Development and Analysis of Double gap Glass Resistive Plate Chambers

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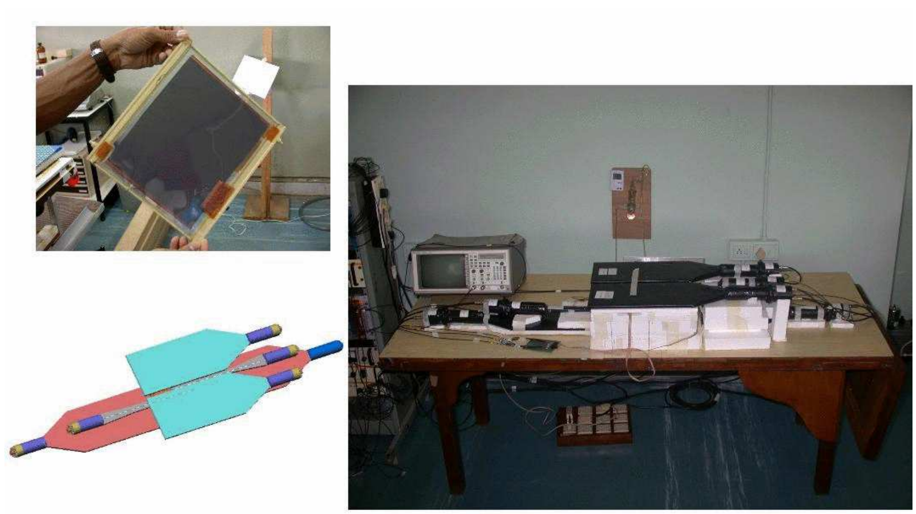
Abstract

We discuss the development of Resistive Plate Chambers (RPC), in particular, a chamber with double gap. Starting with a discussion on the general properties of gas ionisation detectors like proportional counters we discuss in detail the making of a double-gap RPC and how to put it into use. We analyse the efficiency of the detector and the time resolution obtained from it. We also discuss about the pulse shape of such an RPC. We conclude that a double gap RPC shows a little improvement in efficiency over the single gap chambers.



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1 Introduction

Glass Resistive Plastic Chambers (RPC) have a long history dating back to the late 1970s [1]. RPC array is a key component when it comes to the traditional function of muon detection. They were applied as large area RPCs with parallel glass electrodes for a K_L^0/μ detector of the BELLE experiment at KEK [2]. RPCs find use as the active elements in the tracking (iron) calorimeter which can simultaneously measure the energy as well as the direction of the charged particle. The iron calorimeter contains iron plates as the absorber of energy and glass RPCs or Scintillators as the active detector element. RPCs are these days preferred to scintillators because of several reasons [3, 4].

- They give a good position resolution and give a good detection efficiency.
- They can be made to have a large area but at a minimal material cost [5].
- These are easy to assemble and they possess a simple read-out electronics.
- They exhibit better time resolution than scintillators[1] [6].

Because of the above mentioned advantages, RPCs are being used more and more in modern day experiments. The Glass RPCs have been proposed [7] recently as the active element in the iron calorimeter detector for the India-based Neutrino Observatory (INO).

We begin with mentioning the general properties of gas ionisation detectors and proportional counters. We elaborate on the general structures and properties of an RPC. We discuss in details the making of a double gap RPC. We talk about the chance coincidence method in the set-up of such a detector. We discuss about the readout electronics used. We analyse the efficiency of the detector with changing high voltage applied to the electrodes of the RPC. The time resolution obtained using the TDC plots is studied as well. We discuss about the shapes of the pulses generated by such an RPC. We conclude by saying that a double gap RPC shows a little improvement in efficiency over the single gap chambers.

2 Basic detectors

In order to understand the working principle of an RPC we start by talking about the basic detectors [8].

