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

Meghna.K.K

INTRODUCTION:

The Resistive Plate Chamber (RPC) is a gas - based detector with good spatial as well as timing resolution. RPCs are fast, planar, rugged and low-cost gas detectors which are being, and will be, used extensively in a number of high energy and astro-particle physics experiments. They find applications for charged particle detection, time of flight, tracking and digital calorimetry due to their large signal amplitudes as well as excellent position and time resolutions. They are preferred over scintillators because of the following reasons:

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.
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.

PRINCIPLE OF OPERATION OF GLASS RPC:

RPC comprises of two parallel plates of glass and held together by spacers which maintain a gap between the glass plates. A suitable gas mixture is flown at the atmospheric pressure through the gap while an appropriate electric field is applied across the glass electrodes through a resistive coating on their outer surfaces. When an ionizing charged particle passes through the chamber, a charge pair is created in the gas volume. The charge produced in the gap drifts towards the electrodes and they induce charge in the pickup strips placed on the outer surface of the glass. This results in a local discharge of the electrodes. This discharge is limited to a tiny area due to the high resistivity of the glass electrodes and the quenching characteristics of the gas. The discharge induces an electrical signal on external pickup strips on both sides orthogonal to each other, which can be used to record the location and time of ionization. The discharge area recharges slowly through the high resistivity glass plates and the recovery time is about 2secs.

Modes of Operation:

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

1. Avalanche Mode:

Avalanche mode operates at a lower voltage and the gain is less. Typical pulse amplitudes are of the order of a few mV. The 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.

2. Streamer Mode

In the streamer mode the secondary ionisation continues until there is a breakdown of the gas and a continuous discharge takes place. Discharge is localized to a small area of 0.1cm2 due to the high resistivity of glass electrodes (1012 Ω/cm). This mode operates at a high voltage. Signal generated will be large and typical pulse amplitudes are ~100-200mV.

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

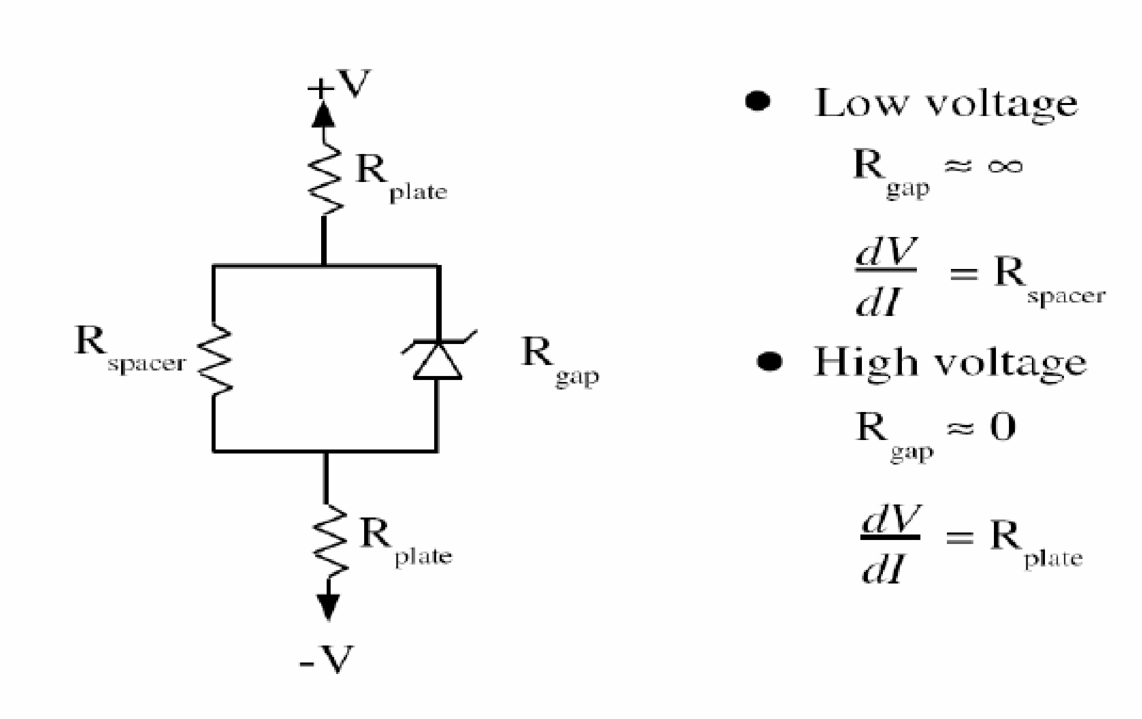

Fig 1. Electrical Representation of RPC

FABRICATION OF 2M X 2M RPC:

Various steps involved in the fabrication of 2mX2m glass RPCs are given below:

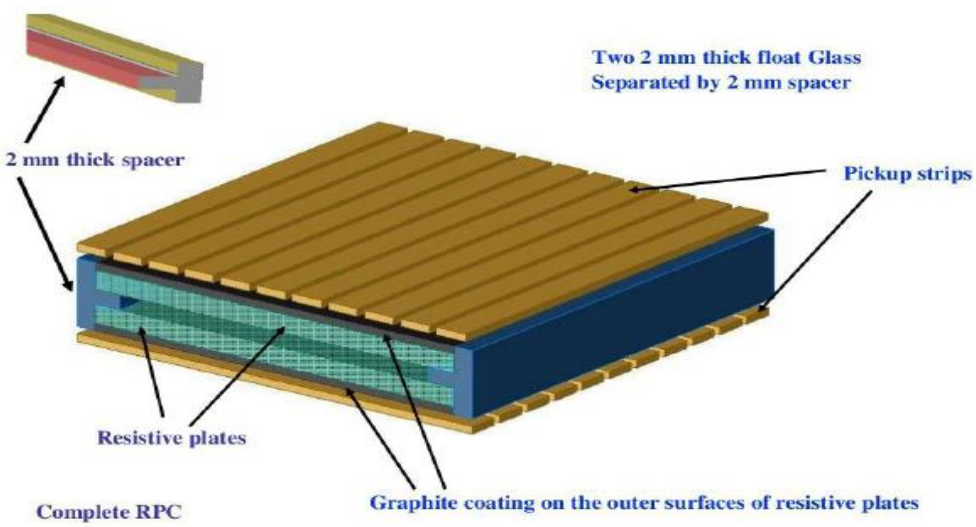

Fig 2. Structure of a standard single layer RPC

1. Glass Cutting and Cleaning:

The glasses 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 1.5-2 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 oh 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 resistivities of both surfaces are measured using two fixed sizes of copper and brass square. 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 from the pickup planes.

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. 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 and left for one day. 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 central hole is where the wedge of the corner spacer fits. It also contains the gas inlet/outlet pipes into which the gas nozzle fits. The glue was poured in the required gap.

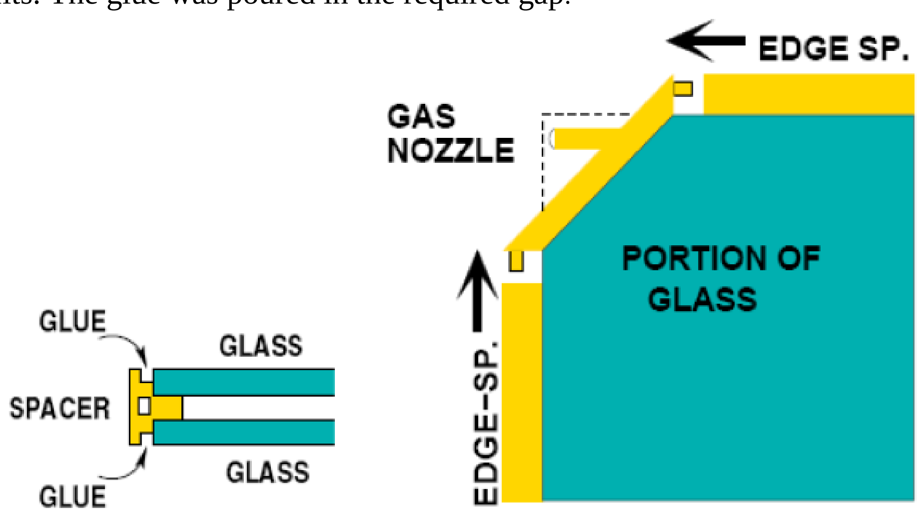

Fig 3. Side-view and Top-view of Spacer

4. Gas Leak Test:

Leak Test, to make sure that no gas leak occurs especially at the glued joints, is done by flowing Freon gas at atmospheric pressure and checked for any leak using a gas leak checker RIKEN GH-202F.

