EXPERIMENTAL PROJECT REPORT

ON

Development and Characterization of 2mx2m Glass Resistive Plate Chambers

Submitted by

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Under the guidance of

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Development and Characterisation of 2m x 2m Glass Resistive Plate Chambers

Abstract:

The present work shows the design, development and characterisation of 2m x 2m glass RPC's .The details of the making of a 2m x 2m RPC, as a gas ionisation particle detector, the gas flow system using MFC (mass flow controller) and the electronic data acquisition system are discussed here. The trigger for the RPC is generated by a scintillator paddle telescope. The efficiency, noise rate, I-V characteristics and TDC plots are then obtained and studied for the RPC.

Introduction:

Glass RPC's have a long history dating back to the late 1970's [1].RPC array is a key component when it comes to the traditional function of muon detection. RPC's 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. They are preferred over scintillators because of the following reasons: [2, 3]

1. They give a good position resolution and give good detection efficiency.
2. They can be made to have a large area but at a minimal material cost.[4]
3. These are easy to assemble and they possess simple read-out electronics.
4. They exhibit better time resolutions than scintillators and long-term stability.[4]

The glass RPC's have been proposed as the active element in the iron calorimeter detector for the India-based Neutrino Observatory. Single and double gap RPCs have found application in cosmic ray experiments, in high energy experiments as well as in astroparticle physics.

Principle of Operation of Glass RPC:

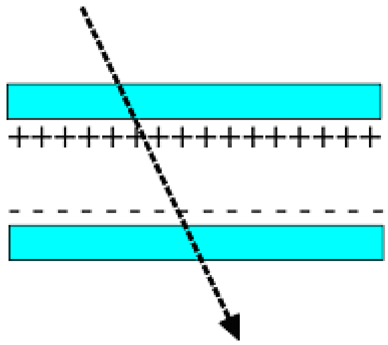
The resistive plate chambers described here are dc operated particle detectors whose sensitive element is a 2mm thick gas layer of Freon (134A), isobutane and SF_6 at normal pressure, under a uniform steady electric field of 4.5-5kV/mm generated by two parallel electrode plates of Asahi float glass with a volume resistivity of $10^{12}\Omega$-cm.When the gas layer is crossed by an ionising particle, an electric discharge is suddenly initiated by the liberated electrons. This discharge is quenched by the following mechanisms:

1. Prompt switching off of the field around the discharge point, due to the large electrode resistivity.
2. UV photon absorption by the quencher preventing secondary discharges from gas photo ionisation.
3. Capture of outer electrons of the discharge due to the gas with high electron affinity, which reduces the size of the discharge and possibly its transversal dimensions.

The duration of the discharge is typically ~ns. The relaxation time of the resistive electrodes plate is τ~2s.The large difference between these two characteristic times insures that during the discharge the electrode plates behave like insulators, so that only a limited area of ~$0.1cm^2$ around the discharge point remains inactive for the dead time of the detector.

Graphite painted high-voltage electrodes of surface resistivity 200-300kΩ/ cm^2, transparent to the electrical pulse originated in the gas; allow a capacitive readout through external pick up electrodes. These are copper strips about 3cm wide, facing the glass electrode (with thin mylar sheets in between for insulation against the high voltage).

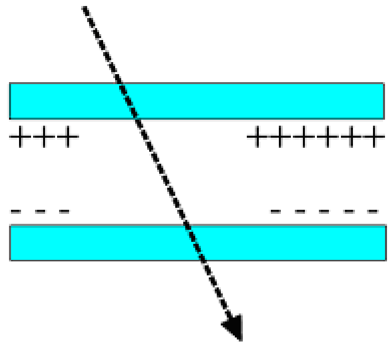
Before,



A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally (r~0.1cm^2) available charge is consumed.

Figure 1.a

After,



The electric field drops only around the streamer location, for a time proportional to the electrode resistivity. The discharged area recharges slowly through the high-resistivity glass plates

Figure 1.b

Modes of Operation:

There are two modes of operation for RPCs depending on the voltage of operation and gas composition used:

1. Avalanche Mode

Charged particles passing through the gaseous medium produce primary ionization. These ionized particles are accelerated by electric field thus producing secondary ionization by colliding with the gas molecules. This avalanche stops as the external field opposes the internal field due to ionization and the charged particles get collected on the respective electrodes. This mode operates at a lower voltage and typical pulse amplitudes are ~mV and hence amplifiers are required in the signal readout system.

2. Streamer Mode

In this mode of operation, the secondary ionisation continues until there is a breakdown of the gas and a continuous discharge takes place. This mode operates at a high voltage. Signal generated will be large and typical pulse amplitudes are ~100-200mV.

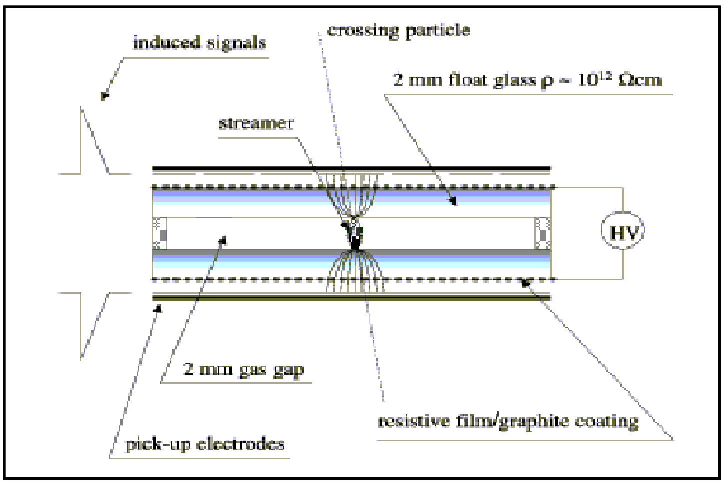


Figure 2.Schematic of a RPC in operation in streamer mode

A streamer mode is adequate for cosmic ray and low rate accelerator experiments, while an avalanche mode is required for high rate experiments such as CMS at LHC.

