Experimental Project Report
On

The Development and Characterization of 2m X 2m Glass Resistive Plate Chambers (RPC).

(Under the guidance of Prof. Naba K. Mondal)

Submitted on 21.05.2010

By,

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The Development and Characterization of 2m X 2m Glass Resistive Plate Chambers (RPC).

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Abstract

This work involves the development and characterization of a 2m x 2m glass RPC (AL03) .The details of the principles of operation and fabrication of a 2mX2m RPC including the gas flow system and electronic data acquisition system is discussed here. The trigger for the RPC is generated by a scintillator paddle telescope. Then the different characteristics of the RPC like efficiency, noise rate and I-V are studied for the main and two adjacent strips.

Introduction:

The resistive plate chambers, introduced in 1981, works on the principles of ionization of gas molecules to detect tracks of charged particles. It is now widely used in high energy experiments and astrophysics experiments.

They are going to be used as the active detector element for the INO-ICAL experiment in the tracking (iron) calorimeter that can simultaneously measure the energy as well as the direction of the charged particle. RPC's are preferred to scintillators due to good spatial resolution, high efficiency of detection, simple design and low cost.

Details of Glass RPC:

1. Structure:

The resistive plate chamber is a dc operated gas based detector with good spatial as well as timing resolution. It is a type of spark chamber with resistive electrodes. Good spatial and timing resolution makes it well suited for fast tracking calorimetry.

It is made of two parallel electrodes (each 3mm thick), made up of float glass with a volume resistivity of $10^{12}\ \Omega$-cm , and with a spacing of 2mm, by means of highly insulated spacers. A suitable gas mixture at slightly above atmospheric pressure is circulated through the gap and an appropriate electric field is applied across the glass electrodes through a resistive coating on their outer surfaces. The gas mixture is required for the multiplication of charge (streamer mode) produced when some ionizing particle passes through the gas volume.

Due to high resistivity and quenching characteristics of the glass electrodes, the discharge is limited to a tiny area of about 0.1cm^2. This discharge induces an electrical signal on external pickup strips, on both sides of the RPC unit, orthogonal to each other. It can be used to record location, and time of ionization. The discharge area recharges slowly through the high resistivity glass plates and recovery time is about 2sec.The structure of a glass RPC is shown in figure 1 followed by a view of the specifications of different parts.

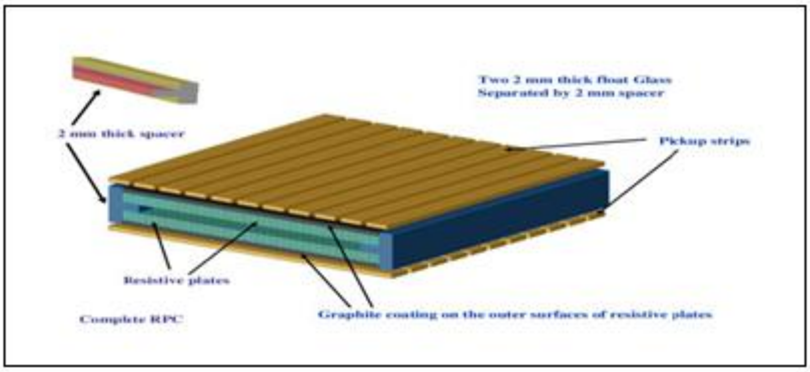


Fig 1: The structure of an RPC.

2. Specification of the RPC AL03:

1. Dimensions of RPC= 2m x 2m.
2. Thickness of glass electrode=3mm.
3. Gap between two glass plates=2mm.
4. Width of pick up strips=28mm.
5. Gas Composition: Freon-95.42% ; Isobutane-4.21% ; SF_6-0.37%.
6. Glass type- ASAI Float glass.

3. Principle of operation:

An ionizing particle passing through the gaseous gap initiates a streamer in the gas volume which results in a local discharge of the electrodes. Owing to the high resistivity and quenching characteristics of the glass electrodes, the discharge is limited to a tiny area of about 0.1cm^2 .This discharge induces an electrical signal on the external pick up strips(figure 2) on both sides of the RPC, which can be used to record the location and time of ionization.

