



Analysis of MediTPC data with MarlinTPC

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September 9, 2014



Abstract

In the following report I will show what I have done in my project during my stay as Summer Student 2014 at DESY, site Hamburg. I have worked for round about seven weeks in the FLC Group, which do research on the future International Linear Collider (ILC) and especially there in the subgroup for research on the Time Projection Chamber (TPC) which will be used in the ILD detector.

My task was the analysis of taken data with the MediTPC prototype with the new analysis framework MarlinTPC. I also implemented some new functions, e.g. a Pad Response Correction (PRC), in comparison to the prior used framework MultiFit.



*A Time Projection Chamber
for a future Linear Collider*

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1 Introduction

The Time Projection Chamber (TPC) in the ILD as one of the detectors for the future International Linear Collider (ILC) will be one of the most important parts. Because of the reconstruction of particle traces and for particle identification achieving a high resolution is the golden aim.

In this report I show at first the basics of the plans for the ILC (Chapter 2) including the physics program which should be fulfilled, some technical design issues and of course the ILC detectors, the SiD and the ILD.

In Chapter 3, I will explain how a TPC is working and show why the previous used amplification technique is not working for the TPC at ILC and instead a new technology called GEMs will be operated in it.

The following chapter (Chapter 4) gives an introduction to the experimental test setups which are in the moment available such as different prototypes. The focus lay there on the test setup out of which the data came on which I have done the analysis.

The next logical step is then to introduce the analysis framework called MarlinTPC (Chapter 5). It is shown there the general structure and especially the reconstruction process on the one side on readout/experimental level and on the other side on the analysis/software level.

A very important point on which I focus my analysis was the phenomena called Pad Response and its appropriate correction then called PRC (Chapter 6) which is introduced there in detail.

In Chapter 7, I show my working steps in the analysis and of course also my results in different plots and interpretation of them.

In the end I will give a short conclusion on my performed analysis (Chapter 8).

2 The International Linear Collider (ILC)

2.1 Introduction

The International Linear Collider (ILC) is a 200-500 GeV (expendable to 1 TeV) center-of-mass high-luminosity linear electron-positron collider, based on 1.3 GHz superconducting radio-frequency (SCRF) accelerating technology. The energy range of this collider was purposed to complete all the recent discoveries at the Large Hadron Collider (LHC) at CERN and measure with high precision therefore it will be a lepton collider. The actual collider design is the result of nearly twenty years of R&D. In 2013 the R&D efforts was culminated in the publication of the "Technical Design Report" [1].

2.2 Physics at ILC

The International Collider was designed to study the Higgs boson and other new particles that might be associated with it and the Higgs field postulated in the Standard Model. The ILC is perfectly matched for measurements around the discovered Higgs boson with a mass of 125 GeV and allows precision measurements of couplings to other Standard Model particles and self-coupling of the Higgs.

Furthermore the ILC will make important contributions to the search for new particles associated with the Higgs field, dark matter and other questions of particle physics. Because of the lower background rate of lepton collisions it will be possible to perform highly precise measurements of established particles like W and Z boson or top quarks. As conclusion of the physics program of the ILC, you can state, that it offers many opportunities for measurements which will address the most important current problems of particle physics. With its very high precision, it will give unique views of the Higgs boson, the top quark, and possible new particles relevant to the mysteries of the matter content of the universe. The ILC is thus an essential tool that will advance our understanding of the basic laws of nature.

2.3 Technical Design

The International Linear Collider (ILC) is a high-luminosity linear electron-positron collider based on 1.3 GHz superconducting radio-frequency (SCRF) accelerating technology. Its center-of-mass-energy range is 200-500 GeV (extendable to 1 TeV). A schematic view of the accelerator complex is shown in Figure 1. The major subsystems are the following:

- a polarized electron source based on a photocathode DC gun;
- a polarized positron source in which positrons are obtained from electron-positron pairs by converting high-energy photons produced by passing the high-energy main electron beam through an undulator;
- 5 GeV electron and positron damping rings (DR) with a circumference of 3.2 km, housed in a common tunnel;

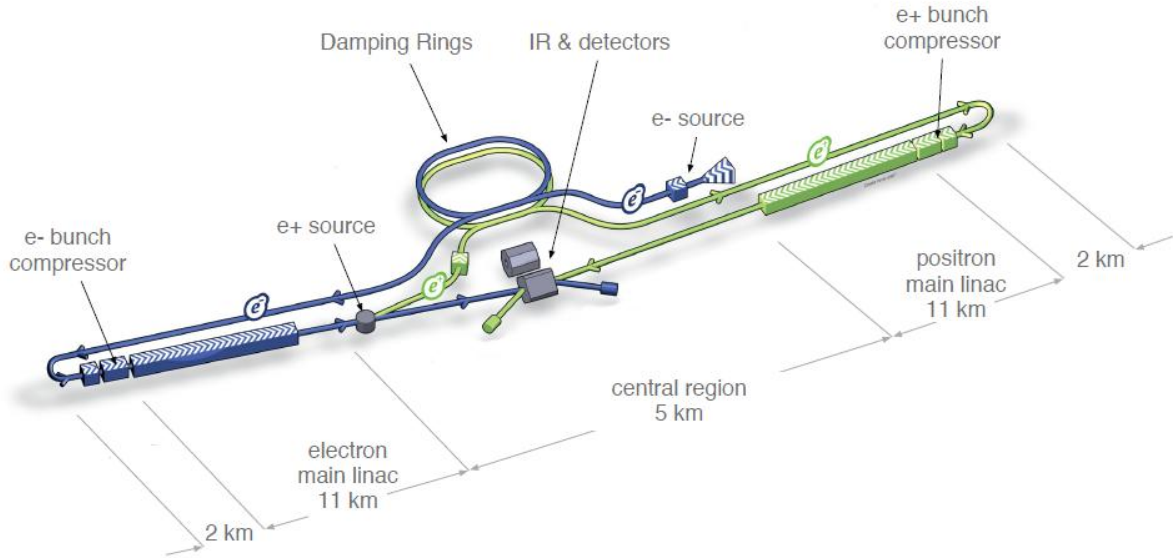


Figure 1: Schematic layout of the ILC, indicating all the major subsystems. [1]

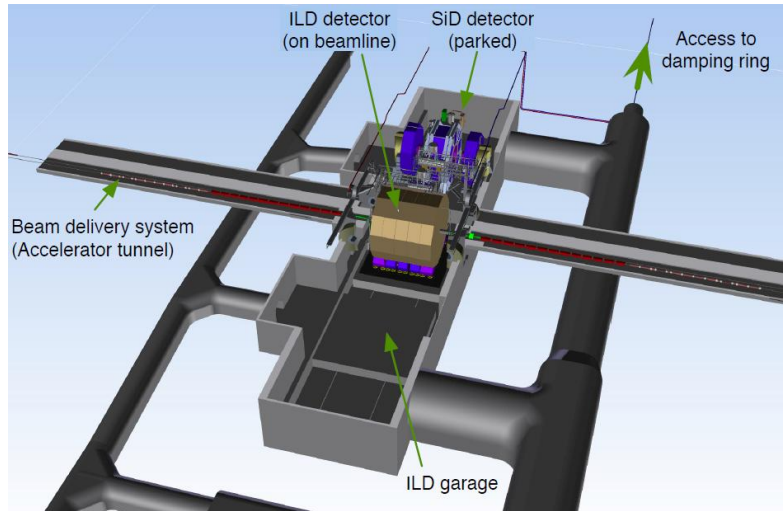
- beam transport from damping rings to the main linacs, followed by a two-stage bunch-compressor system prior to injection into the main linac; two 11 km main linacs, utilizing 1.3 GHz SCRF cavities operating at an average gradient of 31.5 MV/m with a pulse length of 1.6 ms;
- two beam-delivery systems, each 2.2 km long, which bring the beams into collision with a 14 mrad crossing angle, at a single interaction point which can be occupied by two detectors in a so-called "push-pull" configuration.

