Design and Simulation Studies of Resistive Plate Chambers

(Ph.D Progress Report)

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Abstract

During the past year, I had continued my active research work on design and study of Resitive Plate Chambers (RPCs). We had earlier developed, built and characterised a large number of prototype RPCs. We had continued this detector R&D in the past year by fabricating more glass RPC prototypes and studying their operating parameters and characteristics. The performance results of these chambers were comparable to those reported by other research groups. But, we were faced with a serious problem with regard to their long term stability. When operated these RPCs continuously for a few months, we have observed that their efficiencies drop, coinciding with sudden increase of chamber current and background counting rates.

Guided by similar experiences of other researchers in this field, we had initially suspected that this problem is due to the excessive moisture levels in the operating gas mixtures. Even after taking many steps towards monitoring and solving this problem, we didn't see any improvement in the long term stability of the RPCs. We had till then used many locally available brands of float glass for electrodes. During the past year, we have built a couple of RPCs using float glass, which was imported from Japan and operated them in the low gas gain avalanche mode. These RPCs continue to operate till now, without showing any signs of aging even after about a year. These results have for the first time indicated a possible role of electrode glass in the aging problem. We had then initiated a series of glass characterisation studies on various types of glass samples, including the Japanese glass. So far, however we haven't been able to record any significant differences in the characteristics of the Japanese glass vis-a-vis the local glass.

Meanwhile, we have setup a second RPC characterisation lab, equipped with a new sophisticated 4-input gas component mixing and 16-channel flow control system and a multiparameter data acquisition system. We have built about a dozen small size RPCs, arranged them as a detector stack and tracked cosmic ray muons through the same. A scintillator paddle based telescope was used to trigger the data acquisition. We could also extract and analyse a number of RPC operating parameters and characteristics using the data collected by this detector.

We are now in the process of acquiring large area glass sheets from Japan for building the prototype Iron Calorimeter (ICAL) detector for the India-based Neutrino Observatory (INO) collaboration. We have completed design and fabrication of the entire electronics, trigger and data acquisition system to be used for this detector. We plan to fabricate soon 1m^2 RPCs required for the prototype detector, build and operate the prototype detector in the coming months. This detector will provide us with invaluable data, which will be highly useful in designing the final INO detector. We will continue our glass characterisation studies, as these studies will possibly indicate the exact reason for aging of our detectors and also enable us to procure glass from local market, by providing the critical characteristics of the glass found out from these studies to the manufacturers.

Finally, I had made a number of presentations based on my work mentioned above at various national as well as international symposia and INO collaboration meetings held during the past year. A couple of these are going to appear as papers soon in refereed journals. I had also taught two courses on Resistive Plate Chambers and Data Acquisition Systems at the INO school held at VECC/SINP.

Contents

List of Figures

List of Tables

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 by an India-based Neutrino Observatory (INO) collaboration was mooted several years ago. 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 48m $\times$ 16m and height 12m with iron plates used as absorber and RPCs as active detector elements. It will comprise of 140 layers of horizontally arranged iron plates of about 6cm thickness, interleaved with 2.5cm gap between successive layers of iron plates to house the 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 50kTon.

It is proposed that we use large area RPCs of surface area 2m $\times$ 2m for this detector. The total number of detector elements that we therefore need to build is about 27,000. Float glass of about 216,000m^2 in area will be needed to meet this requirement. Assuming a two-dimensional signal pickup pitch of 3cm on either surface of the glass RPC, we need to instrument about 3,600,000 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.

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 Review of earlier work

Principles of operation of RPCs and overview of the field, along with our initial work on development and characterisation of RPCs has been reported in my Ph.D Credit Seminar Report[1]. A detailed account of prototype chambers that we had designed and fabricated, gas mixing and distribution system, cosmic ray muon telescope and data acquisition systems that we have designed and developed is given in my previous Ph.D Progress Seminar Report[2]. We have reported preliminary results of our detector development work in an Interim Report on the INO feasibility study, which was submitted to the funding agencies last year[3]. A brief review of this earlier work is given below.

We have fabricated several dozen *small area* glass RPCs of dimension 30 × 30 cm^2 as well as many *large area* chambers of dimension 120 × 90 cm^2. We have developed a number of jigs and tools that help in ascertaining the quality of raw materials that we use to build the RPCs as well as during various fabrication stages of the RPCs.

A gas mixing unit capable of mixing four individual gas components and control the mixed gas flow through the detector chambers has been designed and developed. We have implemented various changes in the gas system in order to address the problem of reducing the moister levels in the gas mixture. These include installation of silica gel and molecular sieve based moister filters as well as fine dust filters in the gas input line. We have also assembled and installed an alumina based in-line filter with in-situ charging facility. Subsequently, we have designed a six-channel rotameter based gas distribution system, which has helped us maintain absolutely constant flow rate through the chambers. Finally, we have also implemented substantial improvements in the gas system, such as using low vapour pressure oil (DC704) in the output gas bubbles, replacing the gas lines with hydrophobic pipes and fittings, as well as installing an in-line Mass Flow Controller (MFC) for a better gas regulation through the main input gas line.

All the prototype chambers have been tested for their performance using a scintillator paddle based Cosmic ray muon telescope, consisting of four Cosmic ray muon trigger and two veto paddles.A suitable telescope support structure has been designed and built employing light-weight aluminum extruded channels. The Cosmic ray muon telescope was found to exhibit excellent stability.

A data acquisition system for RPC testing has been designed and developed using NIM and CAMAC electronics which is available in the laboratory. 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. 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 on-line 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 these parameters.

We have started our studies by looking at 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. We have established a reliable way of monitoring the stability of the chamber based on its noise rates. We have obtained chamber plateau efficiencies of over 90% for various gas mixtures. We have confirmed that the RPC is operating with a good energy resolution by studying the pulse height (charge) distributions of small RPCs operating them at various high voltages. We have made detailed measurements on the charge-time linearity, time response as well as the time resolution of the RPCs and obtained a typical timing resolution of about 1.2nSec while the RPC is operating on its plateau.The chambers that we had fabricated have shown cross talk of about 6% between the adjacent pickup strips.

In connection with the aging problem of the RPCs, we have also studied various RPC operating parameters just before it is getting damaged. These include monitoring the individual pixels' (overlapping areas between two strips) rates on surface of the RPC to locate sudden increase in noise rates from a region, if any before the chamber is damaged. We have also devised a parameter called streamer size and monitored the same during the RPC tests to see if the size increases steadily with long term operation. We have also looked at noise rate history of individual strips of this chamber and found that certain strips tend to shot up with their rates with continuous operation.

While working mainly on glass RPCs of various designs and sizes, we have also made attempts to gain experience with bakelite based RPCs. We had operated a couple of bakelite RPCs of CMS end cap design along with some of the glass RPCs, which were fabricated by us. While we had used a three component gas mixture of Argon, Isobutane and Freon (R134A) in a typical proportion of 30:8:62, for avalanche mode of operation, we have used a two component mixture of Freon and Isobutane in a typical proportion of 95.5:4.5 for these tests. We have also used low noise, fast preamplifiers on the RPC strip signals in order to compensate for the low amplitude signals from chambers operated in avalanche mode. While the glass RPCs sustained only for about two months of continuous operation on their plateau voltages, the bakelite RPC didn't show any signs of aging or damage. This has demonstrated that if the moister in the gas indeed is the key issue for the possible problem, it seem to affect only glass electrodes, irrespective of the RPC's mode of operation, i.e avalanche or streamer. This was our first such demonstration.

