Development and study of Glass Resistive Plate Chambers

(Ph.D Credit Seminar Report)

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Abstract

Glass Resistive Plate Chambers (glass RPCs, or *chambers*) are rugged and low-cost gas detectors which are being used or planned for 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. Glass RPCs have been chosen as active elements for a massive neutrino detector, which is proposed to be built in India by the Indian Neutrino Observatory (INO) collaboration. A dedicated R&D programme is currently under way to develop and characterise these chambers, ultimately leading to their large scale production required for the INO detector.

We will begin this report with a brief introduction, operating principles of glass RPCs and overview of challenging field of developing these detectors. We will then describe in detail, our efforts in development of various types of prototype chambers, gas mixing and flow control system, Cosmic ray muon telescope, data acquisition system and finally, performance of the developed chambers. We will conclude by mentioning about the RPC aging problem that is still needed to be solved and our proposed future work plan.

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1 Introduction

Neutrinos are one of the fundamental particles, which make up the universe. They are also one of the least understood. Neutrinos are electrically neutral and were initially thought to be mass less. There are three types or flavours of neutrinos known. Recent evidences seem to indicate that neutrinos not only have mass, but also experience mixing among these flavors. This leads to the phenomena of neutrino oscillations that can explain the discrepancy between theory and observations about its flux. Neutrino mass can also be indirectly estimated by detecting its eventual oscillations. The existence of non-zero mass for neutrino has profound implications on fields as varied as nuclear physics, particle physics, astrophysics and cosmology.

Historically, the Indian initiative in neutrino physics experiments goes back to several decades. In fact, the first atmospheric neutrino event was recorded at the Kolar Gold Fields (KGF) underground laboratory nearly forty years ago. The KGF experiments had spanned several decades involving a systematic study of neutrinos and its related exotic processes at great depths underground. To exploit this valuable expertise for the emerging new area of observational neutrino physics, an idea to construct a neutrino detector at an India-based Neutrino Observatory (INO) was mooted a few years ago[1]. This proposal has subsequently been formalised with a Memorandum of Understanding signed by several Indian research institutes and universities.

The proposed neutrino detector will have a modular structure of lateral size 32m $\times$ 15m and height 11.9m with iron plates used as absorber and glass RPCs as active detector elements. It will comprise of 140 layers of horizontally arranged iron plates of 6cm thickness, interleaved with 2.5cm gap between successive layers of iron plates to house the glass RPCs. The iron plates will be magnetised at a field of $1.2 - 1.3$Tesla. The total mass of this detector will be about 35KTon.

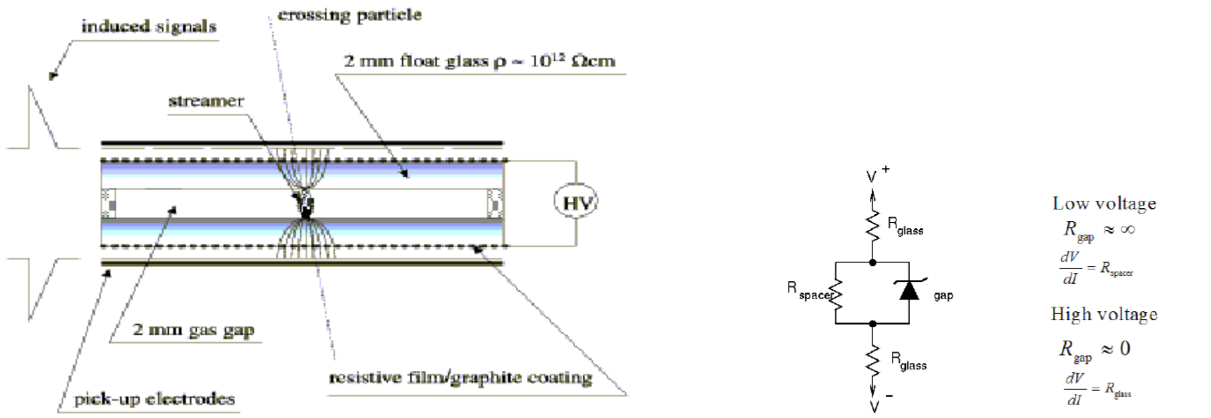
It is proposed that we use large area glass RPCs of surface area 3m $\times$ 2m for this detector. The total number of detector elements that we therefore need to build is about 11,200. Assuming a two-dimensional signal pickup pitch of 3cm on either surface of the glass RPC, we need to instrument about 220,000 signal channels. While, we need to record Boolean status information (i.e. one bit per channel) for all these channels, the signal channels can however be combined for recording signal arrival time information. For instance, we will require about 3000 timing channels, if we combine all the signal pickup strips from one side of rows or columns of the RPCs.

The main characteristic of such a detector would be a clean identification of muon tracks, which are associated with the neutrino interactions that take place inside the detector with good spatial and time resolutions. In addition, the presence of the magnetic field will distinguish positively and negatively charged particles. These properties meet very well the conditions required to unambiguously identify muon neutrino oscillations[2].

2 Principle of operation of a glass RPC

A rich variety of glass RPC configurations, tunable to a variety of requirements exist today. However, we will take a classically simple design as an example to discuss basic operation of a 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} Ω-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 ionising 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, which can be used to record the location and time of ionisation(Figure 1a). The discharge is quenched when all of the locally available charge is consumed. The discharged area recharges slowly through the high-resistivity glass plates. Thus, each discharge locally deadens the glass RPC, the recovery time which is about 2 secs. Typical signal amplitude is about $100 - 200$mV across a 50Ω load and its rise time is less than a nano Second.



(a) Schematic representation[3]　　(b) Equivalent electrical circuit[4]

Figure 1: Basic principle of operation of a glass RPC

Glass RPCs may be operated in avalanche or in streamer modes. Avalanche mode corresponds to the generation in the gas gap of a Townsend avalanche, following the release of primary charge by the incoming ionising radiation. In streamer mode, the avalanche is followed by a *streamer* discharge.

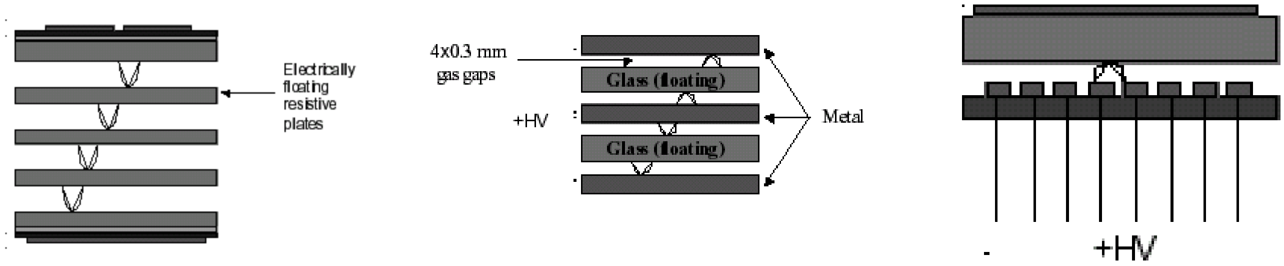
Glass RPCs have a distinctive and readily understandable voltage versus current relationship shown in Figure 1b. At lower applied voltages, the chamber's gas gap offers very high resistance, hence its V$-$I characteristic in this region is mainly characterised by the insulative spacers placed between the electrodes. When the chamber starts operating in the active region, resistivity of the glass electrodes alone determines its characteristics.

