Study of Resistive Plate Chamber Detector for the India - based Neutrino Observatory

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Submitted on 25 june, 2007.

Abstract

This project comprised of the building and studying Resistive Plate Chambers (RPC s) to be used for the India - based Neutrino Observatory. Glass RPC s were built and tested for their performance, efficiency, and stability under various conditions.

In this report, we present the studies of high voltage vs current characteristics, temperature dependence of RPC current, efficiency and cross - talk performed on glass RPC s of size $1\,\mathrm{m} \times 1\,\mathrm{m}$ and of glasses of different makes.

1 Introduction

The INO : The India - based Neutrino Observatory (INO) will be set up to study neutrino physics. The physics goals of INO will be the precision measurement of oscillation parameters, study of matter effects, CP violation and possible CPT violation studies amongst others. INO will initially cover atmospheric neutrinos but later might be used as a far detector of long baseline experiments. Solar, supernova and geo - neutrino studies also feature on the list.

The ICAL Detector : The INO will comprise of an iron calorimeter of modular design, having iron blocks of thicknesses 6 cm and area $2\,\mathrm{m} \times 2\,\mathrm{m}$ interspersed by gaps to hold glass RPC s of the same area, which will serve as active elements of the detector. The detector will be placed in a uniform magnetic field of about $1-1.4$ T to determine the momentum of muons produced by the neutrinos interacting in the iron.

2 The Resistive Plate Chamber

The Resistive Plate Chamber (RPC) is a gas - based detector with good spatial as well as timing resolution. It is basically a type of spark chamber with resistive electrodes. The good spatial and timing resolution makes it well - suited for fast tracking calorimetry.

The glass RPC comprises of two parallel plates of glass, held together by spacers which maintain a gap between the glass plates through which gas flows. The gas is required for the multiplication of charge produced when some ionising particle passes through the gas volume. The glasses have some resistive coat on their outer surfaces on which high voltage is applied. These form the electrodes of the chamber. The charge produced in the gap drifts towards the electrodes and from there they are collected using pickup strips placed on the outer surface of the glass, by induction.

RPC s can be operated in two modes : the avalanche mode and the streamer mode. In the avalanche mode, a charge particle passing through the gas ionizes the gas. The ions being accelerated by the high electric field present produce secondary ionizations by collision with the gas molecules. The electric field of this cluster of ionized particles opposes the external field and the multiplication process stops. The charges then drift towards the electrodes from where they are collected. In the streamer mode, the secondary ionization continues to occur until there is breakdown of the gas and a continuous discharge takes place. Large pulses result.

In INO, RPC s will be operated in the avalanche mode.

3 RPC studies at TIFR

Studies were performed on three glass RPC s of area $1\,\mathrm{m}^2$ at the TIFR C 217 lab. Their characteristics are as follows:

RPC name	Glass type	Glass thickness	Pickup Strip thickness
JB00	Japanese	2 mm	10 mm
IB01	Italian	3 mm	10 mm
JB01	Japanese	2 mm	5 mm

All RPC s have a gas gap of 2 mm. The following studies were performed :

- The high voltage (HV) vs current (I) characteristics of all three RPC s were studied.
- The variation of dark current drawn by the RPC s with temperature was studied for JB00 and JB01. This study was not performed on IB01 as it was drawing a large amount of current and sparks were being produced in the gas gap.
- Manual efficiency counts and detailed study of pulses were done for the RPC s IB01 and JB01. This was not done for JB00 for reasons that will be explained.
- A detailed study of JB01 efficiency was done, using manual counting and two types of amplifiers.
- Study of cross - talk in IB01 and JB01 was undertaken. However the study on IB01 was incomplete due to lack of sufficient amount of electronic components.

3.1 Experimental Setup

The RPC and Trigger Stack : A schematic of the stack is shown in Fig. 1. Four scintillator paddles, P1 through P4, each 1 cm thick were used to trigger the RPC s. The RPC signals were registered only when they were in coincidence with the 4 - fold signals for the trigger scintillators.

