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Development and characterization of glass RPC's.

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Development and Characterisation of (2m x 2m) Glass Resistive Plate Chambers (RPC's)

By

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Introduction:

Resistive Plate chambers (RPC's) were introduced in 1981 as a practical alternative to the remarkable "Localized discharge spark chambers", which ultimately achieved a time resolution of 25 ps s. The resulting detector, being by construction free from damaging discharges and enjoying a time resolution of the order of 1 ns, has found very good acceptance in High Energy and Astroparticle Physics.

In modern language the original RPC's were single-gap chambers operated in streamer mode. Soon the double-gap structure was introduced to improve the detection efficiency along with the avalanche mode of operation, which extends its counting rate capabilities.

Recent innovations in detector construction and read out electronics have extended the timing resolution of RPC's for minimum ionizing particles (MIP's) to 50 ps s , the rate capability to 105 Hz/mm ^{2} and the position resolution for X-rays to 30 µm FWHM in digital readout mode. Single and double-gap streamer-mode RPC's have so far found application in cosmic ray experiments, like COVER_PLASTEX and EAS-TOP being also used in the High Energy Physics experiments L3 at CERN, BABAR at SLAC, USA and BELLE at KEK, Japan. Future applications will include the ARGO experiment at the "YangBaJing High-altitude Cosmic Ray Laboratory" and the OPERA and MONOLITH cosmic ray experiments in LNGS, Italy. The Muon Arm of the ALICE experiment at LHC will also be equipped with streamer-mode RPC's.

Avalanche-mode RPCs will be used for the muon trigger systems of the ATLAS, CMS and LHCb experiments at LHC.

Timing RPC's, a recent development, are already in use by the HARP experiment at the CERN PS accelerator and will equip the 160 m TOF barrel of ALICE's Particle Identification Detector.

In INO (INDIA BASED NEUTRINO OBESRVATORY) project it is proposed to use approximately 29000 glass RPC's in combination with iron layers to detect neutrinos. This combination of glass RPC's and iron layers are together called as ICAL (Iron calorimeter). Here in this ICAL detector the iron layer provide the active interaction medium for the neutrino's to interact and produce muon's.

RPC Design:

The combination of resistive and metallic electrodes with signal-transparent semi-conductive layers, highly isolating layers and different kinds of pickup electrodes endows the RPC's with a rich variety of configurations, tunable to a variety of requirements.

They are,

1. *Single gap RPC's,*
2. *Double gap RPC's,*
3. *Multi gap RPC's,*
4. *Hybrid designs.*

Here the design of single gas gap RPC's that we are going to use in INO project is discussed below,

The original RPC design included a single gas gap delimited by Bakelite resistive electrodes. Naturally the chamber design has evolved since then and a modern RPC example is shown in Fig. 1.

The application of the polarizing potential to the resistive electrode via an electrode with a lower resistivity, but still transparent to the induced signals allows to operate both signal pickup electrodes at ground potential, saving the utilization of high-voltage capacitors and avoiding the need for high voltage insulation of the strips.

Glass electrodes, enjoying a mechanical stiffness and surface quality much superior to Bakelite, has also been considered in the past and remains in use today.

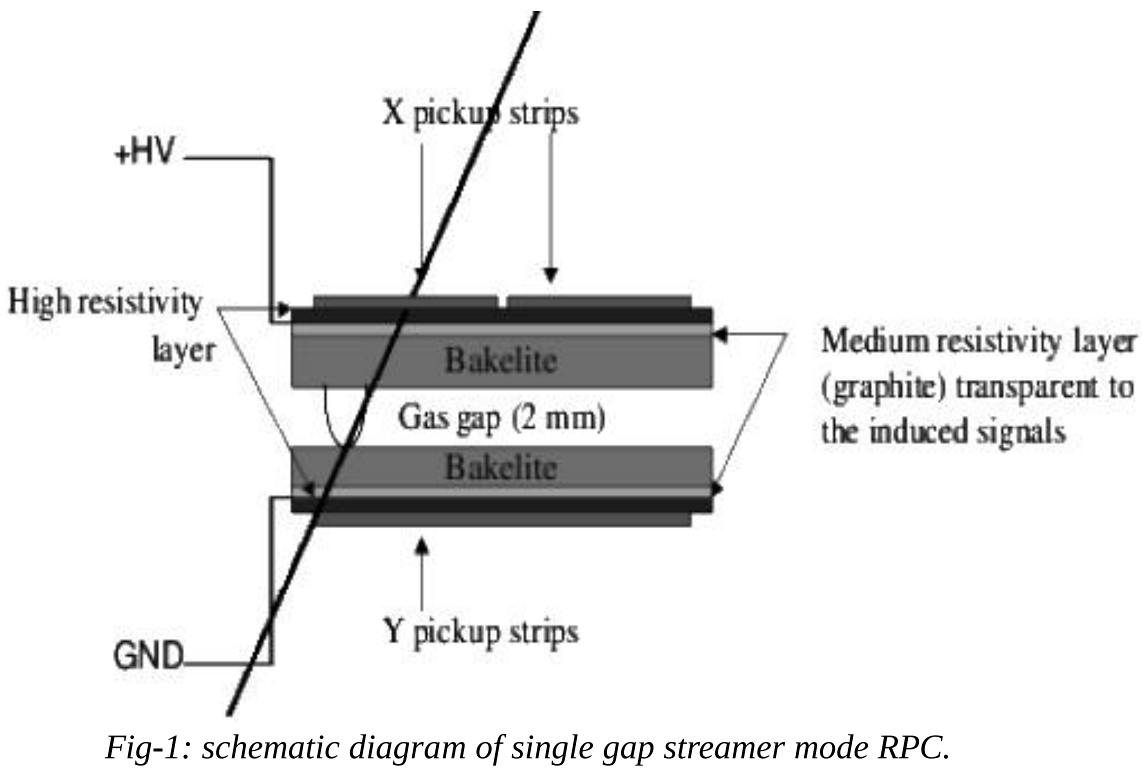

Fig-1: schematic diagram of single gap streamer mode RPC.