3 Overview of the field

Fonte[5] (and references there in) gives an excellent review of the history, technological innovations and current status of this field.

RPCs were introduced in 1981[6]. The field has enjoyed very active progress in recent years in terms of introducing new operating modes as well as improving counting rate capabilities, time and position resolutions of the chambers. The original RPCs were single gap chambers[7], which were operated in streamer mode. The double gap structures were introduced[8] to improve detection efficiency along with the avalanche mode of operation, which also extends their counting rate capabilities.

This was followed by multigap RPC designs[9] (Figure 2a). The prominent feature of this design is the inclusion of resistive, electrically floating electrodes that divide the gas volume into a number of individual gas gaps, without the need of any conductive electrodes. Hybrid designs[10] which use metallic and resistive electrodes(Figure 2b) were the next to follow the suit. A 100μm gap micro RPC(Figure 2c) equipped with a solid X-ray converter and anodic strips placed at a pitch of 30μm has shown a position resolution of atleast 30μm in digital counting mode[11]. Recent innovations in detector construction and readout electronics have extended the time resolution of timing RPCs to 50pSec and rate capability to 10^5 Hz/mm^2. These new developments have opened RPC applications in diverse fields such as in medical imaging.



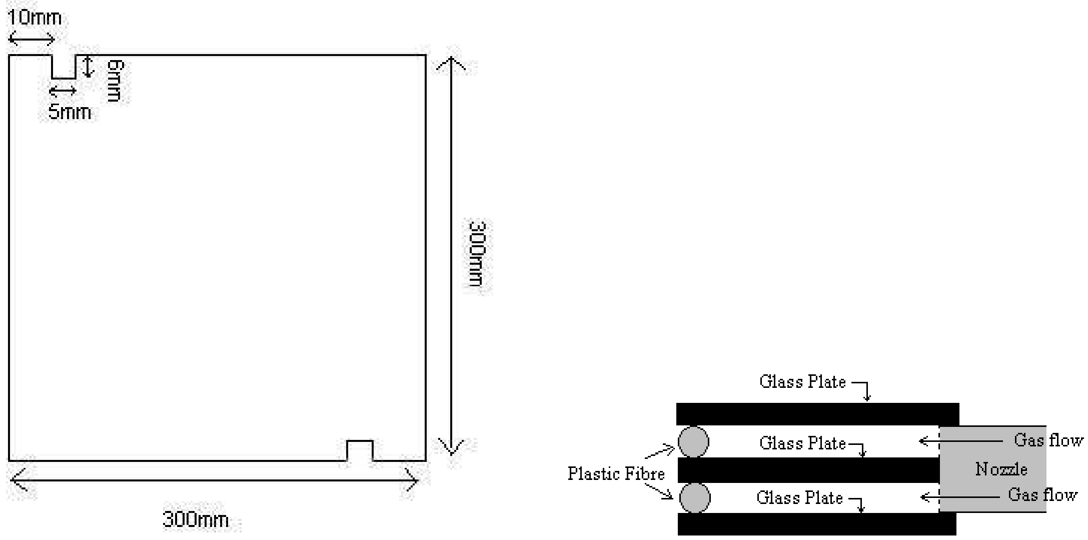
(a) Multigap RPC (b) Hybrid RPC (c) Micro RPC

Figure 2: RPCs of modern designs

Single and double gap streamer mode RPCs have so far found extensive applications in many Cosmic ray experiments like EAS-TOP, COVER-PLASTEX, ARGO and Auger. Accelerator based experiments such as BELLE, BABAR, STAR and HARP were also designed with streamer mode RPCs. All the four LHC experiments under construction - ALICE, ATLAS, CMS and LHCb are equipped with RPCs. A number of new experiments which are being proposed are also planning to use one or the other dialects of the RPCs.

4 Our prototype designs and fabrication

Though glass and bakelite are the most commonly used for electrodes, other resistive materials such as cellulose, melamine laminate with phenolic plates, PVC, ABS etc are also used. We have used 2mm thick standard float glass procured from the local market[1]. We have found that the surface quality of this glass to be remarkably good within a variation of about 10μm over its entire area. The glass sheets after passing through mechanical and dimensional tolerance tests, are cleaned off any possible oil deposits using Labolene cleaning solution.



(a) Top view (b) Side view

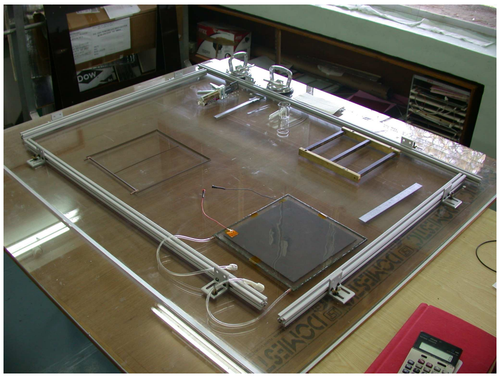
Figure 3: Construction details of a double gap RPC

The insulated spacers used for maintaining precise and electrically isolated gap between the glass electrodes as well as T-shaped frames used for supporting the electrodes and for forming an enclosed gas volume are usually made up of special PVC material, brand named NORYL. We have used the material of the design employed in the Belle experiment. The spacers between the electrodes were so arranged that the gas flow becomes uniform inside the chamber. The glass plates, spacers, frames, gas inlet and outlet nozzles are all assembled using a special 3M Stotch-Weld 2216 epoxy. This adhesive was chosen for its excellent shear and feeloff strengths as well as its non-reactive properties with most of the detector gases.

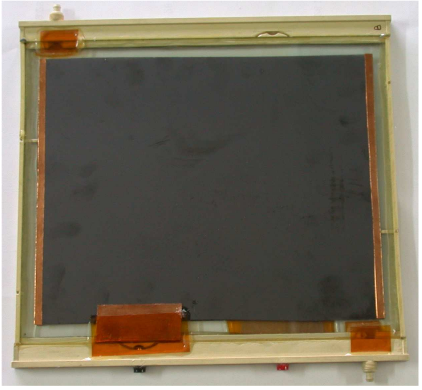
High voltage is applied across the electrodes by means of a semi-resistive coating. A variety of techniques for obtaining this coating can be found in the literature. Monolith collaboration[12] has used a silk screen printing method by which the coat could be controlled precisely. Other techniques such as metal oxide paints, anti-static paints, graphite varnishes, adhesive graphite tapes, special inks and commercial automobile paints are also used. We use the following technique. We have mixed a locally available dry colloidal graphite powder (of Grade 40019)[2]

[1] Glass vendor: M/S Asahi Float Glass (I) Ltd., Mumbai

[2] Graphite vendors: M/S Nikunj Eximp Enterprises (P) Ltd. and M/S Steel Plant Specialities, Mumbai



(a) Jigs for RPC fabrication



(b) A fully assembled glass RPC

Figure 4: Jigs developed for RPC fabrication

and industrial lacquer in about 1:8 ratio by weight along with thinner for consistency. This mixture is sprayed uniformly on the cleaned glass electrode surface using a standard paint spray gun. We have obtained a uniform graphite resistance of 100-200K$\Omega/\square$ using this technique.