2.4 ILC Detectors

In order to realize the physics program, the ILC detectors face challenges requiring significant advances in collider detector performance. It is placed a premium on high-resolution jet energy reconstruction and di-jet mass performance. Event reconstruction techniques based on the Particle Flow Algorithm (PFA) have been developed, which motivates a highly granular electromagnetic and hadron calorimeters and highly efficient tracking systems. Because of the ILC time structure of 1 millisecond bunch trains at 5 Hertz, it is allowed to switch of the detector systems between bunch trains (so-called power-pulsing), reducing the heat load and so the need for cooling.

The ILC has been designed to enable two experiments (SiD and ILD) sharing one interaction region using a push-pull approach. This two-detector design is motivated by the enhanced scientific productivity of past collider facilities which benefited from independent operation of multiple experiments, providing complementary strengths, cross-checking and confirmation of results, reliability, insurance against mishaps and competition between collaborations. In Figure 2 the arrangement of the two detectors is shown.

Figure 2: Layout of the detector hall showing the location of the two detectors in a push-pull arrangement. [1]



2.4.1 SiD Detector

SiD is a general-purpose detector designed to perform precision measurements at a Linear Collider. It integrates the Particle Flow Algorithm (PFA) approach and with its robust silicon vertexing and tracking it is applicable to a wide range of energies from a Higgs factory beyond 1 TeV. SiD has been designed in a cost-conscious manner, with the compact design that minimizes the volumes of high-performing, high-value components. Furthermore it provides a silicon-tungsten electromagnetic calorimeter (ECAL) and a highly segmented hadronic calorimetry (HCAL). SiD also incorporates a high-field solenoid, iron flux return and a muon identification system. The detector outline can be seen in Figure 3.

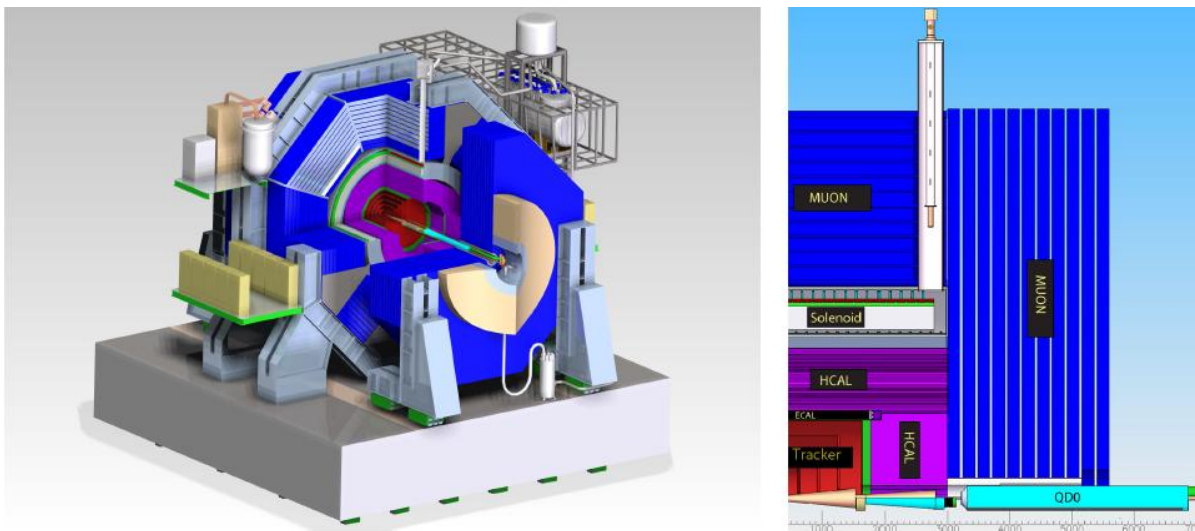


Figure 3: The SiD detector, showing (left) the whole detector outline and (right) the single subsystems. [1]

2.4.2 ILD Detector

The ILD concept has also been designed as a multi-purpose detector which integrates optimal particle-flow performance. A high-precision vertex detector is followed by a hybrid tracking system, realized as a combination of silicon tracking with a time-projection chamber, and a calorimeter system. The complete system is surrounded by a 3.5 T solenoid. The inner-detector system is highly granulated and on the outside of the coil, an iron return yoke is instrumented as a muon system and as a tail-catcher calorimeter. The ILD detector is shown in Figure 4.

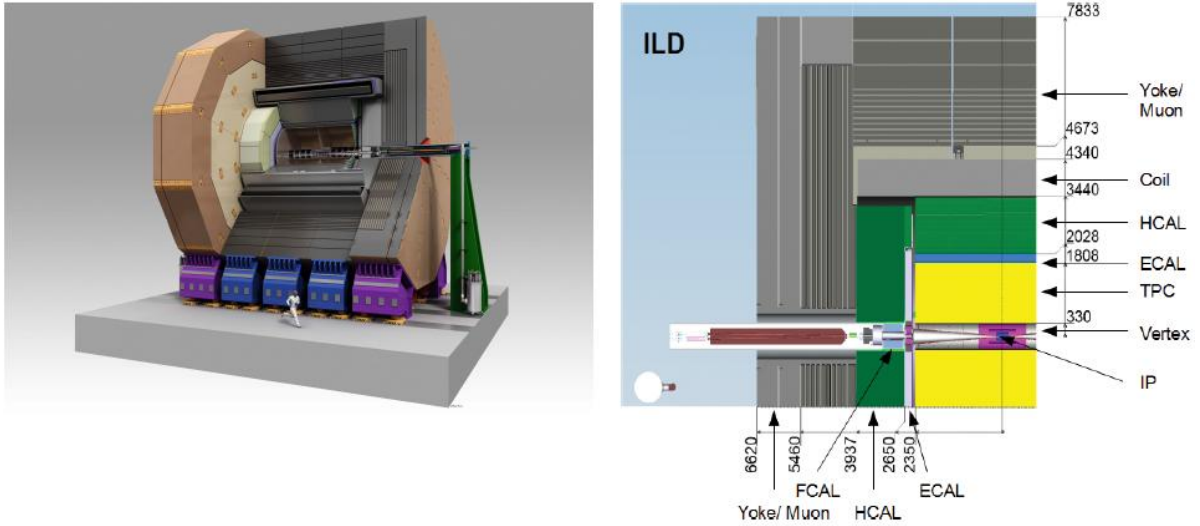


Figure 4: The ILD detector, showing (left) the whole detector outline and (right) the single subsystems. [1]

3 Time Projection Chamber (TPC)

3.1 Introduction

The Time Projection Chamber has been introduced in 1976 by D.R. Nygren. It consists of a gas filled sensitive volume, usually with a central cathode that divides the volume into two identical halves. Each side has an anode with a readout system. The cathode is at a potential that results in a field strength of some 100 V/cm while the anode is at ground potential. Typically, this leads to a potential of some 10 kV at the cathode.

In a 4π -detectors - detectors that cover nearly the whole solid angle - at high energy experiments, the drift volume is usually cylindrical and the beam pipe goes through the rotation axis of the TPC with the interaction point being at the center.

3.2 Measurement Principle

The measurement principle of a TPC (see Figure 5) is such, that an incoming charged particle traversing the gas volume will ionize the atoms of the gas mixture, which consists usually of around 90% noble gas and 10% quencher, along its trajectory (point 1). A high electric field is applied between the endplates of the chamber. So the released electrons will drift in this field towards the anode (point 2). To be able to measure the position of the particle trajectory as accurately as possible, the electric field has to be very homogeneous. To make the field such homogeneous a field cage can be applied, which usually consists of conducting rings around the cylinder. These rings divide the potential from the cathode stepwise down to the anode.