In line with all necessary changes and improvements being carried out in other subsystems of RPC test stand, we have made many changes in the readout and data acquisition system as well. One of the major changes in this direction is to expand the DAQ system to read all individual X and Y strip data parallelly. This has helped us to conclude that when there is sudden increase in the noise rate of the RPC, the increase is not uniformly spread across the area of the RPC, but rather from certain localised regions. Dark current of an operating RPC is an important parameter to monitor its stability. We have therefore decided to power the RPCs with high voltage power supplies which offer current monitor ports of good current resolution. We have developed a NIM module to condition these signals suitably, so that they can be fed into commercial peak sensing ADC modules.

During operation of *small area* RPCs, we have noticed that the operating parameters of the RPCs - dark current and noise rates in particular have shown variations on a definite 24-hour cycle. The ambient parameters that are most conspicuous of the 24-hour cycle are tempertare and barometric pressure. Since the RPC is a gas based detector, variations in these parameters are expected to have considerable effect in its operation. We can also use the measured parameters of temperature and barometric pressure along with the RPC operating voltage in order to correct the RPC efficiency for the changes in the ambient parameters. We have therefore procurred ambient parameter sensors for barometric pressure, temperature and relative humidity and interfaced them to the data acquisition system for recording these data routinely along with RPC test data.

3 Long term stability tests of INO RPCs

Although glass RPCs operating in the streamer mode are known to be stable and have a long lifetime (more than 5 years) as evidenced by the successful operation of these chambers by the Belle Collaboration, those made by us earlier had a much shorter life time. While the problem of short lifetime of the glass RPCs produced by us is being investigated, we fabricated a few RPCs of dimension 40 cm $\times$ 30 cm using glass procured from Japan (from the same source as used in Belle RPCs). The same procedure for fabrication as well as testing as in the case of earlier RPCs was followed for these new chambers using Japanese glass. Two of these new chambers (called J2 and J3) are currently being operated in the avalanche mode, in which a gas mixture of freon (R134a) and isobutane in the proportion 95.5 : 4.5 by volume is used. The chambers are operated at a high voltage of 9.3 kV. Since the pickup signals in the avalanche mode are in the range of few millivolts, external amplification has been provided by preamplifiers of gain 10. The rest of the electronics and data acquisition chain is the same as that used earlier.

A comprehensive monitoring system for the periodic recording of the currents of these two RPCs as well as the ambient parameters such as temperature, pressure and relative humidity both inside and outside the laboratory has been designed and implemented. Using this data several correlations between the ambient parameters and the RPC operating characteristics could be established. The long term stability tests were started on these two chambers from September 2005. As can be seen from the plots in Fig. 1, the performance of these chambers, characterised by their efficiency, leakage currents and noise rates, have not changed over the last seven months. These tests indicate that the aging problem associated with the previous RPCs is related to the quality of glass plates used to fabricate those RPCs. While continuing with this long term stability test, we are also in the process of fabricating large size chambers using glass obtained from the same Japanese source.

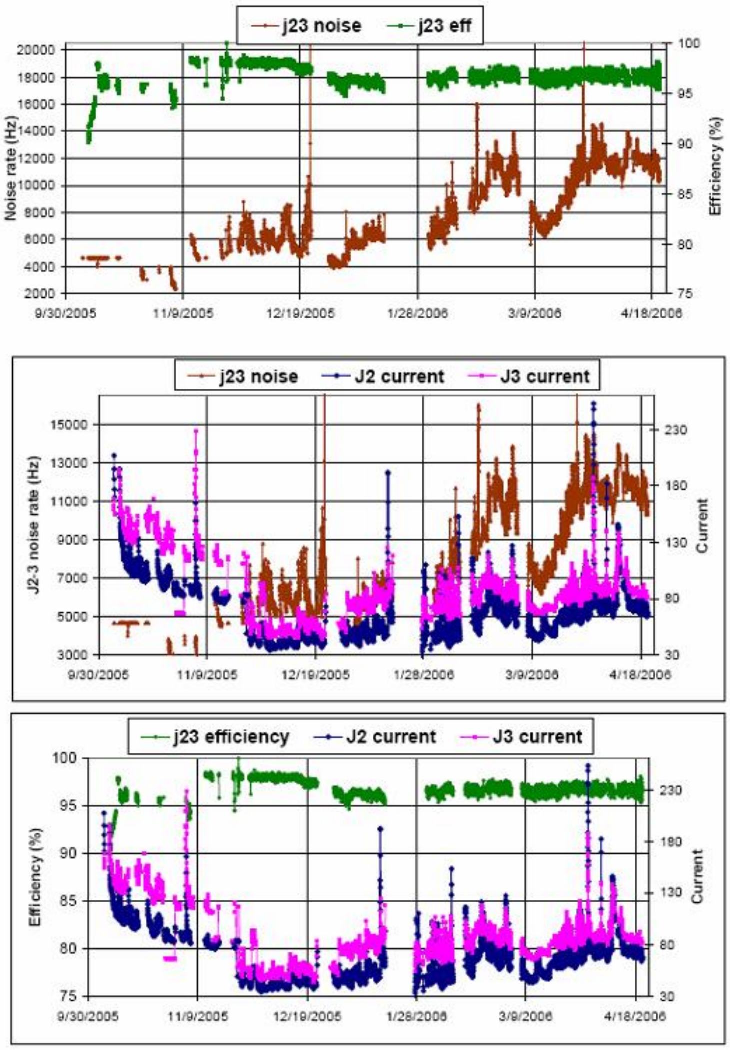

Figure 1: Long term stability monitoring plots of J2 and J3 RPCs

4 Characterisation of electrode glass samples

Drawing a reasonable conclusion from the previous long term study of RPCs fabricated using Japanese glass that the electrode glass seem to be a crucial factor to the aging of RPCs, we have initiated detailed characterisation studies on various glass samples that we have so far utilised for fabricating the RPCs. The motivation was two fold. While we have certainly believed that these studies will throw light on possible reason for the sudden aging problem of our RPCs, we also want find out on comparative scale, the main characteristics of the glass that make a good electrode. We have mainly studied glass samples made by Modi, Asahi and the Japanese glass.

