Timing performance measurements of the INO-ICAL Resistive Plate Chamber (RPC) using Constant Fraction Discriminator (CFD)

Submitted in partial fulfilment of the requirements

For the

Visiting Student Research Program 2012, TIFR, Mumbai

June 29, 2012

Submitted by

Harsh R. Shah

SV-NIT, Surat

Project adviser:

Dr. B. Satyanarayana

TIFR, Mumbai

Index

Abstract:
2m×2m glass Resistive Plate Chambers (RPCs) are proposed to be used in INO's ICAL detector. We have studied one such RPC for its timing performance using two different methods. The leading edge triggering is commonly used in various High Energy and nuclear physics experiments. Constant Fraction Discriminator (CFD) is an advanced method for cosmic ray muons, which is used for more precise timing measurements. We used ORTEC made CF8000 CFD NIM module. The trigger is generated by a couple of 2cm×30cm scintillators mounted above and below the test strip of the RPC. Timing data is acquired by a CAMAC based Philips scientific Time to Digital Convertor (TDC) module. We have also studied efficiency of the RPC under test. Studies with the CFD were also carried out at various internal delays and threshold settings. We have also observed RPC noise rate variation as a fraction of the discriminator threshold.

Introduction

Neutrinos are the most fascinating research topic in the particle physics for several decades. Neutrinos are fundamental particles of the lepton family whose mass is not yet known precisely. They possess many other mysterious properties like phase transition, handedness, very small interaction cross section etc. There are many detectors worldwide for studying neutrinos but many more sensitive detectors are needed to solve many challenging problems related to neutrinos. In this context India has taken an initiative to build a massive neutrino detector, which can solve some of the atmospheric neutrino problems as its primary goal.

The India based Neutrino Observatory (INO) [1] program requires a detector which can distinguish up going and down going neutrinos. The directionality of the detector is obtained by its time resolution. The down going neutrinos travel around 40-60 km distance in the atmosphere before they reach to the detector while upcoming neutrinos cover more than the diameter of the Earth (~12,000 km) before reaching to the detector. As they travel almost with the speed of light, highly precise timing capability is required to distinguish their directionality.

Most common method of a discriminator used with the RPC detector is the leading edge triggering, which works at constant threshold voltage. This method is not reliable for dealing with pulses of different amplitudes. In such cases, Constant Fraction Discriminator (CFD) is a better technique. CFD operates at constant fraction of the input pulse amplitude. More details regarding these techniques can be found in the later part of this report.

We have studied with both the above mentioned techniques on a 2m×2m RPC operated at avalanche mode. We begin this report with provide some basic information of RPC parameters. It is followed by schematic diagrams of our experiment set up and procedure. Then, results of our studies are shown followed by discussion and conclusions.

Resistive Plate Chambers (RPC)

The RPCs, which are going to be used in the INO Iron Calorimeter (ICAL) detector, are an advanced version of gas detectors. It is a type of spark chamber with resistive electrodes. The cubic structure makes them easy to handle. The most striking advantage of this structure is that potential difference remains constant throughout the surface of the detector. Hence spacial and time resolutions are expected to be better than that of any other gas detector system.

RPCs for INO project are made up of two parallel electrodes (each 3mm thick), of float glass with a volume resistivity of 10^{12} Ω-cm, and with a spacing of 2mm, maintained by means of highly insulated spacers. A suitable gas mixture at slightly above atmospheric pressure is circulated through the gap and an appropriate high electric field is applied across the glass electrodes through a resistive coating of graphite on their outer surfaces. The gas mixture is required for the multiplication of charge produced when some charged particle passes through the gas volume, and ionize the gas volume.

Due to high resistivity and quenching characteristics of the glass electrodes, the discharge is limited to a tiny area of about 0.1cm^2. This discharge induces an electrical signal on the external pickup strips, mounted orthogonally on both sides of the RPC unit, orthogonal to each other. It can be used to record location, and time of ionization. The discharge area recharges slowly through the high resistivity glass plates. The structure of a glass RPC is shown in below, [2].

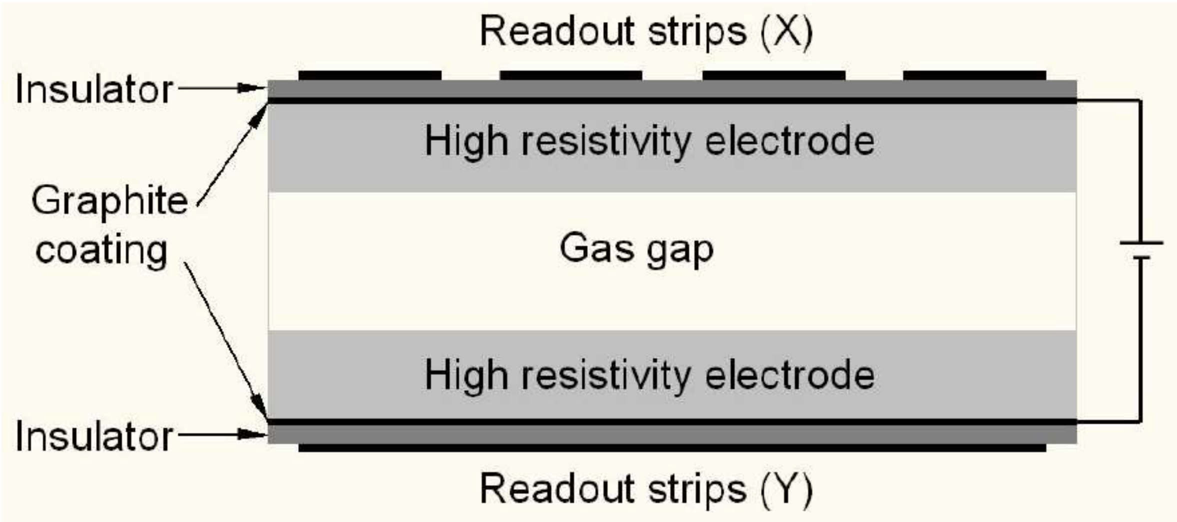


Figure 1: Schematic diagram of a basic RPC

Specifications of the RPC:

1. Dimensions of RPC= 2m x 2m.
2. Thickness of glass electrode=3mm.
3. Gap between two glass plates=2mm.
4. Width of pick up strips=28mm.

Modes of operation

RPC can be operated in either streamer or avalanche mode. In the ICAL, RPCs are proposed to be operated in avalanche mode.

a. Avalanche Mode:

Charged particles passing through the gaseous medium produce primary ionization. These ionized particles are accelerated by electric field thus producing secondary ionization by colliding with the gas molecules. This avalanche stops as the external field opposes the internal field due to ionization and the charges get collected on the respective electrodes. This mode operates at a lower voltage and typical pulse amplitudes are ~mV and hence external electronic amplifiers are required in the signal readout system.

b. Streamer mode:

In this mode the avalanche generated is followed by a streamer discharge. The secondary ionization continues until there is a breakdown of the gas and a continuous discharge takes place. This mode operates at a higher voltage and also results in high gain. Typical pulse amplitudes are of the order of 100-200 mV. The electric field inside the gap is kept intense enough to generate limited discharge localized near the crossing of the ionizing particle. Due to the relatively long relaxation time of the resistive electrode, this mode is preferred only for cosmic ray and low-rate accelerator experiments.

Time measurement techniques

In any detector apart from identification of types of particles various other parameters are there to be measured (e.g. energy, momentum, etc.). To study all these properties two aspects of a detector play vital role (i) spacial precision and (ii) timing precision. The sensitivity of any detector is directly dependent on these two parameters. In our project we are concerned about the timing precision of the ICAL detector element i.e. RPC.