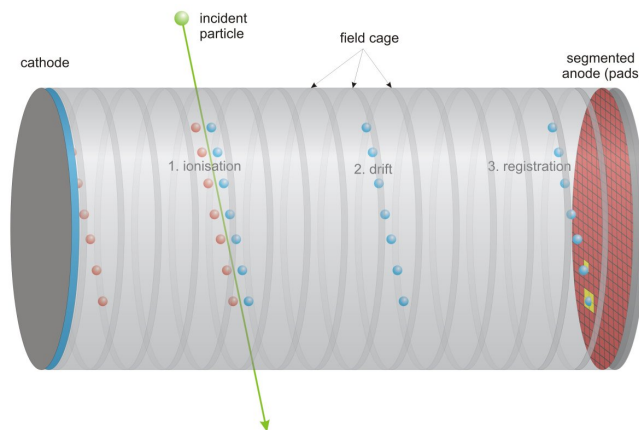


Figure 5: Working principle of a time-projection chamber. [2]

Additionally to the electric field, a high magnetic field parallel to the E-field is used to "bend" the trajectory of the particle on a spiral track due to the Lorentz force. Because of this you get the possibility to calculate the particle momentum from the knowledge of the curvature and the B-field.

Finally at the anode plane, the electrons can be detected on the readout plane which is segmented in the directions perpendicular to the drift direction (point 3). As the electron signal from the primary ionization process is only of the order of 100 electrons per centimeter, the signal needs to be amplified before being detectable. There are different methods available which will be showed in detail in the next subchapter.

The $r\phi$ position, that means the 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, that means 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. Therefore an external timing information, e.g. from a silicon detector, is needed.

3.3 Amplification Wires

In previous Time Projection Chambers (TPC) and some current implementations, proportional wires (see Figure 6) have been and are still used as a device for gas amplification. In this technique, tense parallel wires are mounted in front of the pad plane. These wires are on such a potential, that the arriving electrons are accelerated in their field, gaining energy to the magnitude where ionization happens.

The produced ions drift back into the TPC volume and induce a (very broad) signal on the pad plane behind the wires. So the signal is measured at the wires and - to improve the resolution - also at the pad plane. Since ions in the TPC volume should be avoided, a second layer of wires, which is called the gate, is necessary. When the gate is open the gating wires are at the same potential as the field in this region. In this state, drifting electrons (and ions) pass this grid without disturbance. To close the grid, which is the normal state, and collect the ions, the potential of neighbouring wires is set alternating to $\pm 50-100$ V. At this setting, drifting ions and electrons are collected on the wires.

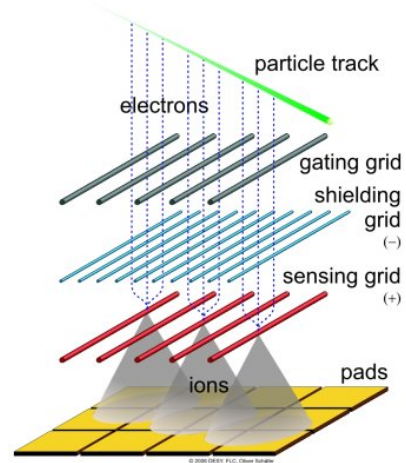


Figure 6: Layout of gas amplification and readout with amplification wires. [2]

Some drawbacks of this technique have led to the development of new amplification structures: so-called Micro-Pattern Gaseous Detectors (MPGDs). Two different technologies of micro-pattern devices are under investigation for their use in a TPC in a detector at the ILC: the Micro Mesh Gaseous Detectors (Micromegas) and the Gas Electron Multipliers (GEMs).

The disadvantages of the proportional wires are, that the signal is very broad and the distance between two wires is mechanically limited. This makes it difficult to separate two nearby tracks and set limits to the possible resolution. A second disadvantage is the high material budget of the support structures that hold the wires. To provide a perfectly parallel alignment the wires have to be mounted under very high tension. This demands for a very solid mounting system with a high material budget. Third, the gating is problematic in experiments with a high event rate, where the time between two events is too short for the gating and measurement cycle. If the events do overlap, which means the drift needs longer than the time between two events, gating becomes impossible.

In the case of the ILC all these three problems are realized. A good two-track separation and precise time resolution is needed to achieve the physics goal of the project. To be able to make a very precise energy measurement in the calorimeter, the material budget is very limited. Furthermore, the collision rate is so high that the gating with a grid would not work anymore. Therefore a new amplification technique is needed, that will be described in the next section.

3.4 Gas Electron Multipliers (GEMs)

The GEM technology, which has been introduced by F. Sauli, is used in high energy physics detectors to amplify an electron signal in a gaseous detector. GEMs consist of a thin Kapton foil (about $50\ \mu\text{m}$) which is coated on both sides with copper layers (about $5\ \mu\text{m}$). This structure is perforated with holes that typically have a diameter of $70\ \mu\text{m}$ and a pitch of $140\ \mu\text{m}$. The holes are arranged in a hexagonal pattern.

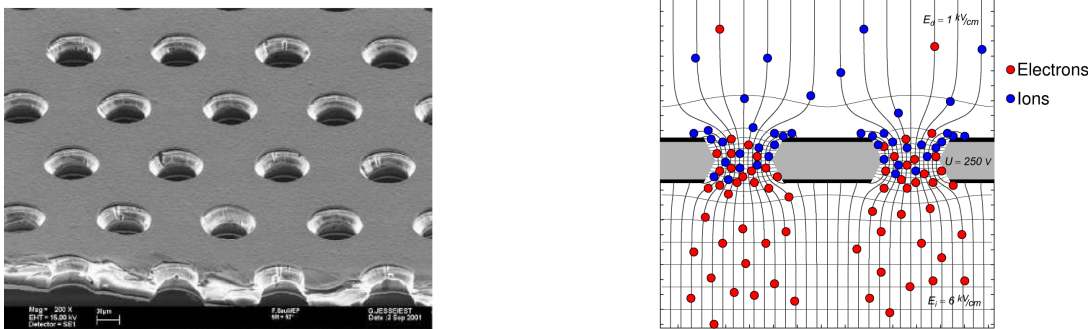


Figure 7: GEMs. Electron microscope picture (left) and working principle (right). [2]

The working principle (see Figure 7, right) is as follows: Between the two copper coatings a voltage of a few 100 V is applied. Since the field lines are focused in the holes, there the resulting electric field strength is in the order of some 10 kV/cm, which is high enough for the gas amplification. It is possible to achieve an amplification up to ten thousand in a single GEM, but usually, a setup consisting of two or three successive GEMs, with a lower amplification per GEM but the same or higher amplification in the

whole system is used. So the single GEMs can be operated at a lower voltage, which lowers the probability of sparking in the GEM holes and makes the system more stable. The field configuration is usually chosen in a way that most electric field lines end on the side towards the cathode, while on the other side most lines go into the direction of the anode. Then, most of the ions from the gas amplification are pulled to and collected on the GEM surface while most of the electrons are extracted out of the GEM holes towards the anode.

The GEM technology provides the possibility to avoid the problems mentioned in the previous section. The above mentioned intrinsic ion back-drift suppression is one of the main advantages of the GEMs and makes a gating grid unnecessary. Other advantages of the GEM amplification are the fast signal and less required mounting structures. Besides, the GEM signal on the pad plane is narrower than in the case of proportional wires. This is an advantage in the two-track separation, but poses new problems in the $r\phi$ resolution. The pads have to be smaller, so that a narrow signal still hits enough pads for a good reconstruction in the plane. However, the number of pads is limited by the feasible number of readout channels and the signal height (smaller pads result in a smaller signal per pad), so a compromise has to be found.

Overall, GEMs are a very promising technique for the gas amplification in a TPC and many of their advantages already have been confirmed experimentally.

4 Experimental Setup

4.1 Introduction

For general testing reasons a test setup was integrated on the DESY laboratory. So at the DESY II testbeam, where electron and positron beams from 1 to 6 GeV are available, a TPC test stand has been build up inside the EUDET project. It is operated and being used by the LCTPC collaboration.

