Digitization Studies & Analysis of RPC Signals

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Abstract:

India Based Neutrino Observatory (INO) is a multi-institutional collaboration which aims to build an underground laboratory for pure Science research, especially in Neutrino Physics. It includes construction of an ***I****ron* ***CAL****orimeter (ICAL) detector. INO-ICAL is a neutrino detector, which will indirectly detect neutrino from the observation of the secondary particles emitted on its interaction with Iron. This report presents the work I did as a part of my Summer Project as a Visiting Students' Research Programme (VSRP), which involved characterization of Resistive Plate Chambers (RPCs), digitization of its signal and their analysis.*

RESISTIVE PLATE CHAMBERS

Introduction:

Resistive Plate Chambers(RPCs) are the active detector elements of the ICAL detectors being made for the INO(Indian Neutrino Observatory).RPCs are gaseous detector made up of two parallel high bulk resistivity material plates, which are kept at high voltages(~10 KV).*Figure 1* shows the components of a basic RPC.

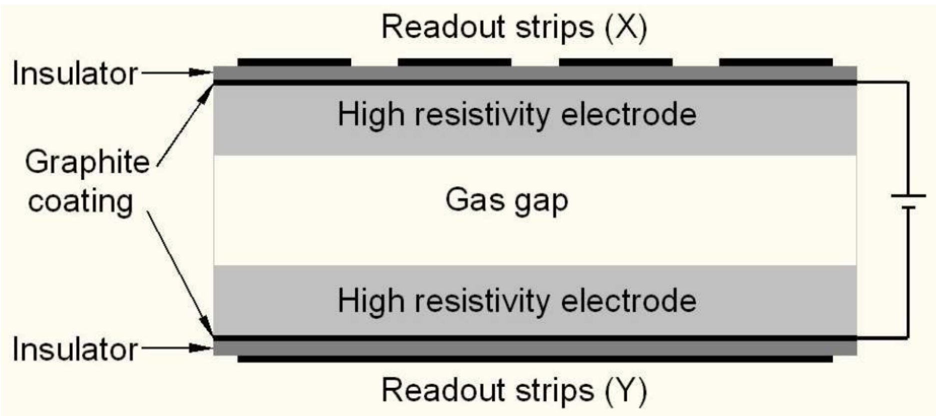

Figure 1: Components of a *basic* Resistive Plate Chamber

Components of RPC

- Two Planar electrodes of high resistivity made up of 2m X 2m glass of 3mm thickness each, separated by a gap of 2mm.

- Glass electrodes with high bulk resistivity of about 10^{10} -10^{12} Ω cm are kept at high voltages and the Glass is externally coated with graphite to increase the surface resistivity, which helps setting of uniform electric field.
- The two plates are separated using polycarbonate buttons shaped spacer, with bulk resistivity greater than 10^{13} Ω cm. Side spacers and corner spacers are used to cover RPC from all 4 side edges and it is sealed using glue.

- Gap Gas mixture:

  The following gases are used in the gas mixture in a particular composition ***based on the mode of operation*** in which RPC has to be operated.

  - ***Argon***: Argon acts as the target for ionizing particle.
  - ***Freon*** :(R134 an eco-friendly Freon is used). An electronegative gas like Freon absorbs free charge particles in the gas before any further avalanche is produced.
  - ***Isobutane***:Isobutane being an organic gas with large surface area is used to absorb photons from recombination process, limiting the formation of secondary avalanche from primary ionization. It is because of this property is known as Quenching Gas.
  - ***SF_6:*** SF_6 is used to trap the excess energetic electrons from the gas volume before they can initiate a new avalanche.

- The RPC is sandwiched between a pair of pick-up panels. The pick-up panels are made up of plastic honeycomb with aluminium sheet on one side for grounding and copper strips on other side. Two pick up panels are place on the either side of RPC, oriented orthogonally to each other each having 64 readout strips, soldered to wire which connects to electronics.

- Pickup panel and RPC are separated by insulating Mylar sheets.

Modes of operation

A RPC based on the composition of the gas mixture can be operated in two modes.
If the gas mixture has Freon**: Isobutane: SF6** in the ratio of **95.5: 3.9: 0.6** by volume then the RPC works in avalanche mode. Whereas if the gas mixture has **Freon: Argon: Isobutane** in the ratio of **62:30:8** by volume then the RPC works in streamer mode.

1.) Avalanche Mode:

The RPCs are detectors based on ionization. The passage of a charged particle through a gas volume ionizes it and if an intense enough electric field is applied throughout the gas volume then the primary electrons produce further ionizations. This multiplication mechanism results in formation of avalanches of free charge in the gas. Recombination processes usually take place during the avalanche development. Photons are produced in such re-combinations and they can in turn start the development of secondary avalanches. If these avalanches are under control then the RPC is said to be operating in the Avalanche mode. The pulse height in this mode is of the order of few milli-volts and amplifiers are required in this mode of operation.

2.) Streamer Mode:

Whereas if the avalanches are allowed to propagate and increase then there comes a regime when several secondary avalanches are produced causing large amounts of free charge in the gas and avalanches transform into streamers. In this mode photons produced by the recombination process, contribute largely to the spread of free charge carriers.

The signal generated will be large in the order few hundreds of milli-volt.

Hence no amplifiers will be needed.

The TIFR prototype is operated in the Avalanche mode.

Working of a RPC

The passage of a charged particle through a gas volume gives rise to the production of electron-ion pairs. If an intense enough electric field is applied throughout the gas volume then the primary electrons produce further ionizations triggering avalanches of electrons. The avalanche propagates through the gas volume and reaches the electrode. Due to the high resistivity of the electrodes, the charge remains concentrated around a small area where the discharge occurred on the glass. These charges are then picked up by the pickup channels to produce a weak electric signal. This signal is amplified through a preamplifier and then sent to the electronic circuit for digitization.

