Measuring TDC values of AL03 RPC using the Leading Edge Discriminator (LED) and Constant Fraction Discriminator (CFD) in parallel

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Abstract

There are two main factors that define the behaviour of a resistive plate chamber; the spatial resolution and the timing. This report is a study on the AL03 RPC for its timing using both a leading edge discriminator and a constant fraction discriminator connected in parallel. We are testing this to see how much of a difference the CFD makes in the timing of the RPC. Due to the more accurate nature of the CFD we expect better results as compared to the LED. The test strip of the RPC was strip 14, the left strip was the 13th and the right strip was the 15th. A voltage scan from 9.7kV to 10.4kV was done. In these results the timing, efficiency and noise rate is calculated. We get TDC values of σ (LED) = ~1.6ns and σ (CFD) = ~1.4ns. Efficiency of the main strip rises to 95% as we increase in voltage. A noise rate is also calculated for each of the HV runs. Further data can be taken to obtain the plateau curve of the efficiency.

1. Introduction

The neutrino; probably the most mysterious particle we have encountered in the standard model. First postulated by Wolfgang Pauli to explain how beta decay could conserve energy, momentum and angular momentum. The neutrino is now an imperative part of universe we live in. However, there are still many things about it that are unknown, like its mass and mixing parameters.

India has taken the initiative to create the most high-tech detector to probe further into properties of the neutrino. The India-based Neutrino Observatory (INO) will consist of an iron calorimeter (ICAL) with 50000 tonnes of magnetised iron plates put in stacks within which there will be small gaps where resistive plate chambers (RPCs) will be housed. The RPC is 2m * 2m and 29000 of them will be needed to act as the active detector within the ICAL. The INO needs precise timing capability to distinguish neutrinos coming from up or down. The only difference between them would be that the ones coming from up will have travelled 40-60km through the atmosphere before hitting the detector where as the ones coming from down will have travelled almost the diameter of the earth ~1200km before hitting the detector.

Currently, a leading edge discriminator (LED) is used to trigger these events. It works with a constant threshold but for pulses with different amplitudes, this method may miss actual data. To overcome this, a constant fraction discriminator (CFD) is used, where no matter the pulse height the event is triggered at a constant fraction value of that pulse. What my work aims to do is to compare these values in parallel to see if the result produced is the same as measuring them separately. The main advantage of putting the CFD and LED in parallel is that other systematic errors are reduced.

This report gives results of the timing (TDC) value, efficiency and the noise for an RPC from 9.7kV to 10.4kV. This is the region in which the RPC will be used.

2. Theory

The main theory in this experiment is seen through how the RPC works and how the triggering system used to measure the timing precision of the RPC.

The RPC:

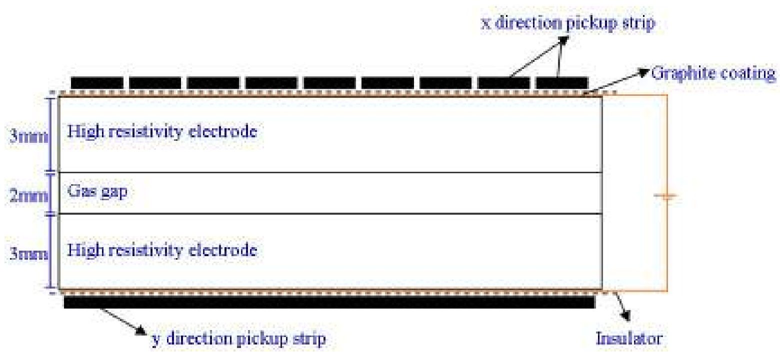


*Figure 1: cross-section of an RPC with different layers up till the pickup strips. The gas gap is held using 2mm thick spacers which are not shown in the diagram, the edges are glued together and an input and output nozzle for the gas is attached on each side. The size of the RPC is 2m * 2m.*

The RPC in basic terms is a gas detector with semi-resistive electrodes on both s ides and a gas gap in between. A set gas mixture is used to allow for the avalanche or streamer processes in the gas before a pickup strip obtains the signal. In the RPCs for the INO experiment, the pickup strips are positioned in the x and y direction to allow for higher spatial and timing precision when taking data. Figure 1 shows a cross section schema of a RPC. Two main properties that can be measured in an RPC are the spatial resolution and the timing precision. We are working towards better timing precision.

