Characterization of ROPPERI using simulations in the MarlinTPC software framework

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Abstract

The International Linear Collider (ILC) to be built in Japan within the next 5 years will incorporate the International Linear Detector (ILD), which will has a Time Projection Chamber as the central tracker. It is necessary to have a high granularity for the TPC readout system in order to achieve a high counter cluster capability. For this reason, a new readout structure known as ROPPERI (Read Out of a Pad Plane with ElectRonics designed for pIxels), has been proposed. This system allows pad sizes of approximately 300 µm to enable cluster counting, which gives a large flexibility and also keeps the channel number low. With the purpose of defining the behavior of the TPC and the novel readout system, several simulations have been developed with the MarlinTPC software. In these, the behavior has been observed in terms of parameters variations such as the pad and readout length dimensions, the number of pads, the distribution of charge on them, the magnetic field inside the TPC, etc.

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1. Introduction

TPC and measurement principle

The Time Projection Chamber was introduced in 1976 by D.R. Nygren. Usually, it is composed by a gas filled volume with a central cathode that divides the volume into two halves. Each side has an anode with a readout system. The cathode is at a high potential that results in a field strength of approximately 100 V/cm, while the anode is at ground potential, this leads to a potential of approximately 10 kV at the cathode. In 4π-detectors (detectors that cover almost the whole solid angle) at high energy physics experiments, the drift volume is normally a cylinder and the beam goes through the rotation axis of the TPC with the interaction point at the center.
A charged particle going through the gas volume of the TPC will ionizes the atoms of the gas mixture (90% a noble gas like argon and 10% a quencher gas) along its trajectory as shown in figure 1. Then a high electric field is applied between the endplates of the chamber. The released electrons drift in this field towards the anode (point 2 in figure 1).
In order to measure the position of the particle trajectory as precise as possible, the electric field must be homogeneous. This can be achieved by a field cage, which usually is composed of conducting rings around the cylinder. The rings divide the potential from the cathode stepwise down to the anode. In addition, a high magnetic field parallel to the electric field is used to "bend" the trajectory of the particle on a spiral track due to Lorentz force, which gives the possibility to calculate the momentum of the particle from the knowledge of the curvature and the magnetic field.

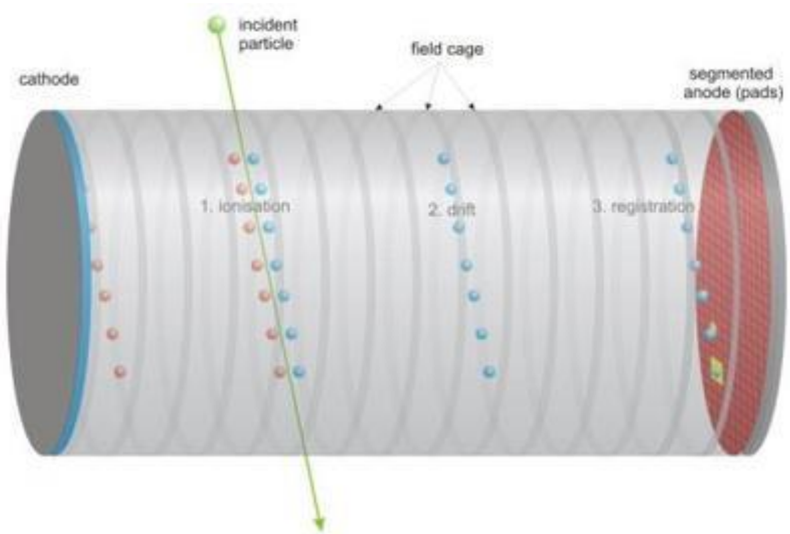


Figure 1. A typical TPC (Time Projection Chamber)

At the anode plane, electrons can be detected on the readout plane which is segmented in the directions perpendicular to the drift direction (point 3 in figure 1). Since the electron signal from the primary ionization process is of the order of only 100 electrons/cm, the signal needs to be amplified before being detectable. This task is typically performed with a high electric field in vicinity of thin wires.

The rφ position (coordinates perpendicular to the cylinder axis) of the trajectory can be reconstructed directly from the coordinates of its projection on the pad plane. The z position (coordinate along the cylinder axis) is reconstructed from the drift time, which is the time between particle passing the TPC volume and measured signal on the pads. Thus, an external timing information, for instance from a silicon detector, is needed.