Errors

There are mainly two types of errors which may occur during the timing measurements walk and jitter.

Walk

The walk is mainly concerned with the delay in timing while measuring time at constant threshold voltage. It appears when two different signals with variation in amplitude and/or rise time. As a result a signal with higher amplitude crosses the threshold earlier than the one with smaller amplitude, as shown in figure 2(a).

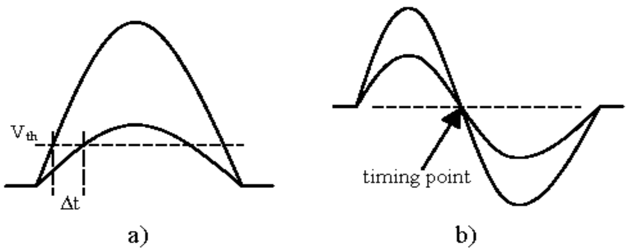


Figure 2: walk error

Another reason for walk is that a specific amount of charge deposition is required to trigger the discriminator. Due to variation in rise time and amplitude, this will also contribute to the time walk.

Jitter

Jitter is an effect of electronics. For any signal, a small component of noise is always there with it. Therefore when a signal is zoomed in at the point where it crosses the threshold, we find that a small time uncertainty is present for similar signals due to system noise. Jitter can be minimized with modified instrumentation but it cannot be completely eliminated.

Time measurement techniques

There are four methods to measure time.

1. Leading edge trigger (LE)
2. Fast zero crossing triggering
3. Constant fraction discriminator (CFD)
4. Amplitude and rise time compensated triggering (ARC).

Experiment setup

For our experiment, we studied the RPC time performance using leading edge triggering which is a well known conventional method used in many nuclear physics experiments. It will also be used in ICAL. We also looked into a more advanced technique, which is of constant fraction discriminator. Due to its complexity in implementation and operation, it is not much preferred. The advantage of CFD over LED is its time walk reduction as it operates on a fraction of input signal amplitude as threshold.

Our project is mainly concerned about timing measurements of 2m $\times$ 2m RPC. We chose AL-03 RPC's 20^{th} strip as main test strip. For studying cross talk information, we have also connected left and right strips of the test strip with the NIM module. The trigger is generated by two plastic scintilators one is over the strip and another is below the strip. The trigger area covered is 30 cm $\times$ 2 cm. Signals we are dealing with are of changing rise time with changing amplitude type. Gas mixture used is: Iso-butane 4.3%, R134a 95.5 %, SF_6 0.2 %.

LED NIM module using a NIM Philips model no. 706.

Module specifications:

1. 8 inputs with each individual input have two output ports.
2. There is a common threshold and width adjustment facility for all 8 inputs.

CFD NIM module is OCTAL CF8000 [4].

Module specifications:

1. 8 inputs each individual input have two B output with width adjustment and an A output with dead time adjustment facility.
2. Each input has individual threshold modification facility ranges from -10 mV to -1 V.
3. All 16 B outputs have common width adjustment point. All 8 A outputs have common dead time adjustment point. Both can be vary from 20 ns to 200 ns.
4. In this module there is internal walk and jitter adjustment facility.
5. There is a factory made internal delay facility with 5 different configurations (2ns, 4ns, 6ns, 8ns and 10ns) for every input.
6. The factory set fraction is 0.4.
7. There are several additional facilities like automatic walk adjustment, ECL o/p, multiplicity o/p, OR logic o/p, analog sum o/p etc.

