Understanding RPC Efficiencies And The Cross-talks

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1 Motivation

The history of **Resistive Plate Chambers (RPC)** is relatively recent, the first publication was in 1982, they had great development in the following years and at the moment they are widely utilized or projected to be in many high energy and **astro-particles** physics experiments. The RPC array is a key element when it comes to the traditional function of **Muon detection**. They were applied as large area RPCs with parallel glass electrodes for a $\mathbf{K_L^0/\mu}$ at the **BELLE** experiment at **KEK**, Japan. **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 or Scintillators 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

- **They have a good position resolution and give good detection efficiency.**
- **They can easily cover substantial amount of area but simultaneously with minimal cost.**
- **The cost of the RPC is much smaller as compared to scintillators.**
- **These are easy to assemble and they require simple read-out electronics.**
- **They exhibit better time resolution than scintillators**[5]

Because of the above mentioned advantages, RPCs are being used more and more in modern day experiments. The Glass RPCs have been proposed recently as the active element in the **iron calorimeter (ICAL) detector** for the **India-based Neutrino Observatory (INO).** We discuss here the development and characterizing the efficiency of Resistive Plate Chambers (RPC) made up with glass.

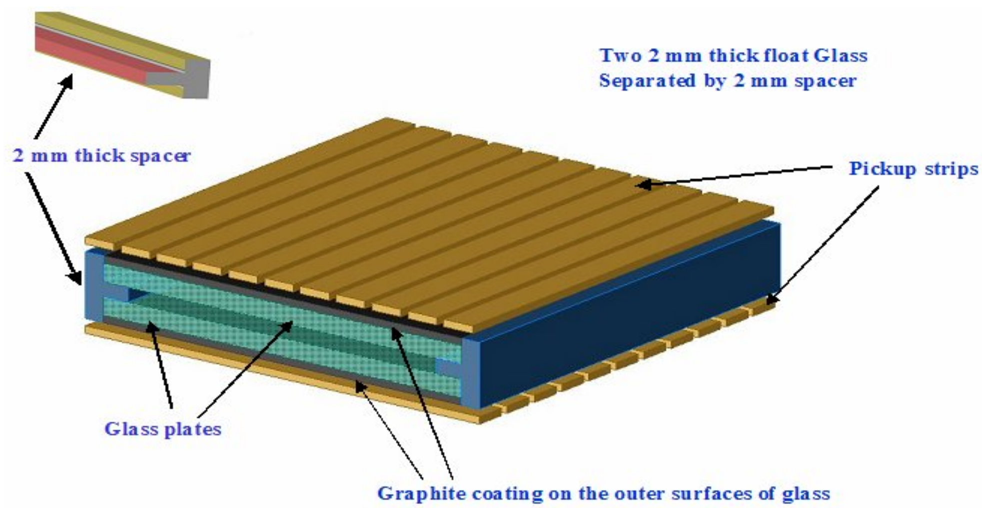
2 Basic Principle of Gaseous Ionization Detectors

Basic configuration of gaseous ionization detector consists at least one gas chamber whose two opposite faces must be made of conducting materials. In these two surfaces we apply high voltages **(~ 10 KVolt.)** is applied. The chamber is filled with gasses (about which I'll write later). When sufficiently energetic radiation penetrates the chamber it ionizes the gas molecules and as a result it produces certain numbers of "electron-ion pairs". Mean number of pairs created is proportional to the energy deposited on the chamber. With the application of the **strong electric field**, the electrons are drawn towards the anode and ions towards the cathode where they are collected. If the electric field is strong enough, the freed electrons are accelerated to enough high energies where they are also capable of ionising gas molecules in the chamber. The electrons liberated in this secondary ionization then accelerate to produce still more ionizations and so on. This results in an ionization **avalanche** or cascade. Because of the greater mobility of electrons, the avalanche has the form of a liquid drop with electrons grouped near the head and slower ions trailing behind. When such avalanches increase in number they form a streamline of continuous flow of charges from one electrode to the other. This forms a **streamer pulse**. The pulses are collected by appropriate **front-end electronics**.

3 Resistive Plate Chamber (RPC)

An RPC is a particle detector that utilizes a constant and uniform electric field produced by two parallel electrode plates which is made of a material of high bulk resistivity. Owing to the high resistivity of the electrodes, the electric charge quickly dies off in a very limited area (typically $0.1cm^2$) around the points where the discharge occurs. The discharge produces signals which are counted and analysed by appropriate read out electronics.

Here we discuss in brief the structure of a standard single layer RPC :



Resistive electrode plates made of commercial float glass with a volume resistivity of the order of 10^{12} Ohms and thickness of 3mm. they are put on top, parallel to each other within the framework.