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 roughly 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.

6. 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 foam and aluminium 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 mode of operation of RPC depends upon the composition of Gas. Though the system is designed in such a way to mix 4 gases, currently only 3 gases are being used as the system is operated at avalanche mode. 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. Therefore the role taken by the gas mixture is essential. 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.

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. *Tetrafluoroethane* (known as *Freon*), which is widely used, has shown these specifics. But here *R134A*(as *Freon*) is used which is eco-friendly. 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 SF6 (Sulphur-hexafluoride) is used to control the excess number of electrons.

Gas Composition

Gas Constituents	Percentage(%)
Freon R134A	95.42
Isobutane	4.21
SF6	0.37

The components of gas flow system are:

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 SF6 (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 dry nitrogen gas.

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.

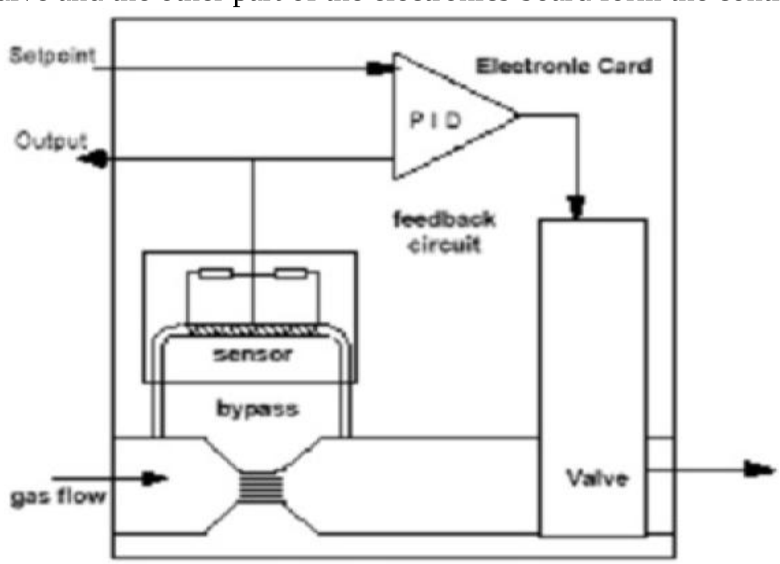

Fig 4. Schematic diagram of MFC

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.

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, dimensions are same for both the bubbler, they differ by the place where we use them. Safety ubblers are connected in parallel with RPC but it is connected so as to bubble only when there is a block in RPC. Isolation bubblers or output bubblers are used to monitor the flow of gas mixture through RPC.