Modes of operation:

RPC's are mainly operated in two modes namely,

1. *Avalanche mode,*
2. *Discharge mode (or) streamer mode.*

This mode of operation depends upon the voltage we applied and the active gas medium that we are providing to the detector.

Avalanche mode:

The avalanche corresponds to the generation of secondary electrons in the gas gap following the release of primary charge by the incoming ionizing radiation. Here the primary ions produced by the incoming ionizing radiation are accelerated by the applied electric field and produces secondary electrons. This process of avalanche stops when the external field opposes the internal field created by the ionized charged particles. These ionized charged particles are collected by the respective electrodes to obtain signal. In this mode the signal pulse amplitude are in the order of mV and therefore pre-amplifiers becomes important thing in this mode of operation.

Discharge (or) streamer mode:

In this mode of operation the secondary ionization continues to happen until gas break down takes place. This breakdown is followed by a “streamer” discharge. This discharge produces signal amplitudes of about few hundreds of mV. So pre amplifiers are not required in this operating mode. Even though this is an advantage in cost consideration point we want to make compromise on life time of RPC's.

The operating mode of RPC’s depends upon its application and the expected count rates the RPC's are going to face. In general Streamer (or) discharge mode operations are suitable for cosmic ray and low count rate experiments, while avalanche mode operations are suitable for high count rate experiment such as CMS (compact muon solenoid experiment) at LHC (Large hadron collider).

Electrical representation of RPC's:

The assembled RPC gas gap can be represented as an electrical circuit containing resistance and diodes. The equivalent electrical circuit of one RPC (either glass or Bakelite) is shown in Fig-2.

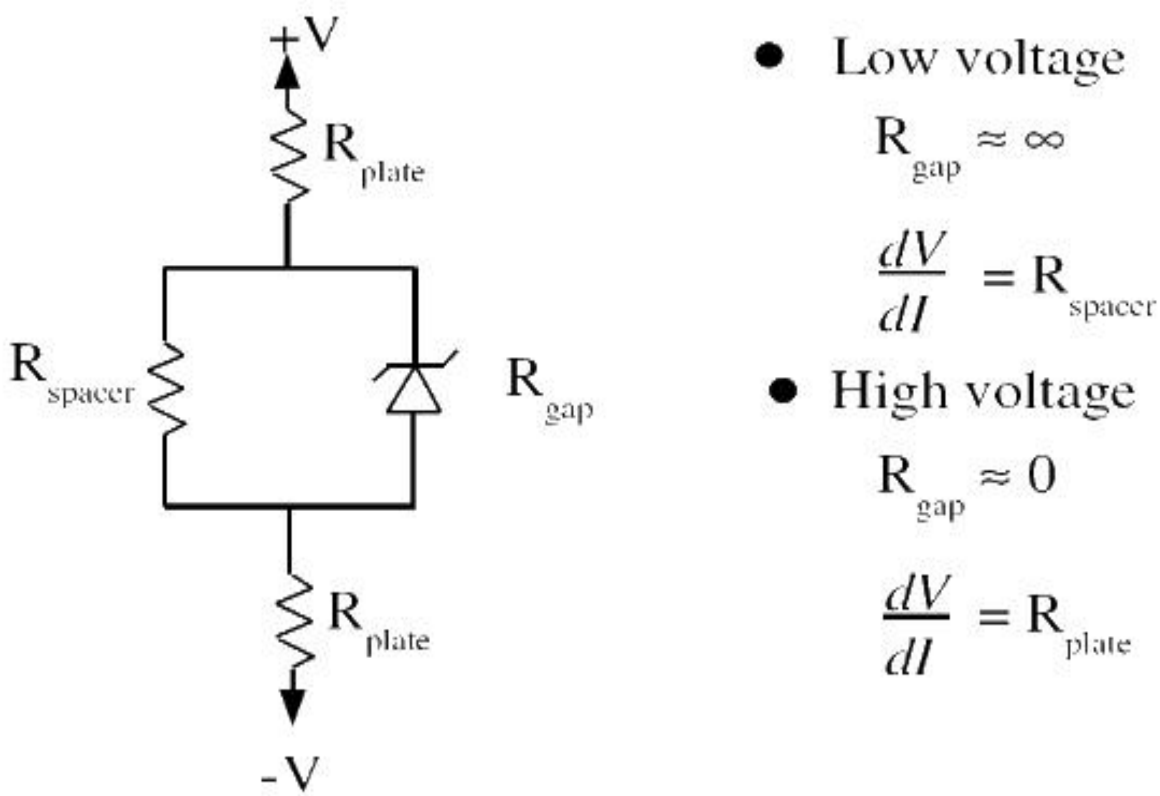

Fig-2: Electrical representation of single RPC gas gap.

In the above diagram $\boldsymbol{R_{plate}}$ *represents the resistance of top and bottom plate.* $\boldsymbol{R_{spacer}}$ *represents the resistance of the spacer sandwiched between top and bottom plates. The zener diode shown in diagram represents the gas gap through which the active detector element i.e. the gas mixture flows.*

Fabrication of single gas gap RPC:

The assembly of single gas gap RPC is an elaborate process and needs careful handling and cleaning of all glass plates, Mylar sheets etc. The process involved in the preparation of glass gaps are discussed in detail below,

1. *Glass cutting and cleaning:*

   The glass plates (2mm thick) procured from local vendor are made to appropriate size by cutting it with diamond cutter and the corners are chamfered in such a way the angle is 45 degree. Then the prepared glass plates are thoroughly cleaned with alcohol, then with labolene and distilled water to make it free from any impurities deposited on the surface. Now the glass plates are ready for conductive layer coating.

2. *Coating the surface of glass with conductive layer:*

   One side of both the glass plates are coated with a conductive paint (dry colloidal graphite and industrial lacquer) made especially for this purpose. In order to have equal surface resistivity all over the plate its necessary to have constant moving speed of spraying gun, uniform pressure (Because the surface resistivity depends on thickness of the conductive coating) and same paint mixture while painting. Here care should be taken to leave ~2cm on all edges unpainted. This precaution is taken to prevent the leakage of high voltage through the spacers placed beneath the glass plates.

3. *Resistance measurements:*

   The surface resistances of the glass plates are measured using a jig (15cm x 17cm) and plotted in root software. By analyzing the plots it is possible to identify the glass plates having uniform surface resistivity and two of those glass plates are selected to make one single gas gap RPC.

