month in the CERN printed circuit workshop. There are also various overheads such as electronics borrowed from the CERN pool and for a supply of gas. Even though our needs are modest, we think CERN support and approval for this project is essential. We also do not want to exclude returning to this committee on the successful completion of phase 1 and requesting a budget to build a phase 2 prototype to be integrated with other detector elements for a hadron collider experiment.

5.1 Phase 1 (1991)

We should get the same type of support as CERN gives to an approved experiment. Being an approved CERN project will make it easier to attract physicists from outside institutes and also CERN fellows. If these physicists are from CERN then we would expect CERN to make a contribution to our running costs. If they are from an outside institute, we hope that formal approval of this project will make it easier when they request the backing of the resources of their own funding agencies. This is especially important as now we want to push technology a bit further than available at CERN. There is no one, as far as we know, that is doing laser ablation at CERN, while the Rutherford Laboratory has a very advanced active group in this field.

We use the CERN IBM computer to perform the electric field calculations with the ANSYS package. This is a very powerful finite element package that allows us to simulate 3-dimensional structures that also contain materials of different dielectric constant. For example in figure 20 we show the field lines of the gaseous pixel device (without considering the surface charge on the Kapton) for a substrate thickness of 200 μm and a plated through hole of 200 μm diameter. Each simulation takes 1 hour of CPU time and we expect to perform up to 50 simulations during 1991. We also use the central VAX cluster to analyse our test beam data. This is rather simple analysis where we produce a selection of histograms with various cuts.

We need test beam time to continue the program outlined in the previous section. We will need an intensity up to 100,000 particles/cm^2/sec (maybe higher if we successfully reduce the pixel size). We request 5 days of test beam every 6 weeks throughout the year.

For this past year, 1990, we have been using the printed circuit workshop at CERN and now we are close to the limits of the technology that they can provide. We would support any improvements suggested for this facility, especially in the use of lasers.

5.2 Phase 2 (1992 and onwards)

We expect that we will know some of the absolute limits of our device by the end of 1991, for instance, the limit of pixel size, which would also affect time resolution and space resolution. These parameters can then be used to study whether this device should be used for any of the applications mentioned in section 4. Then we will want to build a larger scale prototype and integrate it with other devices. We can only start to plan this when we have more results from the phase 1 stage, however we think that already the results are so promising that we are certain that the gaseous pixel device will be the cheapest and best solution for some application at a hadron collider.

Further References

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5. N.A. Cade and R.A. Lee, Vacuum Microelectronics, GEC Journal of Research Vol. 7 No. 3 1990
6. A. Oed, Nucl. Instr. and Meth. **A263** (1988) 351.