2.1 Gaseous Ionisation Detector

Basic configuration of such a detector consists of a cylindrical container with conducting walls and a thin end window. Along its axis is suspended a conducting wire (treated as anode) to which a positive voltage $+V_0$, relative to wall (treated as cathode), is applied. The container is filled with gas. When radiation penetrates the cylinder, a certain number of electron ion pairs is created. Mean number of pairs created is proportional to the energy deposited in the counter. With the application of an electric field, the electrons are drawn towards the anode and ions towards the cathode where they are collected. If

[1] In fact, RPC exhibits much better time resolution than wire chambers or limited streamer tubes. This is an observed advantage arising from the uniform field with respect to the $1/r$ field which introduces large time fluctuations (known as *jitter*) due to the electron drift motion.

the electric field is strong enough, the freed electrons are accelerated to energies where they are also capable of ionising gas molecules in the cylinder. The electrons liberated in these secondary ionisations then accelerate to produce still more ionisation and so on. This results in an ionisation **avalanche** or cascade. Because of the greater mobility of electrons, the avalanche has the form of a liquid drop with electrons grouped near the head and slower ions trailing behind. When such avalanches increase 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.

2.2 Scintillator: Plastic Scintillator

This is another class of detectors which makes use of the fact that certain materials, when struck by a nuclear particle or radiation, emit a small flash of light, i.e., a scintillation. In a scintillating detector, a scintillating material (eg. plastic -*polyvinyltoluene*) is optically coupled to a photomultiplier tube. The light emitted from the scintillating material gets converted into a weak current in the PMT which is then amplified further by an electron multiplier system. The resulting current signal is then analysed 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.

3 Resistive Plate Chambers (RPC)

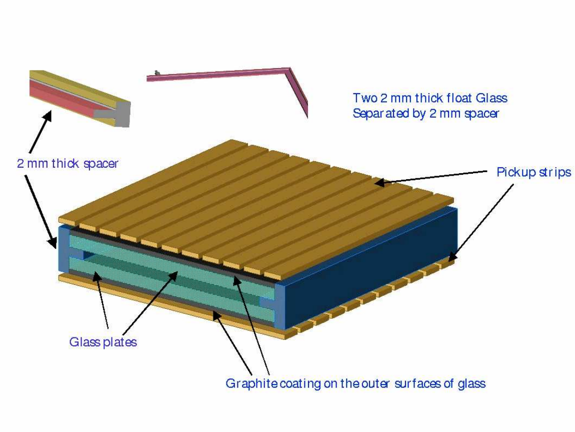
An RPC is a particle detector utilising a constant and uniform electric field produced by two parallel electrode plates, at least one of which is made of a material with high bulk resistivity. The gap between the electrodes is filled with a suitable gas mixture to be discussed later. When the gas is ionised by a charged particle crossing the counter, a discharge is originated by the electric field. The discharge, however, is 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. Owing to the high resistivity of the electrodes, the electric charge quickly dies off in a *limited area* (typically 0.1cm^2) around the point where the discharge occurred[2]. The discharges produce sparks which are counted by appropriate read out electronics.

3.1 Structure of a standard single layer RPC

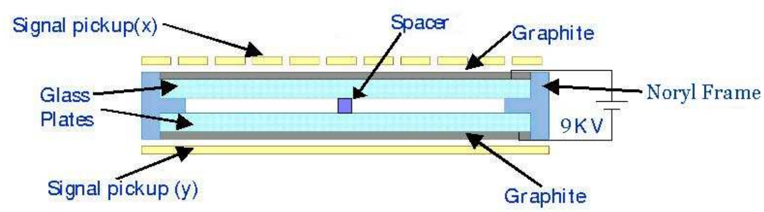
To make an RPC the bare requirements are:

- Resistive electrode plates made of commercial float glass with a volume resistivity of 10^{12} Ωcm and a thickness of 2 mm. They are put on top, parallel to each other within the framework.
- Noryl frame, 1.6 mm thick and 10 mm in breadth, which delimits the active surface of $30 \times 30\text{cm}^2$. Another piece of noryl, which is shorter than 30 cm in length, is used

[2]Each discharge locally deadens the RPC. The recovery time [3] of the resistive electrode plates is of the order of $\tau = \text{RC} \simeq \left(\frac{\rho l}{\text{A}}\right)\left(\frac{\kappa\epsilon_0 \text{A}}{l}\right) = \rho\kappa\epsilon_0$, numerically in MKS units $\tau = 2$s.