A very important characteristic of this gaseous detector is the dE/dx capability. Since the relation of momentum and energy loss (dE/dx) of a traversing particle depends on its rest mass, and hence on its species, measuring both properties allows for a particle identification determined from the Bethe-Bloch-curve.

The energy loss is normally measured by summing all electrons generated from the ionization by the incident particle. For each ionizing interaction the number of generated electrons is given by a Landau distribution which has a long tail towards large numbers of electrons. The relatively large width of this distribution worsens the correlation of the measured energy and the momentum of the particle. Because of this, it is better to instead count the number of ionizing interactions the incident particle goes through. This is given by a Poissonian distribution with a clearly smaller width, resulting in a better correlation and particle identification power. In figure 2, the separation power for pion/kaon-separation depending on the cluster counting efficiency (gain) is shown compared to the conventional dE/dx by charge summation. In former experiments with prototypes, a cluster counting efficiency (gain) of only 20%-30% was reached. However, the resulting separation power is still better than by charge summation.

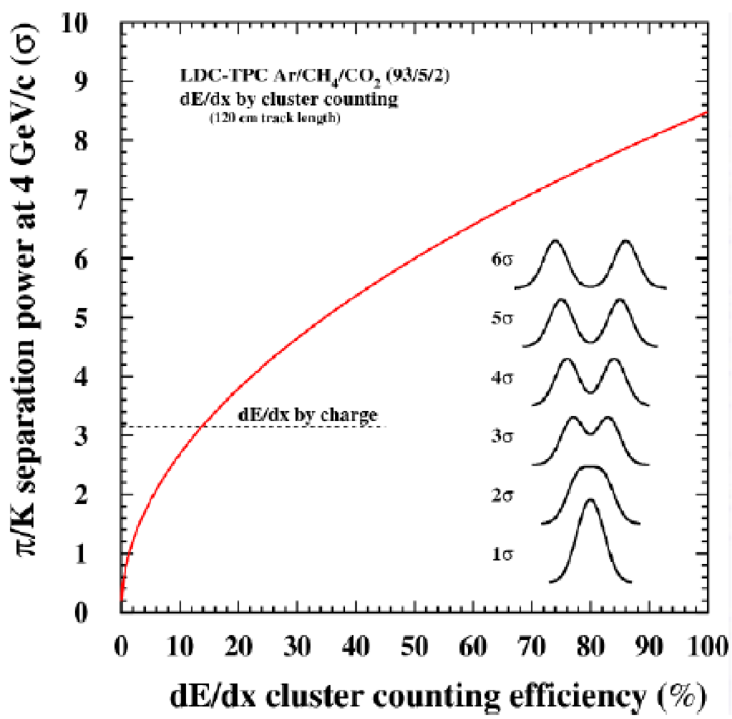


Figure 2. Pion/kaon separation power of dE/dx by cluster counting

ROPPERI

The ROPPERI (Readout Of a Pad Plane with ElectRonics designed for pIxels) system was proposed as a new read out option for a TPC. It allows pad sizes of approximately 300 µm to enable cluster counting. It combines the advantage of the high granularity of a pixelized read out given by the Timepix chip and the flexibility and high anode area coverage of a printed circuit board (PCB). In figure 3 appears a scheme of the PCB. Gas Electron Multipliers (GEMs) are used for amplification of the signal. Small pads on the PCB form the anode and are read out by the Timepix (ASIC) with a matrix of 256x256 = 65536 pixels. The connections from the pads are routed through the PCB to the ASIC which is bump bonded to the PCB surface, so it needs to be sufficiently flat. The Timepix power and communication pads are on the same side of the ASIC as the pixels. They are usually connected by wire bonds. These pads also have to be connected by bump bonds to the PCB, which also contains the further electronic elements including the connectors for the chip voltage supply and an I/O cable plug. The data processing is conducted by the SRS (Scalable Readout System) developed at CERN. An FEC (Front-End Concentrator card) hosts an FPGA (Field Programmable Gate Array) that reads the data from the Timepix ASIC through an adapter card and a VHDCI cable to the ROPPERI board.