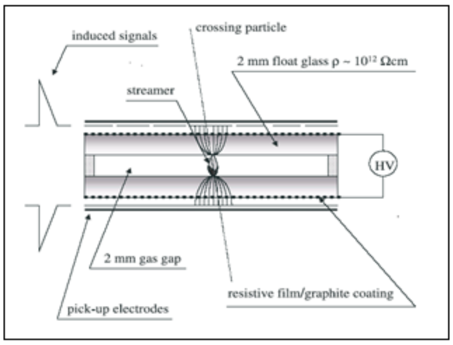
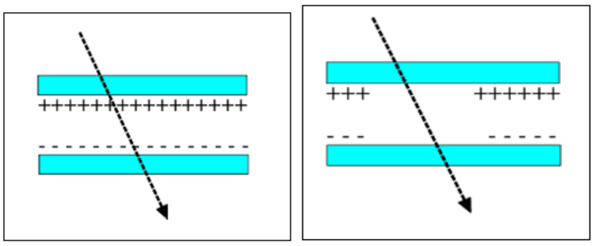


Fig 2: RPC principles of operation.

Before, **After,**



(a) (b)

Fig. 3:a. A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally (r~0.1 cm^2) available charge is consumed.
b. The discharged area recharges slowly through the high-resistivity glass plates.

4. Modes:

Different modes of operation of a RPC are discussed below.

a. Avalanche Mode:

This mode corresponds to the generation of a Townsend avalanche followed by the release of primary charge by the ionizing radiation .It operates at a lower voltage and the gain is less. Typical pulse amplitudes are of the order of a few mV.

A charged particle passing through the gaseous medium produces primary ions. These ions, being accelerated by the electric field, collide with the gas molecule to produce secondary ionization. The external field opposes the electric field of the ionising particles and the multiplication process stops after sometime. Then the charges drift towards the electrodes and are collected there.

The electric field across the gap (and consequently the gas amplification) is reduced and a robust signal amplification is applied at the front end electronic level.The substantial reduction of the charge produced in the gap improves the rate capability by more than an order of magnitude, allowing application of RPCs to high rate experiments.

b. Streamer mode:

In this mode the avalanche generated is followed by a streamer discharge. The secondary ionization continues until there is a breakdown of the gas and a continuous discharge takes place. This mode operates at a higher voltage and also results in high gain. Typical pulse amplitudes are of the order of 100-200 mV. The electric field inside the gap is kept intense enough to generate limited discharge localized near the crossing of the ionizing particle. Due to the relatively long relaxation time of the resistive electrode, this mode is adequate for cosmic ray and low-rate accelerator experiments.

We are operating the RPCs in avalanche mode.

5. Equivalent circuit:

At low voltage: R_{gap} is very high and the conduction is done by R_{spacer} .

At high voltage: R_{gap} becomes very low.

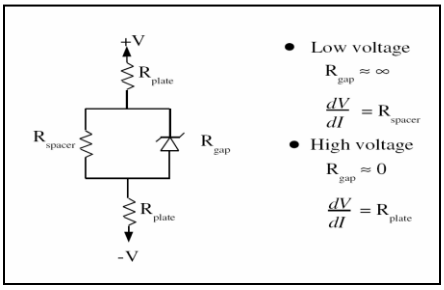


Figure 4: The equivalent circuit of a RPC.

Construction of glass RPC:

We are involved in the development of a 2m X 2m RPC (AL03).

The various steps are:

1. **Glass cutting and cleaning**: The glasses are cut by diamond cutter to the appropriate size. Then the four edges are chamfered using a jig of right dimensions to make a correct 45^0 angle. The glasses thoroughly cleaned with alcohol (propan-2ol), and then washed with labolene and distilled water.

2.**Conductive coating*:*** The glass edges are taped over with masking tape to prevent the conductive paint from being coated upto the edge of the glass. One side of the glass is coated with a conductive mixture of dry colloidal graphite and industrial lacquer in a ratio of 1:8 using a spray gun and then the masking tape is removed.

3. **Resistance measurements**: The surface resistance 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 1MΩ.