The trigger geometry was as follows: P1 is 2 cm wide, P2 4 cm, P3 3 cm and finally P4 20 cm. The overlap along the length of the paddles was 28 cm. The trigger setup was such that its center coincided with one of the pickup strips of the RPC s, labelled as Strip 4. The trigger setup is also referred to as the “telescope”. All RPC s were placed so that their pickup strips were on top of each other. In this way, a 4 - fold coincidence unit was setup such that signal from Strip 4 for each of the RPC s could be handled in coincidence with the trigger signal.

The possibility of either Strip 3 or Strip 5 registering a coincidence with the trigger is negligible. For example, in case of JB01, the RPC farthest away from the topmost paddle, the overlap of Strips 3 and 5 with the telescope is just about 1.6mm each! In the other words, the opening angle of the scintillator paddles is very small and only downward travelling cosmic rays can trigger the RPC s (Strips 4 only) and the scintillators at the same time.

For our purpose, due of lack of sufficient electronics, most studies were performed only on Strips 4 of the RPC s. For cross - talk measurements on JB01, the adjacent Strips 3 and 5 were also used and for IB01, only the adjacent Strip 3 was used. This was done under the assumption that the cross - talk would be symmetric and thus, study on only one side would give a fair idea. This point is dicussed in details later.

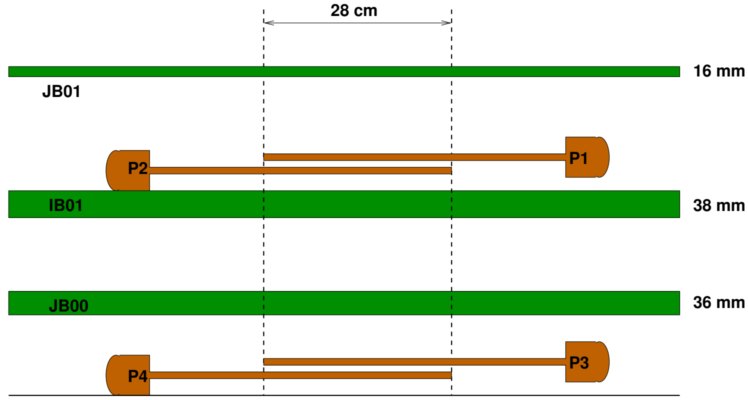


Figure 1: A schematic diagram of the RPC stack, side view. The trigger paddles (scintillators) are also shown. The scale is about 1 : 0.2. [Adapted from Dr Indumathi 's report on the work done at TIFR.]

3.2 High Voltage vs Current Characteristics

The high voltage vs current characteristics (Figs. 2 and 3) for all three RPC s, JB00, IB01 and JB01 were obtained. The HV was varied and the current noted after it had been stabilized. The error bars shown on the graphs are due to the fluctuations of the current meters. IB01 was connected to a NIM module HV power supply having a current resolution of 1nA whereas the other two, JB00 and JB01 were connected to a CAEN power supply having a least count of 20nA. For IB01, the fluctuations were of the order of a few nA. JB00 and JB01 showed higher fluctuations in the readings, which were an order of magnitude greater.

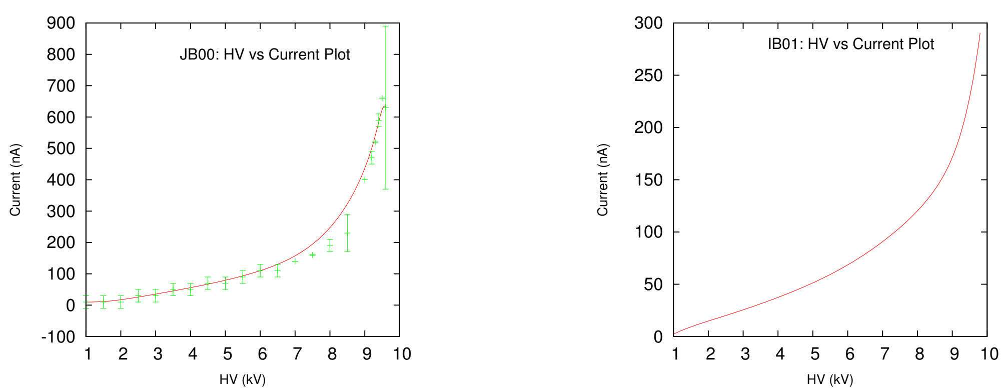


Figure 2: High Voltage vs Current characteristics of JB00 [left] and IB01 [right].