The signal pick-up strips are made up of either a double-sided G-10 material or a polyisocyanurate foam board insulation with reinforced poly-aluminum foil facers on both sides[3]. While on one side of these materials, strips of required pitch are milled, the other surface is used as the ground reference for the picked up signal. While by using G-10 material, we can make thinner layers of pickup panels, the foam based sheets are preferred as their dielectric constant is close to unity. A flat cable may also be used for this purpose, which provides an additional advantage of choosing the signal pickup pitch even during operation of the experiment. Mylar sheets are used for achieving the necessary insulation between the RPC's electrode surfaces and the pickup strip panels which are placed closed to either side of the chamber during the operation.

Gas inlet and outlet ports are implemented by fabricating special nozzles which have standard nipples for holding the plastic gas tube on one side, while the other side of the nozzle is pressed flat to be able to slide in between the electrodes of chamber.

We have fabricated more than a dozen *small area* chambers of dimension 30×30 cm^2. We have also made a couple of *large area* chambers of dimension 120×90 cm^2. Design of the small and large area chambers is identical. We have designed and fabricated a double gap RPC(Figure 3), using a 1mm diameter plastic fiber to separate three glass electrodes of 2mm thickness, as well as a single gap RPC with 1mm gap instead of the usual 2mm, using the same technique.

We have developed a number of jigs and tools that help in ascertaining the quality of raw materials as well as various fabrication stages of the glass RPCs. The jigs also help us to achieve speed and consistency in the RPC production. We have also standardised all the assembly procedures of the chambers. While Figure 4a shows some of these jigs, a fully assembled small area glass RPC is shown in Figure 4b.

[3]Vendor: The Dow Chemical Company, USA

5 RPC gas mixtures and gas system

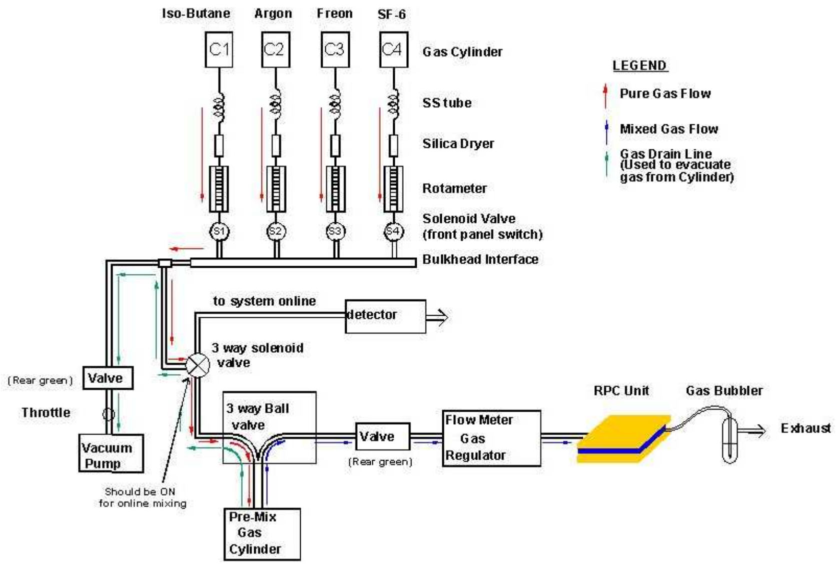


Figure 5: Schematic of gas mixing and flow control system

The choice of a suitable gas mixture for RPCs is governed by factors such as low working voltage, high gain, linearity 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. Because of its higher specific ionisation and lower cost, Argon is usually preferred. But Argon atoms formed in the avalanche, de-excite giving rise to high energy photons capable of ionising the cathode and causing further avalanches. The problem is solved by adding polyatomic gases, such as Isobutane. These molecules act as quenchers by absorbing the radiated photons and then dissipating this energy through dissociation or elastic collisions. The gain can be increased further by adding a judicious amount of electronegative gas such as Freon(R134A is its eco-friendly composition). These gases can also trap electrons from the cathode before they can reach the anode to cause an avalanche. Of late, SF_6 is being preferred for Freon, especially if the avalanche mode of operation is desired for an application. It is also found that the problem of RPC aging which is known to be due to freon and water vapour contamination, is not found if SF_6 is used. We have used Freon, Isobutane and Argon in the ratio of 62:8:30 by volume for most of our preliminary studies[4].

A gas mixing unit capable of mixing these four individual gas components and control the mixed gas flow through the detector chambers has been designed and developed with the help of a commercial vendor[5]. Schematic of this unit is shown in Figure 5. The mixing unit has provision either to flow the mixed gas directly into the detector chambers or to store in a pre-mix gas cylinder (15 litres in capacity) for a later use. We have used rota meters for gas dispensing

[4]Gas vendor: M/S Praxair India (P) Ltd., Mumbai
[5]M/S Alpha Pneumatics, Mumbai

(a) Gas system (b) Gas bubble counter

Figure 6: Gas mixing and flow control system

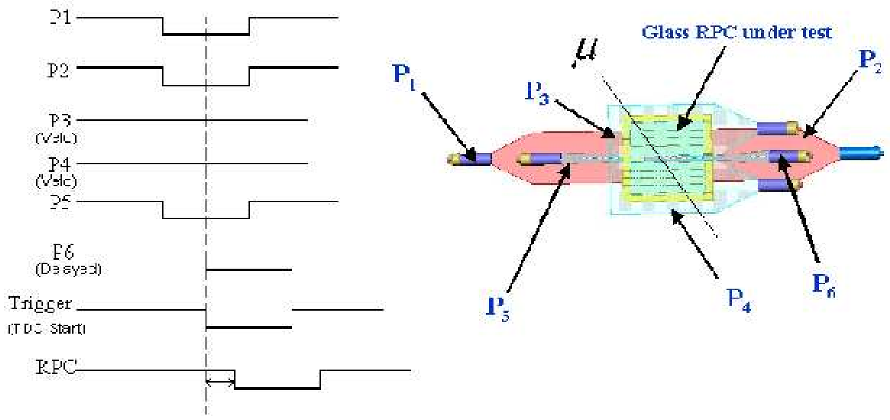
instead of more sophisticated mass flow meters in order to reduce over all cost of the unit. A microcontroller based gas bubble counter is developed and mounted on the output gas line of the chamber for monitoring the gas flow rate through the chamber along with a differential pressure gauge. During normal operation, approximately one volume (of the chamber) change of gas per day is adequate. Figure 6 shows pictures of the gas mixing unit and digital bubble counter.

While we have used steel tubing for gas supply lines, where they run long distances, standard Norton Tygon flexible plastic tubes are used for short distance connections.