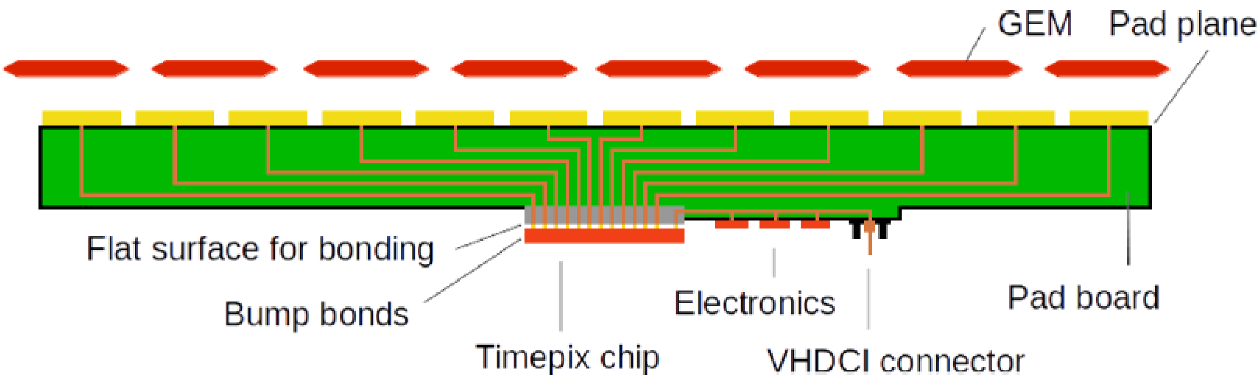


Figure 3. Structure of the ROPPERI PCB

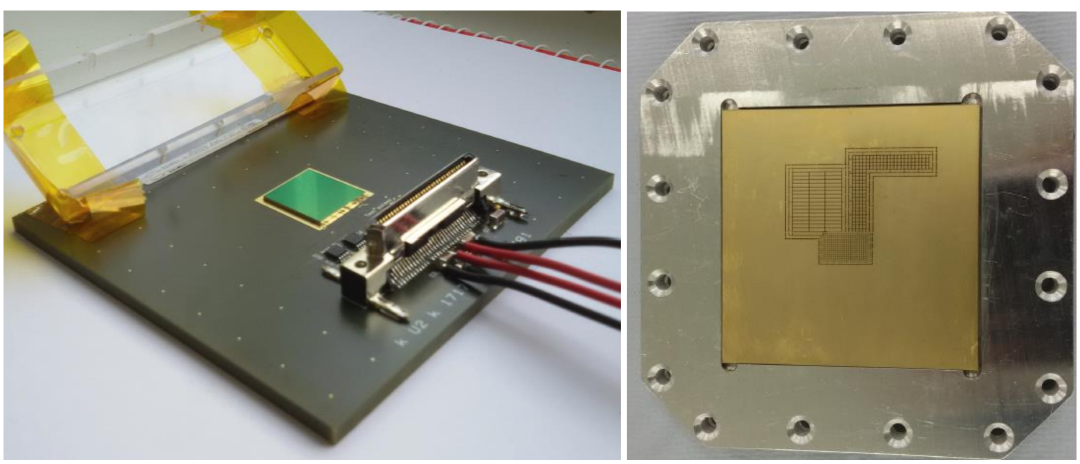


Figure 4. ROPPERI (left) and the reading pads (right)

The first prototype board will be tested with the UNIMOCS TPC at DESY. It consists of a 5 cm drift volume and a triple GEM stack with 10x10 cm^2 GEMs. The PCB will be part of the gas containment. By this way, the VHDCI cable can go from the PCB directly to the read out system, which collects the data and sends it to a PC via Ethernet.

In the future, the pads on the anode plane will have the size of a few hundred µm. The Timepix chip has a pitch of 55 µm. The strip lines of typical FR-4 PCBs have a pitch bigger than 100 µm and a via of 350-500 µm, which limits the number of usable channels and makes the routing much more complex. In addition, bump bonding with a pitch of 55 µm is not an easy task to achieve. The Timepix chip was made for input capacitances of less than 100 fF, with the PCB routing and strip lines of a few cm they will be in the order of pF, which limits the signal-to-noise ratio.

