Design and Characterization of a 2m x 2m Resistive Plate Chambers (RPCs)

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Abstract

The India-based Neutrino Observatory (INO) collaboration is going to build a massive 50kton magnetized Iron CALorimeter (ICAL) detector, to study atmospheric neutrinos and to make the precision measurements of the parameters related to neutrino oscillations, to study matter effects and to use it as a long base-line detector in future. Glass Resistive Plate Chambers (RPCs) of about 2m × 2m in size will be used as active elements for the ICAL detector.

The present work involves the design and characterization of a 2m × 2m glass RPC. The details of the fabrication and operation of a 2m × 2m RPC including gas flow system and data acquisition system discussed here. The trigger for the RPC is generated by a scintillation paddle telescope. Then the different characteristics of the RPC like V-I, Noise rate and Efficiency are studied and also TDC plot is obtained. For the efficiency plot the plateau region has been found from voltage 9.9kV onwards at efficiency 96% for the main strip used in this experiment and so the RPC was operated at 9.9kV.

Contents

Introduction:

The Resistive Plate Chamber (RPC) was introduced in 1981 by R. Santonico and R. Cardarelli and is used in a large number of High Energy and Astroparticle Physics Experiments. Resistive Plate Chambers (RPCs) are parallel plate gas detectors built using high volume resistivity such as glass or Bakelite (phenol formaldehyde polymer). The main features of the RPCs are as follows:

- Built from simple and common materials.
- Low fabrication cost per unit area.
- Easy to construct and operate.
- Simple signal pickup and readout system.
- Large detector area coverage.
- High efficiency (>90%) and time resolution (~1ns).
- Two dimensional readout (x and y) from the same chamber.
- Long term stability.

These Glass RPCs playing main role as active elements in the Iron Calorimeter detector for the India-based Neutrino Observatory, which can measure the energy as well as the direction of the charged particle.

Details about the RPC:

Glass RPC is a gaseous detector composed of two parallel electrodes made up of float glass with 2mm thickness and volume resistivity of about 10^{12} Ω-cm. The two electrodes are mounted 2mm apart by means of highly insulated spacers. A thin layer of Graphite (about 15-20 μm) is coated on external surfaces of the two electrodes to provide the uniform electric field in the gap between them and these electrodes are connected to high voltage power supply of typically about 5 kV/mm DC voltage. A thick layer of gas mixture of Freon (R134a), Isobutene, SF_6 at normal pressure is flown between the gap of glass plates. This gas mixture acts as a sensitive medium to the charged particles entering the detector. A set of pickup strips, made up of copper, are mounted on either sides of the external surface of the RPC in orthogonal directions to each other. Each strip behaves like a transmission line and they are connected to 50Ω resistor to act with characteristic impedance of 50Ω .

<u>Specifications of the RPC used</u> :

- Dimensions of RPC glass: 2m×2m×3mm.
- Glass type: Asahi Float glass.
- Gap between two glass plates: 2mm.
- Spacer thickness: 2mm.
- Width of pickup strips: 28mm.
- Graphite coating: conductive paint about 15-20μm thickness.

