Abstract

This project report discusses the fabrication, setting up and testing of a cosmic ray telescope which is used for muon detection. These telescope tags muons passing through it, using which efficiency, timing and other parameters of newly fabricated particle detectors are measured. We begin this report by outlining the design and characterization of a prototype glass Resistive Plate Chamber (RPC) detector. The motivation for the development of RPC is that larger version of this detector is proposed to be used in India based Neutrino Observatory (INO) experiment which is right now under planning stage. As a part of this project, we have constructed the scintillation paddles which are used to set up the muon telescope. We have then set up a data acquisition system for testing the paddles. We have used these paddles for setting up the telescope and finally tested the telescope itself for the muon detection. The telescope that is being setup may be used to test and characterize the RPCs which will subsequently be mass produced for the INO experiment. In this report we describe the construction of the scintillator paddles. The report also describes the testing of the paddles for their muon detection efficiencies and timing resolution.

CHAPTER 1

Introduction

The detection of any energetic charged particle in a detector is based on the principle that while traversing a medium it looses energy by ionizing the medium. As it passes through matter, the charged particle knocks out the loosely bound outer electrons. If there exists a suitable mechanism in the detector to collect the knocked out electrons and the ions then the detector can serve the purpose of measuring the characteristics of the incident charged particle. The detector essentially measures the energy deposited by the charged particle and the time the particle entered the detector medium. For the detector to measure the energy of the charged particle it is essential that it should loose all its energy in the detector. For it to measure the timing properly it is essential that it should collect the ions and electrons swiftly.

In the present context of detecting the Resistive Plate Chamber (RPC) which will be used for India based Neutrino Observatory (INO), the detector would be used to detect the neutrinos. There will be several layers of these RPCs through which the neutrinos would be tracked. One therefore needs a detector which has very good timing. The RPC which have been used in experiments elsewhere in USA and CERN have shown to have very good timing properties. In addition, there rugged design and low cost make them almost ideal for the use in INO.

Once the detector has been fabricated one needs to test them. For the detector in question therefore, one would need neutrinos. However, the neutrinos being neutral and very weakly interacting cannot be directly accelerated. One often utilizes the pion decay to produce these neutrinos. To produce the pions also one needs an accelerator of sufficient energy, which our country at present does not have. However, another source of neutrinos is the cosmic rays. The cosmic rays when they enter the earth's atmosphere produce muons copiously. Due to their long life time (of the order of 10^{-6}) they are the most energetic particles at sea level.

A muon interacts with matter by electromagnetic force and hence can travel large distances and commonly reach the ground. Like other charged particles, they lose energy proportional to the amount of matter they pass. This is proportional to the density (g/cm^3) times the path length (cm). This "interaction length" has units of grams per square centimeter.

Muons lose energy at a fairly constant rate of about 2 MeV per g/cm^2. Since the vertical depth of the atmosphere is about 1000 g/cm^2, muons will lose about 2 GeV to ionization before reaching the ground. The mean energy of muons at sea level is still 4 GeV. Therefore the mean energy at creation is probably about 6 GeV. Muons arrive at sea level with an average flux of about 1 muon per square centimeter per minute. This is about half of the typical total natural radiation background.

Muons are produced by the weak decay of pions into a muon and a muon anti neutrino. The muon differs from the electron in that it is unstable, decaying with an average lifetime of 2.2×10^{-6} sec (2.2 microseconds) into an electron or positron and a pair of neutrinos.

Pions decay into the muons as

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \text{also} \quad \pi^- \rightarrow \mu^- + \nu_\mu^-$$

Now the muons decays as

$$\mu^{+/-} \rightarrow e^{+/-} + \nu + \nu^-$$

Due to these characteristics of the muons, they are preferred to use in the neutrino detection. And we will be using this decay of muons into an electron and neutrinos to test the Resistive Plate Chambers.

To detect and trace these muons, we are making the scintillation paddles which will easily detect and trace them. The requirement for the paddles is that they should have good timing capability and high efficiency.

1.1 Basic Detectors

In order to understand the working principle of an RPC we review some of the basics of detection mechanism on which these detectors are based.

1.1.1 Gaseous Ionization Detector

Basic configuration of such a detector consists of a cylindrical container with conducting walls and a thin end window. Along its axis, a conducting wire is suspended (as anode) on which a positive voltage +Vo, relative to wall (as cathode) is applied. The container is filled with gas. When radiation penetrates the cylinder, a certain number of electron-ion pair is created. This number of pairs created is proportional to the energy deposited in the counter. With the application of electric field, the electrons are accelerated towards the anode and ions towards the cathode where they are collected. If the electric field is strong enough, the free electrons are accelerated to energies where they are also capable of ionizing gas molecules in the cylinder. The electrons librated in these secondary ionizations then accelerate to produce still more ionization and so on. This results in an ionization **avalanche** or **cascade.** Due to the greater mobility of electrons, the avalanche has the form of a liquid drop with electrons grouped near the head and slower ions lagging behind. When such avalanche increases in number they form a streamline of continuous flow of charge from one electrode to the other. This forms a **streamer pulse.** The pulses are collected by appropriate read-out electronics.

1.1.2 Scintillator: Plastic Scintillator

As mentioned earlier the cosmic muons can be tested by using the resistive plate chambers. However, the muons can enter our detector from any side. We therefore, need to define the path of the muons entering our detector. This is done by placing what are called paddles in front and behind our RPCs. Only those muons which pass through both the paddles as well as in RPC would then be used for studying the characteristics of the RPCs. Thus the scintillator paddles which I have made and tested as a part of this research project will play a very important role in design and testing of any RPC. This therefore form an essential system for any such venture.

CHAPTER 2

Resistive Plate Chambers (RPC)

An RPC is a particle detector utilizing a constant and uniform electric field produced by two parallel electrode plates, at least one of which is made of material with high bulk resistivity. The gap between the electrodes is filled with a suitable mixture to be discussed later. When the gas is ionized by a charged particle crossing the counter, a discharge is created in the electric field. The discharge is however prevented from propagating through the whole gas by the quenching action of the constituent gases in the mixture, thus avoiding the possibility of secondary discharges originating in other parts of the detector. As due to high resistivity of the electrodes, the electric charge quickly dies off in a limited area around the point where the discharge occurred. The discharge produces the sparks which are counted by appropriate read out electronics.

2.1 RPC Theory and Operation

The basic components of RPC are a cuboids container with parallel electrodes, a mixture of gases. The cuboid container is designed in such a way to provide the right volume for the gas mixture and at the same time provide the right geometry for the attachment of an anode and cathode as shown in figure.

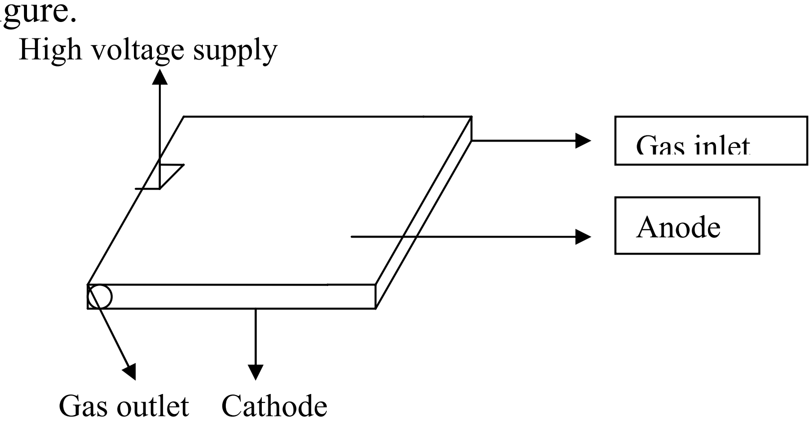


Figure: Diagram of basic RPC

High voltage is used to supply an electric field in the direction from the anode end to the cathode. In some construction a spacer is used to ensure the distance d as shown in figure which is a constant between the anode and cathode. This in turn will provide a uniform electric field E=V/d over the entire volume.