4. *Gluing of glass gaps:*

   After selecting the glass and other things necessary for making the RPC. The next step is to assemble the glass and spacers in exact position. The button spacers (width~1.8mm) are glued in a square array on top of one glass surface (without 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. Next The end spacers and nozzles are kept on the edges thereby providing an enclosed area which is not complete until gluing at edges are done and then whole setup is left undisturbed allowing the glue to set properly (By applying uniform pressure on the whole gap area).

5. *Gas leak test:*

   To make sure that the glue has properly sealed all the openings it's necessary to carry out gas leak test by flowing Freon gas above atmospheric pressure and using a gas leak checker RIKEN GH-202F.

6. *Positioning of high voltage cables:*

   At most care should be taken in connecting high voltage connections to the graphite coated layer. This is done by sticking a copper tape and cable leads are soldered on to it. The high voltage applied here is bipolar with Positive polarity on one layer of the glass gap and negative polarity on the other layer.

7. *Placing pick up strips:*

   In order to get the signal produced inside the glass gap for analysis, it's necessary to have some mechanism which will transfer the signal from gas gap to outside world. Here the mechanism used for this is by using pick up strips on top of the conductive coating layer on both sides (Mylar sheets should be placed in between pickup strips and glass plates).

Gas flow system:

For the assembled glass gap to detect the particles after applying high voltage and connecting all the output to the DAQ electronics, it's necessary to supply a mixture of several gases with different proportions into the gap which acts as the active medium for the detector. The choice of the gas mixture depends on several factors such as,

1. *Low working voltage,*
2. *High gain,*
3. *Good proportionality,*
4. *High rate capability.*

The requirement here is the minimum working voltage and lowest electric field intensity needed for avalanche multiplication. For this requirement Noble gases acts as a good candidate. However the avalanche multiplication is governed by the following factors,

1. *First ionization potential,*
2. *First Townsend co-efficient,*
3. *Electronegative attachment co-efficient.*

Currently the RPC's used here are operating in avalanche mode and hence the main component used in gas mixture is an electronegative gas. The gas composition used here are,

1. *Freon = 95.2%*
2. *Isobutene =4.5%*
3. *SF_6 =0.3%*

In above mixture Freon used in huge proportion acts as electronegative medium for electron production, while isobutene acts as a photon quenching gas as it absorbs u v photon produced during e- ion recombination. While SF_6 controls the excess number of electrons.

The gas flow system is designed for mixing four gases namely: Argon, Freon (134A), Isobutene and SF6 by volumetric method. However in avalanche mode only three gases are used because in avalanche note Argon is not used. In streamer mode all four gases are used.

The gas mixing system consists of the following components:

1. *Purifier Column: The gas which acts as active medium in glass RPC should be free from impurities in order to detect the passage of particles exactly. For achieving the required level of purity the gas before going into mixing unit is allowed to send through a purifier column containing Molecular sieve to absorb moisture and purify the gases.*

2. *Mixing Unit: It works on the principle of Mass Flow Control (MFC) and the flow of the gas is displayed in Standard Cubic Centimeter per Minute (SCCM). In this MFC setup there is an option to set the flow rate manually. The comparator present here will compare the set value and the amplified signal to operate the pneumatic values.*

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. *Bubblers: Two bubblers (both of same dimension) one for safety and other for isolation purposes are used. The function of safety bubblers is to bubble when there is a block in RPC. It is connected in parallel with RPC. The purpose of isolation bubbler is to monitor the flow of gas mixture through the RPC.*

5. *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 inside the manifold with respect to room pressure.*

6. *Moisture Meter: Microprocessor based sensor meter is used to monitor the moisture content in the mixed gas. For this moisture meter to work properly all the gases should pass through this moisture meter. This will measure the moisture content of the gas mixture and gives reading in dew point.*

The block diagram of the gas flow system is shown in Fig-3 and Fig-4.