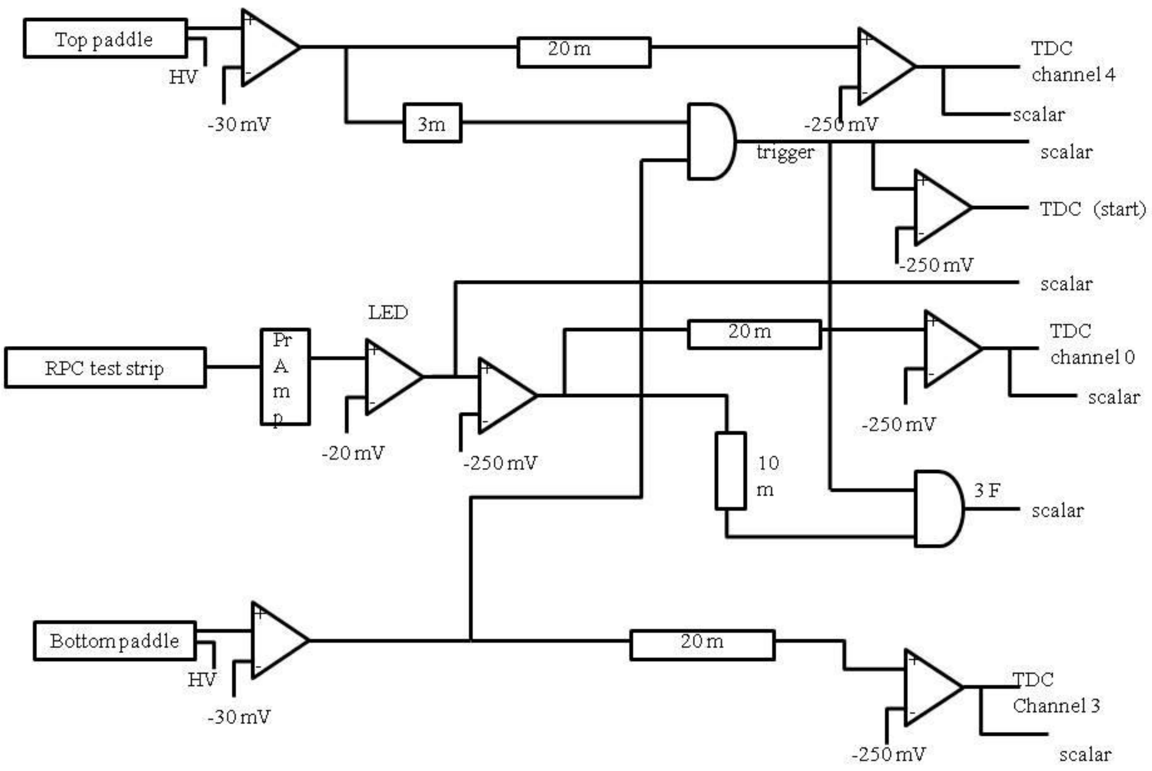


Figure 2: Leading Edge Discriminator experiment set up

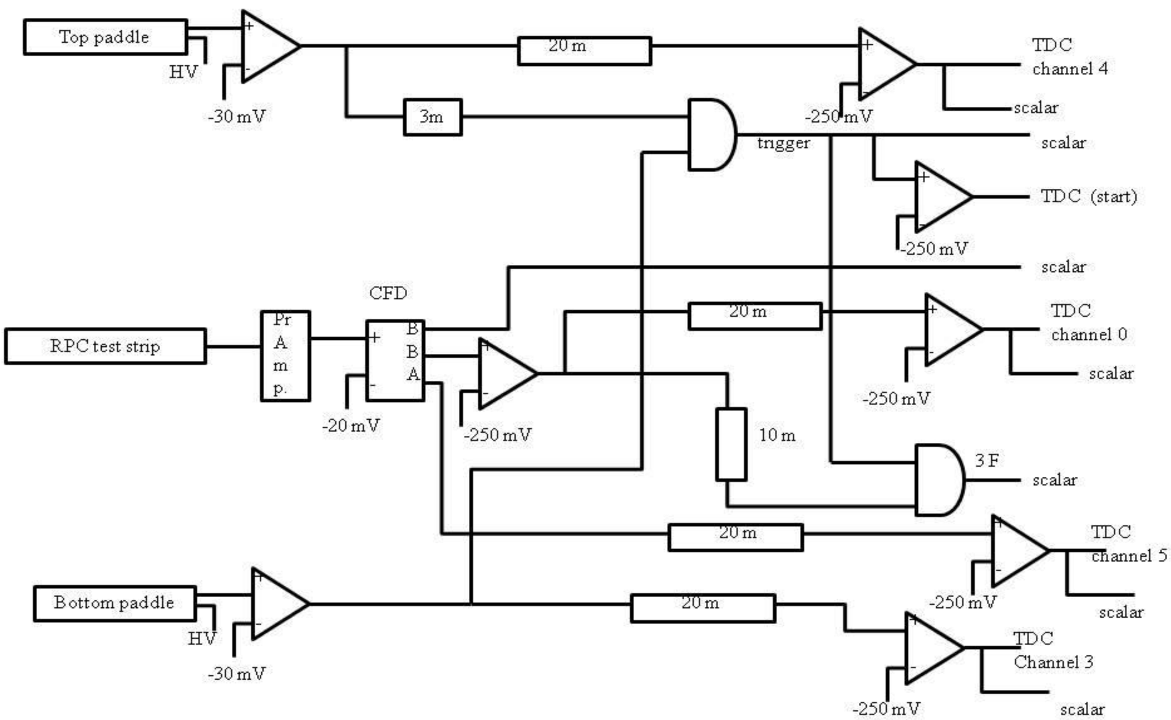


Figure 3: Constant Fraction Discriminator experiment set up

Experiment

The experiment procedure is as below. For LED setup refer (figure 2) and for CFD setup refer (figure 3):

1. Top and bottom scintilators are aligned over the 20^{th} strip for coincidence of events.
2. Both the scintilators are connected to discriminator (V_{th}= -28.2mV) to generate logic pulse. The top paddle is delayed by 3m (15.6 ns) co-axial cable and AND gated with the bottom paddle to generate trigger.
    a. The delay is generated to avoid jitter contribution of both the signals at the trigger. Because trigger is the one with respect to which the TDC of test strip is calculated. Hence least error contribution is expected in the trigger.
3. Now the test strip o/p coming from preamplifiers is connected to discriminator (V_{th} = -20mV) to obtain logic signal.
    a. Preamplifiers are required because signals generated at RPC pickup strips are of very low amplitude.
    b. Before connecting these amplified analogue signals to discriminator we have connected them to CRO and observed signal characteristics.
    c. In the CFD we gave analogue signals to CFD NIM module i/p at -20mV threshold.
4. The individual paddle's signal is moved via 20m co-axial cables to discriminators (V_{th} = -250mV) and their o/p are connected to scalar and TDC channel no. 3 (bottom paddle) and 4 (top paddle).
    a. To TDC for time resolution and to scalar for noise rate counting.
5. The trigger generated is moved to scalar and to an i/p of AND gate for 3 fold generation with the test strip o/p. Another trigger o/p is connected to the inpout of TDC via discriminator (V_{th}= -250mV).
6. The logic signal of test strip is connected to scalar for noise rate counts and another logic output is supplied to input of a discriminator (V_{th}= -250mV) from which one output with 10m delay connected to another input of AND gate for 3 fold generation which again goes to the scalar.
7. Another output from second discriminator is moved with 20m co-axial cable ended at the input of a discriminator (V_{th}= -250mV) whose output is connected to the TDC channel no. 0.
8. The right and left strips are also connected via same path as mentioned in steps 6 and 7. Their TDC channels are 1 (right strip) and 2 (left strip).
9. In the case of CFD technique there is small modification for steps 6 and 7.
    a. The one B o/p is connected to the scalar.
    b. Another B o/p is connected to discriminator (V_{th}= -250mV) whose one o/p goes to 3 fold i/p via 10m co-axial cable and another o/p is transmitted through 20m co-axial cable to i/p of a discriminator (V_{th}= -250mV) and o/p of this discriminator goes to i/p of TDC channel no. 0.
    c. The A o/p is moved through 20m co-axial cable to discriminator (V_{th}= -250mV) and o/p of it is connected to the TDC channel no. 5.
    d. Same steps (a, b and c) are followed for right and left strips. The A o/p of these strips are connected to TDC channel no. 6 (right strip) and 7 (left strip).

Results

Efficiency of RPC

The plot of efficiency as a function of operating voltage is shown below for the test RPC. The efficiency of the RPC goes above 95 % at around 10 kV operating voltage. We operated RPC at 9.8 kV during our experiment.

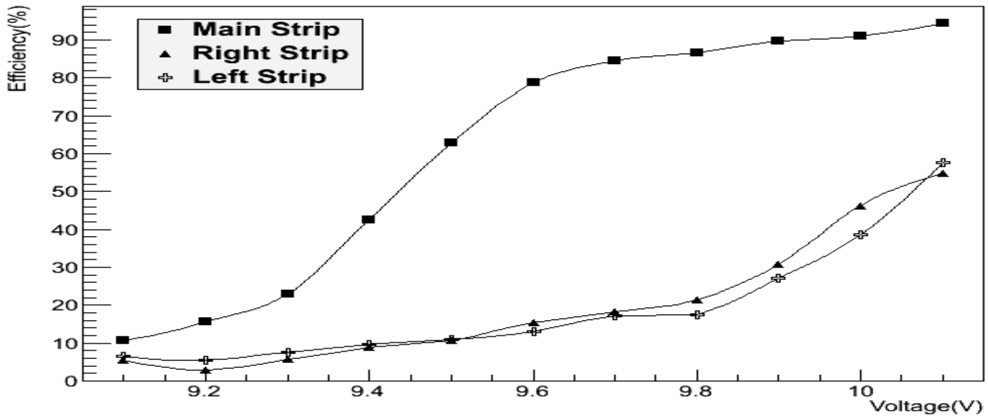


Figure 4: Efficiency vs. operating voltage (kV) of test RPC.

Analogue signals

Analogue signals we are dealing with, have amplitude variation from 40mV to 160mV and rise time variation from 1.92 ns to 4.83 ns.

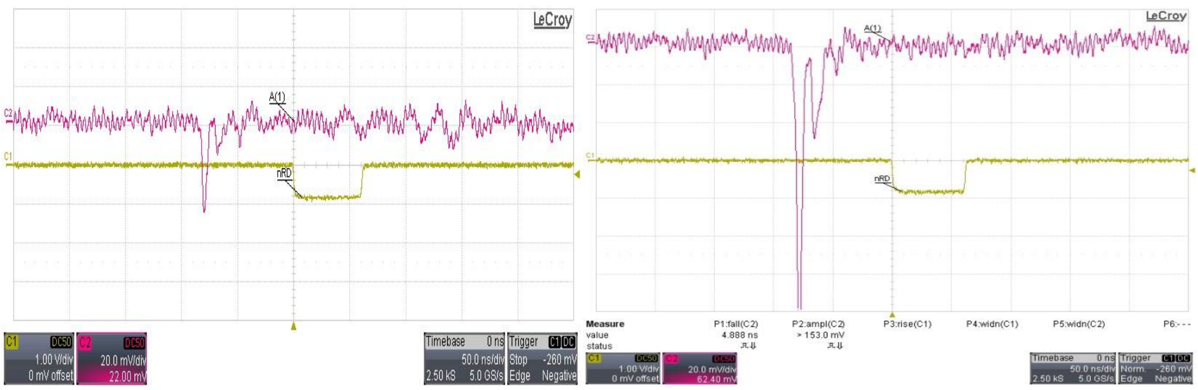


Figure 5: Above figures are obtained from CRO which show that signals have amplitude as well as rise time variation.