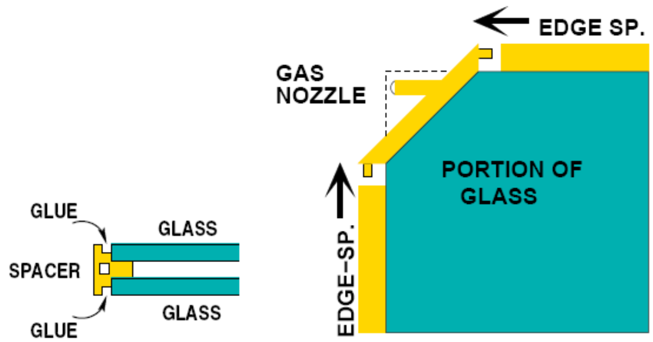


Figure 1: Left: Side view of a spacer, indicating the central gas gap and the position of the glass with respect to the spacers. Right: Top view of the corner piece of an edge spacer, with gas nozzle. The arrows indicate the manner in which the straight edges slot into corner piece. These type of spacers and nozzles are used in 1m by 1m RPCs.

The surface resistivity values of the graphite coating are average; they vary about 40% with respect to the given value not only for the different side but also from place to place on the same side. All RPCs have a gas gap of 2 mm. All the glass thickness is 2mm except for the Italian one which is 3mm. Button spacers having three holes in it and width $\sim$ 1.8 mm.

The glasses are cut by diamond cutter to the appropiate size and the four corner edges are chamfered by a jig of right dimension to make a correct 45° angle, as shown in fig.1. 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. For smaller RPCs the glasses are glued and then coated with graphite and for the bigger ones it is the other way round. The glasses used for making IB01 are already painted. Graphite coating is done on both sides of the RPCs leaving about 2cm gap from all the edges so that leakage of HV can't take place through the edge spacers.

After cutting and cleaning the glasses one glass was put on a plastic sheet and on top of the glass the button spacers were glued in a square array of side 12cm, the glue came out through the three holes of the spacers. Then the other glass plate was placed on those array of spacers. To put a uniform weight throughout the $1m^2$ area the whole set up was wrapped with the plastic sheets and the air inside the plastic sheets was sucked slowly to create partial vacuum and a pressure equivalent to 5cm of water column pressure. The set up was left for one day to be fixed with the spacers. Previously in case of making 30cm by 30cm RPCs lead blocks had been used to put the weight, but they couldn't put uniform pressure for $1m^2$ area.

The straight edge-spacers are also designed in "steps" so that the glass sits neatly within; ref Fig.1. There is a 1 mm gap where the glue can be poured (ref Fig.1). The central protrusion is 2 mm, thus supplying the required gap between glass plates. The central hole (shown in white in Fig.1) is where the wedge of the corner spacer fits. The glue was poured in the required gap and lead blocks were placed along the 4 sides to put pressure and the whole set-up was left for one day, on the next day the same procedure was follwed for the other side of the RPC. Now the RPC became ready to be tested to make sure that no gas leak occurs, especially at the glued joints. After passing the leak tests the base RPC is ready and it needs to be wired 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.

4 Gas 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 potentia**l, 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.

The filling gas is usually composed by an optimized mixture. To work in **'streamer' mode** the main component should provide a robust first ionization signal and a large avalanche multiplication for a low applied field. One typical element can be **Argon**, because of its higher specific ionization and lower cost is usually preferred, which ensures great avalanche increase with electron abundance, good situation to start **streamer production**. To work in **'avalanche' mode** 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. **Tetrafluorehtane** (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 violate 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**. In our gas mixture we have used **Iso-Butane** as the **'quenching gas'**.

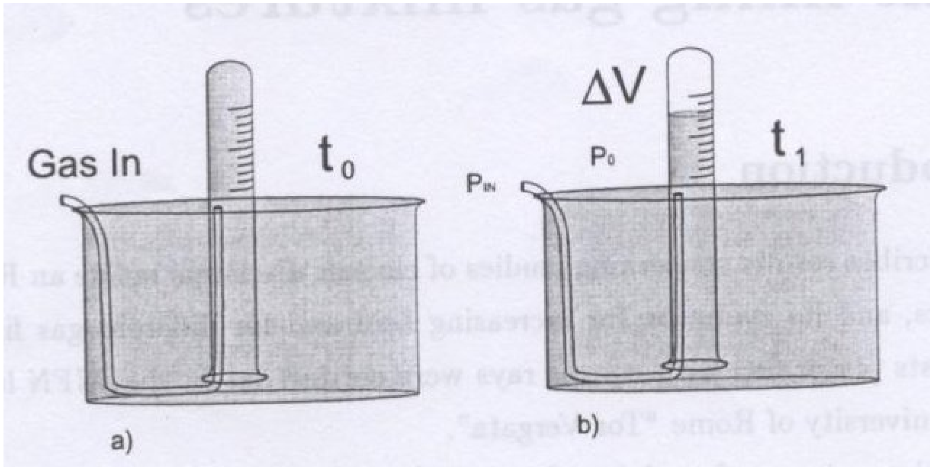
Finally we use **SF_6 (Sulfur-hexafluoride)** to control the excess number of electrons. A small quantity of **SF_6**, in a few per mill fraction of the standard gas mixture could enlarge the pure avalanche mode operating voltage range up to **1 kV streamer free plateau**.

