

SUMMER STUDENT REPORT



FLC-TPC Group

Software development for TPC testbeam data analysis

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Abstract

The International Linear Collider (ILC) is one of proposed future linear lepton collider that is planned to be a highly precise machine. A Time Projection Chamber (TPC) is planned to be a main tracker in the ILD concept for the ILC. The FLC-TPC Group is working on researches and development of the TPC. Along the other things it is involved in studying of gas amplification structures, building and testing readout electronic as well as development of track reconstruction and data analysis.

The report regards my task during working in the FLC-TPC group, that was software development for TPC testbeam data analysis, especially channel mapping and online analysis.

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1 Introduction.

1.1 International Linear Collider.

The International Linear Collider¹ (ILC) is the proposed linear lepton collider that will be able to explore unknown regions of physics. The length of the collider will be approximately about 31 kilometers. The ILC will collide electrons and positrons in bunches of 5 nanometers 14000 times per second. The energy up to 500 GeV will be achieved with an option to upgrade to 1 TeV. The particles will be accelerated in 16,000 superconducting cavities. The International Linear Collider will provide a high level of precision of measurements that could not be achieved by any other accelerator.

1.2 ILD - TPC

ILD (International Large Detector) is a particle detector system proposed for the ILC. It will consist of particular layers surrounding the point where the beams collide. A TPC (Time Projection Chamber) is proposed to be the main tracker of the ILD. It will have 4.7 m length and 3.6 m in diameter. The $r\phi$ resolution will be $< 100\mu m$ at 3.5 T magnetic field and the momentum resolution $\approx 9 \times 10^{-5} GeV^{-1}$.

1.3 FLC-TPC Group

There are about 300 laboratories and universities that are involved in the ILC project¹. The FLC Group (Research with Lepton Collider) is studying hardware and software issues for the International Linear Collider.

The FLC-TPC Group² is the subgroup of the FLC, that is working on researches and development for one of the proposed detector for ILC - ILD Time Projection Chamber. As it was mentioned, a Time Projection Chamber is planned to be the main tracker that will be able to reconstruct the trajectories of charged particles in three-dimensions. Moreover, FLC-TPC Group is involved in studying gas amplification structures with the GEMs (Gas Electron Multipliers), building and testing a read-out electronic, construction a prototypes for the TPC field cage and also in developing a track reconstruction and data analysis.

¹www.linearcollider.org

²www-flc.desy.de

2 Theoretical background.

2.1 Time Projection Chamber.

The Time Projection Chamber is a detector that measures the position of the charged particles. In general, TPC consists of two chambers filled with gas. A high voltage is applied across the length of the TPC. The charged particles from the intersection point are ionizing the gas molecules in a sensitive volume of the detector. The particles from primary ionization are drifting through the chamber due to the electric field and are detected on the end plates.

2.1.1 Working principles.

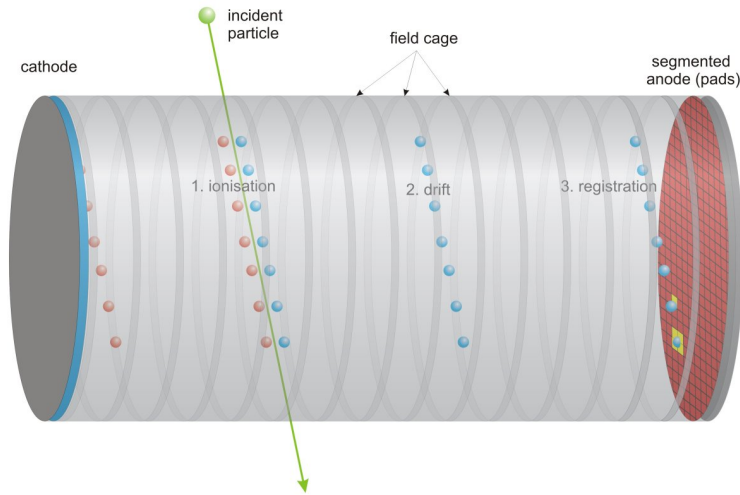


Figure 1: Working principles on TPC.

The passage of the charged particle results in ionizing gas mixture molecules. The point is to generate a very homogeneous electric field to measure precisely the position of the particles trajectory. This was solved by using a field cage that is built on conducting rings surrounding the cylinder. The main goal of the rings is to divide the potential step by step from the anode to the cathode in order to provide greater homogeneity of the field. Moreover, a high magnetic field is applied to bend the tracks. From the curvature one can calculate the momentum of the track

The particles from the primary ionization drift toward the endplate. The signal has to be amplified before being detected on the readout plane. The drift time is used to calculate the Z position (along the length of the cylinder). The $r\varphi$ position is calculated directly from the tracks projection of the pad plane.