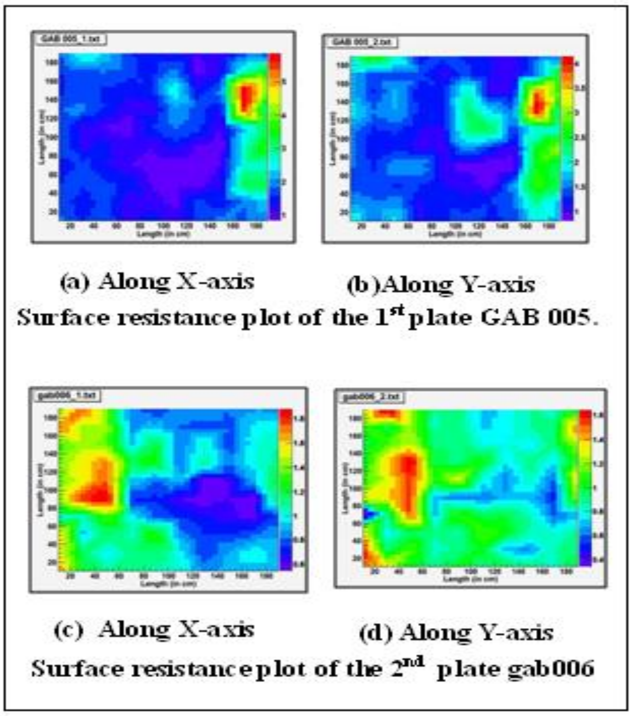


Fig 5: Surface Resistance Plots.

4**. Gluing*:*** The glue used is a 3M Scotch Weld epoxy adhesive in a duo-pack cartridge. The button spacers (of 2mm thickness and 11mm diameter) are glued in a square array (each 20 cm apart) on top of a glass put on a plastic sheet. The glue comes out through the three holes of the spacers, and if needed some more glue is added on the buttons, and then the other glass plate is placed carefully on the spacers. To put a uniform weight throughout the 2mX2m area the whole set up is wrapped with plastic sheets and the air inside the plastic sheets is slowly sucked to create partial vacuum and a pressure equivalent to 5cm of water column pressure, and left for six hours.

5. **The edge spacers*:*** These are designed in sections, a straight piece and an angle or corner piece. The corner piece has two wedges on either side that slot neatly into holes in the straight sections. It also contains the gas inlet/outlet pipes into which the gas tube fits. Every corner has a gas pipe: two to be used as inlets and the other two as outlets.

The straight edge spacers are designed in steps to allow the glass plates to fit neatly as shown in fig.6.There is a 1 mm gap where glue is put (as shown in figure) .The central protrusion is 2mm,thus supplying the required gap between the glass plates. The central hole is where the wedge of the corner spacer fits.

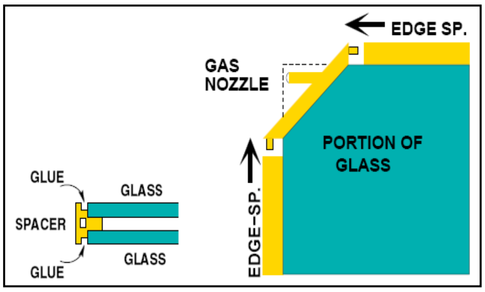


Fig 6: Side-view and Top-view of Spacer.

6. Gas Leak Test: To find if there is any gas leak, especially at the glued joints, a leak test is done by flowing freon gas at slightly above atmospheric pressure and using a gas leak checker RIKEN GH-202F.

7. High Voltage Cables*:* The high voltage (N471A) 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 bi-polar high voltage DC supply, so that both have 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 high voltage leaks. Also it reduces the absolute maximum rating of the resources like HV modules, HV cables etc..

8. Pickup Strips: The RPC is then sandwiched between two honeycomb pickup panels, which are lightweight and provide adequate mechanical strength, 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 (as 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. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the preamplifier. A layer of mylar of thickness ~100μm is placed between the graphite layer and the pickup panel to provide insulation.

Gas flow system:

The system is designed for mixing four gases, but presently we are mixing only three gases as the RPC is operated at avalanche mode only.

Choice of gas: The suitable gases for RPCs were chosen considering the following aspects-low working voltage, high gain, good proportionality, high rate capability.

The gas mixture decides the working mode of the RPC in avalanche or in streamer mode, resulting in different characteristics and performances.

Currently the RPC's are operated in avalanche mode for which the main component should 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 electron number.

Gases used:

Freon R134a: It is an eco friendly electronegative gas with high enough primary ionization production but with small free path for electron capture.

Isobutane: It has high absorption probabilities for UV photons produced in electron ion recombination, so acts as a quenching gas. It limits the charge spread.

SF6: It is added to control the excess number of electrons.