Marlin TPC

It's a software package designed to enable the R&D groups of the LCTPC collaboration in order to develop analysis and simulations. The LCTPC collaboration was created to sum the international efforts to build a high performance Time Projection Chamber (TPC) at the International Linear Collider (ILC). In the collaboration there are groups from America, Europe and Asia. MarlinTPC is based on the ILC software frameworks LCIO (data format, persistency), Marlin (data processing chains), GEAR (geometry description) and LCDD (conditions data handling).
The MarlinTPC package consists of reconstruction and analysis parts as well as a detailed simulation down to the single electron level. It provides algorithms for hit reconstruction for all available readout types and the implementation/integration of different track finding and fitting packages. One of the final goals is to be able to study reconstruction techniques and corrections for field inhomogeneities and misalignments in the TPC.

2. Procedure

During these eight weeks, the work consisted basically in the development of several simulations in MarlinTPC. A set of variables was taken, and then the values of some of them were changed and the values of other ones were fixed. The variables considered were the magnetic field in the z direction, the height and width of the pads (in µm), the number of pads, the maximum drift length, and the readout length (in mm). These changes were made in the GEAR file of the software.
In order to extract the data and add or modify the analysis of it, there were modifications of some of the simulation and extraction source files of MarlinTPC. These changes were mainly made on the ClusterCountingEfficiencyProcessor.cc and ClusterCountingEfficiencyProcessor.h. The information obtained were the cluster counting gain, defined as the ratio between the number of reconstructed hits and the number of primary clusters, the ratio between the number of TPC hits and the readout length, and charge related parameters (mean charge, $1/\sqrt{q}$, $1/q^2$, and truncated mean charge at the 80% of its lowest values). Then the ratio between the RMS values and the mean values of each one of these quantities was obtained.

3. Results and discussion

Since several simulations were made, only the most representatives and with relevant results will be presented. The following histograms were the typically obtained during the simulations. In figure 5, a run can be observed with a fixed magnetic field in z direction of 1.0 T, 256 pads each with 80 µm of height and width, and readout length of 40.96 mm. The histograms observed correspond to the cluster counting gain (left) and the ratio between the number of TPC hits and the readout length (right).
The software also allows a physical visualization of the simulations through the GLCED viewer. At the moment of making them, it is possible to select how many we want to see and what want to see, for instance amplified electrons, clusters, etc. In figure 6, it's shown a run with magnetic field of 1.0 T, 256 pads with 120 µm of height and width, and a readout length of 61.44 mm. The green spots are the amplified electrons, the blue ones are the hits reconstructions, and the red ones are the digital signal on the individual pads.

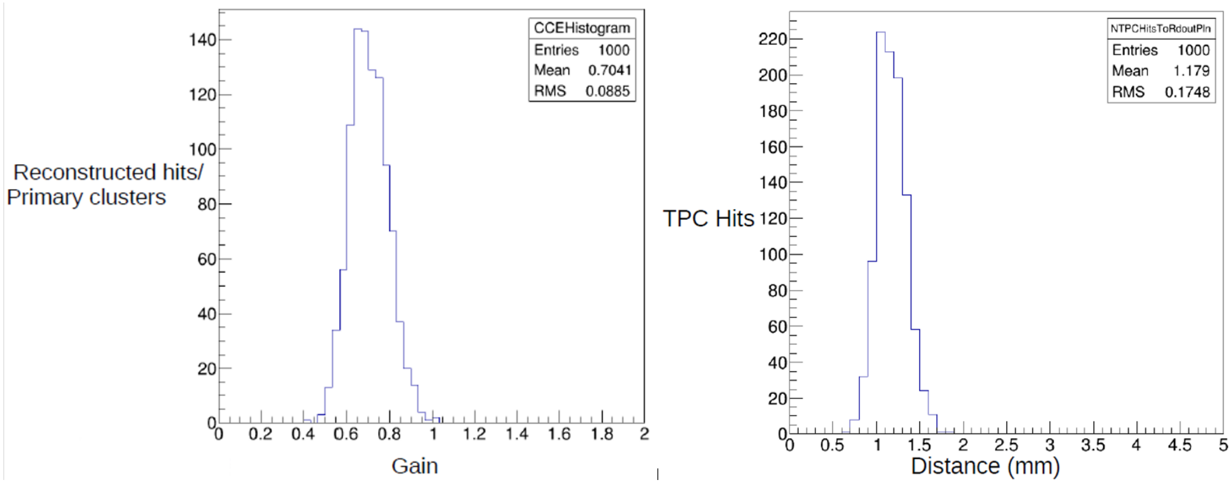


Figure 5. Cluster Counting Gain (left) and Number of TPC Hits / readout length ratio (right)