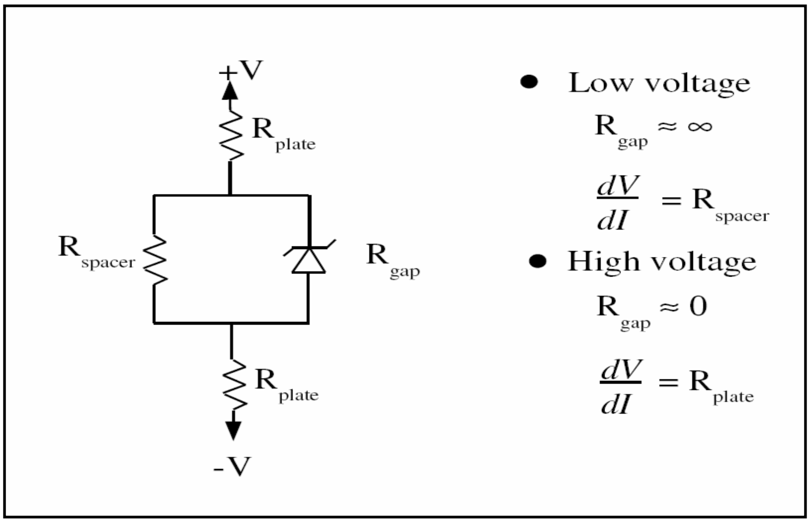


Figure3. Electrical Representation of RPC

Fabrication of 2m X 2m RPC:

Various stages involved in the fabrication of RPC are as follows:

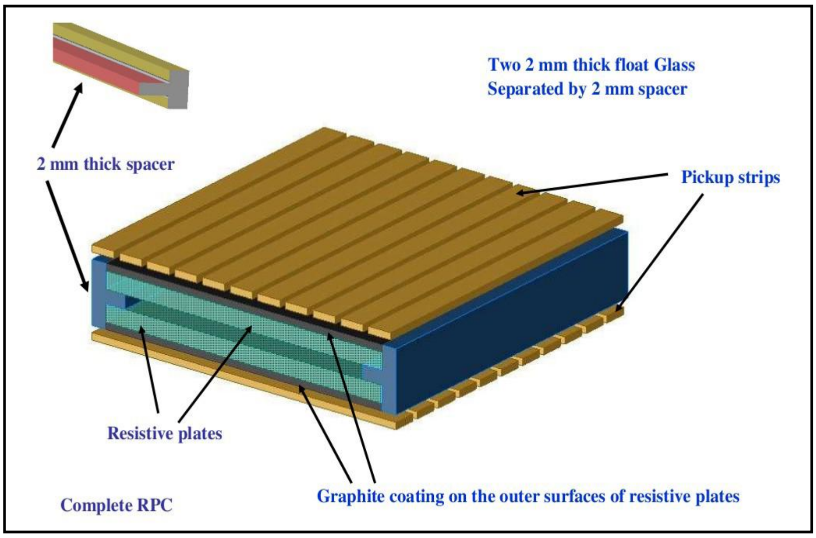


Figure 4.Structure of a standard single layer RPC

1. Glass Cutting and Cleaning

The Asahi float glasses (each 3mm thick) procured by 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 followed by labolene and distilled water. After that the edge spacers, corner spacers (which are connected to the gas nozzle) and polycarbonate button spacers are also cleaned with alcohol. The glass edges are taped over with masking tape with 1 cm being masked or taped off on each side so as to prevent the conductive coating to be painted right up to the edge of the glass so that leakage of high voltage does not take place through the edge spacers

2. Conductive Coating

Conductivity of the glass is increased by coating one side of it with a mixture of dry colloidal graphite and industrial lacquer in a ratio of 1:8 using a spray gun. Once the surface is coated the masking tape is removed and the resistivity of both surfaces is measured using a resistance measurement jig (a copper and brass square about 17.5 x 17.5 cm^2). This layer serves two purposes: it is conductive enough to act as anode/cathode and it is resistive enough to prevent itself from conducting away signal to the pickup strips so as to minimise the lateral spread. [11]

Surface resistance measurement:

The contour plots are obtained for five glass plates and two of them having fairly uniform surface resistance are selected for the construction of the RPC named as Al03. The surface resistance is found to be fairly constant and is about 100-200kΩ/cm^2.

