Characterization and Testing of Multi Wire Proportional Chamber

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Submitted By:

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Acknowledgement

As a M.Sc student,the main purpose of my doing experimental project is to get acquainted with various experimental setups with the necessary tools to bridge the gap between the theory and experiment. I am ever grateful to my project guide Dr. Tilak Kumar Ghosh of Experimental Nuclear Physics Division,VECC for our fruitful discussions, which helped me to understand the essence of the experiment. Under his able guidance, I got a very good overview of the Gas Detectors in general and particularly MWPC. I would like to thank Arijit da for his guidance, teaching,encouragement and constant support. I would like to thank Amiya da for wonderful support and help at every instant. I also must thank the other members of CPDA lab especially Ratan da & Pintu da for supporting me to carry out the experiment. I am highly indebted to all the teachers of my life especially Subrata sir for inspiring and motivating me in life. Also, I would like to thank Bedanga sir (NISER) for giving me such an opportunity. And of course, I am grateful to Hari da & Bipradas da for encouraging me. A special thanks goes to my best friend for supporting me.

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Thanking you.

-Rik Bhattacharyya

Contents

Abstract

A Multi-Wire Proportional Chamber (MWPC) of active area 20X6 cm^2 is tested for the spontaneous fission of Cf^{252} source using isobutane gas at very low pressure. The detector is operated in optimized condition to find the position of fission fragments. Five electrode geometry is used in the detector, and signals from anode, cathode and position (X ,Y) are analyzed and found to be satisfactorily. Also comparison between symmetric and asymmetric bias is studied.

2.Introduction:

The aim of a particle detector is to identity of the particles that pass through it after being produced in a collision or a decay. Most of particle detectors,we are interested to study, are almost all designed to produce electrical signals. They need some method of liberating charge,which is subsequently amplified and digitized. By feeding the signals into a computer, very large numbers of interactions can be analyzed.

In this project,we have aimed to test as well as characterize a Multi-Wire Proportional Chamber (MWPC) for detection of low energy heavy ions (e.g. alpha particle, fission fragments etc.). Actually, here we use a hybrid type of gas detector called Breskin Detector where a MWPC is sandwiched between two Parallel Plate Avalanche Chamber (PPAC) to get very high gain (10^5-10^6; 100 times better than MWPC's),fast rise time (<10 ns), excellent detection efficiency,good time resolution (~200ps at FWHM) and position resolution (~200μm at FWHM)[7].

At first, we start our journey by investigating some basic properties of gas detectors, their region of operation and then we study the basic design of MWPC and how it is used to detect the fission fragments of Cf^{252}. In this project, we also study the experimental techniques to handle the detector and the electronics behind it to process the signals and its optimization.

3.Various Types of Detectors:

When a charged particle passes through a medium, it ionizes the medium. These electrons-ions pair is collected by applying bias voltage on two electrodes and the signal is analyzed. This is the principle working formula of most detectors. For uncharged particle, either the same process is used indirectly that is creating a charged particle by reaction or scintillation technique is used by amplifying photons which are emitted by de-excitation of excited atoms. Depending upon that, mainly three types of detectors are used in nuclear and particle physics experiments.

3.1 Gas Detectors:

These detectors exploit the fact of ionization of gas by the incident particles. Depending upon the operating voltage,the signal is varied interestingly. This idea is applied to operate these detectors into different regime and purpose. Ex.- Ionization Chamber, Proportional Counter, Geiger-Muller Counter, Spark Chamber etc.

3.2 Scintillation Detectors:

Scintillation means "A flash or sparkle of light". A scintillator is a material that emits low-energy photons (usually in the visible range),when they are struck by a high-energy charged particle. These photons are collected in Photo Multiplier Tube (PMT) to generate photoelectrons and amplified them to get signal. But a special type of scintillator is required for a special kind of radiation, which limits its area of operation. Ex.-NaI (Tl), Anthracene etc.[4]

3.3 Semi-conductor Detectors:

These work on the same principle of ionization in solid state materials especially in semi-conductors. The electron-hole pair is created when a uncharged/charged particle enters into the detector. Ex.-Surface barrier detectors, HPGe, etc.[4]

➢ **Advantages of Gas Detectors:**

1.Among all of three, Gas detectors are very cheap and easy to fabricate.

2.Typical energy requirement for information carrier generation[6]:

- Scintillators : ~ 100 eV (Photo-electrons)
- Gas counters : ~ 30 eV (Ion-pair)
- Semiconductors : ~ 3 eV (Electron-hole pair)

So, definitely semiconductor detector produce more carriers (i.e. better signal) for a particular energy deposited by the incident particle. But, the radiation damage it permanently and make it costly. Besides that, the dead layer(formed by diffusion of doping elements) of such detector isn't efficient practically for low energy heavy ion/fission fragments experiments.
Although, Solid state detectors are much compact and smaller in size than gas detectors, as the energy loss is much higher in solids than in gases. However, the energy resolutions offered by solid state detectors are comparatively lower than that of gas detectors.

3. Gas detectors have a long lifetime compare to others[8].

So, to carry out modern nuclear experiments,it is good to choose gas detectors. A unique electric field configuration can be designed to fabricate new detectors for specific purposes like Multi-Wire Proportional Chambers (MWPC), Gas Electron Multiplier (GEM), Resistive Plate Chambers(RPC),Time Projection Chambers(TPC) etc.

➢ Interactions of charged particles with matter (Bethe–Bloch energy loss expression):

For charged particles, the largest fraction of energy dissipated in matter is due to electromagnetic interaction between the Coulomb fields of the charged particle and the molecules of the medium. For low Z particles, the energy loss expression (Bethe–Bloch energy loss) with corrections is given below[1]:

$$\frac{dE}{dx} = -\rho \frac{8\pi N e^2 Z}{mc^2 \beta^2 A}[\ln \frac{2mc^2\beta^2}{I(1-\beta^2)} - \beta^2 - \frac{C}{Z} - \frac{\delta}{2}]$$

where,

e and m are the charge and mass of the electron, Z, A and ρ the medium atomic number, mass and density, and N Avogadro's number, β is the particle's velocity,I is the mean excitation potential ; the additional term C/Z represents the so-called *inner shell corrections*,and $\delta/2$ is a density effect correction[1].

Energy loss depends on the particle's velocity,not on its mass. However, this formula does not exactly describe the energy loss mechanisms of the heavier fission fragments [2], as the fission fragments are highly charged, hence their energy loss is higher than that calculated by the above formula.

4. Operational Region of Gas Detectors:

Fig.1 shows the variation of current with the bias voltage across the detector. At very low voltage, collection of charge begins but due to very weak electric field, recombination is still a dominant process. This region is called Recombination region. Increasing the field causes the electrons-ions pair to drift towards the electrodes without any multiplication and