2.2 Readout Modules.

2.2.1 Large Prototype.

The Large Prototype TPC (LP TPC) was built in order to study technical issues and readout module development. It has a inner length of 610 mm (600 mm are available as drift length) and an inner diameter of 720 mm.

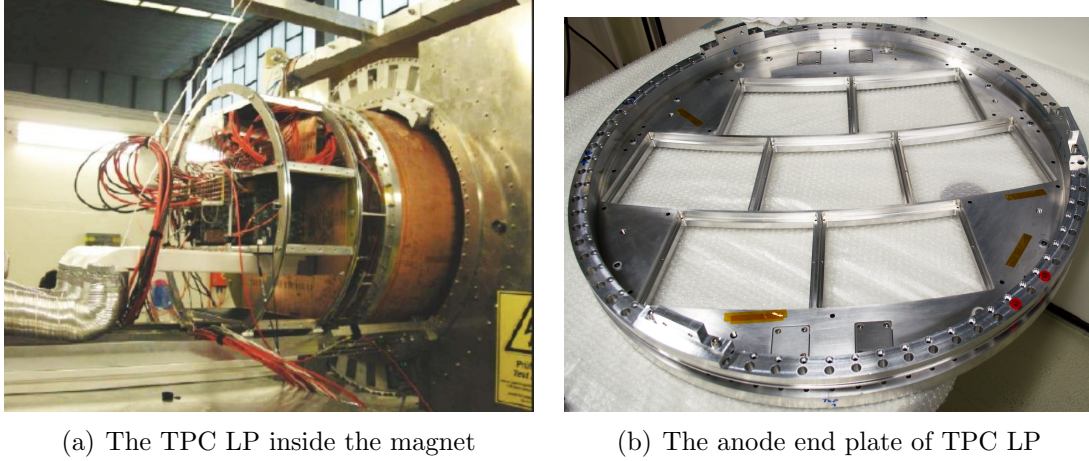


Figure 2: The Large Prototype.

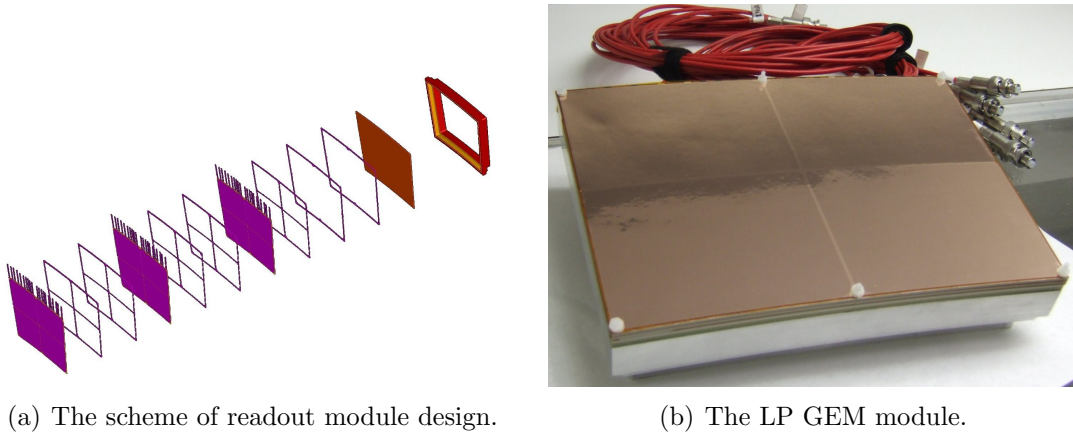


Figure 3: The readout module.

In the previous section the design of TPC was described. Among other things the readout modules were mentioned. The readout modules are one of the most important elements of the detector. Overall, there are two different gas amplification system: GEMs and MicroMegas. In that case the GEM technology is used (see 2.2.2).

The endplate of the LP TPC could host up to seven readout modules. Each of the module has a cornerstone shape and dimension about $23 \times 16 \text{ cm}^2$. The design of the modules is similar to the one foreseen for ILD TPC. The readout module consists of several

basic elements. The scheme of the module design is presented on the 3(a). The most outer one is an aluminum back-frame that is used to align all other parts of the module and to provide gas sealing. The next one is the anode plane with readout board. The pad readout board is build on ≈ 5000 pads each of dimension $(1 - 3) \times (4 - 6)mm^2$. The GEMs are the next elements building the modules. They provide the amplification of the electron signal that is being detected on the pad plane. The GEMs are placed between two ceramic grids in order to keep them stable and flat.