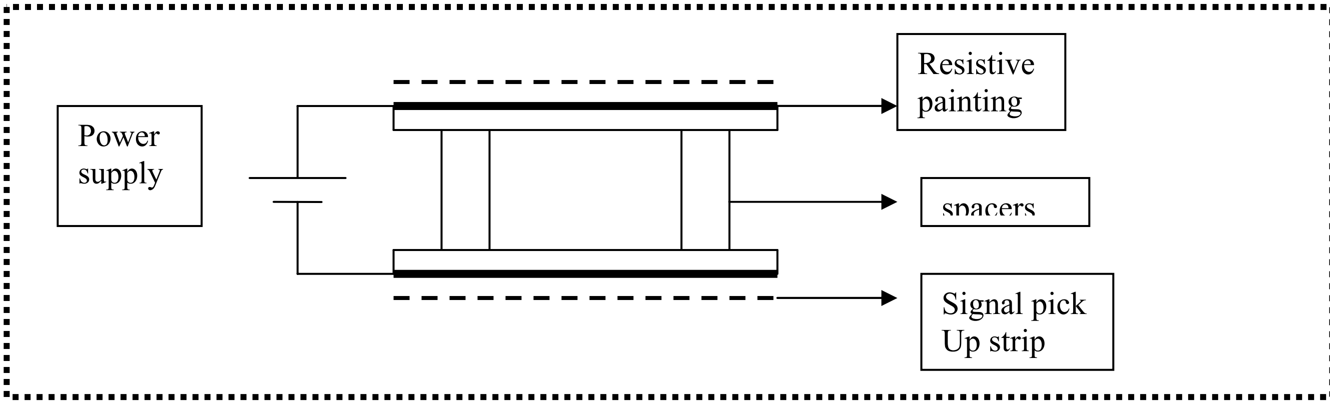


Figure: Glass RPC layout

The two parallel electrodes are made up of float glass with volume resistivity of 10^{12} Ω-cm at the room temperature. The two electrodes 2 mm which are kept at 2 mm apart by means of a suitable NORYL spacers. These spacers sustain both electrodes ensuring a gap tolerance at the level of few microns for uniform working condition in such a large apparatus. The gap between two electrodes defines the gas volume where the particle detection occurs.

The use of highly resistive material as electrodes ensures that the spark discharged just a limited area around the spark location. The time to recover the

Electric field depending on the electrode resistivity is given by,

$$\tau = RC$$
$$\approx (\rho * l/A) * (k\epsilon_0 A/l)$$
$$= \rho k \epsilon_0$$

Where

ρ = the glass volume resistivity
ϵ_0 = permittivity of free space
k = dielectric constant of material

This avoids the self sustaining sparking.

The read out of the detector will be performed with the help of external pick up aluminium strips which picks up the induced pulses allowing a bi-directional localization of the crossing particles along with the time information.

The two glass plates are joined by gluing with spacers and we have to make sure that the possible variation of gas pressure does not change the distance between the electrodes. The high voltage will be applied to the electrodes by means of resistive coating of graphite. Here we use glass electrodes for its high mechanical stiffness and surface quality. The resistive layer is applied directly on the outer side of both glass plates.

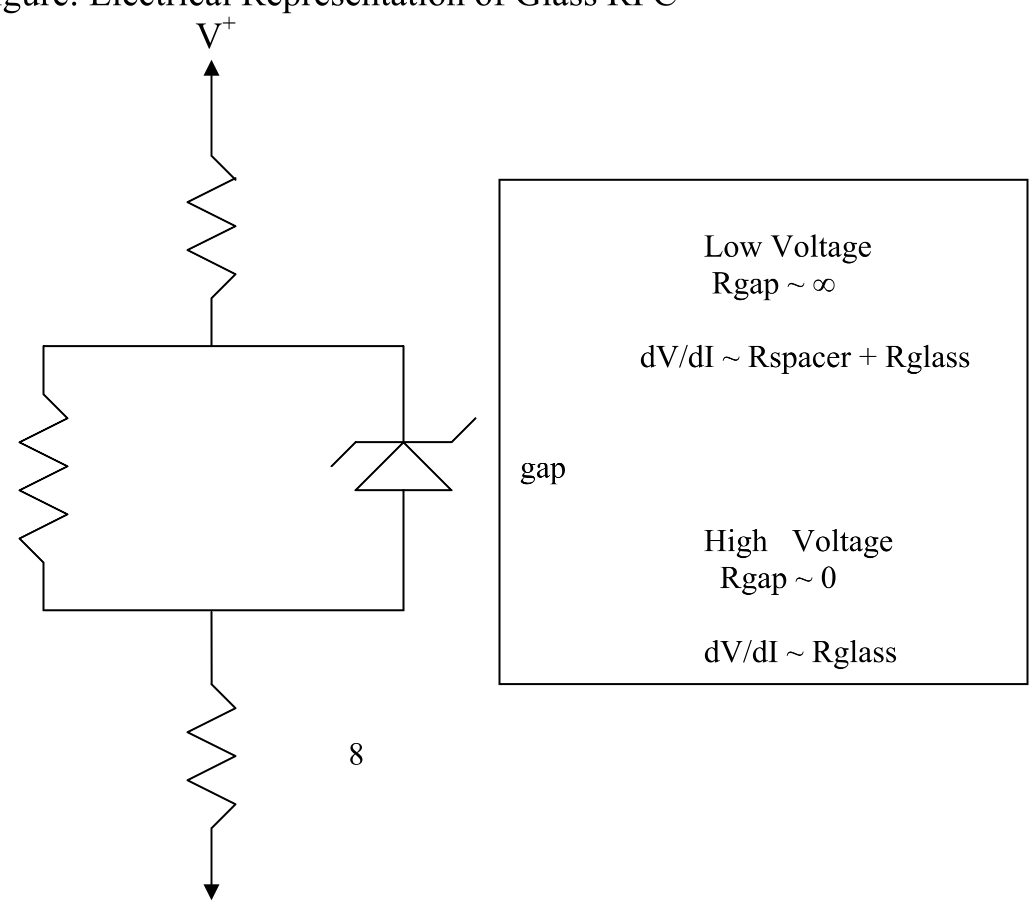
Here the resistive plate preferred because of two functions:

It is conductive enough to serve as the anode and cathode

It is resistive enough to prevent itself from conducting away signals from signal pick up configuration.

At low voltage the gas mixture is insulating so the current passes only through the spacers. At high voltage the gas mixture is shorted out because of the discharge and this make the gas mixture to act effectively as a conductor. As result of the effective voltage is applied on the glass electrodes as shown in figure which results in a high current.

Figure: Electrical Representation of Glass RPC



The gas mixture which we are going to use will be a mixture of Ar, Butane and Freon which is nonflammable and non-ozone depleting in character. The Butane prevents a secondary streamer by absorbing efficiently UV photons which are radiated from a de-excited Ar molecule. Where the excited Ar is mainly formed through a collision of Ar^+ ion and Ar molecule with electrons in the primary streamer.

Freon has high electron affinity and reduces the streamer size from spreading transversely due to electron capture.

For a minimum working of voltage noble gases are usually chosen since they require the lowest electric field intensities for avalanche formation. Because of its higher specific ionization and lower cost argon is usually preferred.