Triggering and errors:
As mentioned before, the triggering of the event data is the most important part of the experiment, a small mistake in the threshold could leave us with no useful data at all. While triggering we also have to take into account the errors associated i.e. walk and jittering effects. Walk is seen when there are two signals with different pulse heights but the same coincidence times (Figure 2). At a fixed threshold the discriminator

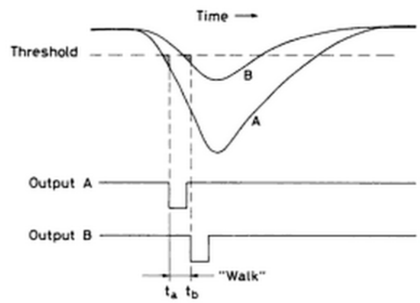


Figure 2: two signals with the same rise time but different heights causes a walk error as the trigger is not doing much between triggering the first and second signal. This is what causes the walk error.

will trigger at t_a for the

first signal and at t_b for the second signal, during which time the logic signal 'walks' about. Timing fluctuations can also be cause by noise and statistical fluctuation in the original detector signal. For this reason, two identical signals from the detector may not be triggered at the same time, thus giving us time variation as a function of amplitude of fluctuation, also known as jittering effect.[1]

LED vs. CFD
The LED gives us good information when the rise time and the amplitude of the signal is the same. It is particularly good for small amplitudes but a walk effect of ±10ns seen more in the amplitude range of 1 to 10. The easiest way to overcome this effect is to reduce the threshold value; however by doing this the signal being picked up is also that of background noise.
The CFD is a very accurate instrument. It uses a constant fraction of the signal as the trigger of the signal. When a signal is given to the CFD, two copies are made; one kept the same, the other is inverted with a change in amplitude by a constant fraction. These signals are summed together to find the 'zero point' of the total signal. This point acts as the trigger for the signal (shown in figure 3). The main advantage of the CFD is that it does not need a bipolar input signal.

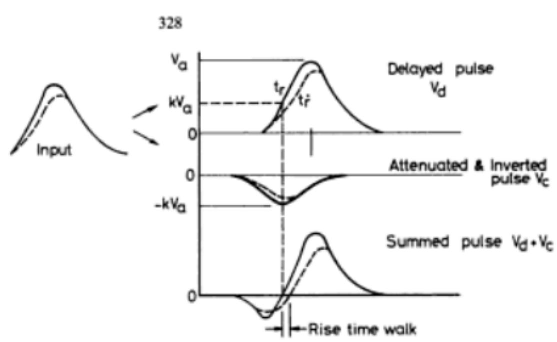


Figure 3: shows constant fraction triggering (CFT) technique. For CFT to work well, signals must have the same rise times else a walk effect is present (as seen by the dotted signal).

[1] Techniques for Nuclear and Particle Physics Experiments: A How-To Approach, By William R. Leo

TDC, efficiency and noise

TDC is also known as time to digital conversion. This is a value we find using the electronics to get the timing of the RPC usually represented as σ. We obtain TDC values from the electronics but efficiency and noise rate come from the data analysis. The efficiency is calculated by a simple formula, *Efficiency of strip = (No. of hits on the strip AND trigger events)/Total no. of triggered events (%).* The noise rate is obtained by taking an average.

3. Experimental method

Before any measurements are taken the RPC is flushed with Isobutene (4.5%), Freon R134a (95.4%) and SF6 (0.2%). The HV is ramped up to 10.4kV and the electronics are set up as shown in figure 4. As we are measuring the LED and CFD TDC values in parallel we use a FIFO unit to give us more fans of the signal. A trigger is set between the top and bottom paddle after which a 3fold coincidence is done with the LED to get efficiency values of the strip. The chosen main strip for this experiment is strip no. 14. Strip 13 is therefore the left strip (LS), and strip 15 the right strip (RS). The paddles are placed on top of the main strip. The wires delay the signal by 5.2ns every meter and this is usually done to reduce errors caused by the jitter in a signal. The LED threshold is set to -20mV. For the CFD, the main strip threshold is set to -20.0mV, LS threshold = -21.2mV and RS threshold = -21.0mV