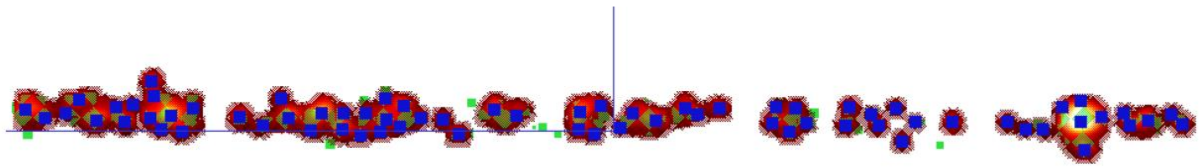


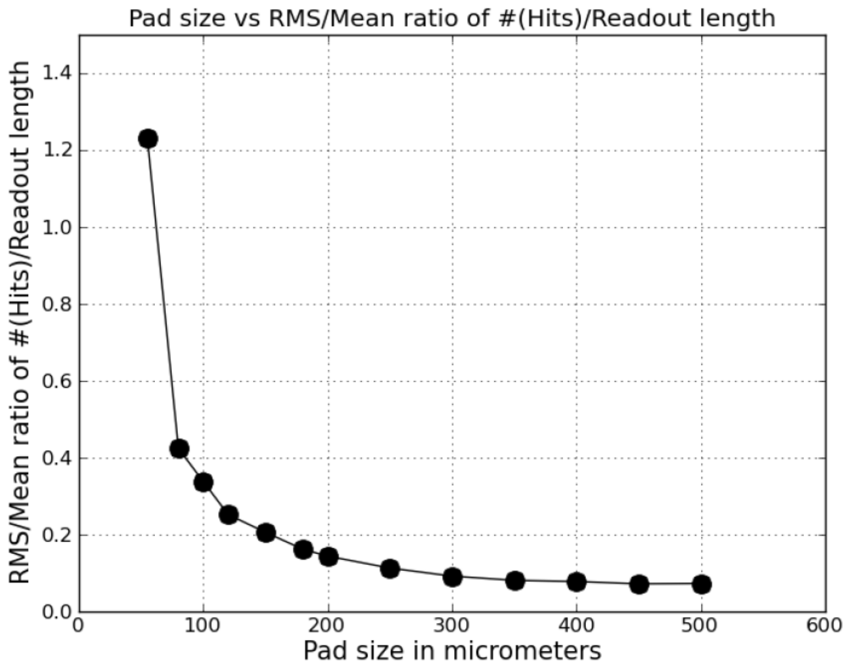
Figure 6. Amplified electrons (green), hits reconstruction (blue), and digital signal on individual pads (red)

The first important result is a set of 13 runs with 1000 events each one. 13 different pad sizes and readout lengths were taken in account with a fixed number of pads of 512. The data obtained in this case is showed in table 1.

Run	Pad size (μm)	CCE (mean)	TPCHits/Read (mean)	TPCHits/Read (RMS)	RMS/mean
1	55	0.7434	0.5125	0.6314	1.232
2	80	1.093	0.9964	0.4232	0.424
3	100	1.139	1.194	0.4038	0.338
4	120	1.152	1.31	0.3305	0.252
5	150	1.07	1.313	0.2712	0.206
6	180	0.964	1.251	0.2029	0.162
7	200	0.8927	1.197	0.1725	0.144
8	250	0.7426	1.042	0.118	0.113
9	300	0.6146	0.8924	0.08265	0.092
10	350	0.513	0.7595	0.06183	0.081
11	400	0.4306	0.6468	0.05099	0.078
12	450	0.3652	0.5564	0.04026	0.072
13	500	0.3107	0.4785	0.03526	0.073

Table 1. Cluster counting gain, No. of TPC hits/Readout length sizes, means and RMS values

Also it is important to mention that in this and the next set of results, a cluster distance factor of 2 was considered. This factor is important because it increases artificially the distance between clusters and allows a simpler reconstruction.
A plot was made taking the pad sizes and RMS/mean values of table 1.