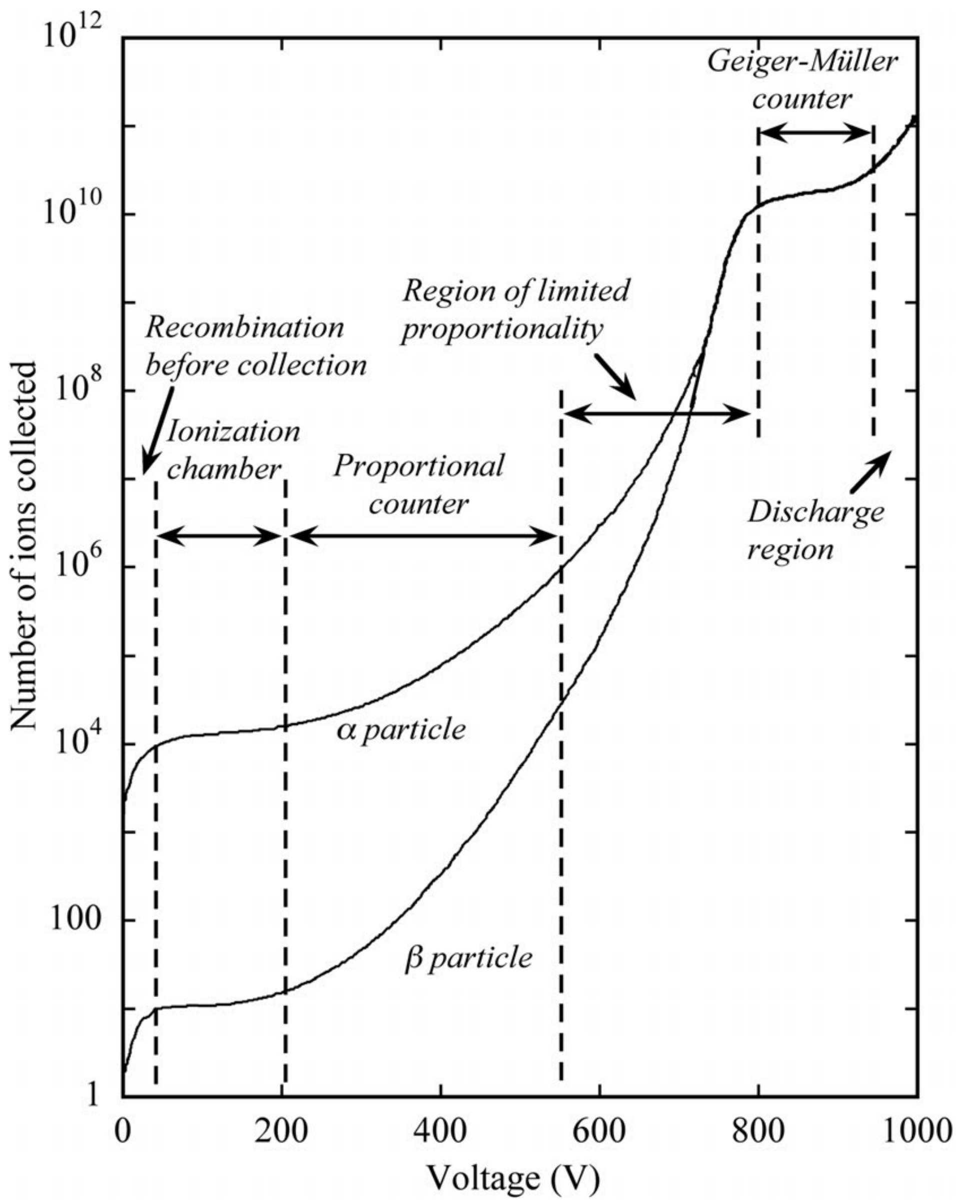


Fig.1 Bias Voltage vs. Current in detector[1]

create a very low signal. Hence, current is saturated in this region called saturation current and is proportional to the energy deposited by the incident radiation. The detectors designed to work in this region are called ionization chambers. After this, local avalanche starts to occur. Primary electrons are accelerated towards anode and produce secondary ionization which is directly proportional to the bias voltage. That is why,it is called Proportional Region(~200-500V). As we increase the bias voltage, more and more charges are produced inside the detector. Now since heavy positive charges move much slower than the electrons, they tend to form a cloud of positive charges between the electrodes. This cloud acts as a shield to the electric field called space charge and reduces the effective field. For this, the linearity between signal and voltage is lost. This region is therefore termed as the region of limited proportionality(~500-650V). Here, MWPC works. After this region we find a plateau like region which arises as the avalanche events are no longer localized and instead spread out over the entire gas volume. This is called Geiger-Muller Region (~700-1000V) ad here GM counter works. After this,the voltage is enough to break down the gas and sparking occurs. Spark chamber works in this region.

5. Gas Detectors (PPAC and MWPC):

We use here Breskin Detector which is combination of Parallel Plate Avalanche Chambers(PPAC) and Multi-Wire Proportional Chambers(MWPC). Hence,now we focus to the basic constructions of these.

5.1 Parallel Plate Avalanche Chambers(PPAC):

A Parallel Plate Avalanche Chamber(PPAC) is basically a capacitor i.e. two plates (cathode and anode) are separated by a small distance and filled with a gas (fig.2). The electric field inside it is uniform and intense.

When a charged particle enters into PPAC, it creates avalanche (Townsend Avalanche) inside the whole volume.

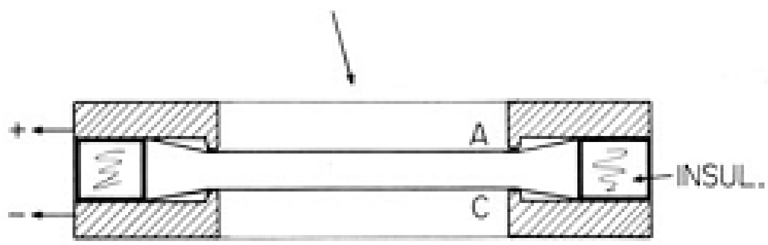


Fig.2. Schematic diagram of a PPAC [4]

According to the Townsend, if n_0 be the no of primary electrons,then after moving distance dx, the no of secondary electrons will be

$$dn = \alpha n dx$$

$$n = n_0 \exp(\alpha x) \; ; \; \alpha = \text{Townsend Coefficient}$$

$$= \frac{1}{(Mean\,Free\,Path)} = N\sigma_i(E_k) \quad [5]$$

$$N = No\,density\,;\,\sigma_i(E_k) = Ionization\,Cross-section$$

The multiplication factor($A=e^{\alpha x}$)or Gas gain is in the order of 10^4.

5.2 Multi-Wire Proportional Chambers (MWPC):

The invention of the MWPC by Georges Charpak in 1968 opens a new era in experimental nuclear and particle physics. It consists of a set of thin, parallel and equally spaced anode wires, symmetrically placed between two cathode planes; Fig.3 shows a schematic cross-section of MWPC.

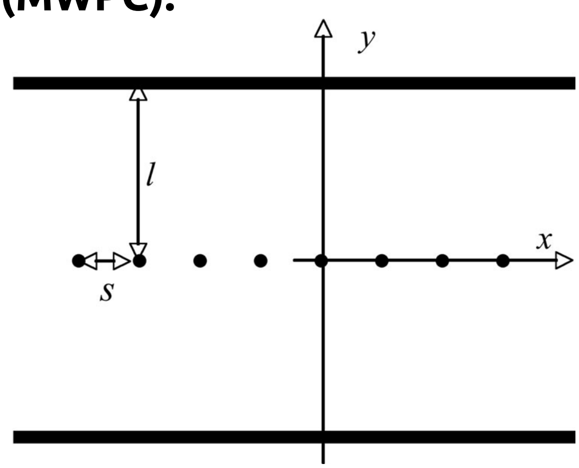


Fig.3 Schematic cross-section of MWPC[1]

Analytically, the electric field for a constant voltage V_0 is given by [1]

$$V(x,y)=\frac{CV_0}{4\pi\epsilon_0}\left[\frac{2\pi l}{s}-\ln\left[4\left(\sin^2\frac{\pi x}{s}+\sinh^2\frac{\pi y}{s}\right)\right]\right]$$

$$So\ ,\ E(x,y)=\frac{CV_0}{2\pi\epsilon_0}\left(1+\tan^2\frac{\pi x}{s}\tanh^2\frac{\pi y}{s}\right)^{1/2}\left(\tan^2\frac{\pi x}{s}+\tanh^2\frac{\pi y}{s}\right)^{-1/2}$$ C=Capacitance

Under approximation

y<<s, $E(x,y)\approx\frac{CV_0}{2\pi\epsilon_0 r}$ and for $y\geqslant s$; $E_y\approx\frac{CV_0}{2\pi s}$

Hence, near the wire, the field is intense and 1/r nature whereas far away from the wire,it is parallel. Fig.4 shows the field lines of MWPC. The charged particle produces local avalanche in this high intense field. Thus, one can get position signal from it. If we place a perpendicular wire structure after it, then from that we can also get another position co-ordinate. In this way, one can easily locate a particle in 2-dimensional space. So, MWPC is a Position Sensitive Detector(PSD).

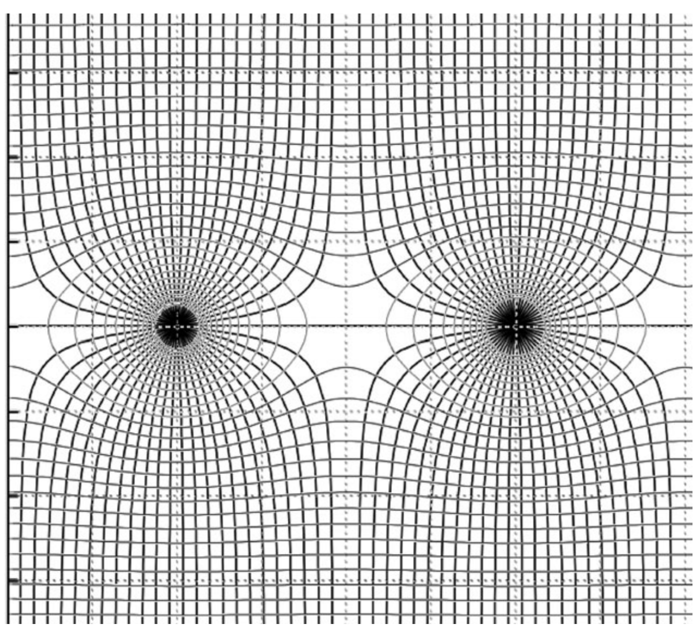


Fig.4 The field lines of MWPC & anode wires[1]

6. Design of MWPC :

1.The Breskin Detector we used, is a 5-stage PPAC-MWPC-PPAC. The active area of the detector was 20 cm × 6 cm. A schematic diagram of the cross sectional view of the detector is shown in Fig.5. There was five wire planes, one anode (A), two sense wire planes (X, Y) and two cathode (C) wire planes.

2.The X and Y sense wire planes were perpendicular to each other and were made of gold coated tungsten wire[20μm diameter],placed 2mm apart. The work function and conductivity of gold is more than tungsten whereas tungsten gives mechanical tolerance to prevent the deformation of wires in high electric field(~600V/cm).