Furthermore there are different prototypes of a TPC available, so for example, the Large Prototype and the MediTPC Prototype.

4.2 MediTPC

The MediTPC prototype has been designed and is used for measurements in a test magnet which can produce magnetic fields up to 5 T. It has a diameter of 27 cm and a length of approximately 80 cm. The sensitive gas volume has a length of around 66 cm. The field cage is built out of a composite material (CFP and Nomex) and on the inside it is shielded by Kapton layers. The innermost Kapton layer has printed-on copper strips that are connected via resistors to divide down the voltage from the cathode to the anode and ensure a homogeneous field in the drift volume.

For the amplification process, a bit more than 10 cm at the anode end of the MediTPC are used. For the gas amplification, a triple GEM structure built of standard CERN GEMs with a size of $100 \times 100 \text{ mm}^2$ is used (see Figure 8, middle). The transfer gaps between the GEMs are 2 mm wide (transfer fields: 1500 V) and the induction gap between the last GEM and the readout plane 3 mm (induction field: 3000 V). The potentials between the GEM surfaces vary between about 320 to 335 V, depending on the used gas and the magnetic field.

There are different readout planes with different number of channels and pads and varying pad sizes. Besides a staggered and not-staggered design can be differentiated.

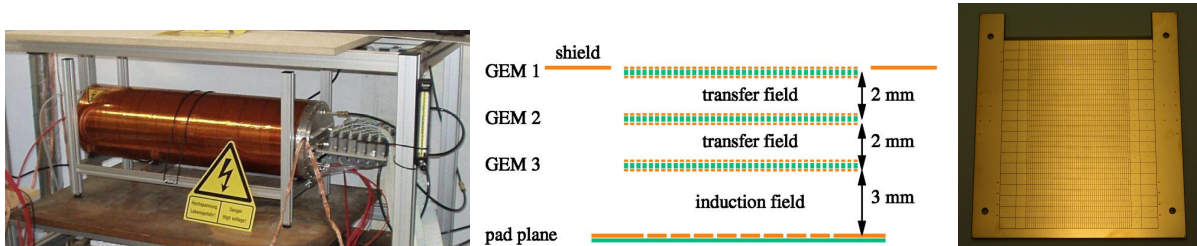


Figure 8: MediTPC setup. The prototype outline (left), the GEM structure (middle) and a pad plane (right). [2]

The data which were used for the analysis were taken with the MediTPC prototype and a B-field of 4 T. Instead of using the testbeam cosmic rays were used for ionization in the TPC volume. Besides two different gas mixtures (P5 and T2K) were used.

5 Marlin Framework

5.1 Introduction

MarlinTPC is a software package with the goal to enable the R&D groups of the LCTPC collaboration to perform detailed analysis and simulations. The development and use of a common software improves the comparability of the analysis results and avoids duplication of development in different groups. MarlinTPC is based on the common ILC software frameworks LCIO (data format, persistency), Marlin (data processing chains), GEAR (geometry description) and LCCD (conditions data handling) (see Figure 9).

Marlin Framework Principle:

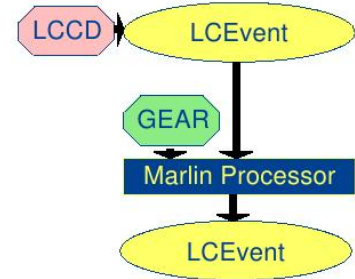


Figure 9: Marlin Framework Principle. [3]

The MarlinTPC package consists of reconstruction and analysis parts as well as a detailed simulation down to the single electron level. The current efforts focus on the optimization of the basic reconstruction. This includes the development of hit reconstruction for all available readout types and the implementation/integration of different track finding and fitting packages. The demand to provide reconstruction schemes for many different technologies is documented in Figure 10.

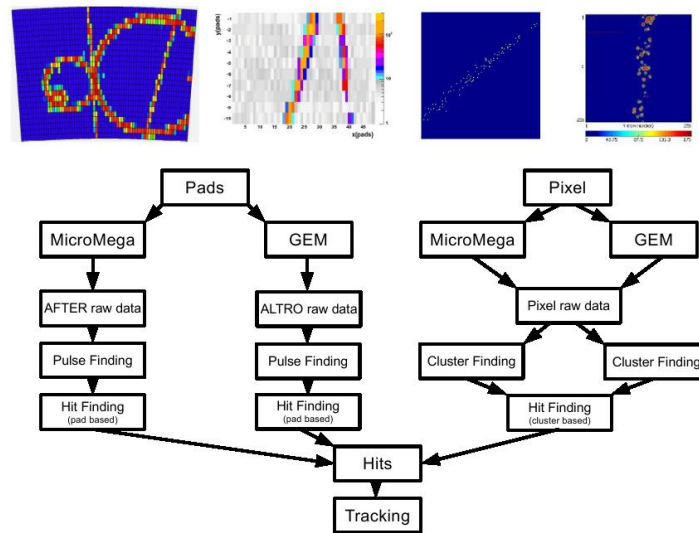


Figure 10: Marlin provides different technologies effective reconstruction schemes. [3]

5.2 Reconstruction Process

At first as a reminder in Figure 11, the general measurement principle in a TPC is displayed, from an incoming ionizing particle to the readout at the pad plane.

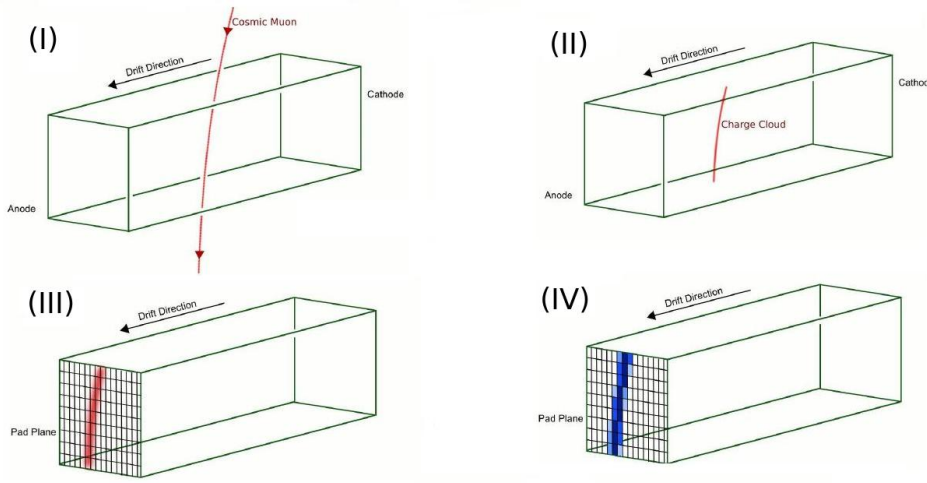


Figure 11: TPC measurement principle. Incoming particle ionizes (I), produced charge cloud is drifting towards anode (II), amplification process takes place before readout (III) and it ends in a electrical signal on the the pad plane (IV). [4]

In terms of the reconstruction process in MarlinTPC, Figure 12 displays the different processing chain steps.

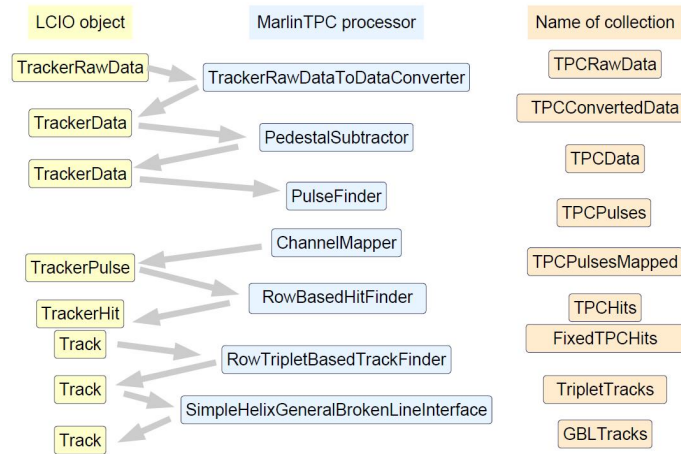


Figure 12: Reconstruction chain in MarlinTPC. [4]

6 Pad Response Function (PRF)

6.1 Introduction

The X position - X is the coordinate parallel to the pad rows - of a hit - integrated charge deposition of one track in a pad row - is calculated by a charge weighted Center of Gravity method. If the width of the charge cloud arriving at the pad readout, i.e. the width of the Gaussian describing the charge distribution, is about the size of the pads, the reconstructed X position will be shifted towards the pad with the highest charge signal in comparison to the true center of the charge distribution. This phenomena - called Pad Response - can be seen in the left side of Figure 13.