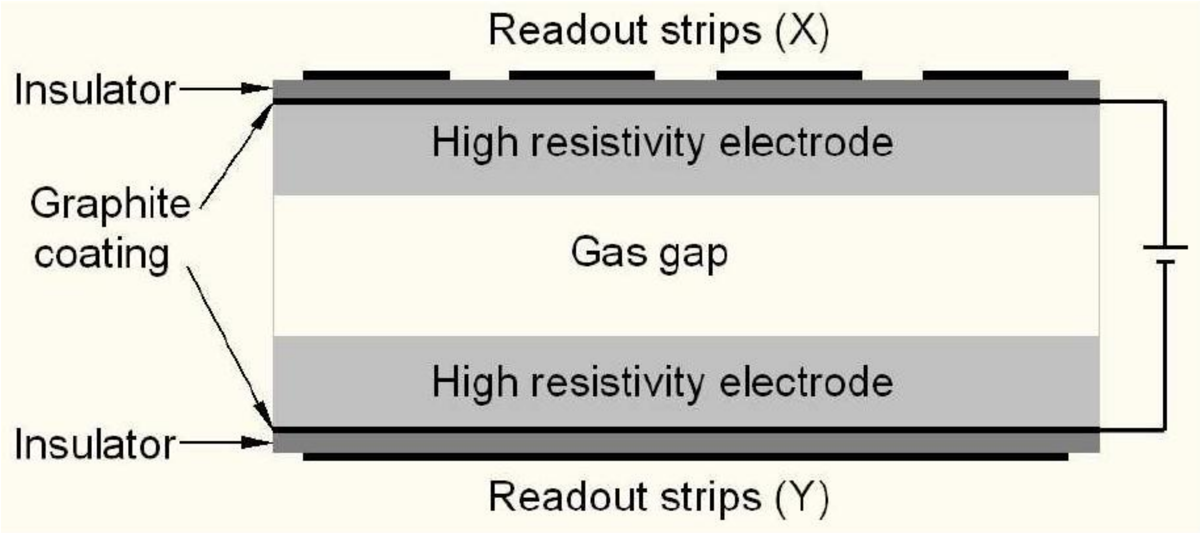


Fig: Schematic diagram of an RPC (transverse view)

Operating Modes of glass RPC:

RPCs may be operated in the avalanche mode or streamer mode and these modes are discussed below.

1) Avalanche Mode:

When a charged particle passing through the gap of the RPC, it ionizes the gas and produces electron ion pair called primary ionization. The electrons are accelerated towards the positive electrode and the positive ones towards negative electrode. In their path towards the anode the primary electrons causes the secondary ionization and the gas leading to a Townsend avalanche formation.
This avalanche can stops by using some poly atomic Quench gases, in our case Isobutene and SF_6 . This mode operates in the voltage range about 10kV, so the typical pulse amplitudes are ~1mV. Hence preamplifiers are required in signal readout system.

2) Streamer Mode:

This mode is operated at very high voltages, hence the secondary ionization continues until there is a breakdown of the gas and a continuous discharge takes place. So the signal generated will be large and typical pulse amplitudes are ~100 - 200mV and hence no need of amplification. Thus the readout of Streamer mode RPCs is quite simple. But the life times of RPCs operation in Streamer mode are less and hence Avalanche mode operation is preferable.

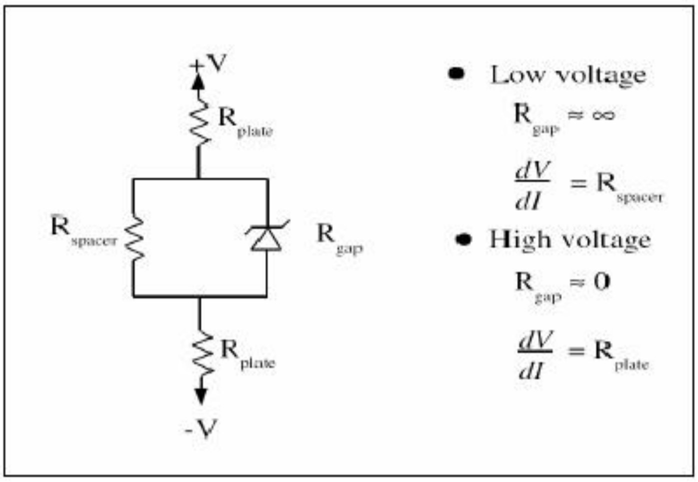


Fig: Electrical Representation of RPC

Fabrication of glass RPC:

Here we fabricated RPC number AL06 (Asahi Layer 06) in our RPC lab and various stages involved in the fabrication are as follows:

1) Cutting and Cleaning of Glass:

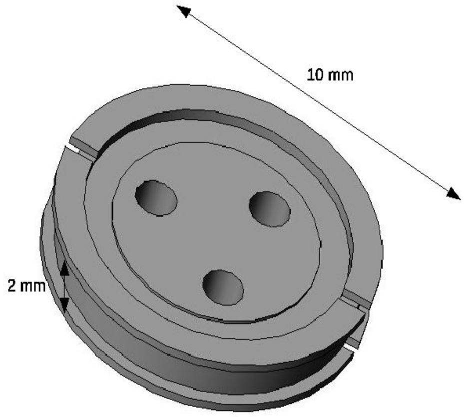
We used the Asahi float glass of 3mm thickness procured from local vendors are cut by diamond cutter to the appropriate size and the four corner edges are chamfered by a jig of right dimension to make a correct 45^0 angle. The glasses are thoroughly cleaned with alcohol (Propan-2-ol). After that the edge spacers, corner spacers connected to the gas nozzle and polycarbonate button spacers are also cleaned with alcohol.