(a) Top view



(b) Side view

Figure 1: Structures of a single layer RPC [9]

as a spacer which is put in the middle of the frame to force the gas mixture to cover the whole volume of the RPC.

- A resistive adhesive, epoxy resin[3] with which the glass plates are glued to the noryl. This special glue has been proven to guarantee a sufficient electrical insulation and mechanical bonding strength.
- Two nozzles, made up of copper, through which the gas mixture coming from the tubes get into the detector, are glued to the frame. Special care need to be taken to ensure that no glue is going inside the nozzle, thereby blocking the gas flowing path.
- In order to supply the high voltage, the glass surfaces not facing the gas are spray-painted with a solution of colloidal grade graphite powder, (graphite being a good conductor) lacquer and thinner. The resistivity of the graphite coating is ensured to be uniform and to be $\sim 300\text{k}\Omega/\square$.
- 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.
- Two *tygon* tubes[4] are used for flowing in the gas mixture at an atmospheric pressure through the RPC and for letting the gas to flow out.
- Sheets of foam, acting as dielectric and mechanical support, which is to be kept over the insulated RPC.
- Aluminium strips (3 cm wide) 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.

[3] Brand used in our lab was 3M Scotch-Weld, Epoxy Adhesive DP190 Gray.

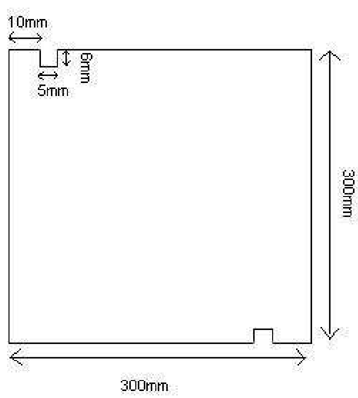
[4] Brand used: Norton tygon, flexible plastic tubing, B-44-3 MEETS NSF-51, Standard maximum temperature 165 F, outer diameter 0.25 inches, inner diameter 3/16 inches.

- 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.

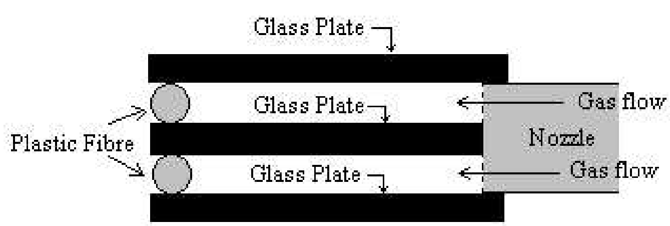
When a charged particle passes through such a detector it induces an avalanche which develops into a spark. The discharge is quenched when all of the locally available charge is consumed. The discharged area recharges slowly through the high-resistivity glass plates. Once in a while these avalanches coalesce and form a streamer pulse when the charge flows continuously from one electrode to the other. The sequence of transitions: free electrons $\rightarrow$ avalanche $\rightarrow$ streamer can occur in very short times (less than 0.1ns [11]) and with minimal fluctuations.

3.2 Double gap RPC

Based on the idea of making a single gap RPC we went on making a double gap chamber, RPC-D1. A *superlayer* module of RPC was suggested [2, 10] to have two RPCs sandwiched between orthogonal pick up strips with ground planes for signal reference and proper impedance. The idea behind this was that even if one of the RPCs goes wrong the other can continue to operate. We modified this model to some extent. Instead of two separate RPCs we divided one RPC into two sections by putting an extra layer of electrically floating glass plate in between the two electrodes. We used plastic fibre (width 1 mm) instead of noryl (width 2 mm) here. The middle glass was cut so as to accommodate the nozzle in the detector (Fig.(2a)). While gluing it was also made sure that the nozzle opens out in both the layers(Fig.(2b)).