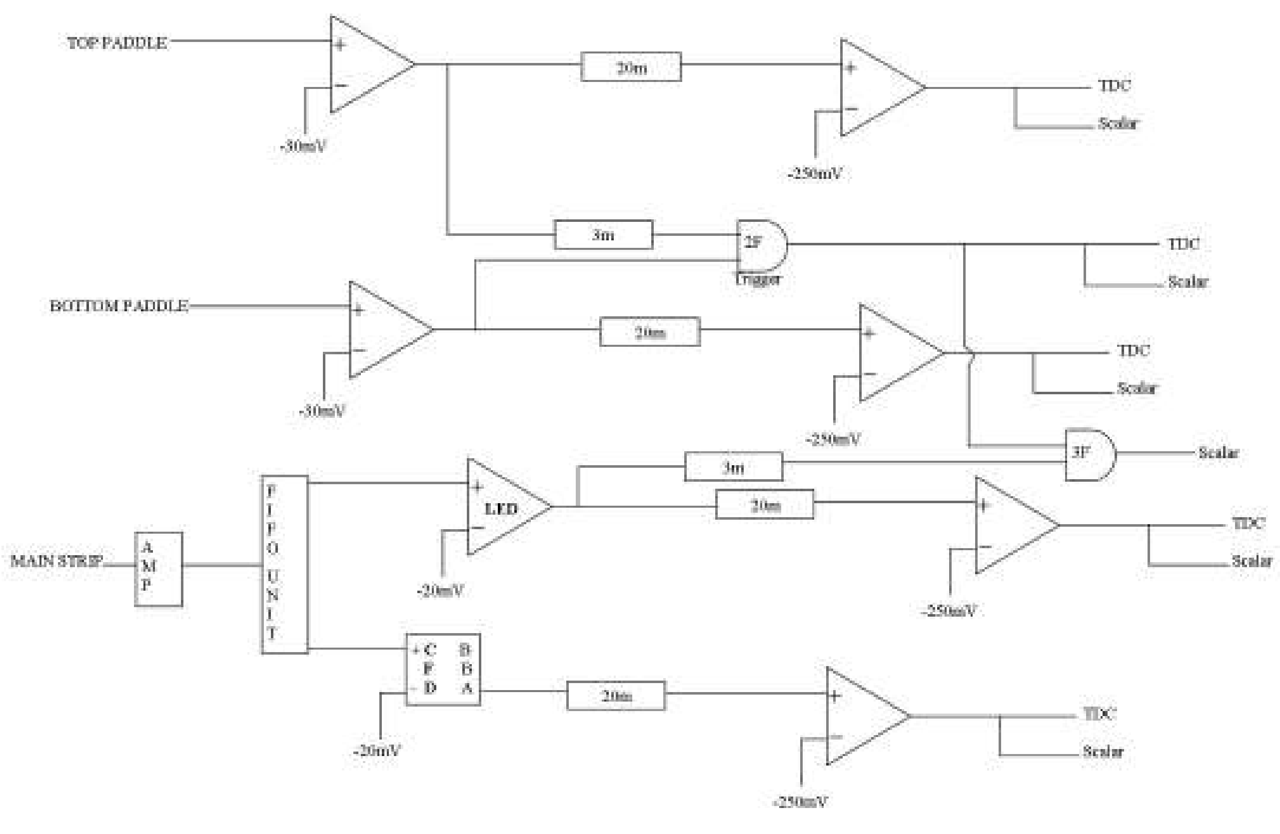


Figure 4: Electronic setup of the experiment. The fan in fan out unit is used to connect the LED and CFD in parallel. Delay boxes of 20m and 3m are used to reduce the jitter in the signal. Additionally, a 2 fold coincidence is first performed with the top and bottom paddles after which a 3fold is done with the LED output, this is then used to calculate the efficiency of the strip.

