Study of Charge Spreading in Resistive Anode Micromegas TPC for ILC and T2K Experiments

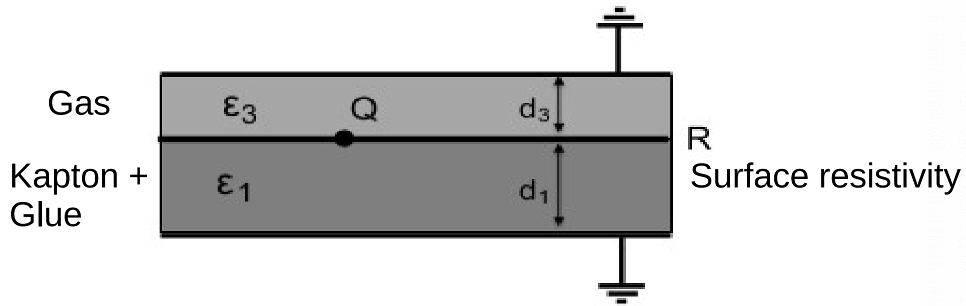
Shivam Joshi
(I15PH002)

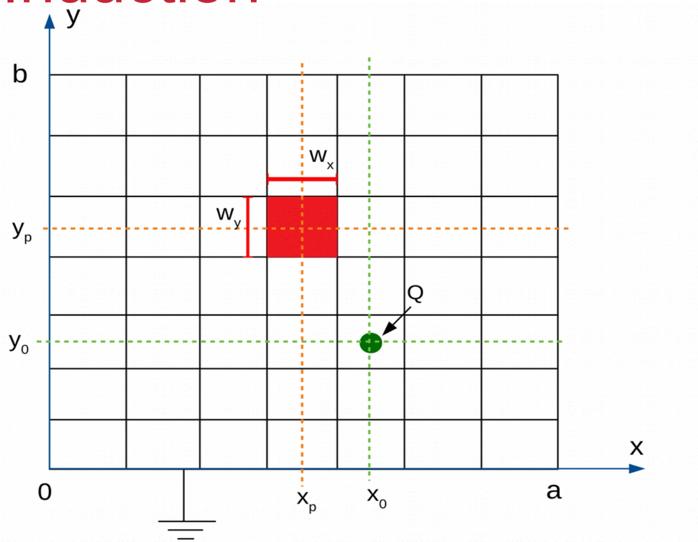
under the supervision of

Dr. Paul Colas
Physicist, CEA Saclay/IRFU/DPhP

Dr. A. K. Rai
HOD, Applied Physics Department, SVNIT

Simulation of Charge Induction





- Werner Riegler calculated space and time evolution of induced charge on resistive foil using electrodynamics. A point charge Q is placed on the resistive foil at time t = 0 and position (x_0, y_0). This results in a charge Q^{ind} induced on the readout pads of dimensions $w_x \times w_y$ at location (x_p, y_p).

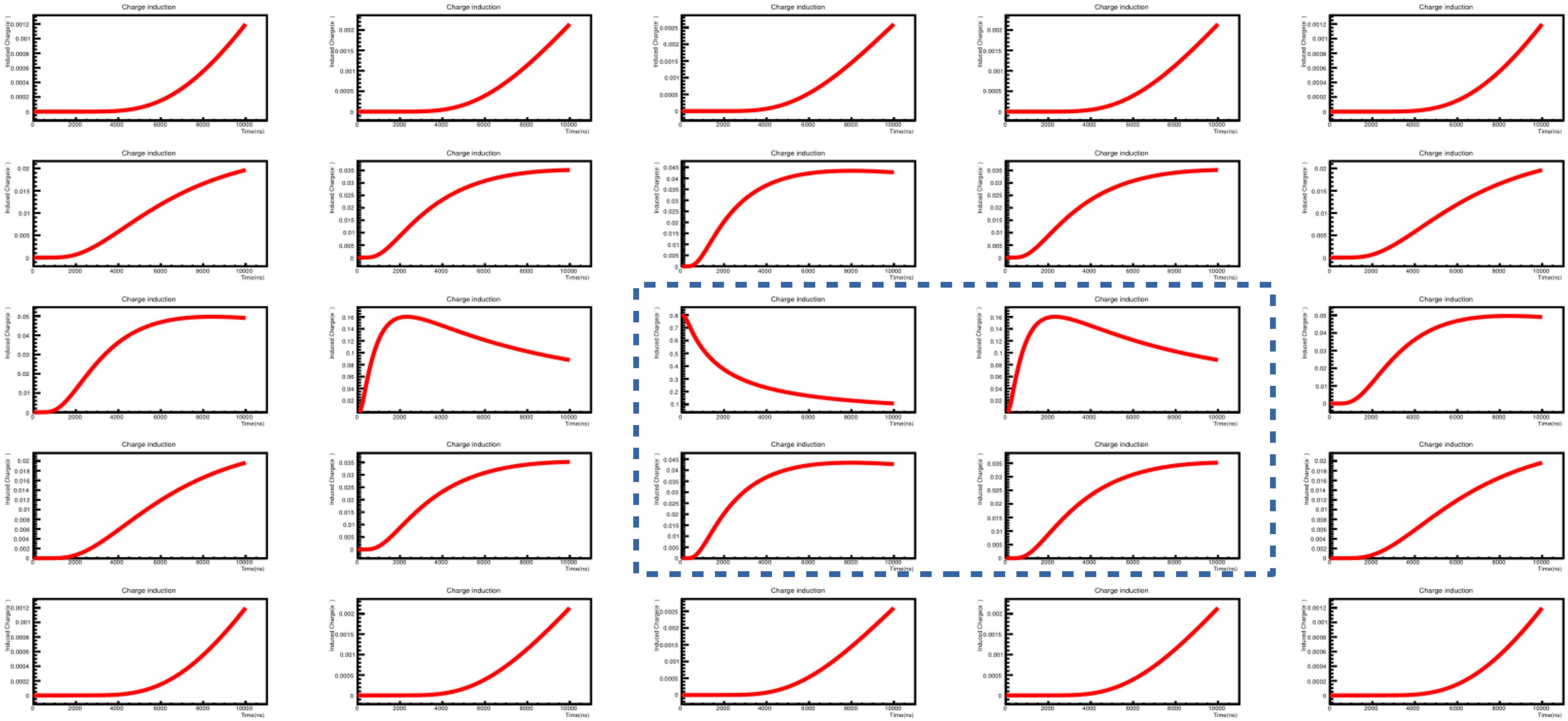
- His expression is a double sum of terms exponentially decreasing with time.