5 Calibration of The MFC in the Gas System

The gas system must be strictly reliable in controlling relative components under studies. It is composed of several **Mass Flow Meters** calibrated for specific gases and one controller station. The gas volume of the RPC gap under test (~ 10 ml) and the chosen number of volume refill per minute fix the total flux flowing through the system, typically **30 SCCM.** During this project I have calibrated all the four gases required for the gas mixture.

In these tests the secondary or tertiary gaseous compounds in the mixture can vary from tenths of percents (e.g. **Iso-Butane**) to a few per mill fraction (e.g. **SF_6**) of total gas flux, i.e. **~ 30 SCCM.** These small fluxes and variety of utilized gases fix sometimes the working condition of **Mass Flow Meters**. Linearity and stability of sharp drops of differential pressure between in and out are guaranteed for these instruments.

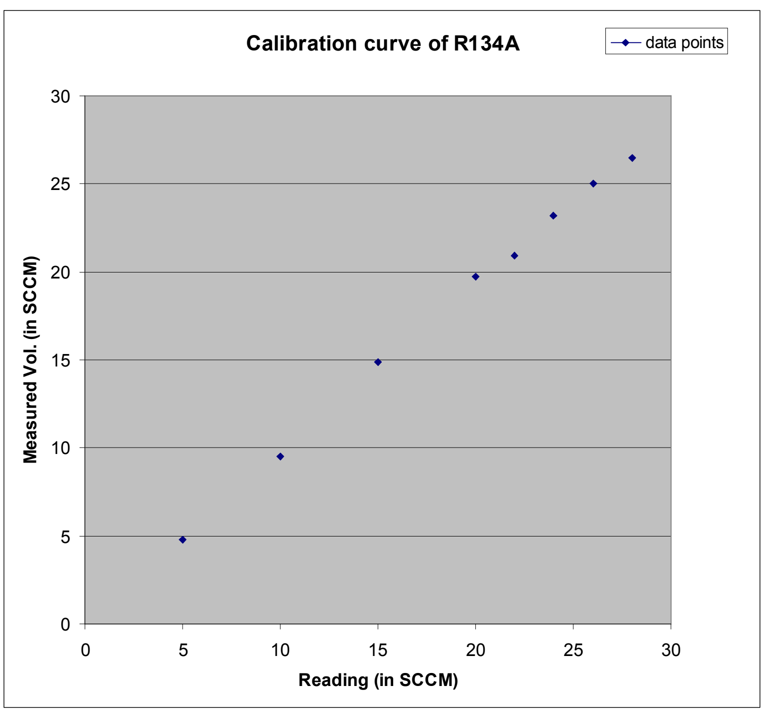
All the mass flow meters used during these tests were recalibrated by a simple but effective and reproducible measurement of the real flux with respect to the set value, as percent of full range.