Under appropriate gas mixture (let 30% Ar, 8% Isobutene, 62% Freon) and electric field configuration, the detector is operated in streamer mode. Where along the path of the charge particle ion electron pairs are formed due to interaction with the gas molecules. The ion pair formation is more likely a stochastic process. There is also a chance of secondary ionization caused by a photon emitted by excited molecules which travel to other part of the container to cause further ionization. Which are so large that the space charge created distorts the electric field eventually causing a discharge in the detector gas.

A quencher gas is added to the original detector gas to control and localize this discharge in the form of streamline. The streamers are picked up by the external strips. In this case the streamer choose low resistance path for the flowing. The side strips are also capable of picking the streamer but it should be less than the main strips.

Typical signal amplitudes of the order of 100-200 mv/50Ω are observed corresponding to a charge of about 100-200 pc (which depends on the intensity of the applied field).

2.2 RPC Fabrication

In this section we will discuss how the RPCs were fabricated earlier.

The fabrication was took place in following steps:

- A pair of float glass are first washed and dried to make them free of streaks and other potential contaminants. The glass plates are then glued to each side of four edger's.

• A spacer is glued between the glass plates to give a precise distance of 2 mm required for uniform electric field between the glass plates. The spacers in between the glass plates should be slightly smaller than edgers in order to keep the gas uniformity inside the chamber.

• The spacers are created on one of the four edgers for fixation of two gas nozzles.

• Two tubes are used for flowing in the gas mixture at an atmospheric pressure through the RPC and for letting the gas to flow out.

• The presence of any substance inside the chamber can affect the system, so before joining the glass plates we have to check it.

• After making the glass chamber, it is coated with graphite uniformly on both sides (graphite being a good conductor). After graphite coating, the resistance of the whole electrodes should be 200 kΩ to 1 MΩ / sq.

• A pair of copper tapes are attached to the graphite coating on either side of the electrodes to apply the high voltage to the electrodes.

• After all the chamber is further glued on four edges in order to avoid any gas leakage.

• Sheets of foam, acting as dielectric and mechanical support, which is to be kept over the insulated RPC.

• Aluminium strips are machined parallel to each other on one side of the foam. They serve the purpose of the pick-up strips.

• On the other side of the foam which is not facing the detector, an aluminium foil is machined. This serves as a reference for signal pick-up.

• A 0.1 mm Mylar sheet (as an insulator) which is to be interposed between each varnished surface of the electrodes and the parallel Aluminium strips.

• The aluminium strips are connected to the electronics, while the aluminium foil is connected to the ground.

• The two pick-up strips give pulses of opposite sign.

• The high voltage is applied symmetrically with respect to the ground.

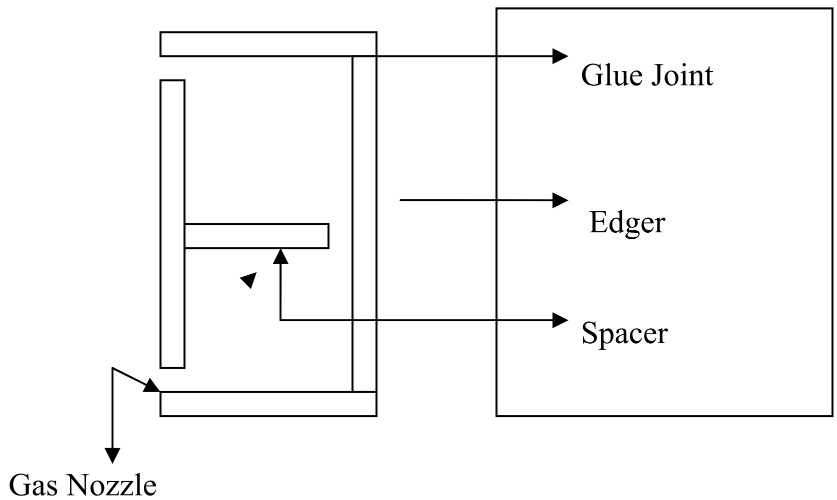


Figure: Gas Nozzle, RPC Frame

CHAPTER 3

Construction of Paddles

The paddles have been made with plastic materials which are broadly called the scintillators. The detector works by absorbing radiation incident on it and then re-emitting radiation of much longer wavelength. This radiation fall on a photo cathode of a photomultiplier thereby emitting electrons which are then magnified by a series of dynodes in the photomultiplier tube. In a scintillating detector, therefore, a scintillating material is optically coupled to a photomultiplier tube. The resulting current signal is then analyzed by an electronics system. Plastic scintillators are more commonly used for laboratory purposes because of their very rapid decay time which is of the order of few nanoseconds or less.

In this chapter we are basically discuss, how we had made the scintillation paddles and electronic set up used for testing those paddles. Along with that we are also studying its different characteristics.

3.1 General Characteristics of Scintillation Detectors:

The basic elements of a scintillation detector are sketched below in figure. Generally it consists of a scintillating material which is optically coupled to a photomultiplier either directly or via a light guide. As radiation passes through the scintillator, it excites the atoms and molecules making up the scintillator causing light to be emitted. This light is transmitted to the photomultiplier where it is converted into a weak current of photoelectrons which is then further amplified by an electron multiplier system. The resulting current signal is then analyzed by an electronics system.

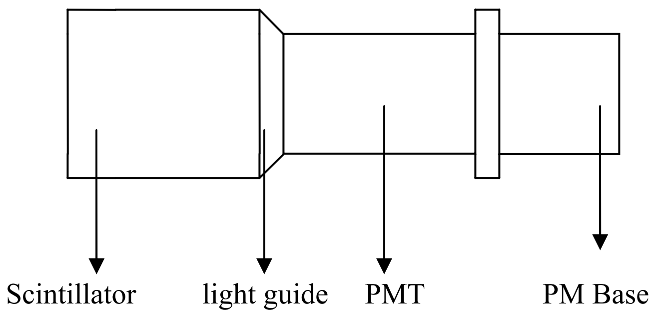


Figure: Schematic diagram of a scintillation counter

3.2 Basic Construction and Operation of Photomultipliers:

Figure shows a schematic diagram of a typical photomultiplier. It consists of a cathode made of photosensitive material followed by an electron collection system, an electron multiplier section (or dynode) and finally an anode from which the final signal can be taken. All parts are enclosed in an evacuated glass tube so that the whole photomultiplier has the appearance of an old-fashion electron tube.