6 Cosmic ray muon telescope

All the prototype chambers have been tested for their performance using a scintillator paddle based Cosmic ray muon telescope. Schematic of this telescope arrangement as well the logic and timing sequence of generation of Cosmic ray muon trigger is shown in Figure 7.

The telescope consists of four (P_1, P_2, P_5 and P_6) Cosmic ray muon trigger and two (P_3 and P_4) veto paddles. Areas of these scintillator paddles are 60×20, 60×20, 30×3, 30×2, 40×20 and 40×20 cm^2 respectively. A paddle is made up of a scintillator tile of 1cm in thickness, which is optically coupled to a Photo Multiplier Tube (PMT) for converting the scintillation light into an electrical signal. When the PMT is operated with a calibrated high voltage, the paddle gives out the signal to indicate passage of a Cosmic ray muon or other charged particle through its scintillator tile volume. The geometry of the telescope using these paddles has been setup such that we define a window of about 14cm × 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(P_5 and P_6) paddles are used to define the telescope geometry precisely. Veto paddles are used to



(a) (b)

Figure 7: Schematic of Cosmic muon telescope(b) and its signal timing(a)

prevent generation of triggers when a muon passes through the rest of the area of RPC which is not under study. We record the data from RPC pickup strips whenever a Cosmic ray muon particle has passed through the telescope window. This is indicated by a trigger signal, which is generated according to the following logic equation: $P_1 \cdot P_2 \cdot \bar{P}_3 \cdot \bar{P}_4 \cdot P_5 \cdot P_6$.

Figure 8: Cosmic ray muon telescope setup

A suitable telescope support structure has been designed and built employing light-weight aluminum extruded channels[6]. This allows us to quickly and accurately rearrange the telescope to meet day to day requirements based on the type of study that we want to perform. Provision has also been made to align the paddles and the RPC under test using a laser pointer for a better geometry alignment. This test setup is shown in the Figure 8.

Stability of the Cosmic ray muon telescope is vital for reliability and accuracy of the measure-

[6]Vendor: 80/20 Inc., USA

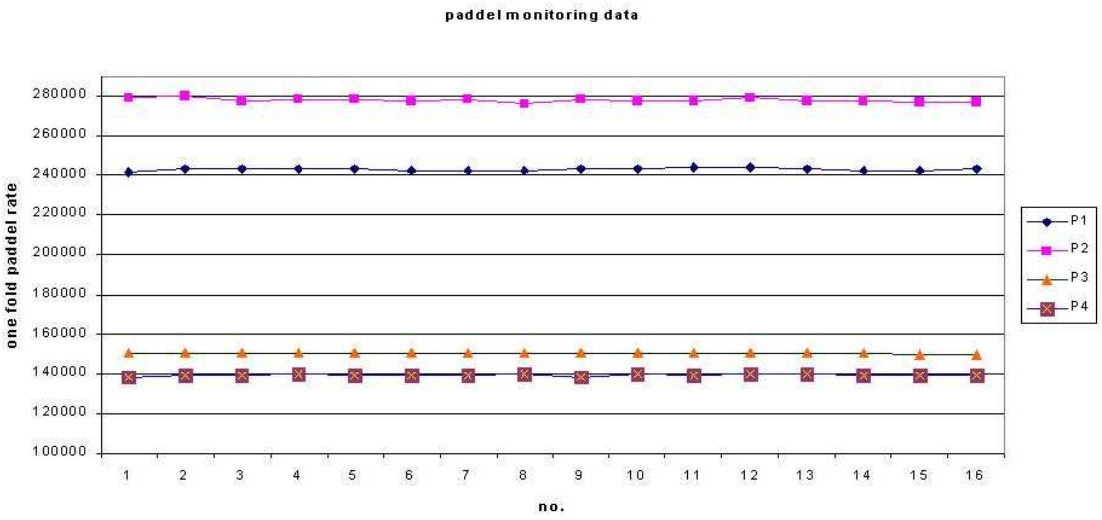


Figure 9: History of Cosmic ray muon telescope rates

ments that we make on the RPC performance. One of the easiest ways to ascertain this is by monitoring the individual counting rates of the paddles as well as various coincidence logic signal rates of the telescope. This is achieved by a dedicated data acquisition system operated on continuous basis. Shown in Figure 9 is a history plot of individual counting rates for four of the telescope paddles monitored over long period of time. The scintillator paddle based Cosmic ray muon telescope was found to exhibit excellent stability.

7 Data acquisition system

A data acquisition system for RPC testing has been designed and developed using NIM and CAMAC electronics which is available in the laboratory. A certain level of redundancy was built into the data acquisition system, in order to monitor the stability of the Cosmic ray muon telescope as well as for acquisition of various test parameters from the RPC under test in parallel. The telescope monitor system could also be used as a backup for the RPC test system.

The telescope scintillator paddle signals are converted to NIM level logic signals by feeding them into discriminator modules operating with a threshold of -30mV and producing a logic pulse of 50nSec in width. The Cosmic ray muon signal is formed by the logic shown in Figure 10, using NIM logic circuits. This consists of 4-input AND of P_1, P_2, P_5 and P_6 paddles and 2-input OR of the veto paddles P_3 and P_4 in the first stage. Outputs from this first stage are AND'ed again to generate the final trigger. Paddle signal into the logic circuit from P_6 is deliberately delayed with respect to others, so as to eliminate possible accumulation of jitter of individual paddle signals on the final trigger. Using this trick, we can make sure that the

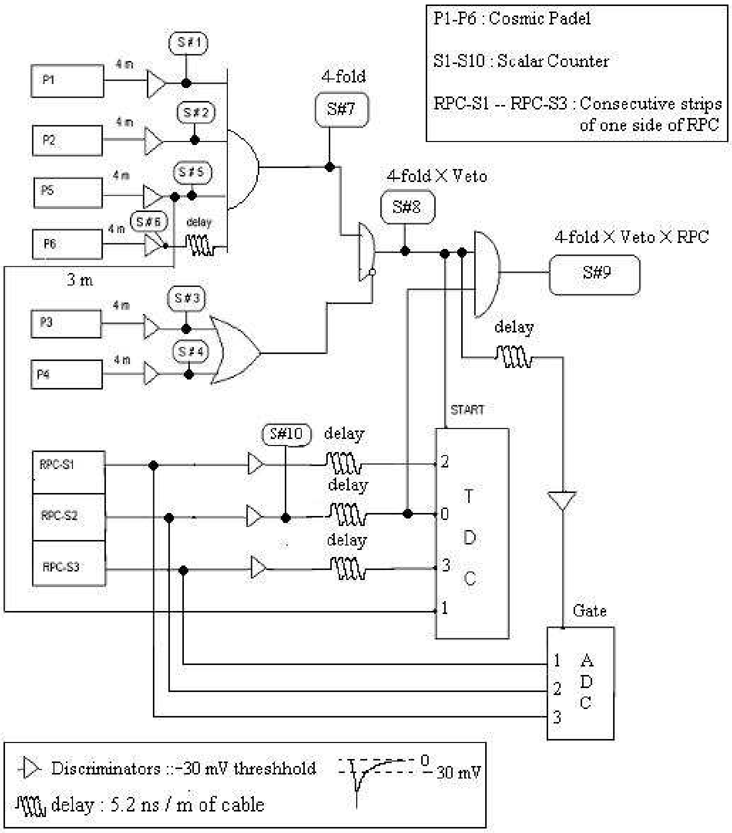
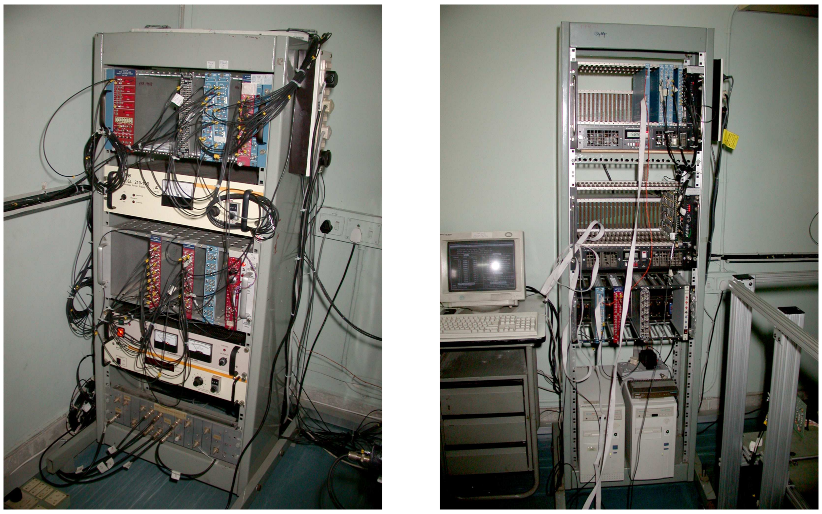