Electrical Representation

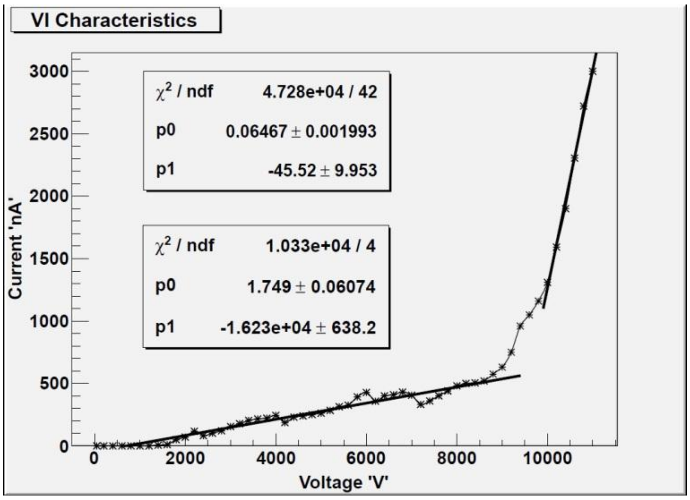

Figure 2: VI Characteristics of RPC

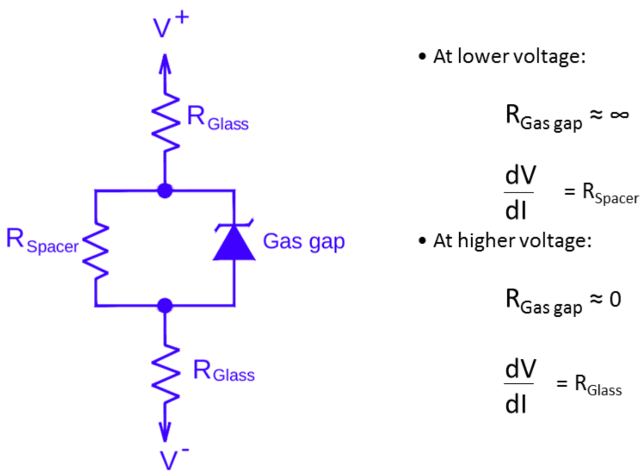

Figure 3: Electrical Representation of RPC

The RPC gas gap can be represented by a parallel combination of **spacer (Ohmic) resistance** and gas ionization volume of the gap (represented by a **Zener diode**). At **lower applied voltages**, the primary ionizations in the gas gap do not lead to development of avalanches. Therefore, the gas gap offers infinite resistance. The current flowing through the chamber then is entirely determined by the **spacer resistance**. Whereas at **higher applied voltages**, the gap resistance almost vanishes and therefore the current flowing through the chamber in this case is entirely determined by the **glass resistance**. The equivalent circuit diagram of the RPC is shown in *Figure 3*.

Figure 2 shows the VI Characteristics plot obtained. From the inverse of its slopes the value of the spacer resistance and the gap resistance were found be 15 GΩ and 0.57 GΩ respectively.

DIGITIZATION OF RPC SIGNALS

To study the parameters of the RPC Pulse Signals they need to be digitized. Sampling the wave form at optimum sample rate makes it easy for the in depth analysis of each of the parameters by proper reconstruction of original wave form.
The accuracy of the generated waveform also depends on the sampling rate. Higher sampling rates allow the generated wave to more accurately represent the original wave.
At TIFR for waveform sampling DRS4 (Domino Ring Sampler) is being used, which is a high speed analog waveform sampler. At a sampling speed of 5GSPS(Giga Samples Per Second) the DRS4 having 1024 bins samples the waveform every 200ps.*Figure 4* below shows the difference between higher sampling speed(more data points) and lower sampling speed(less data points).

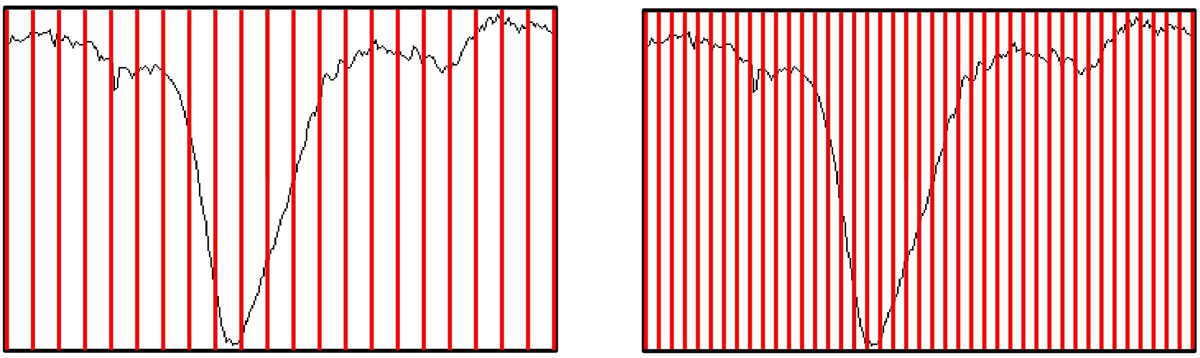

Figure 4: Waveform Sampling
Left –Lower sampling Rate
Right-Higher sampling Rate

Domino Ring Sampler

(Courtesy: Paul Scherrer Institute, Switzerland)
The Domino Ring Sampler (DRS) is a switched capacitor array (SCA) capable of sampling 9 differential input channels at a sampling speed of 700 MSPS to 5 GSPS (6 GSPS for selected chips). The analog waveform is stored in 1024 sampling cells per channel, and can be read out after sampling via a shift register clocked at 33 MHz for external digitization.
The write signal for the sampling cells is generated by a chain of inverters *(domino principle)* generated on the chip. The domino wave is running continuously until stopped by a trigger. A read shift register clocks the contents of the sampling cells either to a multiplexer or to individual outputs, where it can be digitized with an external ADC. *Figure 5* shows that the Switched Capacitor Array used in DRS does the Analog Sampling at high frequency but slow digitization on trigger. It is also possible to read out only a part of the waveform to reduce the digitization time.

The DRS has a voltage limit of -500mV and so any pulse signal more than that is saturated for the DRS. These are generally neglected in the analysis.
Figure 6 shows the picture of the DRS board connected to a PC through USB.

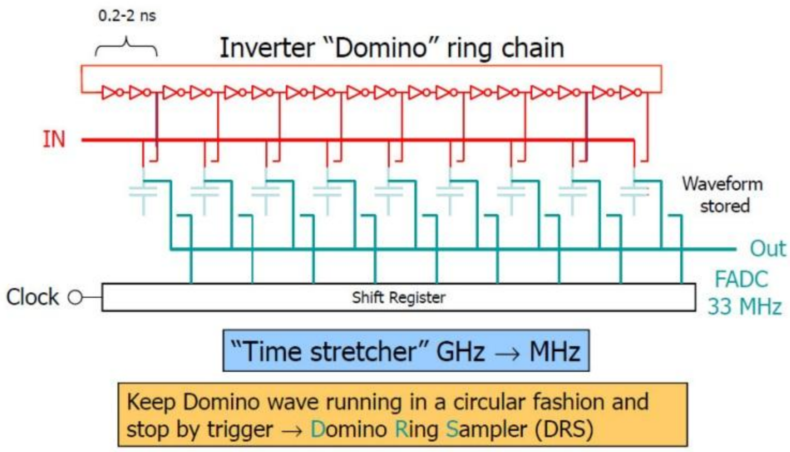

Figure 5: Switched Capacitor Array

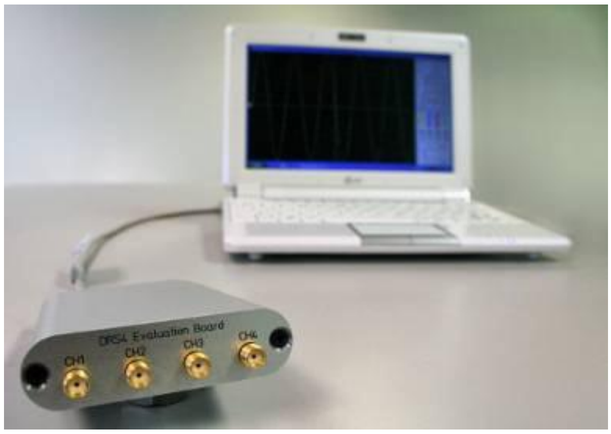

Figure 6: DRS connected to PC(USB)