Figure 4 shows the set up for the main strip, the LS and RS are set up in the same way.

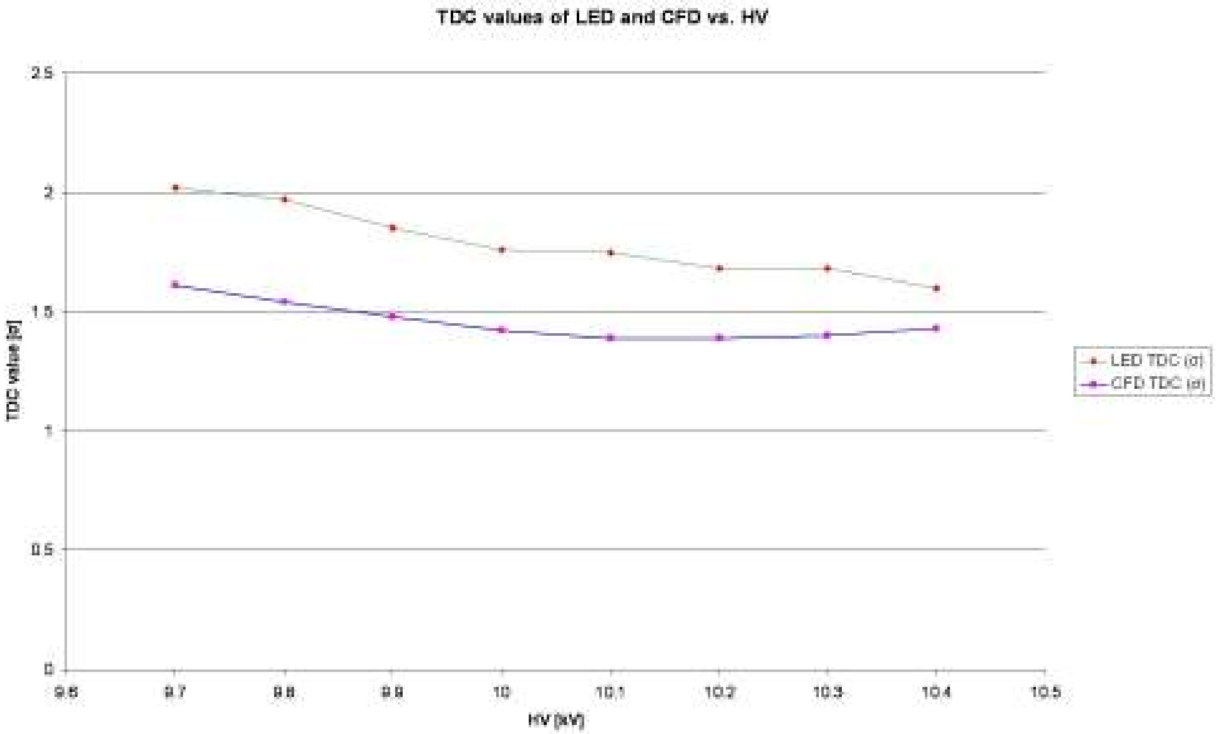
The RPC is used in avalanche mode. A uniform electric field is applied between the gas gap. Ionisation occurs when a charged particle passes through the gap and this initiates the avalanche process. The electrons drift towards the anode where as the ions drift, relatively slowly due to their size, towards the cathode. When the charges reach the resistive layers, a small area around them is influenced due to their electric field. Another mode that the RPC can be used in is streamer mode; this has a different combination of gasses where by the readout signal is so high that there is no need of amplification. The process still undergoes the initial ionisation but the result of this is large distortions in the electric field of the gas. Photons also contribute to the rate and rapid growth of the avalanche and eventually there could be a local discharge in the gap. Over time, this will hinder the performance of the RPC however, using streamer mode will give you signals that need to attenuation or amplification before analysis. We opt for using avalanche mode as we are looking for long term usage in the INO experiment.[2]

After the set up and HV ramp up, data acquisition can start. From data analysis we will obtain TDC values, noise values and trigger coincidence values from which we can calculate the efficiency of the strip. These results can be compared to see how much of a difference using the CFD makes as opposed to using the LED in reference to the timing of the RPC.