Figure 10: Schematic of the data acquisition system

timing resolution of telescope is limited by just one of the paddles (i.e the one that completes the telescope trigger criteria).

The RPC pickup strips act as transmission lines of characteristic impedance of about 110Ω. We match this to the standard 50Ω coaxial cable impedances by placing a suitable impedance matching circuits on the signal lines. Analog signals from the RPC strips are directly fed in as inputs to a CAMAC ADC module. These signals in parallel are also fed into discriminators for logic conversion. The NIM logic outputs of the RPC strips are again fed in as inputs to a CAMAC TDC module. Efficiency of a RPC strip channel is determined by the ratio of its coincidence signals with the trigger signals and the trigger signals counted during the same time. The Cosmic ray muon trigger signal is also used as common START for the TDC module as well as a shaped and suitably timed copy of the same is also used as GATE signal for the ADC module. All the individual paddle signals, RPC signals as well as other coincidence signals are counted using scaler module channels.

The entire data acquisition system electronics is housed in a NIM and a CAMAC rack as shown in Figure 11. The telescope monitor and RPC data acquisition CAMAC crates are individually controlled by dedicated PC hosts, in which the on-line data acquisition system software run.



(a) NIM electronics (b) CAMAC system

Figure 11: Data acquisition system

While the telescope monitor system collects, displays and stores all scaler counter' data at equal chosen time intervals continuously, the RPC system waits for the Cosmic ray muon trigger, to initiate data data acquisition for that event. On trigger, the timing(TDC), charge(ADC) and rates(scalers) data are acquired, displayed and stored.

The data collected by the online systems is analysed using standard physics analysis software packages such as PAW and ROOT. Apart from this, various slow monitor parameters such as ambient temperature, relative humidity, gas flow into the RPC, applied high voltage, chamber current etc are also recorded so that we can easily correlate various results or problems with observations.

8 Preliminary results

In this section, we will present some of the preliminary results obtained from various chambers that we have built and operated. We have started our studies by studying some of the basic operating characteristics of the chambers, such as RPC pulse profiles, voltage−current relationship, individual counting (or noise) rates of the RPC and so on.

Figure 12 shows oscilloscope trace of a RPC signal (Channel 2) captured on a Cosmic ray muon trigger (Channel 1). The shape is typical for a pulse produced by a gaseous chamber. We operate the RPCs in streamer mode. While the regular pulse is due to the streamer produced inside the chamber, we also notice a tiny pulse preceding the streamer pulse. This is the avalanche pulse, produced always with an excellent timing (with low jitter). However, the price that we pay is that its pulse height is very small compared to the streamer pulse and hence needs external electronic amplification, if we want to build electronics based on this signal. We plan to design electronics for using the streamer pulse.

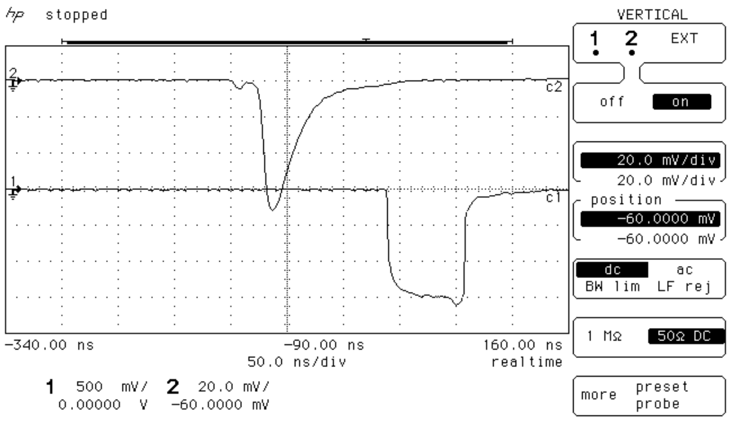
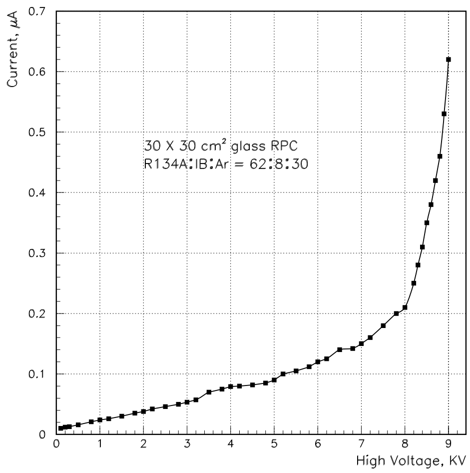
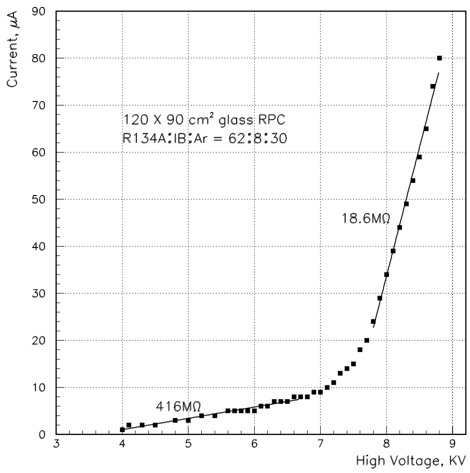