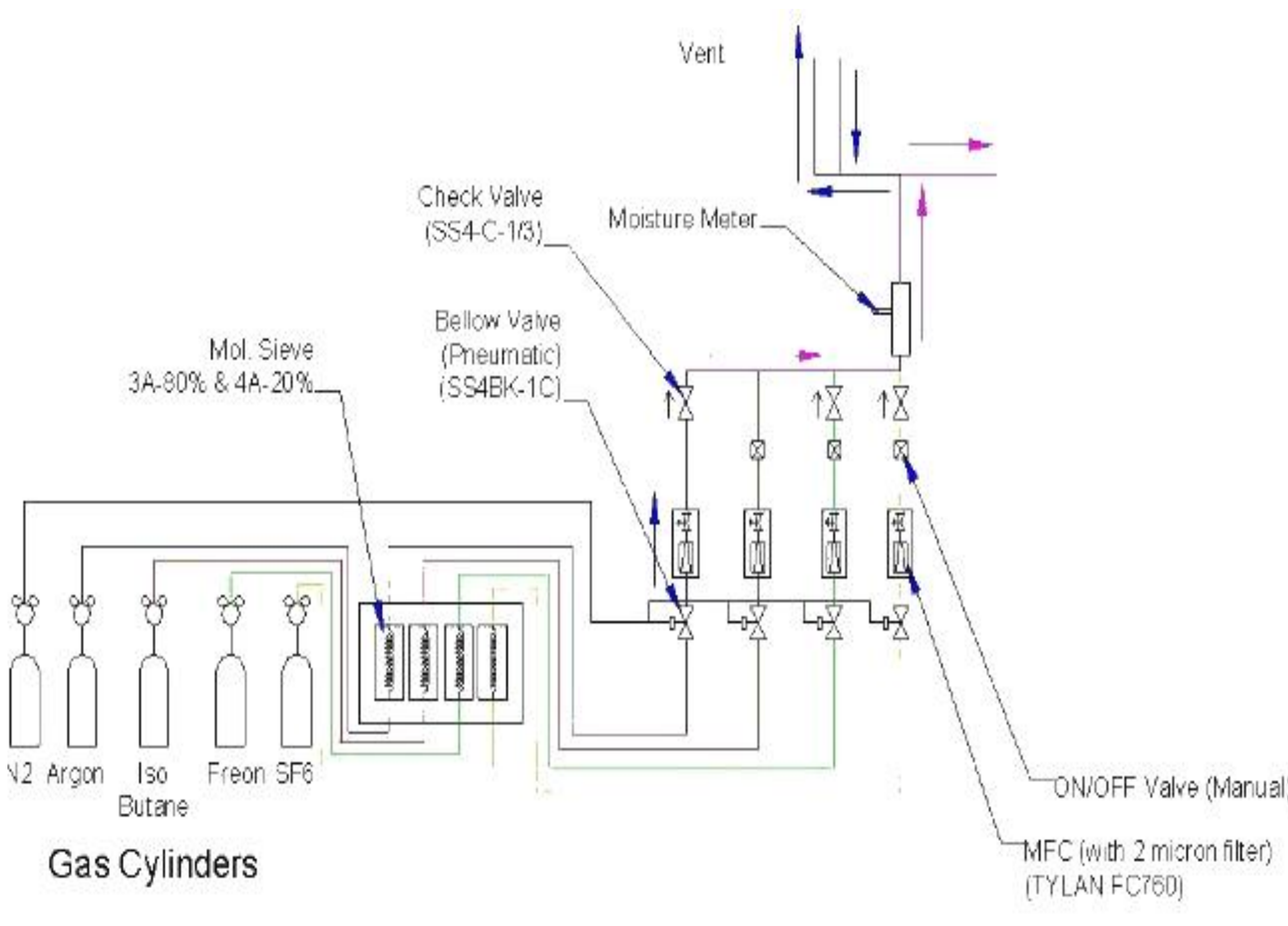

Fig-3: Block Diagram of gas flow system.

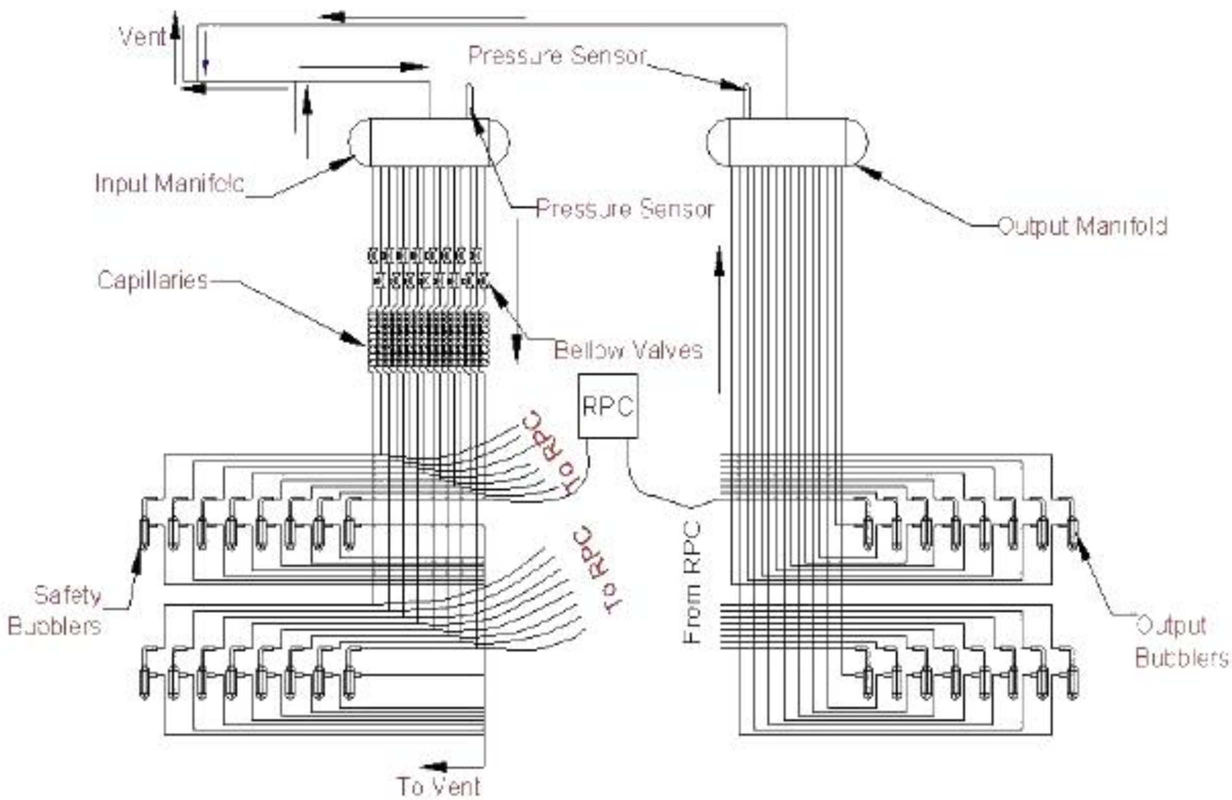

Fig-4: Block Diagram of gas flow system.

Trigger Logic setup for detecting muon's:

Once the RPC is placed in its position and high voltage is applied the next step is to measure the efficiency. Before proceeding to measure the efficiency it is necessary to ensure that the trigger pulse generated is solely due to the atmospheric muon's (Since no iron layers are placed in prototype detector setup in TIFR). For generating the trigger four scintillator paddles are used here. These scintillator paddles are arranged in such a position that if a muon or charged particles passes through all the four scintillator paddles it produces a trigger signal. This four scintillator paddles are together called as cosmic ray telescope. This cosmic ray telescope consists of 4 muon trigger paddles p1,p2,p3,p4 and their area are 40×20, 40×20, 30×2,30×3 cm^2 respectively. The geometry of this telescope is arranged such that we define a window of about 30×2cm^2, for the cosmic ray muon's to pass through the telescope as well as through the RPC under test. This passage of muon will produce both the trigger signal and the signal in the RPC pick up strips. These data from the RPC pickup strip is recorded whenever a cosmic muon generates a trigger signal through the logic P1.P2.P3.P4 i.e., a trigger is formed when a muon passes through the paddles P1, P2, P3 and P4. The RPC trigger logic set up is shown in Fig-5.