Fig. 2 shows Atomic Force Microscope (AFM) surface scans of these glass samples. While the Modi glass surface seem to be bad on a relative scale, the Asahi glass surface quality is

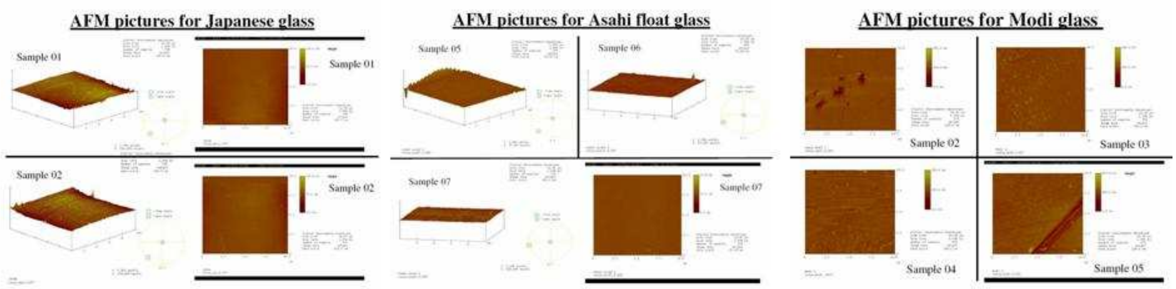

Figure 2: Comparative study of glass samples using AFM technique

as good as that of the Japanese glass. We have also scanned these samples on a Scanning Electron Microscope (SEM) whose results are shown in Fig. 3. Again, there are no appreciable differences on the surface quality of these samples. It is however interesting to note a couple of observations from these studies. These scans indicate debris of tissues used for cleaning of these glass samples as impurities with a high carbon concentration. The Modi sample shows a flaw in terms of a very clear diffraction pattern on the sample.

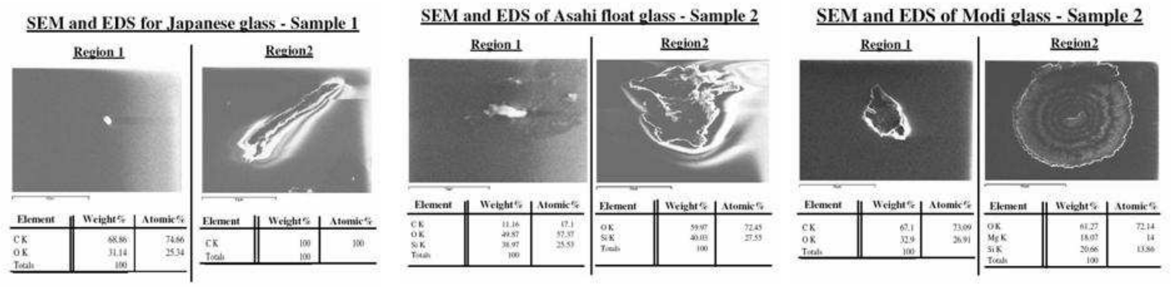

Figure 3: Comparative study of glass samples using SEM and EDS technique

We show in the Table 1, fractional percentages of weights of various elements present in the glass samples obtained using Energy Dispersive X-ray Spectroscopy (EDS) technique. The data is shown for a couple of samples each of different brands of glass. Within the instrument tolerances, we find that the glass samples show consistant values of various constituent elements among them.

We have also studies the transmittance of these glass samples using a light source of UV and visible spectrum. These results are in shown in Fig. 4. All the glasses show expected behaviour, including the sudden drop of transmittance at the UV spectrum boundary. Even though the Japanese glass shows marginally better transmittance by about 10%, we donot believe that this is a significant difference among the samples. So, we conclude that using various surface scan, elemental analysis or the transmittance tests, we donot find any significant differences among various glass samples.

While on the glass characterisation, we wish to report the following work, even though this is

Element	Modi		Asahi		Japanese	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Oxygen	71.0	72.6	69.9	70.1	72.9	73.4
Sodium	8.6	3.3	7.7	7.8	7.6	7.2
Magnesium	1.8	1.8	2.3	2.4	1.9	1.5
Silicon	17.8	15.7	19.0	18.6	16.9	17.1
Calcium	0.9	-	0.7	0.7	-	0.4
Carbon	6.7	-	-	-	-	-
Aluminium	-	-	0.5	0.4	0.7	0.5

Table 1: EDS study summary of glass samples

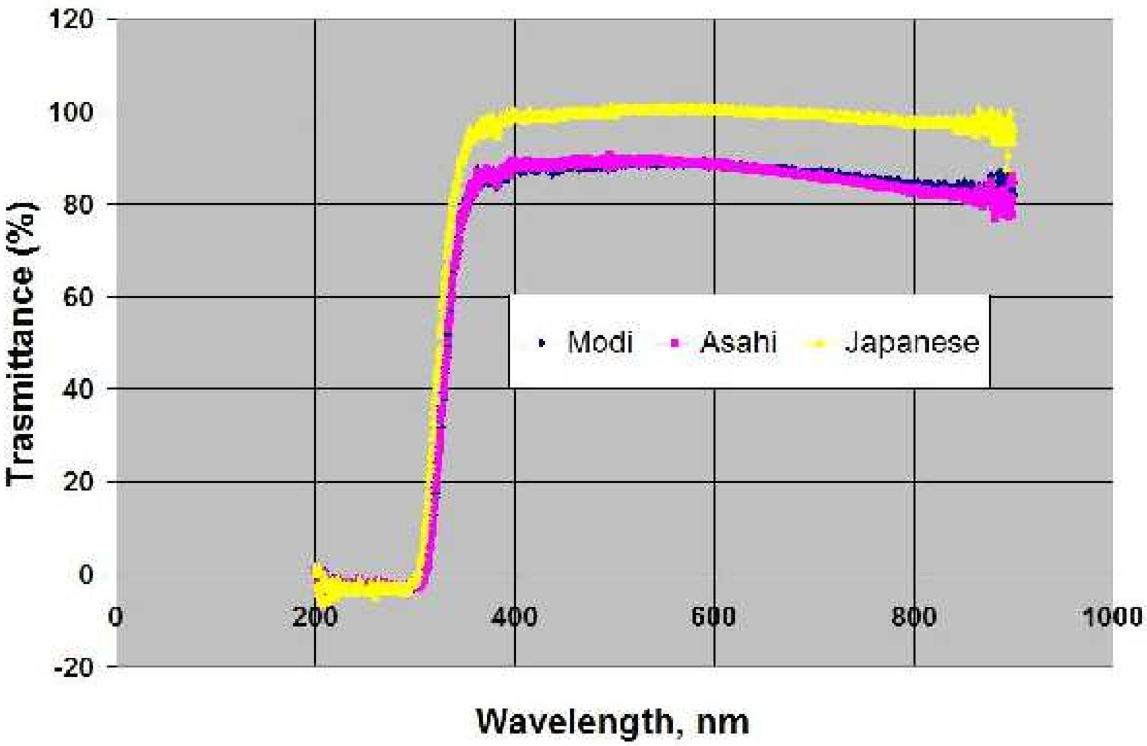

Figure 4: Comparative study of glass samples using transmittance test

not related to finding out the difference between various glass samples. Due to the technique of float glass manufacturing, the quality of two surfaces of the glass is not identical. While the surface, which is in contact with molten tin - on which the glass is floated while manufacturing, is relatively smooth, the surface that is exposed to the air is rough. It is adviceable that we keep two smooth surfaces of the top and bottom electrode glasses facing the gas volume for a better performance of the detector. We have devised a scheme using the reflectance of glass surfaces for the UV radiation to mark the smooth and rough surfaces. Shown in Fig. 5 is a plot of this test on a glass sample using which we could clearly distinguish these two surfaces.