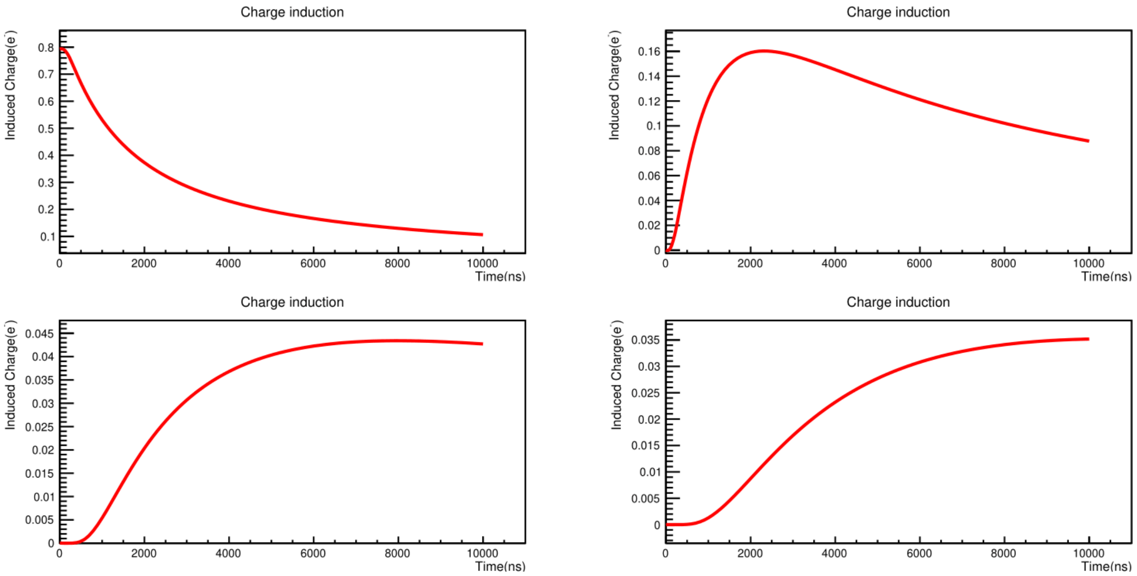
- I simulated his formulation and studied charge spreading in ERAM modules of ILC and T2K geometries in various scenarios.

Specifications of T2K and ILC ERAM module

Parameter	ERAM module for:	
	T2K	ILC
Number of pads in Horizontal direction	36	72
Number of pads in Vertical direction	24	32
a (Horizontal length of Module)	40.2 cm	21.6 cm
b (Vertical length of Module)	32.3 cm	16.8 cm
w_x (Horizontal length of Readout pad)	11.18 mm	3 mm
w_y (Vertical length of Readout pad)	10.09 mm	7 mm
d_1 (Distance b/w Resistive layer and Readout pads)	250 μm	125 μm
d_3 (Distance b/w Resistive layer and Mesh)	120 μm	120 μm
R (Surface resistivity of Resistive layer)	400 kΩ/square	2.5 MΩ/square
ε_1 (Permittivity of d 1 region)	$4 \times \varepsilon_0$	$4 \times \varepsilon_0$
ε_3 (Permittivity of d 3 region)	ε_0	ε_0

$Q^{ind}(t)$ plots of 25 pads in a module of ILC geometry

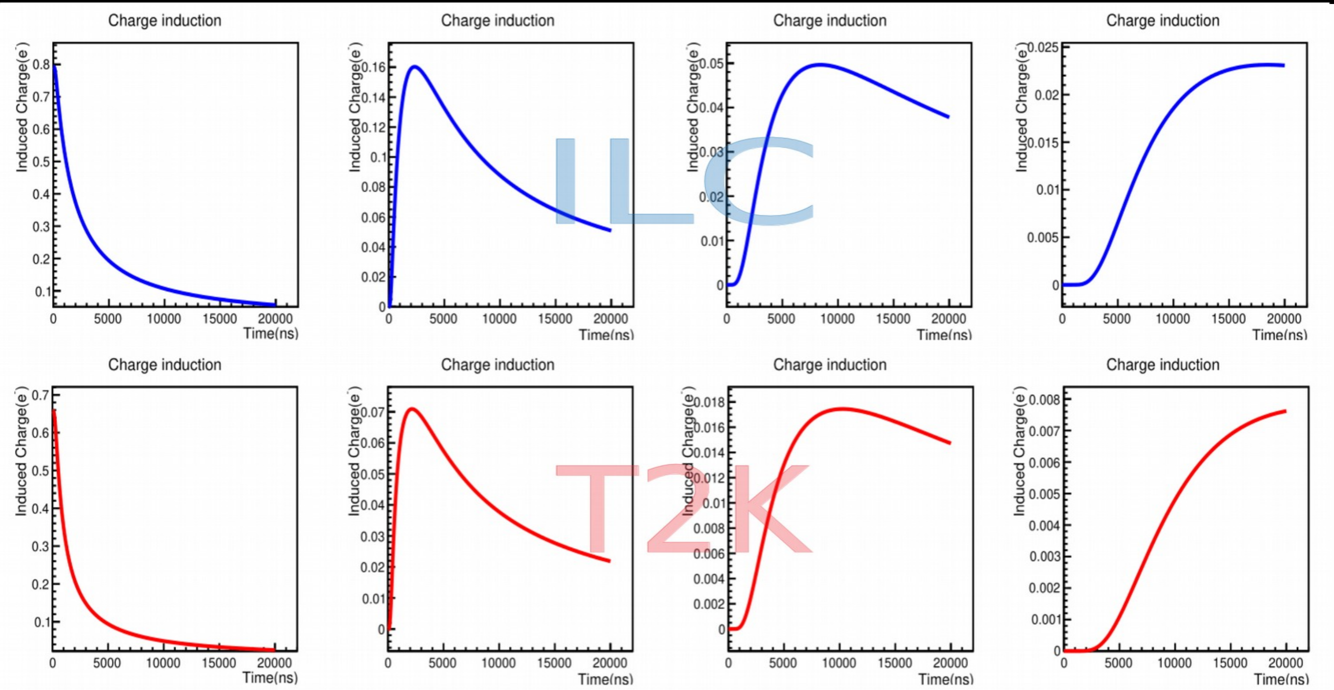




- It is seen that as one moves farther and farther away from the leading pad, peaking time keeps on increasing while the signal amplitude keeps on decreasing

- Despite being immediate neighbours waveforms in vertical and horizintal neighbours are different.

- In reality, it takes about 200 ns for the leading pad signal to peak. But in this formulation of charge induction delta function is used, and to perfectly simulate actual Micromegas signal, one has to convolute this induced signal with the electronics response function.