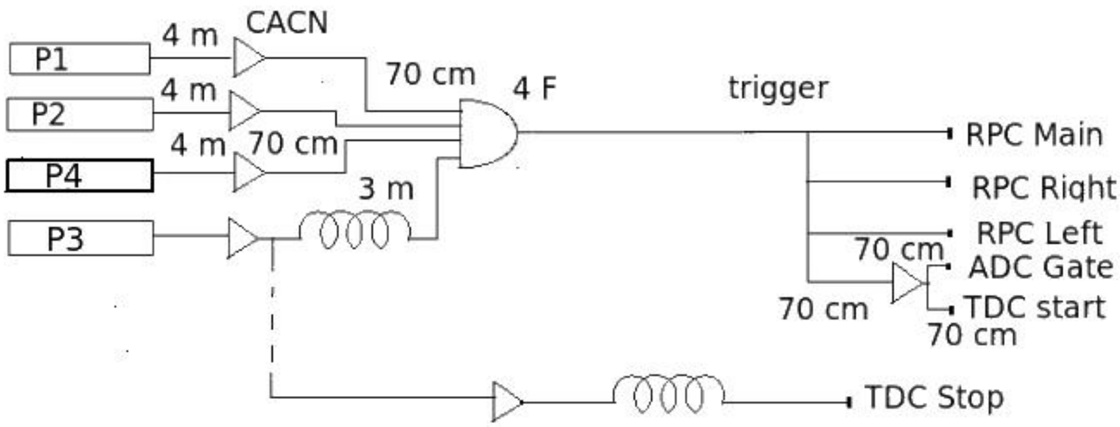

Fig-5: Trigger logic circuit diagram.

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. Scalars 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. Finally this signal is recorded.

Now the Efficiency of the RPC is defined as,

$$E = \text{4-fold} \times \text{RPC} / \text{4-fold} \qquad (1)$$

The circuit diagram used for calculating efficiency is shown in Fig-6.

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

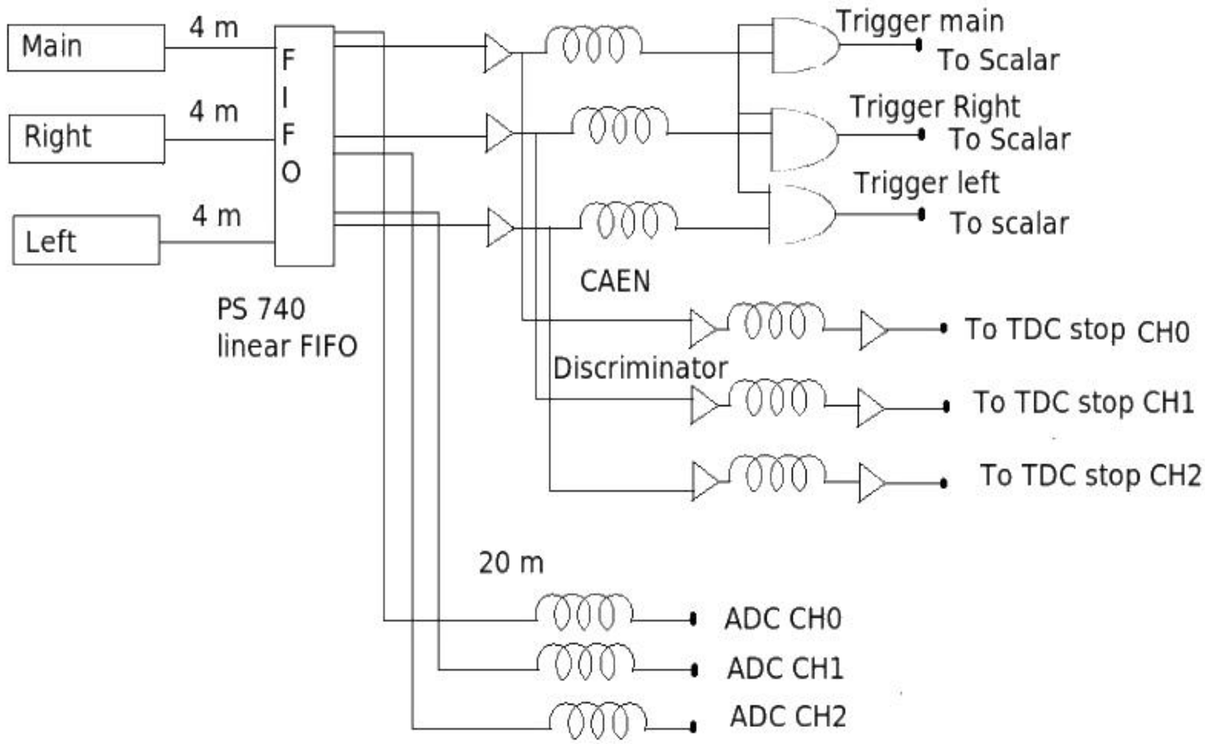

Fig-6: Circuit diagram for efficiency measurements of RPC.

Data Acquisition system:

In order to make the signal generated in the detector for some useful analysis, we need to have some electronics system. This entire electronics system is divided into signal processing and data acquisition system. This is further divided into four modules namely,

1. *Front end electronics (16 channel analog front end and 32 channel digital front end).*
2. *Trigger module.*
3. *Signal routers (Trigger and TDC Router & Control and data Router).*
4. *Back end DAQ system (Data and Monitor Control module & Data and Monitor Readout module).*

The block diagram of electronics setup for x-plane is shown in Fig-7.