Figure 12: Oscilloscope trace of a typical RPC pulse



(a) Small area RPC

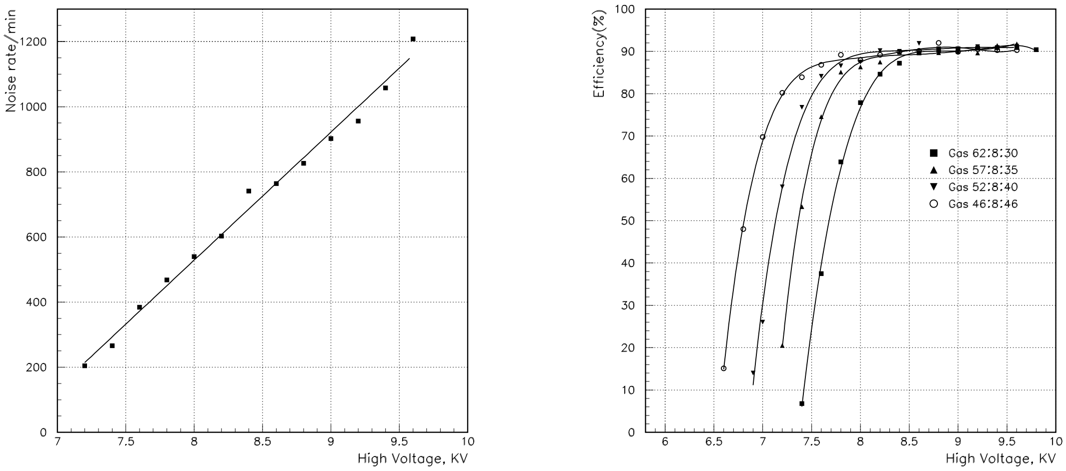


(b) Large area RPC

Figure 13: V−I characteristics of glass RPCs

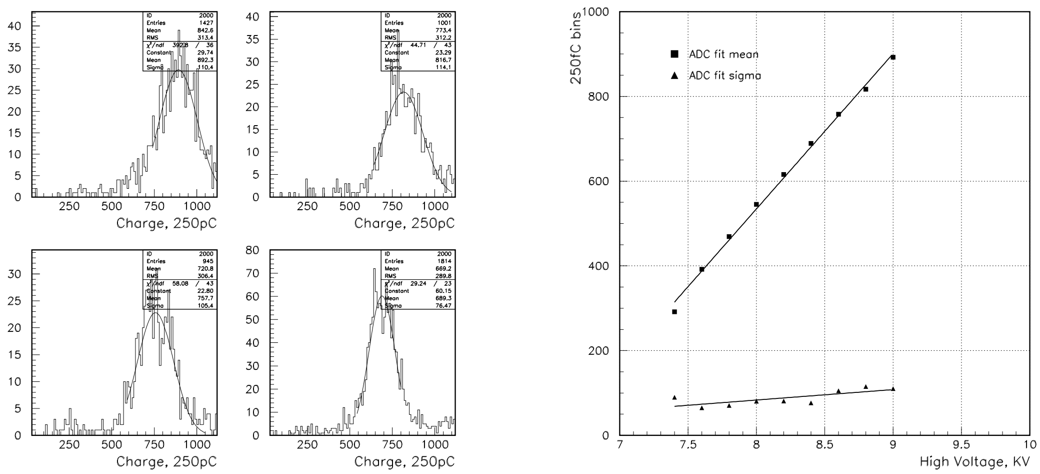
The V−I characteristics of a small(a) and large(b) area chamber are shown in Figure 13. These plots essentially reproduce the voltage−current relationship described by the RPC equivalent circuit shown in Figure 1b. Typical *dark current* is about 1μA per m^2 of the surface area of the RPC.

Noise rate of a RPC is the individual counting rate of its signals above an operating threshold. These signals are produced by the Cosmic ray charged particles of multiple energies as well as due to the dark current of the chamber. This rate per unit cross-sectional area of a particular RPC should be consistent when integrated for a reasonably long period. The noise rate serves as a good measure to monitor long term stability of the chamber as well as its dark current. For instance, if the dark current of a RPC increases drastically, it will be indicated by a sharp



(a) Noise rate (b) Efficiency plateaus

Figure 14: Noise rates and efficiencies of a small area RPC

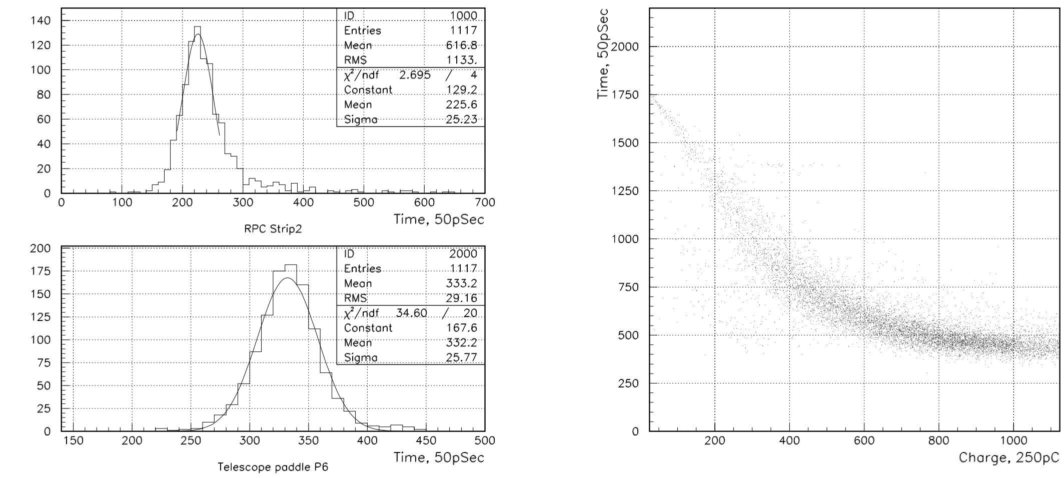


(a) Charge distributions (b) Charge linearity

Figure 15: Charge performance of a small glass RPC

increase in the noise rate. This will result in reduction of actual voltage potential across the electrodes and hence the chamber's gain as well as its efficiency. Figure 14a shows a fairly linear dependence of the noise rate of the RPC on the applied high voltage.

Efficiency of a particle detector element is its ability to respond to external radiation by producing a fast and well-discriminated signal. RPC with a higher efficiency helps in detecting the track and directionality of a particle passing through the detector more accurately. Efficiency of the glass RPC as determined in our test system is defined as the ratio of number of Cosmic ray muon triggers recorded in the RPC to the actual number of muon trigger signals generated