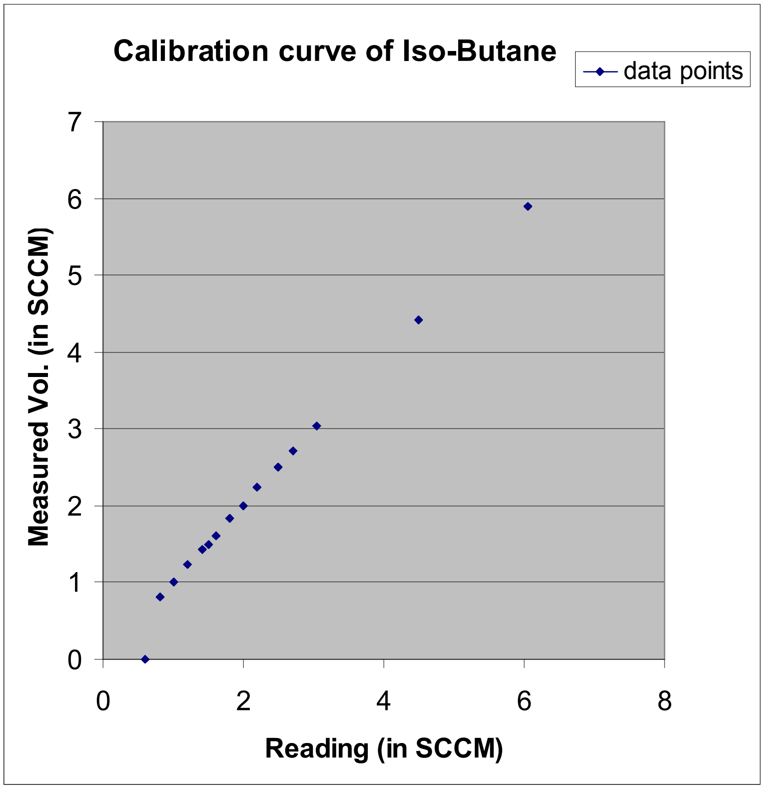


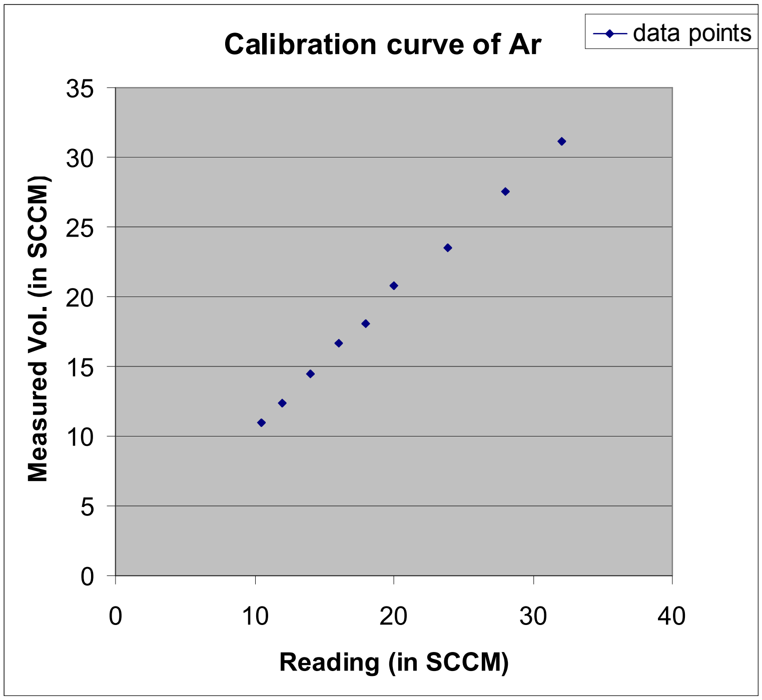
The gas is fluxed into the graduated tube filled with water and turned upside down in a vessel full of water as well. The gas starts to bubble at the time $\mathbf{t_0}$ at the water-air separation surface. By a stop watch we measure the time $\mathbf{t_i}$ and during which the volume V_i it has occupied by measuring the decrease in the water level in the tube. Therefore, the flux is measured as

$$\textbf{Flux} = \textbf{(Change in Volume)}/(t_i - t_0)$$

Here the plots for the calibration of all the four gas system is shown :




Calibration curve of Iso-Butane
data points
Measured Vol. (in SCCM)
Reading (in SCCM)
0
1
2
3
4
5
6
7
0
2
4
6
8


Calibration curve of Ar
data points
Measured Vol. (in SCCM)
Reading (in SCCM)
0
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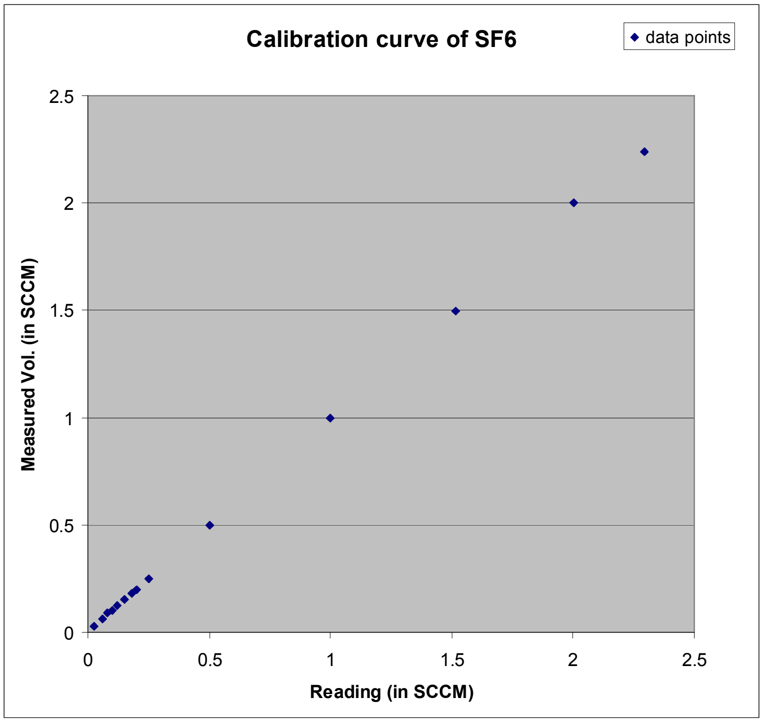


6 Calculating The Gas Flow Rates

As per the reading displayed in the gas system

- **Freon → 28.5 SCCM**
- **Iso-butane → 1.08 SCCM**
- **SF_6 → 0.02 SCCM**
- **Argon → 0.00 (NIL)**

After correcting the value from the **calibration curve**

- **Freon → 25.77 SCCM**
- **Iso-butane → 1.206 SCCM**
- **SF_6 → 0.054 SCCM**
- **Argon → 0.00 (NIL)**

Therefore, total amount of gas flow rate (**Freon + Iso-butane** + **SF_6**)
= (25.77 + 1.206 + 0.054) SCCM
= 27.03 SCCM
= **27.03 c.c./min**.