Their compositions are as follows:

Gas constituents	SCCM (for the two RPC's AL01 and AL03)	Percentage
Freon R134A	17.9	95.42%
Isobutane	0.79	4.21%
SF6	0.07	0.37%

Freon , Isobutane and SF6 are in gaseous form whose pressure is monitored by a two stage pressure regulator connected to the outlet of the cylinder. Freon and Isobutane need low pressure input regulator (0-5 kg/cm^2), while SF6 need higher pressure regulators (25 kg/cm^2).

Purifier column:

Different purifier columns are used for different gases. They contain molecular sieve made of silica gel which absorb the moisture contents of the gases passing through it. These molecular sieves are surrounded by SS tube, which is connected to heaters at the time of regeneration.

During regeneration two heaters of 500 Watts are connected in series and dry nitrogen gas is allowed to flow through the sieve. Even after heater is switched off the dry gas will continuously flow till purifier column attain the surrounding temperature.

Generally regeneration is done once in a year for Freon and once in 2 years for Isobutane and SF_6 (if a flow of about 1 kg/sq cm gas is maintained).

Bellow Valve:

From purifier column the gas goes to the MFC (Mass Flow Controller) through "closed type" pneumatic bellow valves which require a pressure of about 5 bar to operate. The pressure is supplied by using compressed air.

Mass Flow Controller:

Each gas channel is connected to an MFC to regulate and accurately measure the gas flow rate. An MFC consists of 4 main components namely bypass, sensor, an electronic board and a regulating valve.

The bypass, the sensor and one part of the electronics board constitute the measurement side of the mass flow controller and hence form a mass flow meter. The regulating valve and the other part of the electronics board form the controlling side.

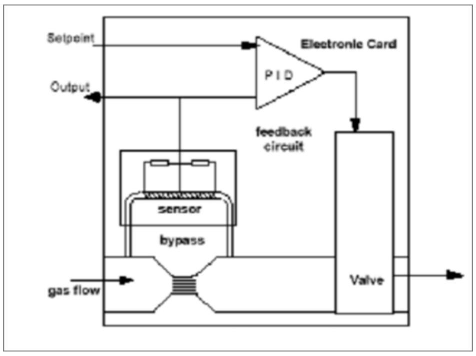


Fig 7. Schematic diagram of MFC

The gas flow is divided into heated sensing tube where the mass flow is actually measured and a bypass, where most of the gas mixture will flow. The gas flow through sensor is always proportional to the flow through bypass for the flow range for which the bypass is built.

The sensor is designed to deliver an output almost proportional to the gas flow circulating through it, i.e., also to the total flow. The electronic board in MFC will amplify the sensor signal. The signal will be of 0-5V. 0V indicates no flow and 5V indicates maximum flow. The sensor response is linear up to 5 SCCM

(Standard Cubic Centimeter per Minute) gas flow and hence bypass is used to take maximum flow and keep the response linear.

In this MFC there is a set point, in which the necessary flow rate can be set up manually. There is a comparator which will compare this set valve and the amplified sensor signal and accordingly operate the control valve.

Moisture meter:

All three gases have to flow through a common moisture meter. This will measure the moisture content of the gas mixture; it will also give reading in dew pt. Its sensitive range is 0.5 to 1000 ppm moisture ie., 80 ˚C to 25 ˚C dew point. For a typical dry gas this meter have to read 1-2 ppm moisture.

Input Manifold:

The gas after passing through moisture meter will get collected in input manifold, from where the gas is distributed to various RPCs through 16 capillaries, isolated by pneumatically activated valves.

Capillaries (Flow dividers):

There are 16 capillaries to be connected to different RPCs. They are of 2m in length and 200μ in diameter. They offer a resistance of 1/14th of a bar to the gas flow when the flow is about 6SCCM. These capillaries are used in order to maintain the uniform flow of gas mixture through all RPCs.

Bubblers:

There are two types of bubblers used in this gas system. Though functioning and dimensions are the same for both the bubblers, they differ by the place where we use them.

Safety bubblers are connected in parallel with RPC but it is connected so as to bubble only when there is a block in RPC. They prevent over pressurization of RPC through blockages in the flow path.

Isolation bubblers or output bubblers are used to monitor the flow of gas mixture through the RPC and isolating the RPC from atmospheric pressure. When the flow is set through a RPC, its isolation bubbler must show bubbling; absence of bubbling will indicate that either the channel is not on or there is a leak before it.

