STUDY OF GLASS RESISTIVE PLATE CHAMBERS (RPC) AND CALCULATION OF EFFICIENCY

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INTRODUCTION

Resistive Plate Chambers (RPC) are going to be used as the active detector element for the INO-ICAL experiment. RPCs 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. The iron calorimeter contains iron plates as the absorber of energy and glass RPCs as the active detector device. The detector working concepts are based on the detection of gaseous ionization produced by charged particles traversing the active area of the detector, under a strong uniform electric field applied by resistive electrodes. RPCs are these days preferred to scintillators because of several reasons:

- Good position resolution and good detection efficiency (>90%).
- Coverage of substantial area with minimal cost.
- Easy to assemble and simple read-out electronics.
- Exhibit better time resolution (~1ns) and long-term stability.

PRINCIPLE OF OPERATION OF GLASS RPC

Glass RPC is a gaseous detector composed of two parallel electrodes made up of float glass with a volume resistivity of about $10^{12}\Omega$-cm. The two electrodes, 2mm thick, are mounted 2mm apart by means of highly insulated spacers. 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. An ionizing charged particle traversing the gap initiates a streamer in the gas volume that results in a local discharge of the electrodes. This discharge is limited to a tiny area of about $0.1cm^2$ 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

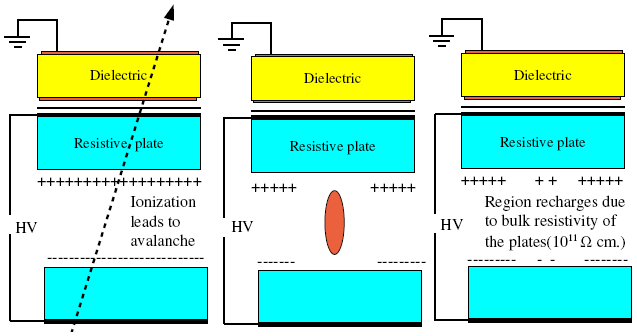


Fig.1 Basic Principle of Operation of Glass RPC

and time of ionization. The discharge area recharges slowly through the high resistivity glass plates and the recovery time is about 2secs.

The RPC can be operated in two different modes depending on the voltage of operation and the gas composition used.

- *Avalanche mode:* The primary ions produced by the charged particle being accelerated by electric field produce secondary ionizations by collision with the gas molecules. The electric field of this cluster of ionized particles is opposed by the external field and the multiplication process stops after sometime. The charges then drift towards the electrodes from where they are collected. This mode operates at a lower voltage and the gain is also less. Typical pulse amplitudes are of the order of a few mV.

- *Streamer mode:* Here the secondary ionization continues to occur until there is a breakdown of the gas and a continuou discharge takes place. This mode operates at a higher voltage and also results in high gin. Typical pulse amplitudes are of the order of 100-200 mV.

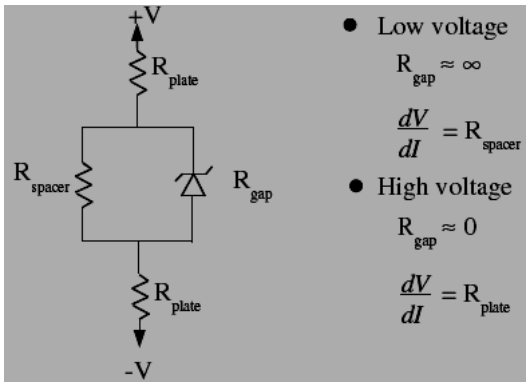


Fig.2 Equivalent Circuit Representation of RPC

CONSTRUCTION OF GLASS RPC

We have seen the development of a 1×1 m^2 RPC with resistive electrode plates made of commercial float glass with a volume resistivity of the order of 10^{12} ohms and thickness of 3mm. The different steps are discussed below:

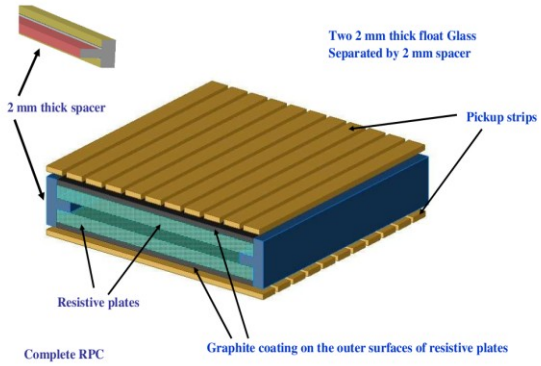


Fig.3 Structure of a standard single layer RPC

- ***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 and then labolene and distilled water. After that the edge spacers, corner spacers(which are connected to the gas nozzle), button spacers(used for bigger RPCs) are 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. This is done to prevent the conductive coating to be painted right upto the edge of the glass.