Hence, each RPC chamber gets an average of (27.03 ÷ 9) SCCM = 3.0033 SCCM = **3.0033 c.c./min**.

Now, the volume of 1-RPC gas-chamber is 1m × 1m × 2mm = 100 × 100 × 0.2 c.c.
= **2000 c.c.**

Therefore, the time required to fill the gas chamber by these desired gas-mixture is = (2000 ÷ 3.0033) min. = 665.9 min. = 666 min. (approx.) = **11.1 hr**.

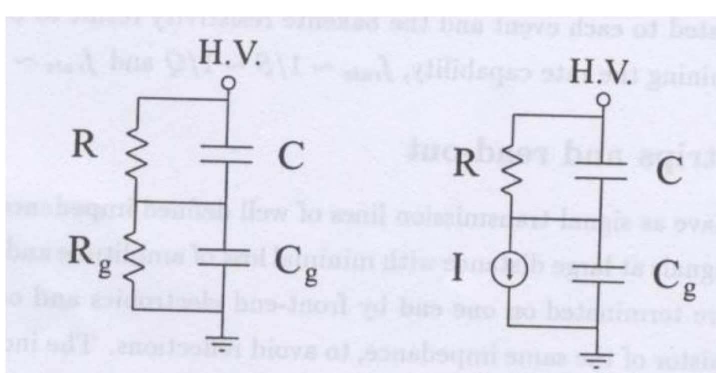
Consequently, in a single day (24 hr.) 24/11.1 = 2.16 "effective" volume of gas will be flown through the RPC chambers.

7 Signal Induction and Readout

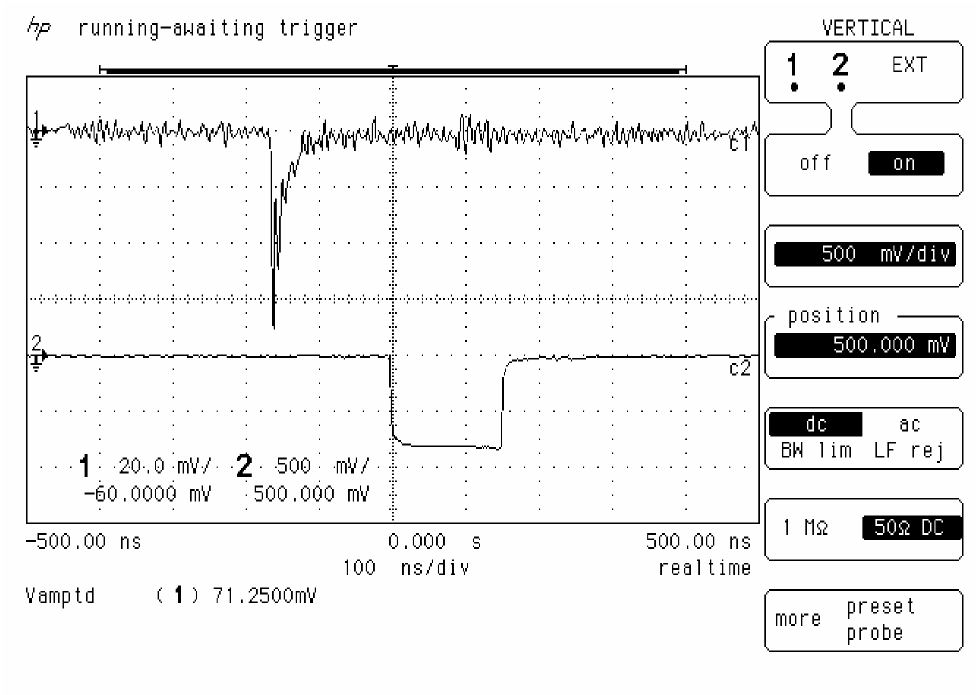
The charge signal drifting in the gas gap generates a current induced on the electrically isolated metallic pick up strips. The electron and ion currents are absorbed through resistive electrodes by high power supply.
The main advantage for their high resistivity, the drop in the applied tension during the discharge in the gas is specially localized. The dead time for the detector is due to the time necessary to restore the voltage tension at the gas gap, but will concern only on a small area of the detector surface.

The discharged area recharges slowly through the high-resistivity glass plates.