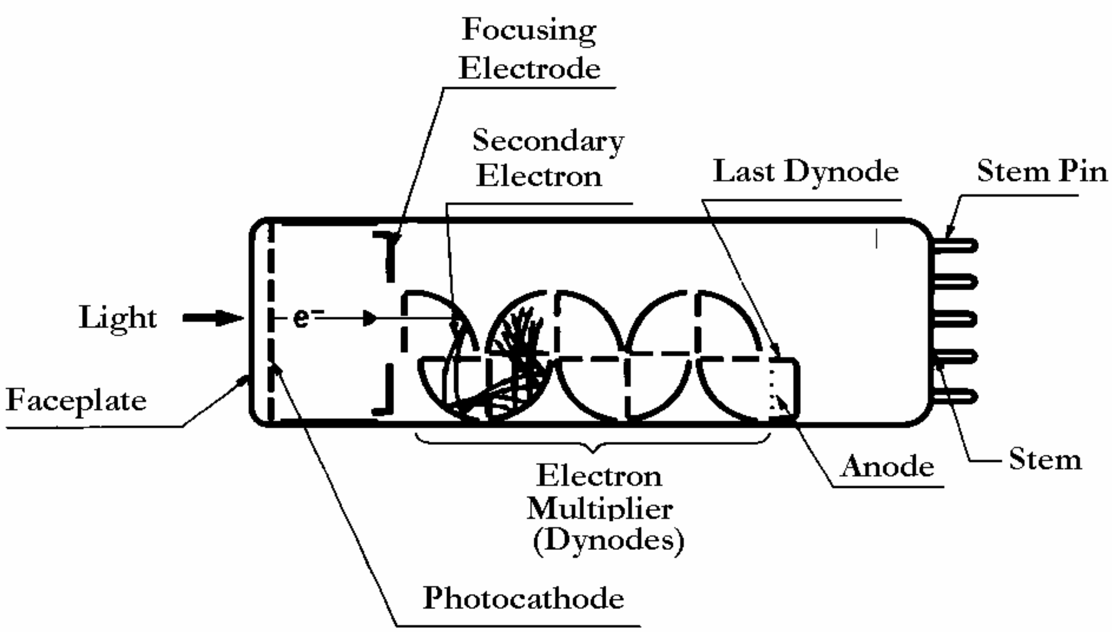


Figure: Schematic Diagram of a photomultiplier tube

3.3 PMT Base:

PMT Base circuit is used to apply different voltages to the different dynodes of PM tubes. It uses the simple circuit containing resistances and capacitors.

Circuit diagram of the PMT Base is as follows:

Tested values of dynode voltage drops in different PMTs. Applied voltage is 500 Volts.

Pin Number	PMT A	PMT B	PMT C
21-1	119.36	118.94	117.18
1-16	146.0	145.66	143.9
16-2	181.45	181.24	180.5
2-15	208.33	208.19	207.57
15-3	235.51	235.38	234.98
3-14	263.21	263.11	262.8
14-4	291.7	291.6	291.36
4-13	321.05	321.1	320.78
13-5	351.63	351.63	351.39
5-12	383.63	383.5	383.36
12-6	417.24	416.99	416.9
6-8	452.73	452.52	452.42
8-7	488.04	487.86	487.77

Therefore total input impedance of the PMT at the input of applying high voltage is around 3.36 MΩ and output impedance at the anode for taking the output signal is approximately 1001 Ω.

Burn in Test:

In this test we are keeping the PMT on high voltage for long time and then We are testing the resistances at different pins. In this case we are applying voltage 500 volt to the PMT A and keeping this for 90 minutes and then tested the voltages in volts.

Pin number	PMT A
21-1	119.58
1-16	146.19
16-2	181.62
2-15	208.46
15-3	235.62
3-14	263.30
14-4	291.77
4-13	321.08
13-5	351.65
5-12	383.63
12-6	417.20
6-8	452.62
8-7	487.92

Here we can see that there is no any drastic change in resistances in all the pin numbers.

3.4 Mounting a Scintillation Detector:

Here we are going to discuss, how we made scintillation paddles. The object was to design three paddles of dimension as follows:

1. $60*20*1\ cm^3$
2. $45*3*1\ cm^3$
3. $45*2*1\ cm^3$

For making these paddles the following steps are taken as:

Step 1
First assembled the necessary materials. These includes the Scintillator, the PMT, it's base and shield, Tyvek paper (white in color), Tedler paper (black in color), optical glue , black tape etc.

Step 1.1
Before connecting (using) these PMT base circuits, we had checked there working condition, which we had discussed earlier.

Step 2
The Scintillator and PMT tubes were cleaned with any old grease. Alcohol was used to clean the PMT but not on the Scintillator. Optical glue was formed using the resin and hardener (in the proportion 100:28 by weight respectively). The scintillator was coupled to the PMT with the help of cookies and the glues. Press the scintillator so that the glue comes out from the cookies and spreads out radially to form a smooth, thin layer coupling the entire surface to the PMT. Spread the glue without using the fingers. Handling the plastic scintillator with bare hands was avoided.

Step 3
Wrapped the scintillator and cookie by the first Tyvek paper and then with the Tedler paper (as we are using this paddle for the muon detection which is a high energy particle, the energy loss and absorption effects are negligible). The purpose for this is to avoid the loss of light from the scintillator and preventing the low energy particle and noises to enter into the paddle.

Step 4
Wrapped the PMT and detector neatly by the black tape along its entire length so as to ensure light tightness. Special attention was paid to the corners and sharp bends where light leaks will most likely occur.

Step 5
Mounted the PM in its base along with its magnetic shielding and outer protective shell.

In this way the counter was assembled.

Step 6
Some times we needed a scintillator paddle which is very wide enough; here we needed one paddle which is 20 cm wide, in that case the scintillator and PMT can not be coupled directly. So to connect this scintillator with the PMT we required to use the light guide which is called the Perspex to couple these.

3.5 The Electronics Used in Testing:

There are various equipments were used for testing these paddles which are listed below as:

3.5.1 Discriminator:

The discriminator is a device which responds only to input signals with a pulse height greater than a certain threshold value. If this criterion is satisfied, the discriminator responds by issuing a standard logic signal; if not, no response is made. The value of the threshold can usually be adjusted by a helipot or screw on the front panel. As well, an adjustment of the width of the logic signal is usually possible via similar controls.

The most common use of the discriminator is for blocking out low amplitude noise pulses from photomultipliers or other detectors. Good pulses, which should in principle be large enough to trigger the discriminator, are then transformed into logic pulses for further processing by the electronics. In this role, the discriminator is essentially a simple analog-to-digital converter. In most discriminators, triggering occurs the moment the pulse crosses the threshold level. This is known as leading edge (LE) triggering. The double pulse resolution is the smallest time separation between two input pulses for which two separate output pulses will be produced. For fast discriminators, this is usually on the order of a few nanoseconds. There is another triggering method called constant fraction (CF) triggering. In this method, the logic signal is generated at a constant fraction of the peak height to produce an essentially walk-free timing signal. Depending on the type of the signal, this level occurs at a certain fraction of the pulse height independent of the amplitude.

DATA:

Pulse width: There are two outputs for each input with different pulse width. And adjustment screw is common for all the output to adjust the width of the outputs. Usually both the outputs are in multiple of five.

Threshold: different threshold level can be selected for the different inputs using the logic buttons.

the output of the discriminator is current output.

0 mA current → logic level 0

20 mA current → logic level 1

this module has delay time of approximate 10 nano second.

Figure: Picture of discriminator and Four fold logic unit

3.5.2 Four Fold Logic Units:

This module has maximum four inputs. We can disable some of the inputs at a time. So, this module can be used as OR and AND gate. Along with this, this can also be used for two fold and three fold coincidence. This gives two input and two inverted inputs which are current outputs (0 mA and 20 mA logic level). Width of the output is adjusted by us.

Coincidence level:

1 → when at least one of the inputs is present, output is high (i.e. work as OR gate)
2 → when at least two of the inputs are present, output is high.
3 → when at least three of the inputs are present, output is high.
4 → when all the four inputs are present, output is high. (i.e. work as AND gate)

Whole apparatus has two parts with similar operations.
This module has also the delay time of approximate 10 nano second.

3.5.3 Counters:

This is used for counting the number of pulses arrived. It has total five channels. The fifth channel can act as both as a counter and also as a time setter. In time setter mode, the counting of all the four channels will automatically stop when the selected time is achieved. This operation is achieved only if we connect timer output to the gate input of the each input. The timing scale has two modes one in millisecond mode and another in microsecond mode, so we can choose either of these two modes.

The inputs of the counter are of two types, one is of NIM type (i.e. current input) and another is of TTL type (i.e. voltage input).

All the inputs have 50Ω impedance termination.

Here we have used NIM input terminal.