- ***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 are measured using two fixed sizes of copper and brass square (about 2 and 20 cm^2). The surface resistance is found to be fairly constant and is about 400KΩ/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 from the pickup planes.

- ***Glueing of Glass***

The glue used is 3M Scotch-weld epoxy adhesive in a duo-pack cartridge. One of the glasses is put on a plastic sheet and on top of the glass the button spacers (width ~1.8mm) are glued in a square array. The glue comes out through the three holes of the spacers. Then the other glass plate is placed on those array of spacers. All RPCs have a gas gap of 2mm. To put a uniform weight throughout the $1m^2$ 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 one day to fix the spacers.

The straight edge-spacers are also designed in 'steps' so 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 and lead blocks were placed along the 4 sides to put the pressure and whole setup was left for one day, on the next day the same procedure was followed for the other side of the RPC.

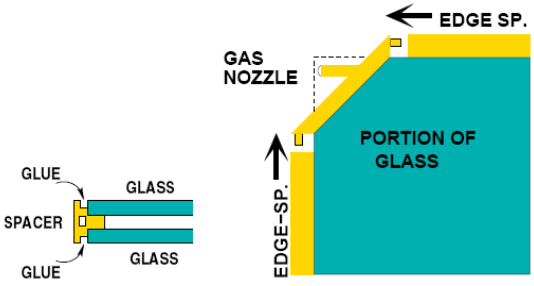


Fig.4 Side-view and Top-view of Spacer

- *Gas Leak Test*

Now the RPC has become ready to be tested to make sure that no gas leak occurs, especially at the glued joints. This is done by flowing Freon gas at atmospheric pressure and checked for any leak using a gas sensor FLON GH-202F.

- *High Voltage Cables*

Now the base RPC is ready and it is to be wired for applying high voltage and picking up the signals as charged particles pass through. 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 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.

- *Pickup Strips*

The RPC is now sandwitched between two honeycomb pickup panels placed orthogonal to each other and then packed in an aluminium case. The pickup panel consists of 32 strips copper foil on one side of a layer of 5mm of foam and aluminium on the other side. Each strip is of width 2.8 cm with a gap of 0.2cm in between two

adjacent strips. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the preamplifier. A layer of mylar of thickness 100 μm 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. 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. 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. *Tetrafluoroethane* (known as *Freon*), which is widely used, has shown these specifics. But here we use *R134A*(as *Freon*) which is eco-friendly.

One more component is constituted by *polyatomic* gases, often hydrocarbons, which have a high absorption probability for ultra violet photons, produced in electron-ion recombination. This gas is known as *'quenching gas'*. This component allows to the energy by vibrational and rotational energy levels, avoiding photo ionization with related multiplication and limiting the lateral charge spread. Here we have used *'Isobutane'* as the *'quenching gas'*.

Finally we use SF_6 *(Sulphur-hexafluoride)* to control the excess number of electrons.

Gas Composition

Gas Constituents	Percentage
Freon	95.15
Isobutane	4.51
SF_6	0.34

The gas mixing system consists of the following components:

- *Purifier Column* : It contains Molecular sieve used to absorb moisture and purify it.
- *Mixing Unit* : Based on Mass Flow Controllers (MFC) and the flow of the gas is displayed in Standard Cubic Centimeter per Minute (SCCM).

- *Distribution Panel* : 16 RPC's can be connected in parallel, which is achieved by "Flow resistors" viz. Capillaries.

- *Safety Bubbler's* : To take care of the back pressure exerted and protect the RPC's from over pressurizing.

- *Isolation Bubbler's* : It prevents back diffusion of air into the RPC and also the indicate the flow of the gas.

- *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.

- *Remote flow setting and monitoring through PC* : On line monitoring and setting of the flow of gas through the MFC's and also has provision for monitoring the pressure on the gas mixing and exhaust manifold sensors.

- *Moisture Meter :* Microprocessor based SHAW sensor meter to monitor the moisture content in the mixed gas.