Plot 1. Pad size vs RMS/mean ratio

It is observed that as the pad size increases, the RMS/mean ratio of the No. of TPC hits/Readout length ratio decreases. This is expected since the number of hits are distributed each time in a larger area.

The following relevant result was a set of 5 runs with 1000 events each one. In this case 3 quantities were fixed through all the procedure: magnetic field (1.0 T), readout length (102.4 mm) and maximum drift length (200 mm). The variables that were changed were the pad dimensions (width and height) in multiples of 55 µm, and the number of pads. The data obtained were the cluster counting gain, No. of TPC hits / readout length ratio, the mean charge, the truncated mean charge at the 80% of the lowest values, $1/\sqrt{q}$, and $1/q^2$. The histograms of these quantities are shown for the run 3 (465 pads of 220 µm of height and width each) from figures 7 to 9.

The ratios between RMS and mean values of each of the mentioned quantities were obtained and are shown in the table 2, together with their respective pad sizes.

Pad Size (µm)	TPC Hits/Rout RMS / mean	Charge RMS / mean	$^1/_{\sqrt{q}}$ RMS /mean	$^1/_{q^2}$ RMS / mean	Truncated charge (80%) RMS / mean
55	0.1204	0.1070	0.0197	0.0482	0.0302
110	0.0793	0.1178	0.0169	0.0480	0.0285
220	0.0688	0.1233	0.0187	0.0488	0.0363
330	0.0709	0.1370	0.0199	0.0502	0.0434
440	0.0724	0.1371	0.0192	0.0514	0.0444

Table 2. Pad sizes and RMS/mean ratios

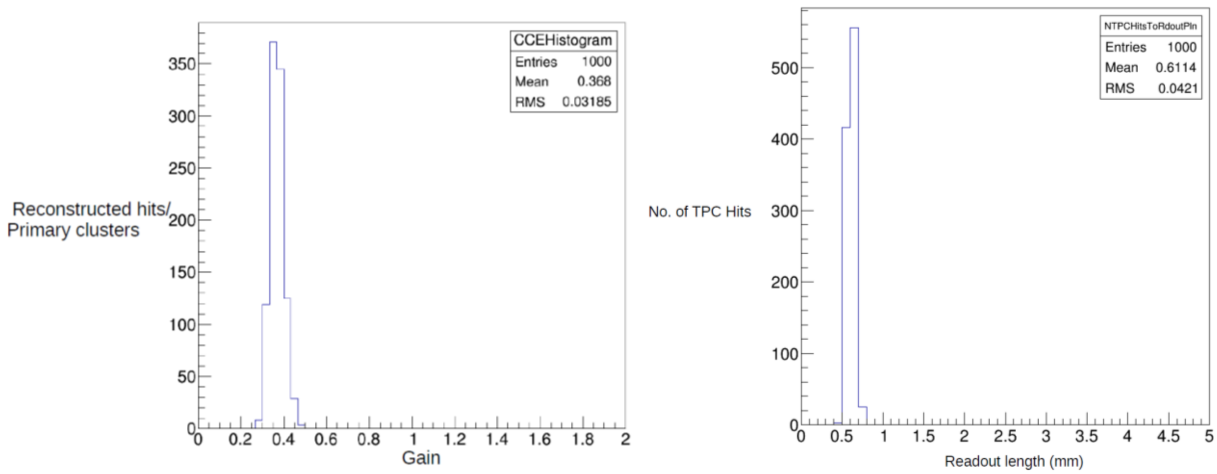


Figure 7. Cluster counting gain (left) and No. of TPC Hits/Readout length ratio (right)