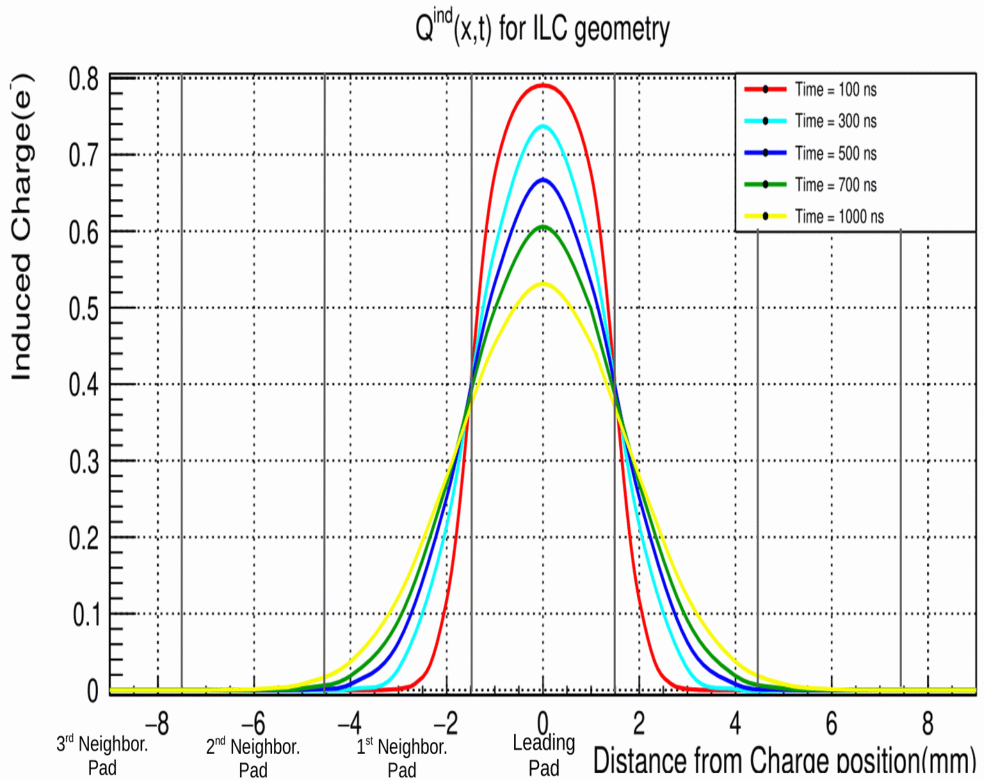


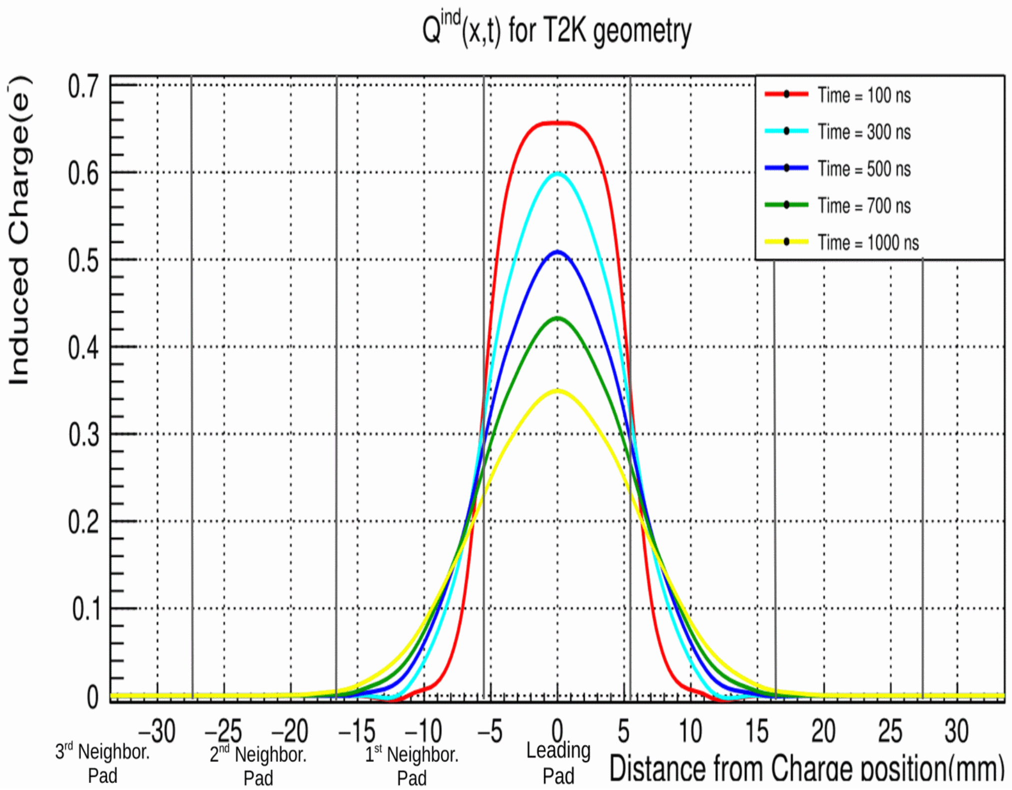
- $Q^{ind}(t)$ plots of leading pad and similarly oriented neighbouring pads relative to the leading pad have similar waveforms along time-axis, but different signal amplitudes.

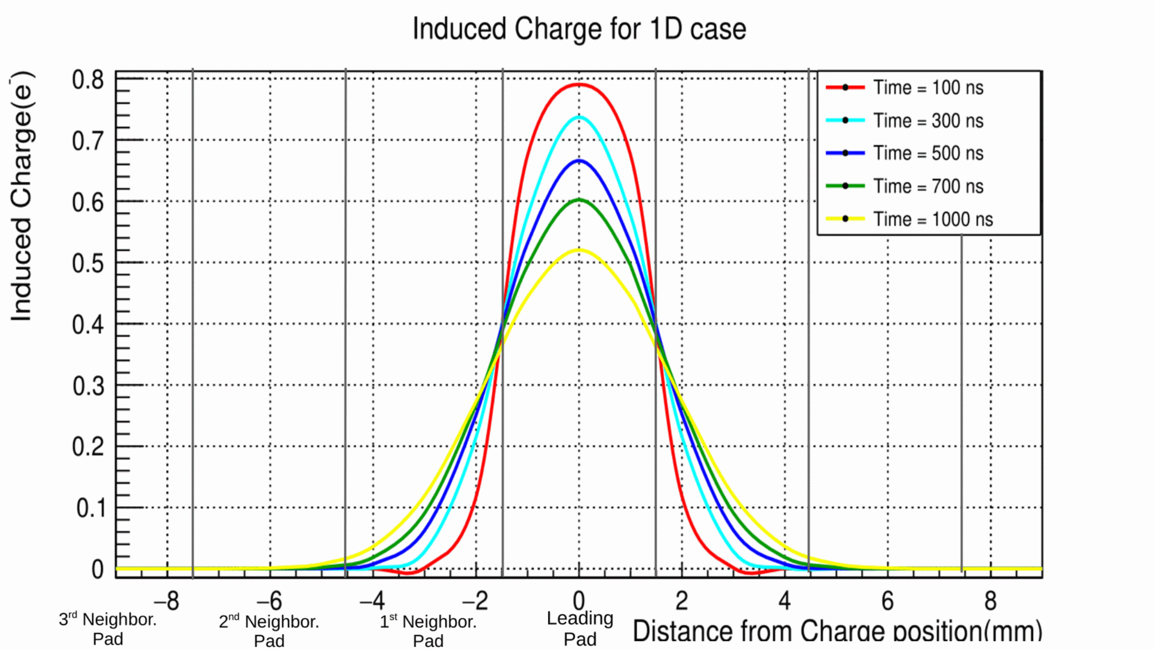
- RC value for ILC module is larger than that for T2K module (≈ 3.5×) =>
  More charge is induced in ILC module than in T2K module at equal time durations.

- Pad width(w_x) of ILC module is about 3.73× smaller than that of T2K module.

$Q^{ind}(x)$ at different times for a segment of ILC and T2K modules with a charge of 1 elecron placed at the center of the central pad.