The pressure of the gases to be mixed are controlled by 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 Iso-Butane 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 2000Kg/cm^2**.**

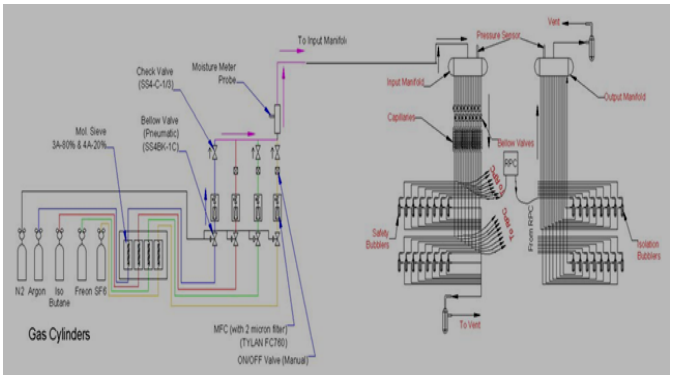


Fig.5 Block Diagram of Gas Flow System

Fig.6 Front Panel of Gas Mixing Unit

❖ *MFC Calibration*

As mentioned above, we have used MFCs(mass flow controller) to regulate the rate of flow of each gas. MFC used here is Nippon Tylan made model FC-760. All the MFCs used are recalibrated using a simple technique mentioned below.

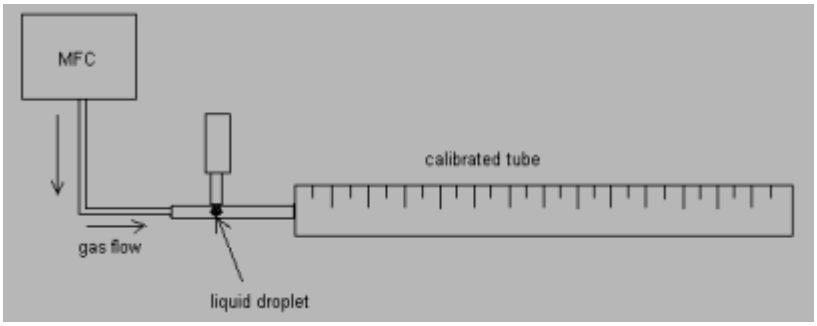


Fig.7 Recalibration of MFC

Gas coming out through the MFC is flown through a graduated tube. At the inlet of the tube we insert a droplet of a viscous liquid. The liquid drop flows along the tube as a result of the pressure exerted by the incoming gas. By a stop-watch we measure the time taken by the liquid drop to flow through a fixed length along the tube. Cross-section of the tube is known to us and thus we calculate the gs flow rate as

$$\text{Flux} = (\text{Change in volume})/\Delta t$$

The actual rate of flow of the three gases as measured by us are as follows:

Gas Flow Rate

Gas	Set/Read Value(SCCM)	Actual Flow (SCCM)
Freon	25.0	25.7057
Isobutane	1.06	1.2189
SF_6	0.07	0.0912

Thus, total amount of gas flow rate (Freon+Isobutane+SF_6)

= (25.7057+1.2189+0.0912) SCCM

= 27.0158 SCCM.

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).

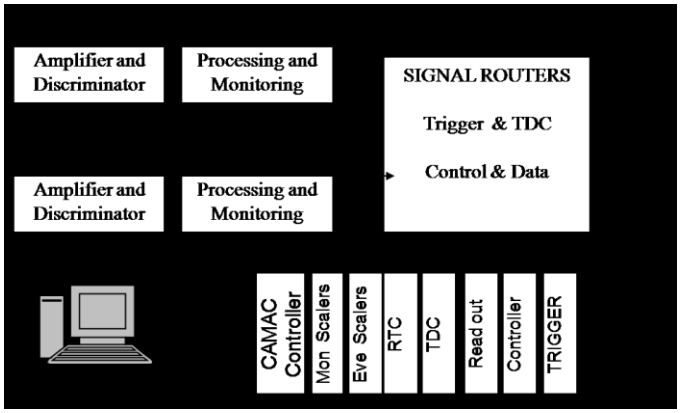


Fig.8 Block Diagram of Electronics Set-up

➢ *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 a 32 channel Front End Processing (FEP) module which converts the ECL i/p to TTL o/p and also generates trigger_1 signals.

➢ *Trigger logic*

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

M × N 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, 4×2. Trigger is implemented in three stages.

In the first stage i.e. trigger_0 logic, the shaped discriminator pulses from every 8^{th} 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 tha 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 scalers. All the triggers are maskable.