The gas mixture after flowing through RPC is thrown to output manifold through isolation bubblers.

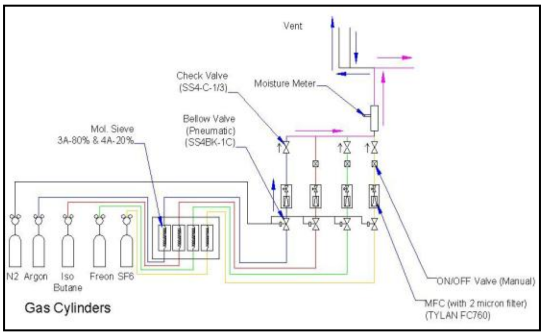


Fig 8. The Block diagram of Gas Flow System.

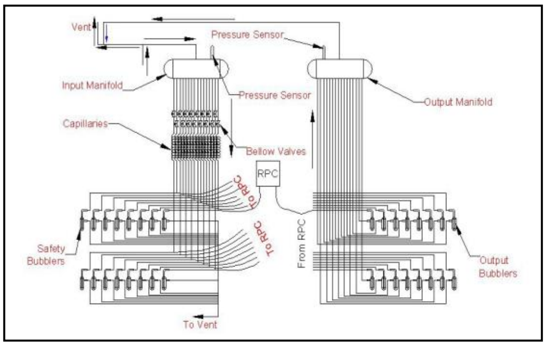


Fig 9. The Block diagram of Gas Flow System.

Alignment of RPC:

To measure the efficiency of the RPC it is necessary to make sure that the trigger pulse generation is solely due to the atmospheric muons. Six scintillator paddles are used as cosmic ray telescopes to set a coincident circuit for this purpose. 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 60cm×20cm, 60cm×20cm, 30cm×3cm, 30cm×2cm , 40cm×20cm, 40cm×20cm 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 30cm×2cm, 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.

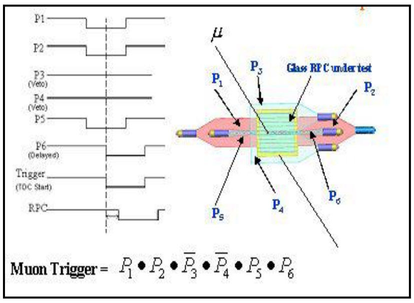
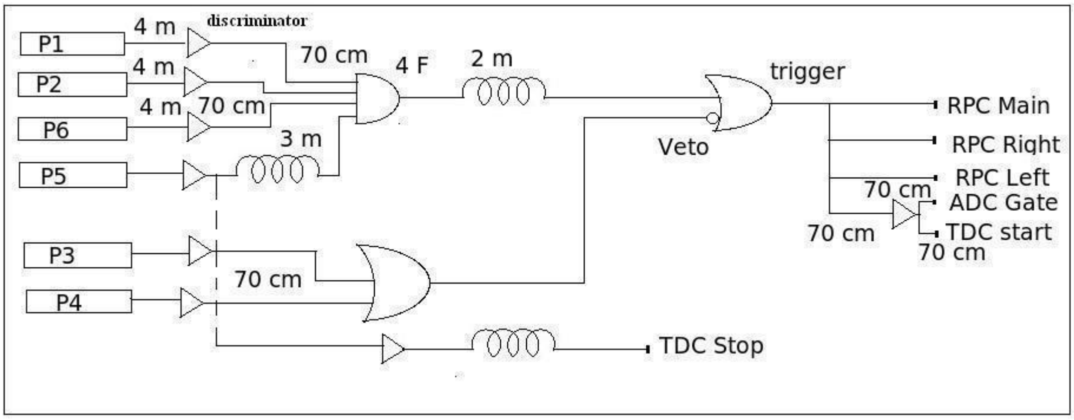
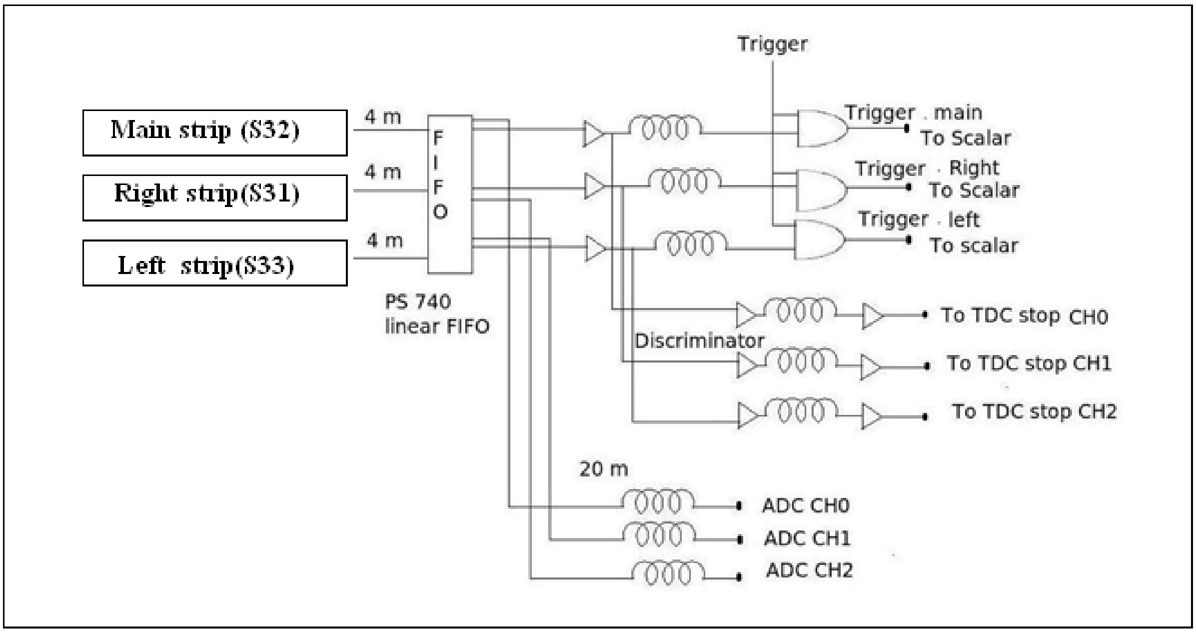