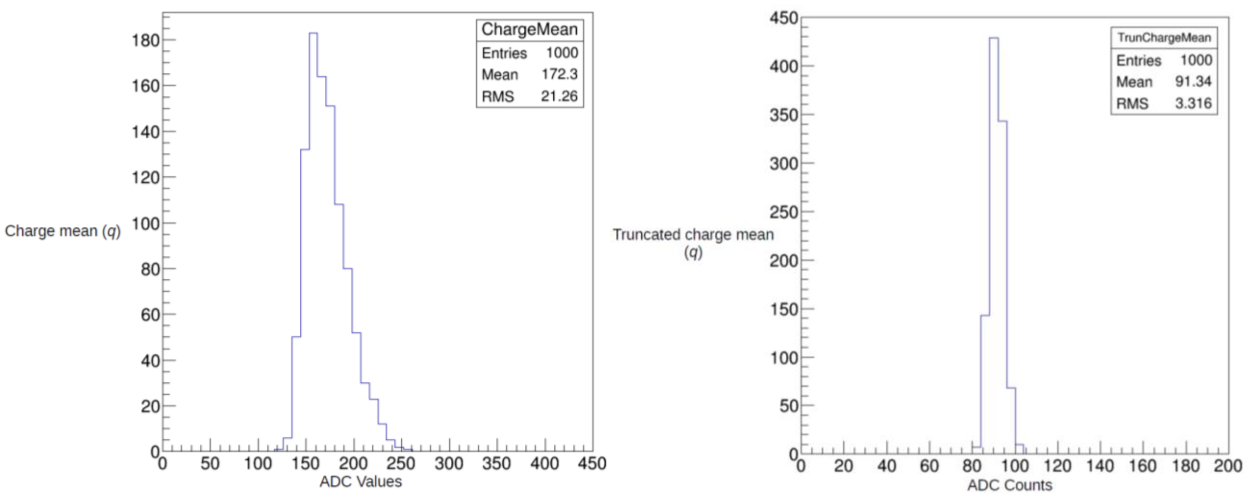


Figure 8. Charge mean (left) and charge mean truncated at 80% (right)

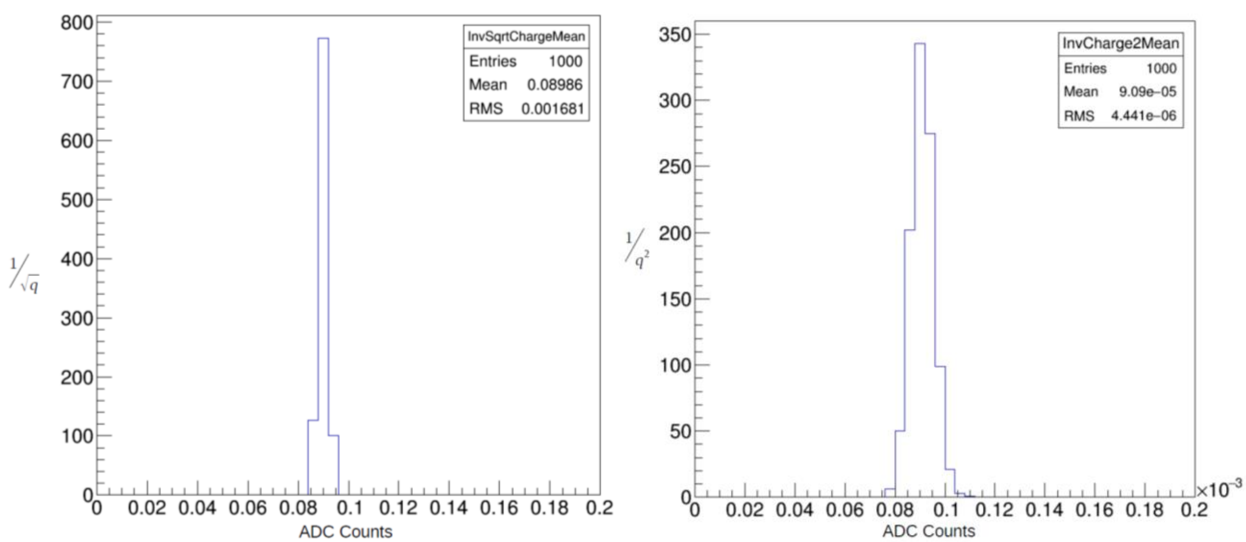
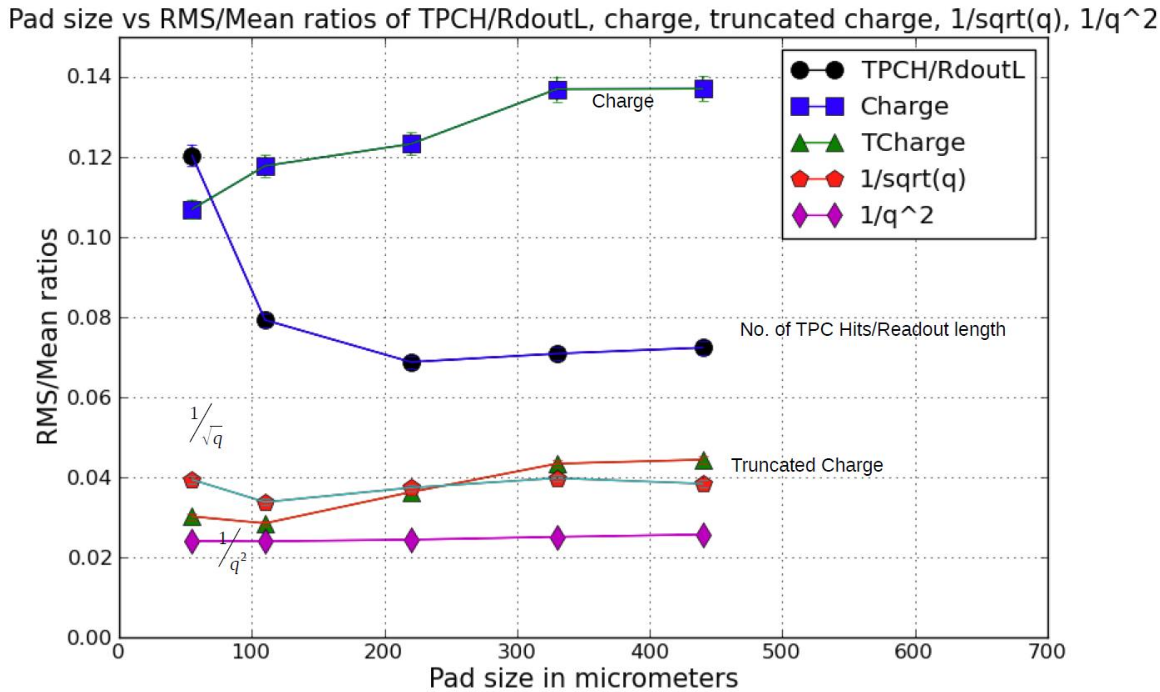