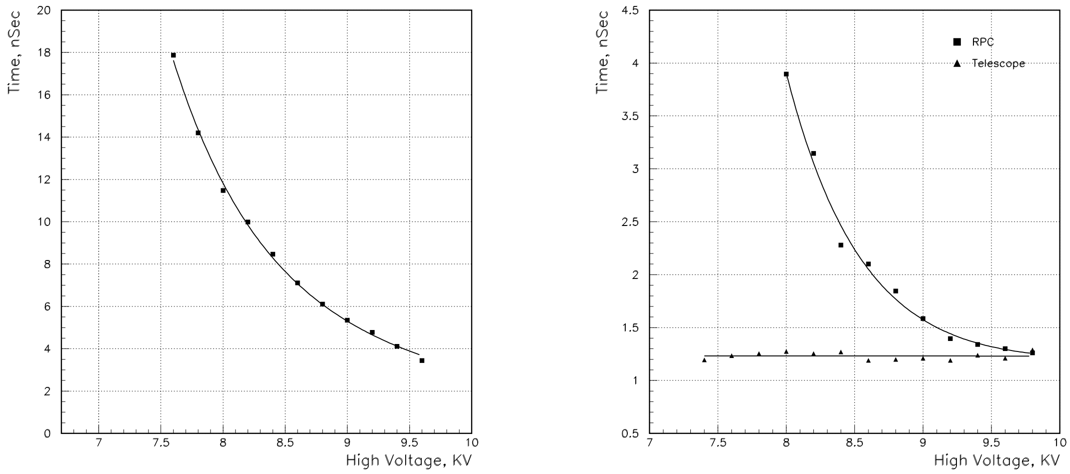


(a) Time distributions

(b) Charge−Time linearity

Figure 16: Charge-Time linearity of a small glass RPC

by the telescope.

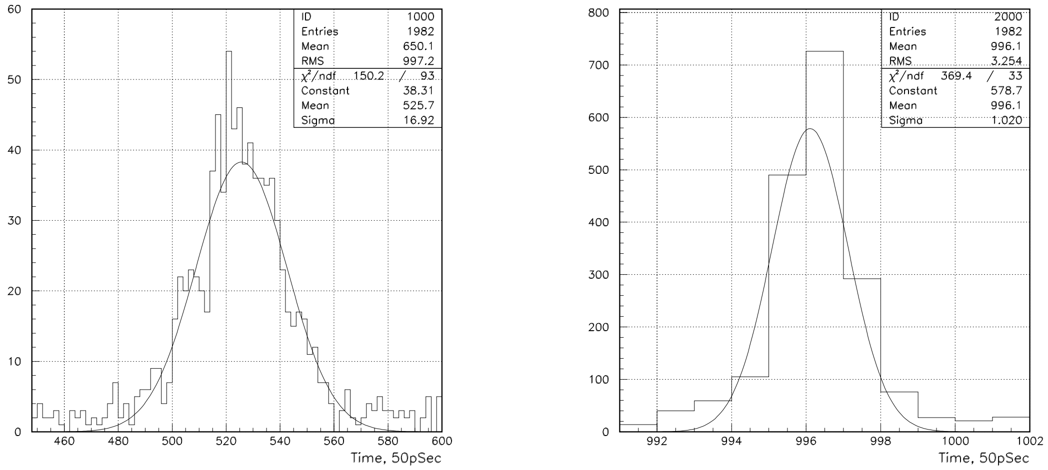


(a) Time response

(b) Time resolution

Figure 17: Timing performance of a small glass RPC

Shown in Figure 14b is a plot of these efficiencies recorded for a RPC as a function of high voltage applied between the glass electrodes and for different gas mixtures. We have obtained plateau efficiencies of over 90% for all the gas mixtures. It may be noted that as the Freon concentration is lowered, we obtain higher efficiencies even at lower electrode voltages due to higher containment of the streamer. In these studies, Argon concentration is increased in order to makeup for the decrease in Freon concentration, thus leaving Isobutane concentration unchanged.



(a) RPC under test

(b) Reference RPC

Figure 18: Timing resolution using two RPCs

While Figure 15a shows a typical pulse height (charge) distributions of a small RPC operated at various high voltages, in Figure 15b we show mean pulse height or gain of a RPC as function of its operating high voltage. The plot indicates a linear response while the standard deviation of the pulse height distribution is fairly constant. We can conclude from this behaviour that the RPC is operating with a good energy resolution.

Typical RPC timing distribution as measured with respect to Cosmic ray muon telescope trigger signal is shown in Figure 16a. While the lower plot in this figure is of one of telescope scintillator paddles, the upper plot is of the RPC. Figure 16b is a scatter plot of pulse height versus timing information of the same signal. It is expected that a signal of larger pulse height should have better(faster) rise time and hence better timing information, and vice verse. This is correlation is well demonstrated by this plot.

In Figure 17a is timing response plot of a typical RPC as a function of its operating voltage. Gain of the chamber increases with the applied voltage and for the same amount of primary ionisation, the mean rise time improves exponentially. This is called timing response of the detector. The timing resolution of an RPC is its ability to resolve time of passing of a charged particle through its gas volume accurately. This capability of the RPC is crucial for recording directionality of incoming particle track unambiguously. Shown in Figure 17b is timing resolution plot of a typical RPC. As can be seen from the plot, the timing resolution improves exponentially with increase of operating high voltage and reaches telescope timing resolution(about 1.2nSec) on the plateau. Shown in the plot with a straight-line fit is the timing resolution of the Cosmic ray muon telescope, which is the reference for the timing measurement. Using signal from another RPC for reference timing, we have obtained sub-nano second resolutions for our prototype chambers(Figure 18).

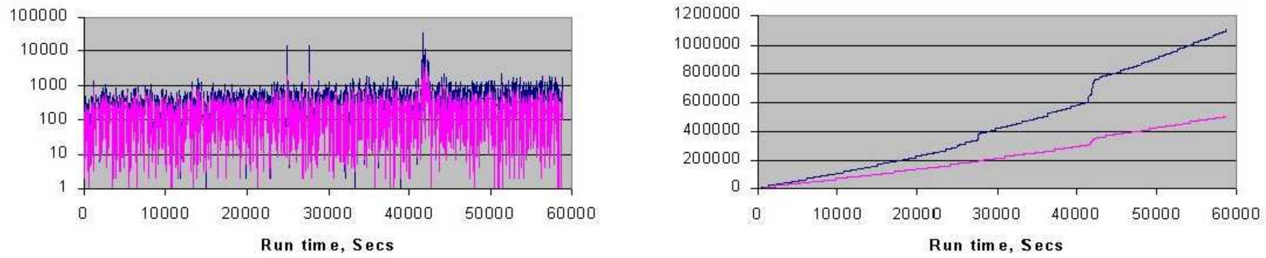
Spatial resolution of the detector is mainly determined by the pitch of the pickup strips. How-

Gas composition Ar:IB:R134A	Telescope window (mm)	Cross talk(%)
62:8:30	10	6.8
62:8:30	15	6.7
62:8:30	20	6.2
57:8:35	20	6.5
52:8:40	20	5.9
46:8:46	20	6.3

Table 1: Typical cross talk measurements

ever, this is limited by the cross talk between the adjacent strips. Among many factors that contribute to the cross talk, electrical characteristics and thickness of the pickup strips, graphite coat resistance as well the driving scheme of the picked up signals are the most influential. The chambers that we had fabricated have shown cross talk of about 6% between the adjacent pickup strips(Table 1). The telescope window shown in the second column of the table is centred on a RPC pickup strip of 30mm in width.

9 RPC aging problem



(a) Differential noise

(b) Integrated noise

Figure 19: Noise history of two RPCs under damage

We have fabricated a number of prototype glass RPCs of various designs and studied their performance in detail. The results obtained from most of the chambers are on expected lines and their measured parameters are in good agreement with those reported in the literature. However, we are currently encountering a rather serious problem with regard to the long term stability of the chambers.