Change in Dark Current due to Temperature and / or Relative Humidity : The changes in RPC characteristics with temperature T were studied. Here, the variation of the dark current with temperature and the variation of the RPC intrinsic noise is reported.

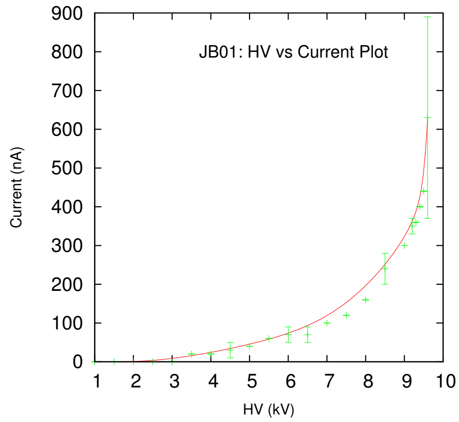


Figure 3: High Voltage vs Current Characteristics for JB01.

JB00 and JB01 were chosen for the study; IB01, because of huge increse in current along with sparking in the gas gap, was not considered.

The general trend found was that the currents drawn by the RPC s increase as the temperature increases. In the C 217 lab, only the temperature could be monitored, by regulating the air - conditioning of the room. The default temperature of the room was around 19.8 °C and the relative humidity (RH), around 52 %. The relative humidity was noted using a sensor but could not be controlled in any way. For the study of temperature dependence of dark current, we have two sets of data:

1. A relatively uncontrolled set where the RH of the room increased with increasing T;
2. A more carefully taken set where we founnd that the RH was high initially (about 77 %)and it decreased over time to a value which was still quite high (around 71 %) compared to the standard value for the lab.

For both the sets, we found that the current drawn by the RPC s increased with temperature, thus overruling the dependence on RH in any way. Three readings for set (1) is given below:

RPC	HV (kV)	10:00 am		10:40 am		10:55 am	
		I (nA)		I (nA)		I (nA)	
		+	-	+	-	+	-
JB00	9200	480	480	460	460	440	440
IB01	9000	850	890	655	675	490	510
JB01	8900	580	620	520	520	460	440
T (°C)		25.63		25.0		23.9	
Rel. Humidity (%)		67.21		60.5		57.9	

For set (2) plots are shown (Fig. 4) for JB00 and JB01 operated at 9.4 kV. The RH is also shown on the same plot, as a function of temperature, although it is strictly not a temperature - dependent parameter.

The noise band of JB01 was very constant at ± 30mV, after passing through a BARC HEX amplifier set at gain 50. It should be noted that due to poor grounding in C 217, the noise levels would sometimes vary and so the absolute value should not be taken seriously. The fact that it was constant and did not change with temperature is important.

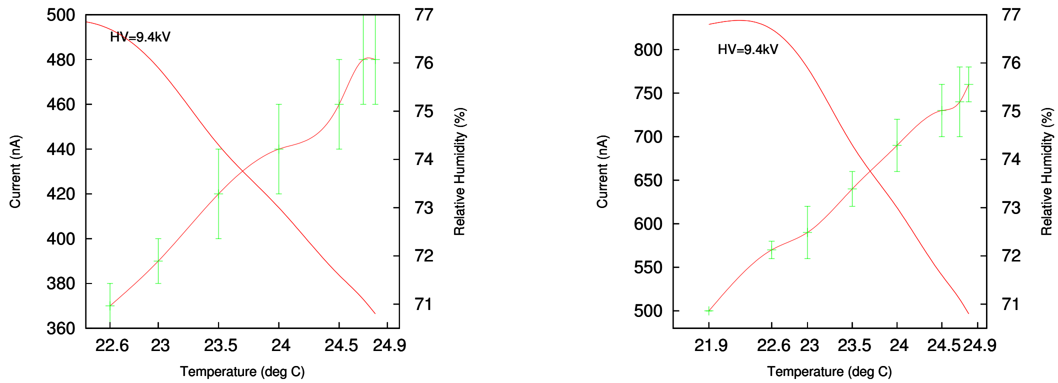


Figure 4: Variation of current drawn by RPC with temperature; the falling graph shows how the relative humidity in the lab changed with temperature for JB00 [left] and JB01 [right].