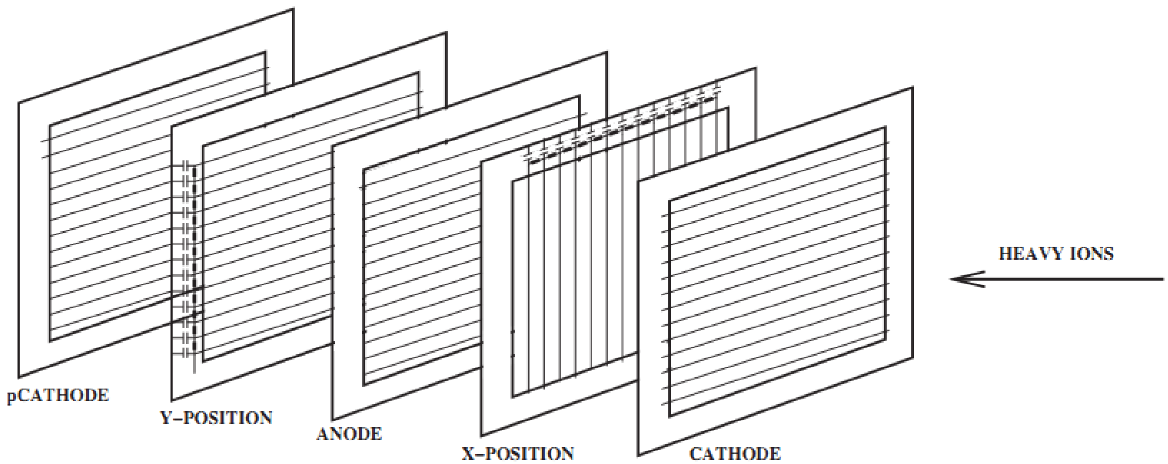


Fig.5. Schematic diagram of the cross sectional view of the MWPC [4]

3. Cathode and anode are separated ~ 1cm whereas the separation between anode(or cathode) and X(or Y) is few mm.

4.The detector is operated at very low pressure(~3 torr) for getting best optimum signal. Since, the mylar foil is too thin, the pressure should be low[7]. Also, at large pressure, the increase of atomic collisions leads to more signal strength,but weakens the timing signal.

5.The X-sensing plane consists of 100 wires while the Y-plane have 30 wires. Hence, minimum uncertainty to locate the particle is 2mm along X and Y. The whole area (200×60 mm^2) is divided into 3000 squares of area 2mm×2mm.So, the probability of arriving two particles at same time at the same location is very low. Thus, it gives excellent efficiency.

6.For Delay line method, X and Y-plane consists of 10 and 3 delay line chip of delay time 20ns respectively. Hence, X and Y plane have end to end delay of 200ns and 60ns respectively.

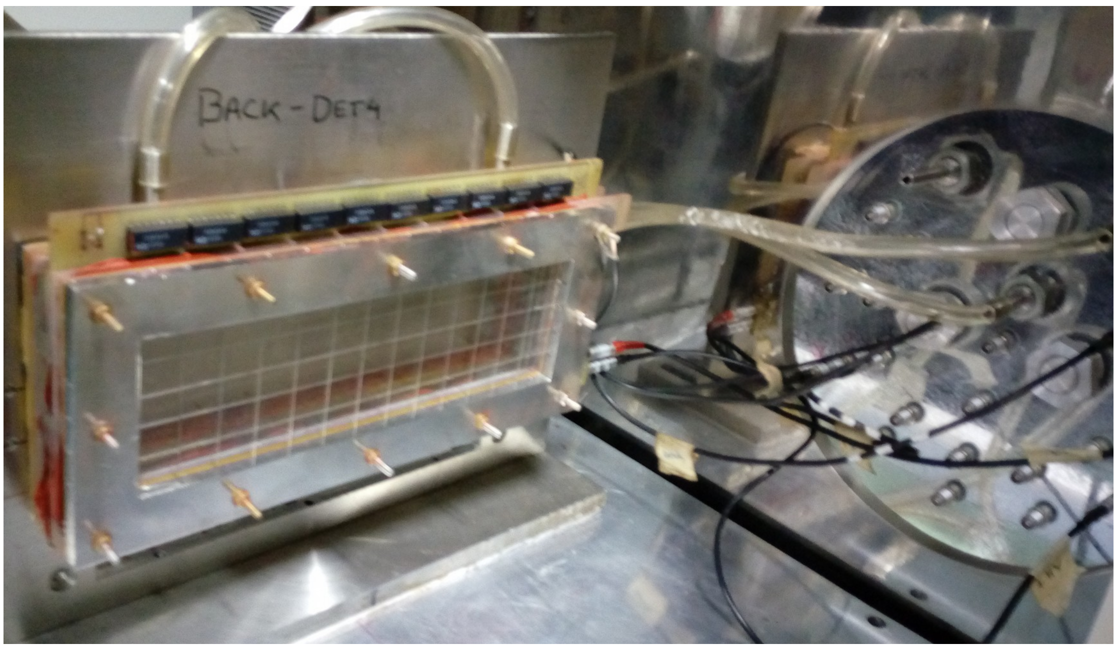


Fig.6 The MWPC in chamber for experiment of fission fragments of Cf^{252}

- **6.1 Choice of Gas:** One of the main criteria of choosing the gas is poor electron affinity[4],otherwise it will absorb the electrons emitted. Also, it shouldn't emit gamma ray during de-excitation otherwise it will create photoelectrons by photo-electric effect by hitting the cathode. So,quenching gases like isobutane is used for continuous flow type detectors. Also it has higher inelastic scattering cross section which leads to a higher loss of energy of the incoming particles as its density is higher compared to other gases. The mobility of electrons in isobutane is also higher, hence a faster rise time is obtained.

- **6.2 What is the advantage of MWPC than others?**

1.If we use single stage MWPC /PPAC,then at low pressure, the loss of energy of the heavy ions is low, so they produce very few primary ions. After amplification in a PPAC (typical gain 10^4) or a MWPC (typical gain 10^5), the signal obtained does not have good timing or position information. So, to improve the primary ionization statistics we use PPAC-MWPC-PPAC [7].

2. It is cheap and easy to construct than the modern scintillation or semi-conductor detector. Also, it has longer lifetime than others.

3.The efficiency of MWPC is excellent (almost 100%). Also, it has a higher event rate due to very small recovery time. Here is no dead time like GM counter. GM counter doesn't measure the energy of incident particle, whereas MWPC measures it and also its trajectory with a good precession.

4.MWPC doesn't show Electromagnetic Interference (EMI) like Spark Chambers and also its slow electronics (comparable to Spark Chamber electronics) consume low power[8].

7.Experimental Set up and Its Electronics:

Signal Processing is one of the most important part of any nuclear physics experiment. The signal from detector is generally very low and filled with noise. Hence, noise reduction is the most important to pick off the useful signal. Actually, noise arises due to the lack of common grounding of various instruments used in the experiment. So, to make all the grounding common, one can use copper grounding cable. Also, the external electric field of environment creates noise. So, we shielded the instruments by aluminum foil (behaves like a Faraday Cage) to penetrate the external electric field. In this experiment, we reduce noise to < 100mV for anode and position signals.

At first, we placed the MWPC in front of a ${}_{98}Cf^{252}$(half life 2.645yr) source inside an evacuated chamber. Fig. 7 (a,b) show the experimental set up of ${}_{98}Cf^{252}$ and MWPC. We use NIM (Nuclear Instrument Module) bus to supply power (N471A,CAEN).Cf-252 is a very strong synthetic radioactive element. It undergoes 96.91% α-decay (to form Cm-248) and 3.09% spontaneous fission (produces ${}_{40}Zr$ with ${}_{58}Ce$, ${}_{42}Mo$ with ${}_{56}Ba$ etc.).

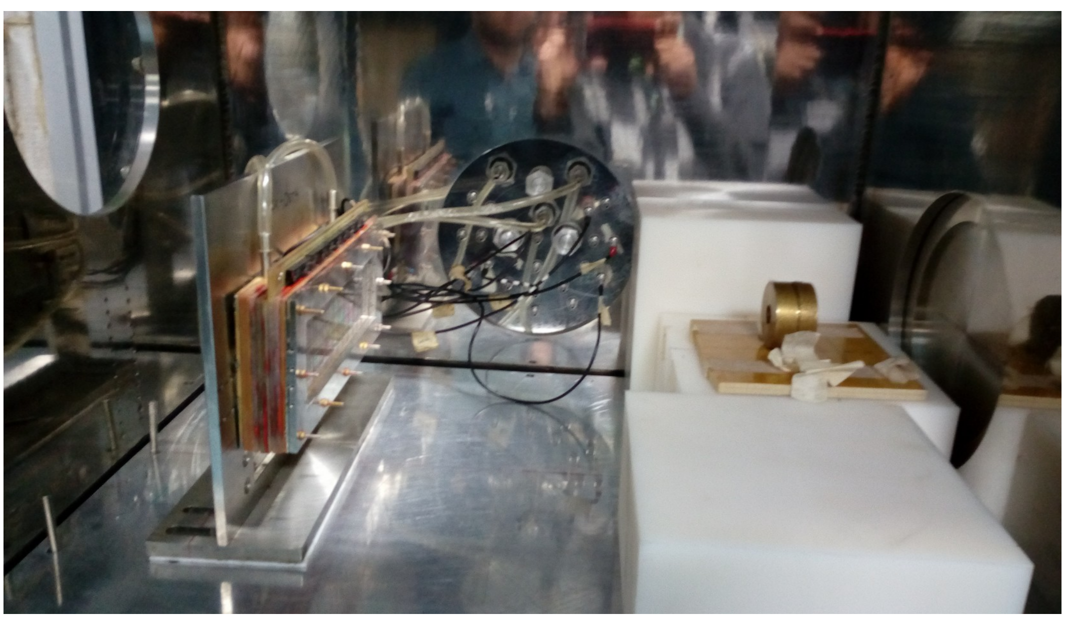


Fig.7(a) MWPC and Cf^{252} source in chamber at CPDA,VECC.