2) Conductive Coating:

The one side of a glass is coated with a mixture of dry colloidal graphite and industrial lacquer in the ratio of 1:8 to increase the conductivity. This layer serves two purposes: the coating is conductive enough to act as electrode and resistive enough to prevent the signal to conduct away from the pickup planes.

3) Gluing of Glass:

One of the glass plates is horizontally mounted on the table by touching graphite coating side to the thermacol sheet placed on the table. The button spacers of 2mm thick and 10mm diameter are glued on the top of the glass plate in a square array by placing 20cm apart from each other with 3M Scotch Weld Epoxy Adhesive (DP190) glue which is in grey colour. The glue comes out from the three holes of the button spacers, and if need some more glue is added on the buttons, and then the other glass plate is placed carefully on the spacers to have uniform gas gap of 2mm between the two plates. The straight spacers and the corner spacer with gas nozzle are also of the same thick and are fit in the gas gap.



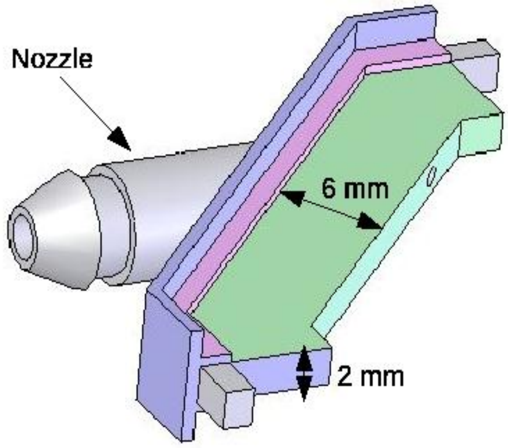


Fig: Button **Fig: Corner Spacer with Nozzle**

To put a uniform pressure on the whole surface, the whole setup is wrapped with a plastic sheet and the air inside is sucked slowly by using a pump to create a partial vacuum and a pressure equivalent to 5cm of water and left for 6 hours. The spacers are also glued to the glass using a syringe.

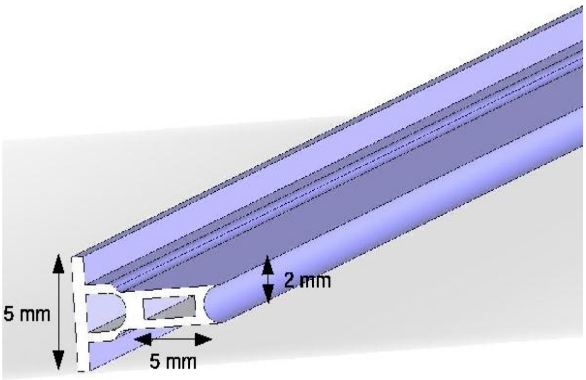


Fig: Straight Spacer

4) <u>Gas Leak Test</u>:

First the air in the RPC is send out through flow test by sending Freon gas from one corner and putting opposite corner to the atmosphere connecting with pipe and the remaining opposite corners are blocked with the blocker. After filling the RPC gap with Freon that end is stopped with constrictor and the opposite corner is connected to manometer to maintain about 25-27mm level difference to atmospheric and RPC gas pressures. Then the system is left for 1.5 to 2 hours for checking whether any decrease in the manometer column or not. If there is no decrease in column then the RPC is passed in the leak test. And if there is any difference there is a leak and we have to conform it by using sniffer RIKEN GH202F, which is sensitive to Freon gas at atmospheric pressure and then we have to glue again for that leak.

5) High Voltage Cables:

The high voltage is applied to the graphite layer by sticking on a copper tape and leads are then soldered on to the copper. Positive voltage is applied to one side and an equal and negative voltage to the other side, using a bipolar high voltage DC supply, so that both see a common ground. The bipolar connection is better than the unipolar since each glass surface sees only half the total voltage, thus decreasing the chances of HV leaks.

6) Pickup Strips:

The RPC is now sandwiched between two honeycomb pickup panels placed orthogonal to each other and then packed in an aluminium case to get common ground. The pickup panel consists of 64 copper strips on one side and a layer of 5mm of plastic and aluminium on the other side. Each strip is machined to a width 28mm and the gap between two adjacent strips is 2mm. Honeycomb panels are lightweight and provide adequate mechanical strength. Each strip is terminated with a 50 Ω impedance to match the characteristic impedance of the preamplifier. A Mylar sheet of thickness 100μm is placed between the graphite layer and the pickup panel to provide insulation.