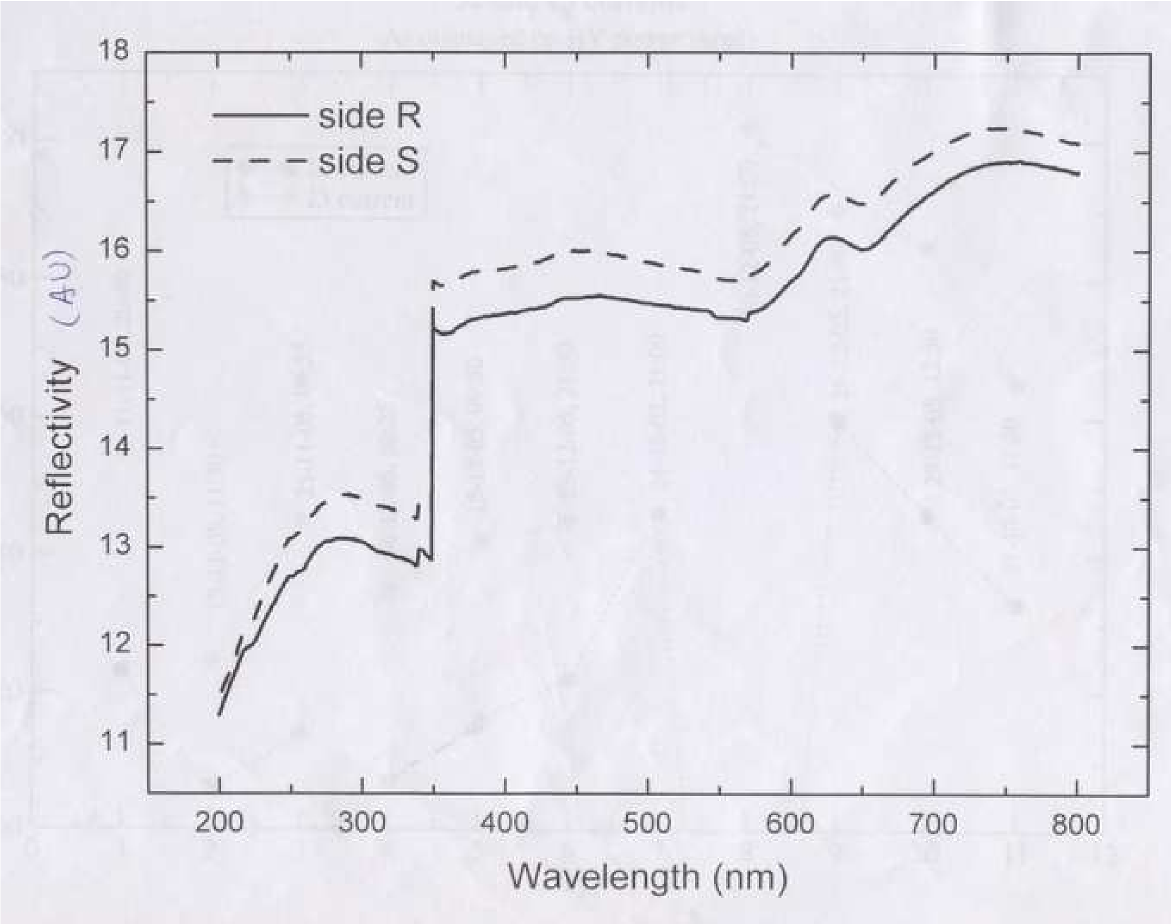

Figure 5: UV scan result of a glass sample

5 Development of 16-channel gas system

We have designed and developed a new 16-channel gas mixing and distribution system using mass flow controllers (MFC), which will be be used for flowing gas to the proposed prototype detector with 12 RPCs. It mixes four input gases viz. argon, freon (134A), isobutane and SF_6 using the volumetric method. The mixed gas can be supplied simultaneously into 16 individually controlled output channels. The gas flow rate in each of output channels is kept the same using flow resistors. The return gas from the connected chambers is collected in a common manifold before it is finally vented out into the atmosphere. Gas flow at every stage of the system is achieved through the use of electrically or pneumatically operated switches or valves. The system is equipped with a host of sensors and monitoring devices and appropriate displays of various crucial operating and quality control parameters. A Schematic diagram of this gas mixing and flow control system is shown in Figure 6. Figure 7 is a photograph of the fully functional gas system.

The main components and salient features of the system are:

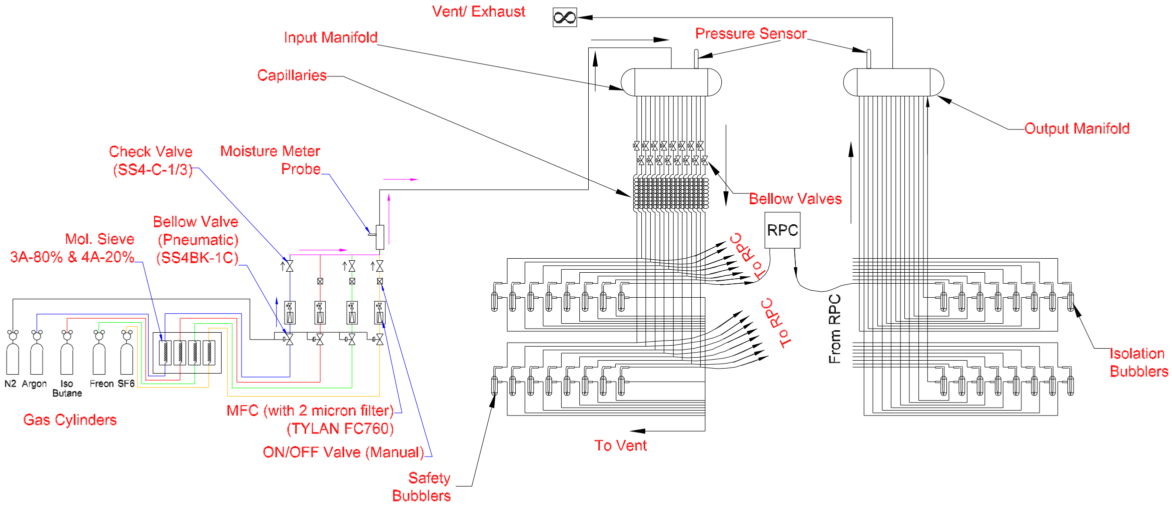

Figure 6: Schematic diagram of gas mixing and flow control system

1. Input gas purifier columns: Four (one for each input gas) in-situ rechargeable molecular sieve based columns, mounted on the input gas lines in order to absorb moister, oil traces and other contaminants from the input gases.

2. Gas mixing section: This crucial section is based on Tylan made FC-760 model Mass Flow Controllers (MFCs). The input section of these filters have 2 μm dust filters. Flow rates of individual gases, calibrated in Standard Cubic Centimetre per Minute (SCCM), are settable from, and displayed on, the front-panel. Small amounts of water vapour are added in the gas mixtures used for Bakelite RPCs. A provision has been made in this section for the same.

3. Moisture meter: A microprocessor based commercial (SHAW make) capacitive type sensor with a suitable display, in PPM as well as the dew point, is mounted on the mixed gas line to monitor the moisture content in the mixed gas.