[2] Design and Characterisation Studies of Resistive Plate Chambers, PhD. Thesis by Satyanarayana Bheesette

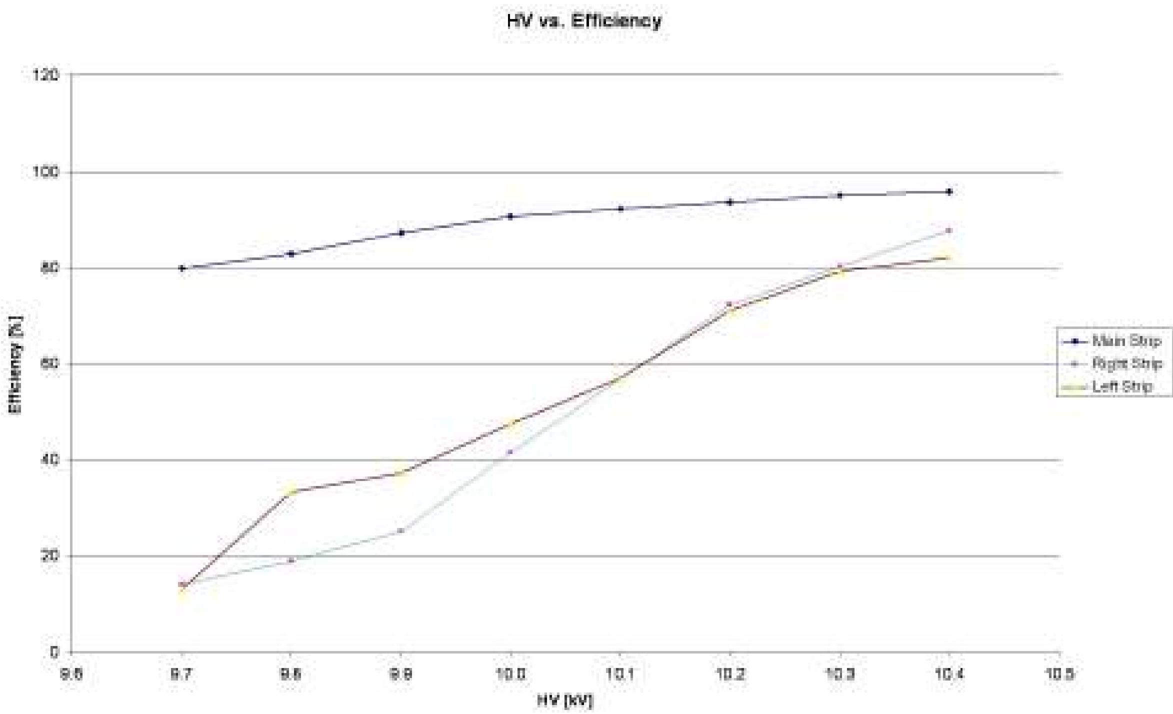
4. Results

There are three sets of results that we compare: timing, efficiency and noise. It is to be noted that the 9.7kV run was taken after ramping down from 10.4kV and waiting for ~24hrs.
The differences in TDC values of the LED and CFD are shown in plot 1.