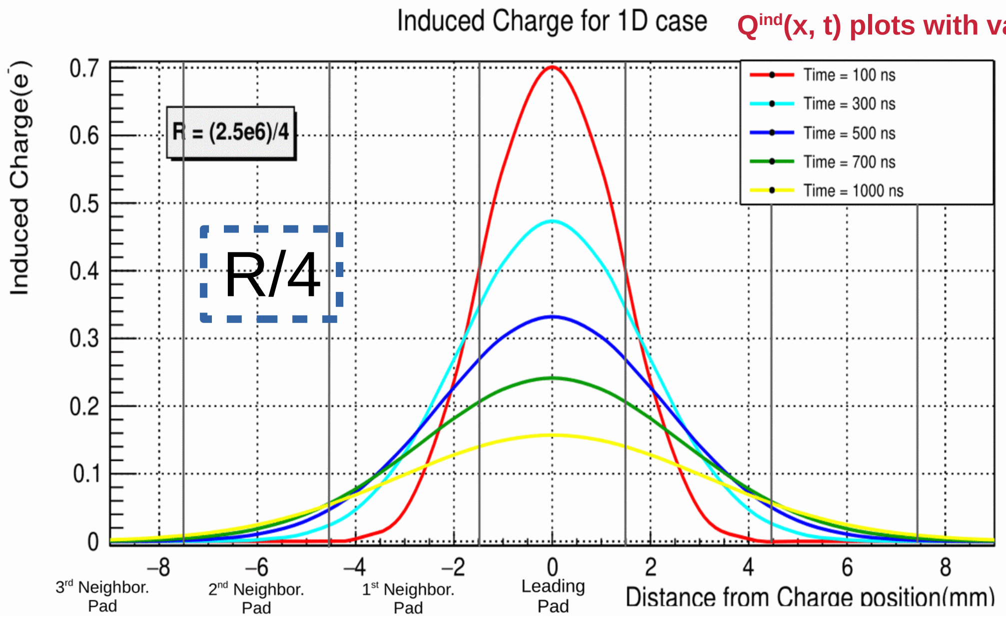


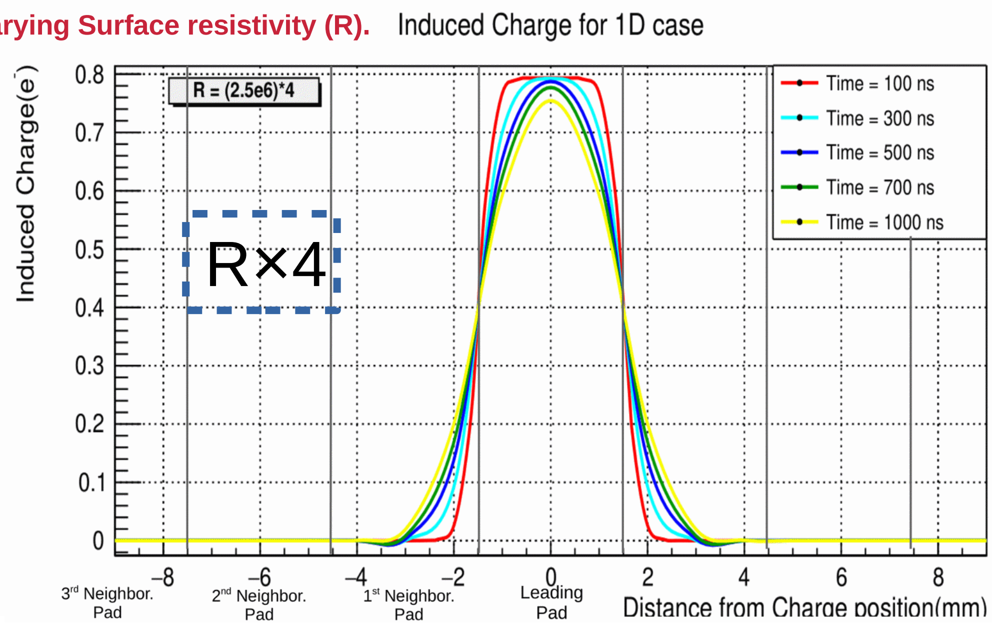


- $Q^{ind}(x, t)$ for a concept-ILC module consisting of 7 pads in horizontal direction only without any pads in vertical direction (dubbed ’1D’).

- Charge spreading is a localised effect and its notable effects are not experienced by pads beyond 3 to 4 neighbours from the leading pad.

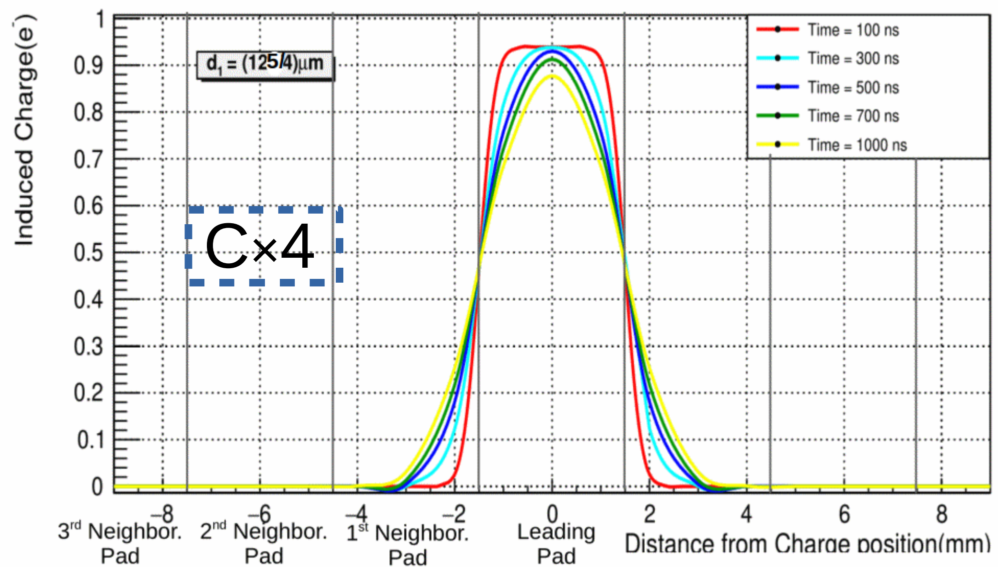
$Q^{ind}(x, t)$ plots with varying Surface resistivity (R).

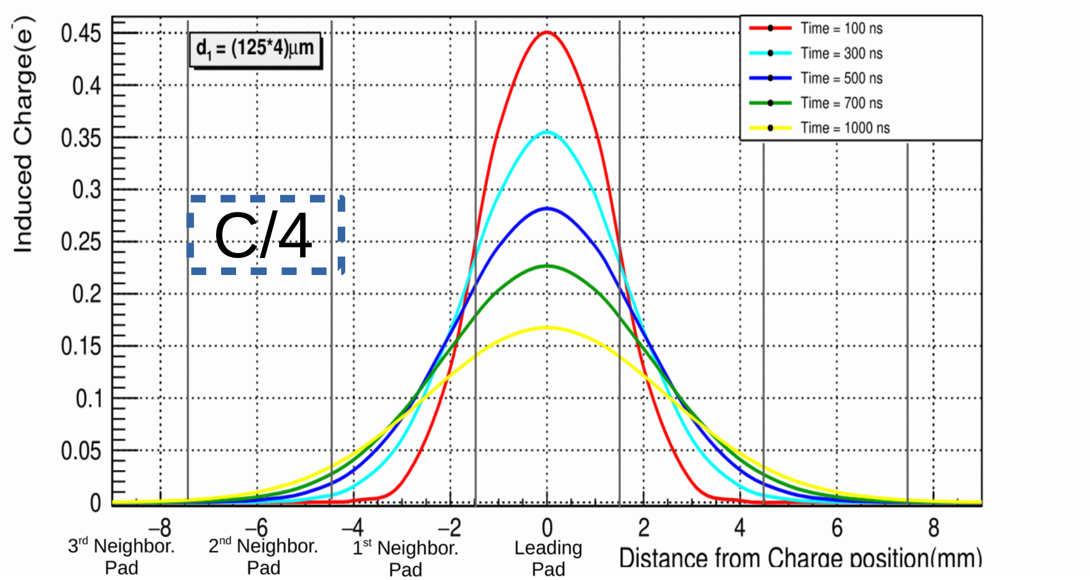




- Vary RC value by changing R.
- Lower RC implies more charge spreading.