(a)Cut-glass



(b)Cross-section of the double gap RPC

Figure 2: Making of a double gap RPC

4 Experimental Set up

4.1 Alignment of RPC in the laboratory

To measure the efficiency of the RPC we set up our experiment in such a way as to ensure that the trigger pulse generated is solely due to the atmospheric muons. To do that we have to exclude all other cosmic rays which form a background noise. We set up a coincidence circuit for our present purpose[5]. For this set up we used six scintillators as six paddles. Thus we made a *cosmic ray telescope* with these scintillators. We named them P1 - P6. We put our RPC as shown in the diagram (Fig.(3)). We kept two big paddles (P1 and P2) at the bottom, two small paddles (P5 and P6) were kept over P1 and P2 such that they shared a common region (as shown in Fig.(3). We put two more big paddles (P3 and P4) on top of the small ones (P5 and P6) such that these two could move horizontally in lateral direction. These two govern the opening of the *telescope window* and hence constitute what is known as *veto*. For such a set up the pulses produced at any random time is shown in the left hand side of the Fig.(3). For this set up the probability of *chance coincidence* is $P_1 \cdot P_2 \cdot \bar{P_3} \cdot \bar{P_4} \cdot P_5 \cdot P_6$. This ensures that a muon trigger will be generated when we have four of the paddles (P_1, P_2, P_5, P_6) in coincidence and (P_3, P_4) in anti-coincidence. We arranged to have the middle pick-up strip of the RPC-D1 to be in coincidence with the telescope window mentioned above.

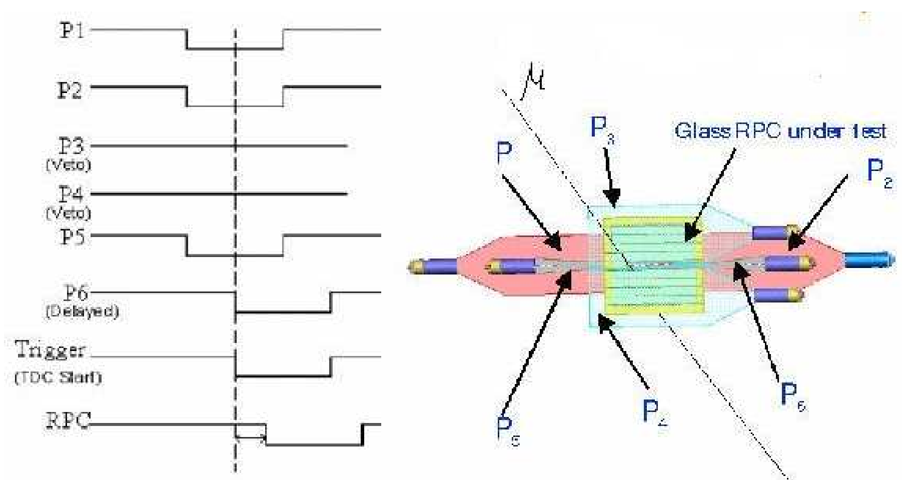


Figure 3: Schematic of the RPC test setup [9]

4.2 Gas system

The choice of filling gas for RPCs is governed by several factors: low working voltage, high gain, good proportionality and high rate capability. For a minimum working voltage, noble gases are usually chosen since they require the lowest electric field intensities for avalanche formation. Because of its higher specific ionisation and lower cost, argon is

[5] A coincidence output signal is produced, ideally, if any part of the two incoming signals overlap (though in real cases a minimum overlap is necessary). Thus all pulses arriving within a time equal to the sum of their widths are registered as coincident.

usually preferred. But argon atoms formed in the avalanche deexcite giving rise to high energy photons capable of ionising the cathode and causing further avalanches. The problem is solved by adding polyatomic gases, such as Isobutane. These molecules act as *quenchers* by absorbing the radiated photons and then dissipating this energy through dissociation or elastic collisions. The gain can be increased further by adding a judicious amount of *electronegative gas* such as Freon. These gases can also trap electrons from the cathode before they can reach the anode to cause an avalanche. For our experimental set up we used Freon, Isobutane and Argon in the ratio of 62:8:30. The flow rate of the gas mixture was monitored by a bubble counter connected to the RPC.

4.3 Circuit

As we have shown in the Fig.(3) to set up a coincidence circuit we need to use logic circuits, e.g. AND, OR gate. Even before that we need to convert the analog pulse that comes from the PMT to digital pulse through discriminators.