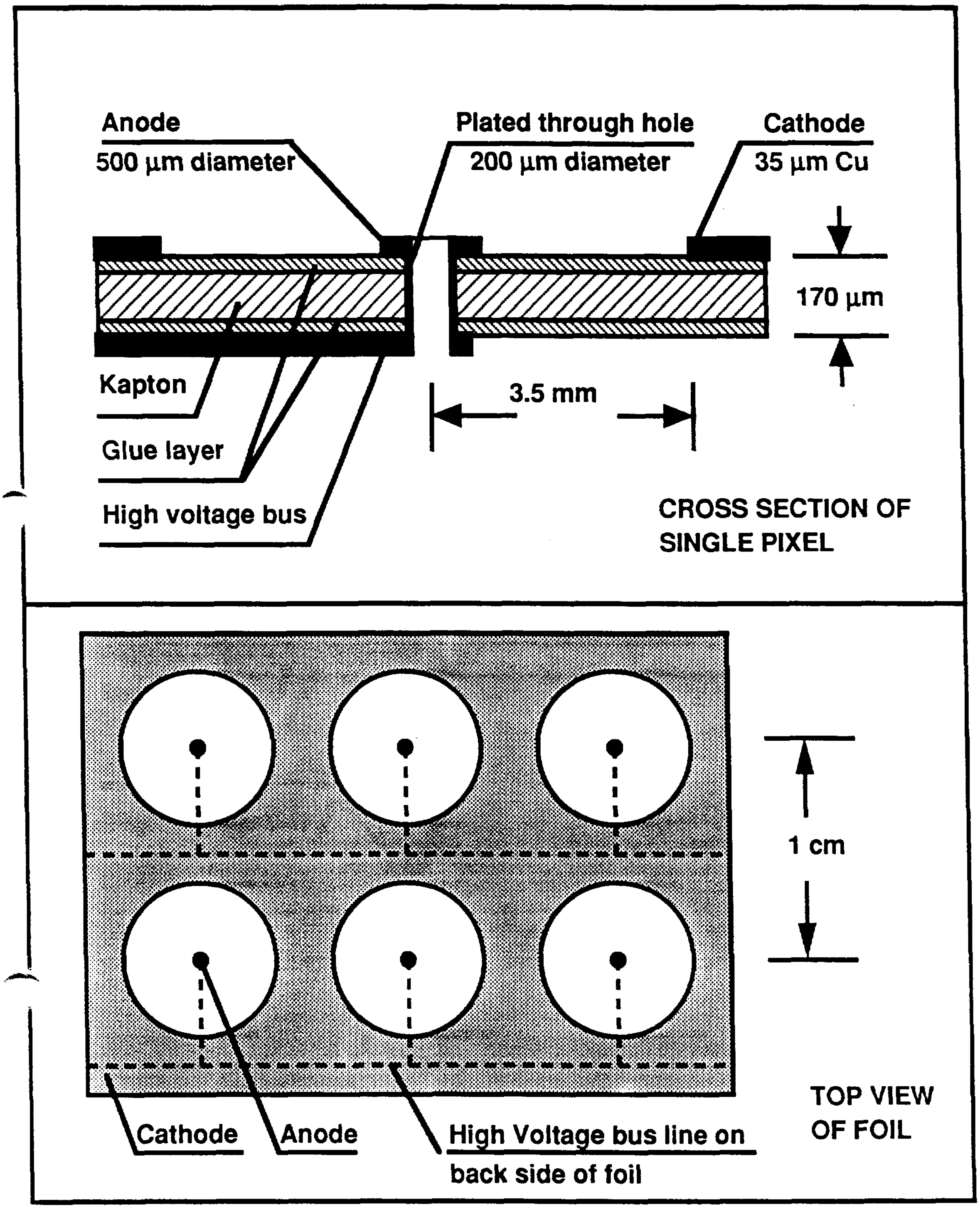


Figure 1: Cross section and top view of gaseous pixel chamber

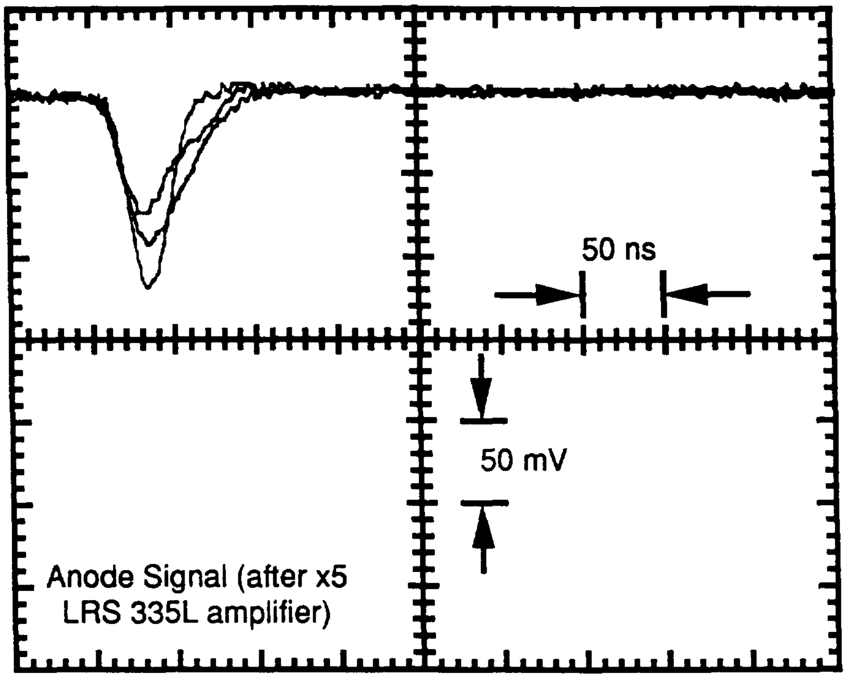
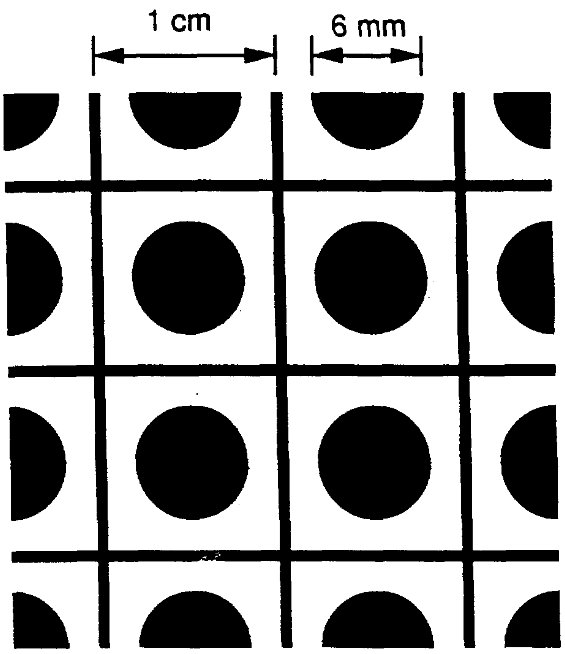
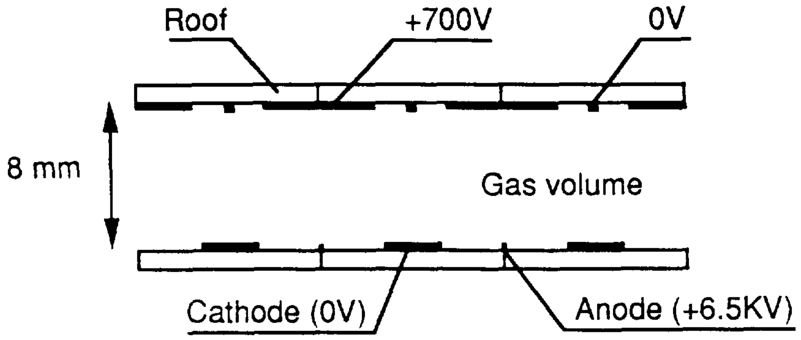


