DESY Summer Student Program 2013

Study of field distortions in a TPC prototype and their influence on the resolution

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Abstract

This report summarizes my work at DESY during the summer student program 2013. The goal was to simulate track registration by MediTPC prototype in order to understand experimental data of hit displacement after reconstruction. Assumption that this displacement was caused by field distortions was proved at least on qualitative level but for better quantitative results further analysis is needed.

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Contents

1. Introduction

The International Large Detector (ILD) is a concept for a detector at the International Linear Collider (ILC). The ILD is a big challenge from technological point of view. In recent years the concept of particle flow has been shown to deliver the best possible overall event reconstruction. Particle flow emphasizes that all particles in an event, charged and neutral, should be individually reconstructed, even in jets. This implies the very high spatial resolution for all detector systems. A highly granular calorimeter system is combined with a tracking system and they are placed in strong magnetic field of 3.5 T. An artistic view of the detector is shown in figure 1.1.

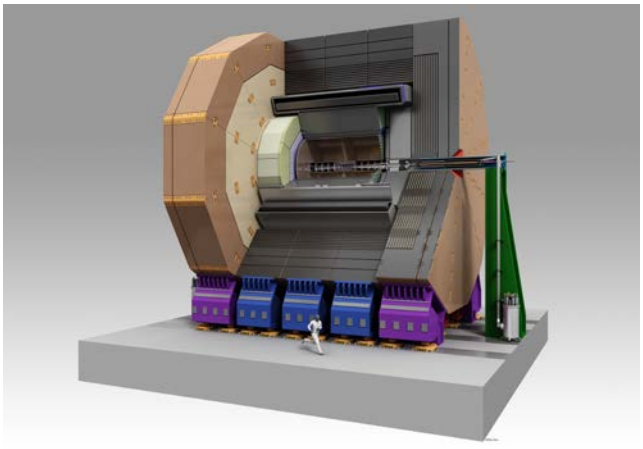

Figure 1.1: View of the ILD detector concept.

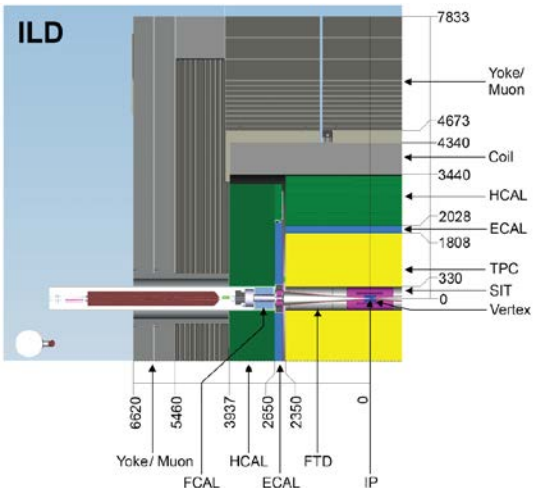

Figure 1.2: Quadrant view of the ILD detector concept. Dimensions are in mm.

As central tracker Time Projection Chamber (TPC) was chosen. It's designed to have single point resolution in ϕr plane better than 100 μm. The schematic of TPC is shown on figure 1.3.

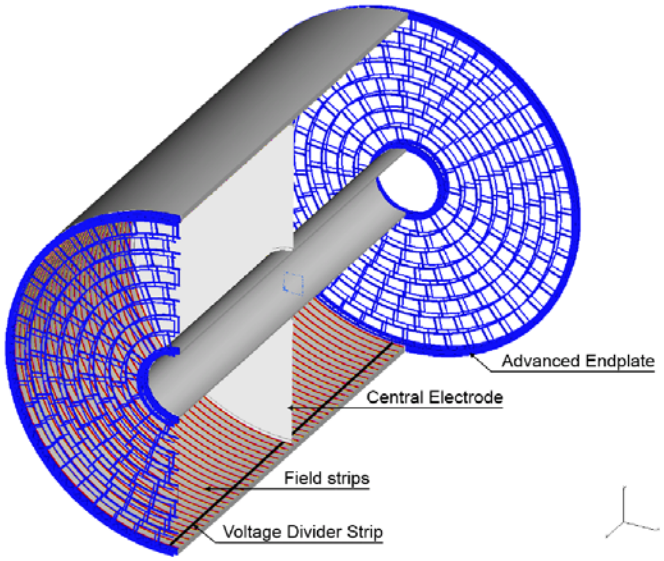

Figure 1.3: Sketch of the TPC system (not to scale).