The function describing this shift in dependency on the position of the center relative to the pad center, which is defined as the pad with the highest signal, is called the Pad Response Function (PRF) and depends on the width of the charge cloud.

As an example (see Figure 13, right): If the width is too narrow, the PRF has a flat area around the pad center. In this area, the information of the true X position is not only shifted, but there is a true loss of information because all positions are reconstructed to zero.

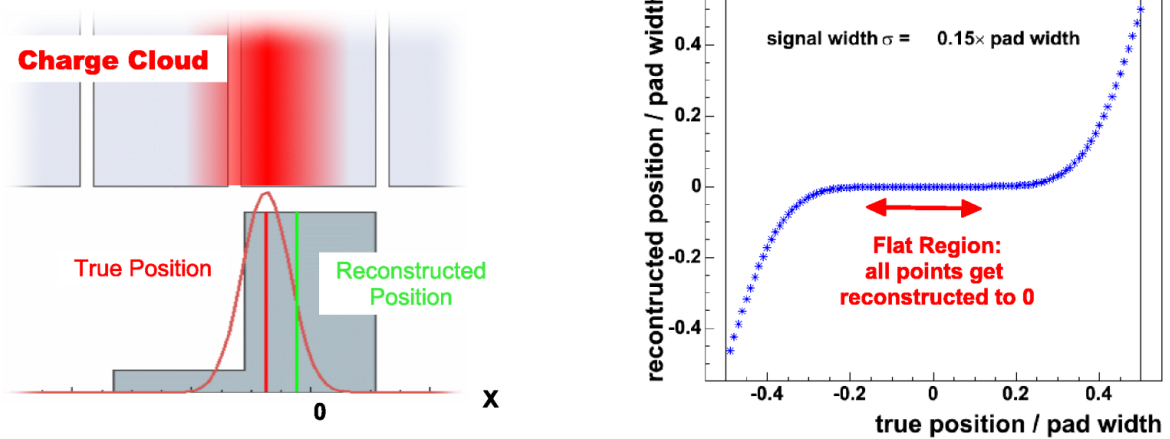


Figure 13: Pad Response Function. Divergence between true position and reconstructed position of a hit, if the signal is too narrow (left). Example for a PRF with a too narrow signal, so that there is a loss of information (right). [2]

The PRF affects the track reconstruction and resolution results in different ways depending on the layout of the pad plane (differentiated between non-staggered and staggered). The effects can be seen in Figure 14.

In the case of a non-staggered pad layout, all hits are reconstructed "wrongly" towards the same direction and therefore the whole reconstructed track is "pulled" in the same direction. This leads to a "wrong" track reconstruction, while the resolution results show too good values since the residuals do not reflect the true distance of the hits from the reconstructed track but smaller values.

In the case of a staggered pad layout, the hits are reconstructed "wrongly" in opposite directions in adjoining rows. So the track is still reconstructed more or less at the right position (since the "pull" from adjoining rows is in opposite directions and therefore "cancels out"). But the distance of the reconstructed hit position from the track is larger than the distance of the true hit positions.

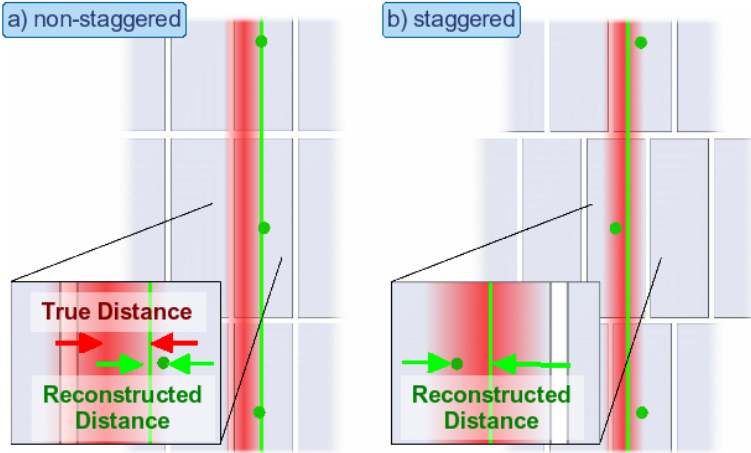


Figure 14: PRF effects on a non-staggered pad layout (left) and on a staggered one (right). [2]

6.2 Pad Resonse Correction (PRC)

It is possible to correct the shift by the PRF after the hit reconstruction in the case when the X position is not inside the flat area of the PRF. This is done by calculating an "inverse" PRF, which is then the true X position of the hit depending on the reconstructed position, depending on the width of the hit.

This function is called the Pad Response Correction (PRC) and is shown for some widths in Figure 15. In the case where the signal is only on one pad (or even smaller signal widths), there is a flat area in this function and the hits in this area can not be corrected and are all being reconstructed to zero. If there is a measurable signal on at least 2 pads, all X positions can be corrected. In the case the signal is broad enough to be spread over 4 or more pads, the PRC becomes a straight line and the correction is not necessary anymore.

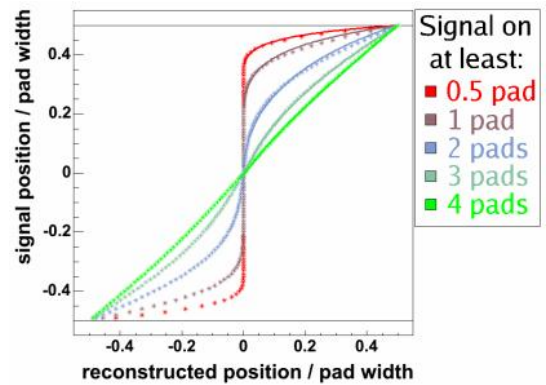


Figure 15: PRC for different widths σ . [2]

7 My Work

7.1 Introduction

The starting point of my work was that I should process MediTPC data of cosmics with the actual MarlinTPC framework. But the data were already processed with the previous framework MultiFit so that I had a comparison point. Out of the MediTPC data I looked on two different sets which had a good run statistic: at first I processed the run0069 with P5 gas afterwards the run0095/0096 data sets with T2K gas.

To make the processed results - especially the resulting $r\phi$ resolution plot - of the two frameworks comparable, I had to adjust reconstruction parameters and cut options which are unfortunately not always the same or defined in a different way. But before I could start I had to create a Z binning of the data because they were taken with cosmic rays (see next sub chapter). After success in making the processing of MarlinTPC and MultiFit comparable, I looked at the Pad Response Correction which was at the state as I arrived a one-to-one copy from the implementation in MultiFit. And the first investigations showed no good results.

Overall I had to implement new processors, understand and controll the already existing processors, write Python steering files, which perform then the dedicated tasks on the data by Marlin, and root scripts for plotting the results.

7.2 Marlin Processor ZBinningForCosmicData

As said before, at first it had to be implemented a Marlin processor which divides the whole data set in pieces depending on the z position of the track. The Marlin framework is normally handled in testbeam mode where you have explicit positions along the TPC and can adjust so a z position respectively a driftlength, but cosmics are arbitrarily distributed and so a distribution by hand had to be performed.