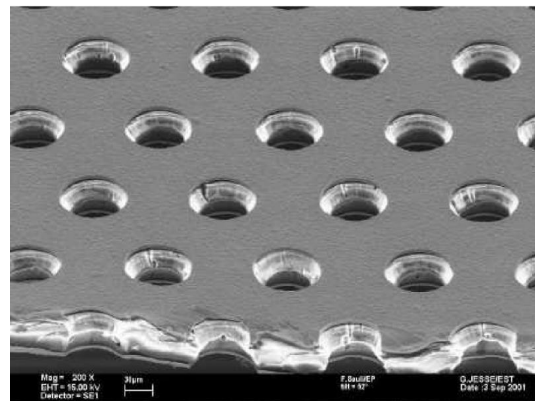
2.2.2 The GEMs.

The electron signal from the primary ionization is equal to about $\approx 100 \frac{e^-}{cm}$, which is not enough for a good signal to noise ratio. The main task of the GEMs is to amplify the electron signal. In general, the GEM consists of kapton foil ($50\mu m$ thick) with is coated on both sides with copper layers. This foil is perforated with double conical shaped holes that were etched in hexagonal pattern. The outer diameter of the cone is $\approx 70\mu m$ and the inner $\approx 55\mu m$.

In principle, the voltage of the order of few $100V$ is applied between upper and lower side of the GEM. The electric field line are focused into the holes and due to that the strength of the field in the holes is increased up to $\approx 10 \frac{kV}{cm}$. That conditions are sufficient for a gas amplification. There is a possibility to achieve the amplification up to a thousand in a single GEM. In practise, three GEMs are used working on lower voltage but overall the same or higher amplification for whole system. In that case there is a lower probability of sparking in the holes and thus damaging the GEMs.



(a) The GEM photo.



(b) The GEM microscope picture.

Figure 4: The GEM.

One important thing is not to allow for ions to drift into the TPC volume. The electric field is set in the way that most lines end on the side towards the cathode but go into a direction of the anode. Due to that ions are pulled and stopped on the cathode but electrons are extracted out through the holes in the direction of anode. Except the electric field the magnetic field perpendicular to the GEM plane is applied. The ions tend to follow the field because of their mass and electron rather move along magnetic field lines. This is the additional feature to increase the electron extraction.

3 Channel Mapping

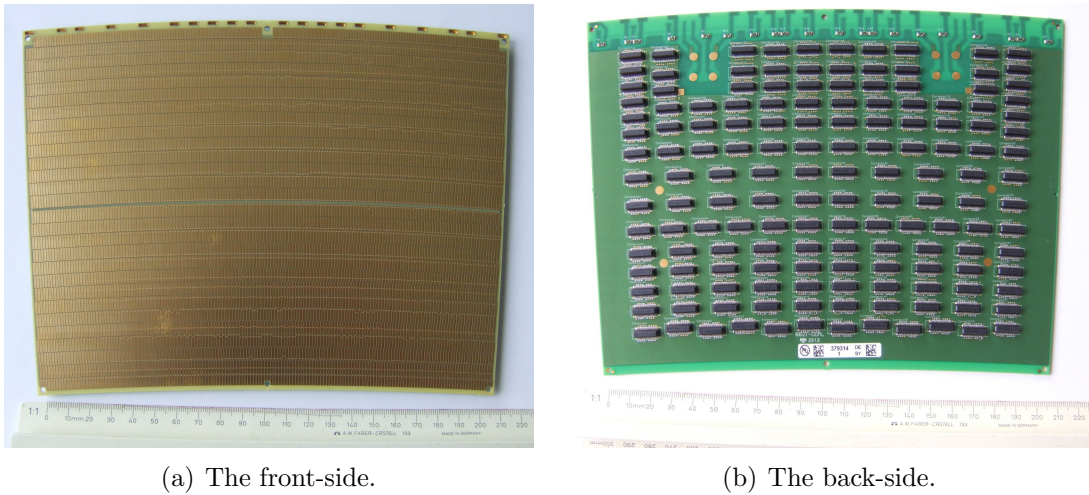


Figure 5: The pad plane.

3.1 The application of channel mapping

As it was mentioned, the pad plane with readout board is one of the basic readout module elements. The board consist of about 5000 pads. In practice, each of these pads should be connected to one particular readout channel in the electronic system. Currently, the group does not have an integrated electronic and due to that each cable connection should be done manually. The information about which pad was connected to which channel is essential. The point is that it is planned to use 3 modules with 5000 pads each but only about 10000 readout channels are available. It means that different configurations of connection between readout board and electronic could be adopted. In that case there is a need to have a channel mapping program, that allows to generate the proper set of information about particular pad-channel relation and about the geometrical position of the pad.