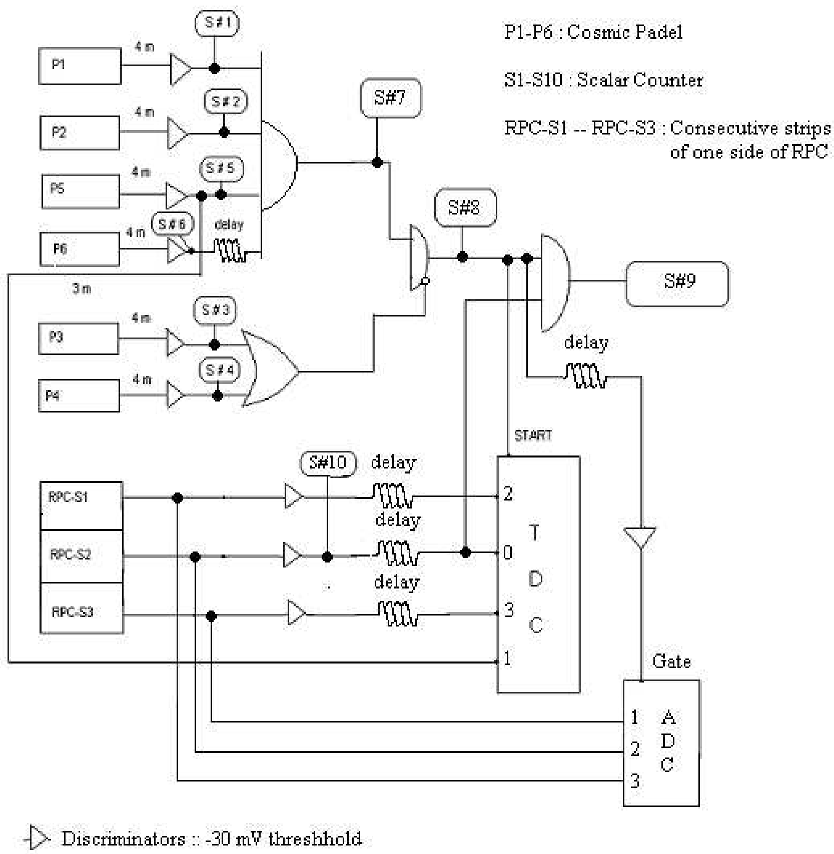


Figure 4: The Circuit

As proposed in the section 4.1, we arranged the digitised pulses coming from the discriminators (kept at a threshold voltage of -30 mV) such that P_1,P_2,P_5,P_6 were ANDed and P_3 and P_4 were ORed. We added *scalars* in every stage to monitor counting rates of these signals and to check whether things are working all right. According to Fig.(4)

$S\#7$ indicates the 4-fold value. Then we did NAND this pulse with the *Veto* (i.e. OR-ed P_3 and P_4) to get 4-fold $\times$ Veto. As each of the scintillator will have its own jitter, it will be difficult to keep them in coincidence. Therefore, we applied a delay of 12 ns[6] and set the TDC START at that point. Then we connected the pick-up strips of the RPC to discriminator by using *twisted pair cables* and took the output to different channels of TDC with some delay. We took the trigger from the middle strip of RPC-D1 and ANDed it with the 4-fold $\times$ Veto. Finally in Scalar $S\#9$ we recorded the 4-fold $\times$ Veto $\times$ RPC trigger. Thus we define the efficiency of the RPC as the ratio of the no. of counts in $S\#9$ to the no. of counts in $S\#8$.

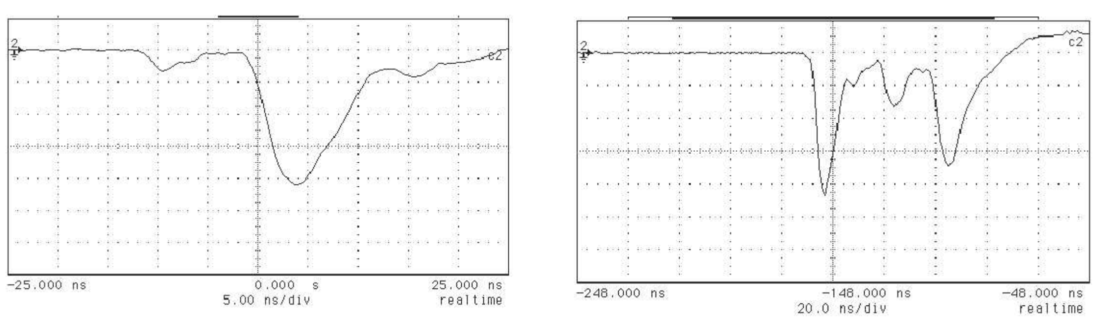
Efficiency of RPC = (4-fold $\times$ Veto $\times$ RPC) / (4-fold $\times$ Veto)