Gas Flow System:

The choice of fill gas largely depends on the following factors:

- Low working voltage
- High gain
- High rate capability

Noble gases like Argon and Freon require minimum ionization energy and hence are the ones usually used. If the primary electrons created by the passage of the charged particle are n_0, then the number of electrons reaching the anode is given by

$$n = n_0 e^{\eta x}.$$

Here

$$\eta = \alpha - \beta$$

where, α: First Townsend coefficient (represents number of ionizations per unit length), β: Attachment coefficient (represents number of electrons captured per unit length) and this parameter becomes particularly important for electronegative gases.

In our case we used Freon (134a) gas is used for operating the RPC in Avalanche Mode. For absorbing the ultraviolet photons produced in electron-ion recombination, when the detector is in Avalanche Mode we require some Quenching gas. Generally, polyatomic gases, often hydrocarbons are used for this purpose and we are using Isobutene. Finally, we need some gas to absorb the excess electrons and we are using SF_6 (Sulphur hexafluoride).

Gas Composition:

The gas composition using in our RPC is as follows:

Freon (R134a)	- 95.15%
Isobutene	- 3.90%
SF_6	- 0.60%

Gas Flow System:

Our system is designed for mixing of four gases and presently we are using three gases as our RPC is operating in Avalanche Mode. The mixing unit consists of the following components:

1) Purifier Column:

It consists of molecular sieves used to absorb moisture and purify the gas.

2) Mixing Unit:

It based on Mass Flow Controllers (MFC) and the flow of the gas is displayed in Standard Cubic Centimetre per Minute (SCCM).

3) Distribution Panel:

16 RPC's can be connected in parallel, which is achieved by “Flow resistors” viz. capillaries, which are 2 m long and 200 m in diameter. These offer a resistance of 1/14th of a bar to the gas flow when the flow is about 6 sccm.

4) Safety Bubblers:

To take care of the back pressure exerted and protect the RPCs from over pressurizing.

5) Isolation Bubblers:

It prevents back diffusion of air into the RPC and also indicate the flow of the gas.

6) Exhaust Manifold:

All the gas to be vented is collected in this manifold and a single output is provided to vent the used gas into the atmosphere. This manifold has a pressure sensor to indicate the pressure with respect to the room pressure.

7) Remote flow setting and monitoring through PC:

Online monitoring and setting of the flow of gas through the MFC 's and also has provision for monitoring the pressure on the gas mixing and exhaust manifold sensors.

8) Moisture Meter:

Microprocessor based SHAW sensor meter to monitor the moisture content in the mixed gas.

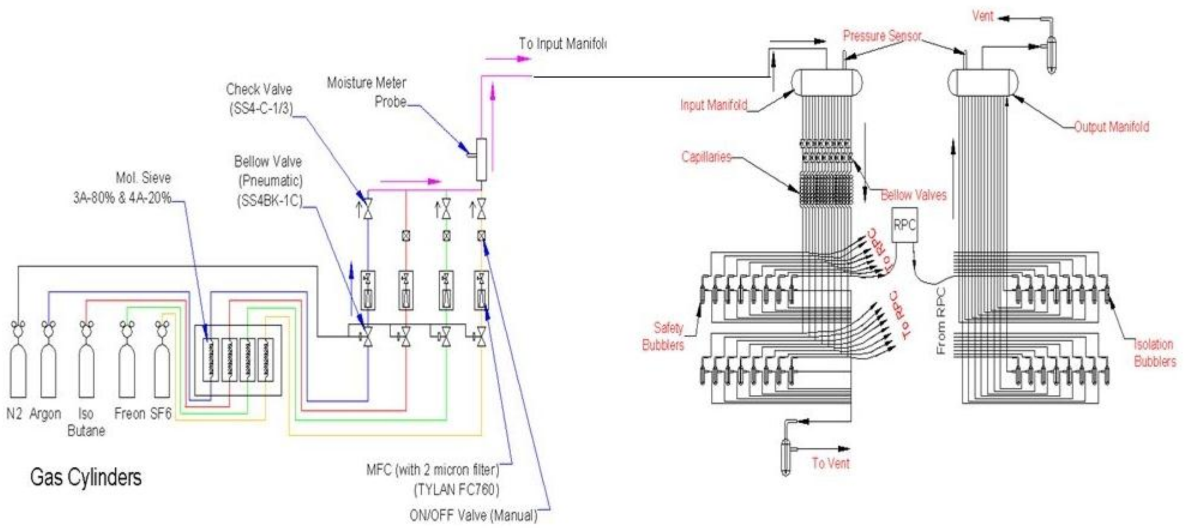


Fig: Block diagram of Gas Flow System

Signal Processing and Data Acquisition System:

In order to analyse the data, we have to store the signals generated by the RPC. A sophisticated electronics system has to be used for this purpose. The whole of the system can be broadly divided in to two major components, viz. Signal processing and Data acquisition system.