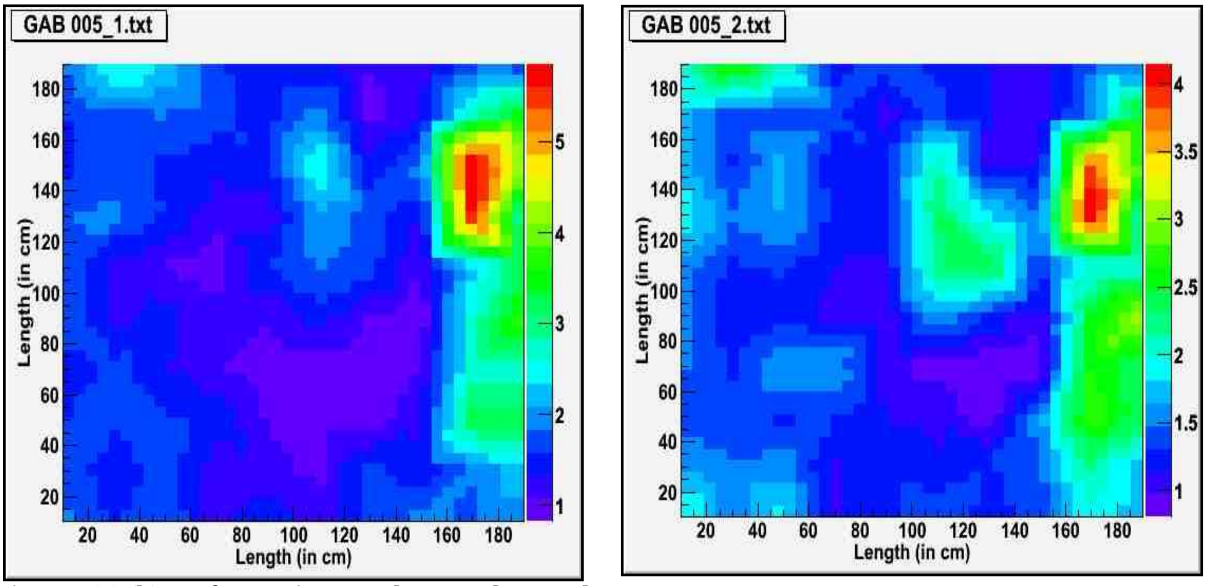


Figure 5(a),(b).Surface resistance along X-plane and Y-plane

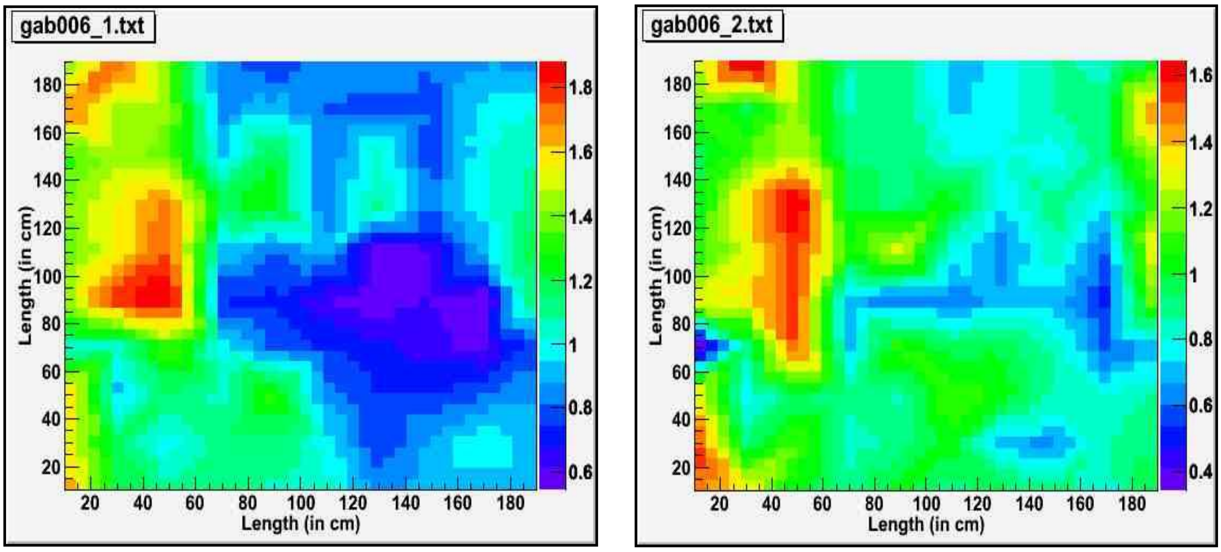


Figure 6(a), (b).Surface resistance along X-plane and Y-plane

There is variation in surface resistance near the edges due to non-uniform coating of graphite.

3. Gluing of Glass

The glue used is 3M Scotch-weld epoxy adhesive (DP 190) in a duo-pack cartridge. The button spacers (width ~1.8mm) are glued in a square array on top of the glass surface without the graphite coating. The glue comes out through the three holes of the spacers, and glue is again applied on top of the buttons. Then the other glass plate is placed on this array of spacers thus obtaining a gas gap of 2mm. To put a uniform weight throughout the 4m^2 area the whole set up is wrapped with plastic sheets and the air inside the plastic sheets is sucked slowly to create partial vacuum and a pressure equivalent to 5cm of water column pressure. The set up is left for six hours to fix the spacers. The straight edge-spacers are also designed such that the glass sits neatly within. There is a

1mm gap where the glue can be poured. The central protrusion is 2mm, thus supplying the required gap between glass plates. The corner spacers (gas nozzles) contain the gas inlet/outlet pipes. The glue is poured in the required gap and lead blocks are placed along the 4 sides to put the pressure and whole setup is left for one day, on the next day the same procedure is followed for the other side of the RPC.

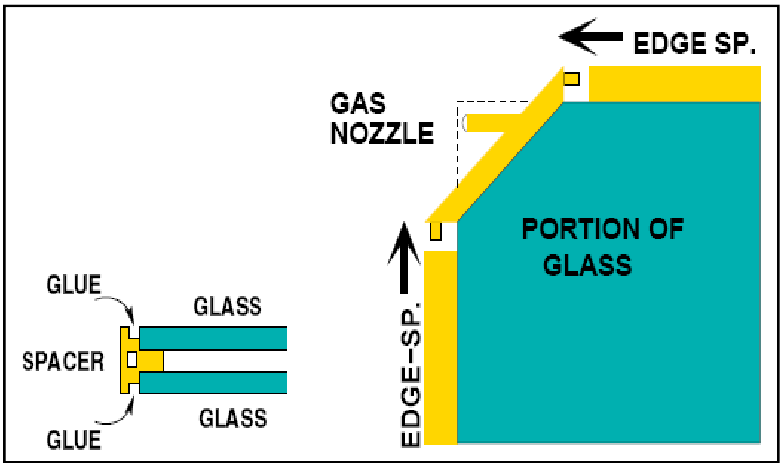


Figure7. Side-view and Top-view of Spacer

4. Gas Leak Test

To ensure against the gas leak (especially at the glued joints), a test is done by flowing Freon gas at slightly above atmospheric pressure and using a gas leak checker RIKEN GH-202F.Re-gluing is done on the edge spacers wherever a gas leak is detected.

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 a equal and negative voltage to the other side, using a bi-polar high voltage DC supply (N471A), so that both see a common ground. The bi-polar connection is better than the unipolar since each glass surface sees only half the total voltage, thus decreasing the chances of HV leaks. Also it minimises the maximum absolute rating of the resources used e.g. HV modules and HV carrying cables.

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. The pickup panel consists of 64 copper strips on one side and a layer of 5mm of plastic and aluminium(serving as a ground) on the other side. Each strip is machined to a width 2.8 cm and the gap between two adjacent strips is 0.2cm. Honeycomb panels are lightweight and provide adequate mechanical strength. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the strip. A layer of mylar of thickness 100μ is placed between the graphite layer and the pickup panel to provide insulation.

GAS FLOW 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. The first ionization potential, the first Townsend co-efficient and the electronegative attachment co-efficient determine the avalanche multiplication, the presence and relative importance of photo production, the saturated avalanche range to the streamer mode. The gas mixture fixes the working mode of the RPC in 'avalanche' or in 'streamer' mode, resulting in different characteristics and performances.

Currently the RPCs are operating in the avalanche mode and hence the main component could be an electronegative gas, with high enough primary ionization production but with small free path for electron capture. The high electronegative attachment coefficient limits the avalanche electrons number. Here we use Freon (as eco-friendly R134A) which meets the above requirements. Polyatomic gases, often hydrocarbons, have a high absorption probability for ultra violet photons, produced in electron-ion recombination. This gas is known as quenching gas and limits the lateral charge spread. Here 'Isobutane' is used as the quenching gas. Finally SF_6 (Sulphur-hexafluoride) is used to control the excess number of electrons.