Fig 10: The RPC test setup.



(a)



(b)

Fig 11: The Logic diagrams for (a) Trigger formation, (b) Efficiency determination.

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 .This pulse is connect ed 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 then the discriminators are connected by coaxial cables. Trigger is taken from the middle strip of RPC and ANDed with 4fold X veto. In the final scalar, 4fold X veto X RPC trigger is recorded.

Efficiency of RPC is defined as:

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

The RPC pulses are connected to ADC before digitizing 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.

The electronic DAQ system:

The entire system can be divided into the following modules:

1. Front end electronics (four 16-channel analog front ends, two 32-channel digital front end for each plane).
2. Final trigger module.
3. Signal routers (Control and data router, Trigger and TDC router).
4. Back end DAQ system (Data and monitor control module, and Data and monitor readout module)
5. Power supplies (high and low).

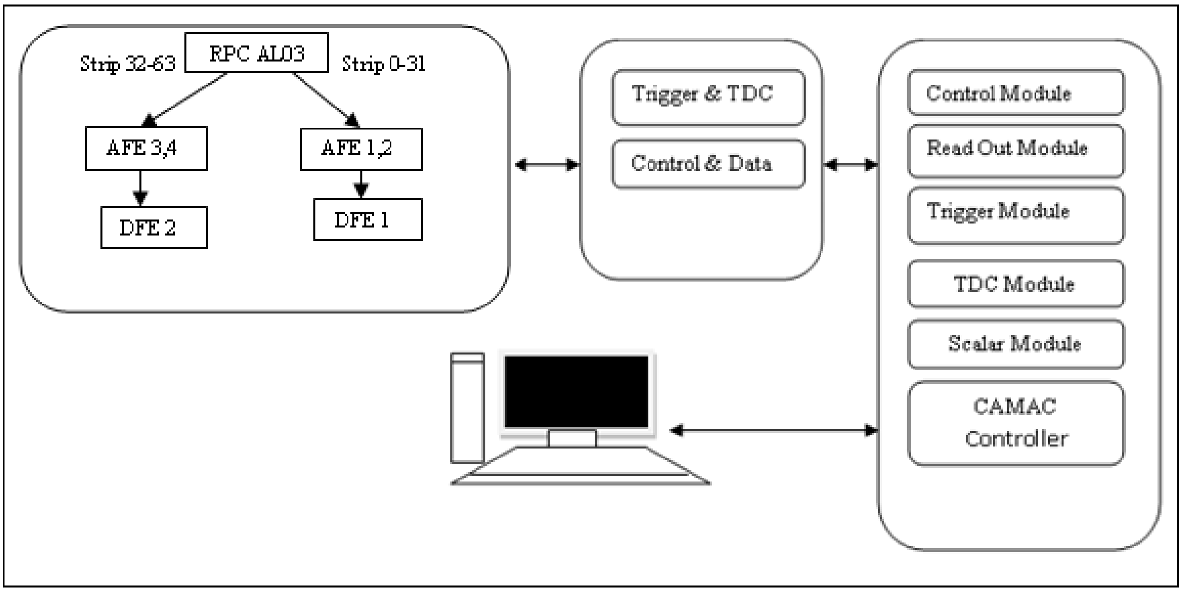


Fig 12: Block diagram of electronics set-up.

1. Front end electronics:

The signals from a pick up strip are passed through a cascaded two stage pre amplifier. It consists of positive and negative pre amplifiers. -ve pre amp is IC 1595 for the X-plane and +ve pre amp is IC 1597 for the Y-plane. Second stage pre amp is IC 1513. Ideal gain of both the stages is 10 and that of the cascaded stage is 100. Practically, gain is about 80. Output is fed to 4 discriminator modules. The threshold of the discriminator is currently set at -20 mV and signals crossing this threshold generate the differential ECL output. This section also houses primitive trigger _0 logic.

The discriminator modules are connected to a front end (FE) processing module. It connects the ECL input to TTL output and also generates trigger_1 signals.