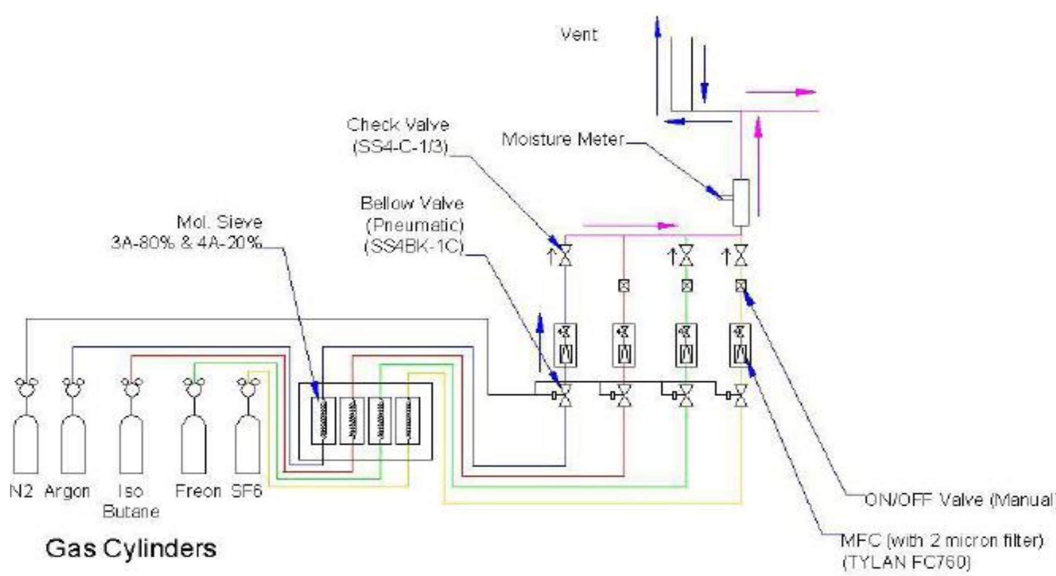

Fig 5. Block diagram of the gas flow system

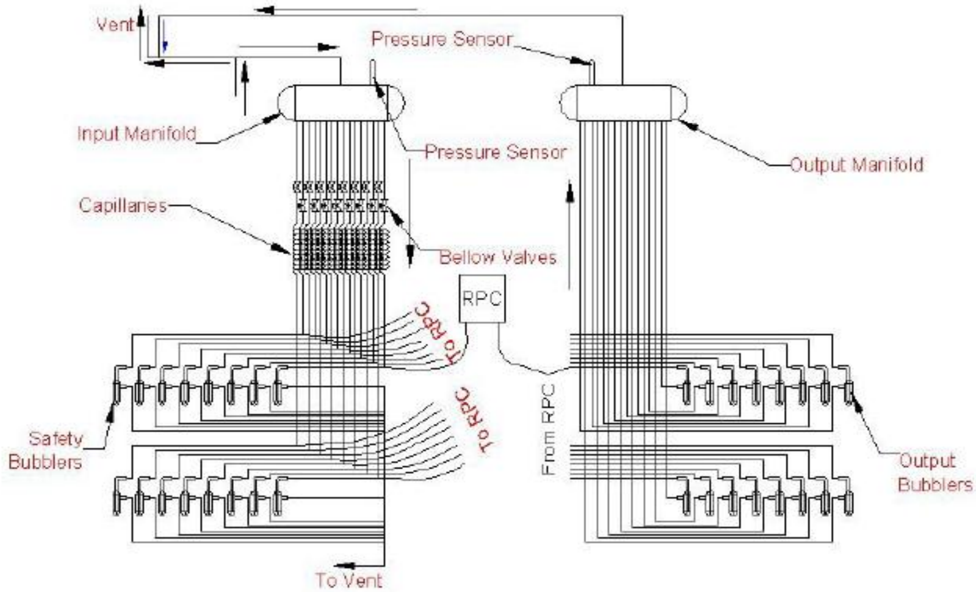

Fig 6. Block diagram of the gas flow system

TRIGGER SELECTION MECHANISM:-

To measure the efficiency of the RPC, firstly we ensure that the trigger pulse generated is solely due to the atmospheric muons. Four scintillator paddles are used to set up a coincident circuit for this purpose. Four scintillator paddles are used to set up a coincident circuit for this purpose. They are P1, P2, P3 and P4. The areas of these scintillators are 20 cm X 40, 20 cm X 40, 2 cm X 30 cm and 3cm X 30cm. These paddles produce a signal when a cosmic ray muon or other charged particle passes through them. The geometry of the telescope using these paddles is set up such that a window of 2cm X 30cm is available for the cosmic ray muons to pass through the telescope as well as through the pick up strips of the RPC under test. Narrow paddles are used to define the telescope geometry precisely. The data from the RPC pickup strip is recorded whenever a cosmic muon generates a trigger signal through the logic $P_1 .P_2.P_3.P_4$ i.e., a trigger is formed when a muon passes through the paddles P_1, P_2, P_3 and P_4.