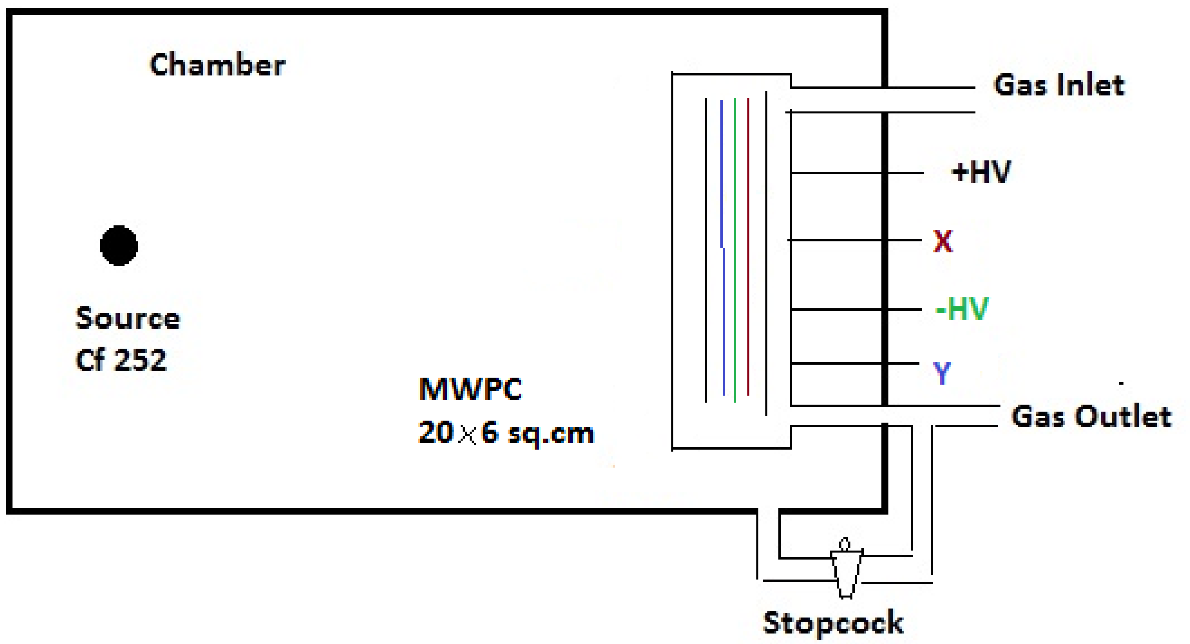
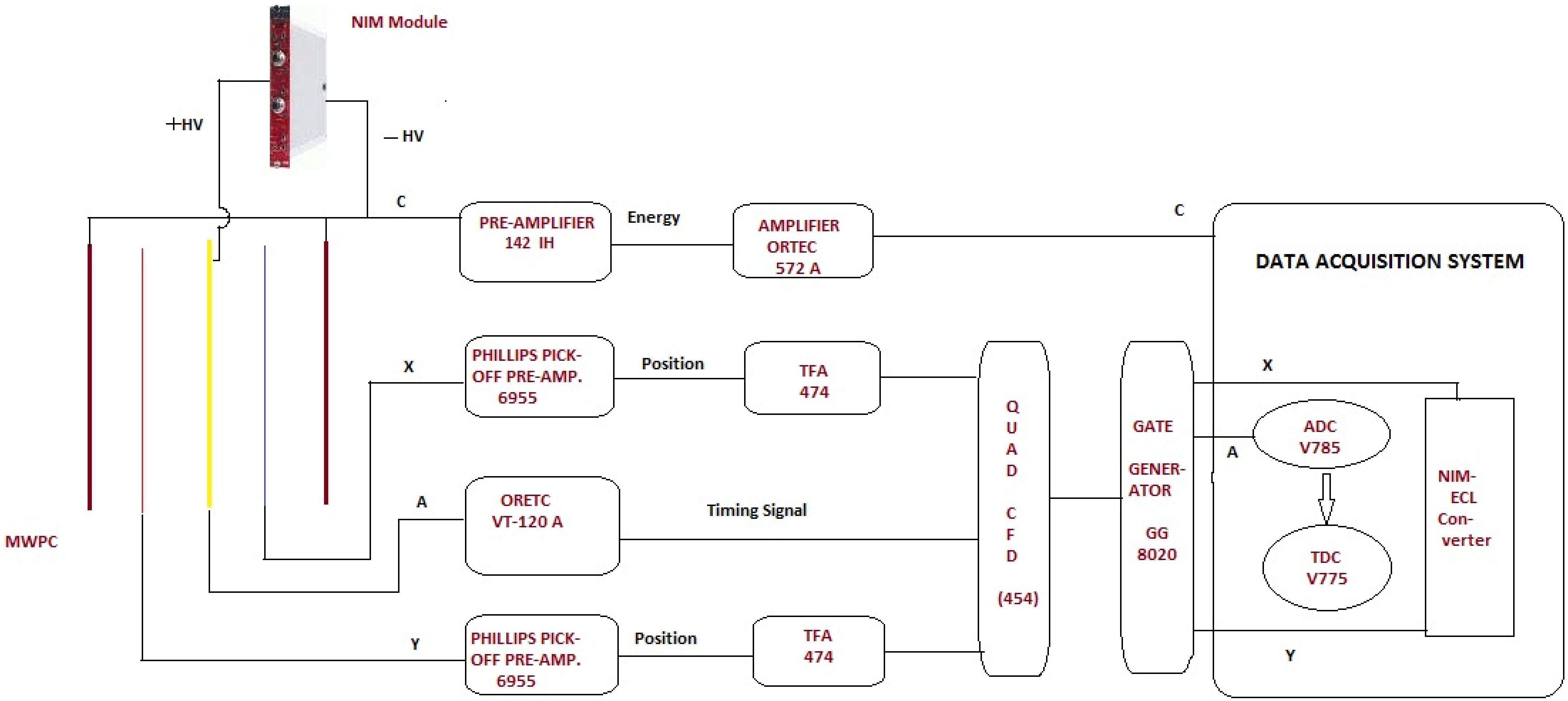


Fig.7(b) Block diagram of source and MWPC in chamber.

The electronics set up is shown in below(Fig.8).

I. Pre-amplifier: A Pre-amplifier is used to couple the detector to the subsequent modules[4]. The weak detector signal amplification, pulse-shaping and impedance matching are the main principle function of it. For anode signal, charge sensitive pre amplifier VT120A (pick off negative pulse; ORTEC) is used whereas for the position signal, current sensitive PHILLIPS PICK-OFF 6955B (with gain 100) pre amplifier is used. And for energy signal, pre-amplifier 142IH (ORTEC) is used. The impedance across the pre amplifiers was 50 Ω.

II. Amplifier: Amplifier is used to amplify the output signal from pre-amplifier and shape its pulse by using CR-RC circuits. But it is generally slow [4],so we don't use it for timing signals. Although an amplifier ORTEC 572A is used for energy spectrum.


NIM Module
+HV
— HV
C
PRE-AMPLIFIER 142 IH
Energy
AMPLIFIER ORTEC 572 A
C
DATA ACQUISITION SYSTEM
X
PHILLIPS PICK-OFF PRE-AMP. 6955
Position
TFA 474
Q U A D C F D (454)
GATE GENER-ATOR GG 8020
X
ADC V785
A
NIM-ECL Con-verter
TDC V775
A
ORETC VT-120 A
Timing Signal
MWPC
Y
PHILLIPS PICK-OFF PRE-AMP. 6955
Position
TFA 474
Y

III. Timing Filter Amplifier (TFA): Generally the timing pulse output from the pre amplifier, with a quick rise time, is too small to trigger the time pick off unit, so an amplification of the pulse is required[4]. So a timing filter amplifier (ORTEC TFA 474) is used for X,Y sensing signals. Some noise is also reduced by adjusting the time constant of the differentiator-integrator circuit[4].

IV. Constant Fraction Discriminator (CFD): A Constant Fraction Discriminator (CFD) is a time pick off unit, which picks-off the timing pulse from the TFA shown in Fig.9. This process allows the elimination of the problems of walk and jitter [2][3].