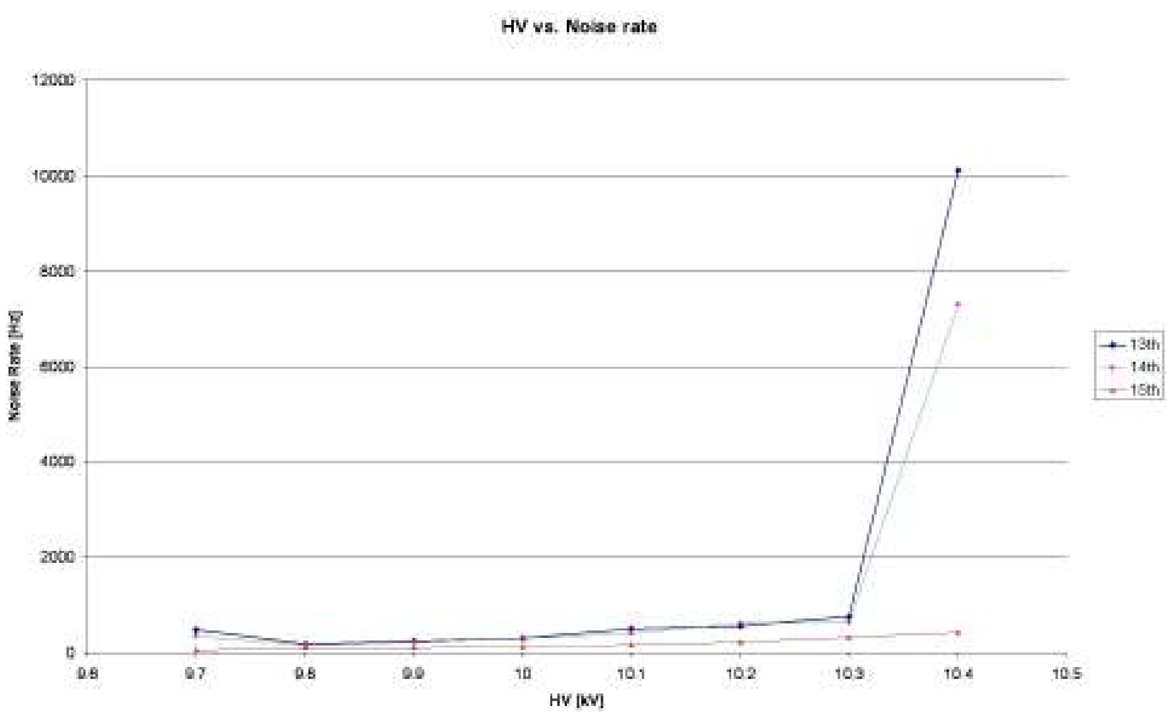


Plot 1: shows the TDC values of the LED and the CFD as a function of high voltage.

The efficiency of the strip is calculated using the triggered events and looking at the coincidence of them with the top and bottom paddle along with the strip itself. This setup uses the LED to calculate the efficiency and it is shown in plot 2.
The last thing that was analysed was the noise. This is a very important factor in measurements because you want to keep it as low as possible so that it doesn't interfere with the data acquisition. Sometimes the efficiency of the strip might be ~95%, at first glance that seems like a good value, however if in that run the noise is too high, the trigger could have detected more noise events compared to real data thereby increasing the efficiency of the strip. Plot 3 shows the noise rate vs. the high voltage. The steep increase from 10.3kV to 10.4kV it was expected because at such high voltages, very small signals can be picked up from the background.



Plot 2: the efficiency as a function of high voltage as measured by the LED



Plot 3: The noise rate as a function of high voltage, the sudden spike up is expected at such high voltages

5. Discussion and summary

From plot 1 we can see that the CFD does give us a better timing value. This is what is expected due to the more complex nature of the CFD and the way that it triggers its data. The number of events triggered by the CFD is less than the LED because the LED has a constant threshold. At that threshold even noise or unwanted data can be produced and triggered. The CFD is a very good method to use and gives much better timing information for the RPC.

Plot 2 shows the efficiency of our main strip, RS and LS. As expected the main strip efficiency is above 95% which is what the INO needs. The LS efficiency at points 9.7kV and 9.8kV give a dip. It could be that the 9.8kV efficiency was higher than normal in this case however as a trend, both the LS and the RS efficiency start at approximately the same level and rise to approximately the same level as well.

The noise plot, plot3, is an important plot to look at when comparing efficiency and timing values. Our main aim is to make sure that the data that is shown in plot 1 and 2 is due to actual event data and consists of as less noise as possible. Through the voltage scan the noise level is quite minimal. The 10.4kV run shows just how sensitive the detector will be when it is on such a high HV. There is a small variation in the 9.7kV run, however that could be due to the ramp down from the 10.4kV. The RPC will ideally be running at 10kV and at this point the noise level is in a good region to acquire true event data.

As a continuation to this experiment, one may want to take readings from 9.2kV up till 10.4kV to get a plateau curve for the efficiency and the timing values.

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