The Signal Processing unit can further be classified into:

1. Frontend electronics. (16 channel Analog frontend and 32 channel Digital front end)
2. Trigger module,
3. Signal routers (Trigger and TDC Router & Control and Data Router).

The figure below is for electronic setup for x plane:

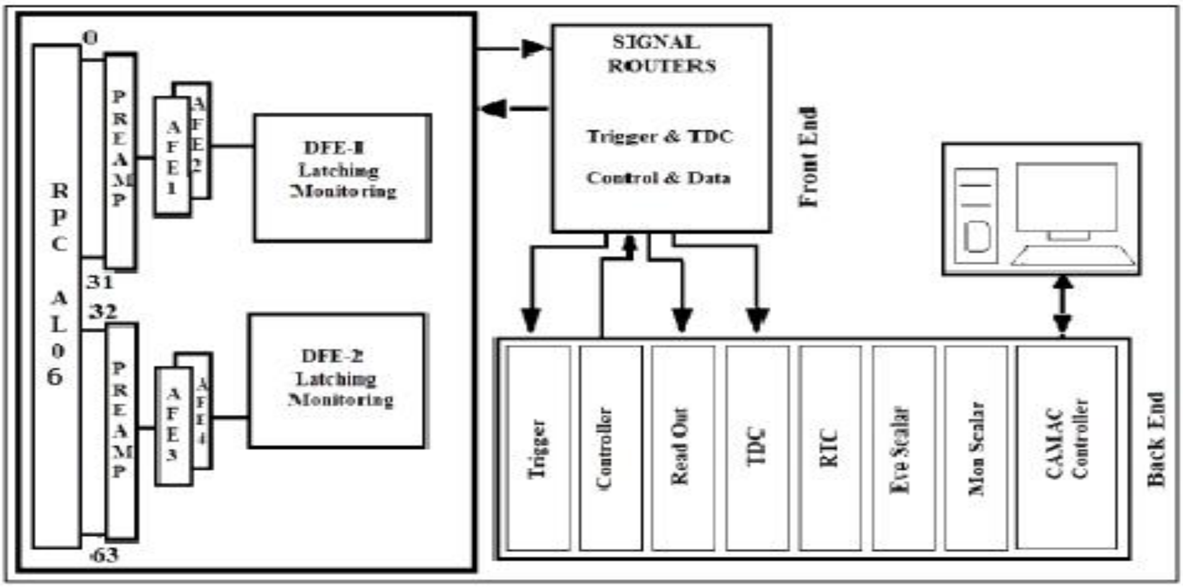


Fig: Block diagram for electronic setup for x - plane of RPC

<u>Trigger logic for calculating the RPC Efficiency and Time Resolution</u> :

In order to record the signal that we are getting is from the cosmic muons, we have to employ appropriate trigger logic. For this scintillator paddles are arranged in such a fashion that if a muon passes through all of them, it produces a trigger signal. Four scintillator paddles P1 (30cm×3cm), P2 (30cm×2cm), P3 (40cm×20cm), and P4 (40cm×20cm) were used and together are called as cosmic ray telescope. The passage of muon through the cosmic ray telescope a trigger signal is generated and the signal is recorded by RPC under test. The RPC trigger logic set up is shown in the below figure.