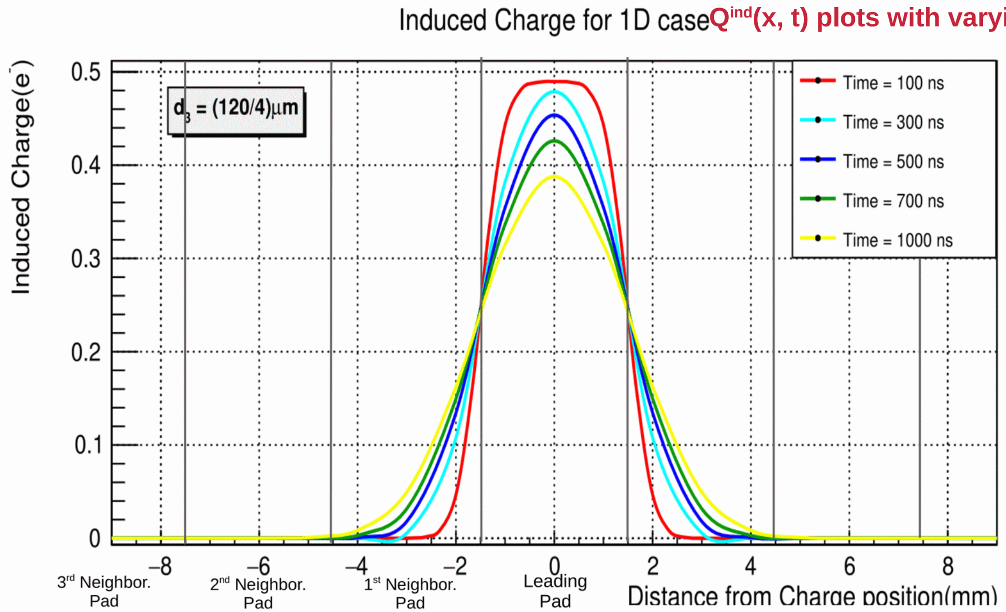
Induced Charge for 1D case $Q^{ind}(x, t)$ plots with varying Insulation thickness (d_1). Induced Charge for 1D case

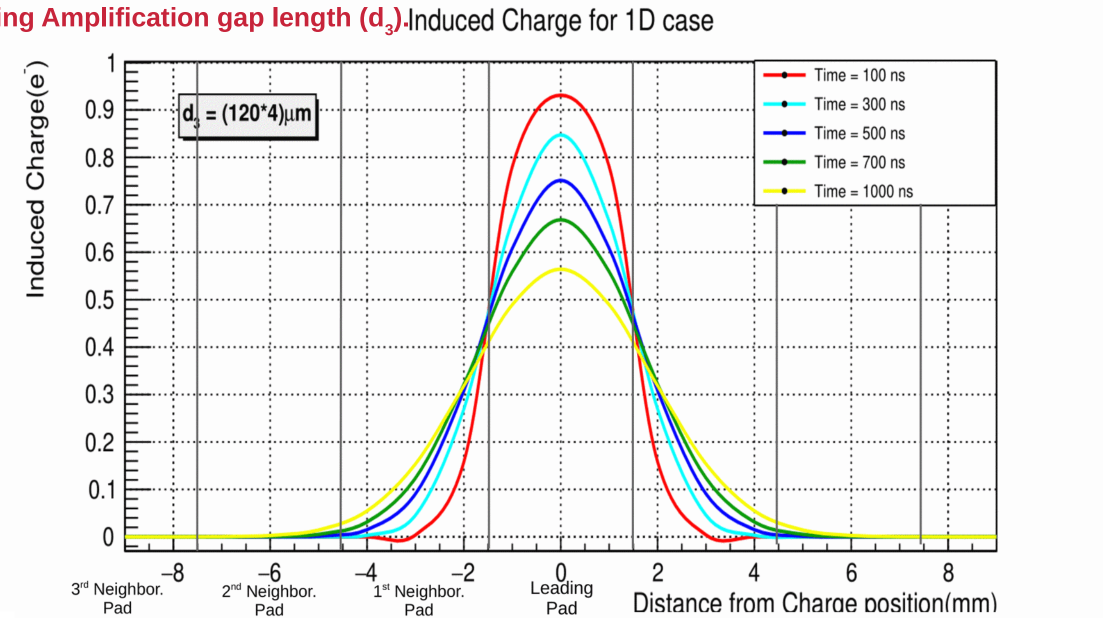




- Vary RC value by changing C.
- Capacitive coupling of resistive foil to pad plane also varies, thus signal strength.

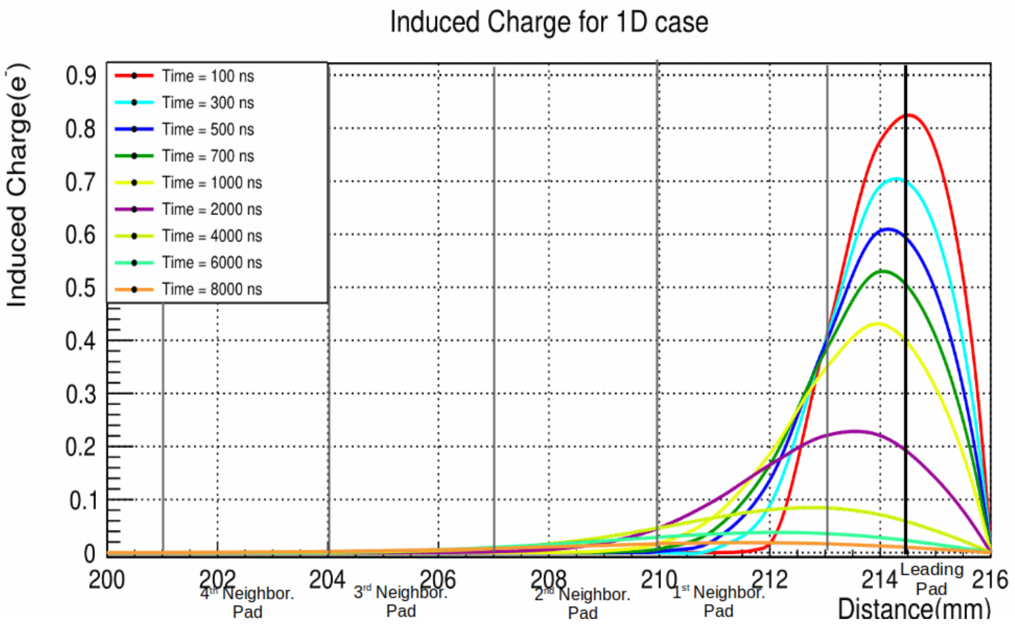
$Q^{ind}(x, t)$ plots with varying Amplification gap length (d_3).





- Changing amplification gap length inversely affects the sharing of signal between the pads and mesh.