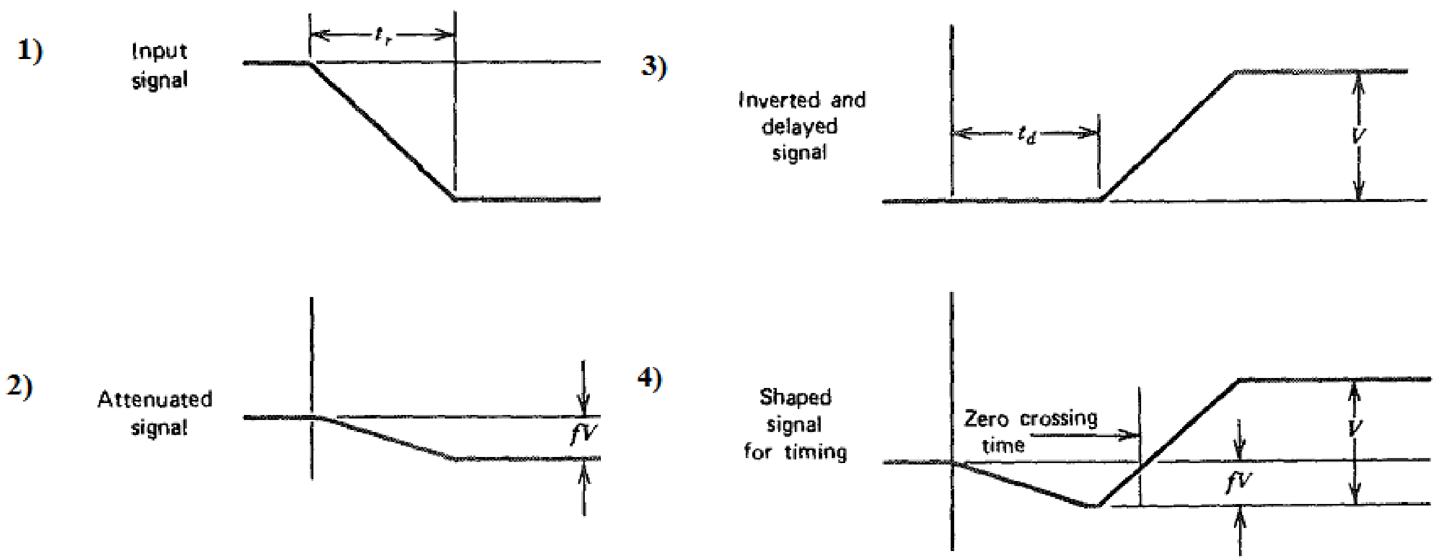


Fig.9. The process of CFD[2]

The process is multiplication of the pulse by a constant fraction, inversion of the original pulse, then addition to the fractional pulse, followed by pick off at the zero cross over[4]. The negative outputs of position and anode signals are fed into a QUAD CFD 454(CANBERA). Appropriate delays are given between start (anode, delay 2ns) and stop (for X,Y- delay 8ns) signals [delay is 4ns/meter].

V. Octal Gate Generator: The outputs of CFD are fed into Octal Gate Generator (ORTEC GG8020) to generate appropriate gate in which DAQ can work.

VI. Time to Digital Converters (TDC): Time to amplitude converters are modules which converts the time interval between two pulses into proportional amplitude. This is done by feeding START input, which starts a charging of a capacitor and continues till a signal is encountered in the STOP input. This results in a signal with amplitude which is directly proportional to the interval between the two inputs[3]. This analog signal is converted into logic pulse. In our experiment, we use 12-bit Time to Digital Converter (TDC, V775;CAEN) for anode signal.

VII. Analog to Digital Convertors (ADC): It converts analog signal to digital signal. The energy analog pulse is digitized by ADC (V785, CAEN).

The X,Y output from GG8020 is fed into NIM-ECL (Emitter Coupled Logic)Translator . Then all signals are analyzed in DAQ software in computer.

8. Results:

In the experiment using isobutane , the detector is tested and we conclude that the detector is working satisfactorily in CPDA lab, VECC. The picture of anode signal,energy signal(from cathode) and position signal(X,Y) after pre-amplifier are attached below:

Anode Signal:

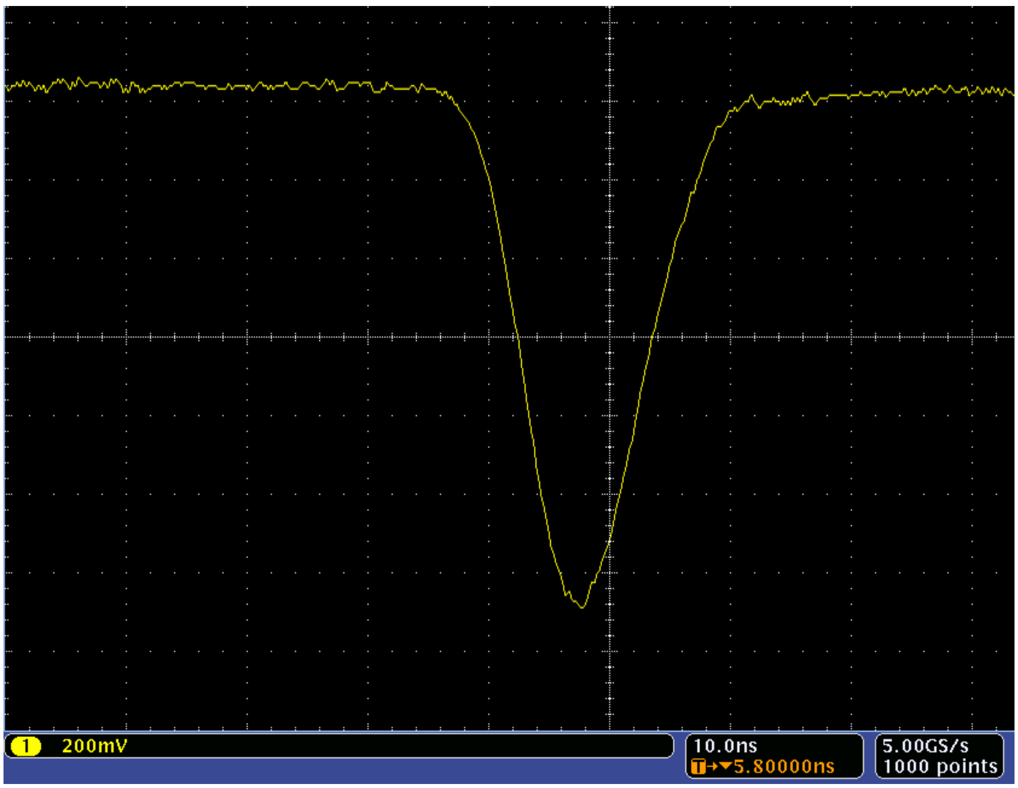


Fig.10. Anode signal (Timing signal) with rise time in ns.

Clearly, we see that the timing pulse(anode pulse) has maximum height of ~1.3V with rise time ~6ns.

Energy Signal:

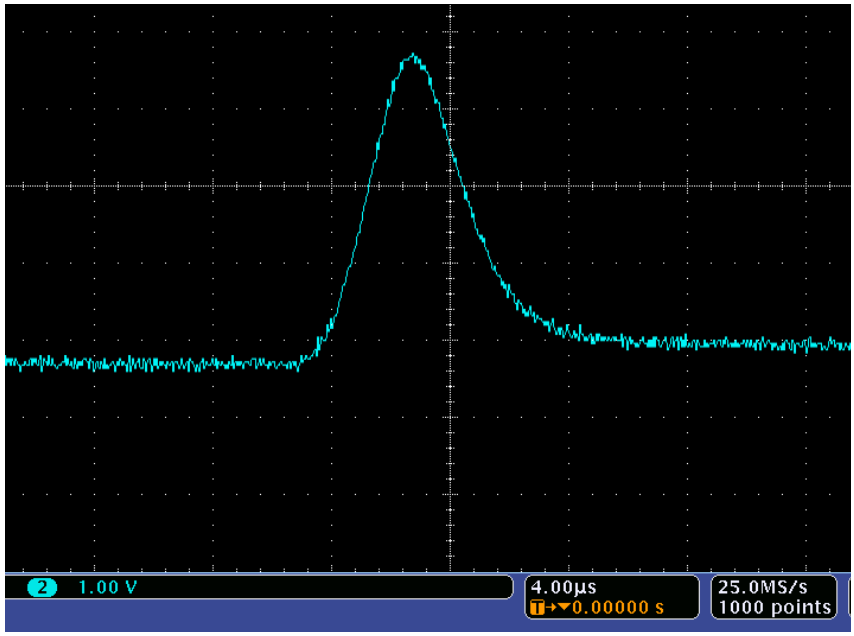


Fig.11 Energy signal using isobutane

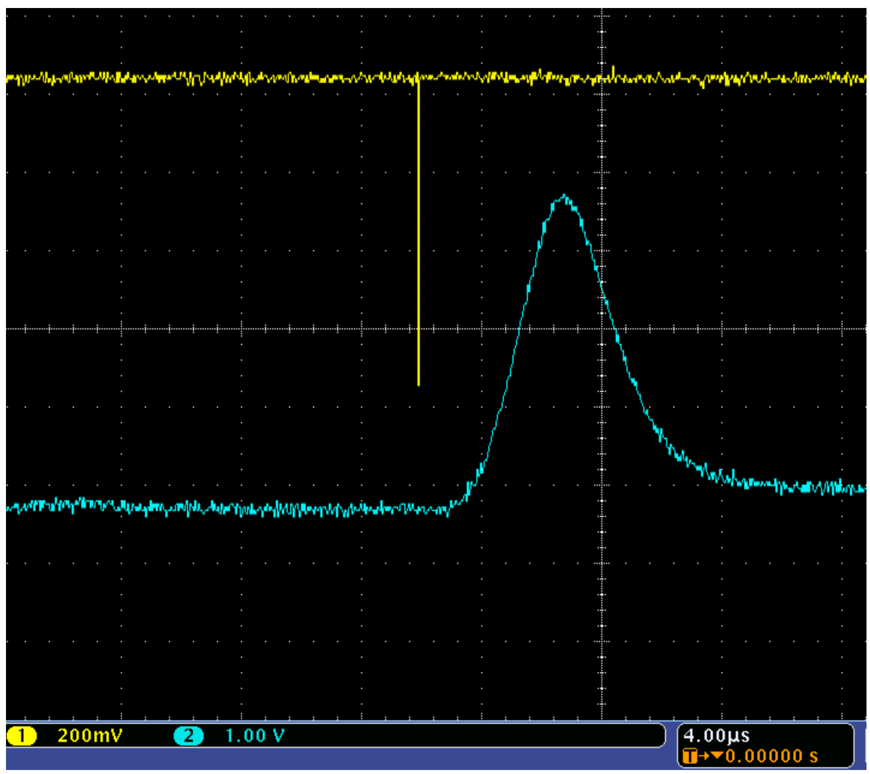


Fig 12. Anode signal (yellow) and Energy signal (blue)

X-position Signal:

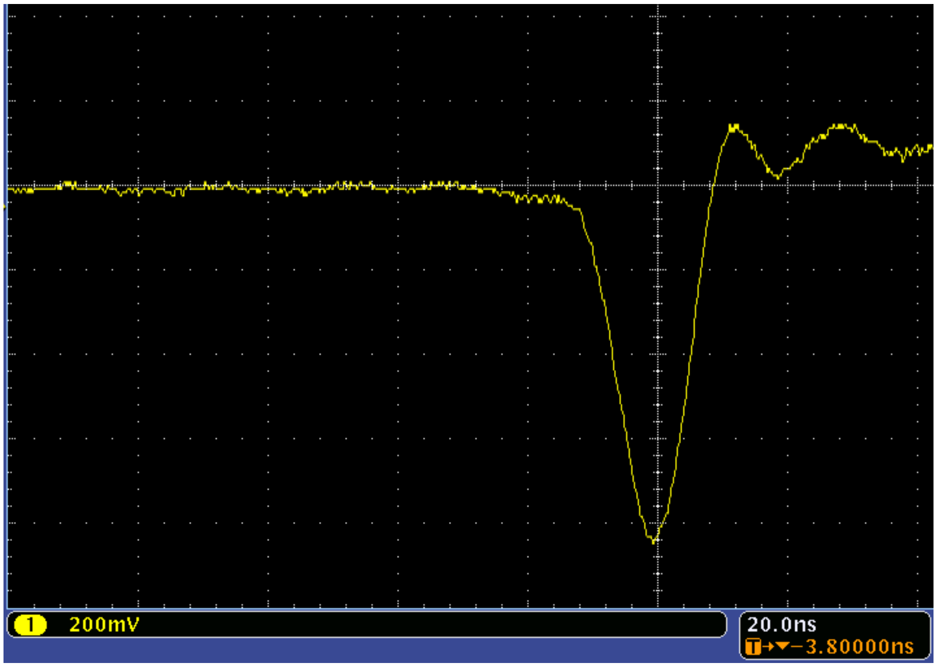


Fig.13. X-position signal(After TFA)

Y-position Signal:

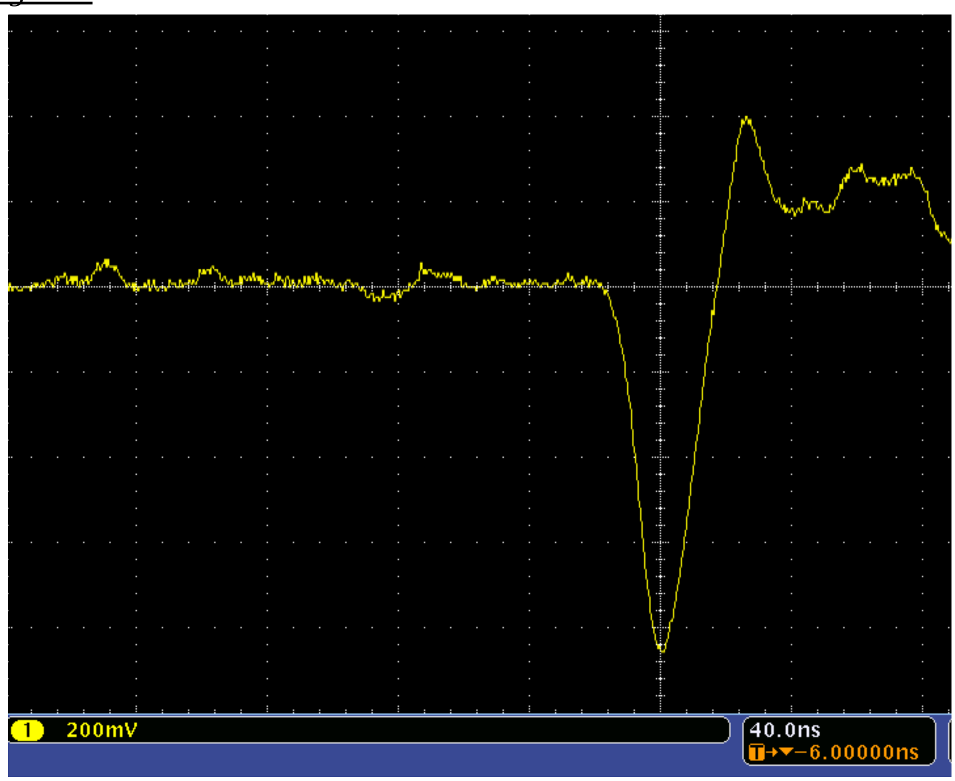


Fig.14. Y-position signal (After TFA)

Noise in Anode Signal:

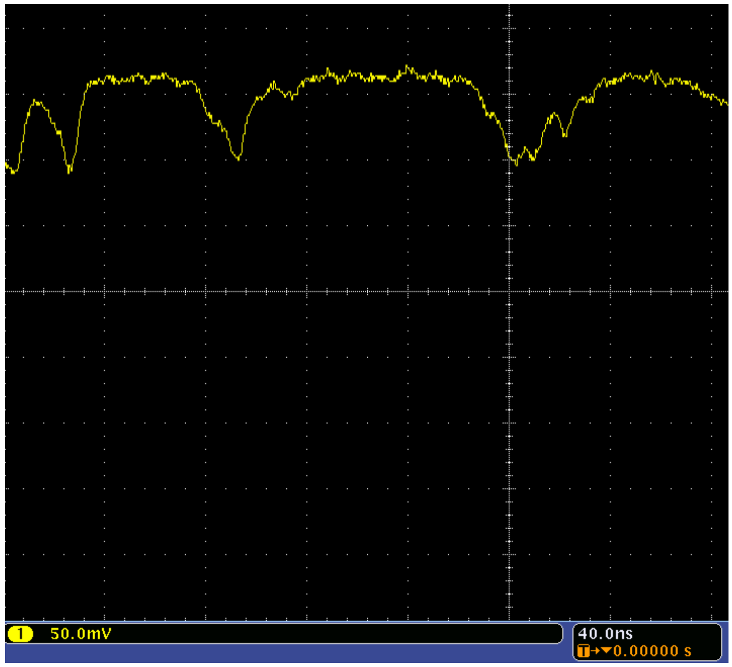


Fig.15 Noise in timing pulse

So, we can easily construct the following table from the above pulses:

Gas	Isobutane
Operating Pressure	3.024-3.026 torr
Operating Bias Anode Cathode	 +332V -243V
Anode Pulse Fission Fragments Noise Rise time	 ~1.3V ~50mV ~6 ns
Energy Pulse	~ 4 V
Position Signals X Y	 ~840mV ~1V

These signals are fed into QUAD CFD (ORETC 454) and 12-bit (having 4096 channel) TDC (CAEN V775).The outputs are analyzed in DAQ software and we plot the following spectrums to test the detctor:

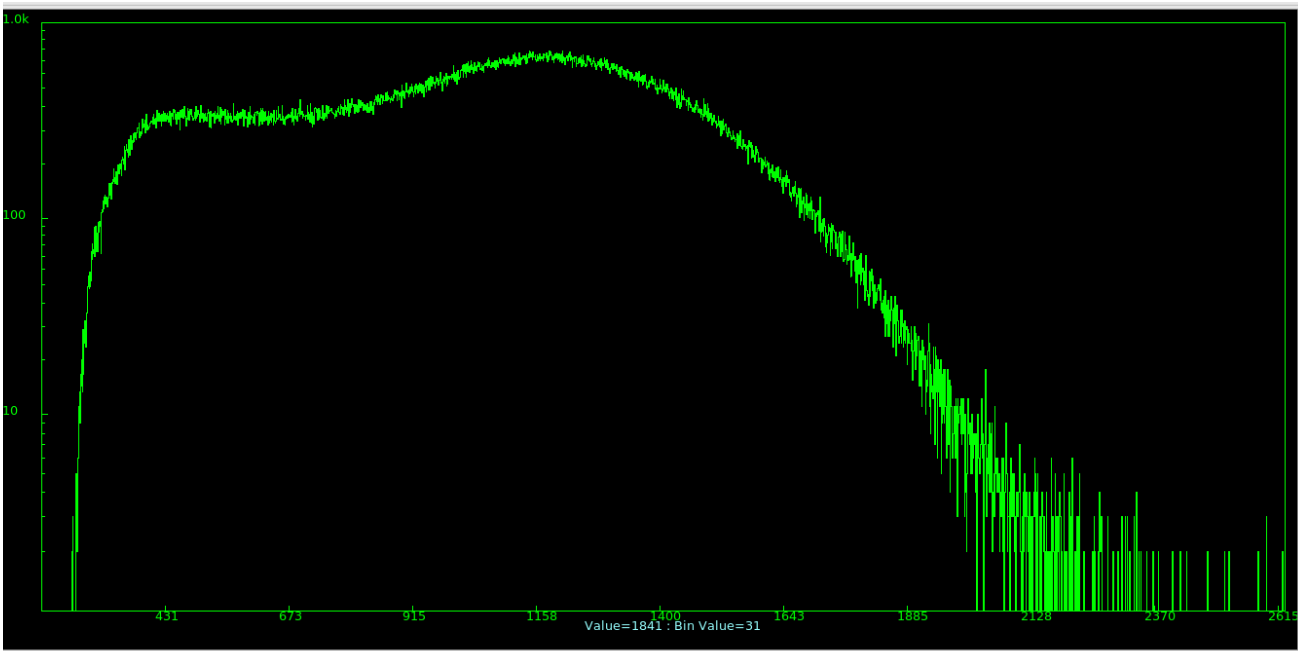


Fig.16 No of channel (Energy can be calibrated) vs No of counts

(in logarithmic scale)

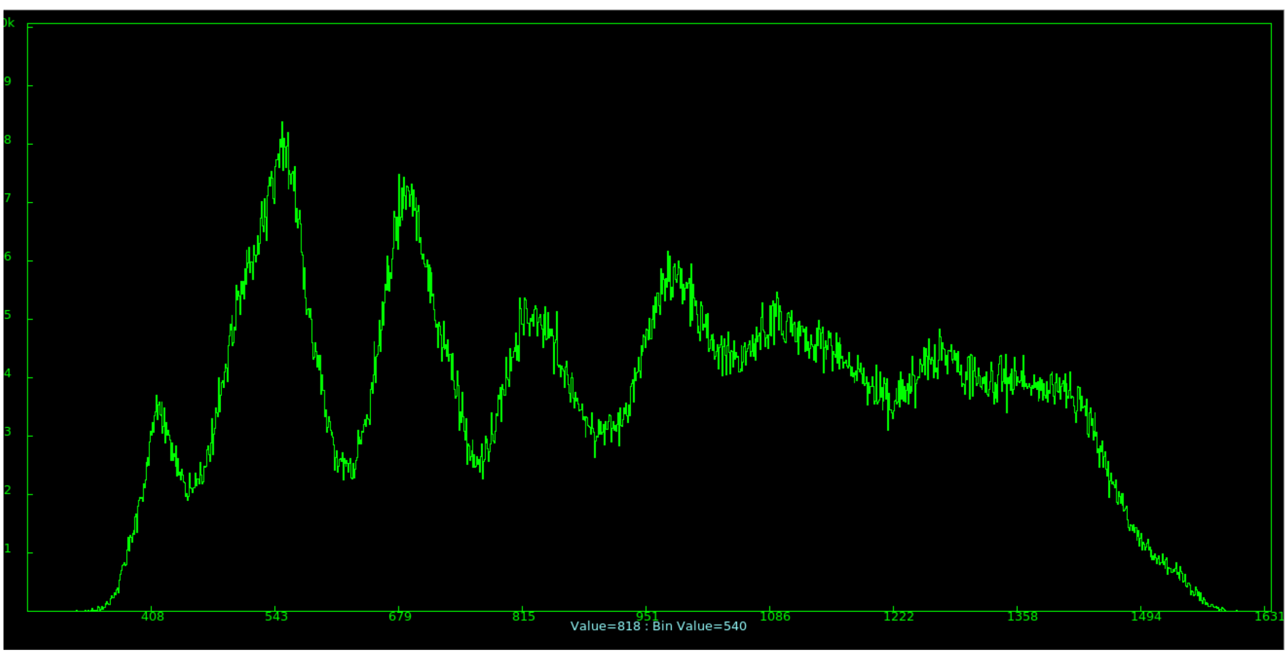


Fig.17 No of channel vs No of Counts for Y-sensing plates

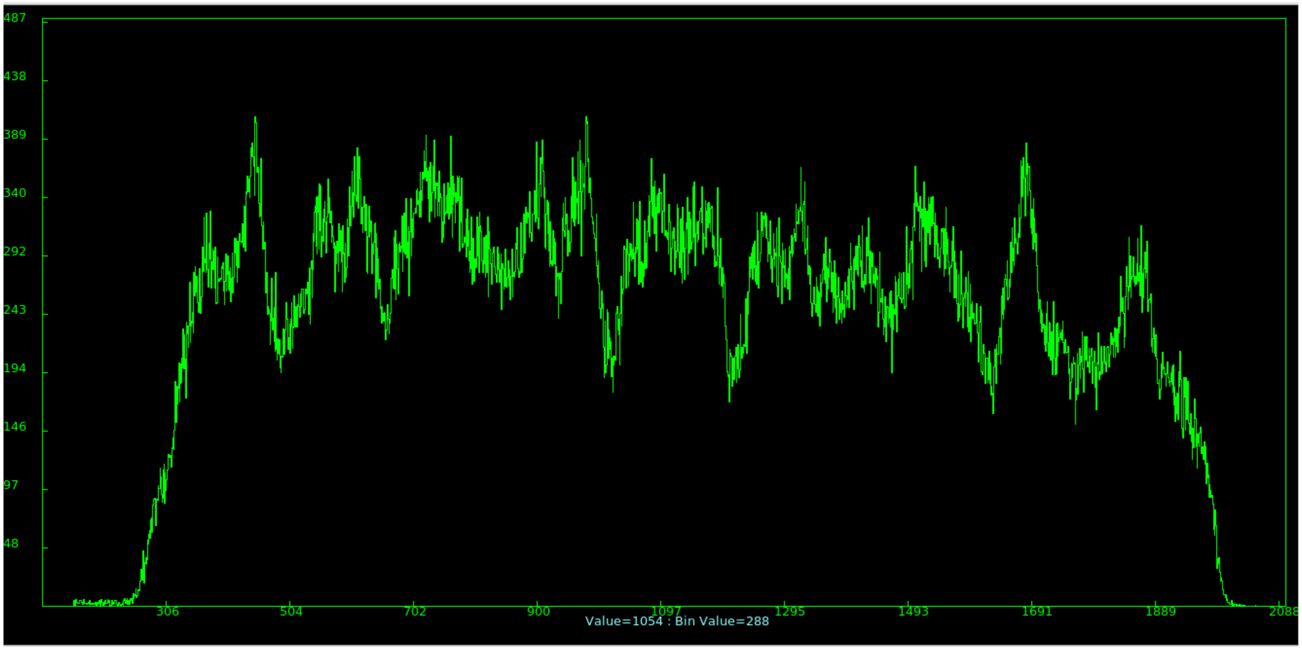


Fig.18 No of channel vs No of counts for X-sensing plates

One can easily calibrate the channel with the value of X,Y coordinate. The total channel in X-spectrum is equivalently to 20cm and for that in