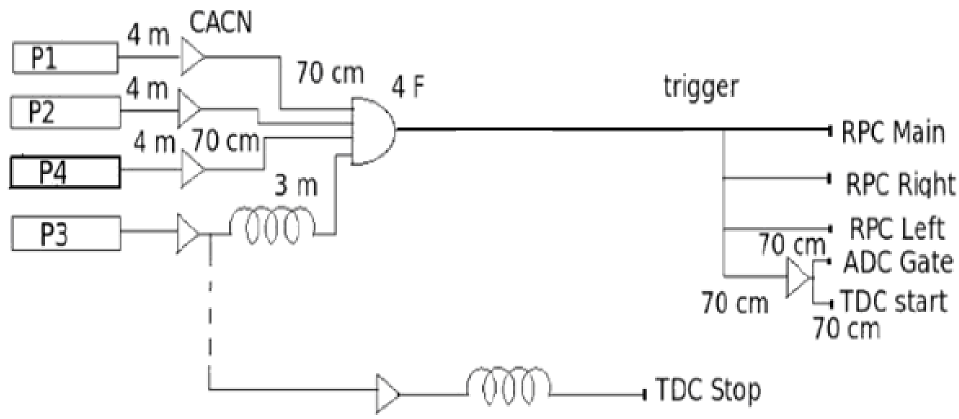

Fig 7. Circuit diagram for trigger logic for RPC

The analog pulses that come from the PMT's are converted to digital pulses through discriminators kept at a threshold of -20mV. P1, P2, P3 and P4 are ANDed to give 4-fold signal. Scalers are added at different stages to monitor counting rates of these signals. The P3 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's are connected to discriminators by twisted pair cables and output is taken to different channels of TDC with some delay. RPC Trigger is taken from the middle strip of RPC(Main #20) and ANDed with 4fold signal to get 4-fold x RPC trigger signal. Efficiency of RPC is defined as:

$$E = \frac{4F \times RPC}{4F}$$

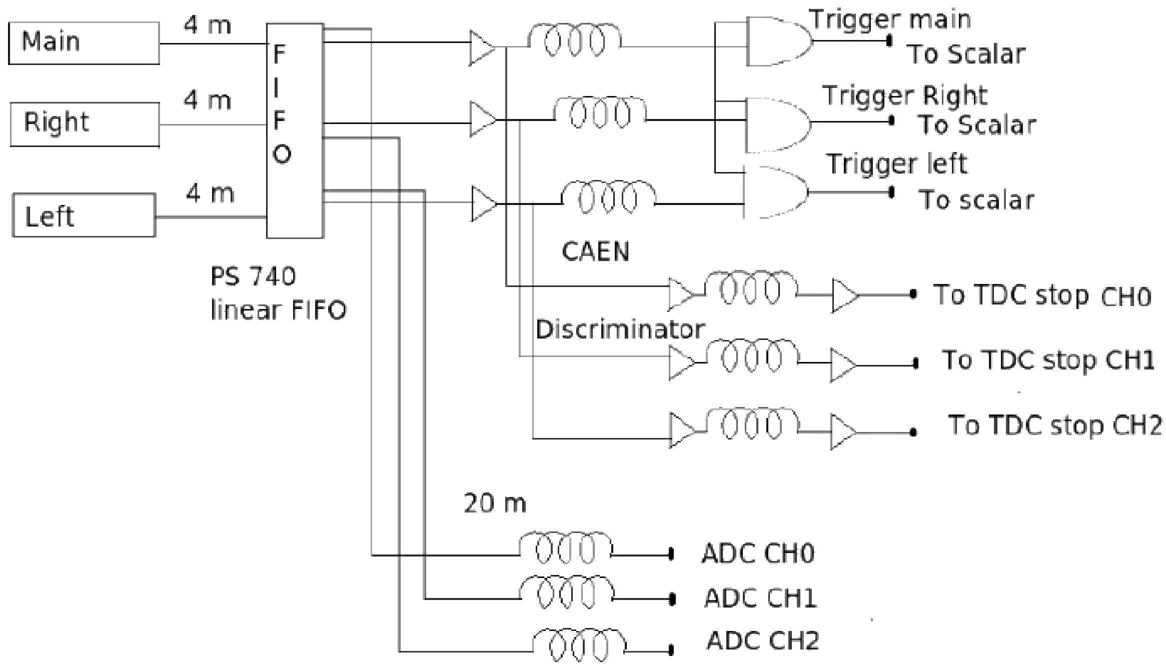

Fig 8. Circuit diagram for efficiency calculation.