4. Distribution unit: The mixed gas is distributed into 16 individually controlled gas outlets in parallel. This is achieved by using SS capillaries, 2 m long and 200 μm diameter, as flow resistors. A pressure sensor is mounted on this line to indicate the inside pressure of the system. A Parker made fine particle filter is mounted on this unit in order to purify the mixed gas further, before it enters the chambers.

5. Safety bubblers: These bubblers are mounted on individual output lines in order to take care of the back pressure exerted from, and to protect the RPCs from damage due to, over pressurising.

Figure 7: Front view of the 4-component gas mixing unit with 16 output channels

6. Isolation bubblers: These bubblers serve the dual purpose of preventing back diffusion of air into the RPCs as well as indicating the flow of gas through the chambers. The silicon oil levels in the safety and isolation bubblers are chosen taking into account the pressure gradient in the gas system.

7. Exhaust manifold: The return gas from all connected chambers is collected into this manifold, and a single output is provided to vent the used gas into the atmosphere. This manifold too has a pressure sensor to indicate the system pressure with reference to the ambient room pressure.

8. Remote control and monitoring: The required flow rates of individual gases in the system can be set and monitored through a PC interface. Other important system parameters such as pressures at various stages of the unit can also be monitored using this interface.

6 Tracking of cosmic ray muons using small size RPCs

We have setup a separate laboratory for this test, in which the newly developed 16 channel gas mixing unit described earlier was installed. The RPCs for this setup were fabricated using the same materials and fabrication procedures and parameters as those described earlier. Float glass of thickness 2 mm and size 30 cm $\times$ 30 cm was used. RPCs using glass from different manufacturers were also used in the setup. This was done in order to make a comparison of the RPCs made using the glass sheets from different vendors and their deterioration with time.

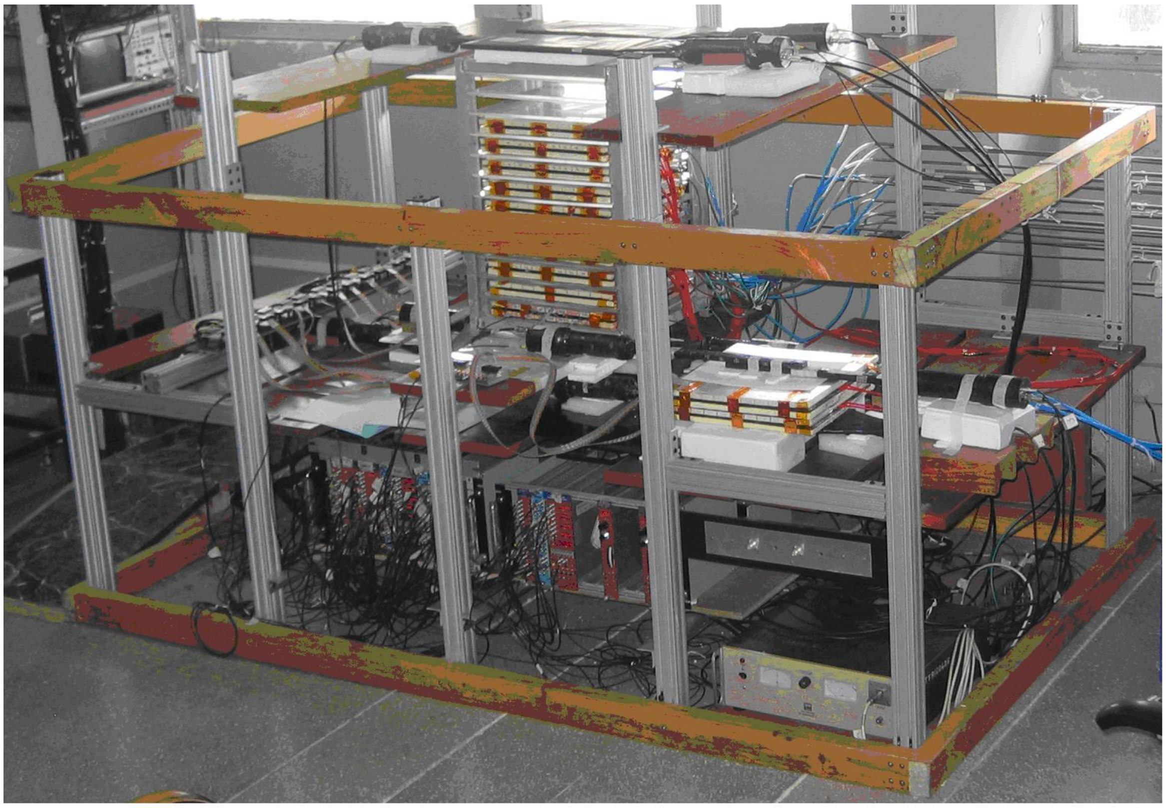

Figure 8: Muon tracking setup using RPC stack

A suitable rack to house 12 RPCs of the above size was fabricated. The rack allows easy access to any individual chamber in the stack. It also integrates a spring loaded mechanism to keep the signal pickup panels pressed uniformly against the chambers.

The cosmic ray muon telescope seen in Fig. 8 was set up using seven scintillator paddles. These include one narrow paddle of 2 cm width to define the telescope window such that it centres on an individual signal pickup strip as well as two more to veto muons which are passing outside the strip of interest. This allowed a measurement of the cross talk between adjacent strips.

A stack of 10 RPCs, as seen in Fig. 9 was mounted in the above mentioned rack such that the signal pickup strips of all the chambers were well aligned geometrically. The chambers