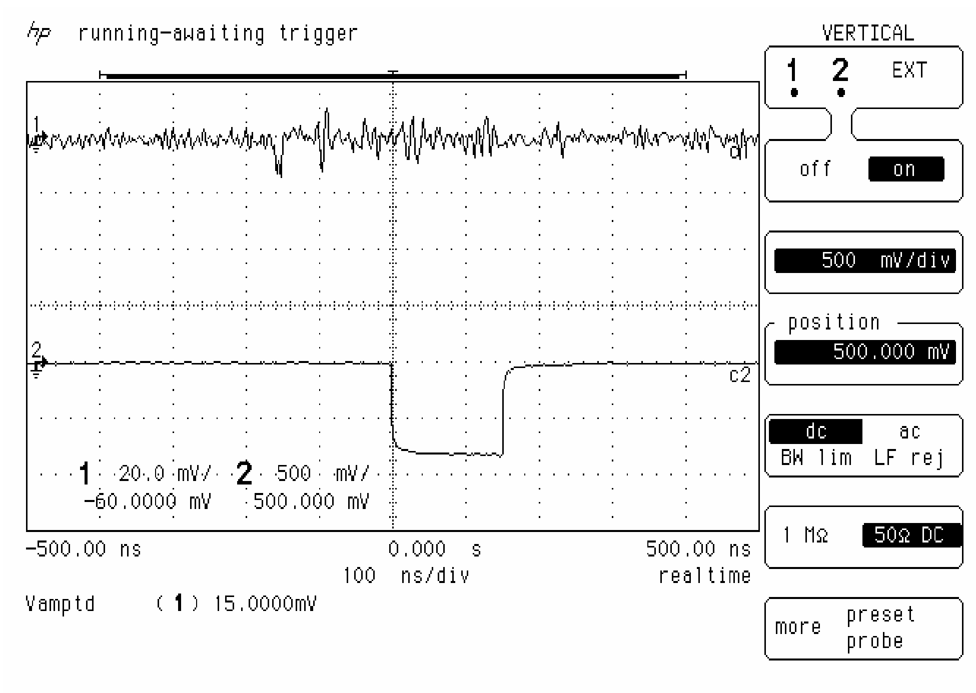
An easy circuital working model (see the figure below) can give an idea of the characteristic process involved :



Here I am presenting some of the typical signal output as seen by **CRO**



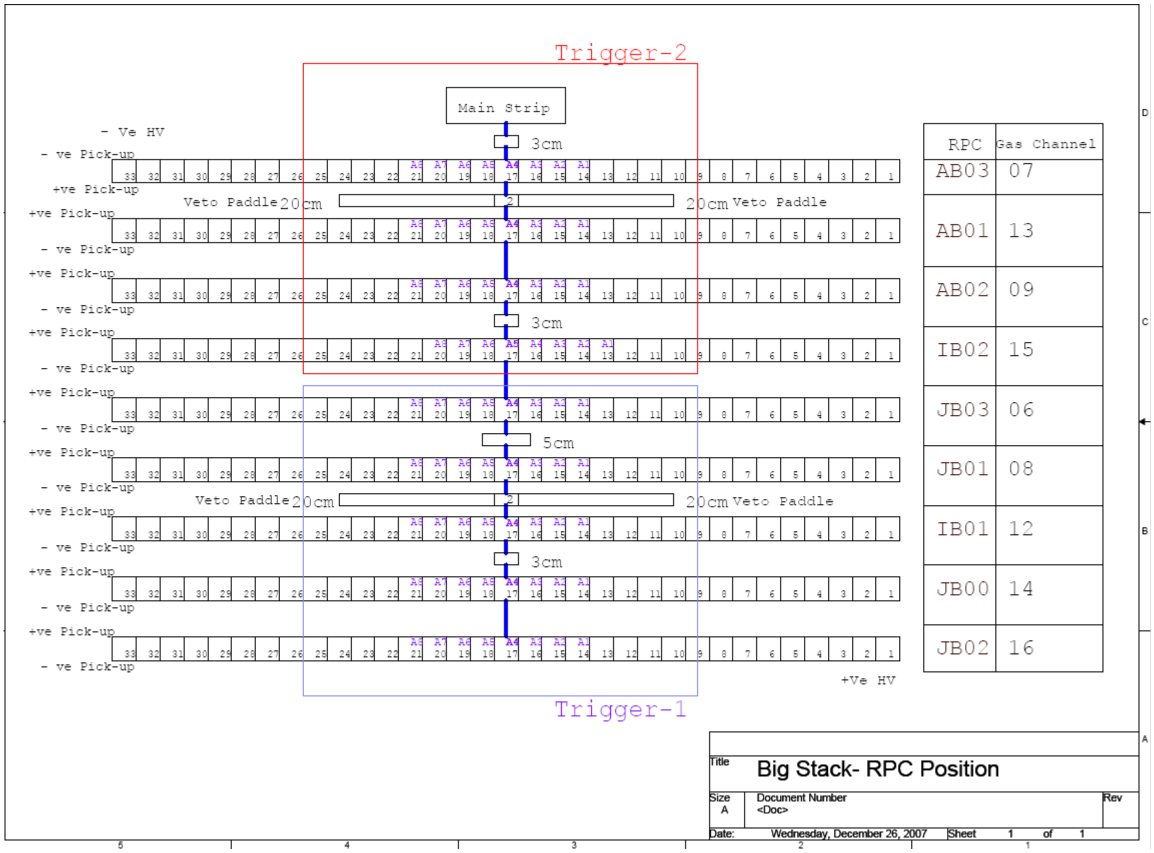
A typical signal in the avalanche mode



In this case the RPC missed to detect the muon

8 RPC Efficiency

Here is the schematic diagram of the big-stack RPC system :