ELECTRONIC DATA ACQUISITION SYSTEM:

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

- Front end electronics (16channel 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).

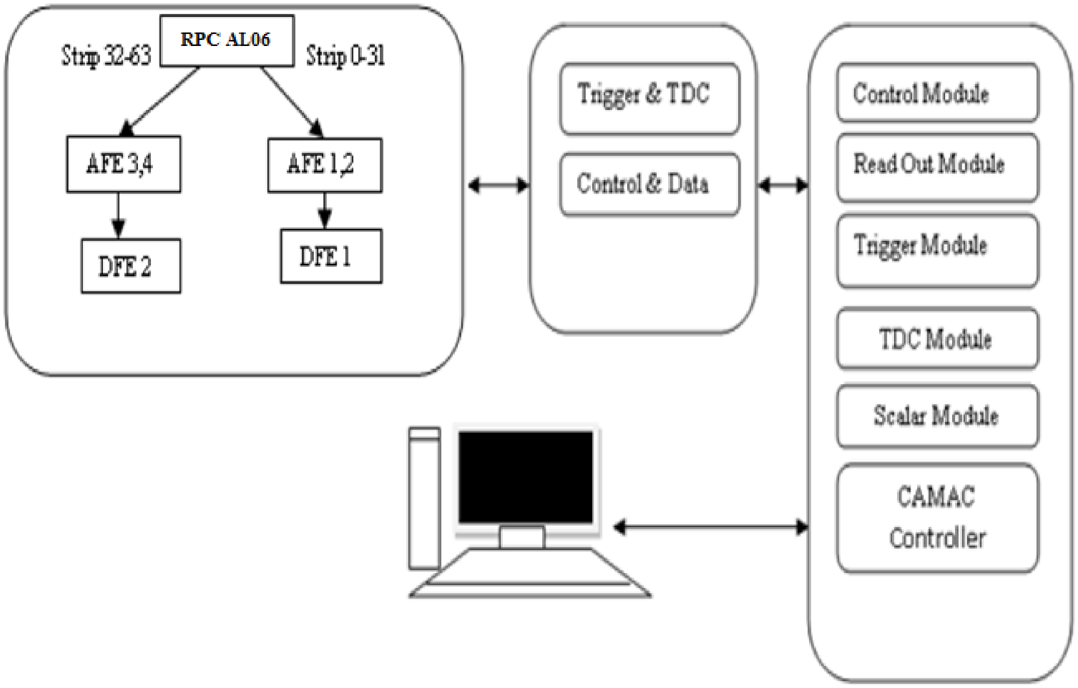

Fig 9. Block diagram for electronics setup.

FRONT END ELECTRONICS:

The signal from a pickup strip is passed through a pre-amplifier (gain 70-80) and the output is fed to two 16-channel discriminator modules. 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.

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 8th channel of 64 channels logically ORed to get to get 8T0 signals.

Second: T0's are ANDed to generate M fold T1 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 trigger generation rate is monitored with in built scalars.

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.

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. For the purpose of data acquisition the 64 strip RPC is considered equivalent to two 32 strips RPCs and hence the read out mechanism for 32 strip RPC is employed here also. 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 informationResults:

I-V Characteristics: The I-V characteristics of RPC is studied and plotted.