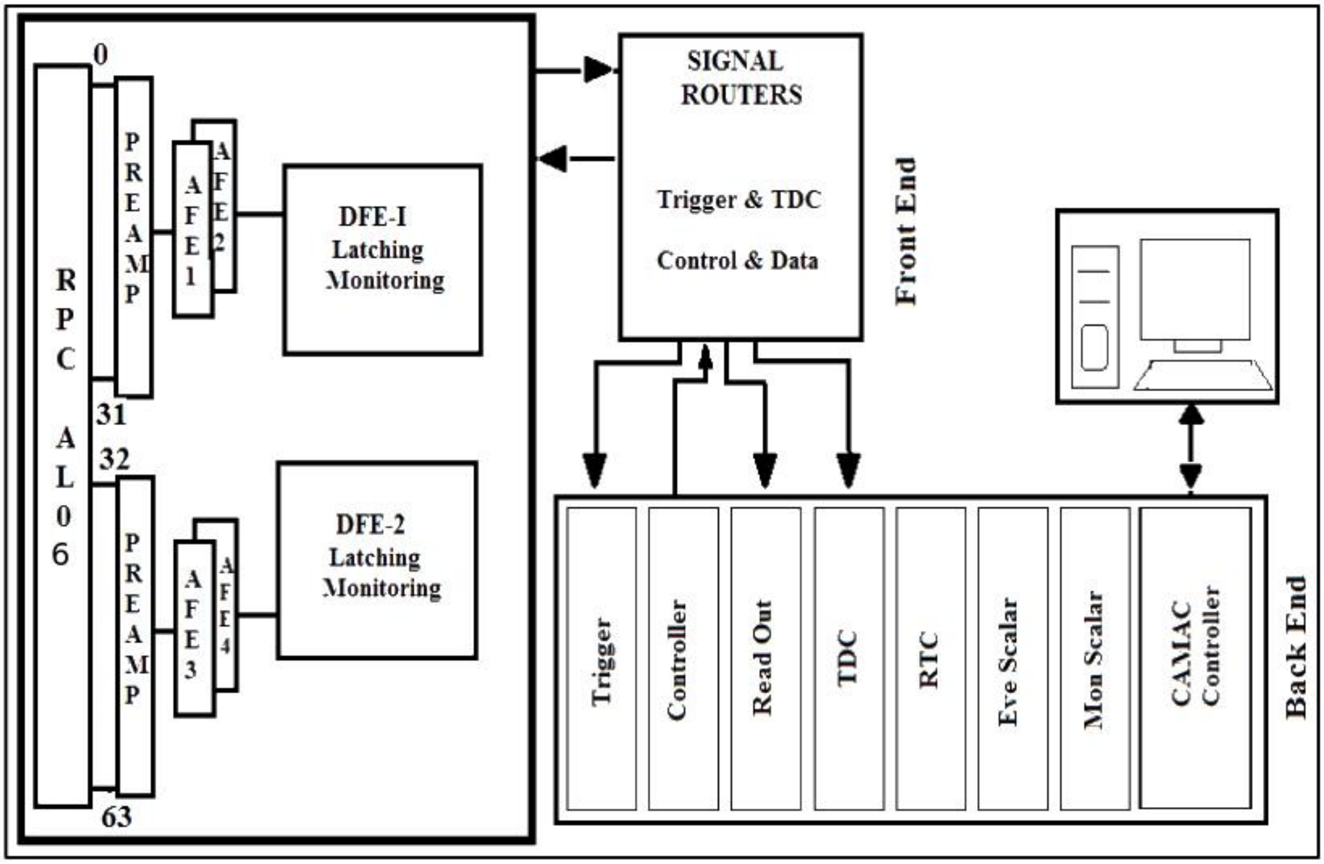

Fig-7: Block diagram of electronics setup for x-plane of RPC.

Front end electronics:

The signal that is induced in pick up strips is made to pass through a pre amplifier having a gain of ~70-80 and fed into four 16 channel discriminator modules (Analog front end). When the signal crosses a particular set threshold limit in discriminator the discriminator will generate an 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 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 M fold 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 mask able.

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. 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 RPC's are daisy chained into two groups for event data recording. At present no daisy chains are used for monitoring purpose and hence all the RPC's 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 channel's 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:

The efficiency of the right (S20), main (S21) and left (S22) 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.

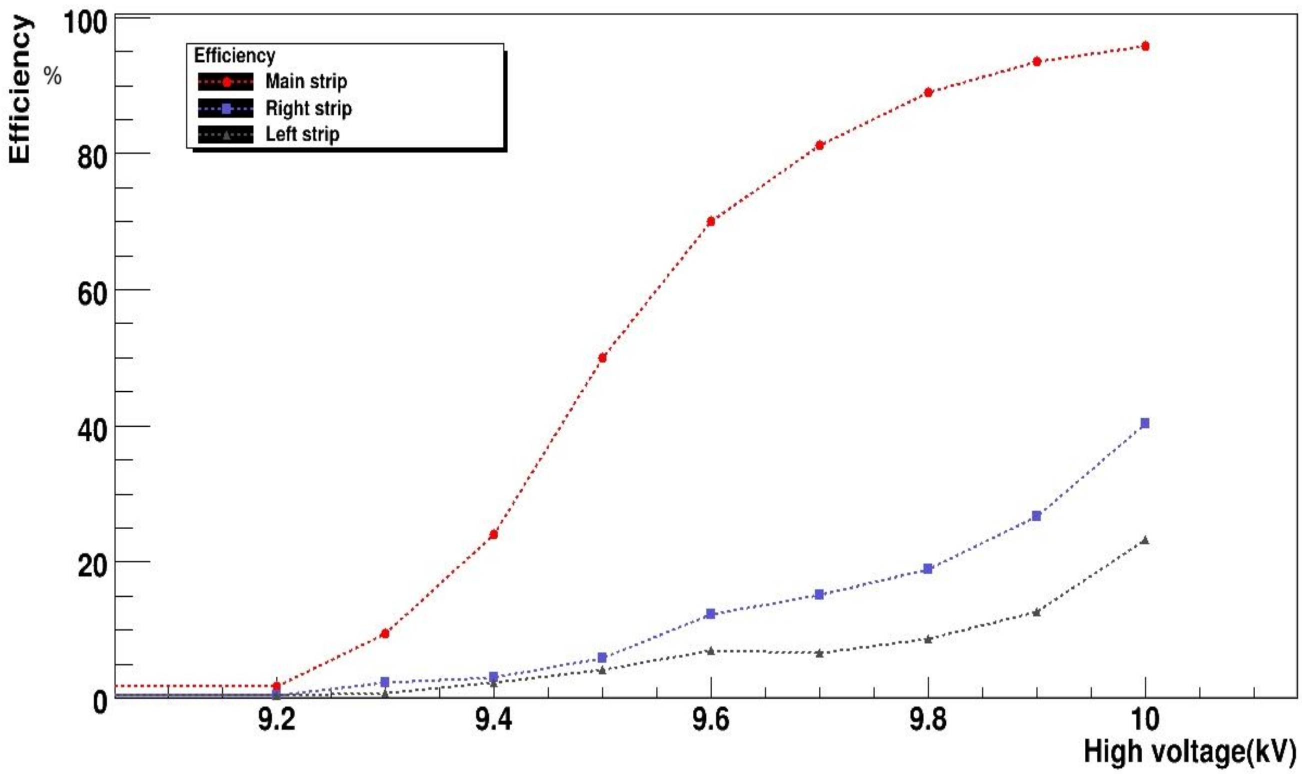

Fig-8: Efficiency Vs voltage.