So the processor calculates the mean z position of the hits on a track which is then defined as the z track position. Now there are two modes available to divide the data set in z direction:

1. for general purpose the user can choose a binning number and then the tracks are distributed in equidistant bins appropriate to the given number
2. for a good comparability to the MultiFit results the same binning as there is used can be chosen

7.3 Adjusting Cuts

Then the main task was to adjust the cuts on the data appropriate to MultiFit's to get comparable results. Unfortunately there are some differences between the frameworks:

- in MultiFit cutting quantities - like ϕ angle - are defined hit based, in MarlinTPC track based

- other coordinate systems or orientation of axes are used, e.g. definition of cutting angle θ respectively λ
- some cuts were at the current status not available at all in MarlinTPC, e.g. a X cutting

The same as pronounced before for the analysis process with cuts, it is in the step before in the reconstruction process where other criteria and parameters are not the same in MultiFit and MarlinTPC. So I had to spend much time on comparing the data and looking on plot distributions for both frameworks of things like "number of pulses per hit" and adjust some of the general pulse and hit based reconstruction schemes. But finally I reached a status where you can say that the results are now more or less similar.

7.4 Pad Response Correction

The next step in my work was to make the pad response correction (PRC) work in MarlinTPC. To the begin of my efforts the actual implementation was performing no correction at all. So I reviewed the implementation and found finally an error: in the implementation there was no request for the module design, so everything in there was handled as the pad plane is spherical with coordinates (r, ϕ, z) and not rectangular with coordinates (x, y, z) as in the MediTPC GEM module.

After correcting this only a little correction on the hits occurred which was far not enough in comparison to MultiFit's PRC data. For searching the error there I implemented a PRFAnalysis processor which shows histograms of the uncorrected, reconstructed center of gravity of the hits and the corrected ones. Furthermore it creates a scatter plot where the real correction value is evaluated against the center of gravity position. After comparing these plots between MultiFit and MarlinTPC the second error was found: the directions of axes was mixed up, that means instead of the driftlength the z position was given in the pad response correction and so a false correction value was calculated. After repairing this I was happy to see that now the PRC works in principle in MarlinTPC.

7.5 P5 data set

7.5.1 Results

The results - in terms of the $r\phi$ resolution plot - for the data set run0069 with P5 gas is shown in Figure 16. The filled orange circles are the uncorrected resolution values processed with MultiFit and the unfilled ones are the corrected ones. So you see that the correction let the curve decrease in the first part, so it corrects the so-called holoscopic effect. The dark blue stars are the data points for the uncorrected data processed with MarlinTPC and correspondent the cyan unfilled stars shows the data after PRC.

The PRF parameters for this plot were in both cases with MAGBOLTZ simulated parameters which will become interesting in the next chapters.

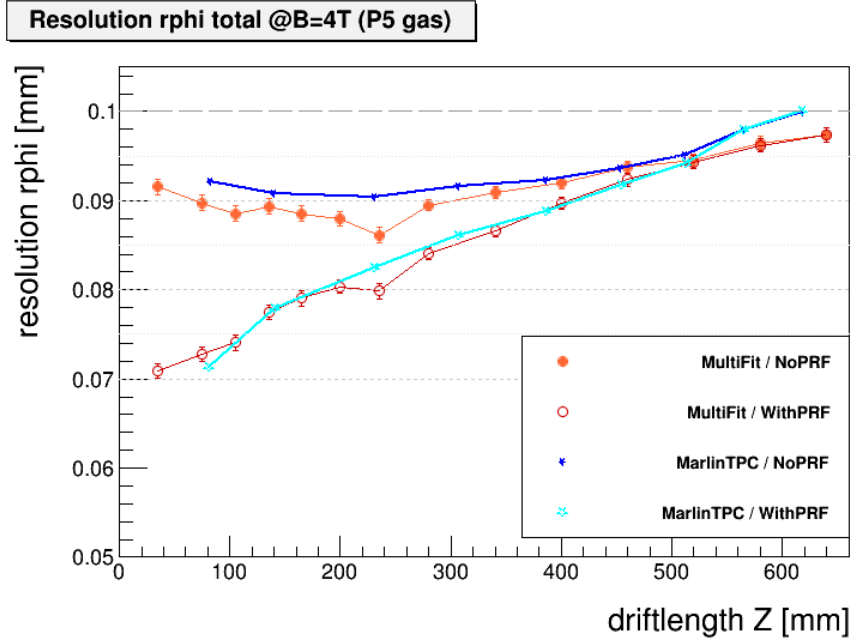


Figure 16: Results for run0069 with P5 gas.

7.5.2 σ_0 problem

The Pad Response Correction needs two parameters as input: the defocussing σ_0 and the diffusion D^2 . In the above plot simulated values by MAGBOLTZ simulation of the gas behaviour was inserted and how you can see they worked in terms of $r\phi$ resolution. But nevertheless it would be nice to extract the PRF input values out of the data itself. So you can test to fit the reconstructed PRF hit width by a Gaussian and then fit the resulting values with the function $\sigma = \sqrt{\sigma_0 + D^2 \cdot L}$ where L is the driftlength. But as you will see in the next plot, the results are not so good. Therefore I tested an alternative in which the induction phenomena is included. Induction means here that the arriving charge cloud induce signal charge not only on the central pad but also on its neighbours. Simulations showed that a value of 10% induction describes it well. So now I fit the reconstructed PRF hit width with a superposition of three Gaussian (see Figure 17) as described here:

$$\begin{aligned}
 \sigma_{fit} = & 0.1 \cdot [0] \cdot \exp\left(-0.5 \cdot \left(\frac{x - ([1] + [2])}{[3]}\right)^2\right) \\
 & + [0] \cdot \exp\left(-0.5 \cdot \left(\frac{x - [1]}{[3]}\right)^2\right) \\
 & + 0.1 \cdot [0] \cdot \exp\left(-0.5 \cdot \left(\frac{x - ([1] - [2])}{[3]}\right)^2\right)
 \end{aligned}$$

So parameter [0] describes the amplitude of the central Gaussian, [1] the mean of the central Gaussian, [2] the displacement of the neighbouring Gaussians (should be in the range of (half a) pad size) and fit parameter [3] the overall Gaussian width.

In Figure 18 you can find a comparison of the different input parameter by using the methods of MAGBOLTZ simulation (labeled "MAGBOLTZ"), normal fitting (labeled "fit") and fitting with induction phenomena (labeled "fitInduction") in terms of a $r\phi$ resolution plot.

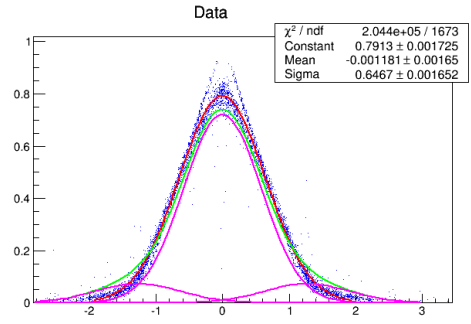


Figure 17: Superposition of three Gaussians to fit the reconstructed PRF hit width.