Edge effects



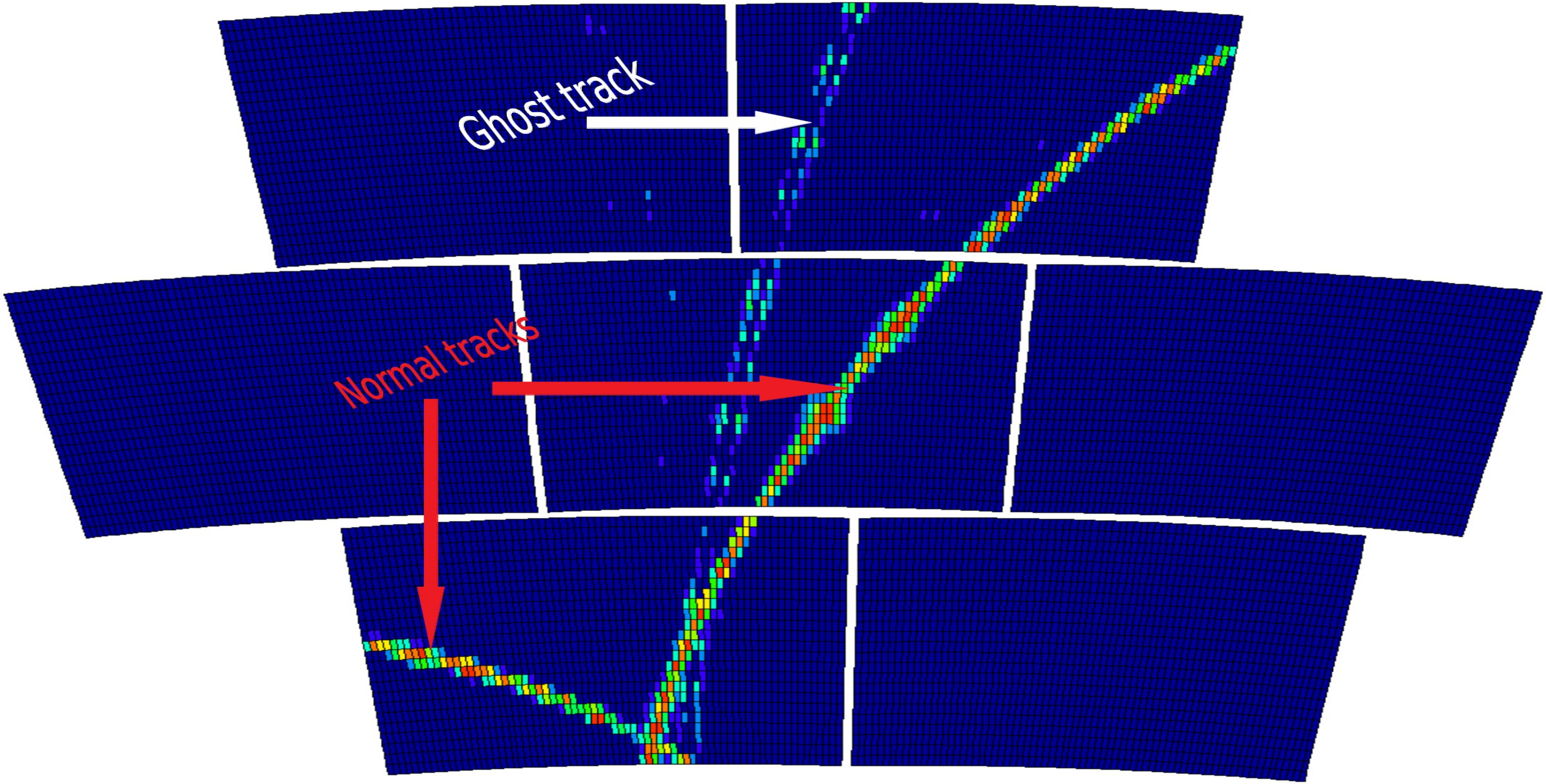
- Q ind (x, t) plot portraying Edge effects in a concept-ILC module of 1 pad length (1D) and 72 pad width. A charge of 1 electron is placed at 214.5 mm from one end of the module i.e. on the center of last pad.
- At earlier times, charge spreading is mostly symmetric on both sides of the charge. But after about 100 ns the curves start skewing towards the module-end.
- When a charge is induced at the edge of a module, lesser charge is induced in a pad near to the edge than in a pad which is at equal distance but in the opposite direction.

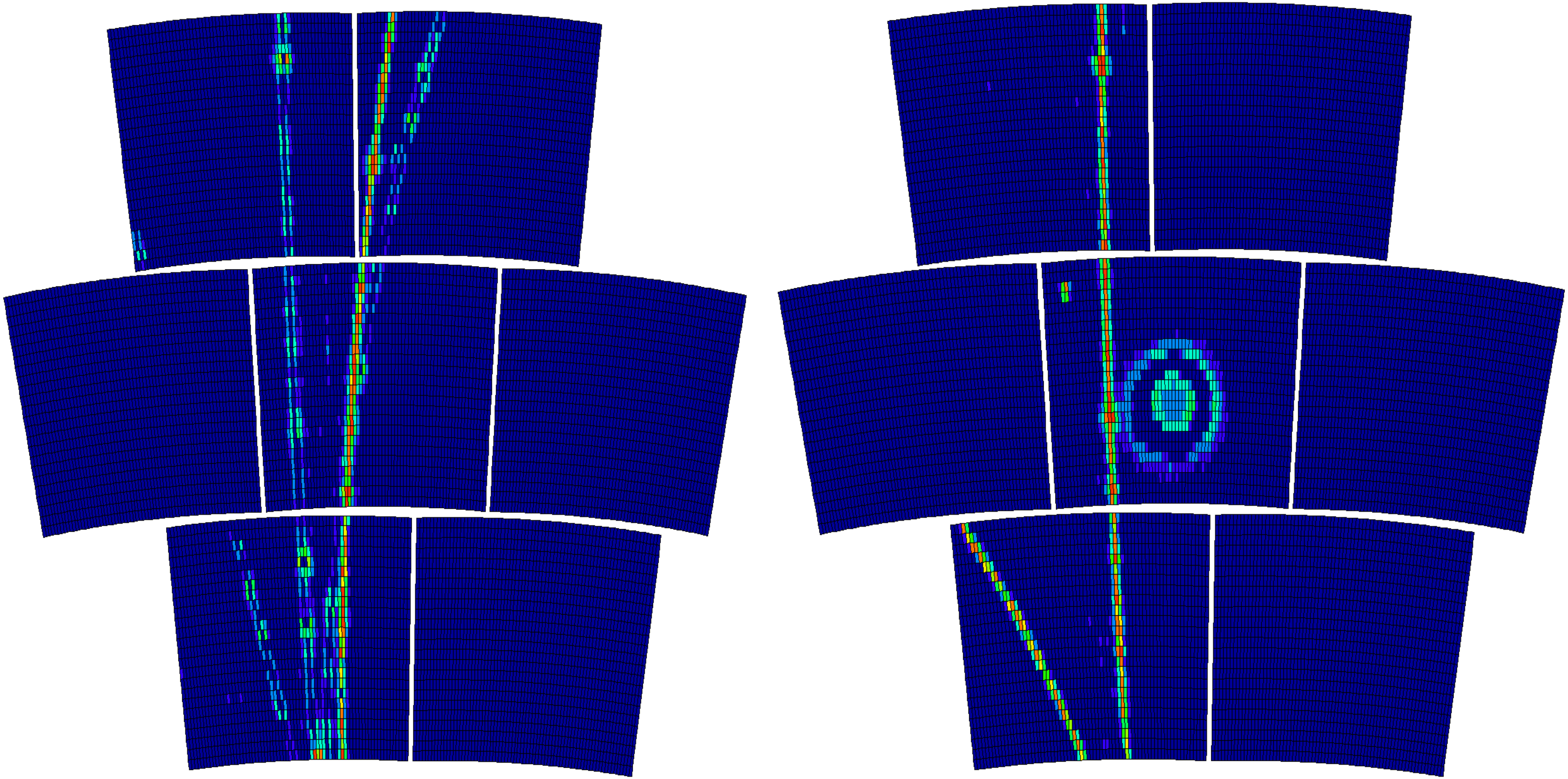
Ghost tracks

- Ghost tracks are anomalous electron tracks appearing in the data from ERAM TPC tests conducted at DESY, Hamburg.
- The probability of occurence of a Ghost track in a standard data-run is about 0.4% - 0.6%. Understanding the cause of these tracks is essential as it might indicate some imperfection in the detector or electronics.
- Here are some of its characteristics:

1) Weak signals- Waveforms of the pads that recorded Ghost tracks have much weaker signals than that of pads which recorded actual, triggered particle tracks.