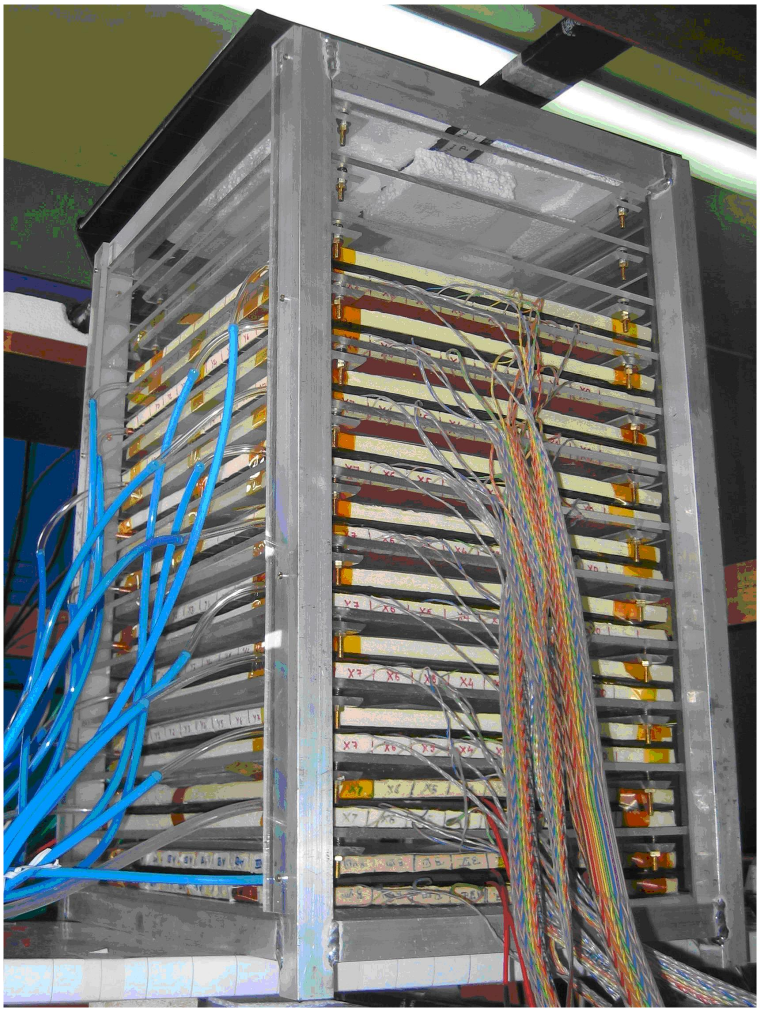

Figure 9: Close-up view of the stack of 10 RPCs mounted in a rack

were operated in the streamer mode, using a mixture of argon, isobutane and freon (30:8:62 by volume) from the new gas system described above. The operating high voltage for the tests was kept at 8.6 kV using a high voltage mainframe system, controlled via a PC ethernet interface. The high voltage supply current was monitored on-line to diagnose any possible instability in the RPCs.

The signals from the pickup strips were transmitted through twisted pair cables onto patch panels, where the line impedances are transformed in order to match those of the NIM electronics. The RPC strip analog signals are fed to discriminator and latch modules. The cosmic ray telescope trigger signal is used as the strobe signal for the latch modules, which record binary information on the presence or absence of a signal on the RPC strip of interest for every trigger. The counting rates of the RPC strips of interest are measured with scalers using the corresponding logic signal. The logic signals from the strips are also used to record the timing information from the RPC, with respect to the cosmic muon trigger, using TDC modules. The

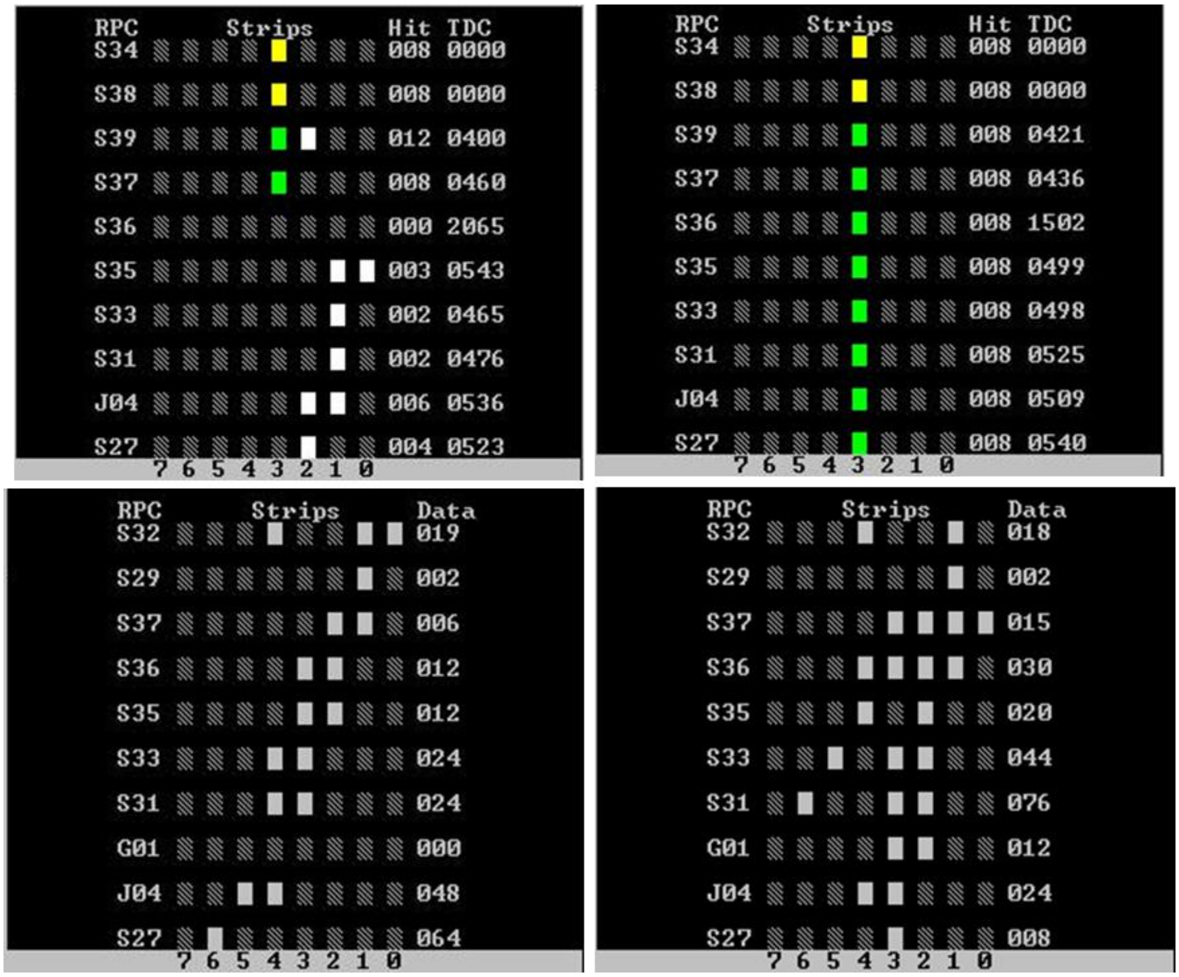

Figure 10: Some interesting tracks recorded in the detector

strips of only one pickup panel are read out. I have developed an on-line data acquisition software, which records event data on trigger, reconstruct and display the tracks, save event data etc. The software runs monitoring jobs such as trigger and RPC strip counters in the background. The software also offers a host of off-line facilities such as replaying the recorded data, binning and generating data histograms in the Microsoft Excel data format etc.

Fig. 10 shows some interesting cosmic ray muon induced tracks recorded using the above setup. Muons arriving at different angles could be captured simply by relocating the telescope window. This has demonstrated that indeed these prototype chambers are capable of effectively tracking cosmic ray muons.