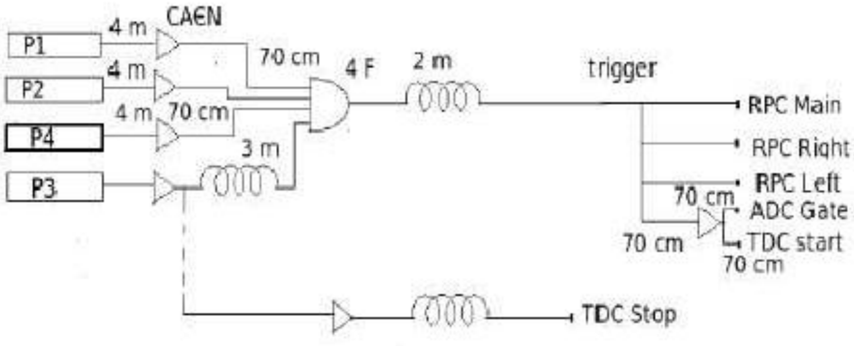


Fig: Trigger Logic circuit diagram

The analog pulses that come from the preamplifiers and the PMTs are converted into digital pulses using discriminator with a threshold voltage of 20mV. The paddles P1, P2, P3, P4 are AND to give 4fold signal. Scalars are employed at different stages to monitor the count rates of these signals. The P3 signal is delayed by a 3m cable (approximately 15ns) to take care of the jitter from the scintillation paddles. The pickup strips of the RPC are connected to the discriminators and the output is taken to different TDC channels with some delay. RPC trigger is taken from the main strip of RPC (main strip in our case was strip#20) and is ANDed with the 4fold signal to get a 4fold × RPC signal. So the efficiency of RPC becomes

$$E = \frac{4-fold \times RPC}{4-fold}.$$

The figure below shows the circuit diagram for calculating efficiency of RPC.

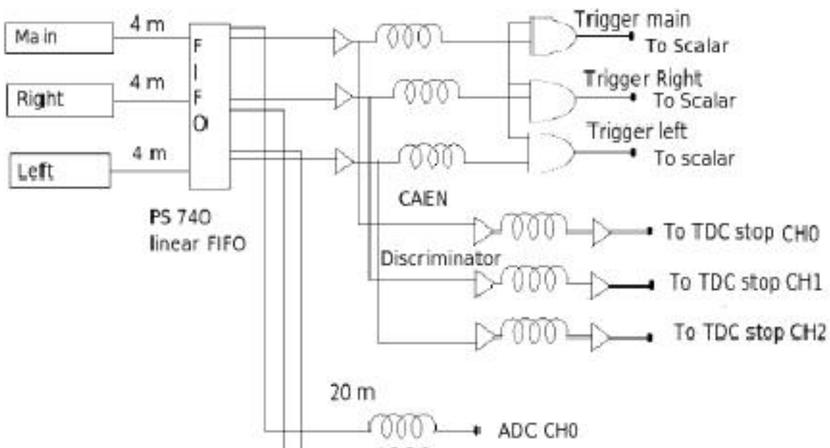


Fig: Circuit diagram for efficiency measurement of an RPC

Characteristics of the RPC:

The main characteristics of the RPC are as follows.

1) V-I Characteristics:

The V-I characteristics of the RPC AL06 are plotted and are as follows. Here Channel-A corresponds to Positive voltage side and Channel-B corresponds to Negative voltage side.

For Channel A:

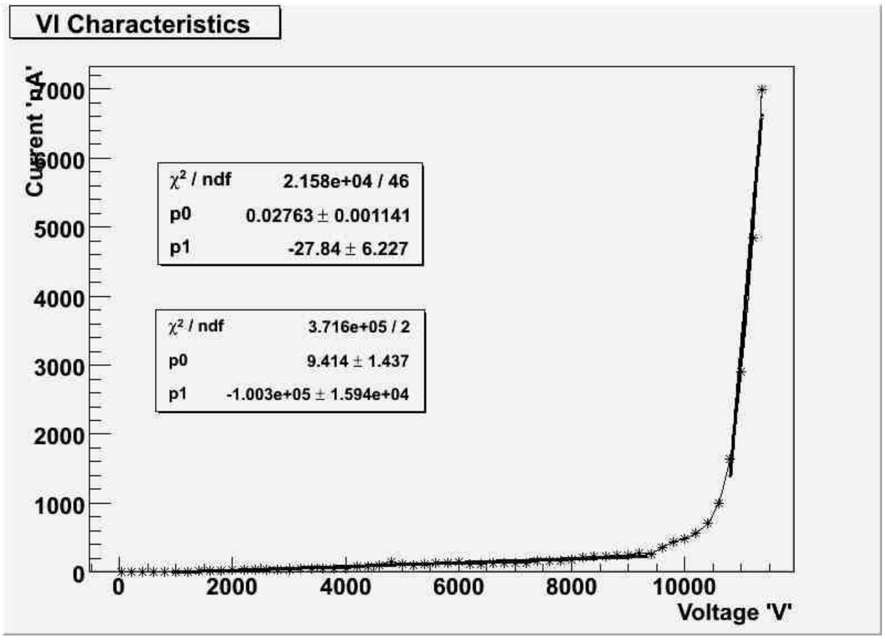


Fig: V-I Characteristics, Channel A

From plot

Space Resistance=36.193 GΩ (low voltage region)