figure 2 : Typical signals produced by foil being irradiated with ^{55}*Fe*



Pattern of electrodes on roof



Cross section of foil with roof

figure 3: Diagram of roof electrodes

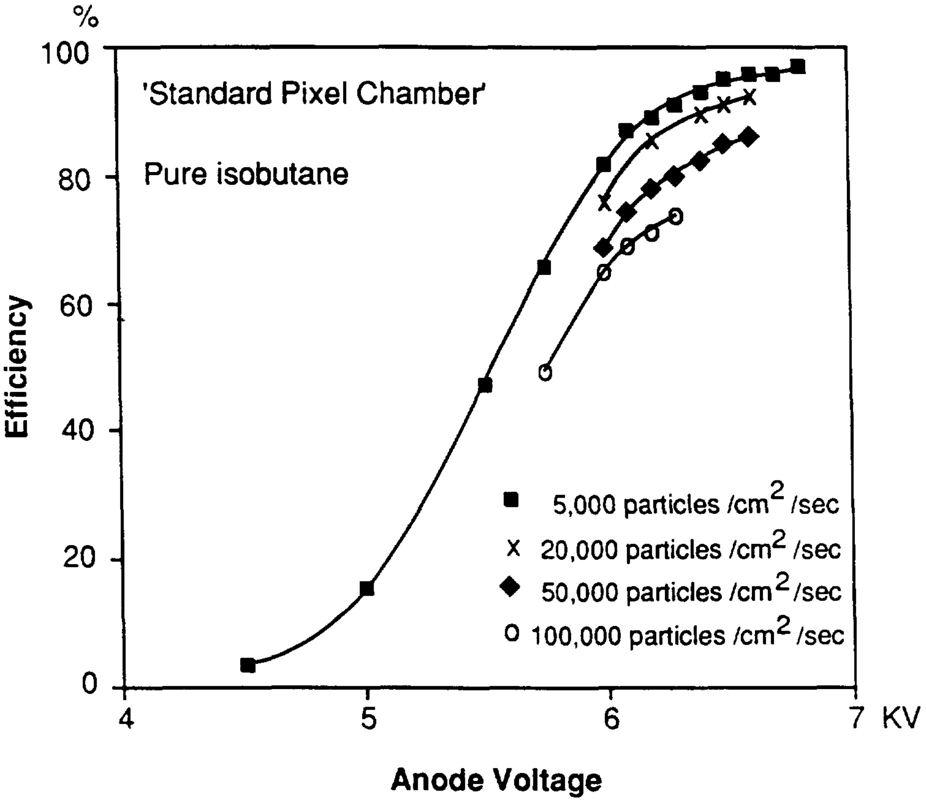


figure 4: ***Efficiency versus high voltage for various particle flux***

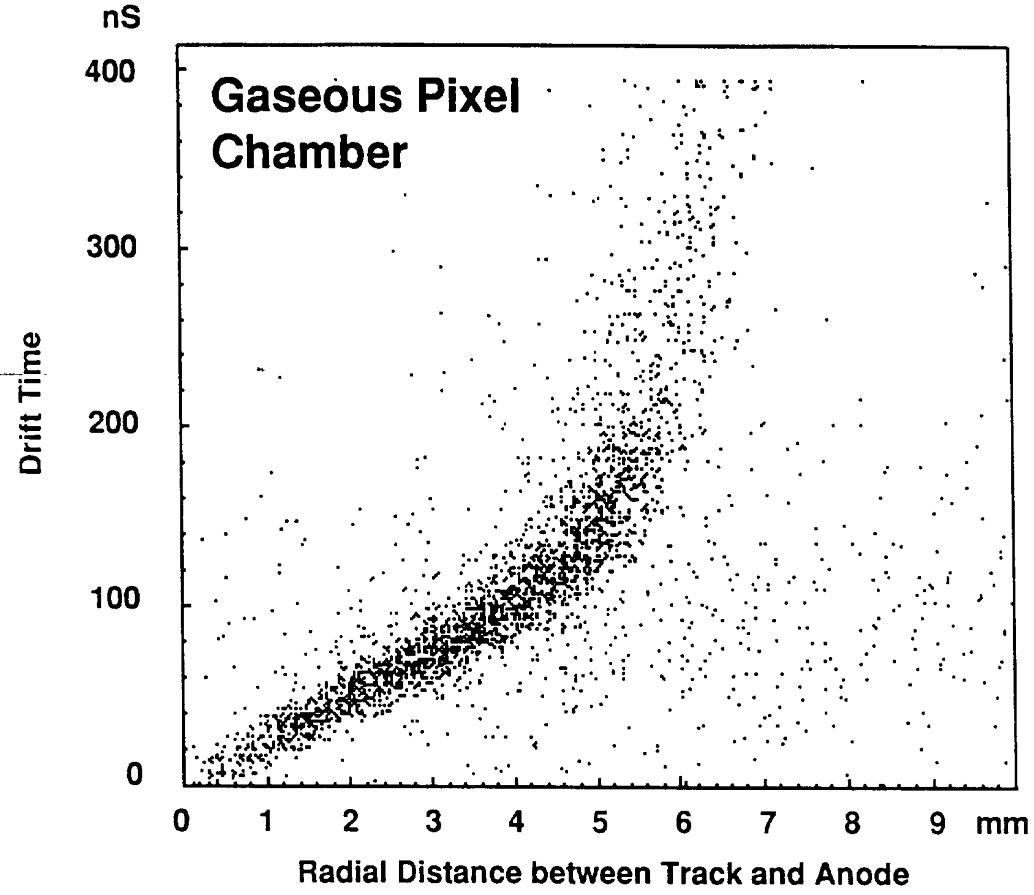