The information recorded in these tests could also be used extract other parameters of interest, such as efficiency, noise rate and timing of individual RPCs and their long term stability. Shown in Fig. 11 are individual RPC efficiencies with reference to cosmic ray tracks, their total hit distributions and strip hit multiplicity distribution patterns of a couple of RPCs. Parameters

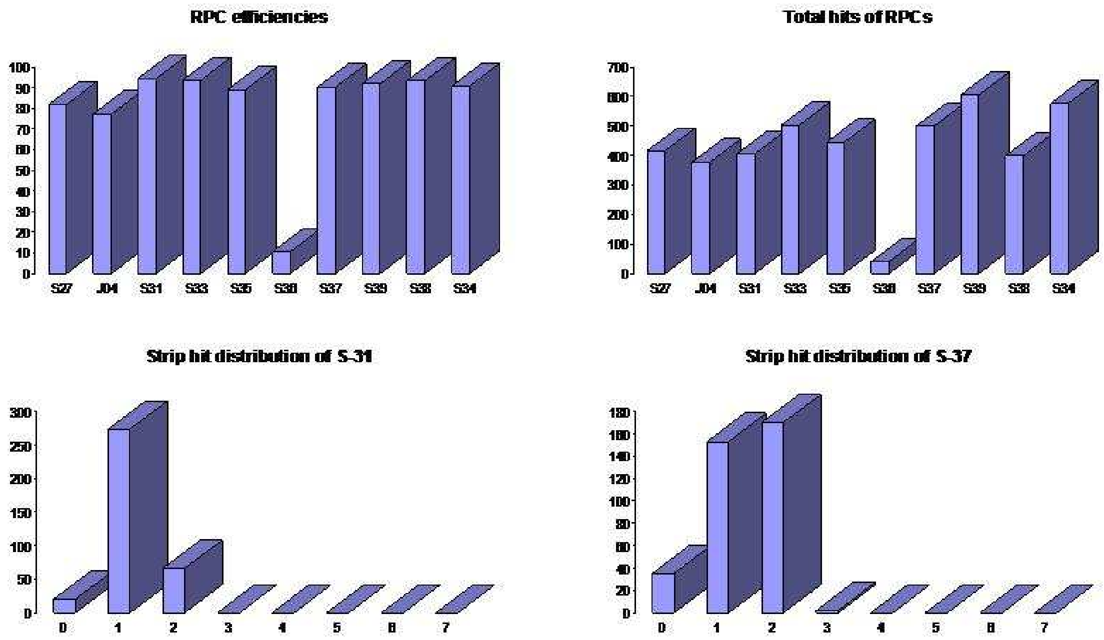

Figure 11: Extracted parameters from the data recorded by the stack

such as temperature, barometric pressure and relative humidity are also being monitored on-line in order to collate and correlate the dependence of chamber performance on these ambient parameters.

It was also established from these studies that the chambers made with Modi, Asahi and Saint Gobian float glasses suffered from the aging problem which was observed in the previous studies. However an RPC fabricated using the glass procured from Japan is surviving the long term stability tests up to the time of writing this report.

7 Development and study of electrode coatings

Resistive coating of the outer surfaces of the electrodes plays very crucial role in the operation of the RPC detector. While surface resistivity of this coating should be small enough so that the bias voltage that is required for the RPC operation can be applied on these coats, it should be high enough to render it *transparent* to electric pulses generated by the charge displacement in the gas gap. This way, the charges produced inside the gas gap on passage of a particle, can induce electric signals on the external metallic pickup strips, which are capacitively coupled to the gap. Needless to say that the uniform response of the RPC is dependent on the uniform resistivity of the coating across the surface of the electrodes. It is also important for longterm stability of the RPCs, that the binding strength of the coat to the electrodes is strong. Finally, the materials used as well as the technique employed for coating should be adaptable for large scale industrial production.

There is another important consideration of this electrode coat on the performance of the RPC. Every charged particle passing through the RPC, produces a tiny charge spot of about 0.1cm^2 in area. This area is too small to result in any noticeable cross-talk between two adjacent pickup strips on which signals are induced. However, if the surface resistivity of the graphite coat is *too* small, the induced charge is more localised and spreads laterally across the graphite coat, producing large cross-talks between the pickup strips and thus severely affecting the position resolution of the detector.

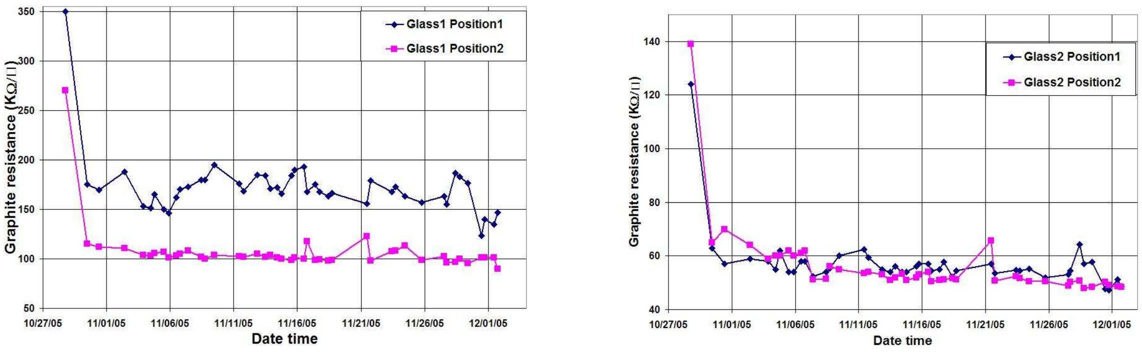

Figure 12: Surface resistivity of graphite coatings on electrodes

I have developed and studied an optimum proportion of suitable materials for the coat and a reliable technique to apply the same on the electrodes of up to 1m^2 in area. Graphite paint prepared using colloidal grade graphite powder(3.4gm), lacquer(25gm) and thinner(40ml) is sprayed on the glass electrodes using an automobile spray gun. A uniform, stable graphite coat of desired surface resistivity (100-200 KΩ/□) could be obtained by this method. While the graphite powder of appropriate grade provides the required surface resistivity, the lacquer binds the graphite to the smooth glass surface. Thinner is added to obtain the required consistency of the mixture that allows spraying using a spray gun. As shown in the Figure 12, the surface resistivity of the coat drops swiftly during the first few days of application - essentially due to drying of thinner from the coat, it remains reasonably stable there after. All the prototype RPCs which were made by us were graphite coated using this technique and was found to be cost effective, reliable and adaptable for large scale production. We are now working with a paint company (M/S Nerolac Paints) to perfect this technique, leading to large scale coating of electrodes for the final INO chambers.

I have also developed a simple but very useful jig to measure the surface resistivity of the graphite coats. It works on the following principle. The resistance, R of a surface film of thickness, t as measured between two conductors of length, L and separated by width, W is proportional to $L \div (W \times t)$. So for a given square of side, L (which is equal to W), R is independent of L (and W) and depends only inversely on t. The jig essentially consists of two conducting bars fixed in frame so as to form a square. Provision is made to measure the resistance across these conducting bars, using a multimeter. The resistance value is directly read as $\Omega/\Box$. The jig is intentionally made heavy so that it makes good surface contact with coat and thus provides reliable measurements. Jigs of small and big squares were fabricated so that the resistivity measurements on both fine and coarse scale can be made.

8 RPC materials and assembly procedure development

RPC fabrication involve a large number of materials as well as many assembly procedures. So, production of high performance and reliable chambers involve choosing the right type and quality of materials as well as optimisation various assembly and quality control procedure involved in the fabrication. Materials such as glass used for electrodes, individual gases used for mixing and flowing the gas mixtures for the operation of the chambers, spacers, buttons, gas nozzles etc which are needed for the assembling the chamber, graphite coat on the electrodes, epoxies used for gluing together different types of materials, pickup panels used for external signal pickup from the chambers, Mylar films used for insulating the pickup panels from the graphite coated electrodes and the list goes on. We have studied a number of different type and quality of these materials and optimised most of these items. We have built RPCs using these chosen materials and found that these make a good chambers.