The system is designed for mixing four gases: Argon, Freon (134A), Isobutane and SF_6 by volumetric method. The gas mixing system consists of the following components:

1. Purifier Column: It contains Molecular sieve used to absorb moisture and purify it.
2. Mixing Unit: It is 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 2m long and 200μ in diameter. These offers a resistance of 1/14th of a bar to the gas flow when the flow is about 6sccm.
4. Safety Bubblers: To take care of the back pressure exerted and protect the RPC's from over pressurizing.
5. Isolation Bubblers: It prevents back diffusion of air into the RPC and also indicates the flow of the gas. It also isolates RPC from the atmospheric pressure, thus acting as a buffer.
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. Moisture Meter: Microprocessor based SHAW sensor meter to monitor the moisture content in the mixed gas. [6]

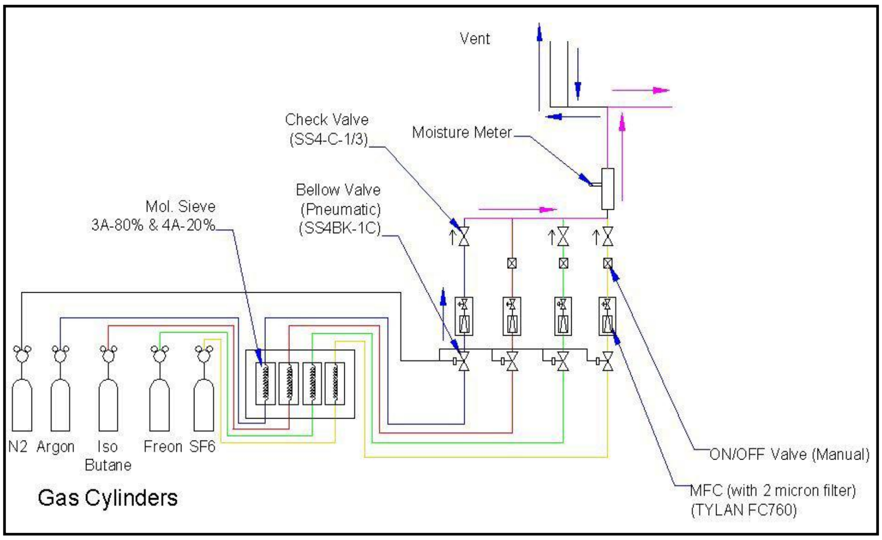


Figure 8.Block diagram of Gas Flow System

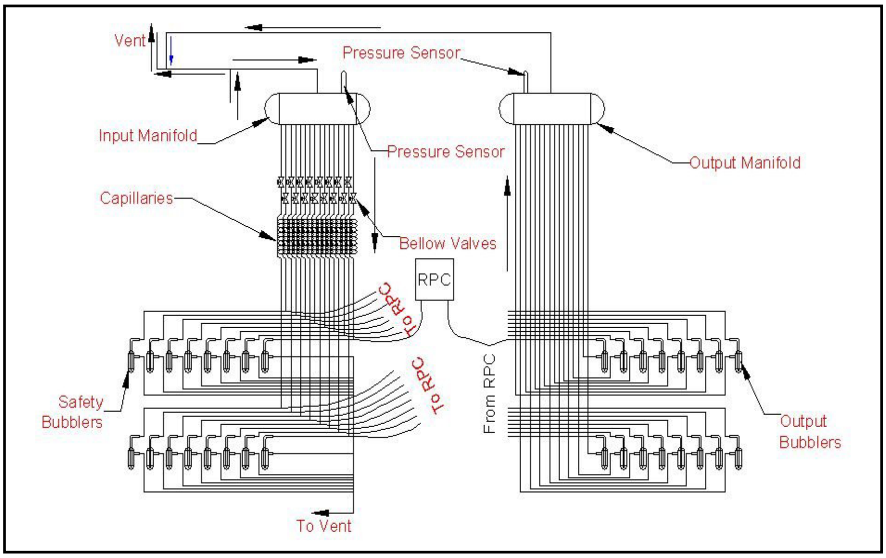


Figure9. Block diagram of Gas Flow System

The pressure of the gases to be mixed is controlled at the output of the cylinder itself by using two stage pressure regulators. The pressure set is 0.5 to 1 kg/cm^2 but as Freon (134A) and Isobutane gases are in liquid form low pressure input regulator of the order of 0 to 5 kg/cm^2 to be used, while for Argon and SF_6 the pressure is of the order of 25kg/cm^2.

On the display unit of the MFC, we have:

Gas constituents	Gas Flow (in SCCM)
Freon(R134A)	17.90
Isobutane	0.79
SF_6	0.07

There are two RPC's connected so each is getting 9.38 SCCM of total gas mixture.
The composition of the gases used thus is given below:

Gas constituents	Percentage
Freon(R134A)	95.42%
Isobutane	4.21%
SF_6	0.37%

Alignment of RPC in the laboratory:

To measure the efficiency of the RPC, firstly we ensure that the trigger pulse generated is solely due to the atmospheric muons. Six scintillator paddles are used to set a coincident circuit for this purpose, .i.e., a cosmic ray telescope with these scintillators. The telescope consists of 4 cosmic ray muon trigger paddles P1, P2, P5, P6 and two veto paddles P3, P4. The area of these scintillation paddles are 60×20, 60×20, 30×2,30×3 , 40×20, 40×20cm^2 respectively. The scintillation paddle gives out a signal when a cosmic ray muon or other charged particle passes through it. The geometry of the telescope using these paddles has been setup such that we define a window of about 30×2cm^2, for the cosmic ray muons to pass through the telescope as well as through one of the pickup strips of the RPC under test. Narrow paddles are used to define the telescope geometry precisely and veto paddles to prevent generation of triggers when a muon passes through the rest of the area of RPC which is not under study. The data from the RPC pickup strip is recorded whenever a cosmic muon generates a trigger signal through the logic $P_1 .P_2.\overline{P_3}.\overline{P_4} .P_5 .P_6$ i.e., a trigger is formed when a muon passes through the paddles P_1, P_2, P_5 and P_6 and does not pass through the veto paddles P_3 and P_4.

The recorded data of the RPC is used for its characterization by finding its efficiency, time resolution and other parameters.