3.2 Channel mapping program

In that paragraph I will describe a technical details according to the channel mapping program, that I have written.

The channel mapping program needs two parameters to be executed. As a parameter the user should provide two input files, which content is described below. The first input file is completely defined by a board design and in principle will not change during the operation. The second one provides the information about cable connections so it will change along to the different modes of connections between readout plane and electronic.

Input file 1.:

Module - number of the module.

Pad - number of the pad [column] on the pad plane.

Row - number of the row on the pad plane.

Board Connector - number of connector on the back-side of the pad plane.

Pin - number of the pin on particular board connector. Each board connector consists of 32 pins connected to the pads and 8 to ground.

Input file 2.:

RCU - number of the Readout Control Unit. In general, RCU collects data from FEC and monitors FECs.

Board Connector

Module

FECNumber - number of the Front-End Card. FECs are amplifying, shaping, digitalizing and processing signal from TPC.

FECConnector

Orientation - gives the information about how a cable was plugged in into a cable connector on the back-side of pad plane. Overall, there are two possible options of plugging in the cable.

Basically, the channel mapping program calculates the readout channel from the data from the second input file (a proper equation for that is hard-coded in the program), finds the x- and y-position using a GEAR software³ and finally match the proper information about particular pads and readout channels from the first and the second input file in order to generate relevant output files.

In principle channel mapping program should provide two output files. The first

³GEAR is a geometry description toolkit for ILC reconstruction software.

one is used by MarlinTPC, which is the software to data analysis. The second one goes to AltroDAQ software used by readout electronics's developers. The scheme of output files is showed below.

<p><i>Output file 1.:</i></p> <p>RCU</p> <p>Readout Channel</p> <p>Module</p> <p>Pad</p> <p>Row</p>	<p><i>Output file 2.:</i></p> <p>RCU</p> <p>Readout Channel</p> <p>X-Position</p> <p>Y-Position</p>
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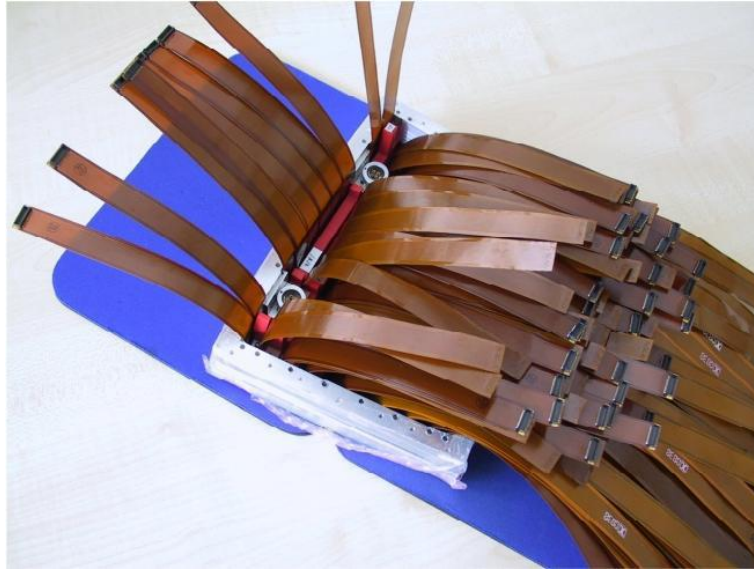


Figure 6: The module after cable connection.

4 Online Analysis

4.1 Main goal of online analysis.

The online analysis is a procedure of creating a set of plots from obtained data. There is a couple of basic applications of the online analysis. The online analysis allows to monitor if any of the testbeam parameters have to be changed or not. Simply, the plot analysis gives a possibility to check if the obtained data are more or less as expected. One of the other application is setting proper cuts for raw data.

4.2 Software.

My second task was to develop a part of the existing software TestBeamAnalysisLibrary in order to generate a proper sets of plots.

4.2.1 TestBeamAnalysisLibrary.

The test-beam analysis library is a software used in the FLC group that allows to analyze the test-beam data for the large prototype. TestBeamAnalysisLibrary uses ILCSOFT packages and ROOT⁴.