DRS and Trigger Setup:

At TIFR there is a RPC Prototype stack having 12RPCs (1m x 1m) each having 32 strips. For study four strips of the X side(namely Strip no-16,17,18 and 19) from each of the three RPCs top(Layer11),middle(Layer6) and bottom(Layer0)were taken and all the other channels were disconnected.

Trigger Generation

The trigger was formed by taking the coincidence of the three layers of the RPCs .The trigger logic is explained in *Figure 7*.

Block Diagram of the Setup

The signal output of each RPC strip after amplification was fed into a linear Fan In Fan Out (FIFO)from which the connections were routed to Data Acquisition(DAQ) chain *(Analog Front End(AFE)->Digital Front End(DFE)->Control and Data Router(CDR)->Read Out (VME Based)->DAQ PC)*and the DRS simultaneously.

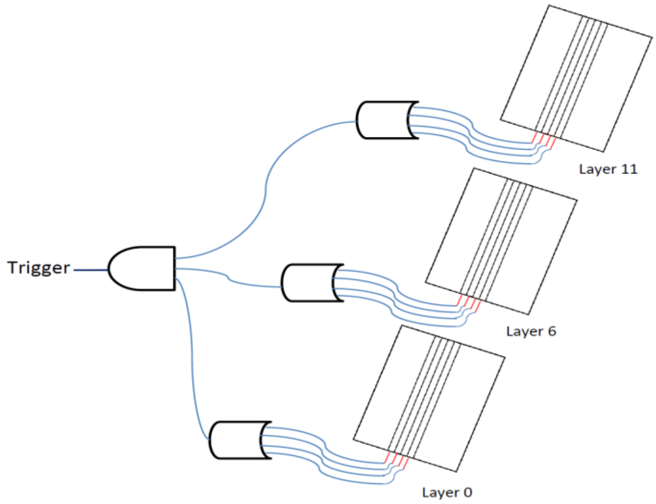

Figure 7: Trigger generation logic

Figure 8 shows the complete block diagram of the setup The DRS and the DAQ were manually synchronized and started.

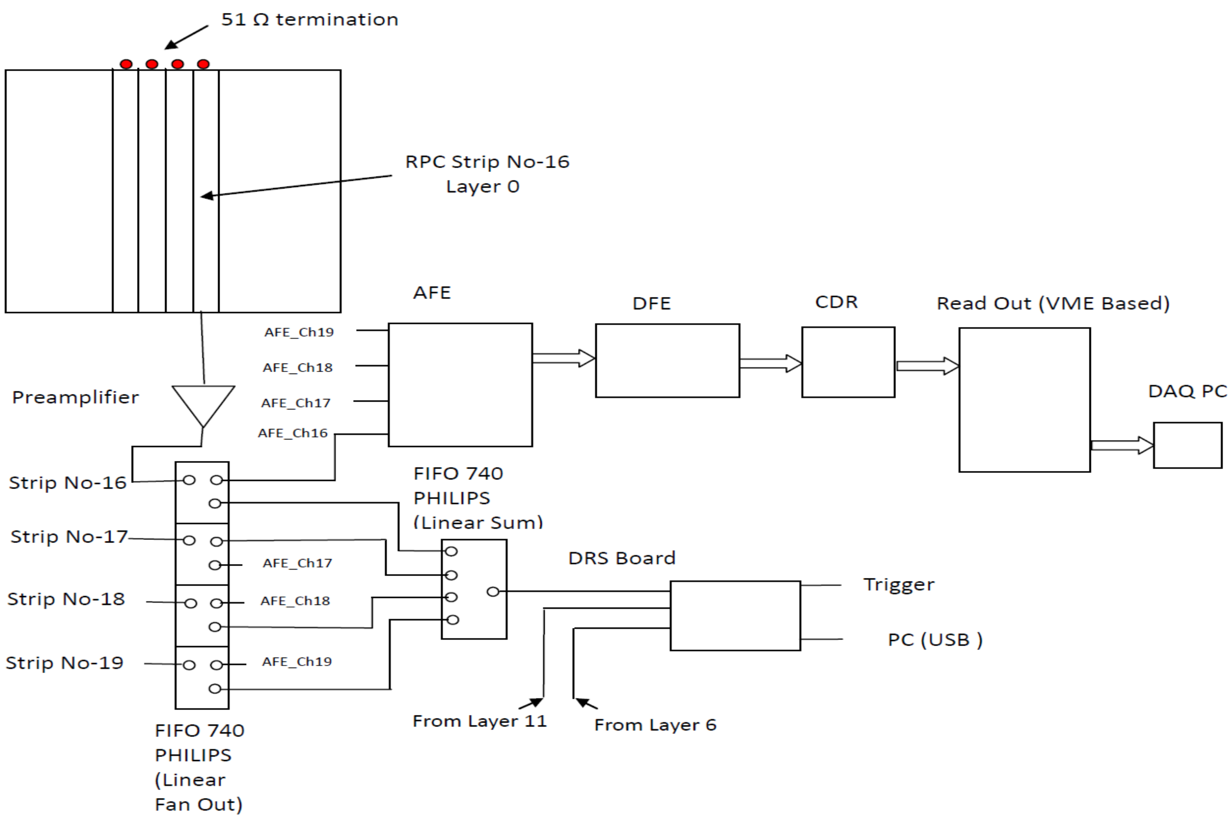

Figure 8: Block Diagram of the setup

Pulse Shape

The data collected by the DRS was then analyzed using the software package ***Root by CERN*** to plot the pulses and different graphs. The pulse parameters to be studied has been shown in *Figure 12.*It was observed that most of the pulses have a second peak on the falling edge of the pulse as shown in *Figure 10*.
Different types of pulses obtained from DRS are shown in *Figure 11* while *Figure 9* shows a RPC pulse as seen on an oscilloscope.