The noise band for JB00 was not recorded all through the observations but was around ± 2mV as seen on the oscillosccope directly.

Though the noise bands for the RPC s were low and under control, pulse shapes were distorted and the whole screen would be engulfed in bad pulses whenever the RPC s fired. A lot of streamers were seen.

3.3 Efficiency of the RPC s

The efficiency of the RPC s built is one of the most important issues and much effort in the whole study was devouted to it.

The setup used was the same as that of Fig. 1. Of the 33 strips on each side of the RPC s (the strips on two sides were laid out mutually transverse) only one strip was chosen from one of the sides (the top side, for each of the RPC s). This was due to dirth of sufficient electronics and trigger scintillators. Further, as shown in Fig. 1, of the total length of the RPC strips (1 m), only a 28 cm part was chosen by controlling the overlap of the 4 - fold coincidence paddles. The opening angle of the telescope was calculated to be such that its overlap with the adjacent strips didnot execeed more than a couple of millimetres. cf. Fig. 7. This point is important as it points out that the signals we are viewing essentially comes from only the strip (in this case, Strip 4) which is supposed to be in coincidence with the trigger paddles and that only the vertically travelling muons induce signals in the stack. The limitations of this point will be taken up when we present our results on "cross - talk" measurement.

Thus, the aperture so defined for cosmic ray muons to interact in the RPC volume is an area of 28×2 cm^2 of Strip 4 of the RPC s.

The efficiency is defined as

$$\mathrm{E} = \frac{\text{Number of times RPC fires}}{\text{Number of counts registered by the } 4 - \text{ fold coincidence}} \quad (1)$$

The Electronics Involved : Signals from the RPC s were amplified 50 times, sometimes by gain 50 BARC HEX amplifiers or by putting two stages of amplification: a gain 10 preamplifier and then a BARC HEX amplifier set at gain 5. Then the amplified signal was fed to discriminator whose threshold, V_{Th} was set according to noise levels present in the system.

Because of certain unfavourable conditions in the lab such as poor grounding and stray noises which could not be traced, we resorted to manual counting of efficiency by viewing pulses on the oscilloscope. By this, we did not have to worry about noise level all the while and keep on adjusting V_{Th}. Sometimes we viewed RPC pulses directly on the oscilloscope, which were generally good and free from noises; but for recording data, we only accepted pulses that had been amplified, just as they would have been for scaler counting of efficiencies. All through the experiment, V_{Th} had to varied anywhere between -22mV and -50mV! depending on the RPC and the noise at the time.

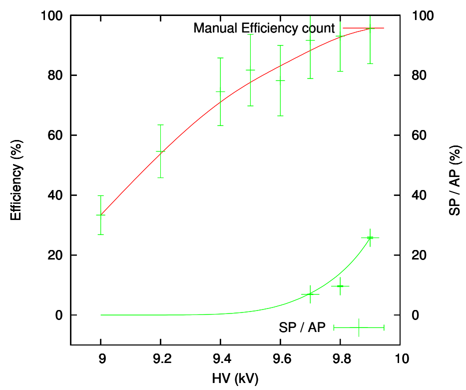
A similar arrangement was made to process the signals from the four PMTs. The discriminator pulses were then fed to a four - fold logic unit (LU) which produces an output only when all signals from all four PMTs are present (ANDing). This we will call the “4f logic pulse”.