Constant threshold discriminator

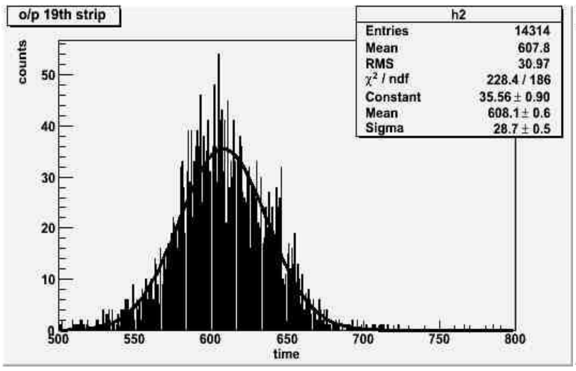
It is simplest method for deriving timing logical signal. In this technique the logic signal is generated at the moment when it crosses the threshold. An alternate method is to trigger on the falling edge.

In this method walk plays major role in error. But for small amplitudes this method can give good results. But for 1 to 10 range of amplitude the walk error goes to $\pm$ 10 ns [4].

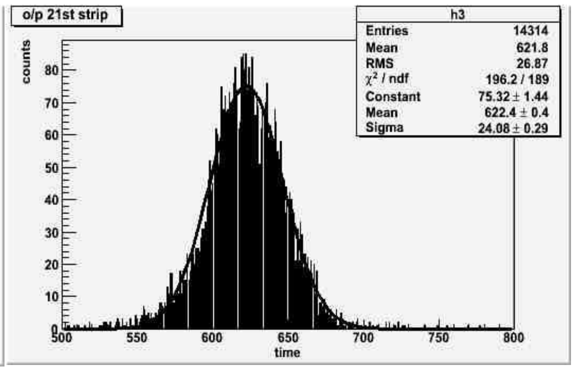
Walk can also be reduced by keeping threshold low enough as permitted by electronic noise. This is easily verified that by lowering threshold line.

TDC results

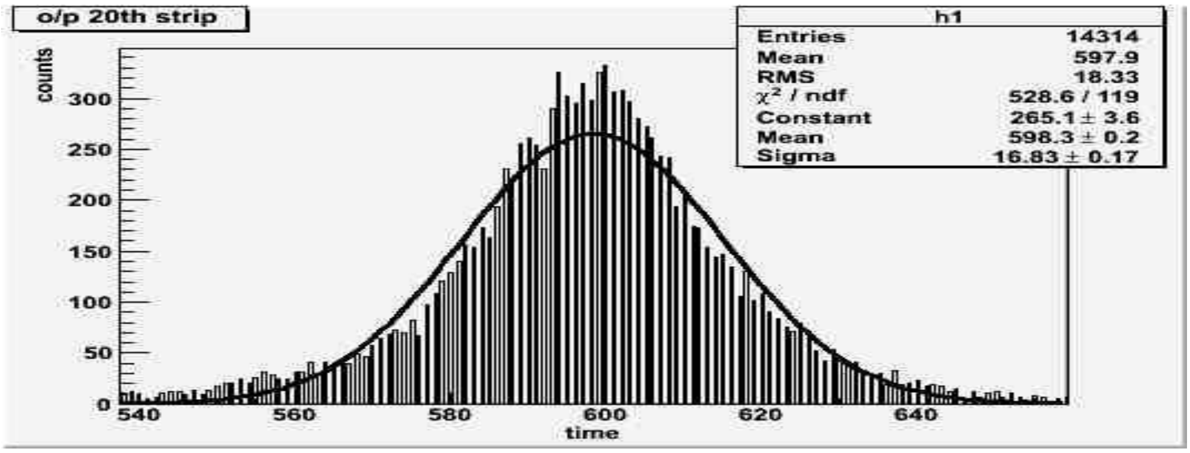
Results obtained for LE triggering are shown below for various strips. We obtain best σ value by LED is 1.683 ns. The threshold is set at -20 mV.



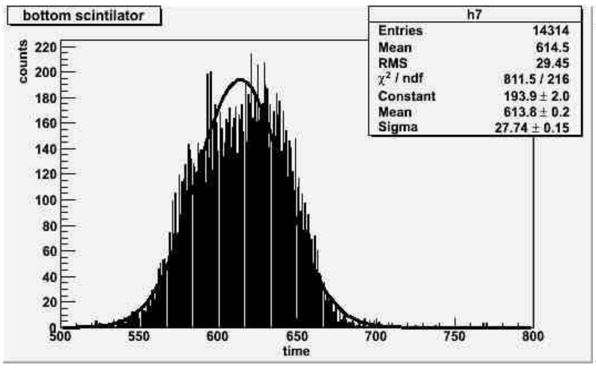
(a)Right strip



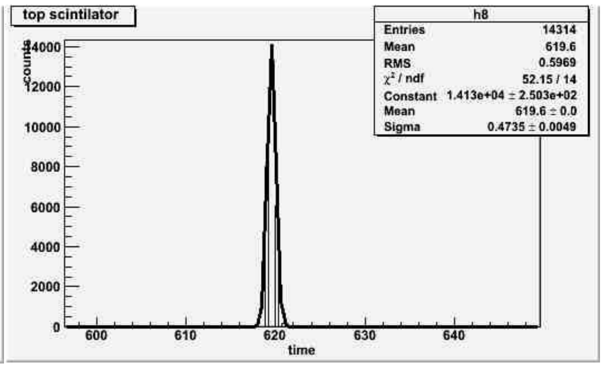
(b) Left strip



(c) Main strip



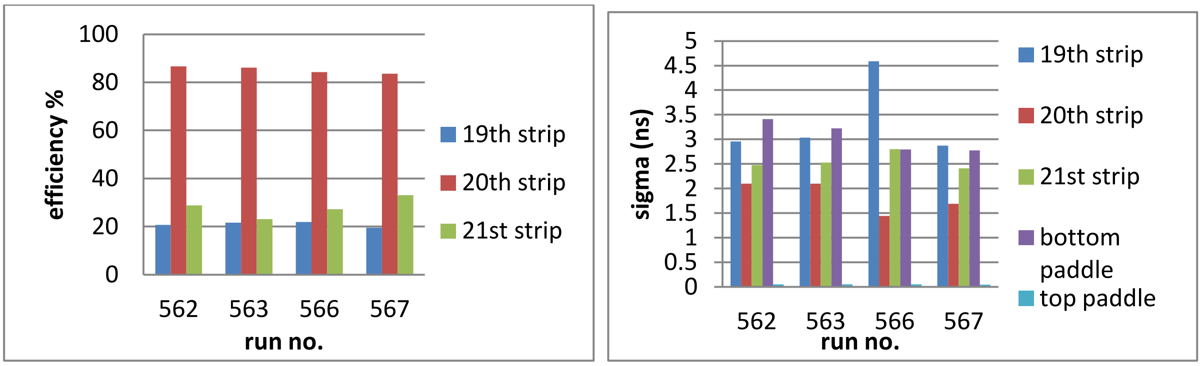
(d) Bottom paddle



(e) Top paddle

Figure 6: Results obtained from leading edge triggering TDC outputs. The σ value in ns can be obtained by multiplying the sigma value with 0.1 ns; least count of TDC.

The efficiency of test strip and strips besides test strip in LED for different scintilator conditions are shown as below with sigma values in the plot (b):



(a) (b)

Figure 7: Efficiency plots of RPC strips under observation at different run conditions. (a) (i) run 562 is with 2 cm wide bottom scintillator, (ii) in 563 3 cm wide scintillator is at bottom (iii) 566 and 567 are with both top and bottom scintillators are of 2 cm width. (b) The σ values for different run are also shown below along with that of bottom and top paddle.