The plateau region is achieved around 9.8KV (efficiency~95%) for the main strip.

The I-V characteristics for both the glass plates of RPC AL03 are plotted in Fig-9 and Fig-10.

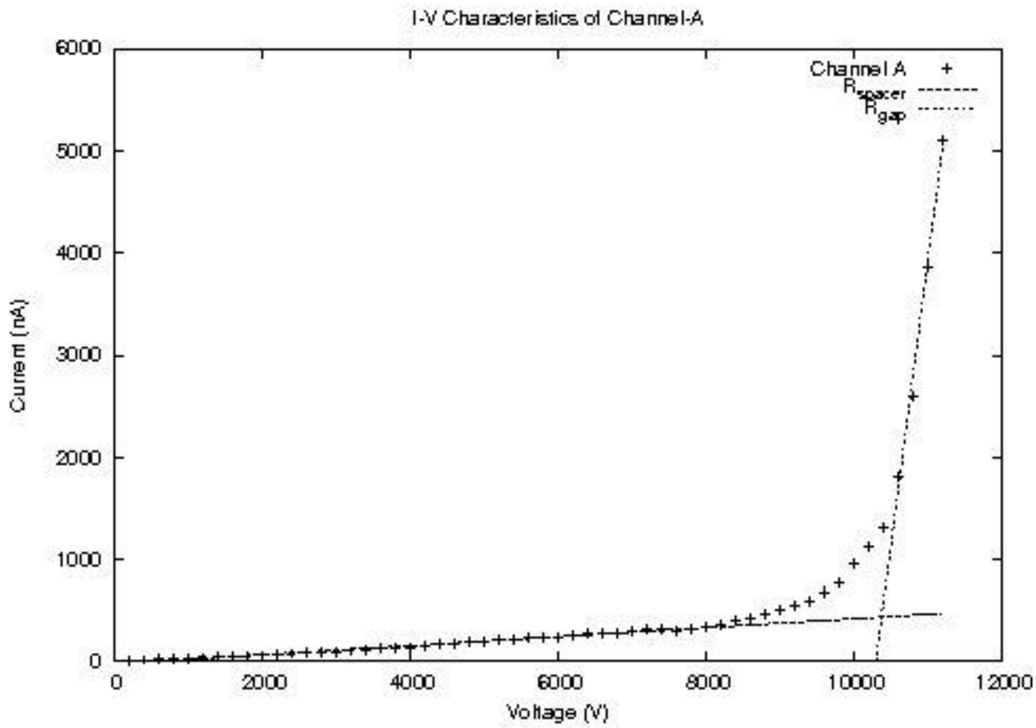

Fig-9: Current Vs voltage for channel A.

The fit parameters for gap resistance region are,
Slope = 0.0441228 +/- 0.0009103 (2.063%)
Intercept = -20.8559 +/- 3.968 (19.03%)

The fit parameters for glass resistance region are,
Slope = 5.57 +/- 0.3934 (7.064%)
Intercept = -57368 +/- 4289 (7.477%)

From Figure 09, we get
Gap resistance= 22.66 GΩ, at low voltages
Glass resistance = 0.179 GΩ, at high voltages (above 9kV)

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

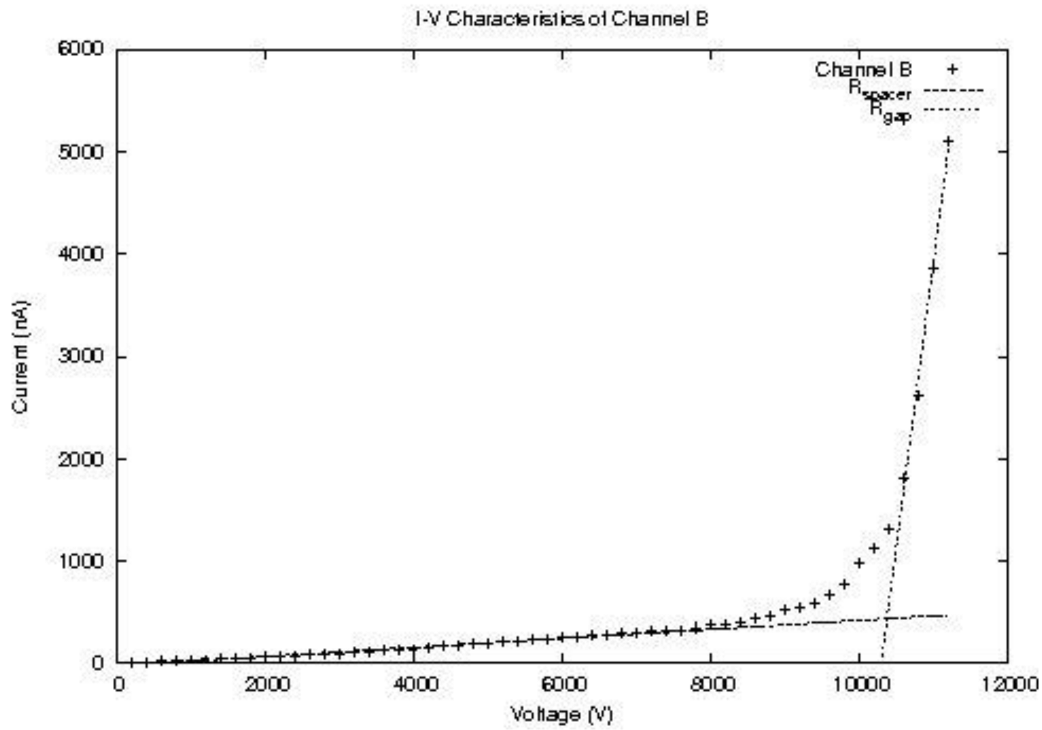

Fig-10: Current Vs voltage for channel B.