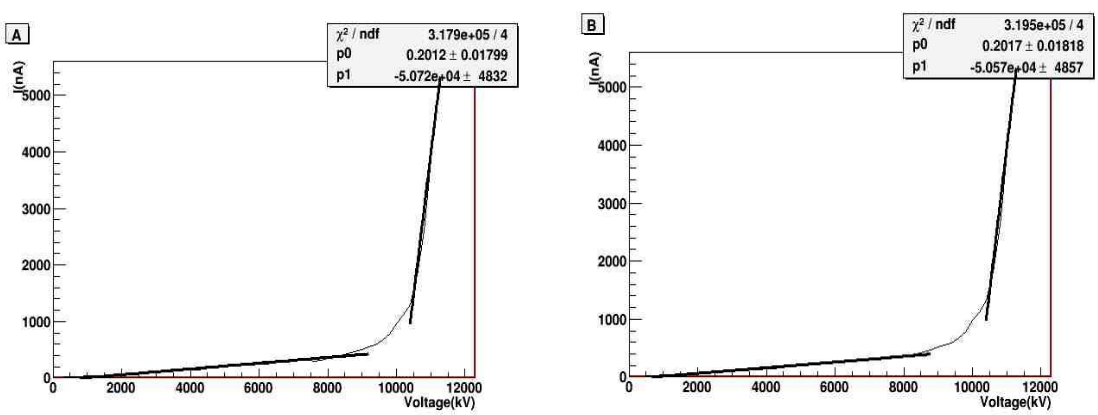

Fig 10. I-V plot**.**

Channel A corresponds to the positive voltage side and channel B corresponds to the negative voltage side.

Channel A: Gap resistance (low voltages) =19.62±0.0024 GΩ
Glass resistance (high voltages) =0.201±0.018 GΩ

Channel B: Gap resistance (low voltages) =20.47±0.002 GΩ
Glass resistance (high voltage) = 0.202±0.018GΩ

Efficiency: The efficiency of the right (S19), main (S20) and left (S21) strips is calculated and plotted as a function of voltage applied. The main strip will show the maximum efficiency since the 2cm paddle is kept along the main strip.

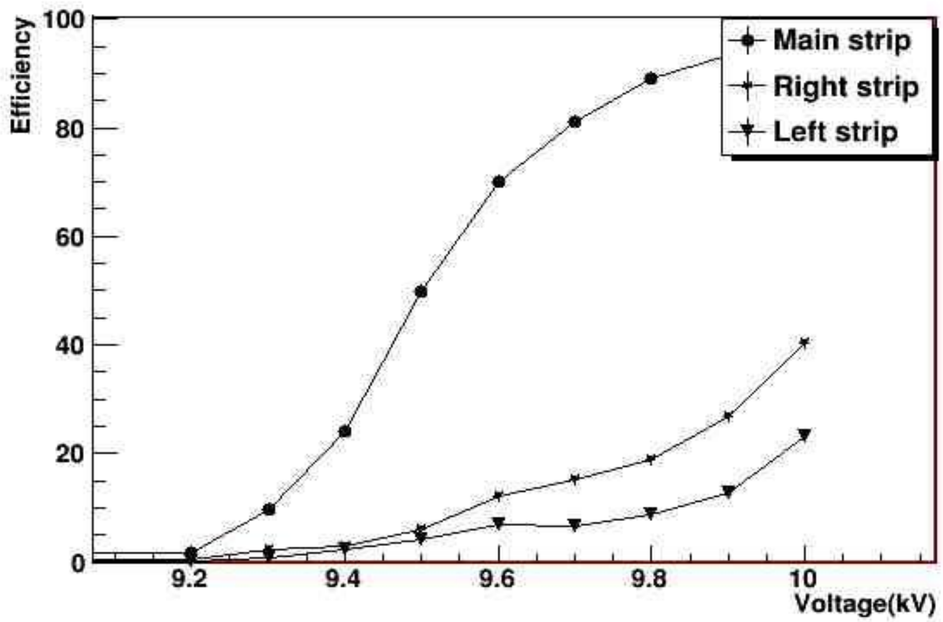

Fig 11. Efficiency (%) Vs high voltage(kV).

It is observed that the efficiency values are almost constant for voltages higher than 9.7kV but falls sharply with decreasing voltage below it. The horizontal part of the plot in the high voltage region is known as 'plateau' region of operation of the RPC. Here the plateau region is achieved around 9.7kV (efficiency~81%) for the main strip. So the operating voltage of the RPC is 9.7kV.

Noise Rate: Noise rate is plotted as a function of voltage.