We have also obtained results at strip no. 9 of the RPC and results are shown below where efficiency of test strip is 89.24 % and σ = 1.89 ns.

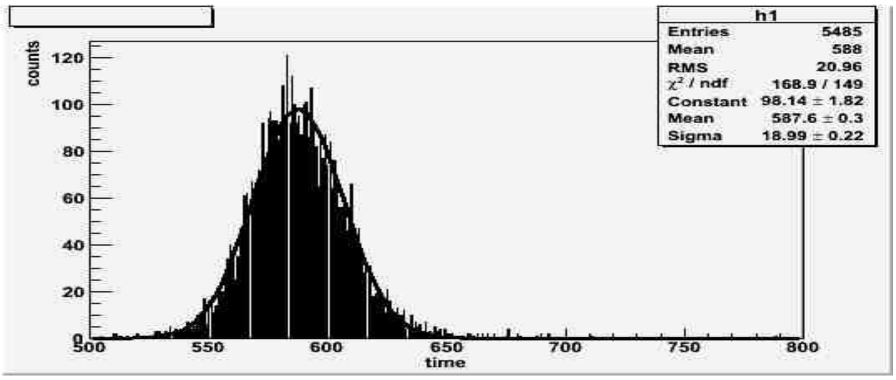


Figure 8: Results obtained from leading edge triggering TDC outputs. The σ value in ns can be obtained by multiplying the sigma value with 0.1 ns; least count of TDC.

Noise study

The variation in noise level in different runs using LED is shown below. Main reason for high noise in main strip is, HV co-axial cable is passing over it and may be sensitive preamplifiers have captures its signals.

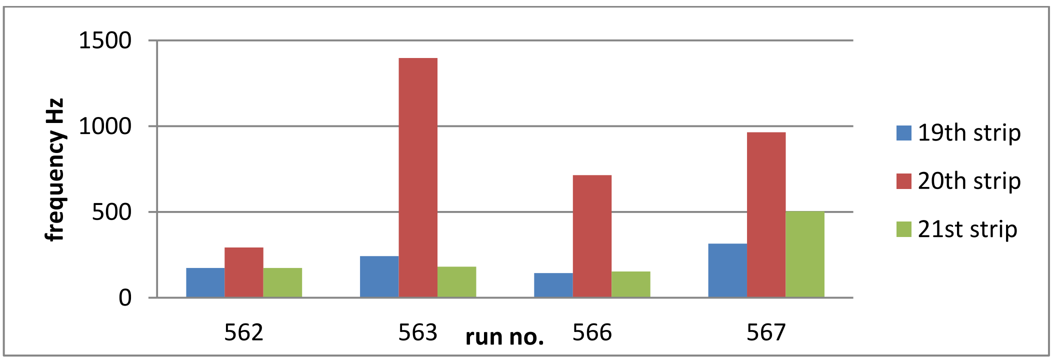
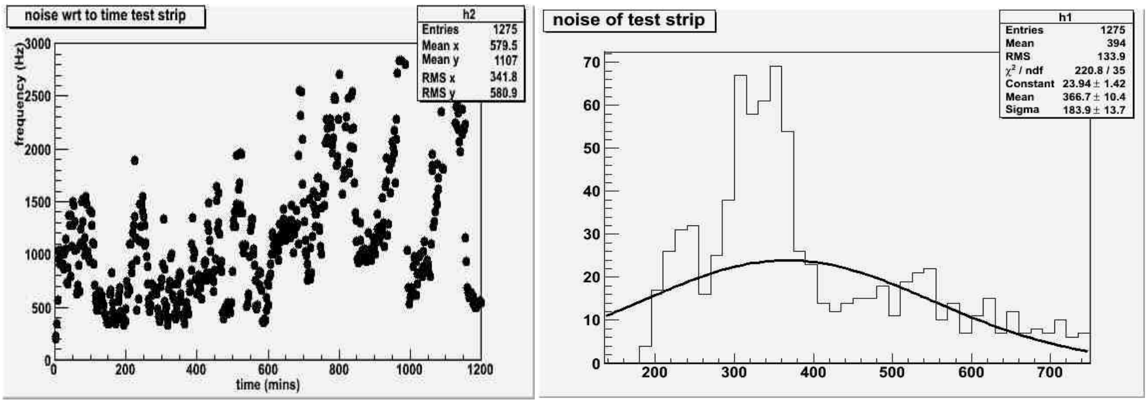
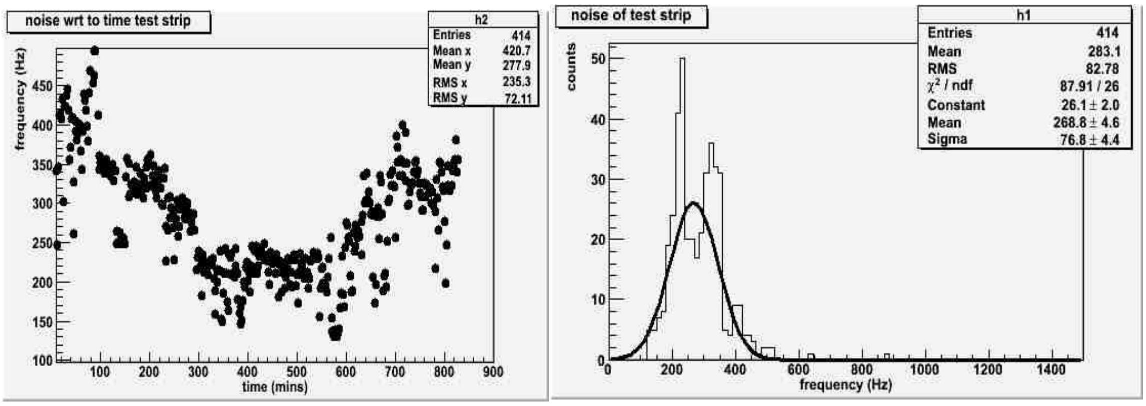


Figure 9: Noise level in RPC test pickup strip and its neighbouring strips.

Here below noise variation with respect to time is plotted for LE triggering. Plot (a) shows noise variation has vast variation which indicates noisy system while in the (b) noise variation in a respectively stable system, (a) is results of 20th strip, (b) plot is of noise variation in 9th strip.



(a) 20th strip



(b) 9th strip

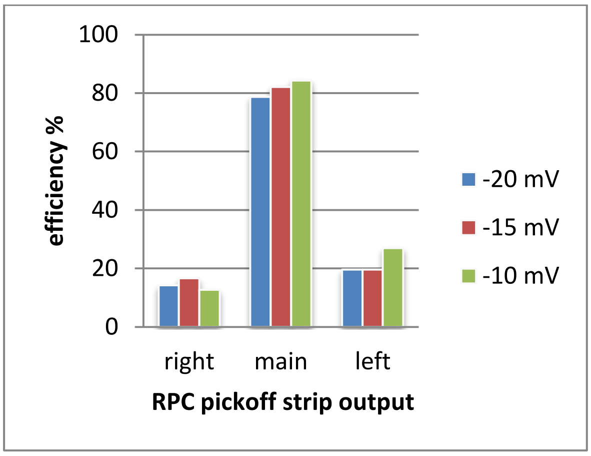
Figure 10: Noise variation with respect to time for LE triggering

Constant fraction discriminator

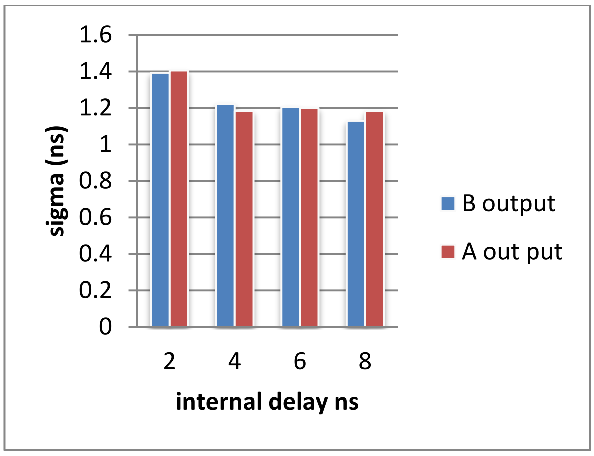
It is considered as most accurate method for timing measurement. In this method, logic signal is produced at a constant fraction of the peak height in the i/p pulse and produce a walk free signal. Depending on the type of the i/p signal, a constant fraction of the amplitude acts as a threshold.