The fit parameters for gap resistance region are,
Slope = 0.0442639 +/- 0.0008874 (2.005%)
Intercept = -20.7432 +/- 3.868 (18.65%)

The fit parameters for glass resistance region are,
Slope = 5.559 +/- 0.3845 (6.917%)
Intercept = -57248.6 +/- 4192 (7.323%)

From Figure 10, we get
Gap resistance = 22.59 GΩ, at low voltages
Glass resistance =0.1799 GΩ, at high voltages (above 9kV).

The noise rate as a function of voltage and the TDC plot are obtained at 9.8kV for the RPC AL03.

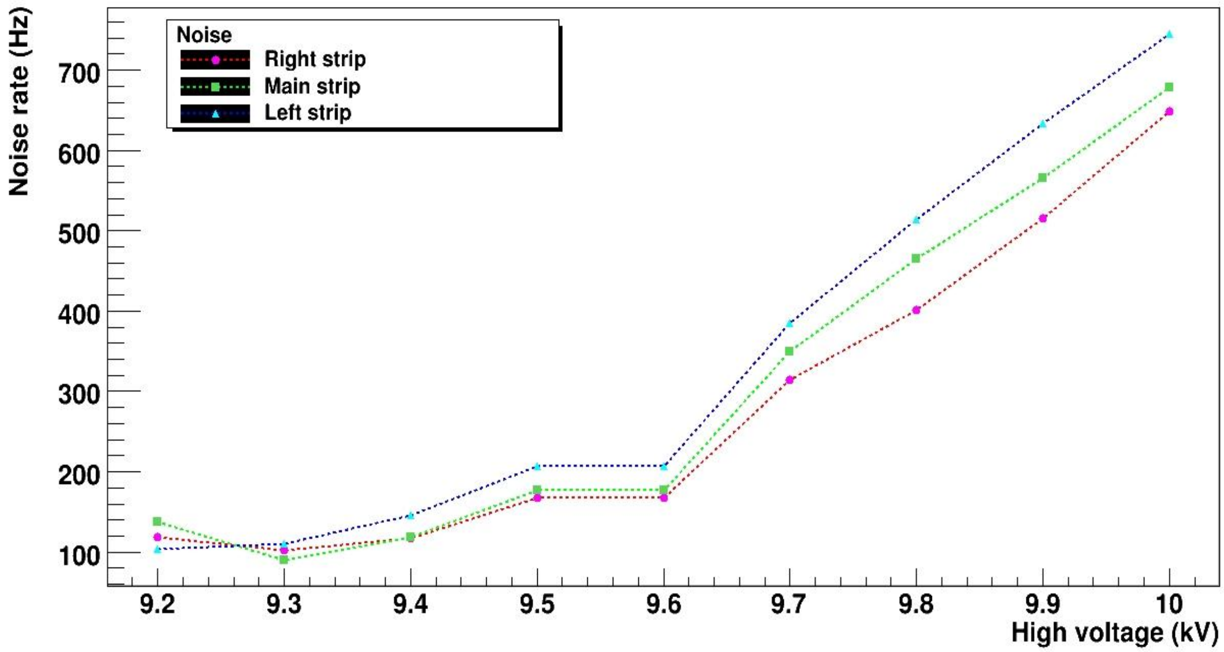

Fig-11: Noise rate Vs voltage.

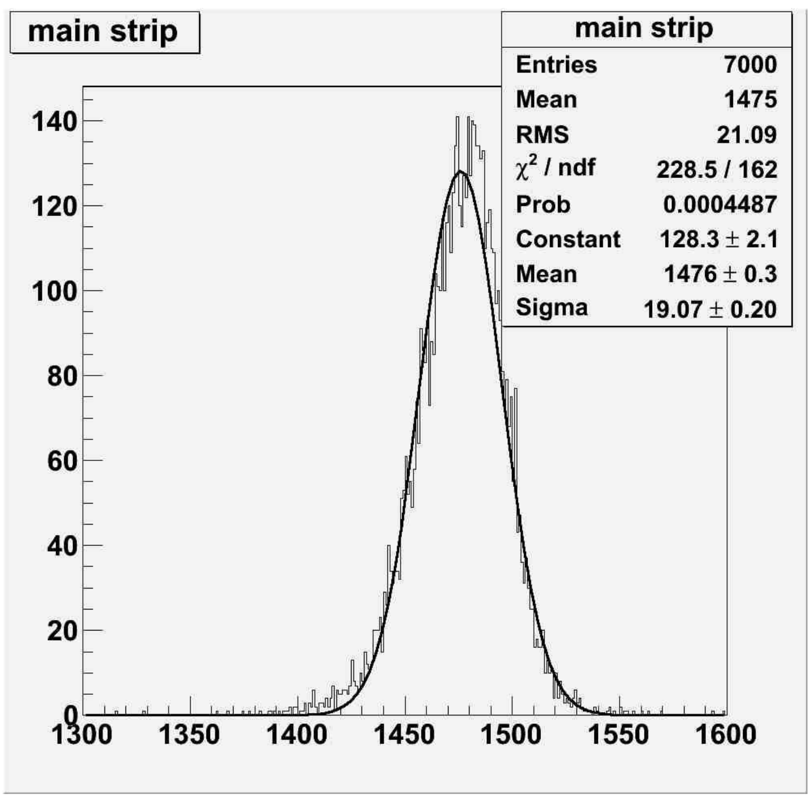

Fig-12: TDC plot at 9.8 KV.

The time resolution of the RPC is $\sigma = 1.9 \pm 0.1$ ns.

Conclusion:

Thus the construction of single glass gap RPC AL06 and its characteristics are studied. It's found that the suitable operating high voltage for this RPC as 9.8KV.

Teams:

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4) *Meghna.K.K.*

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