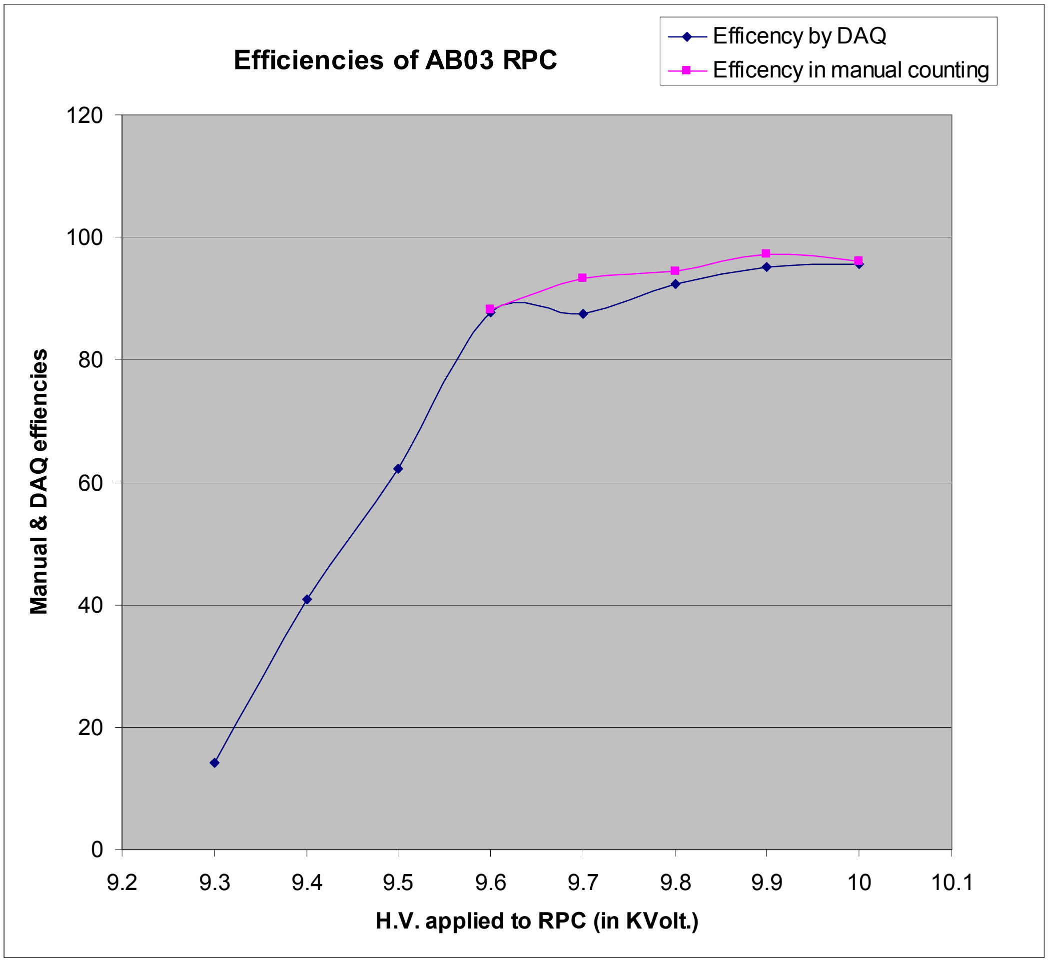


To measure the efficiency of the RPC we set up our experiment in such a way as to ensure that the trigger pulse generated is **solely due to atmospheric muons**. To do that we have to exclude all other cosmic rays whish form a background noise. We set up a coincidence circuit for our present purpose. For these we use five scintillators as five paddles. Thus we make a cosmic ray telescope with these scintillators. We named them **P1-P5**. We put our RPC as shown in the diagram above. We keep **three 3 cm. paddles (P1-P3)** along the main strip and **two 20 cm wide Veto paddles (P4-P5)** across the middle paddle **P2**. the two big paddle P4 and P5 can move horizontally in lateral direction. These two govern the opening of the **telescope window** and hence are known as **Veto**. For this set up the probability of the **chance coincidence is P!.P2.P3.P4*.P5*** . This ensures that **muon trigger** is generated when we have three of the paddles (P1, P2, P3) are in coincidence and (P3, P4) in anti-coincidence.

Now, Efficiency of RPC = (3-fold × Veto × RPC)/ (3-fold × Veto)

i.e., (# of pulses in the RPC output above some threshold value 20mV.)/(# of muon trigger).