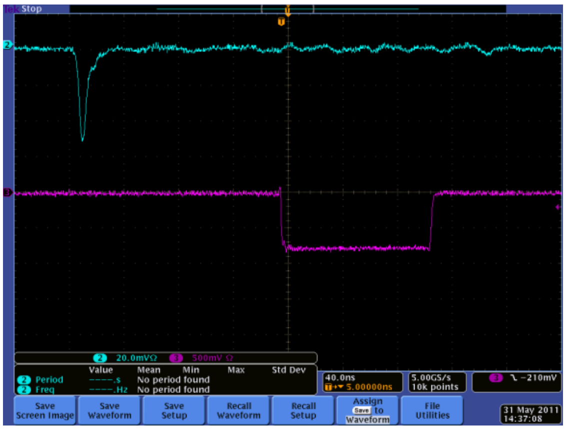

Figure 9: RPC Pulse on oscilloscope

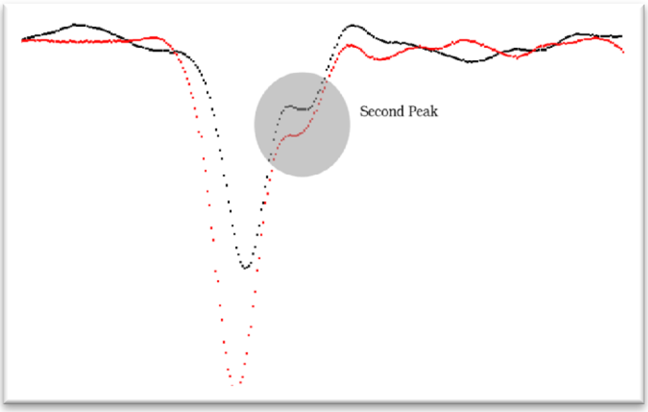

Figure 10: A typical RPC pulse

Different Types of Pulses

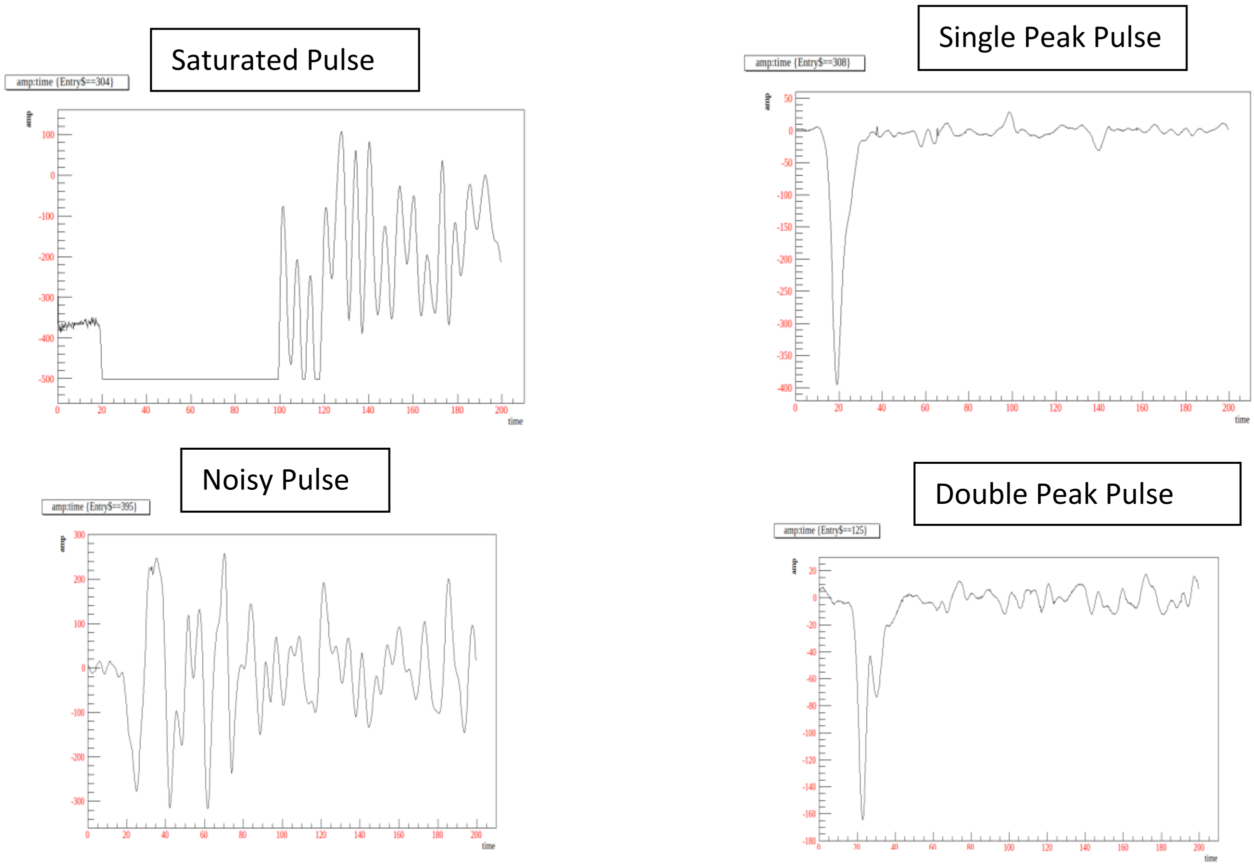

Figure 11: Different types of RPC Pulses

Signal Pulse Parameters:

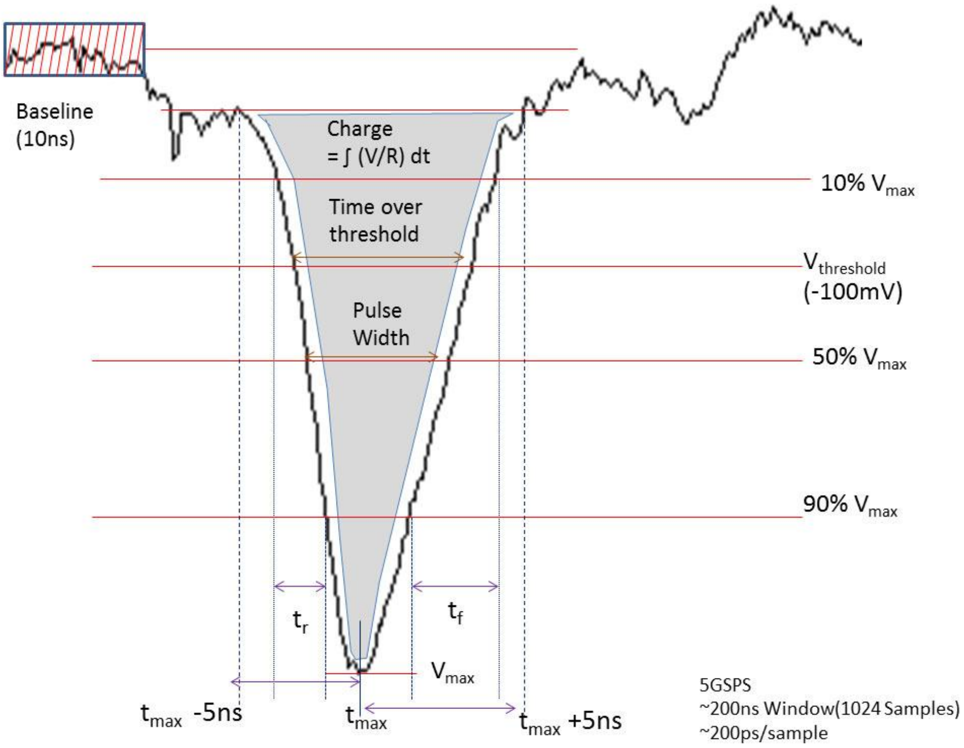

Figure 12: RPC Signal's Pulse Parameters

Parameter	Description
Baseline	It is calculated by taking the mean of the first 50 points (~10ns) of the waveform.
t_r (Rise Time)	It is the time taken for the pulse to rise from 10% to 90% of the maximum amplitude.
t_f (Fall Time)	It is the time taken by the pulse to fall from 90% to 10% of its maximum amplitude.
Time over threshold	It is the time difference between the two points where a pulse crosses a particular threshold voltage.(The threshold voltage has been taken to be -100mV)
Pulse Width	Pulse Width is the FWHM(Full Width at Half Maximum)
V_{max}	Pulse Amplitude is the maximum amplitude of the signal.
t_{max}	The time taken for the pulse to reach its Pulse Amplitude
Charge =∫ (V/R) dt	Charge was calculated by taking25 points (~5ns) more and 25 points (~5ns) less than the t_{max} and calculating the area under the waveform between these two time intervals.

Signal Analysis:

Baseline Distribution

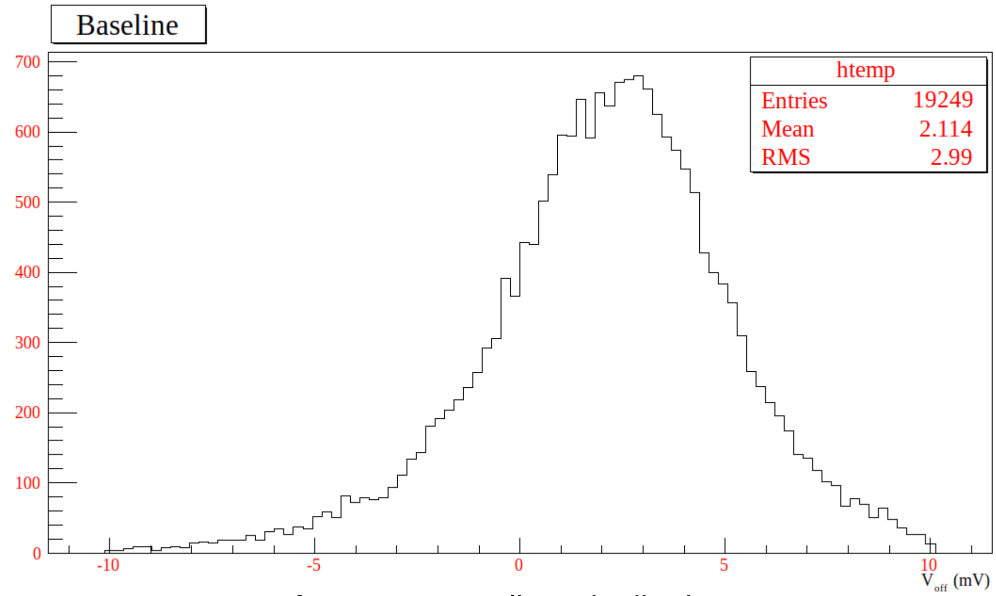

Figure 13: Baseline Distribution

The baseline is the voltage level to which the pulse decays. It was calculated by taking the mean of the first 50 data points of the waveform.

Baseline RMS

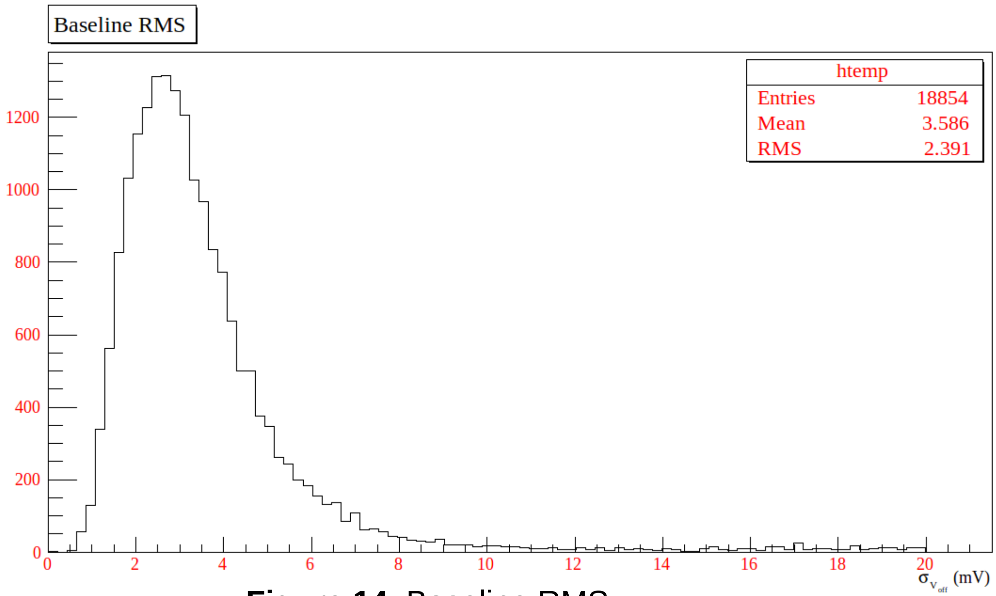

Figure 14: Baseline RMS

Baseline RMS is the Root Mean Square value of the first 50 data points.
It gives broader insight into the quality of the signal by giving the information regarding the fluctuations in the base line. The mean of baseline RMS is close to the RMS of baseline distribution as expected.