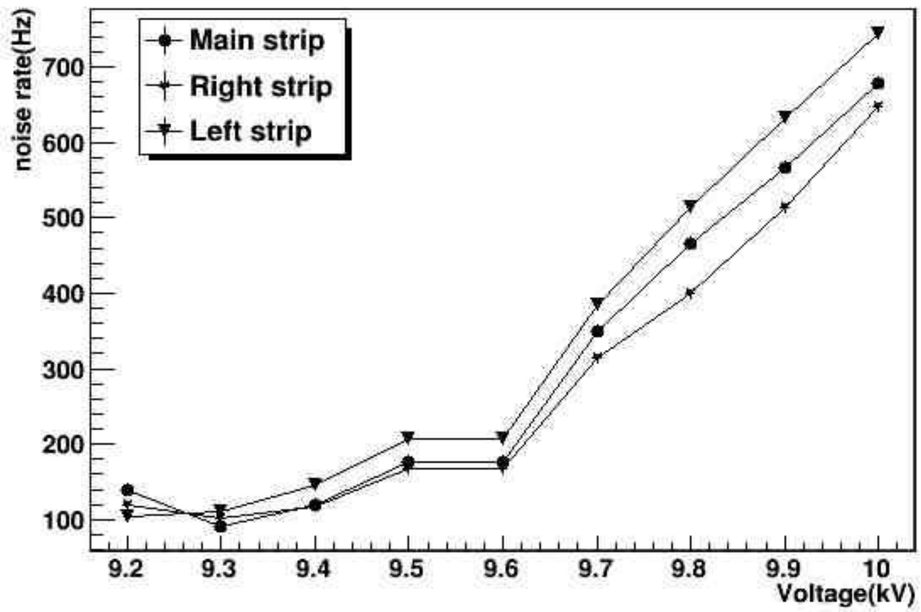

Fig12. Noise rate (Hz) Vs High voltage (kV)

TDC distribution plot:

The time different between the arrival of trigger and firing of RPC, taken for operating voltage 9.7kV are used to plot a histogram and fitted with a Gaussian fit.

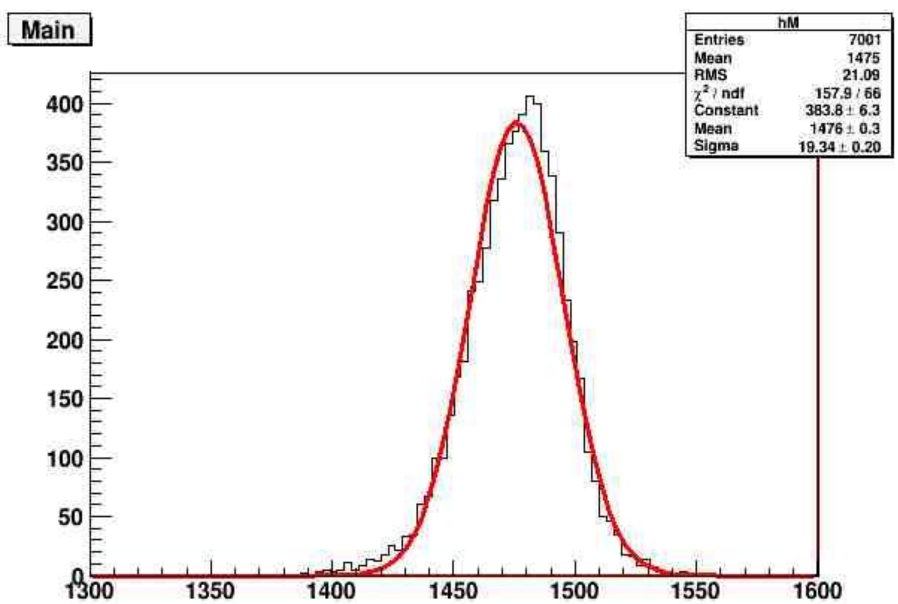

Fig 13. The TDC plot at 9.7kV

The time resolution of RPC is found to be (1.9±0.2)ns at 9.7 kV.

Conclusions:

The construction of 2m x 2m RPC AL06 is successfully completed and it can be operated at a volage of 9.7kV in the avalanche mode. It is characterised and the time distributions are also studied. The time resolution of AL06 is found to be (1.9±0.2)ns at 9.7 kV.

REFERENCES:

1. Radiation Detection and Measurement, G.F.Knoll.
2. Techniques for Nuclear and Particle Physics Experiments, W.R.Leo.
3. B.Satyanarayana, "Design and Characterisation Studies of Resistive Plate Chambers"
4. S.Bhide, et.at. "Development and characterisation of large area glass Resistive Plate Chambers for the ICAL detector at INO"