Figure 5: Scatter Plot of Drift Time versus Radial Distance from Anode

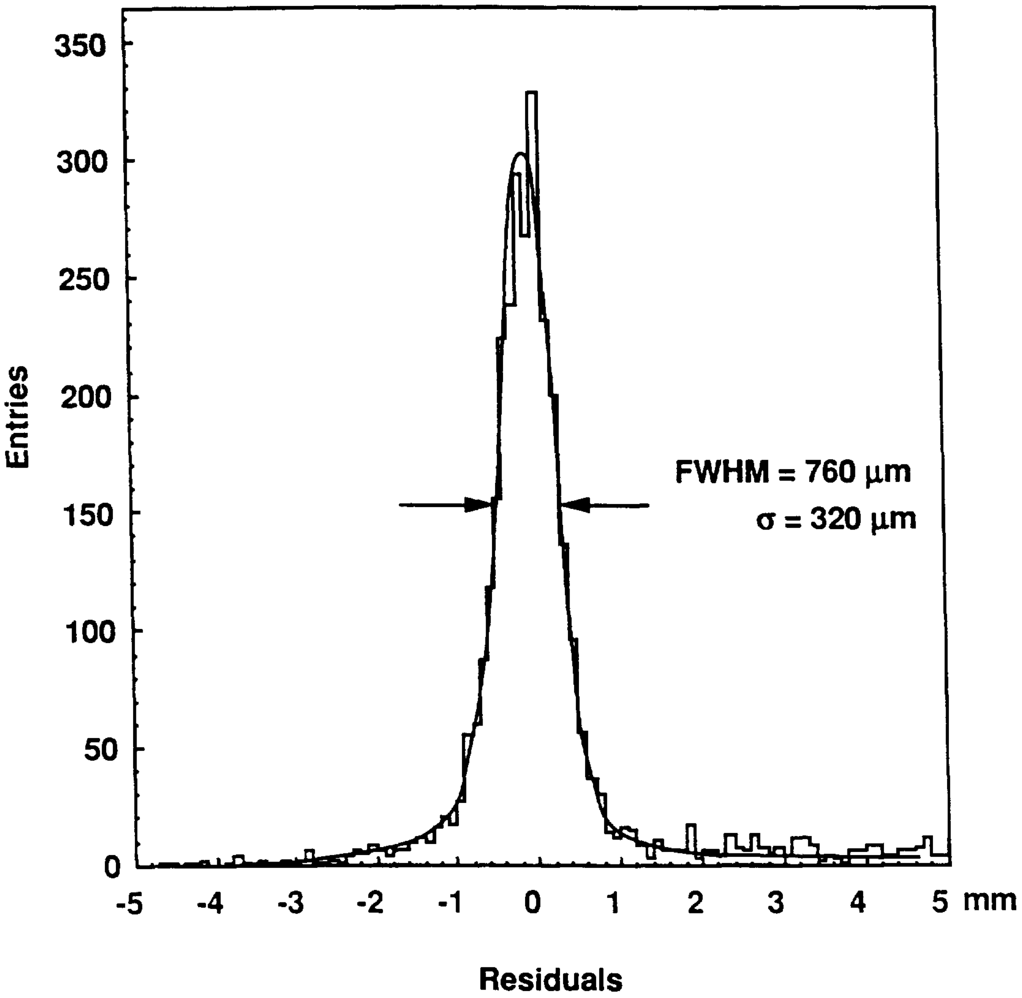


Figure 6: Distribution of Residuals for the radial distance

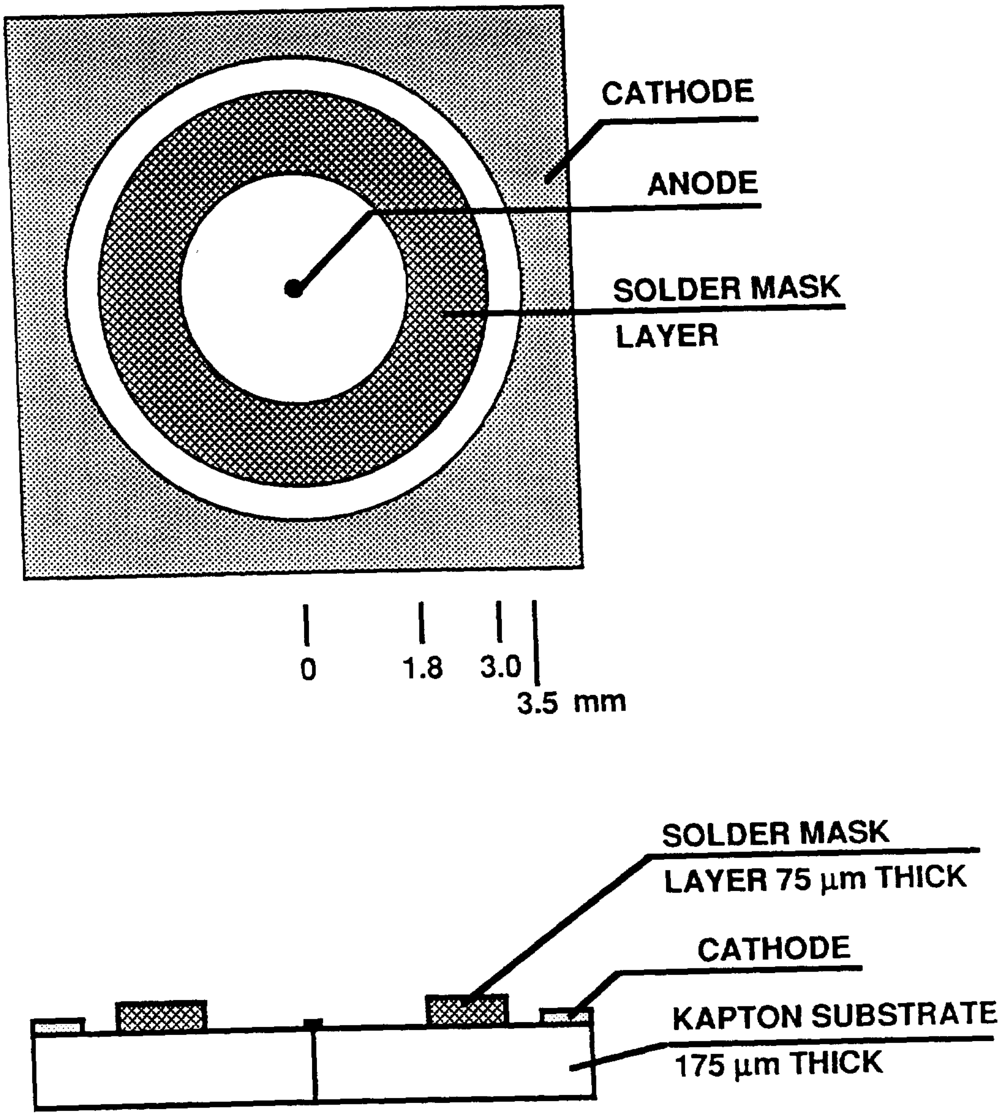


Figure 7: Solder Mask Layer applied to Gaseous Pixel

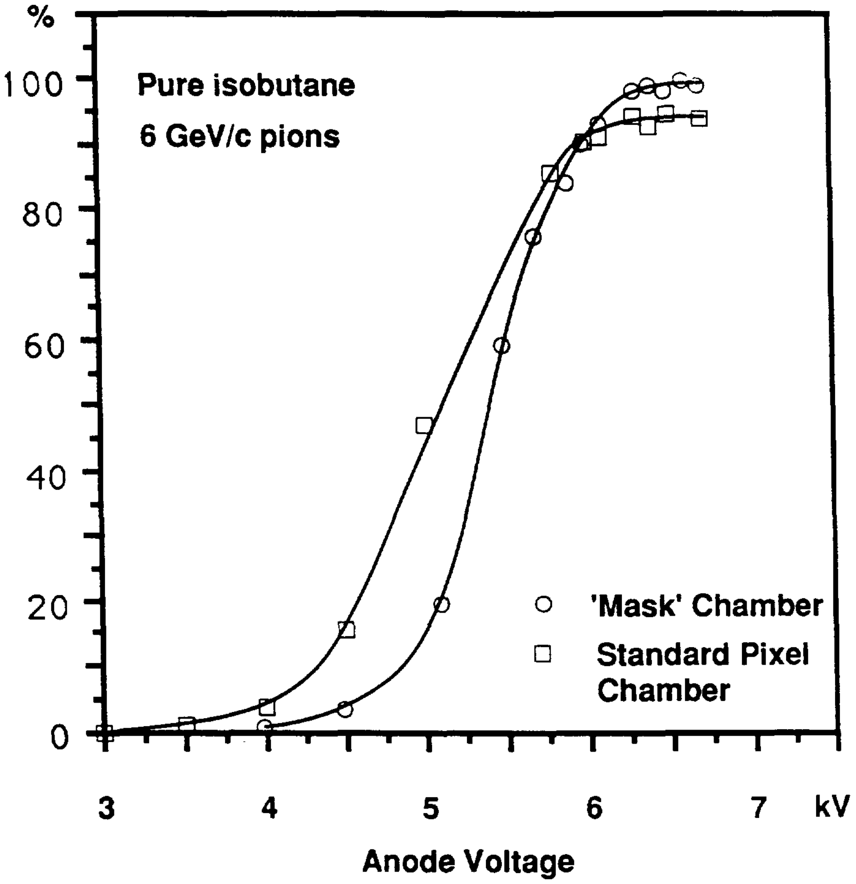


Figure 8: Efficiency for detecting 6 GeV/c pions