2. Trigger logic:

The events to be recorded are picked up by the trigger logic. The basic principle of trigger generation is, M X N fold coincidence, where,

M = the layer coincidence of M consecutive signals out of 64 pick up signals.
N = the number of consecutive layers satisfying M fold layer coincidence.
M X N folds implemented are, 1 X 5; 2 X 4; 3 X 3; 4 X 2.

Three stages of trigger:
First: trigger_0: shaped discriminator pulses from every 8^{th} channel of 64 channels logically ORed to get to get $8T_0$ signals.
Second: T_0's are ANDed to generate M fold T_1 signals 1F, 2F, 3F, 4F, in each layer. The trigger1 logic is implemented in the FEP (Front End Processing) module using CPLDs.
T2 trigger: M X N coincidence is implemented to generate T2 trigger signals in the module in CAMAC crate using T1 signals.
The M fold signals from (T_1) from X plane at all RPC layers are routed via trigger and TDC router module to the final trigger module in the CAMAC crate.
The T2 sigals from X plane and Y plane are logically ORed to get a final trigger, signaling a valid event to be recorded. The trigger generation rate is monitored with in built scalars.

3. Signal Routers:

The trigger and TDC routers route the M fold T_1 signals and TDC signals from the FEP modules to the final trigger module and TDC modules respectively.
Control and data router routes control signals from the controller module to the individual FEP modules. Also, it routes latched data from all FEPs to the readout module. Then it strips signals from FEPs to scalars for noise rate monitoring.

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 in the next cycle. 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.

Results:

1. Efficiency:

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.

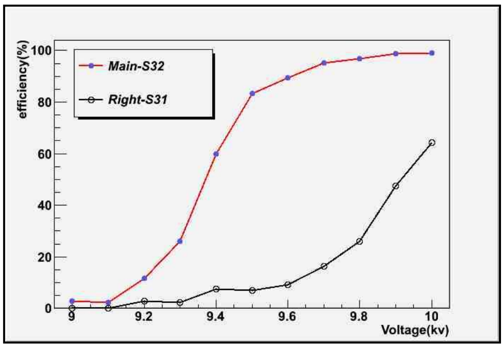
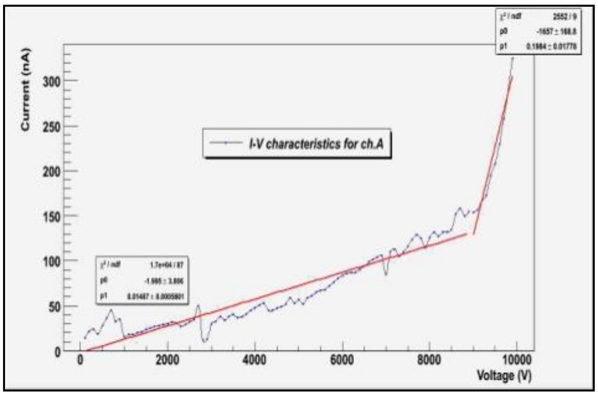


Fig 13: Efficiency plot.