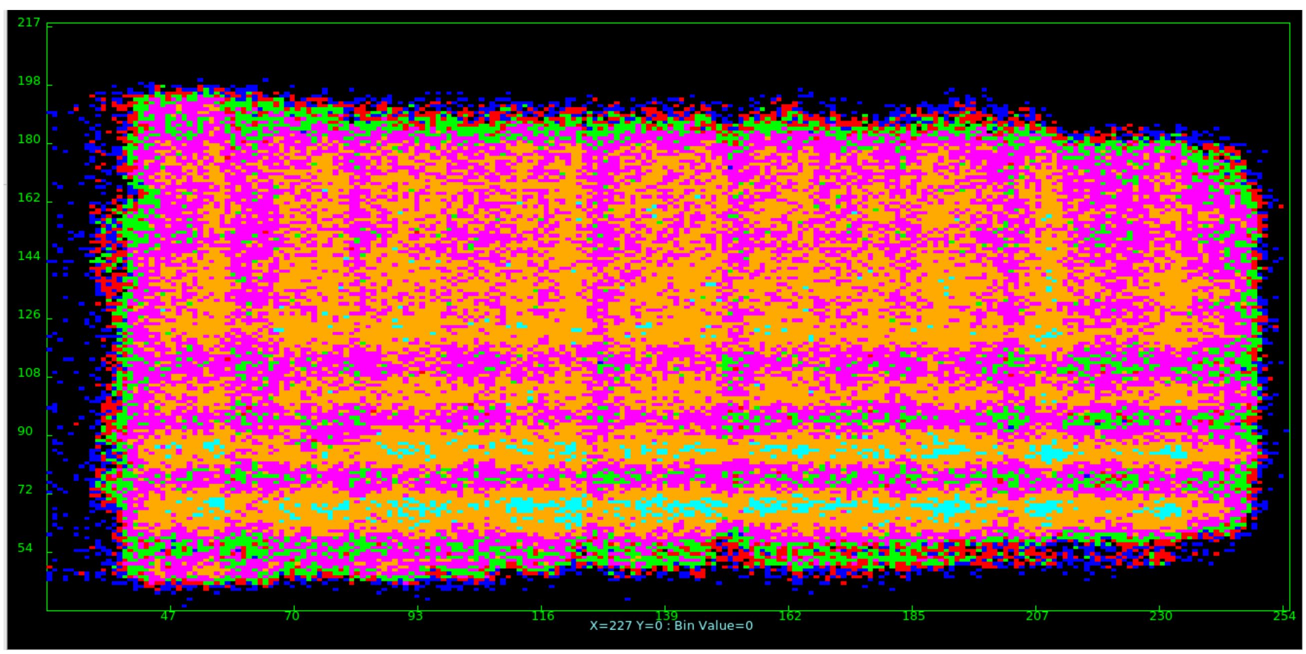


Fig.19 X-Y spectrum (2-dimensional plot)

Y-spectrum is 6cm. So, one can find the position of particles from the position (X,Y) spectrum. The dip in the X,Y spectrum represents that the no of counts are smaller than its surroundings. Actually, the cross-wire that supports the mylar foil in detector window is opaque for fission fragments which leads to the dip in spectrum.

We also study the 2-dimensional X-Y spectrum (Fig.19)of the particle. Here, the no of particles in a point is represented by various colour.

We run the detector for 1hr 8min (=4080sec) and get the total event counted is 443021 from X-Y spectrum.

So, counts rate is $\frac{443021}{4080} \simeq 108$ counts/sec.

➢ Comparison between symmetric and asymmetric applied bias:

In this project, we also study the anode signal (i.e. timing signal) for a fixed anode-cathode bias for two cases with isobutane operated in 3.020 torr :

(I) Bias is applied in anode and cathode symmetrically i.e. same.

(II) Bias is applied in anode and cathode asymmetrically i.e. different.

(I). Bias is applied symmetrically:

We apply symmetric bias across anode and cathode. The picture with details is attached:

Operating Bias: Anode: +281V

Cathode: -280V

Rise time: Approx. 6 ns.

Max. height of pulse: 1V

Although the maximum height of the anode pulse is 1 V.

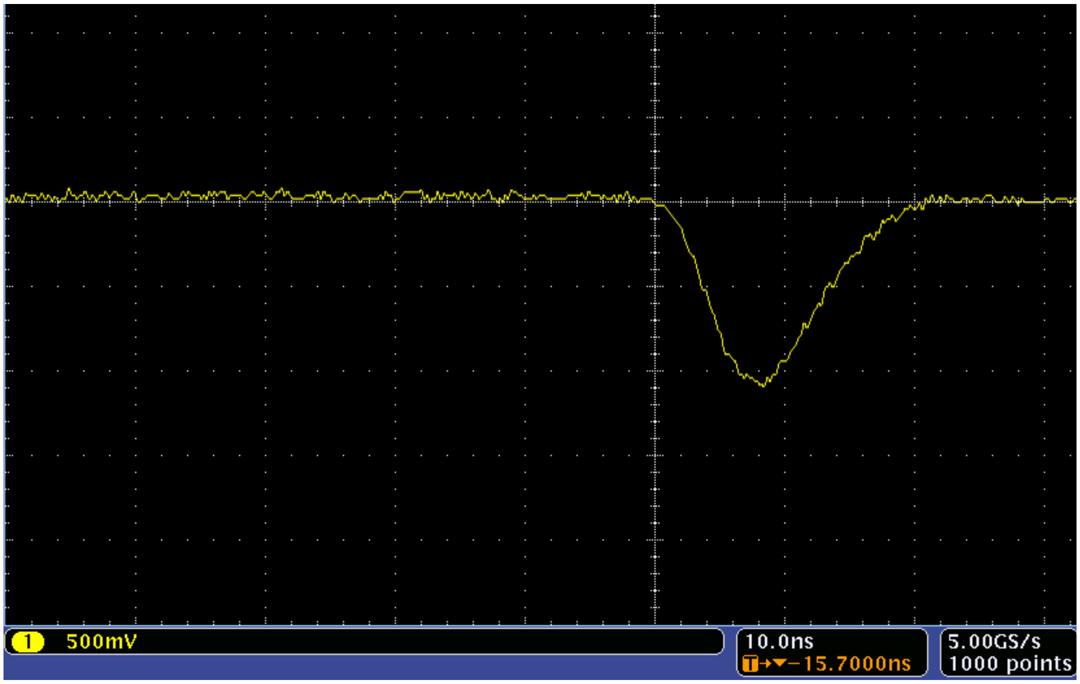


Fig. 20. Bias is applied symmetrically across the electrodes

(II). Bias is applied asymmetrically:

We apply symmetric bias across anode and cathode. The picture with details is attached:

Operating Bias: Anode: +328V

Cathode: -239V

Rise time: Approx. 6 ns.

Max. height of pulse: 1.1V

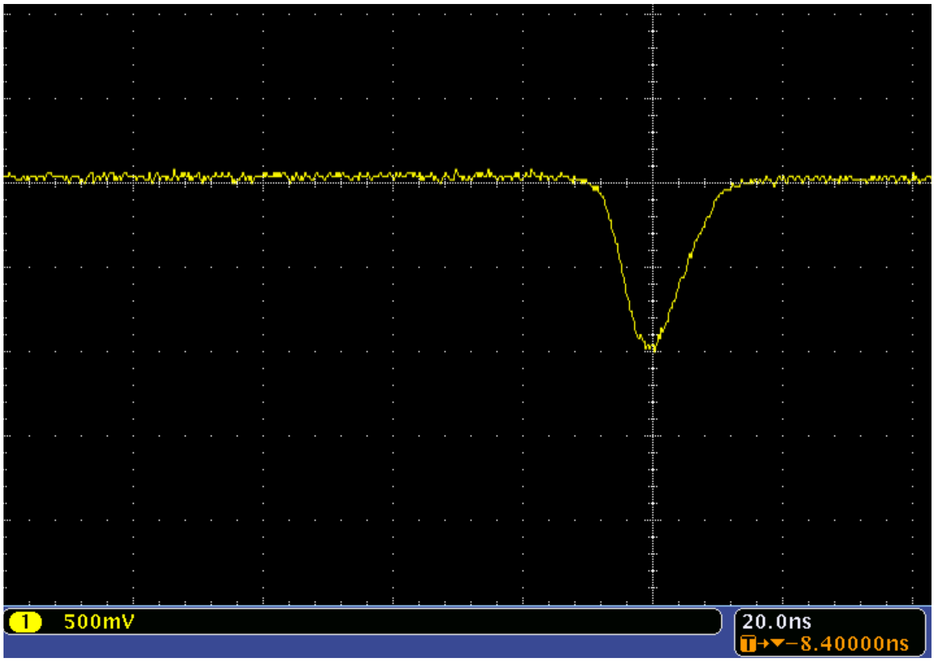


Fig.21. Bias is applied asymmetrically across the electrodes

Although the maximum height of the anode pulse is 1.1 V.

From the experiment, we can conclude that for a fixed anode to cathode voltage, bias should be applied asymmetrically across the electrodes to get better response, but for both cases, rise time is approx. 6ns ;so, rise time of the pulse doesn't depend on the nature of applied bias.

9.Conclusions:

In this project, we find that the MWPC is working satisfactorily and it is now ready to use in any nuclear physics experiments or high energy cosmic ray experiments where determination of particle's trajectory with great accuracy is most important. Noise is also optimized upto ~50mV for anode whereas <100mV for X,Y plates. Although the energy curve [Fig.16] isn't properly Gaussian in nature due to noise in experiment,but from Fig.19 we can conclude that the position sensing plates are working very well. Also, we see that the asymmetric bias in electrodes leads to better response under very low pressure (~3.02 torr) of isobutane.

The detector can be used in nuclear fission experiments to find the angular distribution of the fission fragments. The study of angular distribution of the fission fragment constitutes an important part in understanding the dynamics of fission. The detector can also be used in co incidence with neutron detectors and other charged particle like proton detectors for fission dynamics studies [4].

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