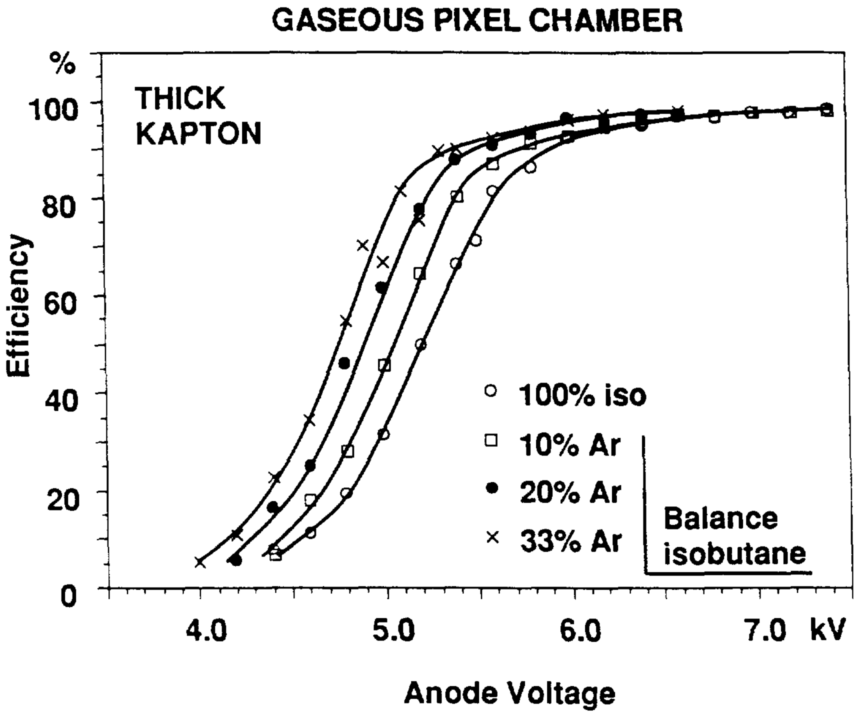


Figure 9: Efficiency for detecting 6 GeV/c pions for Ar-isobutane

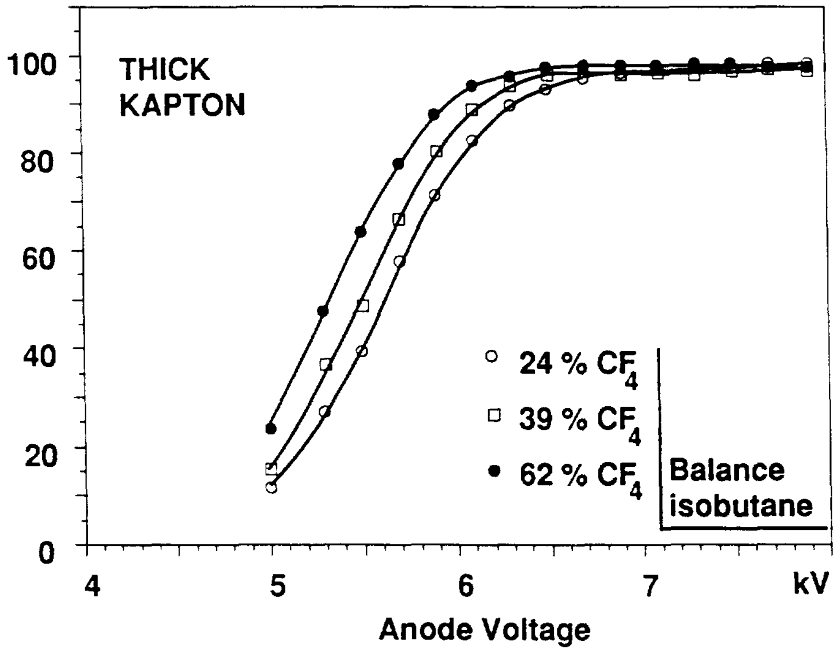


Figure 10: Efficiency for detecting 6 GeV/c pions for CF_4-isobutane

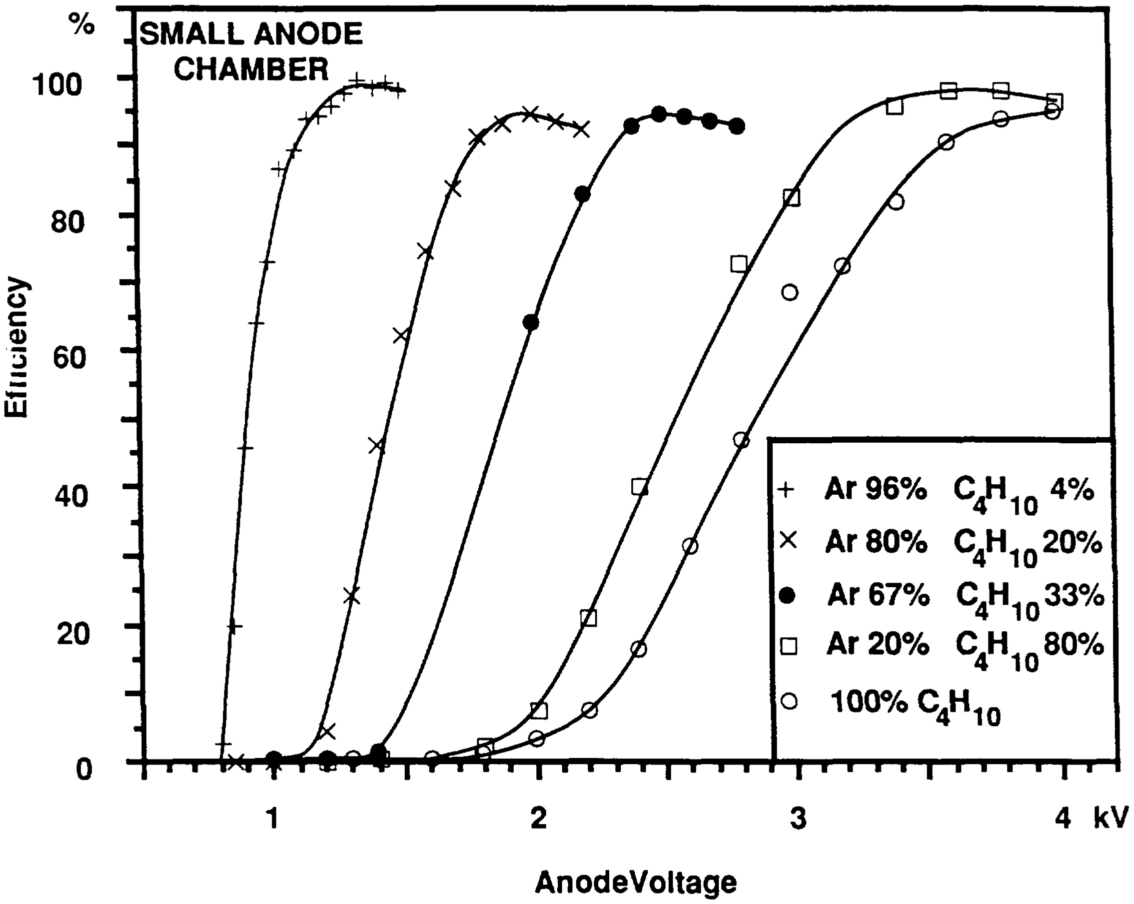


Figure 11: Detection efficiency for 6 GeV/C pions for various gas mixtures.