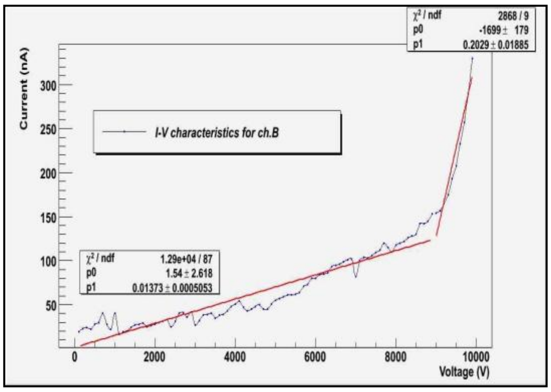
The plateau region is achieved around 9.6kV (efficiency~95%) for the main strip. So the RPC AL03 was operated at 9.6kV. From the plot, it is seen that cross-talks become prominent at higher voltages.

2. I-V Characteristics:

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



(a)



(b)

Fig 14: I-V plot.

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.

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

From Figure 13, we get

Gap resistance = 72.8188 GΩ, at low voltages.

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

3. Noise Rate:

Noise rate as a function of voltage are plotted.

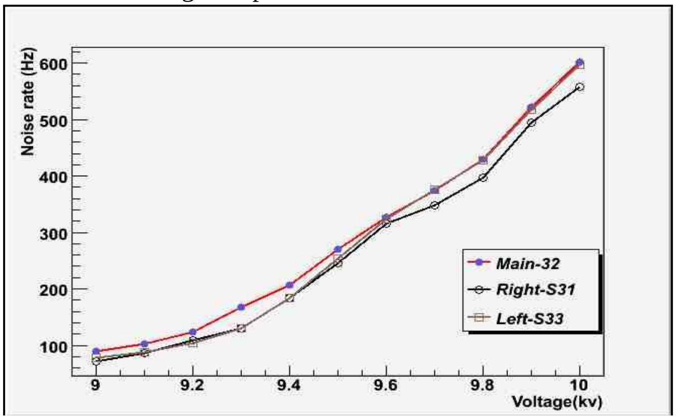


Fig 15: Noise Rate plot.

4. TDC distribution plot:

The time different between the arrival of trigger and firing of RPC, taken for operating voltage 9.6kV are used to plot a histogram and fitted with a Gaussian fit.

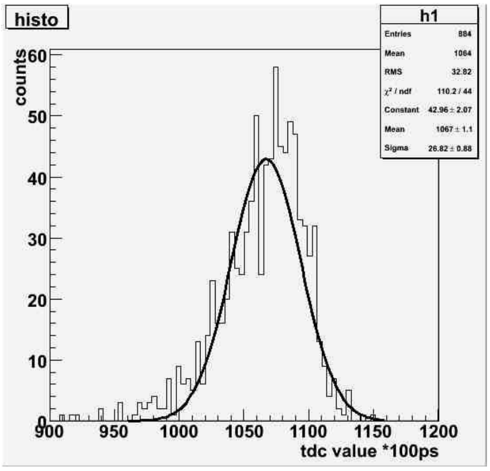


Fig 16: The TDC Plot.

From the plot, the time resolution is found to be (2.682±0.088) 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 characterized and the time distribution are also studied.

Acknowledgement:

I would like to extend my gratitude to Prof. N.K.Mondal for providing an excellent opportunity to work in the INO RPC lab, and motivating us throughout the work. I am very thankful to Dr. B.Satyanarayana for his guidance, especially in learning the DAQ system. I am also thankful to Mr. S.D. Kalmani for explaining the gas flow system. I would also like to thank Mr. R.R. Shinde and Mr. Manas R. Bhuyan for their help throughout the work. I am very grateful to Md. Salim who helped us in learning ROOT to make the plots. Last but not the least; I thank my colleagues Neha, Mathimalar and Animesh for their supportive company and co-operation.

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