Pulse Height Distribution

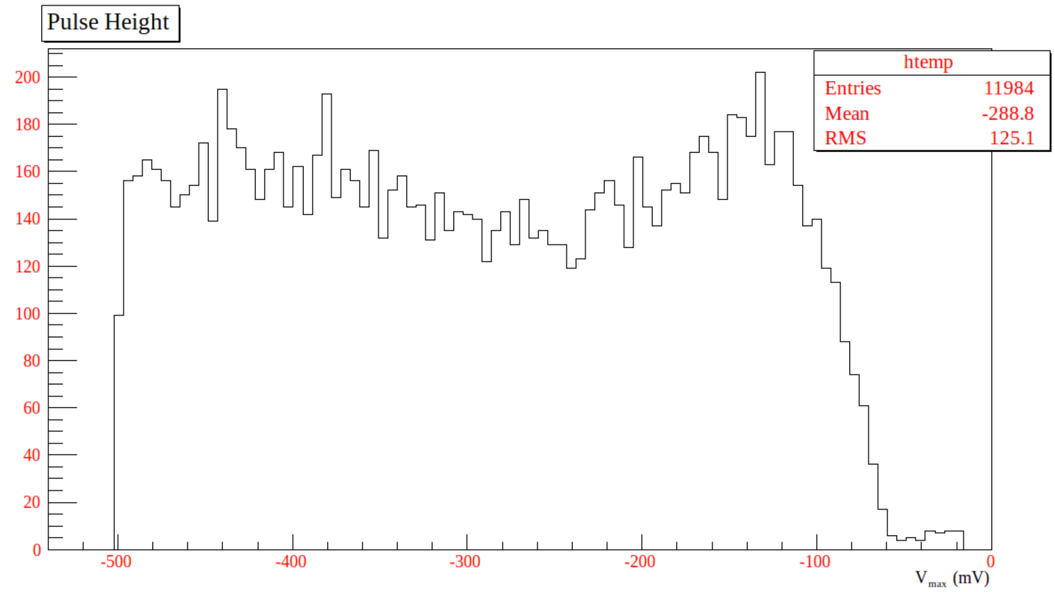

Figure 15: Pulse Height

For the Pulse Height Distribution shown in *Figure 15* above, all the saturated pulses (i.e voltage<-500mV), which almost constitute half of the total pulses were rejected in all the following plots.

Charge Distribution

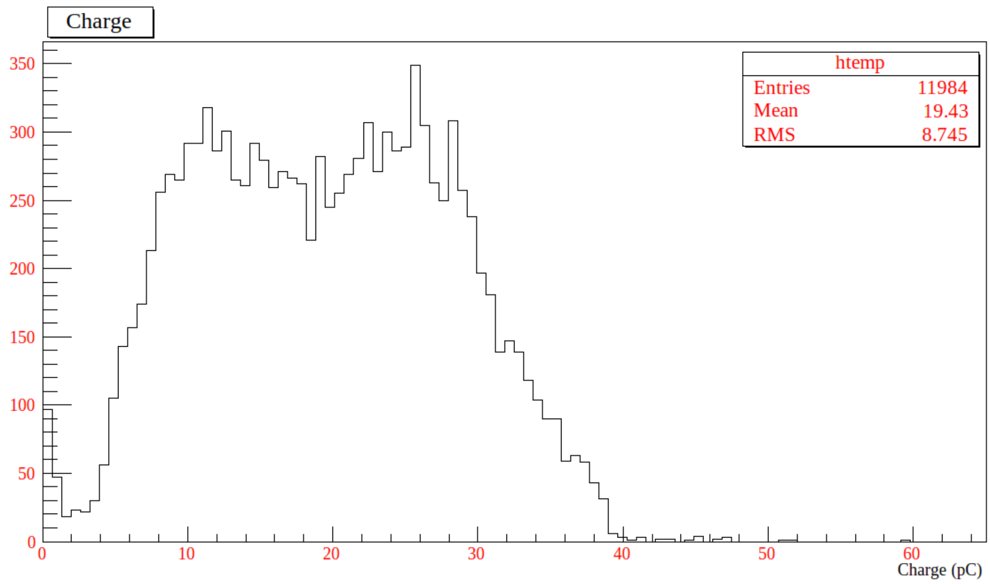

Figure 16: Charge Distribution

The charge is calculated by dividing the area under the signal near the peak position by the strip impedance (50 Ω).

Rise Time

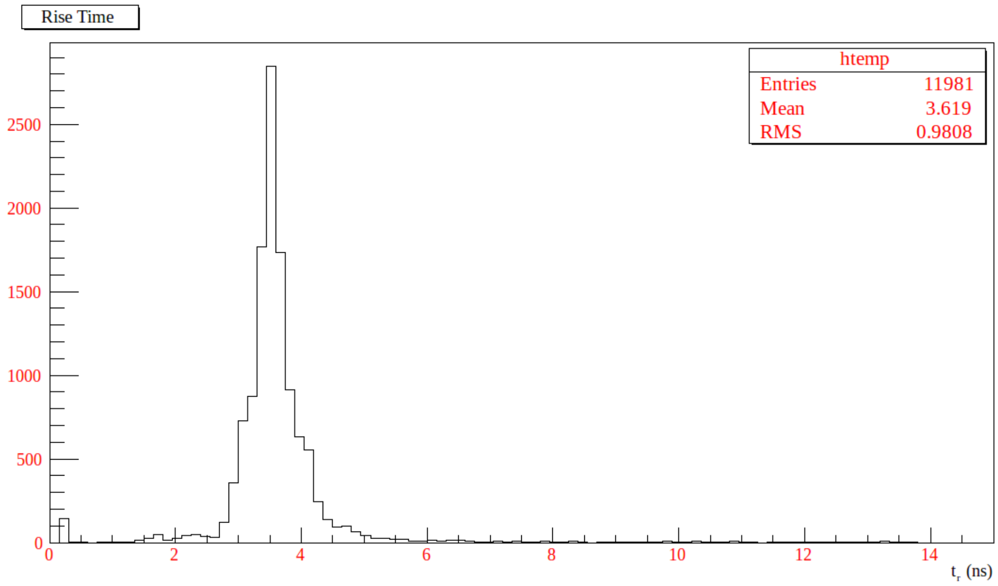

Figure 17: Rise Time Distribution

The mean rise time is 3.619 ns after rejecting those events with negative Rise time.