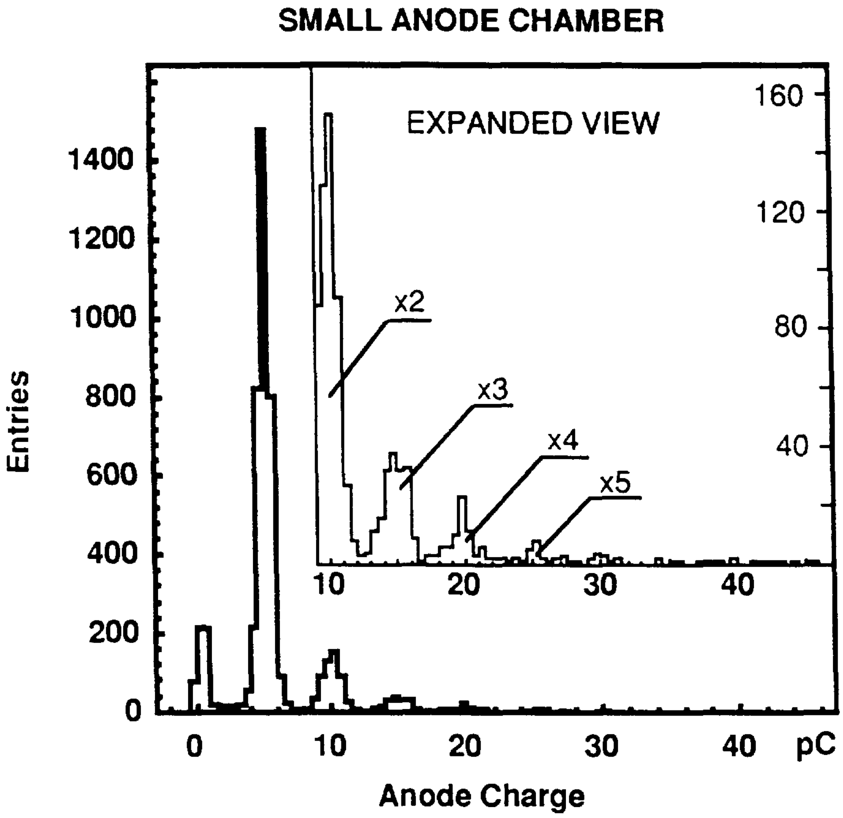


Figure 12: Charge spectrum of small anode chamber

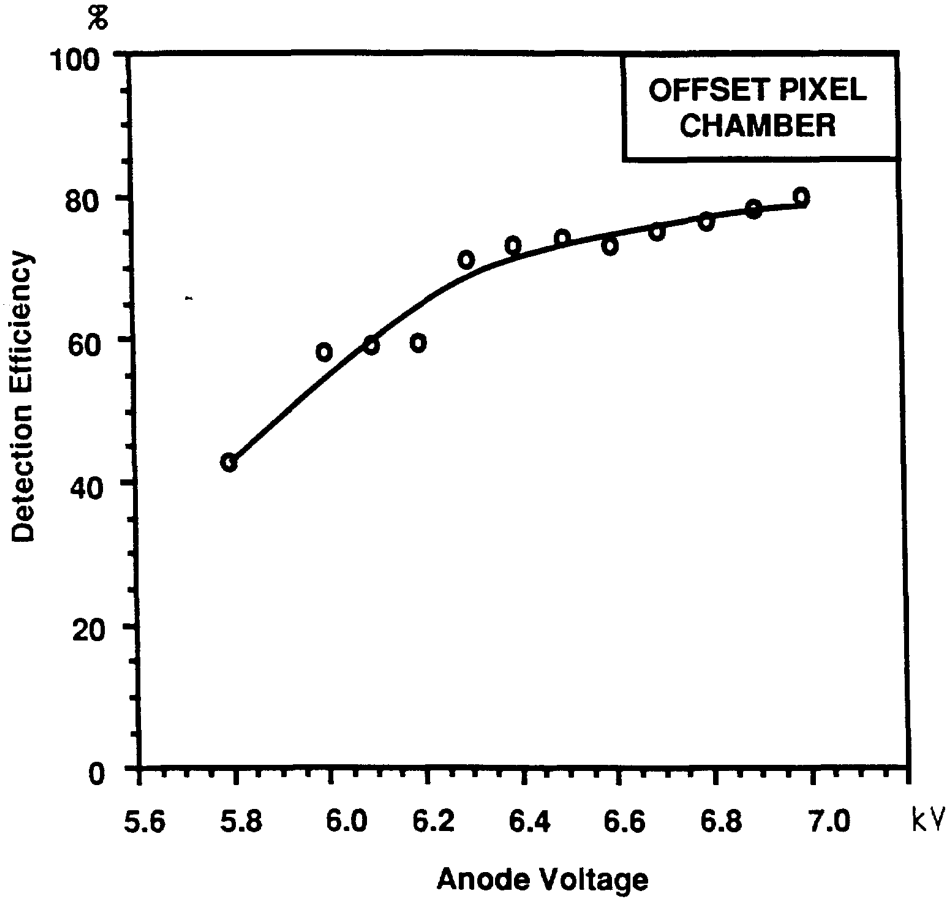


Figure 13: Detection efficiency for 6 GeV/c pions with the Offset Pixel Chamber

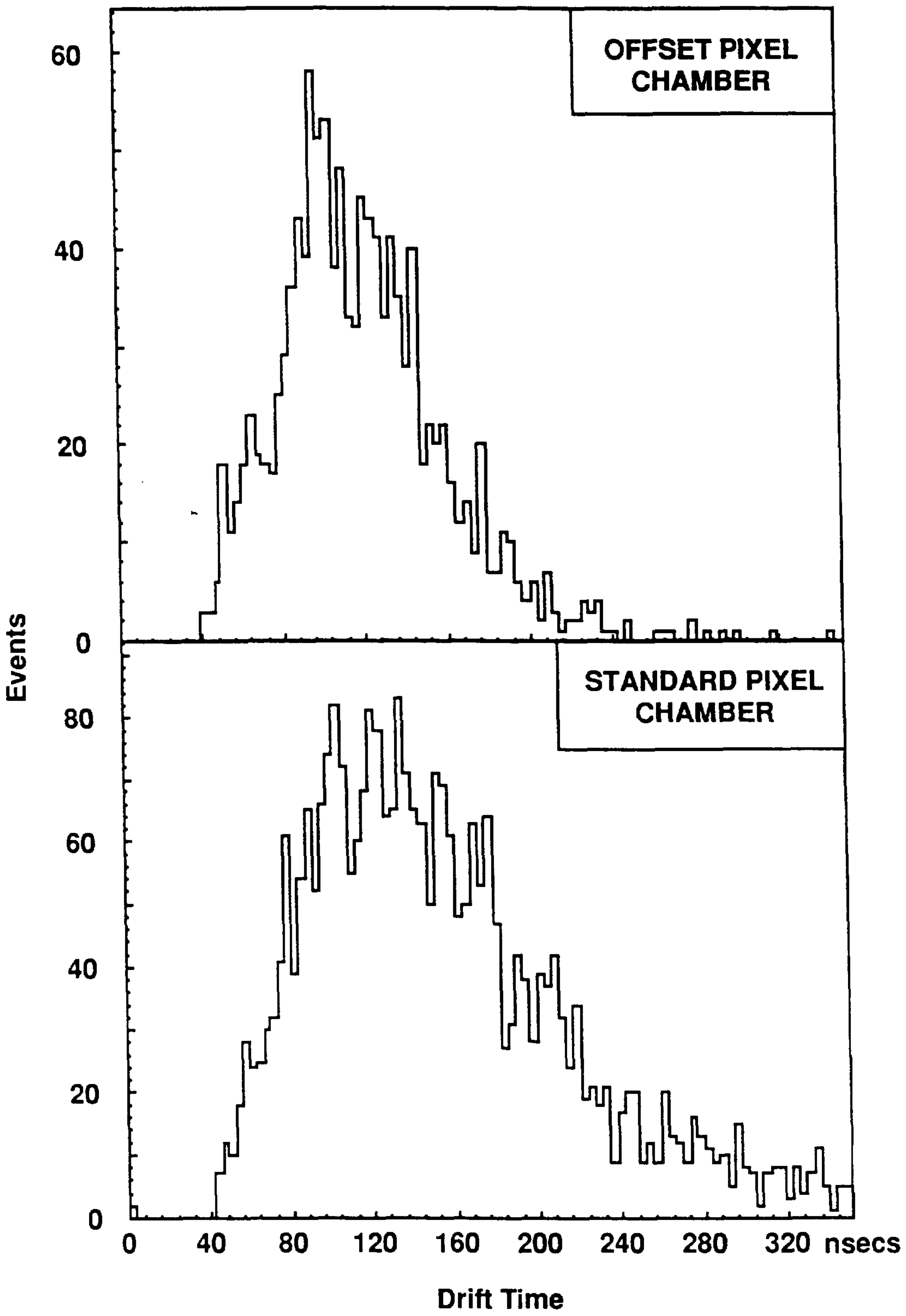


Figure 14: Drift time Distribution of Offset Pixel Chamber (single foil) and Standard Pixel Chamber