3.6 Testing of Scintillation Paddles:

In this part we have tested the individual paddles made by us.

We are applying voltage to the PMT of each paddles and then doing the measurement on CRO directly and also via discriminator. We have measured the pulse height of the output when output is directly connected to the CRO. And also pulse width of the discriminator through CRO and count rate of each paddle is measured by using the counters.

3.6.1 Preliminary Testing of scintillator paddles:

Voltage applied to the PMT = 1600 Volt

Threshold voltage of discriminator V_{th} = 50.3 mV

Pulse width, T^1_{pulse} = 50 nano second from output B

T^2_{pulse} = 10 nano second from output A

From CRO,

V_{trigg} = -248 mV

Pulse height V_{pulse} = -750 mV

Number of counts in 900 second:

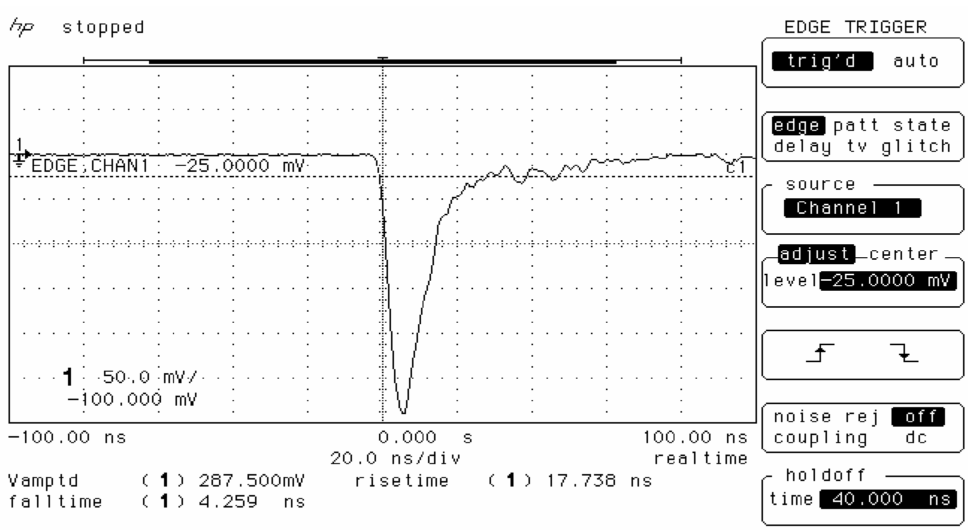
Voltage applied to the different PMT's = 1700 Volt