Fall Time

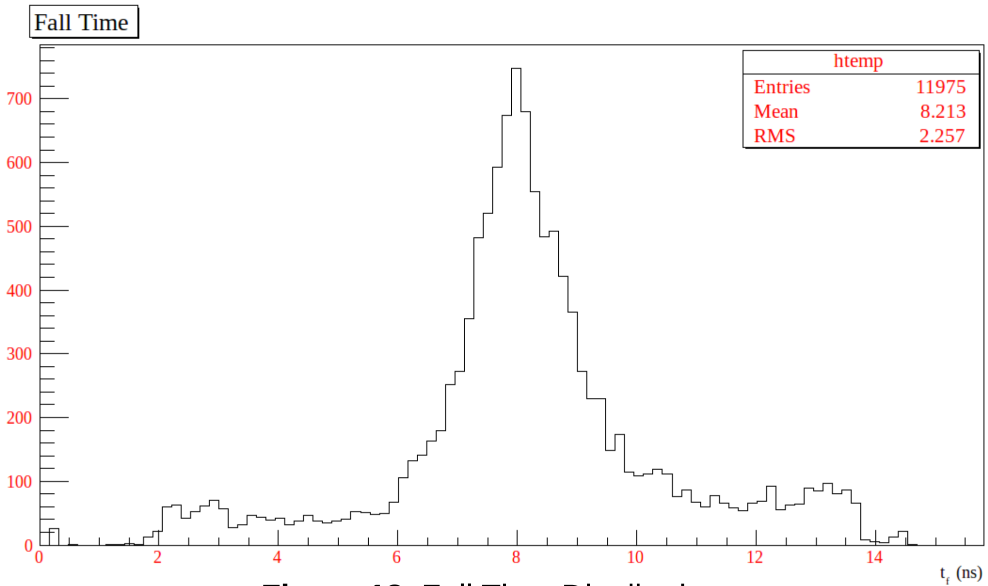

Figure 18: Fall Time Distribution

The mean fall time is 7.82 ns. Here also the events having negative time of fall have been rejected. The fall time distribution is wider as compared to the rise time. This is because of the second peak on the falling edge of the pulse.

Time over Threshold

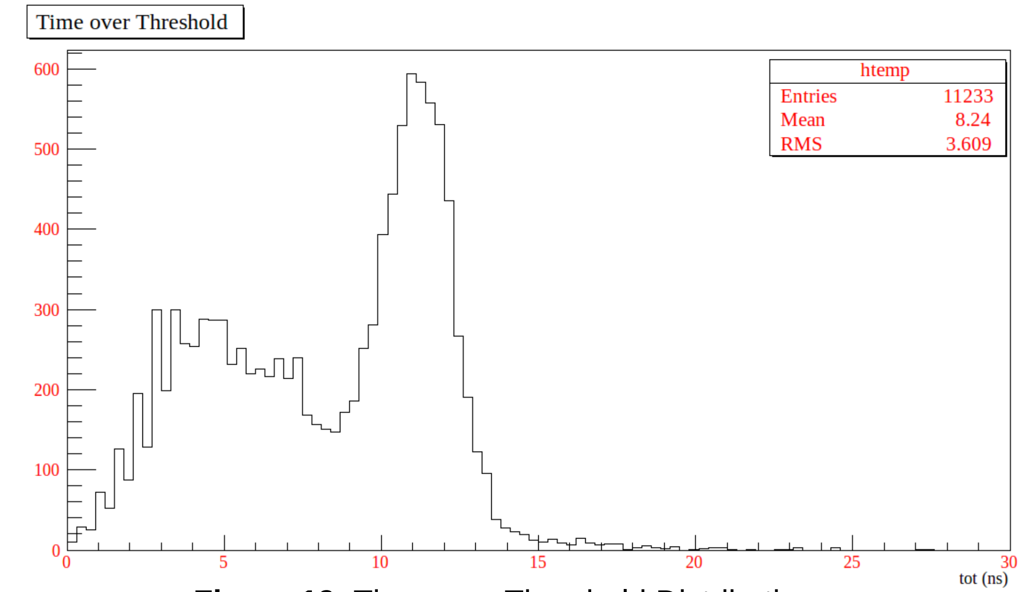

Figure 19: Time over Threshold Distribution

The threshold voltage was taken to be -100mV and the distributions were obtained by neglecting events having negative time over threshold values.

Charge Vs Pulse Height

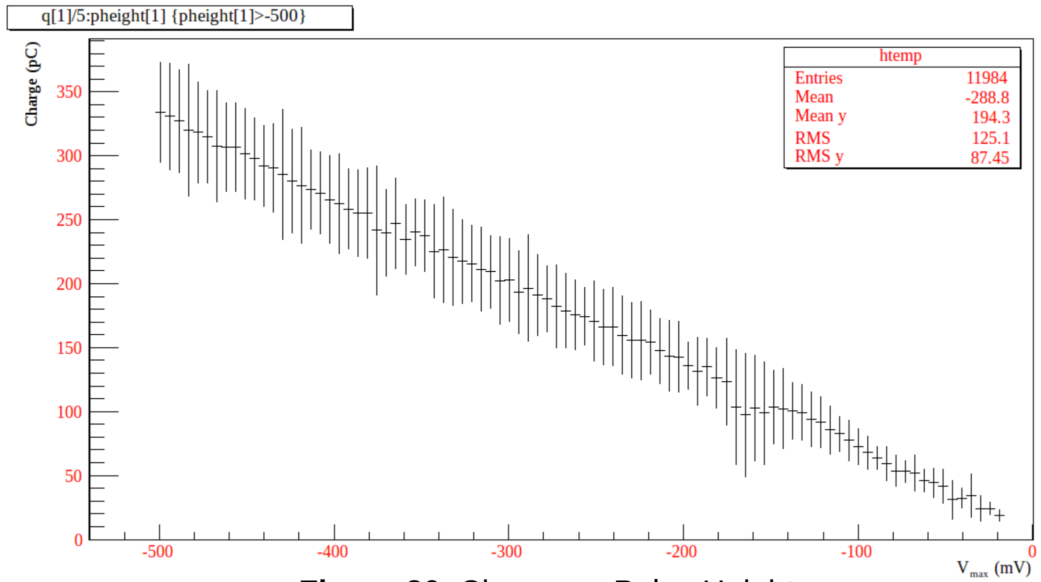

Figure 20: Charge vs Pulse Height

From the above plot it can be seen that the charge increases with the increase in pulse height which is as expected since the area under the curve will increase with the increase in the pulse height.