We looked at the RPC pulses only when there was a 4f logic pulse, i.e. the four scintillators triggered the RPC s. Before counting the RPC and the coincidence pulses using an electronic scaler, the 4f logic pulse and the raw RPC pulses were seen together on the oscilloscope. It was seen that the RPC pulse arrived about 75ns ahead of the 4f logic pulse. Additional cables were then introduced in the circuit to adjust the RPC signal delay so that it comes within the width of the 4f logic pulse, which was about 60ns. Then the RPC discriminator output and the 4f logic pulse were made into a 2 - fold coincidence and that output was then sent to an electronic scaler to be counted.

Studies were performed on IB01 and JB01 only. JB00 had gain 10 discrete preamplifiers wired to its pick up strips whicih intorduced a lot of noise while amplifying the signal. The output of the preamplifiers were taken via cables which picked further stray noises. For these reasons, JB00 was left out of the study.

Fig. 5 are the efficiency plots by manual counting for IB01 [left] and JB01 [right].The same figures also give the ratio of avalanche to streamer pulses for the two RPC s. For JB01 there are only three counts manually. It is seen that there is a sharp increase in the ratio of streamer pulse to avalanche pulse after about 9.4kV while the efficiency remains more or less constant

Fig. 6 shows the efficiency of JB01 as obtained by manual counting, using HEX amplifier set at gain 50 and a hybrid amplifier from BARC, which has two stages cascaded and of gain 50. It is one of those rare data sets where noise levels were extremely low using all the devices mentioned and clean signals could be seen. For manual counting, the pulses were observed on the oscilloscope after amplification by a factor of 10, using a discrete preamplifier. The noise level was 2 to 4 mV and pulses about 10 to 15 mV typically (after multiplying by 10). All error bars shown are statistical.



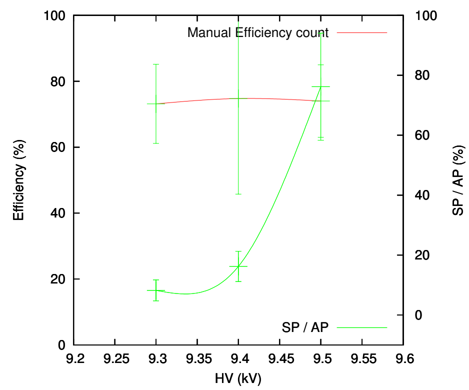


Figure 5: Manual Count of Efficiency for some values of HV alongwith the ratio of Streamer pulses to Avalanche pulses for IB01 [left] and JB01 [right].

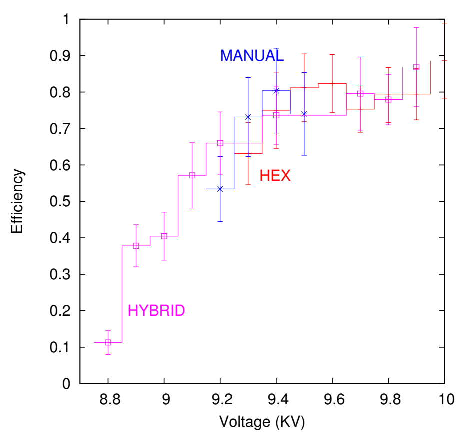


Figure 6: Efficiency vs HV plots for JB01 using manual counting, HEX amplifier and hybrid amplifier of gains 50

The main difference between IB01 and JB01 is that the former has thicker glass plates resulting in more drop of voltage there; thus the effective voltage applied to the gas gap is reduced. This in turn means that the optimal operationg voltage for IB01 is higher than that for JB01 which is clearly seen from the efficiency plots: IB01 reaches its plateau on the efficiency curve later than JB01.

3.4 Cross - Talk

We were interested in knowing how much the signal in one RPC strip affects its neighbours. This is cross - talk. Cross - talk can happen if the ionisation of the gas due to the passage of charged particles doesnot remain confined within a gas volume corresponding to one strip only. This may happen frequently if a large ionisation occurs, or if the ionisation occurs near the boundary between two strips. A further reason for cross - talk would be the induction of signal on the adjacent pickup strips from the central strip. This we would identify as electronic cross - talk.