For PMT20 = 33785

For PMT02 = 16990

For PMT03 = 13682

3.6.2 Shape of the pulse from CRO:



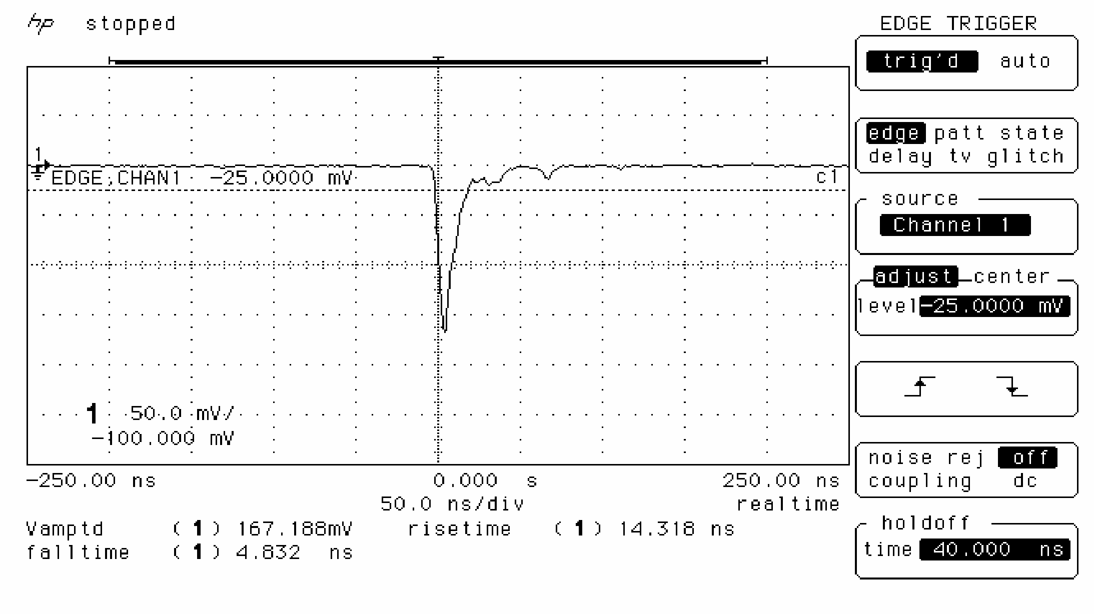


Figure: Shape of the Pulse from PMT20 on CRO

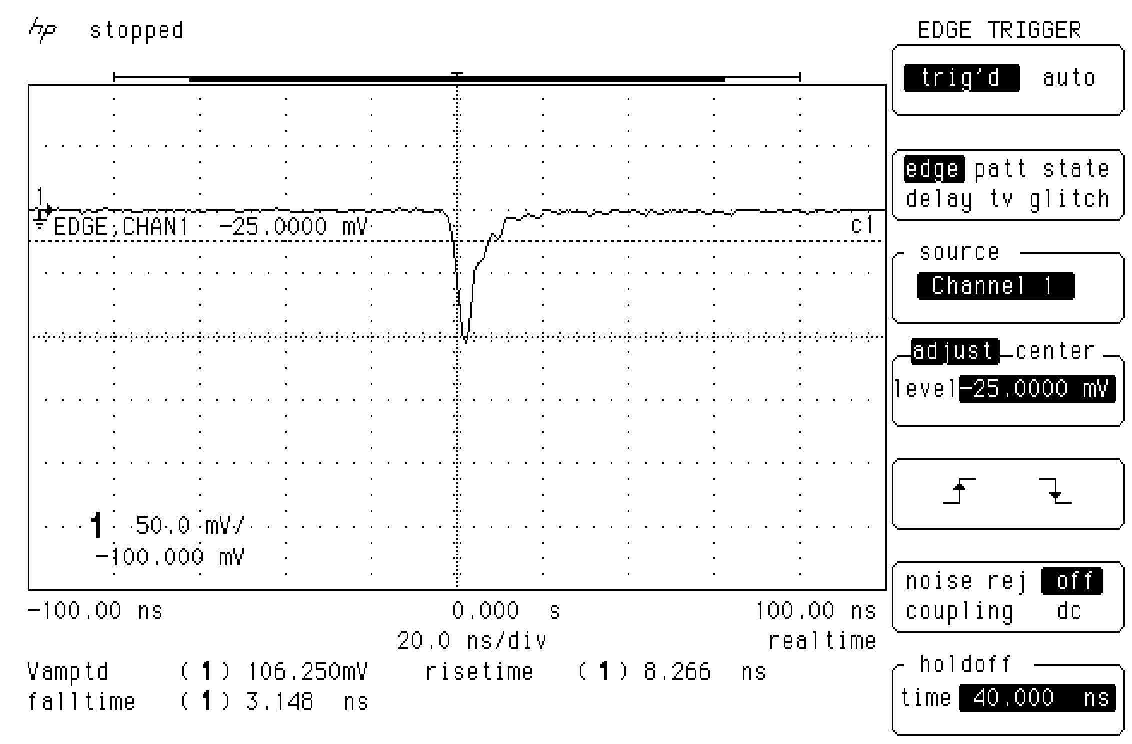


Figure: Shape of the pulse from PMT02 on CRO

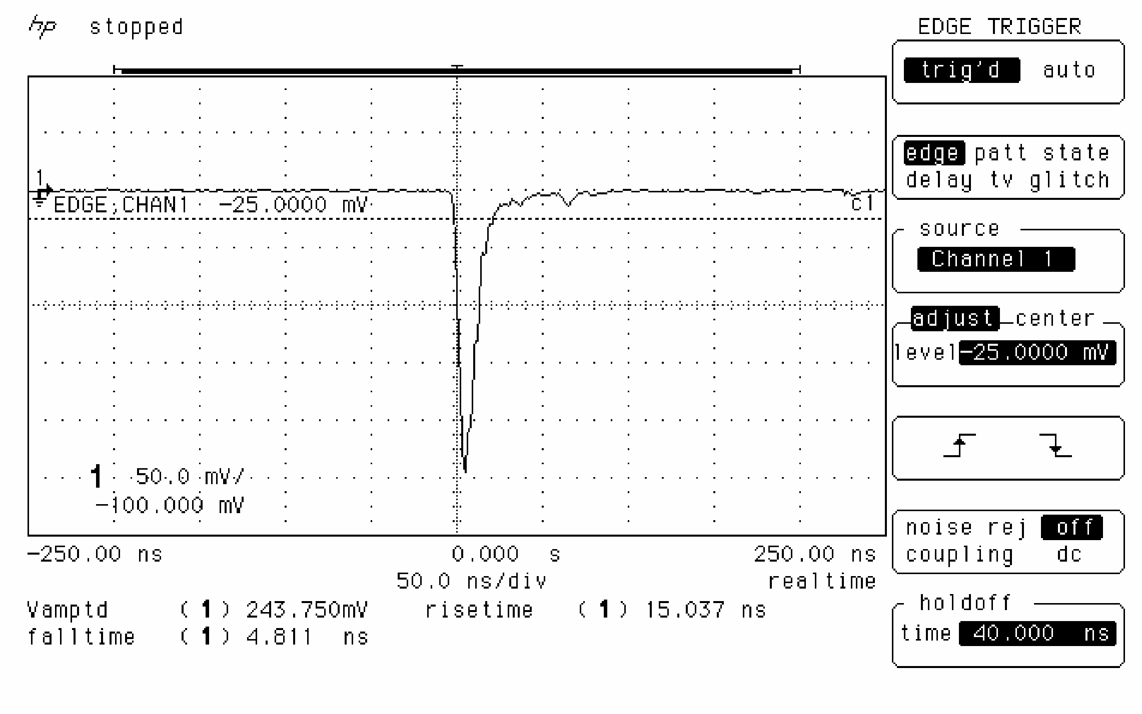


Figure: Shape of the pulse from PMT03 on CRO

CHAPTER 4

In this chapter we are going to discuss, how we had tested the newly made paddles with all the set ups to obtain there operating voltage by plateau. Along with this we have taken the data to estimate there timing resolutions.

4.1 Laboratory Test Set Up

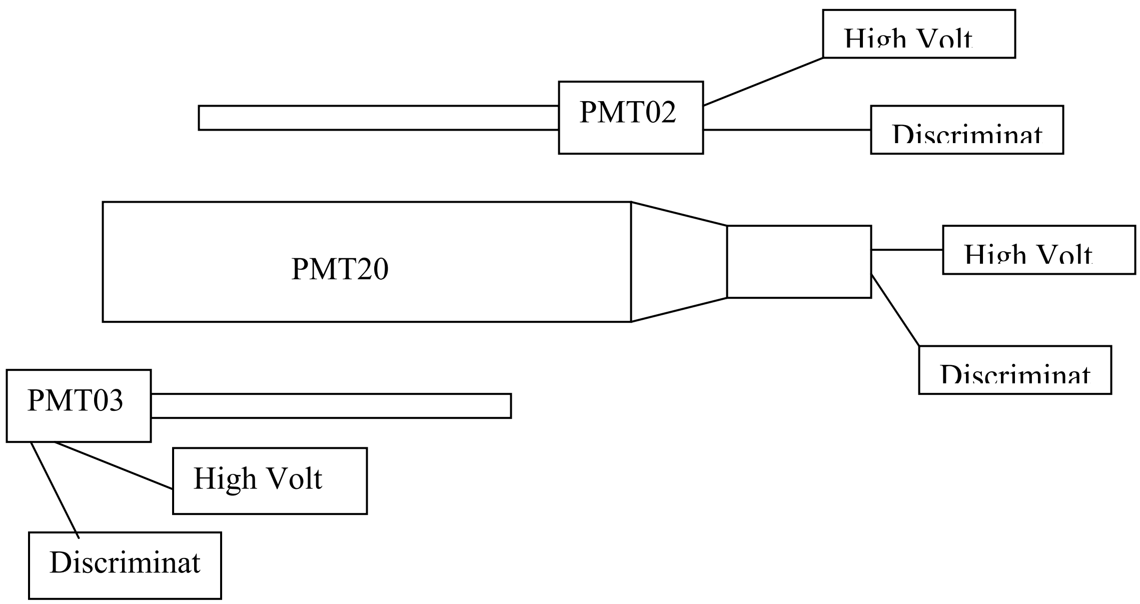


Figure: Laboratory set up of paddles for testing

The trigger in this case is decided by two paddles which are kept at constant voltages. The third paddle which has to be tested is kept at variable voltage source.

Whenever the Muon particle enters through paddle 2 and 3, it creates the trigger along with that when it passes from the testing paddle it creates one 3-fold coincidence.

Signal from the scintillator paddles is converted into the digital circuit using the discriminator module. A module that gives out a standard logic signal when the pulse height of the signal is greater than the certain threshold value. The value of threshold is adjusted in our case is -30 mV to avoid the noise.

These pulses are counted by using the counters and also we are doing the AND operation of all these three pulses which gives us the 3-fold coincidence.

The set up of paddles and its electronics is shown as in figure

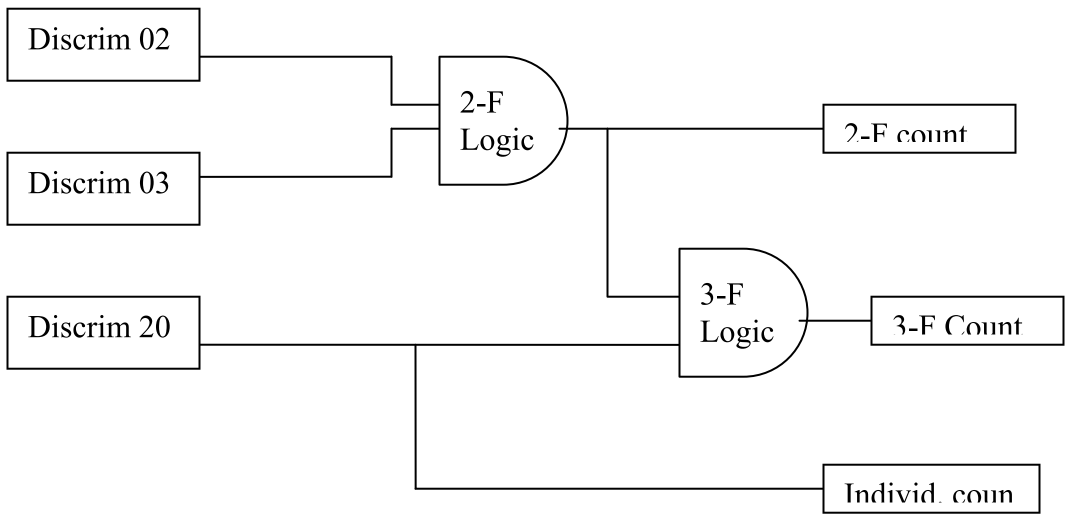


Figure: Electronics set up of Paddles

4.2 Data Collection for Plateauing:

Data time = 900 seconds

V_{th} = -50 mV

T_{pulse} = 50 nano second

4.2.1 Plateauing of PMT03:

Voltage applied at PMT02 = 1620 Volt

Voltage applied at PMT20 = 1650 Volt

Voltage applied at PMT03 (Volt)	Count Rate of Paddle # 03	2-Fold Coincidence	3-Fold Coincidence	Efficiency =3F/2F
1350	1518	516	3	0.0058
1410	2394	546	6	0.0116
1470	3666	610	8	0.0131
1530	5231	543	26	0.0478
1590	7019	538	49	0.091
1680	11586	615	106	0.172
1740	17266	578	112	0.193
1800	24902	548	121	0.209
1860	33762	509	126	0.247
1890	38591	542	155	0.285