The technique used in CF is, the o/p pulse is first split into two with one part inverted and delayed. The other part is attenuated by a constant factor. The delay of inverted signal is set in such a way that a peak of attenuated signal matches with the constant fraction of the inverted signal. Then both the pulses are added and the point where zero crossing occurs a timing pulse is generated. Advantage of CF is that it doesn't require bipolar signals. It also generates walk less logic pulses. The only restriction is that pulses should be of constant rise time [3].

We attempted to operate the ICAL RPCs first time on CFD. Hence we have gone through various test runs and analysed the results for best performance for analogue signals generated in our system. Shown below are results for time resolution (σ) values of the test strip for various internal delays at a constant threshold of -20 mV (Figure 10(b)). We have also carried out studies with various values of threshold at 2 ns internal delay for CF8000 module. The outputs of main strip are shown below in (Figure 10(a)).



(a)

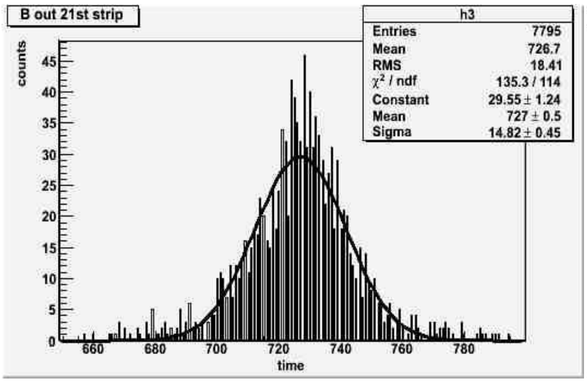


(b)

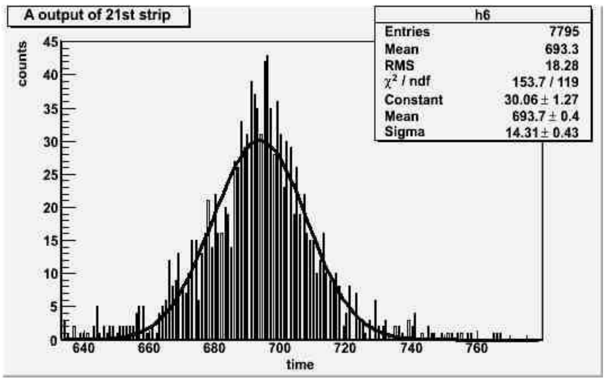
Figure 11: (a) Efficiency plot with different threshold values in CFD. (b) Plots of variation in σ value of test strip with different internal delay.

TDC results

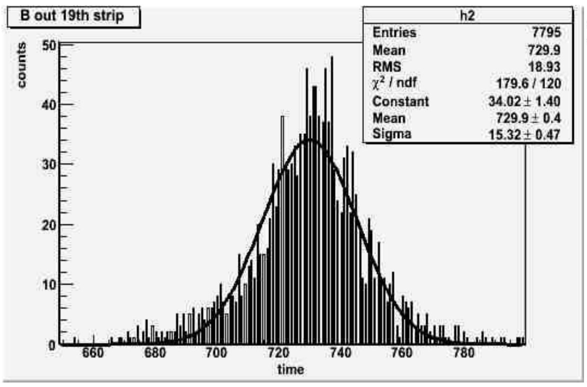
The best TDC value is obtained at 4 ns internal delay at -20 mV threshold. We obtained σ = 1.183 ns for our test strip.