2) Time delayed- Ghost track signals are very much delayed in time as compared to normal particle signals. In fact, this is their main defining property.


Ghost track
Normal tracks



- SCA (Switched Capacitor Array) used in data taking for this test had 512 bins of 40 ns width that can store signals up until 20 μs after an event was triggered.

- ‘t_0’ is minimum time taken between trigger generation and recording of event, and ‘z_{drift}’ is the distance from the anode where electron beam was targeted. Hence, an event will take t_0 time to be recorded when z_{drift} is very small.

- Both these parameters are important in ascertaining time at which an event was recorded in SCA.

$$t = \frac{z}{v_{drift}} + t_0$$

- Value of t_0 during DESY beam test was 864 ns, which is equal to 21.6 bins of SCA. Thus, there is no way an event is recorded in first 21 bins of SCA. But as it turns out, all the Ghost event signals are recorded before 21 bins. This anomalous behaviour is the reason it got its name.

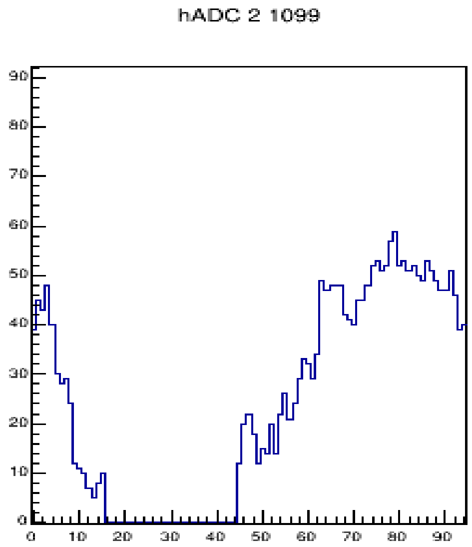
- These events were obviously not triggered; so the only explanation is that they are very much delayed signals from past events.

- Although the origins of Ghost tracks are yet speculative. Some possible reasons for these occurences are trigger inefficiency and delayed signal in second and third neighbouring pad.

- It is possible that these signals were legitimate event signals in the past, but failed to generate a trigger and now they are appearing out of time along with next batch of events. We verified that the previous recorded event had nothing to do with the Ghost track in current event.

- It can be seen in the plots of previous chapter that signals in third, fourth and other distant neighbours were very delayed compared to signal in leading pad. So it is possible that these signals are sometimes recorded in the few tens of SCA cycles.

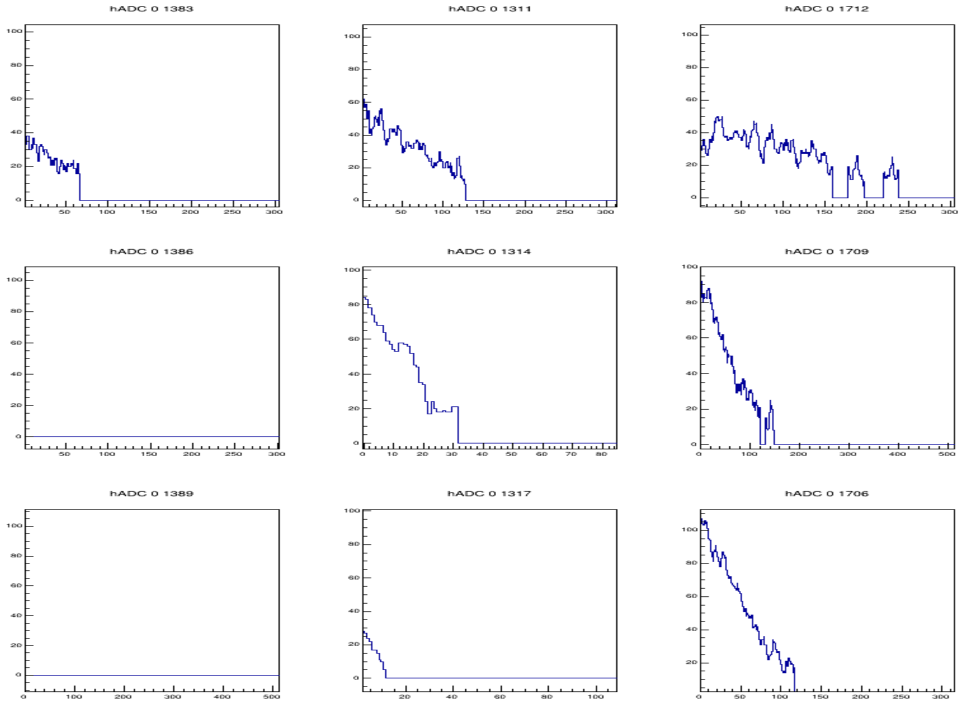
  - The following histogram displays the waveform in a pad overlapped by a normal electron track and a Ghost track.
  - Here, the y-axis represents 4095 ADC channelswhich correspond to a total charge of 120 fC.



Selection of Ghost tracks

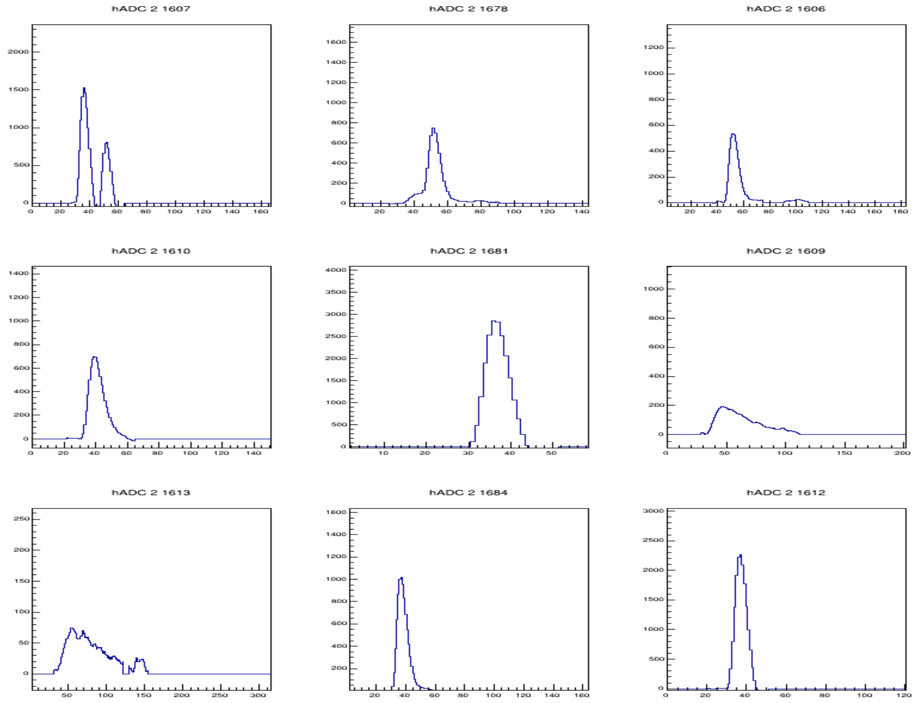
- I modified the pad-click enabled waveform display of the ILC-TPC monitoring code to include 3×3 (unlike pre-existing 1×3) matrix of ADC v/s time histograms of selected pad and its 8 surrounding neighbours.