Table: Data for the Plateauing of PMT03

4.2.2 Plateauing of PMT02:

Voltage applied at PMT03 = 1700 Volt
Voltage applied at PMT20 = 1670 Volt

Voltage Applied at PMT02 (Volts)	Count Rate of Paddle # 02	2-Fold Coincidence	3-Fold Coincidence	Efficiency =3F/2F
1400	1150	919	13	0.0141
1460	1776	900	12	0.0133
1520	2530	887	25	0.0281
1580	3523	876	30	0.0342
1640	4714	863	60	0.0695
1700	6507	837	94	0.112
1760	10194	880	135	0.153
1820	16939	925	177	0.191
1880	24018	895	173	0.193
1920	28518	818	164	0.2004

Table: Data for the Plateauing of PMT02

4.2.3 Plateauing of PMT20:

Table 1:

Voltage applied at PMT02 = 1800 Volt
Voltage applied at PMT03 = 1770 Volt

Voltage Applied at PMT20 (Volts)	Count Rate of Paddle # 20	2-Fold Coincidence	3-Fold Coincidence	Efficiency =3F/2F
1500	5595	580	19	0.0327
1560	9595	538	47	0.08736
1620	15620	626	108	0.1725
1680	27491	559	160	0.286
1740	47265	581	285	0.490
1800	73296	601	345	0.574
1860	105675	607	446	0.7347
1920	146262	594	495	0.8333
1950	179149	551	464	0.8421

Table 2:

Voltage applied at PMT02 = 1740 Volt
Voltage applied at PMT03 = 1700 Volt
V_{th} = -30 mV

Voltage applied PMT20 in Volt	Count rate of PMT02	Count rate of PMT03	Count rate of PMT20	2-F	3-F	Efficiency = 2-F/3-F
1100	8048	7963	60	555	3	0.54
1200	7589	7354	705	547	5	0.91
1300	7613	7390	4518	556	12	2.15
1400	7398	7230	12345	500	64	12.8
1500	7418	7140	24786	531	256	48.2
1550	7453	7192	33504	543	383	70.3
1600	7130	6963	43997	552	453	86.8
1650	7285	7060	56598	511	477	93.34
1700	7518	7192	72890	530	507	95.66
1800	7450	7074	108587	532	511	96.05
1900	7425	7167	166571	504	489	97.02

From the graph, we can say that the operating voltages of these paddles are in between 1700 Volt to 1900 Volt.

4.3 The Time-to-Digital Converter (TDC):

To obtain a time interval measurement in digital form, one method is to digitize the TAC using an ADC. Another method used involves the basic principal that as use the START signal to gate on a scaler which counts a constant frequency oscillator (or clock). At the arrival of second STOP signal, this scaler is gate off to yield a number proportional to the time interval between the pulses.

Calibrating the Timing System:

To calibrate the time scale of the TDC, we followed the method as to use the single source of a photomultiplier to drive both the START and STOP channels. The output signal is split in two with the STOP channel signal passing through a variable delay. Simple cable delays are used for this purpose. The distance between peaks produced by the different delays then gives a calibration of the time scale.

In this way the calibration is obtained as 50 picoseconds per channel.

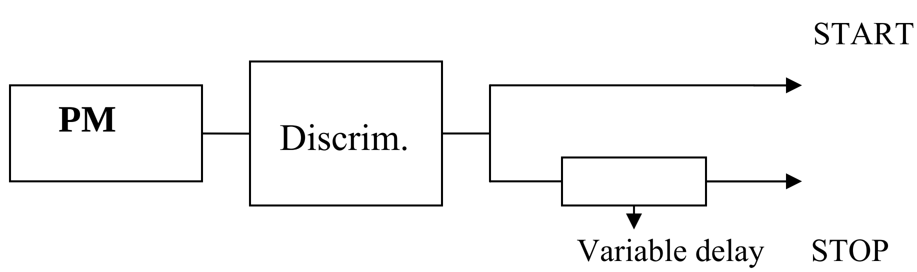
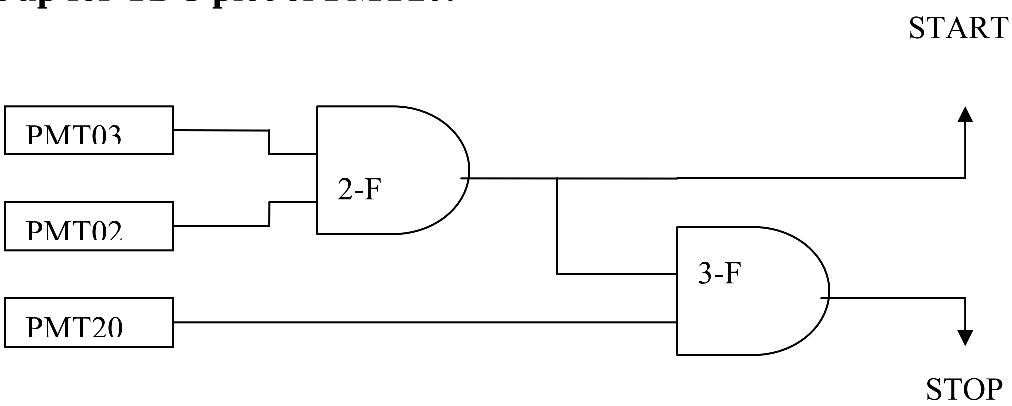


Figure: Time scale calibration with a single source

Set up for TDC plot of PMT20:



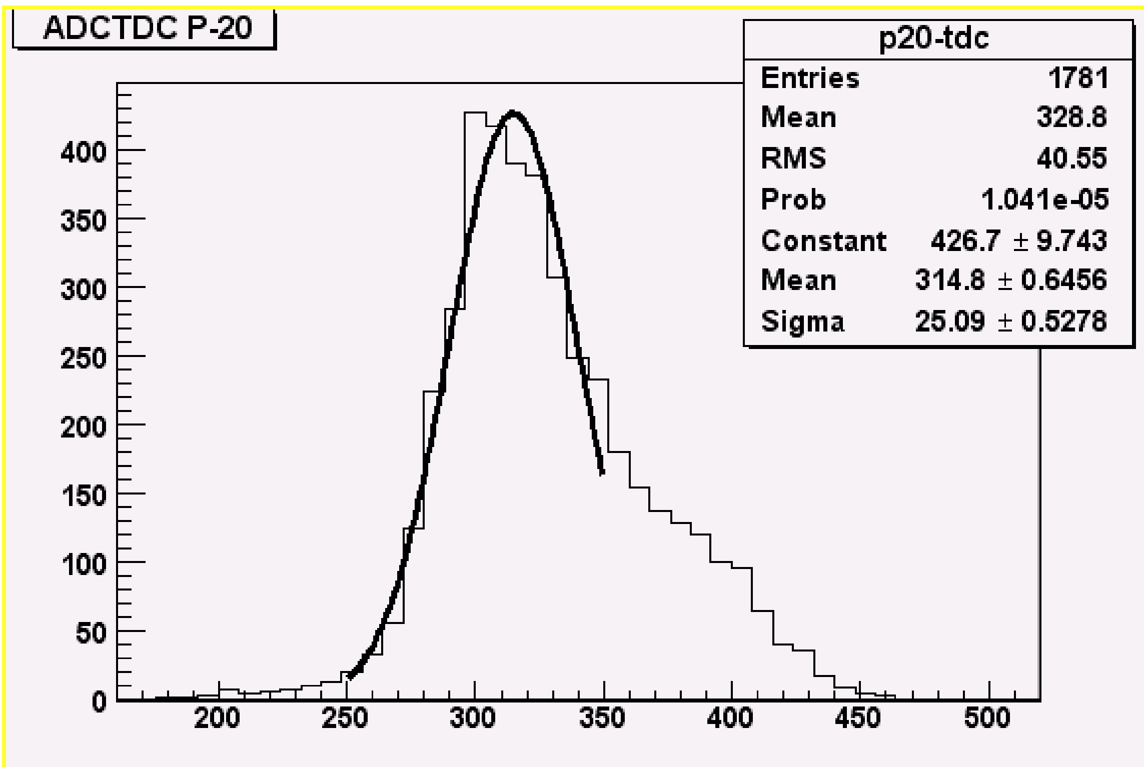


Figure: TDC plot of the PMT20

In this plot, x-axis is the time bins each 50 picoseconds and y-axis is the number of counts for that time interval. Here we are using the 2-F coincidence as a START pulse and signal from third paddle is used as a STOP pulse.

In this plot, we are not interested in the mean value of delay between START and STOP pulse, but are interested in the spread around this mean value which is the standard deviation Sigma. This will be used in finding the timing resolution of the paddle which is working as a STOP pulse generator.

So, from the plot we can calculate the timing resolution of the paddle as,

Timing resolution = Sigma * time bin

$$= (25.09 +- 0.5278)*50*10^{-12}$$

$$= (1.2545 +- 0.02639)*10^{-9} \text{ seconds}$$

$$= (1.2545 +- 0.02639) \text{ nano seconds}$$

Hence, the timing resolution of our newly built scintillation paddle is approximately 1.25 nano seconds.

4.4 Analog-to-Digital Converters:

The ADC is a device which converts the information contained in an analog signal to an equivalent digital form. This instrument is the fundamental link between analog and digital electronics. The resolution of the ADC depends on the range of digitization. If numbers between 0 and 10000 were generated instead of 0 and 1000, a finer digitization and a higher resolution would be obtained.

In the ADC plot, x-axis is the charge bins each 250 pC and y-axis is number of counts for that charge output.

In our case, we are using the 2-F logic as GATE pulse and third paddle is used as source of charge which is to be digitized. So after a large number of events we are getting this ADC graph.

From the ADC plot, we may calculate the number of photoelectrons at the PMT photo cathode from the scintillator paddle for a minimum ionizing cosmic muon as,

Since, mean = 237 +- 1.206

Sigma = 59.88 +- 1.017

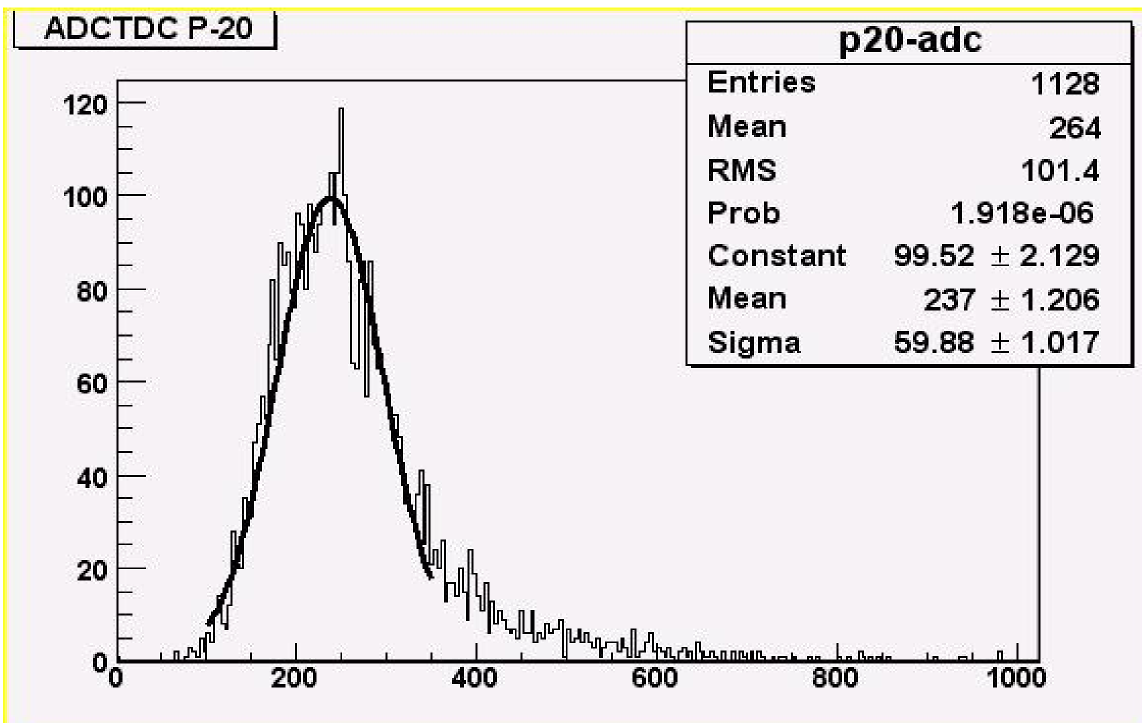
So,

Number of photoelectrons = (mean/sigma)^2

= (237/59.88)^2

$= 3.958^2$
$= 15.66 \sim 16$

Hence, we may say that we are seeing about 16 photoelectrons at the PMT photo cathode from the scintillator paddle for a minimum ionizing cosmic muon as a mean value.



CHAPTER 5

Summary and Conclusions

In this report, we report the fabrication, testing and setting of three scintillator paddles to tag the cosmic ray muons. I have also been involved in the setting up and then using of the data acquisition system in the laboratory.

The timing and the efficiency obtained by the paddle has been reported in chapter 4. The best timing obtained for the paddles was 1.25 nano seconds. The average efficiency of the three paddles is of the order of 80%. Once an RPC is fabricated, we believe that as a first step towards tagging of muons may be provided by the telescope which has been fabricated. However, we do believe that the system can be improved further.

We tried to improve the timing resolution and the efficiency by regluing the scintillator with the PMT. This only improved things marginally.

One of the reasons for bad efficiencies could be that we have directly connected the plastic to the photomultiplier tubes. There is no coupling between the detector and the PMT. It is known that coupling improves the light collection efficiencies of the setup. This is because the shape of the coupling is such that it allows total internal reflection and therefore all the radiation produced by the scintillator material is collected by the PMT. In this case some of the light may be escaping. The bigger the paddle more severe the problem is. This could also be reason for bad timing resolution.

The original goal of the problem was to test this set-up with an RPC which is existing in the laboratory. However, due to limited time and due to above mentioned problems and some issues with the data acquisition system, this could not be achieved.