4.2.2 Data Structure.

In principle, three sets of plots from different data structures were generated. These structures are Raw Data, Pulse Data and Hit Data. Raw Data contains data after zero suppression. It means that all the data that are compatible with being just noise fluctuations were removed. Pulse Data store the information about pulses, that denotes the time-integrated charge deposition of one track on a one pad. The pulses are detected by searching for a value that rises above a certain threshold. In the next step of reconstruction the hits are selected. Hits merge pulses from one row. The x-position of the hit is calculated by a Center of Gravity method, which uses the information about gathered charge and x-position of the pulses.

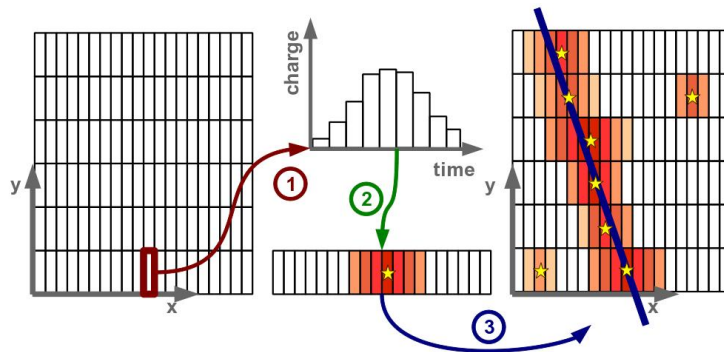


Figure 7: Pulse and hit reconstruction scheme.

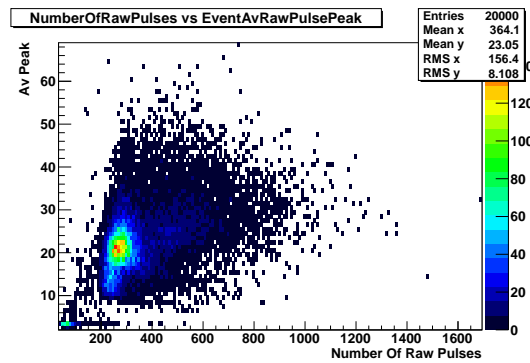
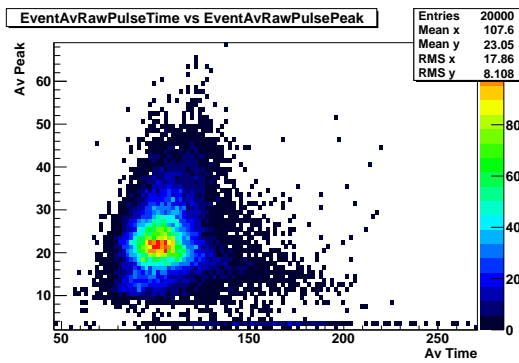
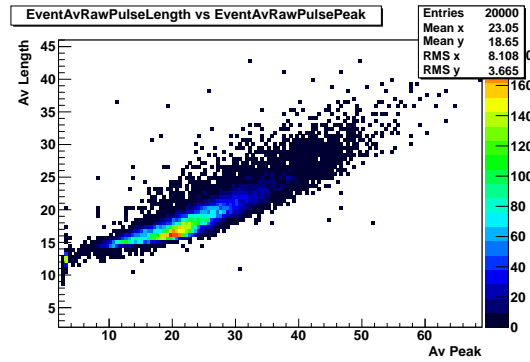
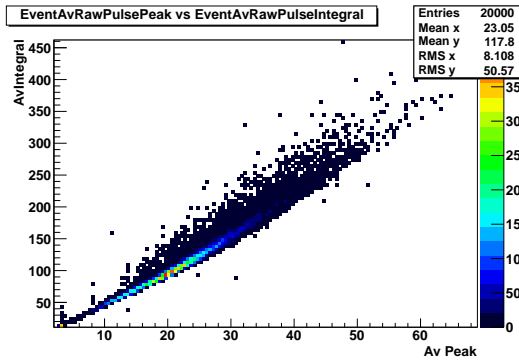
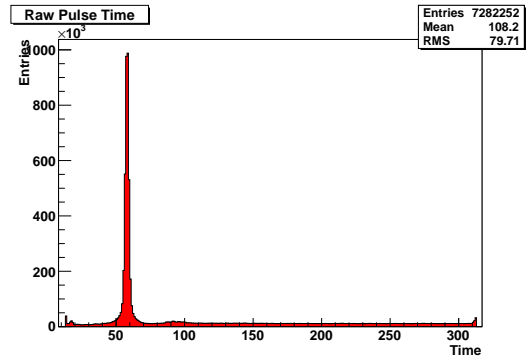
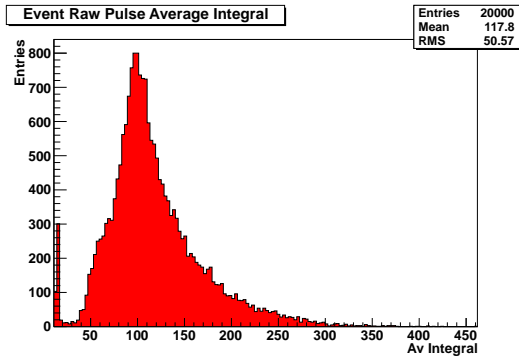
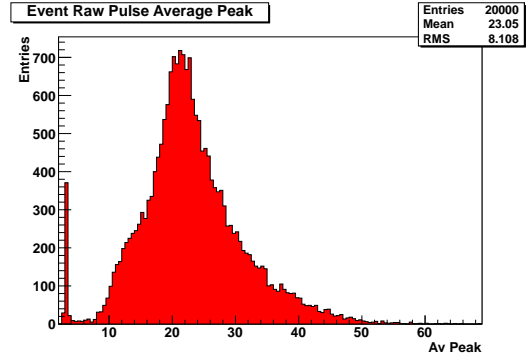
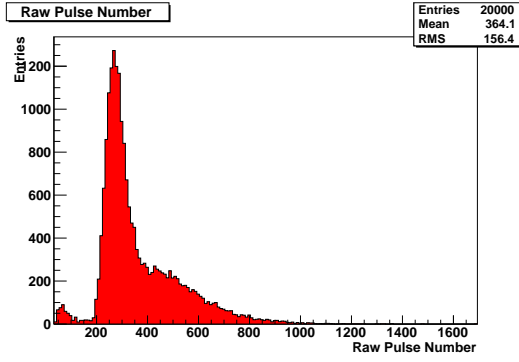
⁴<http://www-flc.desy.de/flc/flcwiki/TestbeamAnalysisLib>