We have also designed a developed a large number of assembly and quality control procedures and invented a number of useful jigs that are extremely useful in production of good quality detectors. Coating of resistivity paint on the electrodes, assembling and gluing of chambers, leak testing of the finished chambers are some of the important assembly procedures. We are working closely with various R&D institutions as well as many industrial houses in developing these materials and designing and developing the assembly procedures. I have taken a leading role in all of these research activities. I have also devised a strict quality control specifications and generated QC log sheets, samples of which are shown in Figs 13-16 in Appendix B.

9 Construction of INO prototype detector

It is proposed that we build a prototype of the magnetised iron calorimeter and study cosmic ray muons using the same, in order to understand and estimate performance of the final detector. This prototype detector will also be used to test the results obtained from the physics and detector simulation studies that are currently underway as well as will provide some measured data back to the simulation group.

We plan to build a prototype of about 1m^3 in volume. It will comprise of 12 layers of RPCs each of about $100 \times 100\text{cm}^2$ in area and will have 6cm iron as the absorber between the layers. The electronics, trigger and data acquisition systems will need to handle about 1000 channels for this detector. There are two analog front-end boards per signal plane per layer of the detector. Detector signal conditioners, translators, Boolean latches, multiplexers for event data and monitoring and trigger system as well as timing measurement primitives are some of the major components that reside on the digital front-end board that feeds on two analog front-end boards. Event data from either signal planes of a layer are mixed and routed to the back-end on high-speed serial links. The CAMAC back-end is driven by a Linux host and will house master trigger generator, TDC, scaler, real-time clock and other front-end control modules designed by us. All the electronics, trigger and data acquisition systems were designed and fabricated and are currently being integrated using the RPC test stands. Work on magnet design and fabrication for this prototype detector is progressing well. We plan to build the detector in the coming year. Recent progress of these various detector R&D activities are reported in INO Project report [4].

10 Future work plan

The coming year is very crucial in terms of RPC detector R&D related work. We plan to find the reason and a possible solution for the problem facing the glass RPCs soon. We wish to continue our glass characterisation studies until we either findout clear differences among the glass samples or rule out the role of electrode glass in the detector aging process. Meanwhile, we will procure large area glass sheets fro Japan and make RPCs required for the ICAL prototype detector. We will be able to study detailed characteristics of these chambers by operating more than a dozen of these large area RPCs as part of the prototype detector. Developing RPC detector technology in the country will be a major milestone for the INO experimental programme.

Having made this much progress on building and characterising the RPC detectors using the infrastructure which is built completely in house, we want to initiate a fullpledged device level simulations of the RPC[6]. We would like to simulate the device in terms of its electrical model and study the signal formation, pickup etc. We also plan to study the operating modes of the RPC and effect of various gas mixtures and other operating parameters. Simulating effect of impurities such as moister on the performance will be a very useful exercise in this area. We plan to use Garfield[5] along with Maxwell, Magbolz and Heed programs for RPC geometry field map calculations, for computation of charge transport properties and simulation of ionisation processes respectively. We setup and installed these packages on our servers and have started working with Maxwell package for field map calculations.

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A Presentations and papers on my work

I have made the following technical presentations on my work at various symposia and meetings mentioned below. I have also indicated where appropriate, names of journals in which these results are going to appear as papers.

1. On aging problem of glass Resistive Plate Chambers, The VIII Workshop on Resistive Plate Chambers and Related Detectors, Korea University, Seoul, October 10-12, 2005, Nuclear Physics B, In press

2. Development of Resistive Plate Chambers for the INO detector, 50th DAE-BRNS Symposium on Nuclear Physics, BARC, Mumbai, December 12-16, 2005

3. Status report on RPC R & D at TIFR, INO detector meeting, VECC, Kolkata, December 24, 2005

4. Status report on electronics, trigger and data acquisition systems for the INO prototype detector, INO detector meeting, VECC, Kolkata, December 24, 2005

5. Electronics, trigger and DAQ system for INO prototype detector and A few thoughts for ICAL detector, INO Interaction meeting, IMSc, Chennai, February 22-24, 2006

6. Preliminary results from INO detector R&D programme, Linear Collider Workshop 2006, IISc, Bangalore, March 9-13, 2006, Pramana, In press

7. Course on Resistive Plate Chambers, INO School, VECC/SINP, Kolkata, May 1-13, 2006

8. Course on Data Acquisition Systems, INO School, VECC/SINP, Kolkata, May 1-13, 2006

9. Experiences of using float glass as electrodes for radiation detectors, National Symposium on Science & Technology of Glass/glass-ceramics (NSGC-06), BARC, Mumbai, September 15-16, 2006

B QC specification and log sheets for INO RPCs

RPC prototypes fabrication for INO experiment

Quality control data

RPC identification	

Overall QC summary

Table 1: Glass plates

Glass make		
Glass cut or resized by		
Parameters	*Sheet 1*	*Sheet 2*
Length (mm)		
Breadth (mm)		
Thickness (mm)		
Comment on dimensions		
Comment on surface quality		
Cleaned by		

Table 2: Spacers & gas nozzles

Parameters	*Values*
Spacers prepared & cleaned by	
Spacers checked by	
Nozzles prepared & cleaned by	
Nozzles checked by	

Figure 13: QC sheet for INO RPCs - Page 1

Table 3: RPC assembly

Parameters	Values
Glued on (Date & Time)	
Glue used (Description)	
Glue prepared by	
RPC glued by	
Gluing checked by	
Comments & Observations	
Second side gluing done on (Date & Time)	
Second side gluing done by	
Comments & Observations	
Glue repairs done on (Date & Time)	
Glue repairs done by	
Comments & Observations	

Table 4: Leak tests

Parameters	Attempt 1	Attempt 2	Attempt 3
Date & Time			
Done by			
Over pressure (mm)			
Time waited (hh:mm)			
Pressure drop (mm)			
Result (Pass/fail)			

Figure 14: QC sheet for INO RPCs - Page 2

Table 5: Gas flow tests

Parameters	Attempt 1	Attempt 2	Attempt 3
Date & Time			
Done by			
Flow rate (SCCM)			
Bubbles/min			
Result (Pass/fail)			

Table 6: Graphite coating

Parameters	Attempt 1	Attempt 2	Attempt 3
Date & Time			
Preparation			
Coat prepared by			
Coated by			
Comments			

Table 7: Graphite resistance measurements

Date & Time	Side 1		Side 2	
	Orientation1	Orientation2	Orientation1	Orientation2
HV polarity				

Figure 15: QC sheet for INO RPCs - Page 3

Table 8: RPC preparation

Parameters	Values
HV contacts prepared on (Date & Time)	
HV contacts prepared by	
RPC cleaned & mylars stuck on(D & T)	
RPC cleaned & mylars stuck by	

Table 9: High voltage tests

Date & Time		Date & Time		Date & Time	
Done by		Done by		Done by	
Result		Result		Result	
Voltage, KV	Current, uA	Voltage, KV	Current, uA	Voltage, KV	Current, uA

Figure 16: QC sheet for INO RPCs - Page 4