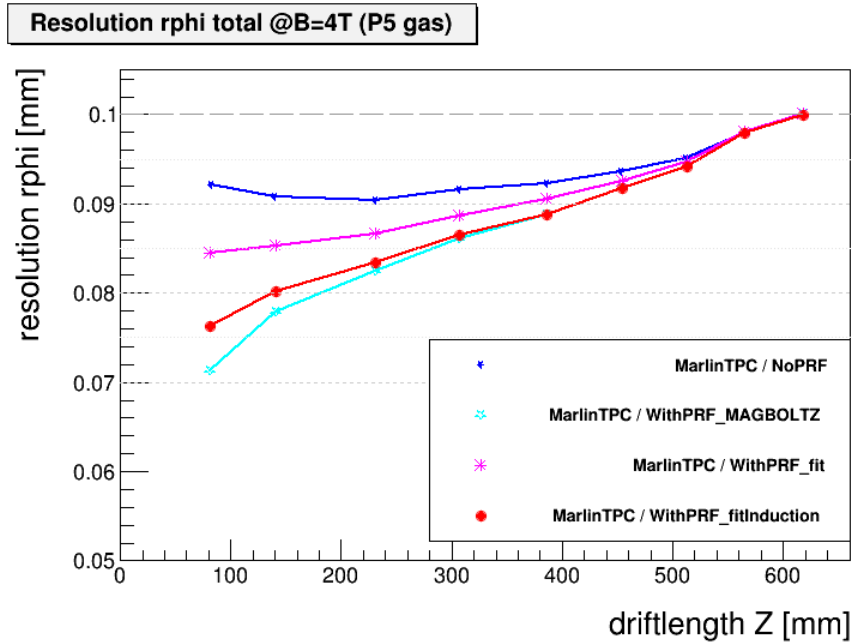


Figure 18: Comparison of different PRC for run0069 with P5 gas.

So you can see there that the "fitInduction" method is nearly similar to the MAGBOLTZ graph. Perhaps this can then be an alternative to extract the values out of the data. But to decide if the correction works it is not sufficient to look only on $r\phi$ resolution plots, therefore you can look also on control plots like a histogram where the center of gravity position normalized by the pad width is plotted for the different cases. Such a plot is shown in Figure 19. A good correction provides a flat distribution with exception of the null position. Now you see that the corrections are comparable.

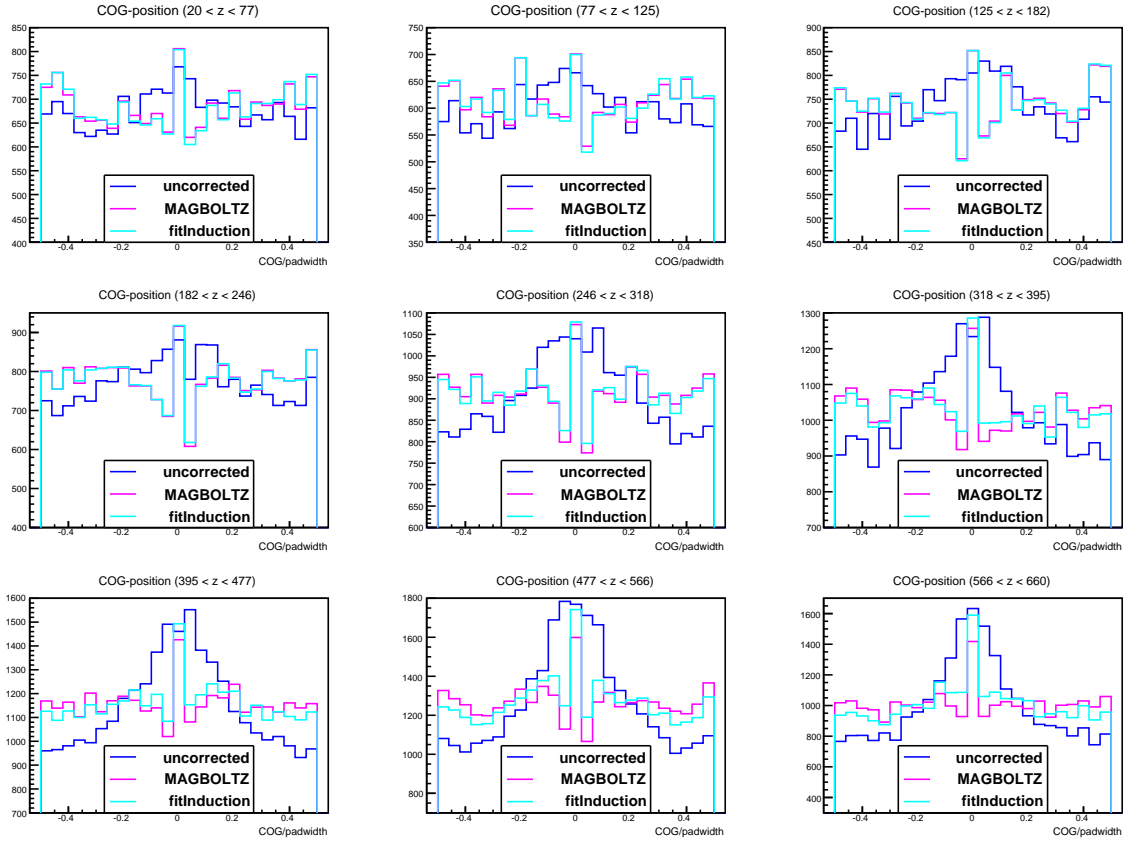


Figure 19: "Center of gravity" plot for different PRCs (P5).

7.6 T2K data set

7.6.1 Adjusting of cuts

At first here again the cuts and reconstruction parameters had to be adjusted. Furthermore a new cut had to be implemented: a X cut. Because of a special construction of the GEMs only hits with a X value between 16 and 40 mm should be included. Therefore a similar cutting processor as the Z binning was implemented where only tracks with all their hits in this X region are used.

7.6.2 Results

The results - in terms of the $r\phi$ resolution plot - for the data set run0095/96 with T2K gas is shown in Figure 20. As you can see the difference between the uncorrected graph of MultiFit (orange triangles) and appropriate of MarlinTPC (dark blue stars) is in the magnitude of about 15 microns so here you get no such good agreement as with P5 gas.

Furthermore referring to PRC there is happening something strange:

1. The with MAGBOLTZ simulated PRF parameters work in the simulation and for the P5 data, but unfortunately not for the T2K data, as you will see in the upcoming plot (labeled with "MAGBOLTZ").
2. With an arbitrary chosen parameter set, which came originally form MultiFit (and the plot "MultiFit-WithPRF" is processed with this parameter set) because of a miscalculation, a good correction in terms of resolution is performed (labeled with "MF").
3. Again, the fitInduction method which worked fine on the P5 data is included in the hope that it provide again a good correction (labeled wit "fitInduction").

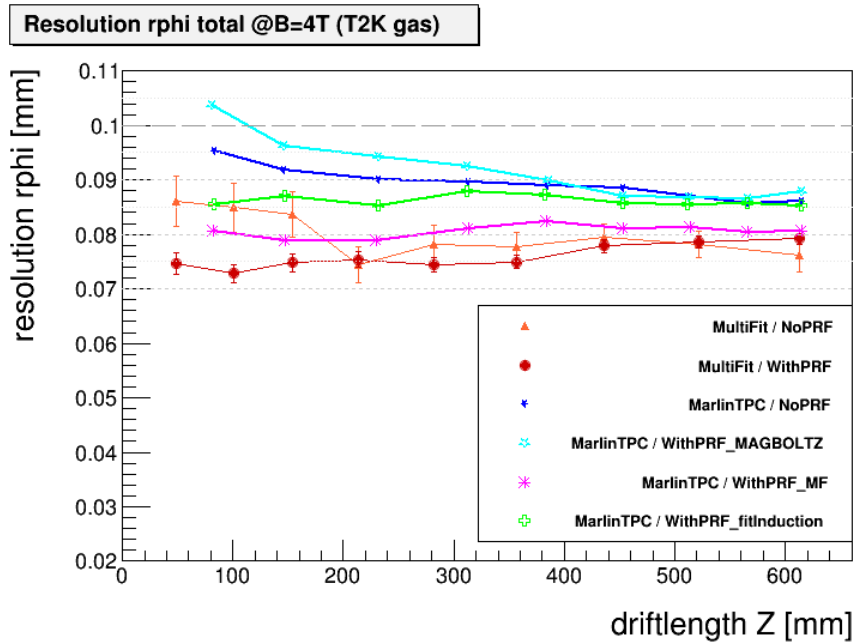


Figure 20: Results for run0095/96 with T2K gas.