4.3 Plots.

All created plots are shown below. Before that the whole list of plots and a short comment to selected plots are given.

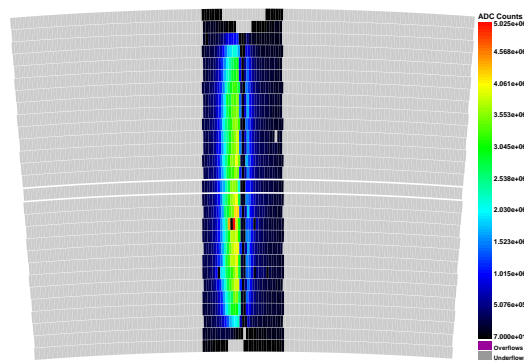
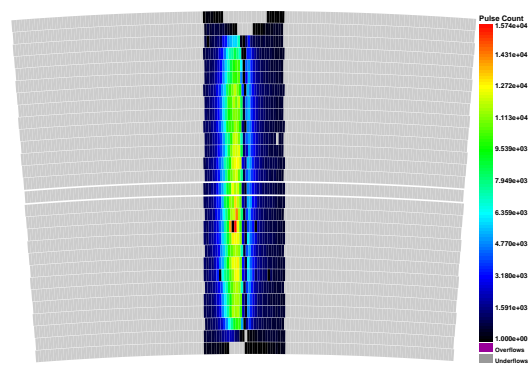
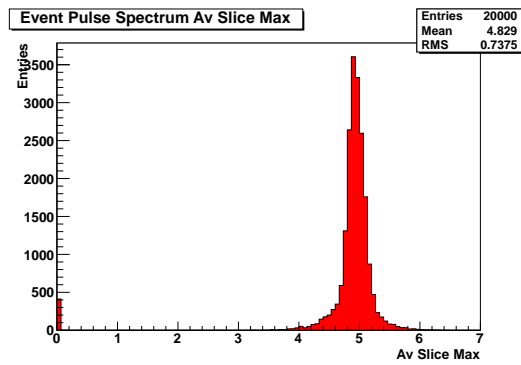
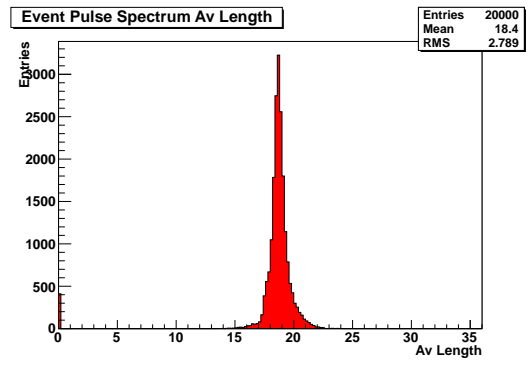
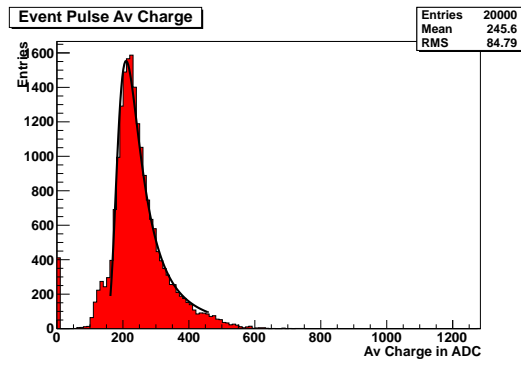
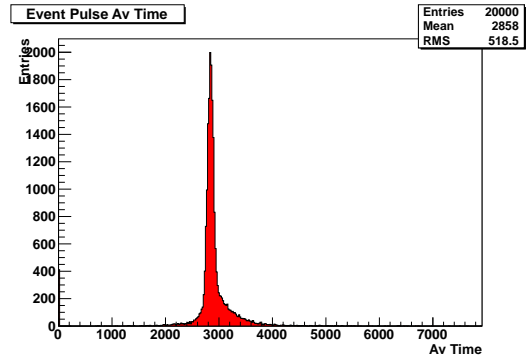
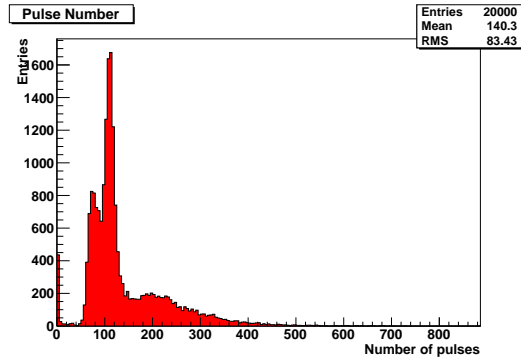
4.3.1 Raw Data Plots.