In the actual case, signals can be seen from to adjacent strips at the same time for a number of reasons. All of them may not be attributable to the above definition of cross - talk. We identify the various causes for this :

1. The real cross - talk, as expressed, above;
2. Misalignment of the scintillator paddles such that the telescope is not coincident with only the central strip;
3. Large opening angle of the telescope such that the adjacent strips also come within its coverage.

The second cause enumerated above is asymmetric in that the coincidence counts for the central strip and one neighbour, towards which the telescope is displaced, will be more than that between the central strip and the other neighbour. This cause was eliminated from our setup.

Calculation shows that the overlap of the adjacent Strips 3 and 5 with the telescope is just 1.6mm for JB01, the RPC farthest from the scintillator paddles. That is a very small fraction of the total width of the strips, which is 28mm and so we also rule out significant contribution to cross - talk study from the third cause. IB01 has no overlap of Strips 3 and 5 with the telescope. Fig. 7 illustrates this. Omitted from the picture are the 2mm gaps between the RPC strips.

Studies of cross - talk was performed on IB01 and JB01. JB00 was not studied for the problem of noise from the connections, as stated above.

The electronics for the cross - talk measurement : As per the previous discussion, measuring cross - talk amounts to seeing signals in either Strips 3 or 5 or both while there is a signal in Strip 4, which is the central strip in coincidence with the telescope. Of course, all thins would be in the present of a trigger signal from the paddles.

But due to shortage of electronics in the lab, we did the following measurements:

- For JB01, we counted the number of times

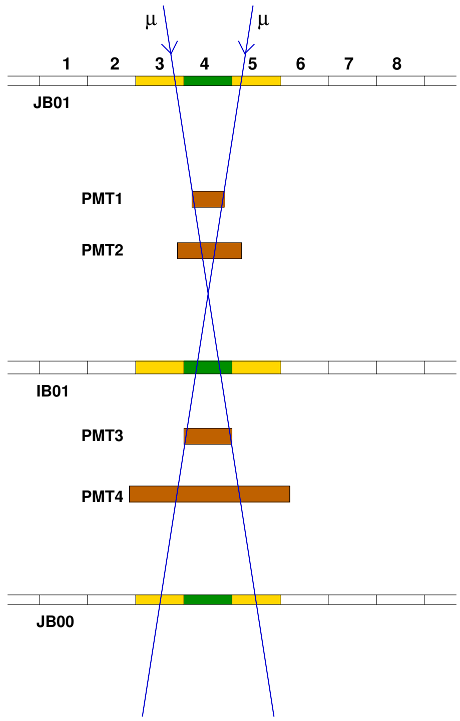


Figure 7: A "backside" view of the RPC stack and the trigger paddles. [Adapted from Dr Indumathi's report on the work done at TIFR.]

1. only Strip 4 fires *and* Strips 3 and 5 donot fire, $\Rightarrow 4 \cap \left(\overline{3 \cup 5}\right)$.
2. Strip 4 fires and either Strip 3 or Strip 5 fires, $\Rightarrow 4 \cap (3 \cup 5)$.

- For IB01 we only counted the number of times either Strip 4 or 3 fired, $\Rightarrow 4 \cup 3$.

So, for JB01, we have the ratio of cross-talk to "no cross-talk", as shown Fig. 8. For IB01, we get the "inclusive efficiency" which is the efficiency of Strips 3 and 4 taken together. Comparing with Fig. 5 [left] we have an estimate of the amount of cross-talk in IB01.

The points marked with + in Fig. 8 [left] correspond to the "total efficiency " of the RPC in the sense that it includes counts from Strip 4 irrespective of whether there was cross-talk or not. Naturally this is greater than the "inclusive efficiency".

It should be noticed that JB01 had a suddn increase in the ratio of streamers to avalances beyond about 9.4 kV. It might be possible that there is a correlation between this and the heightened extent of the cross-talk present in JB01.