- *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 sytem 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 12 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 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 the track at each layer is recorded in the TDC which gives the directional information.

❖ *Some Specifications*

- 12 layers of RPCs of area $1m^2$ each having 32 pickup strips.
- Total no. of information channels = 12 × 32 × 2 = 768.
- Expected trigger rate is a few Hz.
- Coincidence window for trigger generation = 100ns.
- Clock pulse frequency is 1MHz.
- Timing resolution of TDC is 100ps.
- Data Format: Event data — 167 words (167 × 8 = 1336 bytes).

  Monitor data — 62 words (62 × 8 = 496 bytes).

  Data is written to a file for every 100 events.
- Power consumption = 25mW/channel.
- Monitoring of ambient conditions of the environment housing the detector is done on a regular basis and favourable temperature and relative humidity conditions are suggested to be $20\pm2^{o}C$ and 50±5% respectively.

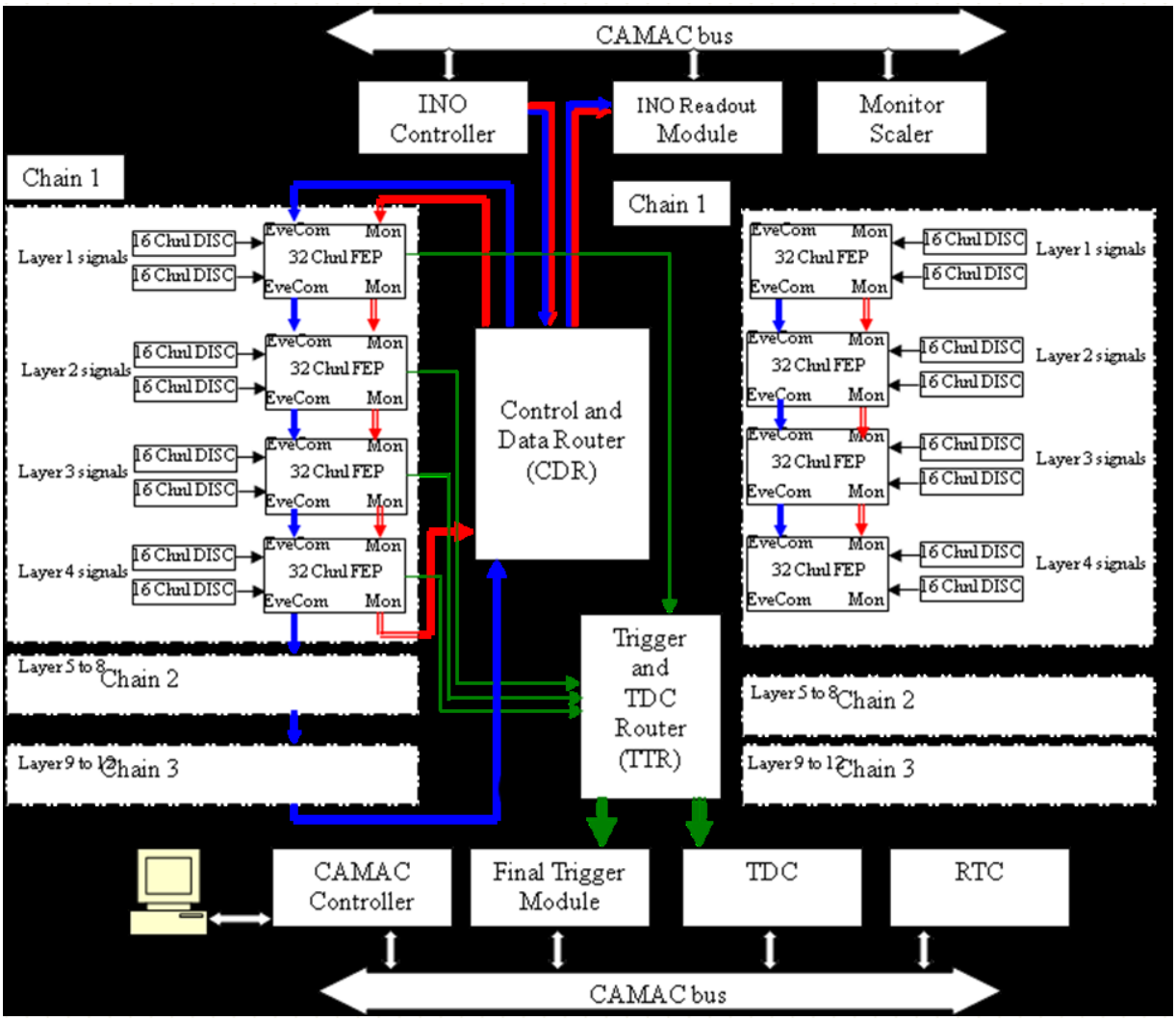


Fig.9 Electronics Set-up and DAQ

EFFICIENCY CALCULATION

We have calculated efficiency of one of the twelve RPCs at different values of the high voltage. The RPC that we have chosen is AB10. Normally the RPCs are operated at a high voltage of 9.8KV. Keeping high voltage for all other RPCs constant at 9.8KV, we varied the same for AB10 from 9.0 to 10.0 KV.

Calculation of efficiency is done using a C++ code written by us. The efficiency at a particular value of the high voltage is calculated as

Efficiency = (No. of times RPC actually fires) / (No. of times it should fire)

The denominator is obtained by fitting the data in the datafile. Only those data are fitted which satisfy the following two conditions:

- No. of strips hit in a RPC for a single event should be less than three.
- No. of such RPCs fired in a single event should be greater than four.

The data matching above two conditions are fitted using linearfit and then another iteration is done only with those data which satisfy following two conditions:

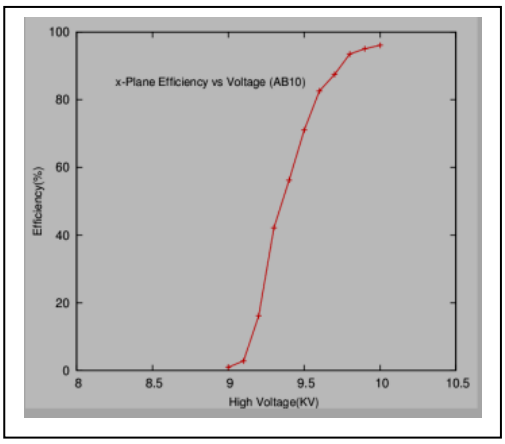
- Data points should fall within ±6.5 cm of the line obtained using the fitted parameters obtained in the first iteration.
- Those events are accepted where no. of RPCs that are fired is greater than four.

Now the ideal strip position at which the RPC should fire is calculated using the fitted parameters generated in the second iteration. If it falls within the fiducial region, the RPC is considered to fire actually if its actual strip position falls within ±1.5 cm of the ideal position. No. of times the RPC actually fires at a particular strip position and the no. of times it should fire in that position are counted over the entire datafile. Ratio of these two counts gives the efficiency of the RPC.

Now, while putting the RPCs one above the other, all the layers may not be placed exactly at the same position. Hence some +ve or –ve residual values are there for each layer which should be kept in mind at the time of calculation. Here, we also have calculated the residue values for each RPC layer. This is done by obtaining the difference between the actual and ideal strip position of firing in a particular RPC for the entire set of events and binning the difference values so obtained. Point at which the peak is obtained gives the residual value for that particular layer.

The X-plane and Y-plane efficiency of the layer AB10 as obtained against the different values of high voltage are given below:

High Voltage (KV)	**X-plane Efficiency (%)**	**Y-plane Efficiency (%)**
10.0	96.08	94.04
9.9	95.05	92.3
9.8	93.5	90.8
9.7	87.45	82.4
9.6	82.57	74.68
9.5	71.05	62.08
9.4	56.25	46.52
9.3	42.19	33.50
9.2	16.18	12.19
9.1	2.86	2.08
9.0	1.03	0.79



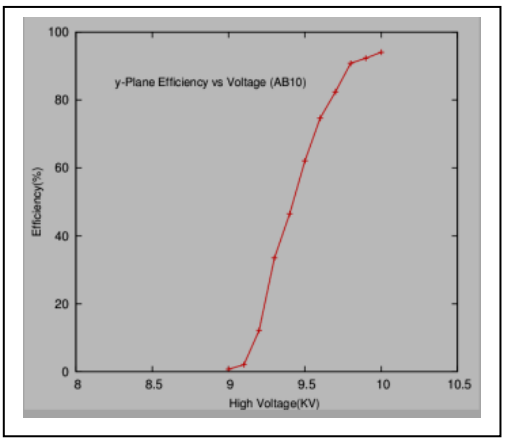


Fig.10 X-plane and Y-plane efficiency vs high voltage for AB10

It is observed that the efficiency values are almost constant for voltages higher than 9.8 KV 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.

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