Charge Vs Time over Threshold

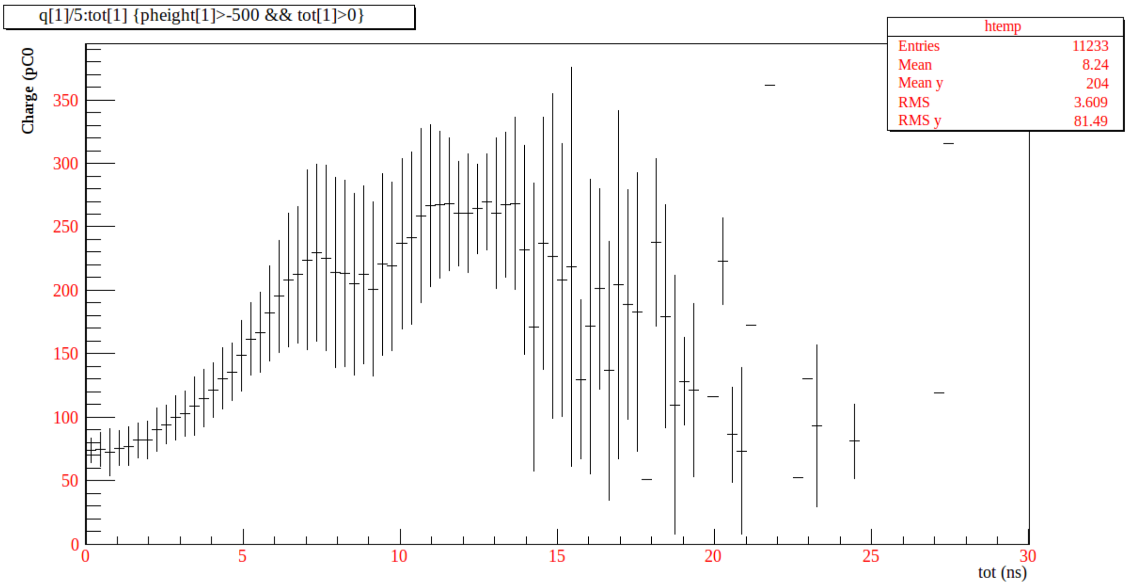

Figure 21: Charge vs Time over Threshold

The above plot was also obtained by neglecting the negative Time over Threshold values.

Time at peak distribution

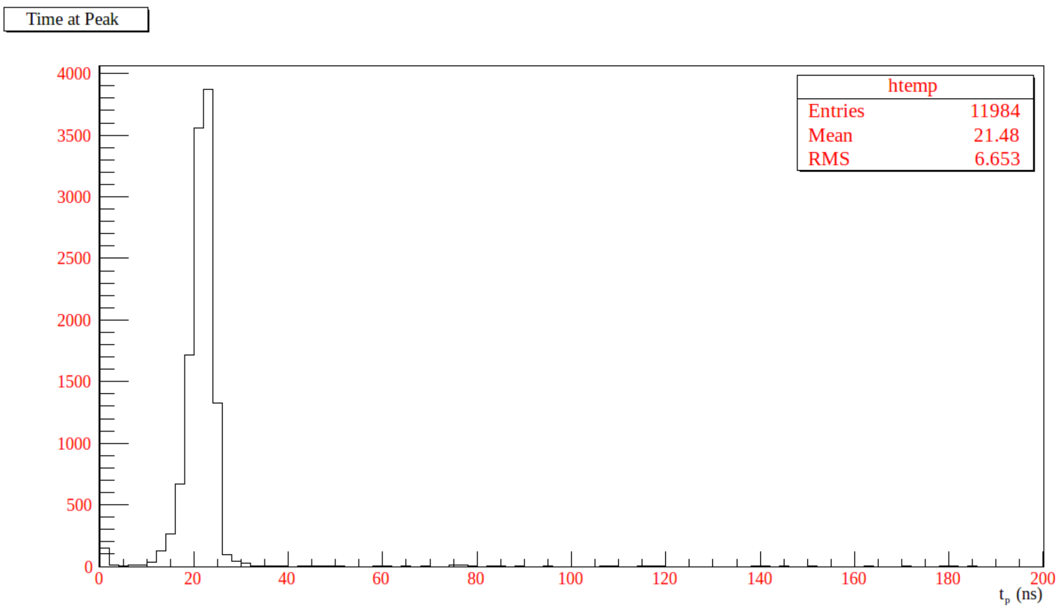

Figure22: Time at Peak Distribution

The RMS value is seen to be 6.653 ns which probably implies that there is a jitter of 6.653 ns in the trigger.

Pulse Width

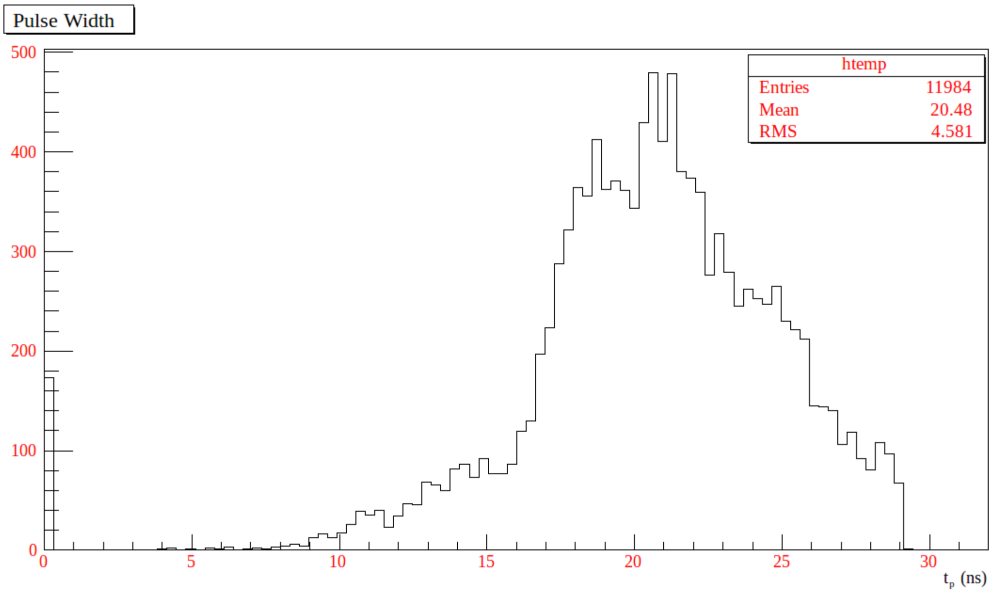

Figure23: Pulse Width Distribution

The pulse width distribution has also been affected by the second peak and it is reflected in the above plot as the distribution is wider than expected.

Conclusion:

After looking at a number of pulses and their plots it was observed that in most of the pulses there is a second peak formation on the falling edge which tends to distort the pulse parameters. It seems like that these double pulses are due to the superimposition of the real pulse with the reflected pulse but studies are being done on these double pulses to get more insight into the characteristics of these double pulses. After knowing the characteristics of these double pulses pulse parameters it would be possible to calculate the pulse parameters more accurately.

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4. Personal Website of Dr. Satyanarayana Bheesete:
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5.Paul Scherrer Institute website http://drs.web.psi.ch/

6. Root Website by CERNhttp://root.cern.ch/drupal/

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