We connected the RPC pulses without digitising by the ADC and we made a connection of the ADC Gate to the the 4-fold $\times$ Veto to make sure that when TDC gives a START the ADC Gate is also open at the same time. The TDC data obtained from TDC and ADC were obtained from PCs (PC1 and PC2) using suitable softwares.

5 Results

5.1 Oscilloscope output

We present the shapes of the pulses of RPC-D1, triggered by cosmic muons, as observed in the oscilloscope. The pulse heights are typically of the order of 100mV across a load of 50Ω. The first one shows formation of an avalanche pulse (short height) and a streamer pulse (longer one). The second one shows more than one streamer pulse. This happens as there are two layers in the double layer RPC. So streamer pulses are formed in both the individual gaps. If it so happens that these two streamer pulses are formed at the same time then we see only one long pulse on the oscilloscope. If their times of formation do not match then we get to see two streamer pulses. Some times one sees more than two as well, which is because there may be more than one streamer pulses at times.



(a)Avalanche + Streamer pulse (b)Multiple Streamer pulses

Figure 5: Shapes of pulses as seen from the oscilloscope

[6]Actually, we used a of 3m length with a delay of 5.2ns/m, the length of the wires used in between the discriminator and the AND gate being 70cm; the delay effectively turned out to be $(3-0.7)\times 5.2$ ns $= 12$ ns.

5.2 Data Counts on PC1 & PC2

Two PCs are used for data acquisition and monitoring. PC-1 is used for non-stop monitoring of all counting rates. PC-2 is used for TDC readout, based on cosmic muon triggers.

5.2.1 TDC distribution plot of RPC and Cosmic paddle

The data obtained from TDC channels are plotted using a software called **ROOT**. We concentrated on data from two channels: one for the middle pick-up strip of the RPC and one from the fifth cosmic paddle (P_5). We took data for every HV we operated the detector with. Only one of the plots is shown here which was taken at 11.5 kV. From such a graph (Fig. 6) we measure the standard deviation(σ) of time resolution for the RPC pick-up strip and that of the cosmic paddles.

It can be seen from the Histogram plot that the scintillator (cosmic paddle) gives a uniform Gaussian distribution but the distribution obtained from one of the pick-up strips of the double gap RPC shows two peaks, differing in height. We selected one of the peaks (the bigger one) to get the σ for time resolution. The appearance of two peaks can explained from the appearance of two streamer pulses as discussed in section 5.1.