Gap Resistance =0.106 GΩ (high voltage region)

For Channel B:

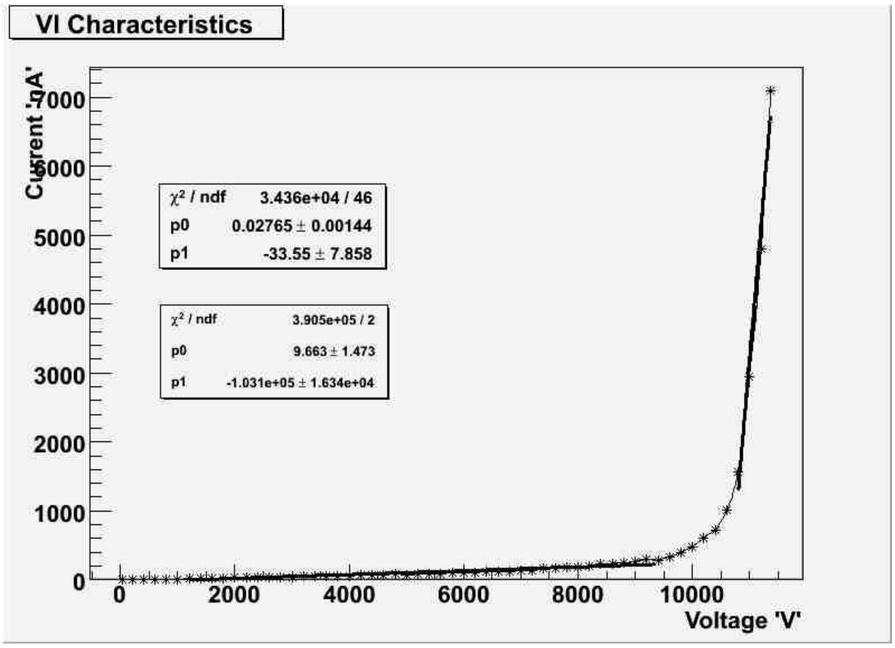


Fig: V-I Characteristics, Channel B

From plot

Spacer Resistance=36.166 GΩ (low voltage region)

Gap Resistance =0.103 GΩ (high voltage region)

2) Noise Rate:

Noise rate in Hz versus High Voltage of RPC is plotted and is as follows.

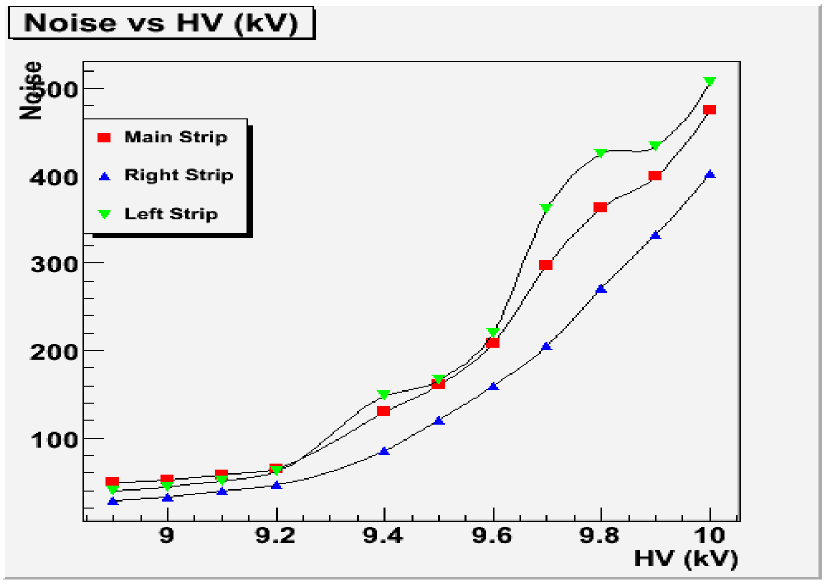


Fig: Noise Rate

From plot noise rate at 9.9 kV is 400±20 Hz

3) Efficiency:

The efficiency of the Right (19), Main (20) and Left (21) strips of the RPC is plotted as a function of High Voltage and is shown below.