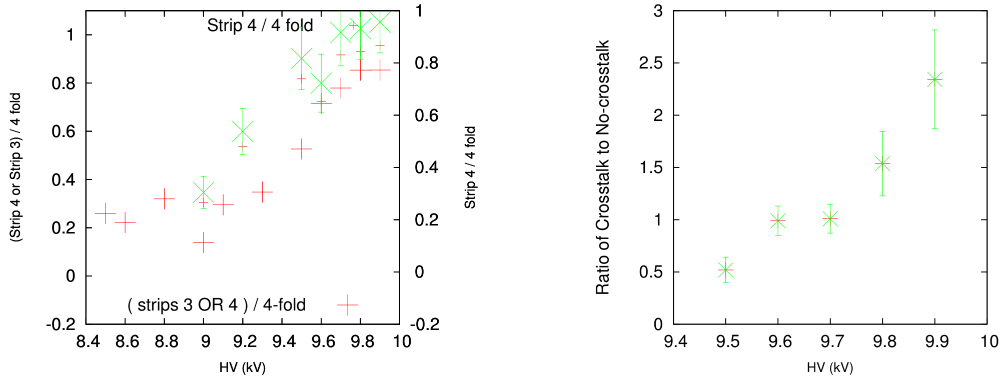


Figure 8: The left panel shows the ratio of Strips 3 or 4 firing in coincidence with the trigger for IB01 (marked with +). As a comparison, coincidence count of strip 4 only, with no information about the adjacent strips, is also given (marked with ×). This is the same plot as in Fig. 5 [left, Manual Efficiency count]. The right panel shows the ratio of Strip 4 firing together with Strips 3 OR 5 to that of Strip 4 firing alone for JB01. This gives an estimate of the extent of "cross-talk" present.

4 Summary

The work reported herein are not all flawless and conclusive for the following reasons:

1. Although the HV vs I characteristics of all the RPCs are quite sound, nothing definite can be said about the variation of current with temperature. There were two parameters, temperature and RH and we could independently regulate only the temperature. Which of those affects the current and upto what extent requires a more careful study.

2. In most cases, the manual efficiency determination of any of the RPCs did not agree with that using an electronic scaler. The reason was that in many of the cases pulses which could be seen on the oscilloscope were not being counted on the scalers and conversely, the scaler would sometimes trigger on the noise as well, which we would never consider as a count while seeing on the oscilloscope. All these happened because the grounding was poor and stray signals were regularly picked up by the cables and the electronics. Further, the preamplifiers we used were not in good shape and the signal shapes were often accompanied by a very noisy baseline.

3. The cross-talk measurement of IB01 was not systematic due to shortage of electronics. For JB01, cross-talk measurement was done systematically with the ambient parameters constant over the data taking period, but the very high level of cross-talk is unexpected. The actual rate of cross-talk needs to be ensured by repetition of the experiment.

4. Inspite of the above-mentioned deficiencies of our study, we may still comment positively about the robustness of the RPCs themselves and the soundness of their performances. The raw pulses seen from the RPCs were clean and the noise levels,

well within tolerable limits. All through their running for some months now, the current drawn have not fluctuated much. Repeated plateauing (process of obtaining efficiency curves) have shown that their efficiencies are stable. The highest efficiency obtained can be further pushed up by choosing much lower V_{Th} than we worked with, once grounding and noise problems, both from the amplifiers and the ambient, are dealt with.

Acknowledgment

This report is a part of the work done by myself and Anirban Saha in the INO labs at TIFR. I would like to extend my gratitude to him for his company and support. I owe a lot to members of INO here at TIFR : B Satyanarayana, G K Padmashree, L V Reddy, Mandar, P Verma, Ravindra, Sarika, S R Joshi, whose contributions, in all ways made the tenure of my project enlightening as well as entertaining. I would like to specially mention Satyanarayana who was my de facto guide and who constantly motivated us throughout our work. Dr Indumathi spent a few weeks with us in the lab and it is impossible for me to over-emphasize her contribution to the completion of our work. Finally, I would like to thank Prof N K Mondal for providing us the opportunity to work in the INO group and for providing us necessary advice and supervision from time to time.

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