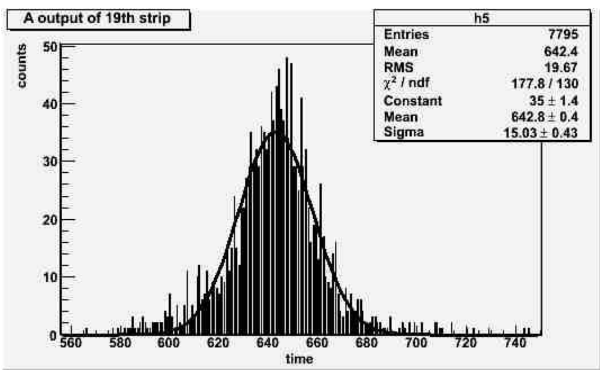
(a) Left strip



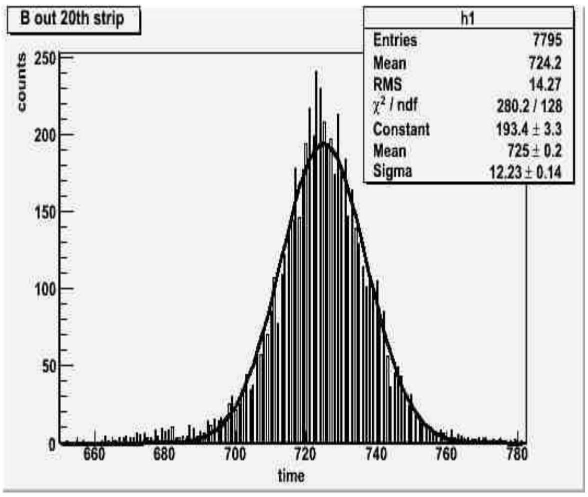
(b) Left strip



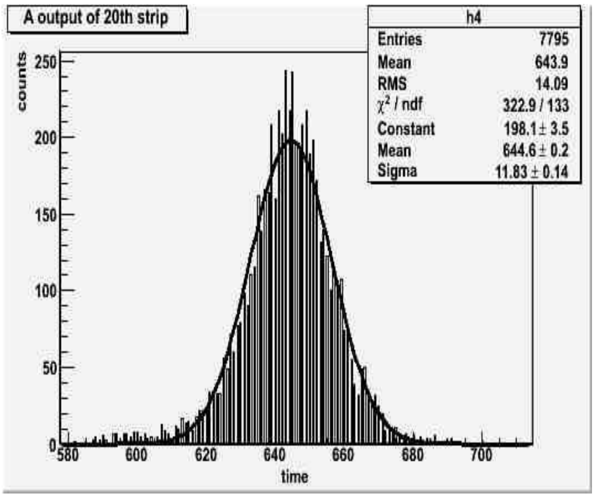
(c) Right strip



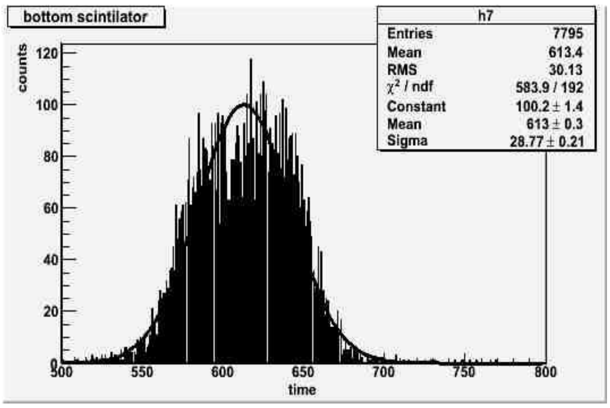
(d) Right strip



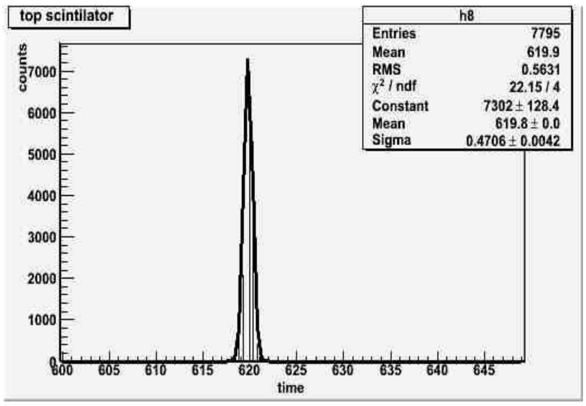
(e) Main strip



(f) Main strip



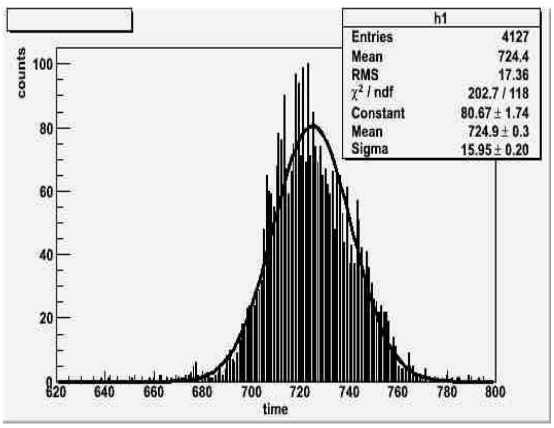
(g) Bottom paddle



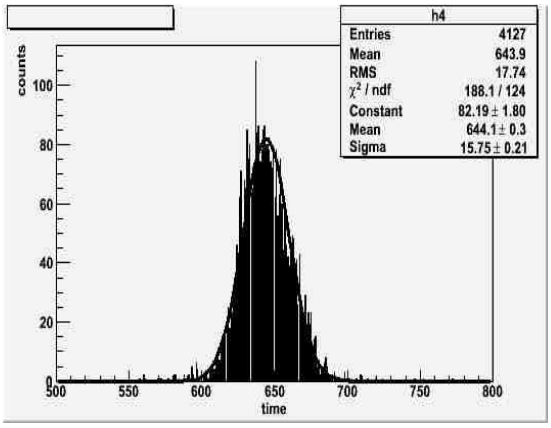
(h) Top paddle

Figure 12: Results obtained from constant fraction triggering TDC outputs. The σ value in ns can be obtained by multiplying the sigma value with 0.1 ns; least count of TDC.

We have also obtained TDC value for the strip no. 9 and results of that run are shown below. Threshold is -20 mV and obtained σ = 1.57 ns.



(a)B output



(b) A output

Figure 13: TDC output of 9th strip for CF triggering

Noise study

The noise rates of different runs are shown below. In CFD, automatic noise reduction technique is used hence noise level is low compared to LED. In run 574 very high value of noise is due to system error which was subsequently solved and stable noise rate of following runs are shown below.

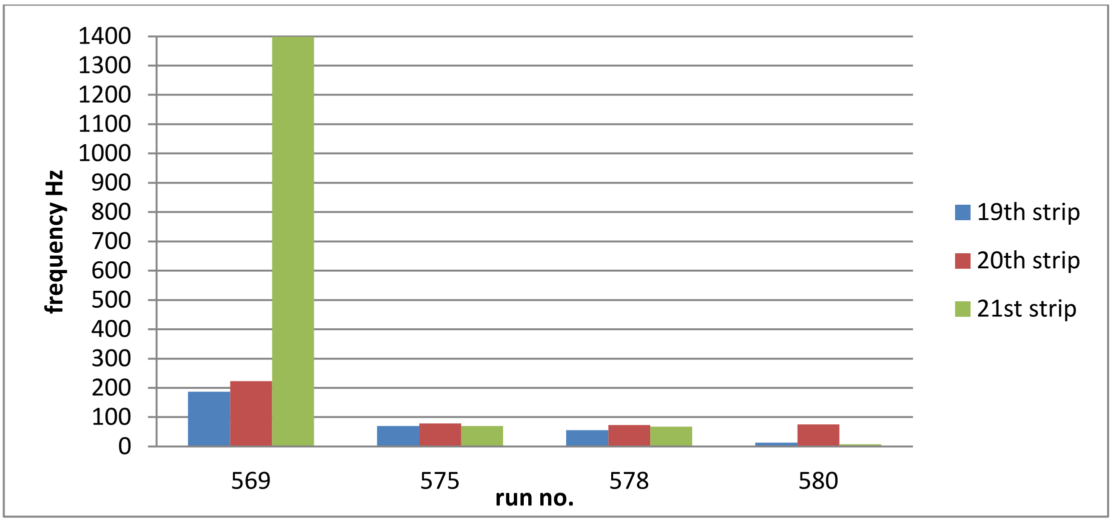
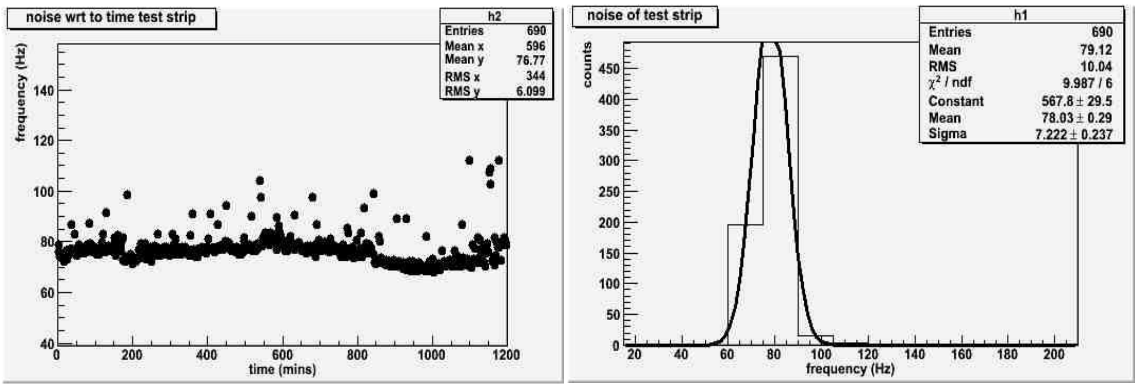
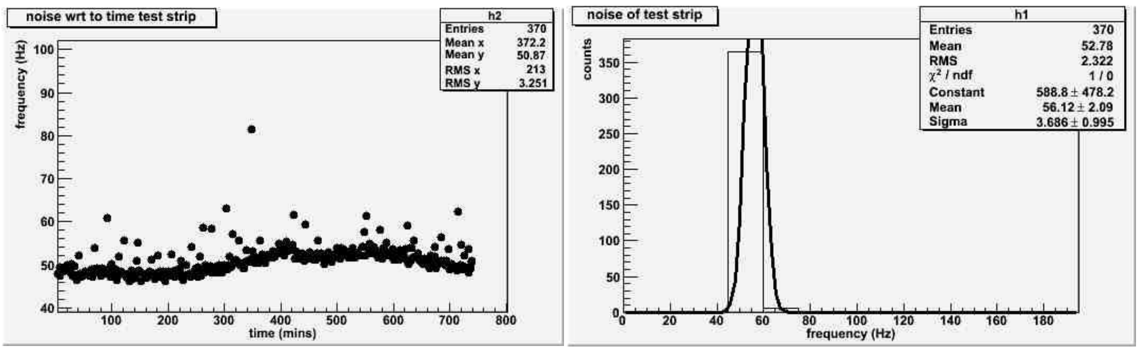


Figure 14: Noise rates using CFD module.