While the newly fabricated chambers start showing good efficiency, timing, V−I characteristics as well as noise rates to begin with, their performance is found to degrade suddenly after a few weeks of continuous operation. While the efficiencies drop, chamber current and noise rates shot up. This problem has been reported in the literature[13]. Figure 19 shows differential (a) and integrated (b) noise rate history of two glass RPCs which are being operated simultaneously, getting damaged. We can notice sudden changes in the integrated noise rate slopes of both the chambers, further accelerating the damage process.

The reason that was suggested for this problem is possible contamination of the detector gas with impurities - moister being the most responsible. Controlled studies have shown that moister contamination to a level of 1000-2000 ppm in the detector gas can damage the RPC after a about month of continuous operation(Figure 20). While some forms of this damage could be reversed by switching back to the dry gas, other forms cause irreversible damage to the chamber.

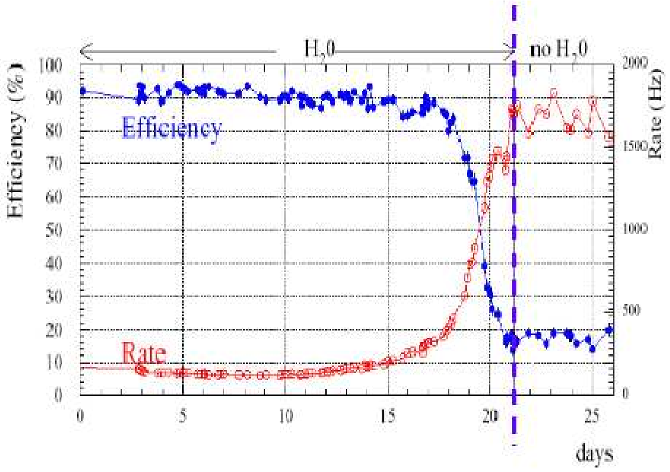
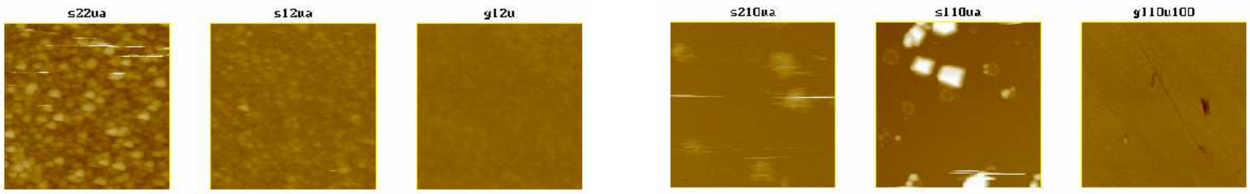


Figure 20: Controlled humidity test of a RPC[14]

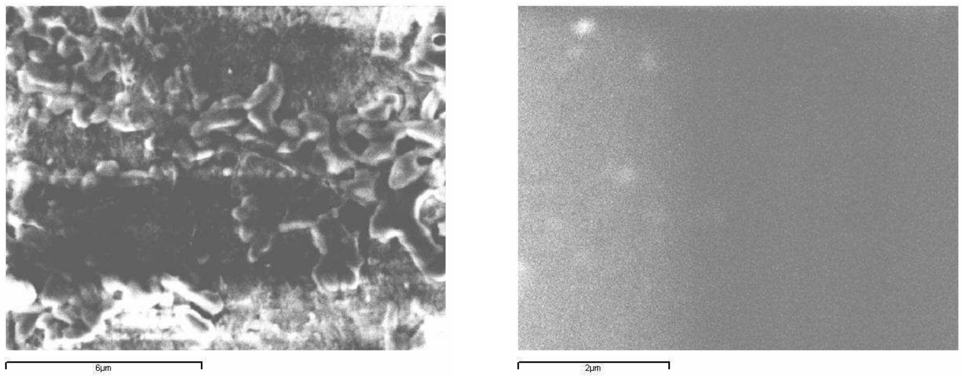
We have also tried the following recipe for recovering the damaged chambers, with limited success. The method involves flushing the chamber for a day with argon bubbled through water containing about 3% ammonia, followed by a few weeks of training the chamber with dry gas. Chamber parameters such as the efficiency and noise rate could be recovered close to their original values, but the chamber couldn't sustain the performance for long after the recovery.



(a) 2μm scans (b) 10μm scans

Figure 21: AFM pictures of damaged electrode surfaces

One of the plausible chemical reactions causing the damage to the electrodes is formation of Hydro Fluoride(HF) by Fluorine which is present in R134A gas and the moister. This problem was found only in the chambers operated with gas mixtures containing R134A and with moister contamination. This reaction causes etching of the glass surfaces, thus reducing the work-function of the electrode surfaces, leading to the field emission of electrons from the cathode. This in turn reduces the electric field inside the chamber below the efficiency plateau and causes a permanent efficiency drop[15].



(a) Damaged electrode(6μm scan) (b) Reference glass(2μm scan)

Figure 22: SEM pictures of damaged electrode surfaces

This was confirmed by studying the damaged electrodes using Atomic Force Microscope(AFM) and Scanning Electron Microscope(SEM) techniques[7]. The damaged glass surfaces are shown in Figures 22 and 21 along with raw glass surfaces for reference. We have noticed deposits of about 500nm in area and about 100nm in thickness. AFM pictures shown here are of two samples studied at different areas on the electrodes and with different resolutions. An element analysis on the samples has shown that while the Fluorine content in the raw glass is about 4% by weight, in the damaged electrode sample it is about 38%.

We have also taken direct measurements of moister levels on the input gas lines using commercial moister meters[8]. We have noticed higher moister levels in the R134A gas (400ppm), while the moister levels in the Argon and Isobutane gas seem to be under reasonable limits(60ppm and 140ppm respectively). We have subsequently installed silica gel and molecular sieve cartridges on the input gas lines to filter out the moister from the bottled gases. We have also installed a dehumidifier in the laboratory.

10 Future work plan

Our immediate task clearly is to perform more systematic studies and measurements in order to understand the aging problem of the chamber completely as well as to find a permanent solution for the same. We would then will be in a position to fabricate many large area chambers and study their performance in terms of their operational parameters as well as their long term

[7]Thanks to Mr J.John and Ms B.A.Chalke, Department of CMP&MS, TIFR

[8]M/S Hemaki Lab-Services (P) Ltd., Mumbai

stability. We also want to initiate fulpledged device simulation studies of the glass RPCs, for understanding their detector physics as well as to characterise their operating parameters.

We are planning to build a prototype detector of about $1m^3$ in volume for studying various RPC and detector parameters and also for comparing these measured parameters with the detector simulation results on which our colleagues are working. This detector will have about 14 large area glass RPC layers, sandwiched between 6cm thick iron plates. Our next task therefore is to fabricate the RPCs for this prototype detector. We hope to to master the science, technology and art of this field by the end of this activity and thus preparing ourselves for the large scale production of glass RPCs for the INO detector.

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