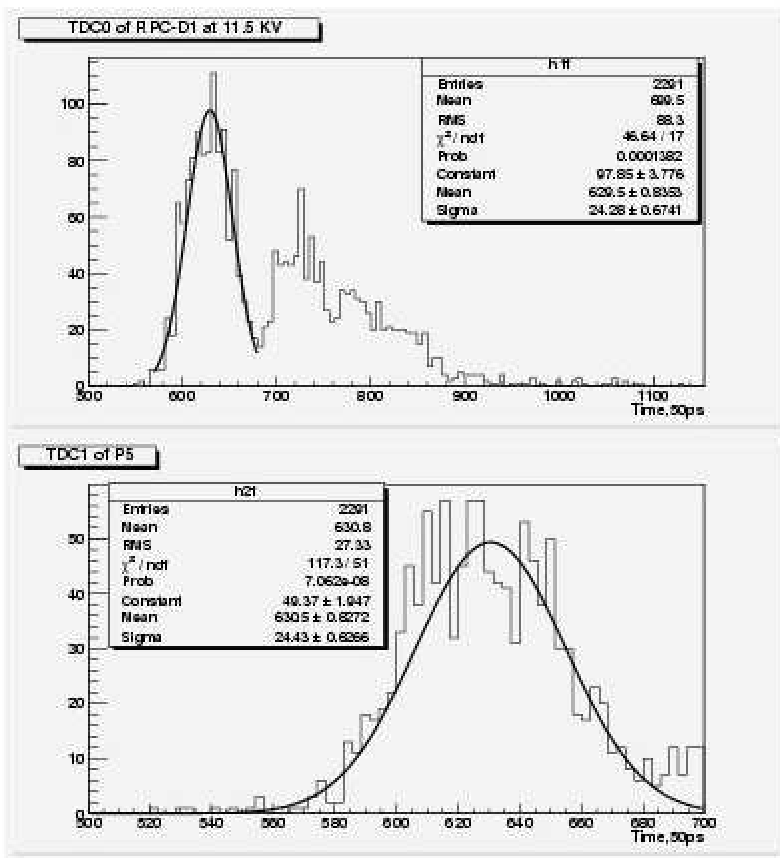
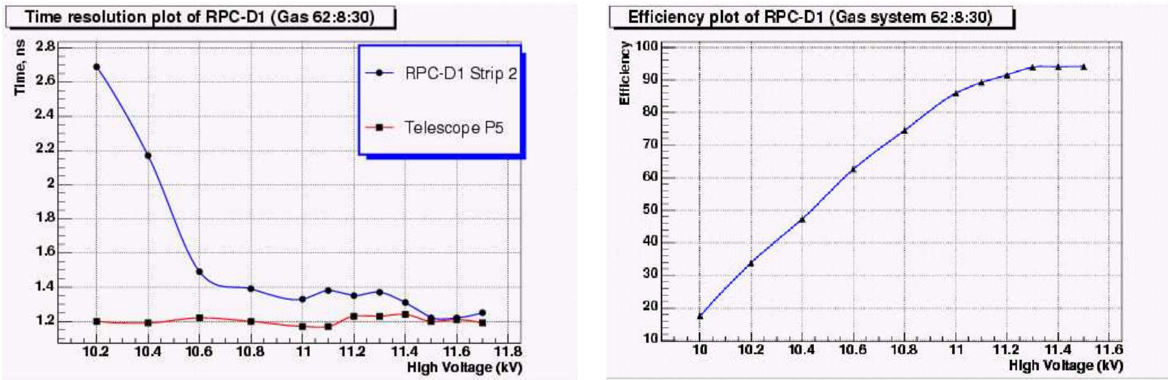


Figure 6: Time resolution of RPC-D1 and cosmic paddle P5

5.2.2 Time resolution plot of Double gap RPC

As can be seen from the plot (Fig.(7a)) the σ for time resolution is decreasing with the increasing high voltage. It is to be noted that the values for the σ are in ns[7]. The scintillator, kept at a constant HV shows an almost constant σ, around 1.2 ns. The behaviour of the RPC can be explained as with the increasing voltage the jitter formation of streamer pulse is decreased. Thus it takes less time to form a streamer. Therefore, we see the σ of time resolution is decreasing with the increase in high voltage.



(a)Time resolution vs HV

(b)Efficiency vs HV

Figure 7: Plots for Time resolution and Efficiency with increasing HV

5.2.3 Efficiency of Double gap RPC

We observe from the graph (Fig.(7b)) that the efficiency rises with the HV and saturates around 95% at a HV of 11.5 KV.

6 Conclusion

We fabricated and studied the efficiency and time resolution of the detector, RPC-D1. We discussed about the pulse shape of such an RPC. We saw that RPC-D1 gave a time resolution as low as 1.22 ns at 11.5 kV where the efficiency curve began 'plateauing' with an efficiency of 95%. A single gap RPC usually shows plateau at around 92% at an HV of 9.2 kV. Thus from our observation we conclude that a double gap RPC shows a little improvement in efficiency over the single gap chambers. But to achieve the plateau we need to ramp the voltage upto 11.5 kV which is quite high compared to that for the single gap RPCs.

[7] E.g. at an HV 11.5 kV the corresponding value of σ was 24.3 in units of 50 ps $\Rightarrow \sigma = 24.3 \times 50\text{ps} = 1.22\text{ns}$.

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