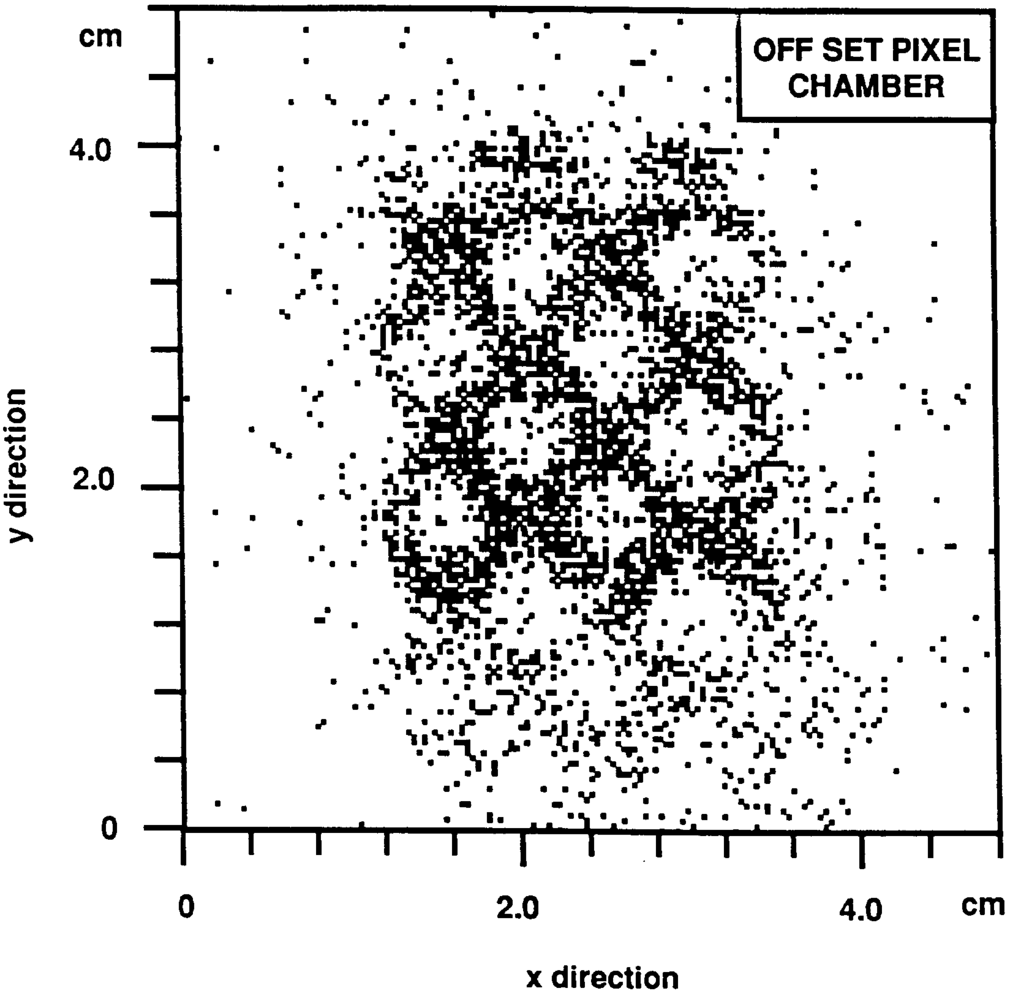


Figure 15: Impact point of particles that do not fire either foil

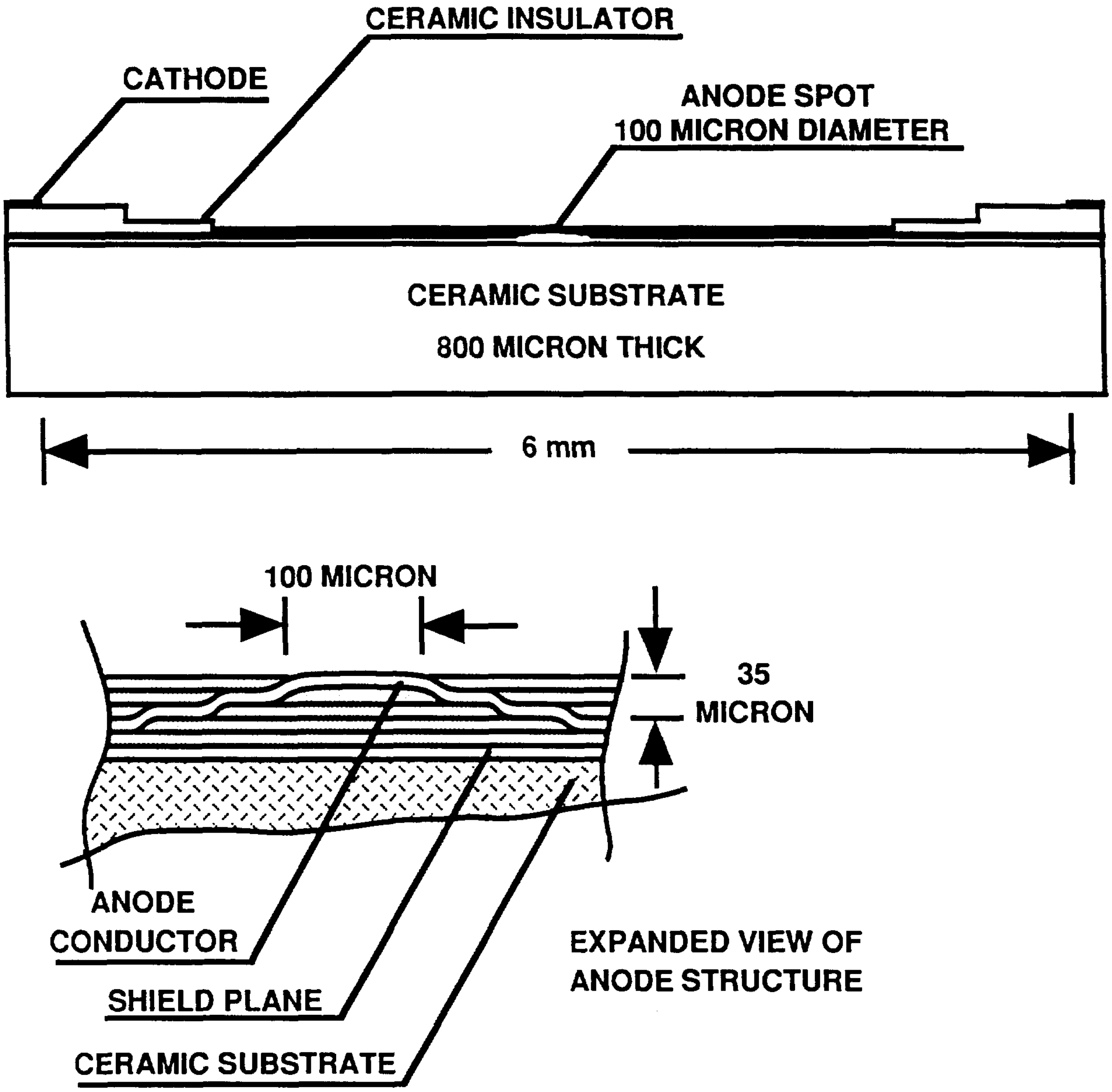


fig 16: Cross section of a single cell of the ceramic pixel chamber

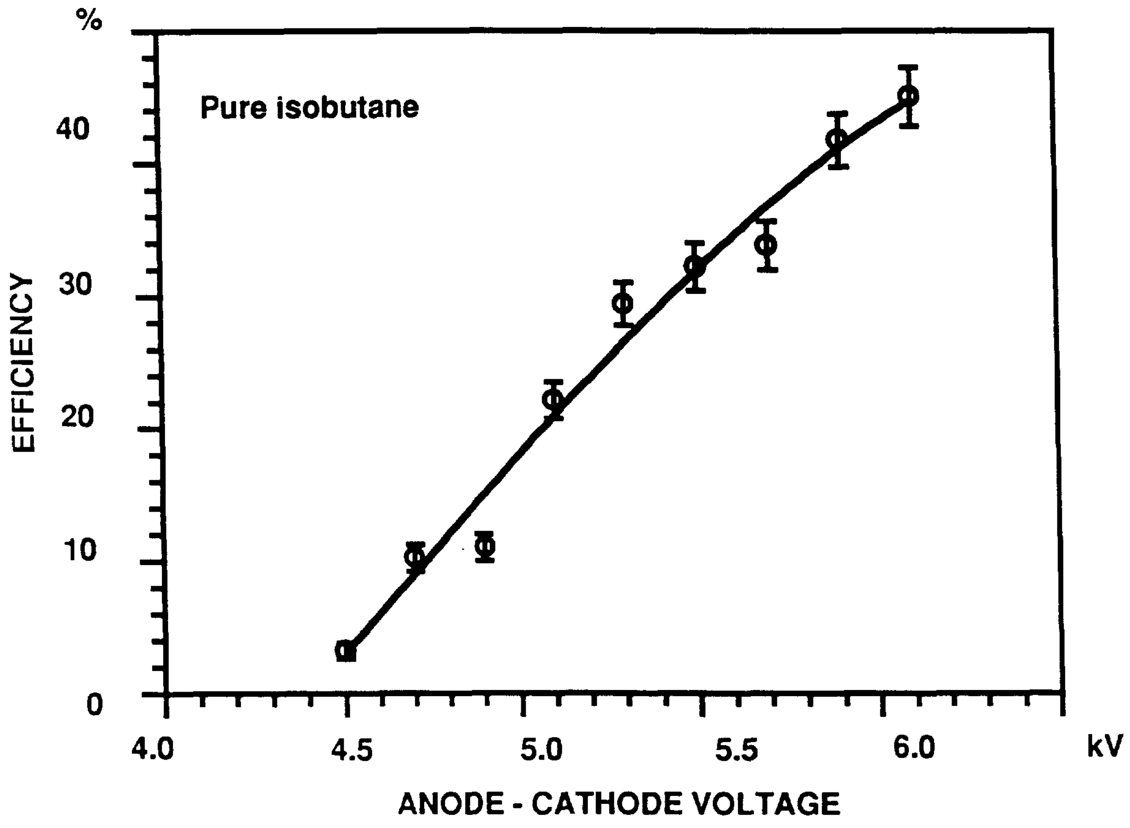


Figure 17: Efficiency for detecting minimum ionising particles