Figure 9. $1/\sqrt{q}$ *(left) and* $1/q^2$ *(right)*

With the results of table 2, the following plot was constructed.



Plot 2. Pad size (μm) vs RMS/Mean ratios

It can be appreciated that the truncated mean charge curve and the mean charge one have a similar shape. This is expected since the first one represents the same quantities of the second one just without 20% of its highest values. The curves of $1/\sqrt{q}$ and $1/q^2$ behave almost constantly through the 5 pad dimension changes, and the No. of TPC/Readout length ratio curve presents the same behavior that one in the plot 1. With this last it can be corroborated that in fact the TPC/Readout length ratio must decrease with larger pad dimensions.

4. Conclusions and future work

Talking about the cluster counting gain, actually is very difficult to set the increasing and/or decreasing factors of it since we could not observe a tendency or a particular behavior after making many combinations of variable values. This also applies for the charge related quantities. Also, the preliminary results presented an unexpectedly low resolution. This is mainly due to the fact that in all of these runs, noise wasn't introduced.

Considering all the above, it is recommended to perform a considerably bigger amount of simulations, and also to make additional combinations of variable values that weren't developed during this work (including the noise). This may allow to stablish a clearer relation of certain changes in the variables and parameters like the cluster counting gain and mean charge distribution.

Finally, it is important to mention the MarlinTPC is an extensive software with several functions and applications, so it is also necessary to take in account that it will have upgrades constantly.

5. References

- FLC Forschung mit Lepton Collidern. https://flc.desy.de/tpc/projects/software/marlintpc/index_eng.html [Consulted on September 4th, 2017].
- FLC Forschung mit Lepton Collidern. https://flc.desy.de/tpc/projects/hardware/ropperi/index_eng.html html [Consulted on September 4th, 2017].
- Einhaus, U., Kaminksi, J. (2016). ROPPERI, A TPC readout with GEMs, pads and Timepix. Talk presented at the International Workshop on Future Linear Colliders, Morioka, Japan.