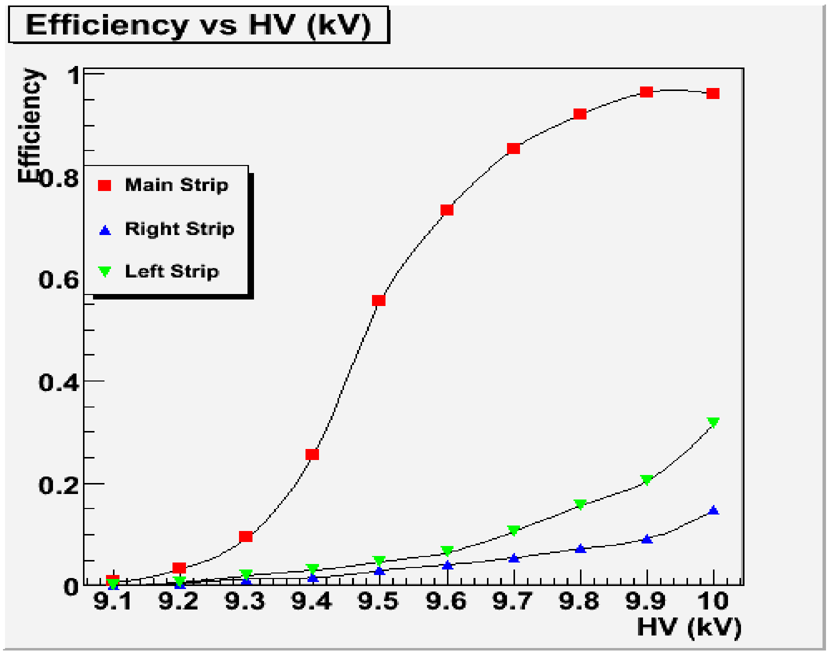


Fig: Efficiency

The 2cm paddle was along the main strip and hence it shows the maximum efficiency. The plateau region starts from 9.9kV and the maximum efficiency is 96%.

TDC Plot:

The time difference between the arrival of the trigger and firing of RPC is taken and binned in a histogram and it fitted to a Gaussian Distribution as shown in the below plot.

From the plot we obtain

The value of $\sigma = 17.38 \pm 0.10$
The least count of TDC is 0.1ns
And therefore the time resolution of RPC is 1.738 ± 0.01 ns.

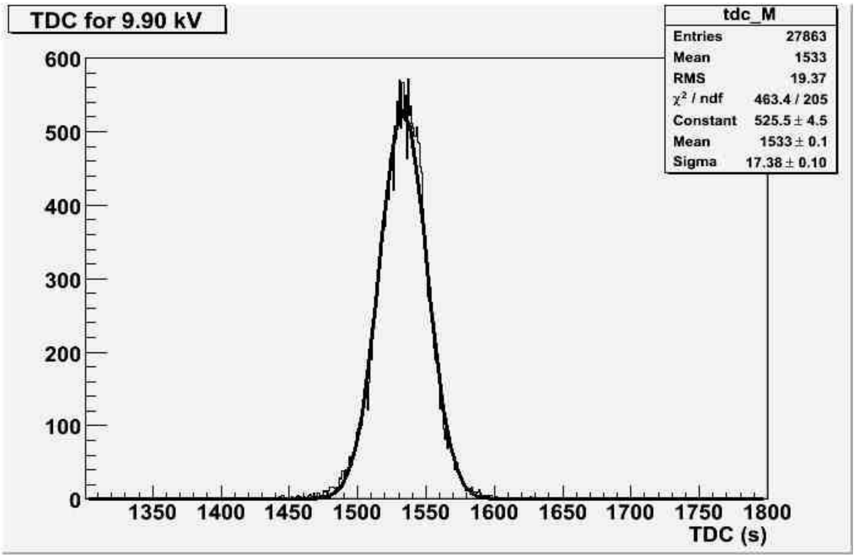


Fig: TDC Plot

Conclusions:

We successfully completed the construction of 2m x 2m RPC AL06 and it is operating in the avalanche mode region with an efficiency of about 96% at a voltage of 9.9kV. The Characteristics and time distributions are also studied.

Acknowledgments:

I would like to thank to Prof. Naba K Mondal for providing this great opportunity to do work in the INO RPC lab. I would like to thank to Dr Satyanarayana for guiding us to do this experiment and to Mr R R Shinde for arranging the experiment setup in the lab and his great help. I would also like to thank to my seniors and colleagues Varchaswi K S Kashyap, Rajesh Ganai and Asmita Redij who answered all my questions.

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