Noise variation with time in CF triggering is shown below. Stable values for the noise rates were obtained as shown.



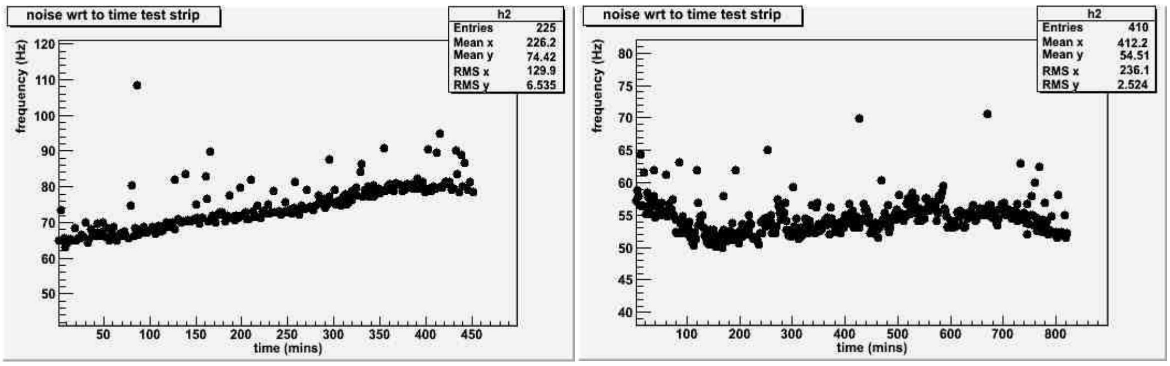
(a) 20th strip



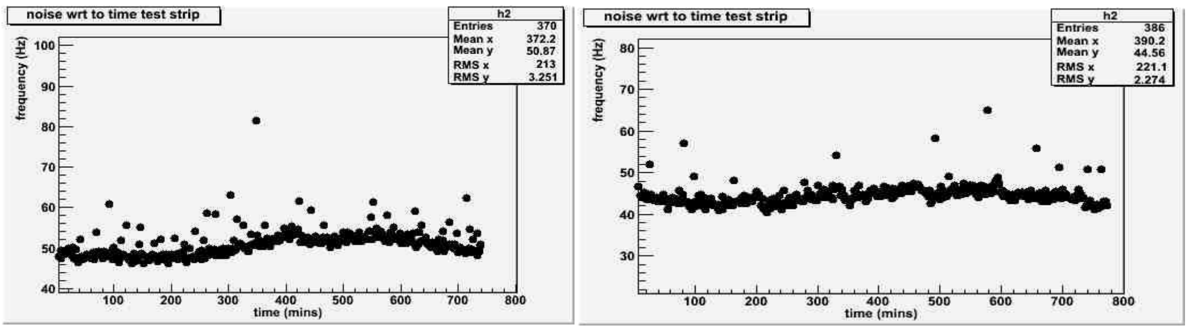
(b) 9th strip

Figure 15: Noise variation with time in CF triggering.

For more detailed analysis we kept our system in isolation. To further reduce the external electronic noise, we have switched off power supply of all other RPCs of the stack and disconnected preamplifiers for those RPCs. In this situation, the electronic noise in the signal is due to the test RPC electronics only. Noise variation in CF triggering as function of its threshold is shown below.



(a) -10 mV threshold (b) -15 mV threshold



(c) -20 mV threshold (d) -25 mV threshold

Figure 16: Noise variation with change in threshold in CF triggering

Above results imply that with CF triggering the noise level doesn't increase drastically even at lower thresholds. In contrast noise level of the LE triggering gives 130 Hz rate at -20 mV threshold.

Detailed investigation leads us to conclude that the automatic walk adjustment facility in CF module of our experiment ignores signals having width less than 7ns even though the signal has amplitude higher than threshold. This is not the case with the LE module. Our studies show that in such cases, the amount of reduction in unwanted signals is very high compared to that of genuine event signals. In support of our conclusion we can interpret that such short lived signal is generated by some very low energy charged particles. They may be generated inside the system or near surroundings of the detector, but not by the events of interest. Hence, we can accept such automation in favour of stability of our detector system. From fig. 10 and 15, we can conclude that using CF module even in the presence of external electronics, noise level remains below 100 Hz.

Conclusions and discussions

Using the measurements of LE triggering and CFD we compared their results for best achieved time resolution (σ), efficiency of test strip and noise level in test strip at threshold of -20 mV. The results are tabulated below.

Type of triggering	σ (ns)		Efficiency of test strip (%)		Noise in test strip (Hz)	
	20th strip	9th strip	20th strip	9th strip	20th strip	9th strip
Leading edge	1.68	1.89	83.54	89.24	366.7±183.9	268.8±76.8
Constant fraction	1.18	1.57	79.49	82.93	78.0±7.2	52.8±3.7

On the use of CF triggering the improvement in timing resolution is significant. The automatic walk adjustment capability of the CFD results in rugged logic level conversion, but produces lower efficiency. CFD is insensitive to narrow pulses of less than 7 ns. Accountability of such ignorance is a matter of study in this case. This can be accounted by adjusting the operating voltage of the RPC. The reduction in the noise is observed as 1/4th of the noise in LE triggering. Moreover with the variation in the threshold, noise doesn't vary rapidly in CF module. At INO project as we mentioned earlier in the report, the timing precision is very much important. Constant fraction triggering can play a major role at this stage. We require more detailed study to optimise the CF triggering scheme. RPC signals are of varying rise time with varying amplitude. In such circumstances LE triggering is not a suitable option. A CF technique with optimised delay, fraction and threshold will be an ideal option.

Summary

We have studied LE and CF triggering for 2m × 2m RPC strip no. 20th and 9th at avalanche mode. From our study we found that CF triggering method provides better time resolution than that of LE. Besides of results in stable RPC strip, noise rates even under noisy system conditions remains less fluctuated. This shows that for INO's ICAL experiment, CF technique can provide better results than LE. Though, we are dealing with signals of varying rise time as well as amplitude, a more precise study is required for utilisation of CFD for INO project.

Acknowledgements

I am thankful to so many people who are involved directly or indirectly for the progress of my VSRP project at TIFR, Mumbai.

First of all, I am grateful to the Tata Institute of Fundamental Research (TIFR) for selecting me for its prestigious Visiting Student Research Program (VSRP). I am grateful to Dr. J. Dasgupta, Co-ordinator VSRP program, for his arrangements to make my stay fruitful and comfortable. I am also obliged to Kishore Vaigyanik Protsahan Yojana (KVPY) for providing the contingency grant.

I am thankful to Dr. B. Satyanarayana, TIFR for accepting me as a VSRP fellow and managed to transmit to me a bit of his enthusiasm for detector physics. He always supported me and discussed my ideas and doubts carefully. My sincere thanks to Mr. Ravindran Sinde for his guidance and help throughout my project work. Without his help it is not yet possible for me to reach at this extent in this critical project.

I am also grateful to several other people of the INO group at HEP department with whom I interacted during my project.

My gratitude to Dr. G. Mohanthy for his informative interactions and discussions over some deeper aspects of heavy ion physics.

Last but not the least, I am very much thankful to my parents and my younger sister for their support and encouragement.

References

1. INO project report, (2006).
2. Dr. Satyanarayana Bheesette, Design and characterisation studies of resistive plate chambers, ph.d. thesis (2009).
3. W. R. Leo, Techniques for nuclear and particle physics experiments, (Springer International publication, 2010).
4. ORTEC CF8000 Manual.