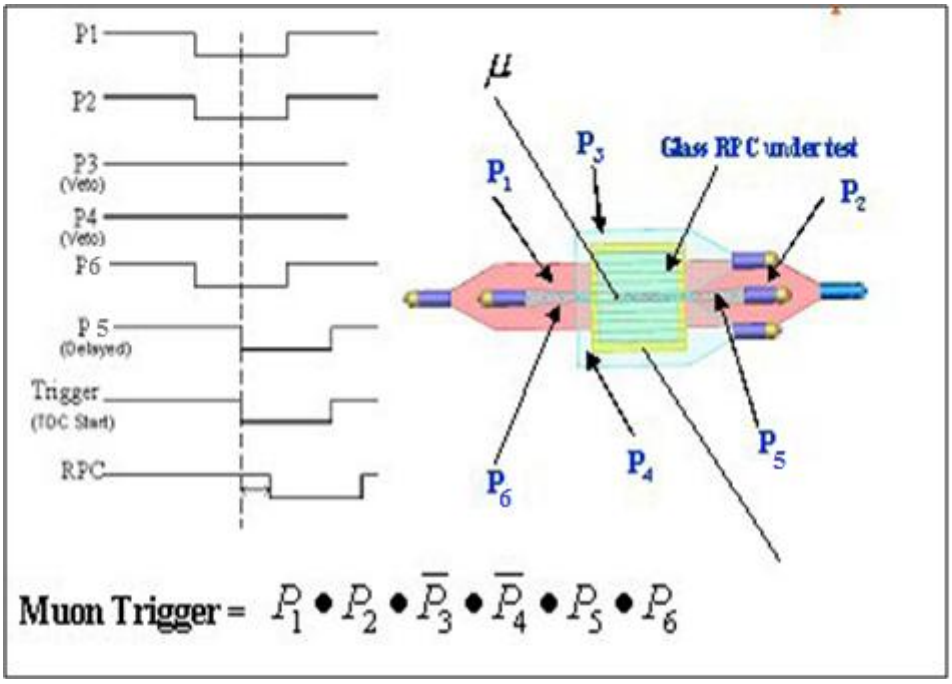


Figure10. Schematic of the RPC test setup

The analog pulses that come from the PMT's are converted to digital pulses through discriminators kept at a threshold of -30mV. P_1, P_2, P_5 and P_6 are ANDed and the veto paddles P_3 and P_4 are ORed. Scalars are added in every stage to monitor counting rates of these signals .The 4-fold pulse is NANDed with the veto to get 4fold x veto. The P_5 signal is delayed to take care of the jitter from the scintillation paddles which arises due to its finite time resolution. The pick-up strips of the RPC are connected to preamplifiers by twisted pair cables and to discriminators by coaxial cables and then output are taken to different channels of TDC with some delay. Trigger is taken from the middle strip of RPC (Main #32) and ANDed with 4fold x veto. Finally, 4fold x veto x RPC trigger is recorded.

Efficiency of RPC is defined as:

$$\mathrm{E} = \frac{\text{4fold x veto x rpc}}{\text{4fold x veto}} \qquad ---(1)$$

The RPC pulses are connected to ADC before digitising and the 4fold x veto is given to the ADC gate to ensure that when TDC gives a START the ADC gate is also open at the same time.

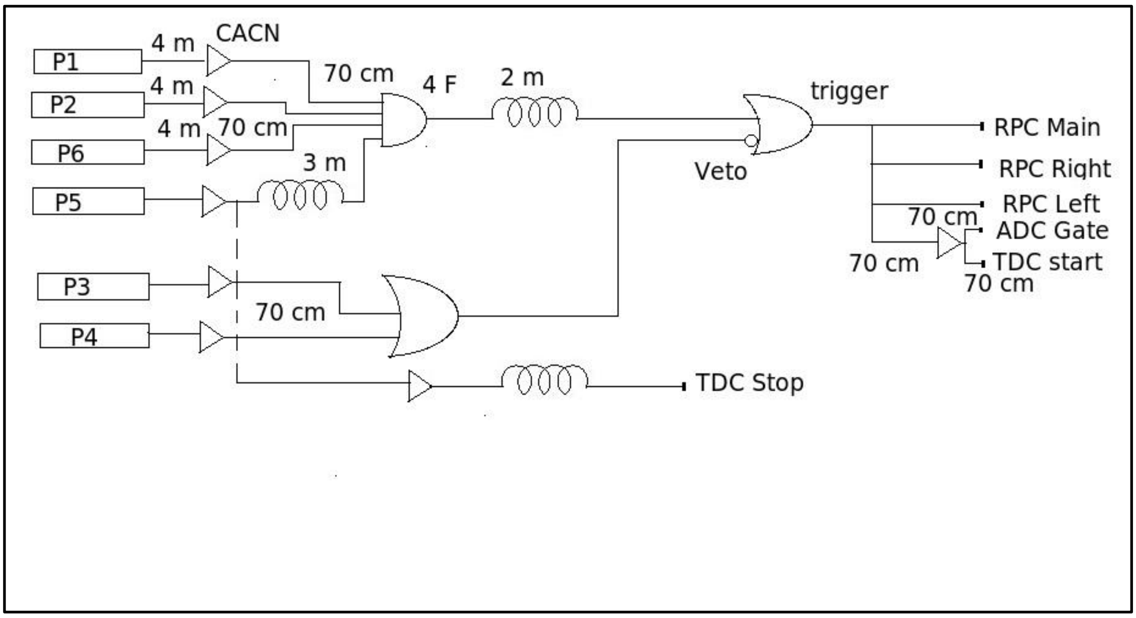


Figure11 (a). The circuit diagram for the trigger set-up

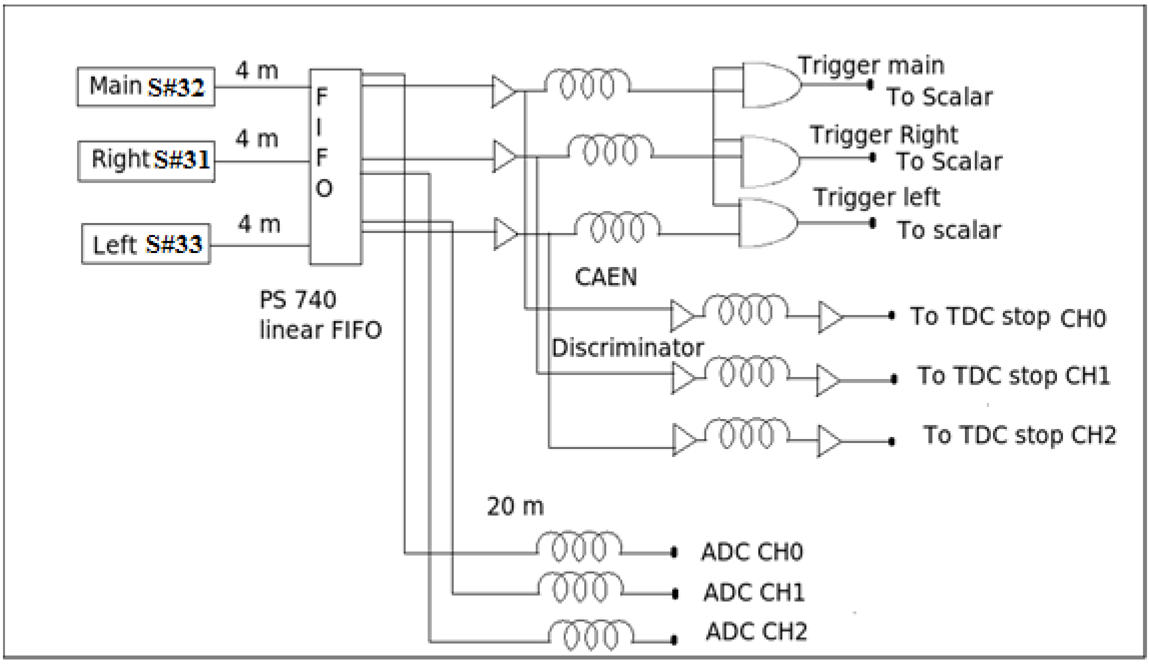


Figure11(b). The circuit diagram for the trigger set-up from the RPC

Electronic Data Acquisition System:

The entire signal processing and data acquisition system can be divided into the following modules:

- Front end electronics (16 channel analog front end and 32 channel digital front end).
- Trigger module.
- Signal routers (Trigger and TDC Router & Control and data Router).
- Back end DAQ system (Data and Monitor Control module & Data and Monitor Readout module).[5]

1. Front End Electronics

The signal from a pickup strip is passed through a pre-amplifier (gain70-80) and the output is fed to four 16 channel discriminator modules(Analog Front End).For channel-A, IC's 1597-1513 and for channel-B IC's 1595-1513 are used respectively. The signal crossing the set threshold in the discriminator generates differential ECL output. At present, the threshold is kept at -20mV. This section also generates the primitive trigger_0 logic. The discriminator modules are connected to two 32 channel Front End Processing (FEP) module (Digital Front End) which converts the ECL i/p to TTL o/p and also generates trigger_1 signals. Both the DFE's work independently.

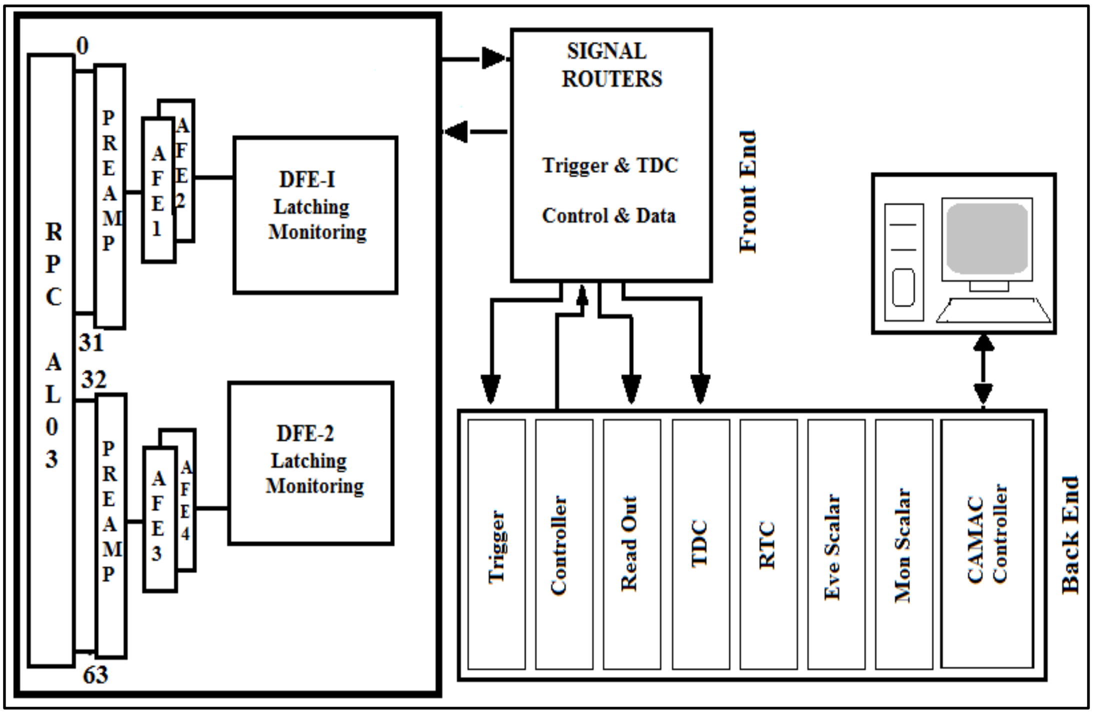


Figure12. Block Diagram of Electronics Set-up for x-plane of RPC

2. Trigger logic

The trigger logic picks up the event to be recorded. The basic principle of trigger generation is

$$M \times N \text{ fold coincidence}$$

where M is the layer coincidence of M consecutive signals out of 32 pickup signals and N is the no. of consecutive layers satisfying M fold layer coincidence. The M×N folds implemented are 1×5, 2×4, 3×3, and 4×2. Trigger is implemented in three stages. In the first stage i.e. trigger_0 logic, the shaped discriminator pulses from every 8th channel of 32 channels in the X-plane of RPC are logically ORed to get eight T0 signals. Similar signals are obtained for the Y-plane of each RPC. These eight T0 signals are logically ANDed to achieve the required Mfold triggers (T1 signals – 1F, 2F, 3F, 4F) in each layer. The trigger_1 logic is implemented in the Front End Processing (FEP) module using CPLDs. The M-fold signals (T1) from X-plane of all RPC layers are routed via Trigger and TDC Router module to the Final Trigger module in the CAMAC crate. The M×N coincidence logic (T2 trigger) is implemented in this module using T1 signals. T2 signals from X-plane and Y-plane are logically ORed to get the final trigger output which indicates the valid event to be recorded. The trigger generation rate is monitored with in-built scalars. All the triggers are maskable. [7]

3. Signal Routers

Trigger and TDC router receives the M-fold T1 signals and TDC signals from the FEP modules and routes them to the Final Trigger module and TDC module respectively. Control and Data Router receives control signals from the INO Controller module and routes them towards the FEP modules. It also receives data and feds the same to the Readout module.

4. Data Acquisition

A PC based data acquisition system is built using CAMAC standard modules in the back end which is connected to the front end with a fast serial link. The two main functions of the DAQ system i.e. Event Data Recording and Monitoring is controlled by the INO Controller module housed in the CAMAC crate. The Front End processing module of X and Y planes of all the RPCs are daisy chained into two groups for event data recording. At present no daisy chains are used for monitoring purpose and hence all the RPCs can be monitored simultaneously. On a final trigger, CAMAC controller invokes an interrupt handler routine where INO controller initiates data transfer from front end modules in a bit serial mode via daisy chain and data is buffered in the Readout module for further CAMAC readout. A set of 40 signals are selected in each monitoring cycle by the INO controller, which invokes interrupt handler at pre-defined monitoring period (10sec) where rates of the selected signals are recorded and the next set of signals are selected for monitoring. The set of signals monitored in each cycle consist of 32 pickup signals of one RPC, 4 fixed frequency signals and 4 M-fold trigger_1 (1F, 2F, 3F, 4F) signals. The next 32 pickup signals of the same RPC are monitored simultaneously through the second DFE. The need is to record the event time, three dimensional interaction tracks and its direction in the detector. The event initiated by the final trigger records the Boolean status information of all pickup channels contributing to the track information. The relative time of interaction of track at each layer is recorded in the TDC which gives the directional information. [8]

Results:

1. The efficiency of the right (S31), main (S32) and left (S33) strips is calculated and plotted as a function of voltage applied. The main strip will show the maximum efficiency as the 2cm paddle was along the main strip.