7.6.3 σ_0 problem

Because of the resulting plot above, it is unclear which parameter set works in the best way. Therefore I made something like a parameter study and varied especially the defocussing value because this is the dominant part. The results are shown in Figure 21. Finally you can find with the parameter set ($\sigma_0 = 0.12$, $D^2 = 9 \cdot 10^{-5}$) an optimum in terms of $r\phi$ resolution (red line in Figure 21).

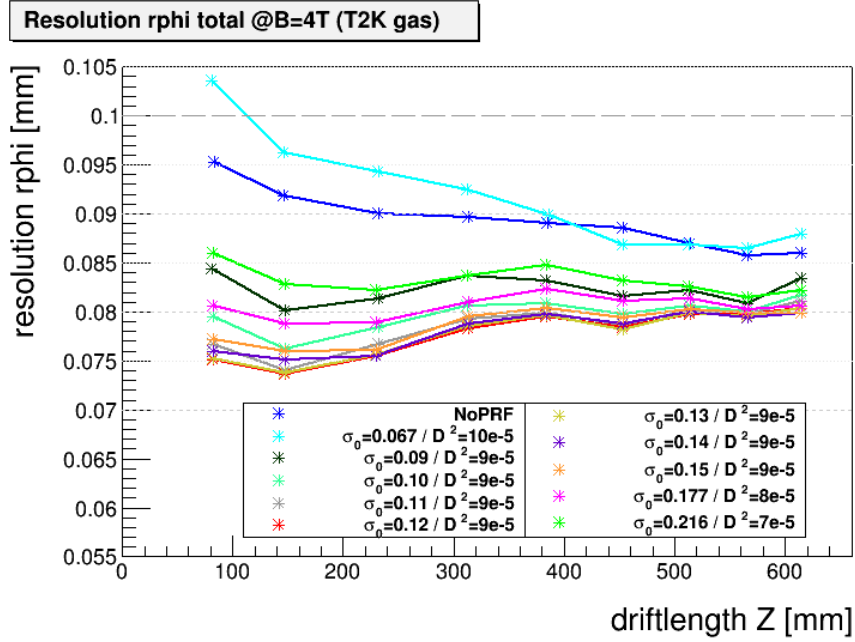


Figure 21: Results of the parameter study for PRC (T2K).

Furthermore, I looked again for the most promising value sets to the control plot of the center of gravity position (see Figure 22) to check the real goodness of the correction. Here you see, that the for P5 functioning value from MAGBOLTZ makes too hard correction so that the hit positions are corrected too far to the pad sides and are not resulting in a flat distribution. The in terms of $r\phi$ resolution as optimal set labeled values show in this control plot a very flat distribution so that you can speak of a good PRC.

The question is how you can motivate this value as it is gained from a parameter swap and why the further working values from MAGBOLTZ do not work for real data with T2K gas. To check for this parallel to my studies some simulation was performed where you saw that you can not retrieve the hit charge width after reconstruction because of a dependency on the pad width so that there has to be an effect which is until now not took into account.

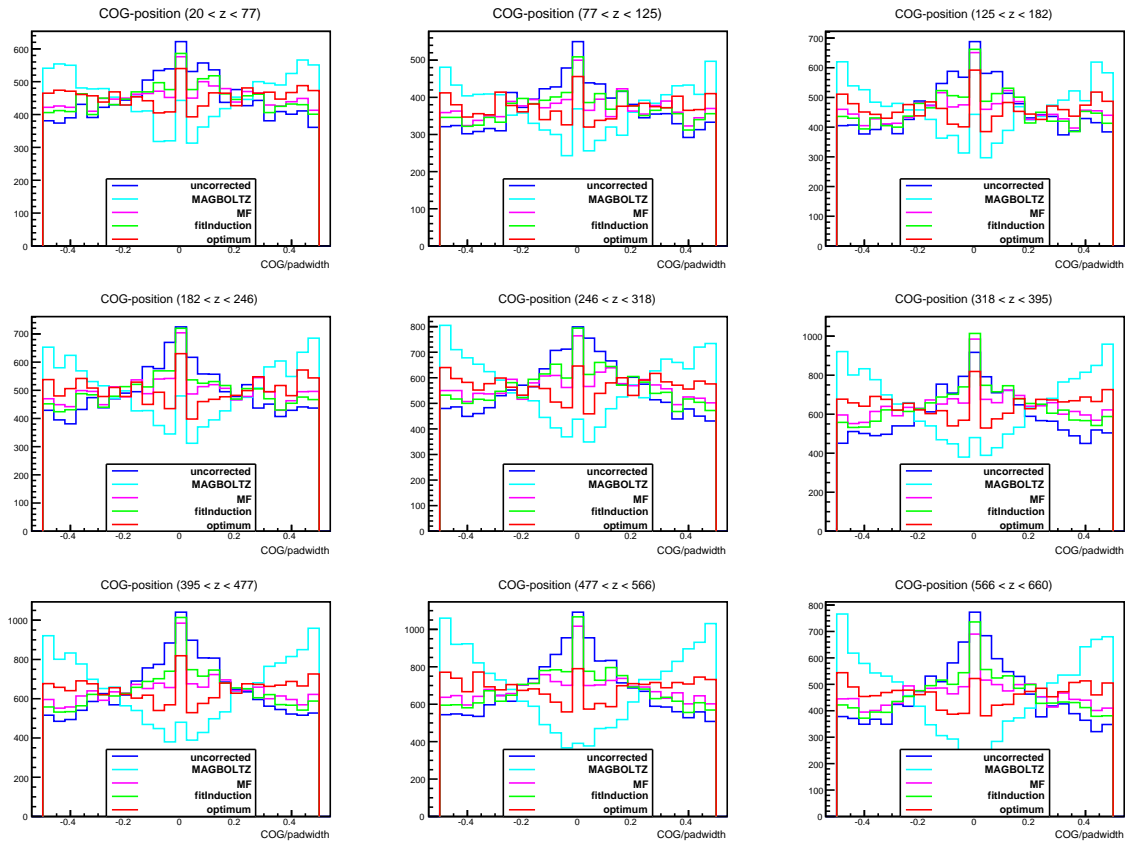


Figure 22: "Center of gravity" plot for different PRCs (T2K).

8 Conclusion

As a conclusion of my work in the FLC-TPC group I can state that I successfully performed analysis of MediTPC data with two different gases (P5 and T2K) with the MarlinTPC framework. I have adjusted the reconstruction parameters and cutting options so that you can now compare the analysis results of MultiFit (as the prior framework) and MarlinTPC on an equal basis. Furthermore I spend much time on the integration of the Pad Response Correction in MarlinTPC. In the end I can say that the PRC is now working but unfortunately there remain some problems.

So the whole PRC works very well for the P5 data set, both in MultiFit and MarlinTPC, and the results are comparable. Besides I could show a method, the fitInduction method, which can extract the PRF input values approximately good in comparison to the optimal simulated ones by MAGBOLTZ. In contrast to this fine results the T2K data set show a very different side: here is a bigger offset between MultiFit and MarlinTPC for the uncorrected analysis and much more strange is that in both cases the PRC do not work in that way it has worked for P5 gas. Here I had to assert that the simulated PRF inputs by MAGBOLTZ do an overcorrection on the data and with the help of a parameter study I could found a - out of the momentarily perspective - arbitrary chosen optimal value set. So in this topic some further research has to be performed but my time is unfortunately now over.

All in all I could get a good insight in the topics round about the analysis of a tracking tool like a TPC during my stay here. I have now some knowledge about the software framework MarlinTPC and know how the reconstruction process is working. Furthermore I got a glimpse of the problems which can occur and hopefully find a solution for them. So I had a very interesting and informative time.

Acknowledgment

I would like to thank the whole FLC group and especially the TPC subgroup with my supervisors Astrid Muennich and Ralf Diener for the good and interesting time I was allowed to spend here at DESY. It was a really nice summer as a SummerStudent 2014! Thanks a lot!

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