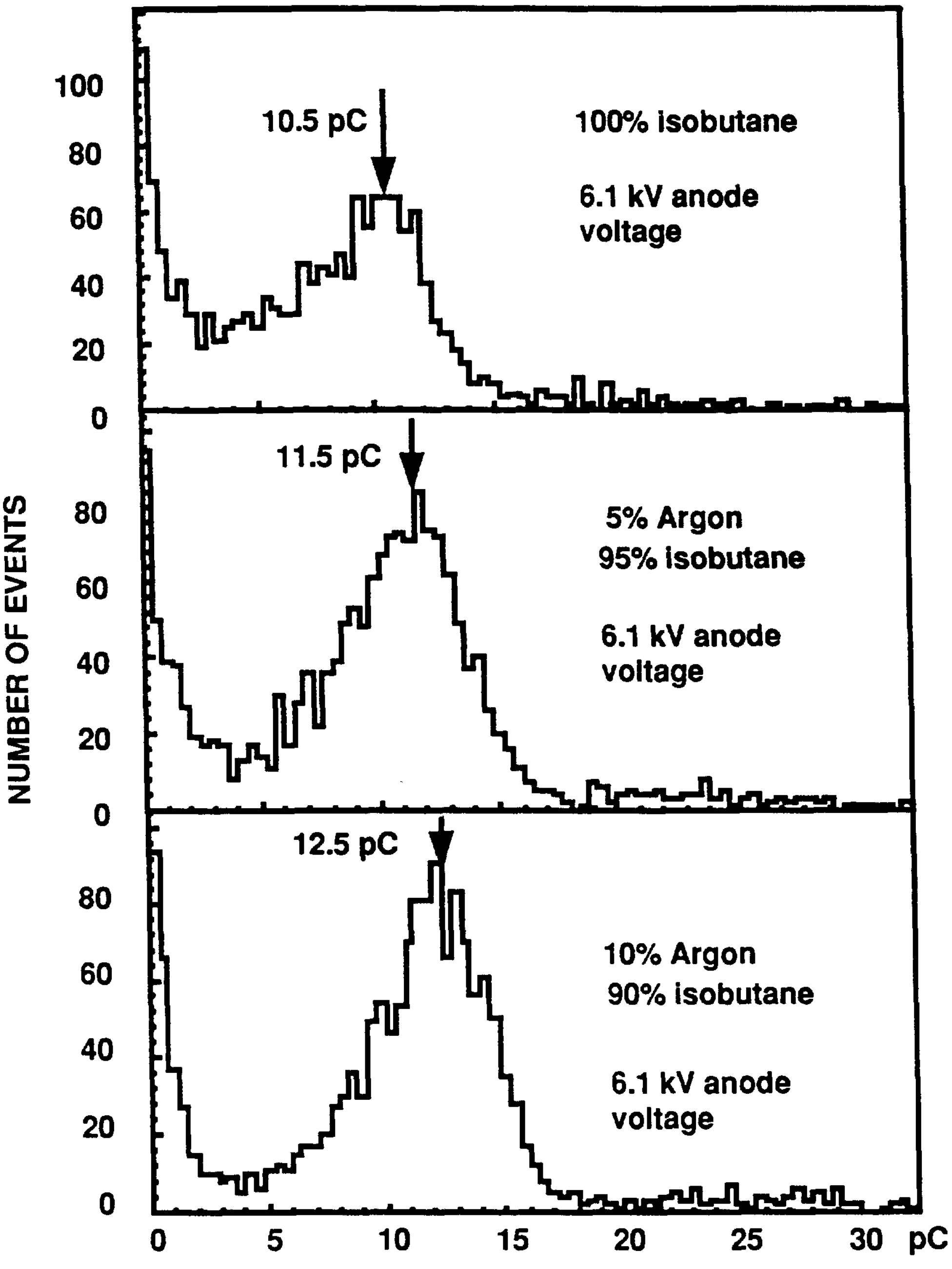


fig 18: Charge of the cathode signal for minimum ionising particle for various gas mixtures

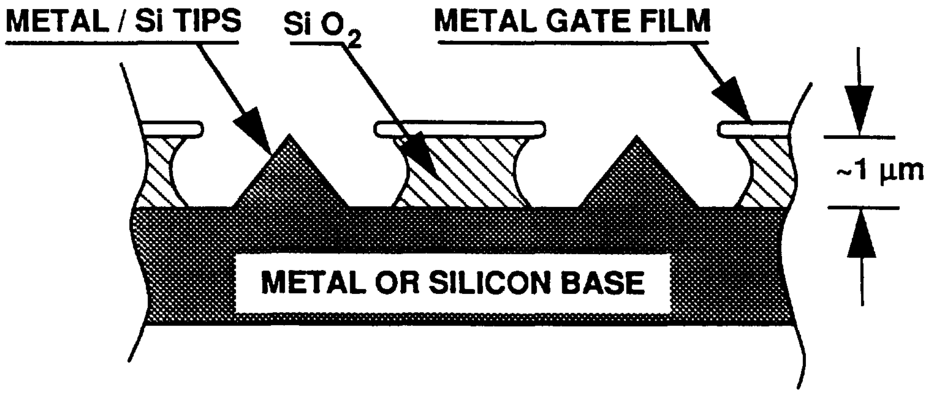


Figure 19: Cross section of Typical Field Emission Diode structure

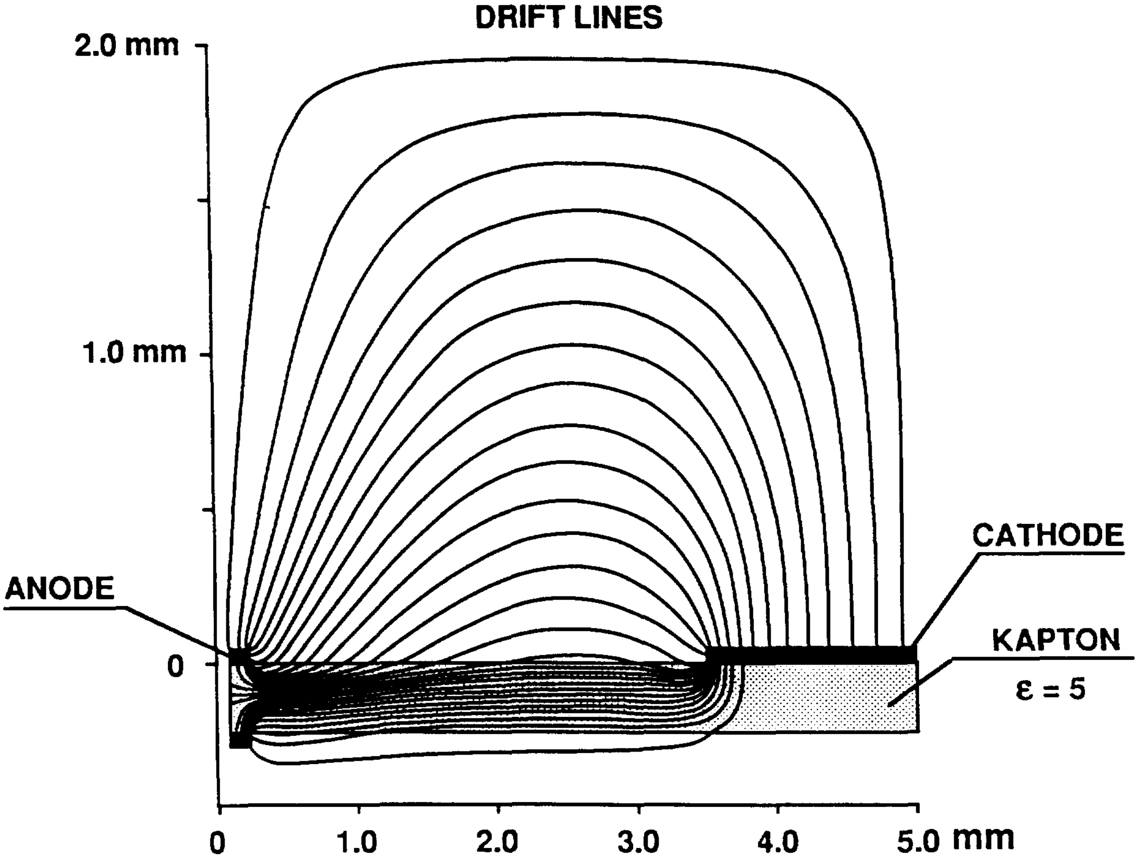


Figure 20: Drift lines of Gaseous Pixel Chamber with uncharged Kapton surface