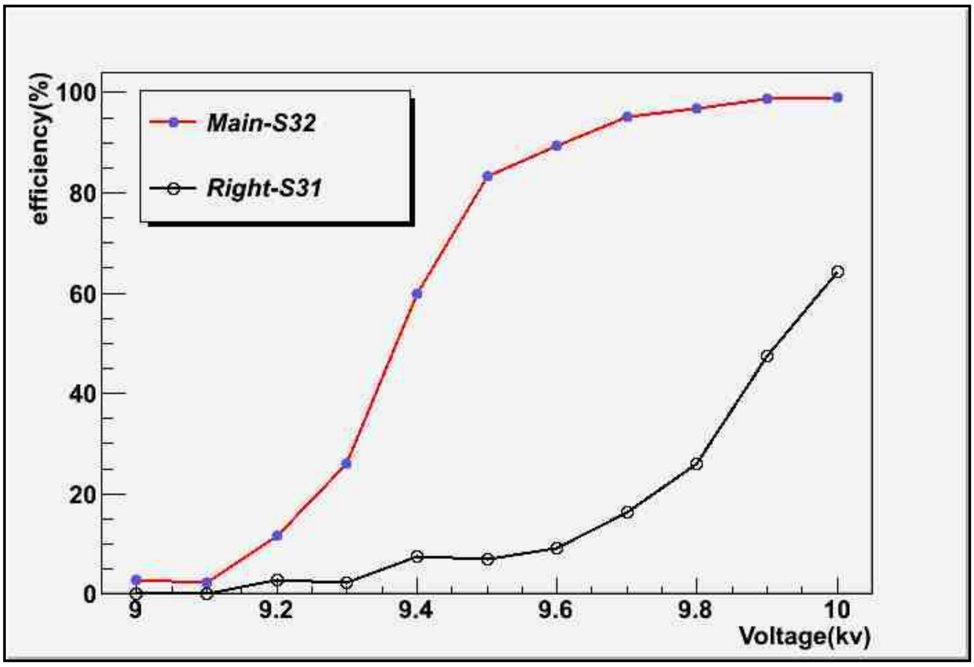


Figure 13.Efficiency vs. Voltage

The plateau region is achieved around 9.6kV (efficiency~95%) for the main strip. From the above graph, we see that cross-talks become prominent at higher voltages.

2. The I-V characteristics for both the glass plates of RPC AL03 are plotted.

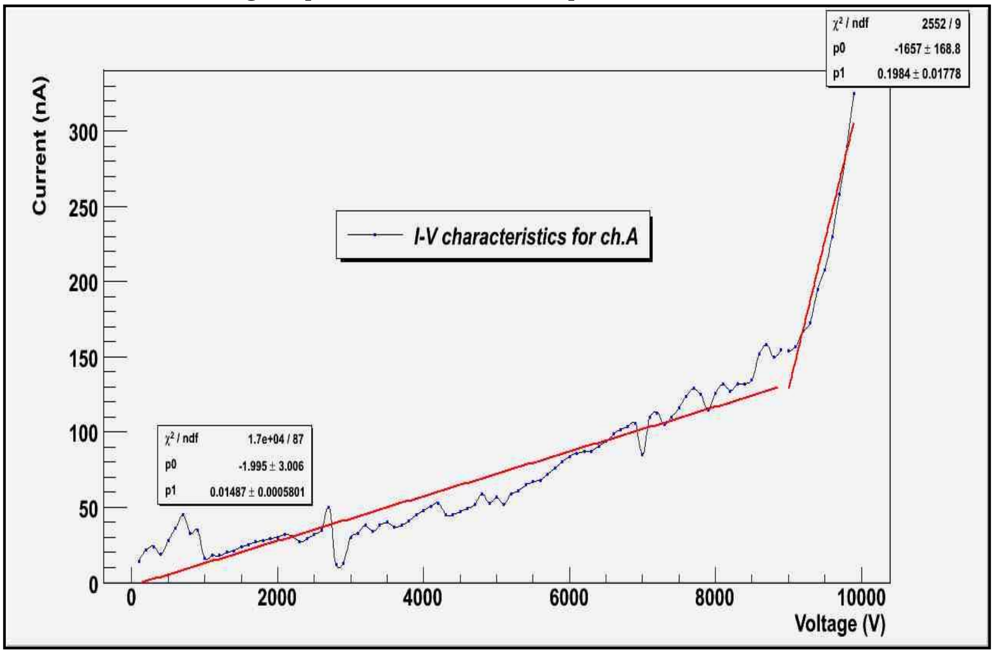


Figure14.Current vs. Voltage for channel A

Channel A correspond to the side on which negative voltage is applied and channel B on which positive voltage is applied.

From Figure 12, we get

Gap resistance = 67.2598 GΩ, at low voltages

Glass resistance = 5.04133 GΩ, at high voltages (above 9kV)