1. **Raw Pulse Number** - number of raw pulses in event. It provides the information about the stability of the base line.
2. **Event Raw Pulse Average Peak** - the histogram of average raw pulse peak value per event. It finds the application in setting a cuts for pulse finding.
3. **Event Raw Pulse Average Integral** - the histogram of average raw pulse integral value per event.
4. **Raw Pulse Time** - the time is always correlated with the z-position of the beam. Moreover, the histogram provides the information about the time of data acquisition.
5. **Event Av Raw Pulse Peak vs Event Av Raw Pulse Integral** - the two-dimensional plot of raw pulse peak versus raw pulse integral. The charge gathered by a particular pad is proportional to the peak value. There is a linear correlation between peak and integral value. It means that charge value could be calculated from the integral value. For the high values of pulse peak the correlation is distorted because of the limits of the electronics. The high peaks are saturated and cutted down.
6. **Event Av Raw Pulse Length vs Event Av Raw Pulse Peak**
7. **Event Av Raw Pulse Time vs Event Av Raw Pulse Peak** - provides the thresholds for pulse finding.
8. **Number Of Raw Pulses vs Event Av Raw Pulse Peak** - provides the thresholds for pulse finding.



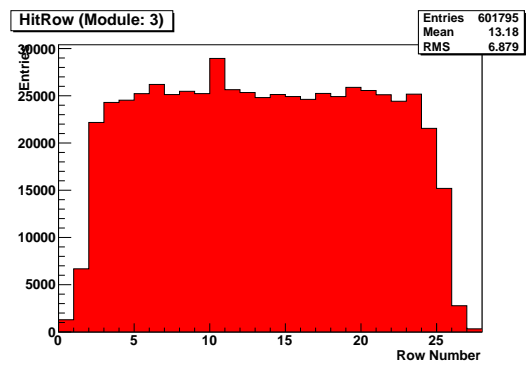
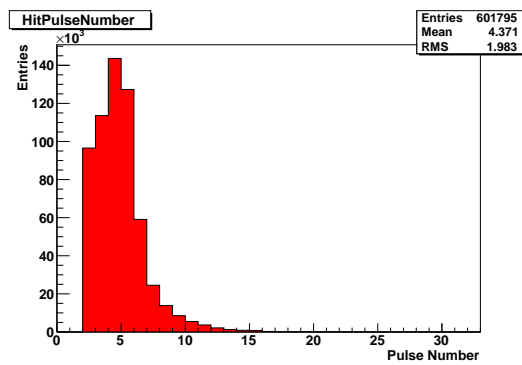
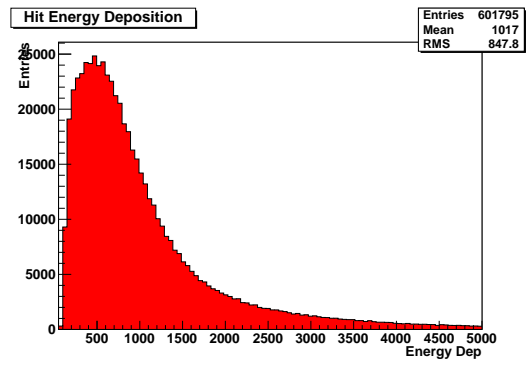
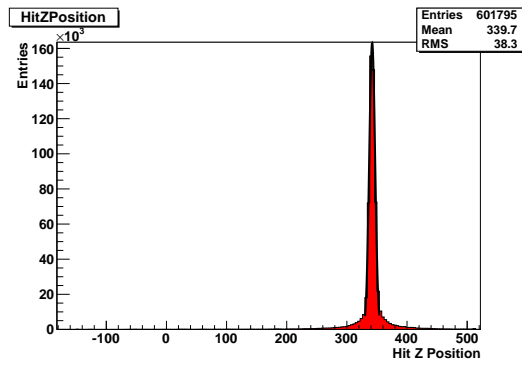
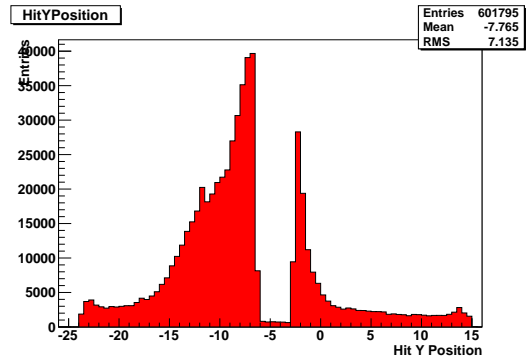
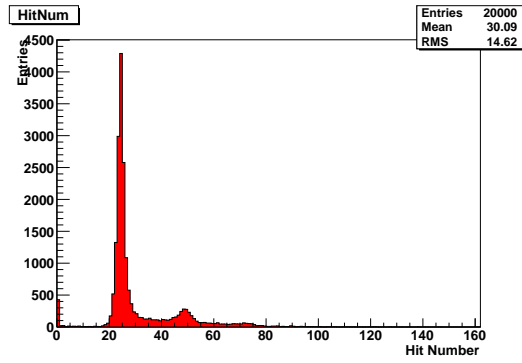
4.3.2 Pulse Data Plots.

1. **Pulse Number** - number of pulses in event.
2. **Event Pulse Av Time** - average pulse time per event. A plot provides the information about beam position.
3. **Event Pulse Av Charge** - average pulse charge per event. Landau curve was fitted.
4. **Event Pulse Spectrum Av Length**
5. **Event Pulse Spectrum Av Slice Max** - average number of time slices between '0 time' and the peak maximum per event.