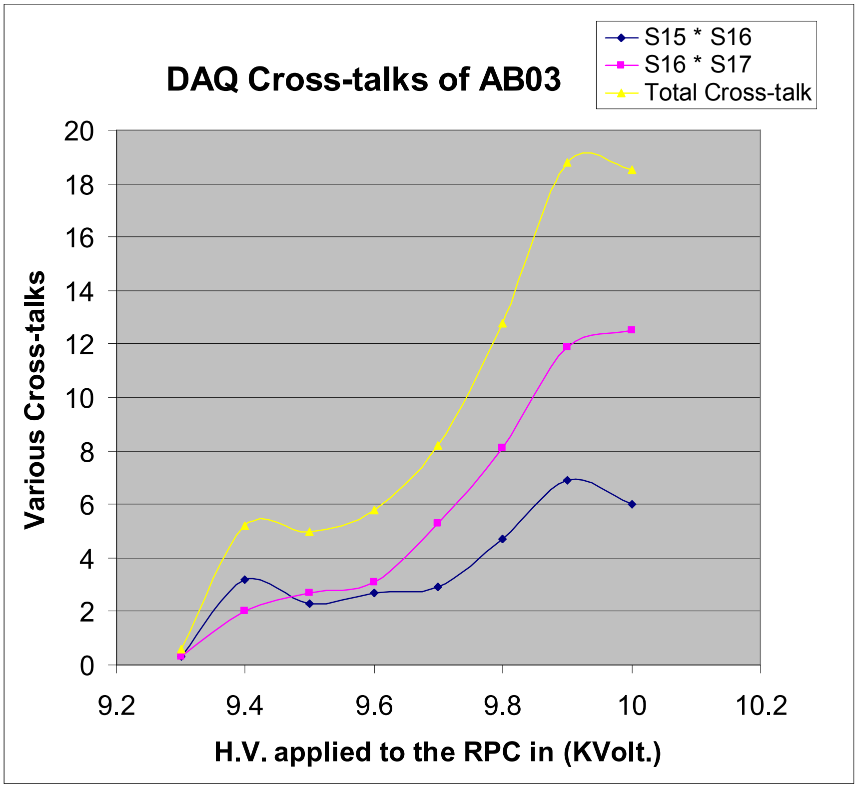
I present here the shapes of few sample pulses, triggered by cosmic rays, those I have observed in the oscilloscope while doing the manual counting of the **RPC "efficiencies"** and **"Cross-talks"**.



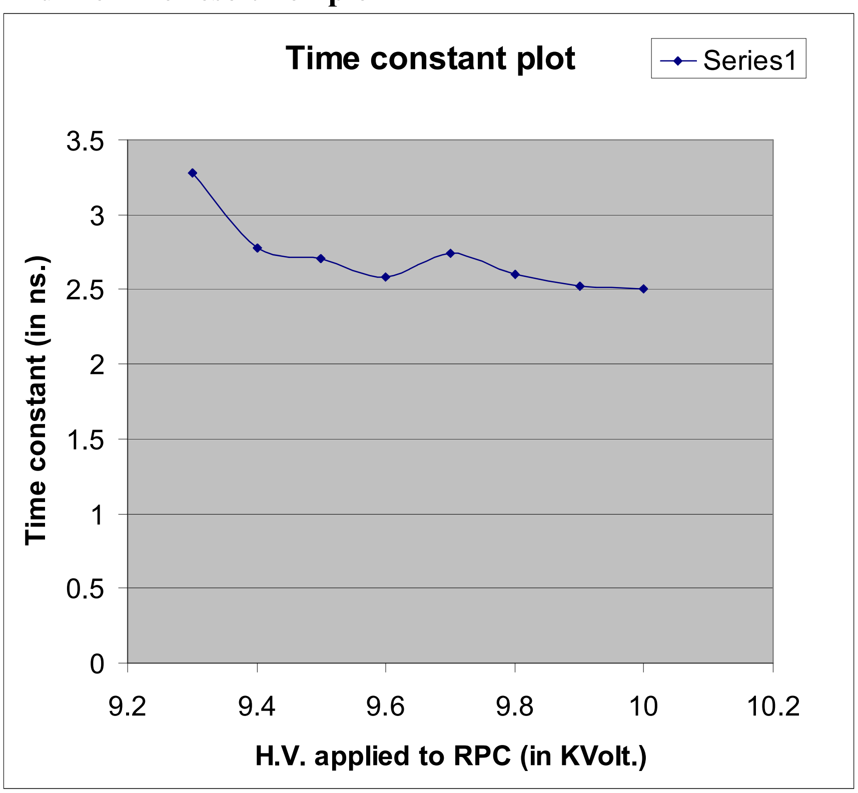
"Plateauing" of the RPC

And the Cross-talks plots by DAQ:

Here the Cross-talk is defined by
(3-fold × Veto × adjacent RPC)/ (3-fold × Veto)



And the time resolution plot



9 Acknowledgement

I would like to take the opportunity to acknowledge the invaluable and indispensable guidance of Prof. N. K. Mondal, without which this project would not have materialized. I would like to thank S.D. Kalmani and A. Joshi for guiding me through the actual hardware for building RPCs. I appreciate the help extended to me by M. R. Bhuyan and B. Satyanarayana. I also thank to Ravindra R. Shinde, L. V. Reddy, Shekhar Lahamge and P. Verma for their their kind co-operation.

10 References

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