- This would help in checking the t_0 criteria of the pad under scrutiny along with all its first order neighbouring pads.



<- Ghost

Normal ->



- The second and arguably more important modification I made in the monitoring code is the capability to find and filter out the Ghost tracks from all the recorded events in a data-run.

- I tested my code on multiple data-runs and it was able to detect all the Ghost tracks (with small error) which were found manually.

- Here are some of the statistics- Data-run 6197 was run for 3000 events and 18 of them were found to possess Ghost tracks. My code was able to filter out 32 events which had a high probablitiy of possessing a Ghost track. Hence, the probablitiy of finding a Ghost track in this particular run hiked from 0.6% to 56.25%. Similarly, Data-run 6172 had 24 events with Ghost tracks in them out of 5000 events. My code filtered out 36 events, hiking the probability of finding a Ghost track in this run from 0.48% to 66.67% (1 Ghost track in every 3 events).

- My code checks the ADC vs. time histogram in all the 1728 pads of the 4 working ERAM modules for each event for maximum ADC value and content of each bin.

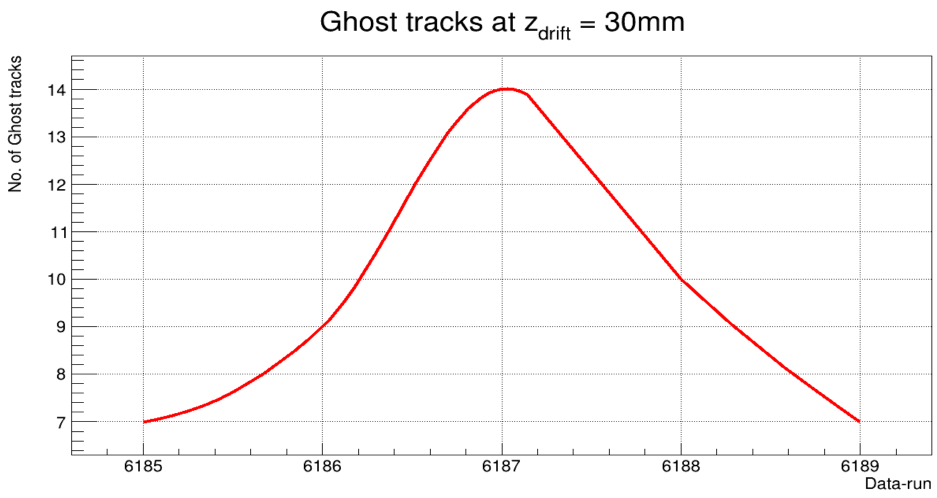
- If the maximum ADC value in a pad is ≤ 60 ADC channels (and obviously > 0 ADC channels), if atleast 18 of the first 21 bins has some finite value and if atleast 40 out of 4×1728 pads in an event satisfy the previous two criteria, an event is considered to possess a Ghost track.

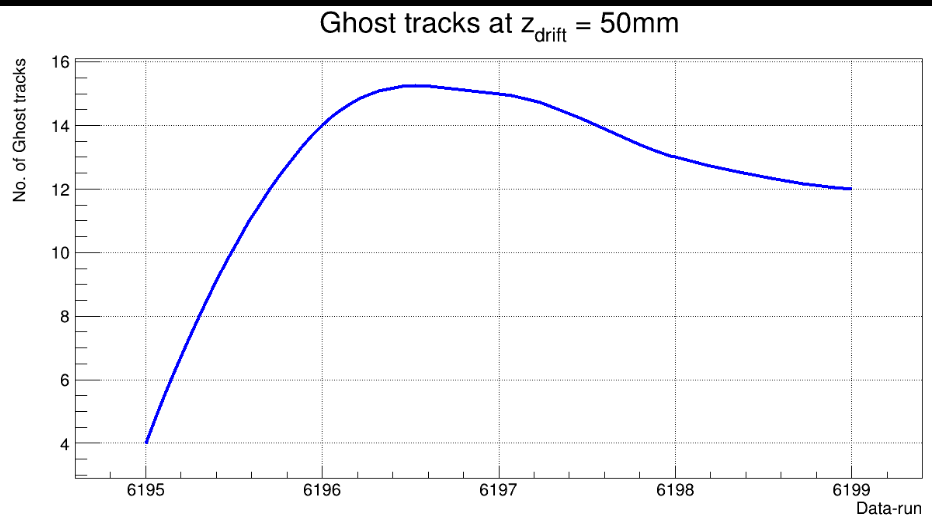
- The filtered events are automatically saved as an image(with its run-number and file-number in its name) and stored in a manually created folder called ’Ghost events’; their event numbers are also noted in a text file.

Ghost track analysis

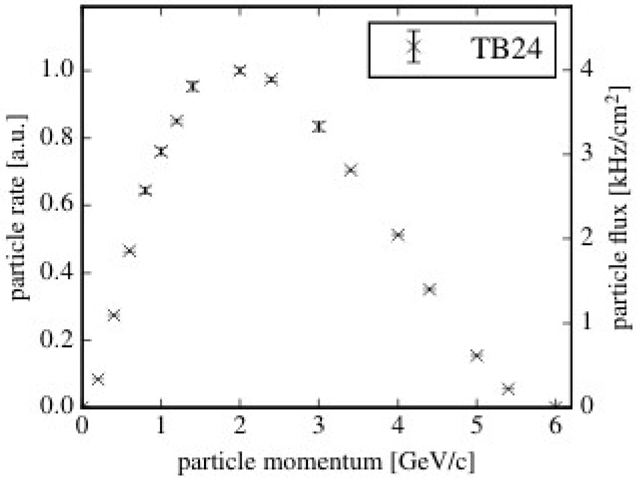
- A study was conducted to understand how the number of Ghost tracks in a run are affected by z_{drift} and electron beam energy.
- Following table includes the data-runs upon which this study was conducted classified as per their z_{drift} and beam energy used-

Electron beam energy (GeV)	Data-run	
	z_{drift} = 30mm	z_{drift} = 50mm
1	6185	6195
2	6186	6196
3	6187	6197
4	6188	6198
5	6189	6199





We can compare these results with the particle rate vs. selected beam momentum plot of the beamline at DESY, used for this experiment.



- we can see that the number of Ghost tracks in a data-run more or less follows the same pattern as particle rate, against electron beam energy.
- Also, the Ghost track counts in both the cases of z_{drift} is very similar. Hence, the number of Ghost tracks in a run depend on particle rate in the beam used for that run and not the distance from anode where the beam was incident.

END