6. **Number of pulses per channel** - gives the information about number of pulses collected per channel for one particular module. It allows to monitor which pad did not work properly.
7. **Total charge per channel**



4.3.3 Hit Data Plots.

1. **Hit Number** - number of hits in the event. Hit merges pulses from one row so the highest peak are expected on a value close to the number of rows (28). The second peak appears on the value two times larger then the first one and could give the information about the events with two tracks.
2. **Hit Y Position** - Y coordinate of the hits. Shows the information about beam's Y-profile. The gap in the center of the histogram is caused by the presens of the ceramic grid on the GEM.
3. **Hit Z Position** - Z coordinate of the hits.
4. **Hit Energy Deposition**
5. **Hit Pulse Number** - gives the information about how many pulses created one hit. The plot provides the information about charge sharing.
6. **Hit Row** - number of hits per row in one particular module. The plot allows to gain a information about efficiency of the rows. In that case it is rather flat except the boundary rows, witch was caused by the border of the pad plane.



5 Summary

During the practice two separate tasks were done. The first one was to write a channel mapping program for the module's readout electronic. The program allows to easily gain the information about channel mapping in case of different configurations of connections between readout board and electronic. It generates two output files that are used by MarlinTPC and AltroDAQ softwares.

The second task was to improve the online analysis for the testbeam measurements. The online analysis allows to get the summary of obtained data as a list of plots. I have written a classes that could be used in TestBeamAnalysisLibrary, which allows to generate the sets of proper plots from all data structures. The plots are used to monitor testbeam parameters, check data correctness and set a proper cuts during data analyzing.