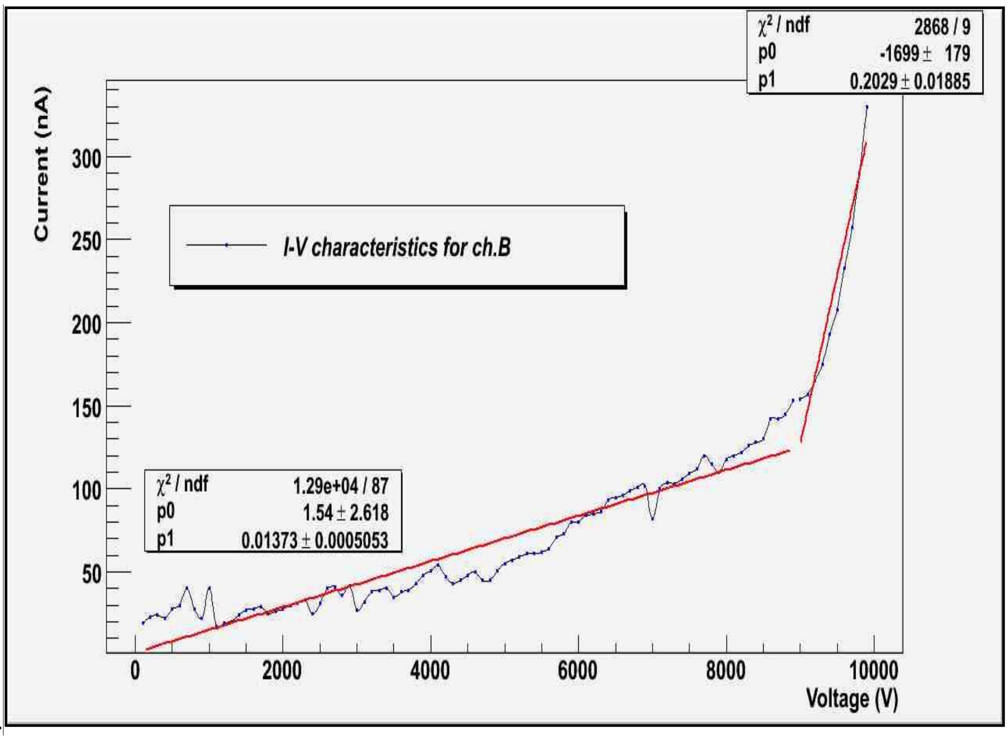


Figure15.Current vs. Voltage for channel B

From Figure 13, we get

Gap resistance = 72.8188 GΩ, at low voltages

Glass resistance = 4.9283 GΩ, at high voltages (above 9kV).

3. The noise rate as a function of voltage and the TDC plot are obtained at 9.6kV for the RPC AL03.

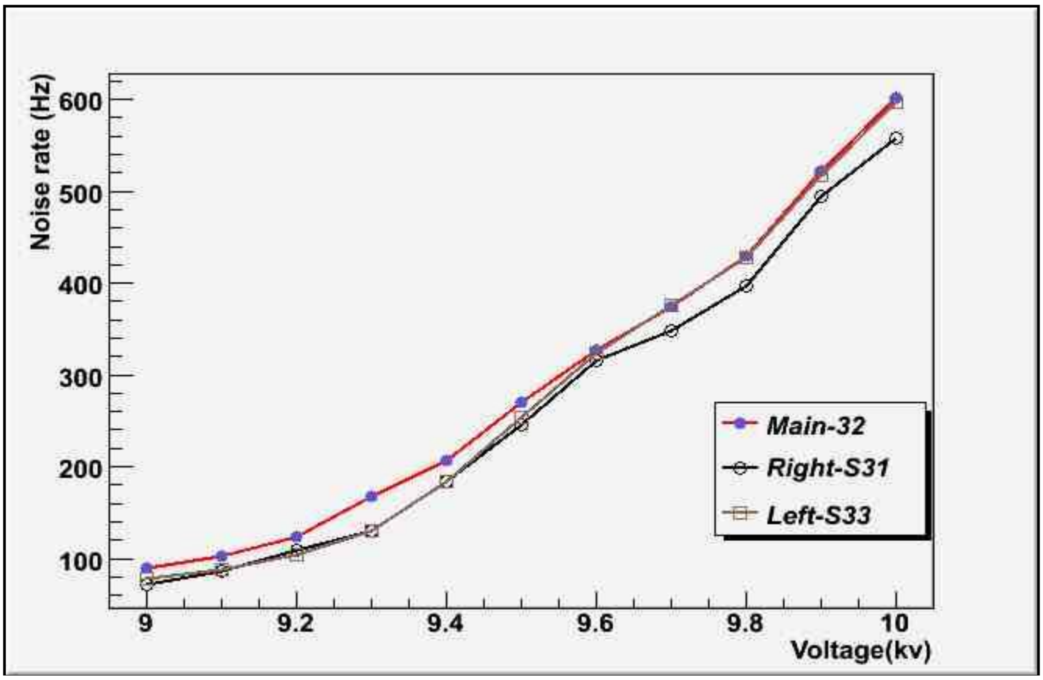


Figure16.Noise rate vs. Voltage

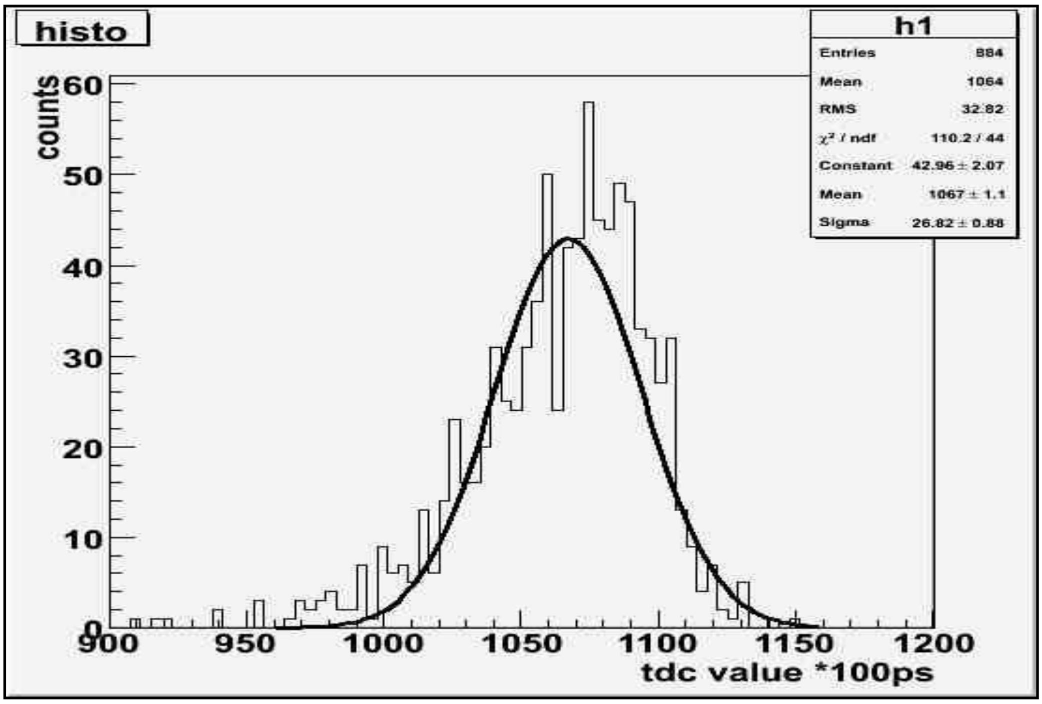


Figure17.TDC plot at 9.6kV

The time resolution of the RPC is $\sigma = 2.7 \pm 0.1$ ns.

Conclusions:

The construction of 2m x 2m RPC AL03 is successfully completed and it is operating in the avalanche mode with an efficiency of about 95% at a voltage of 9.6kV.It is characterised and the time distributions are also studied.

Acknowledgement:

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