In order to achieve such resolution Gas Electron Multipliers (GEMs) are used. Two or three GEM foils are stacked together to achieve sufficient charge amplification. For the GEM readout the transverse diffusion within the GEM stack itself is enough to spread the charge over several 1 mm wide pads, which enables a good point reconstruction.

2. MediTPC prototype

MediTPC is one of the prototypes used to test technologies applied to TPC. You can see the photos of this prototype on figures 2.1-4.

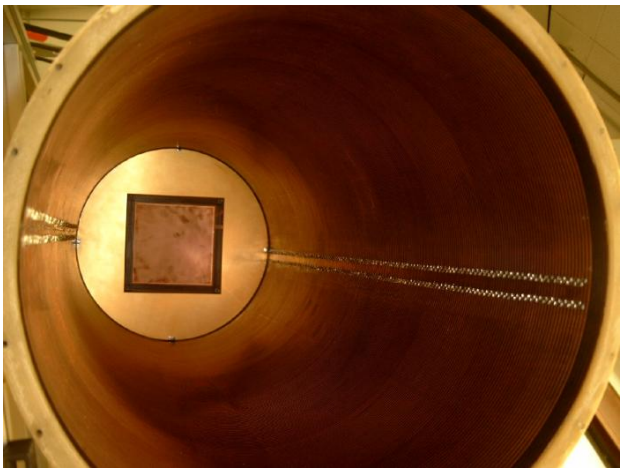

Figure 2.1: MediTPC prototype.

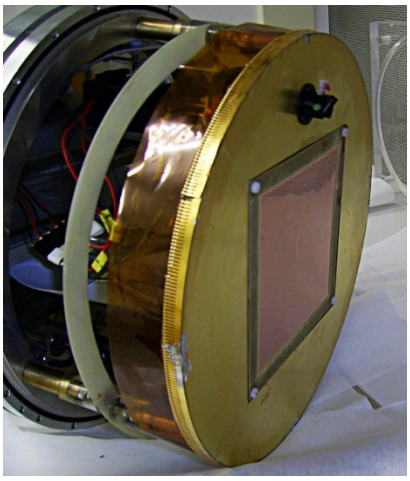

Figure 2.2: Anode plane.

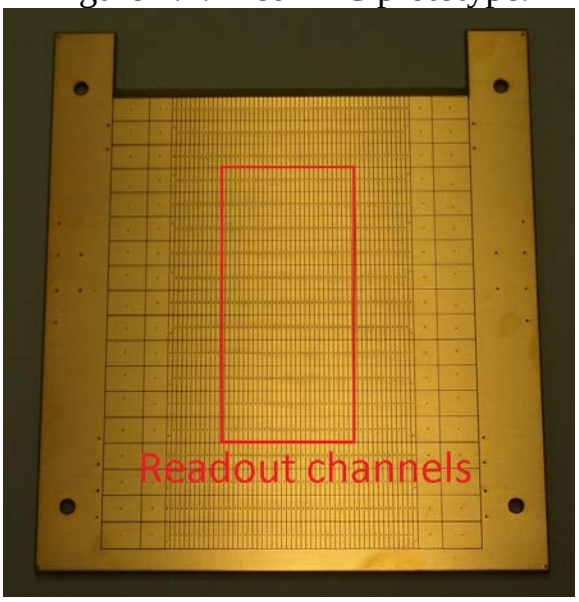

Figure 2.3: Pads plane (dimensions of one pad are 1.3x7 mm).

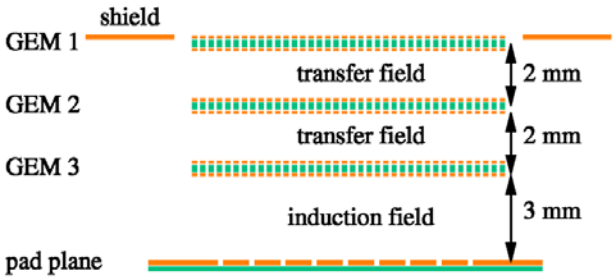

Figure 2.4: Sketch of the GEM tower.

It was placed in magnetic field of 4 T. Due to lack of readout channels only central part has been read (see figure 2.3). Experimental data for comparison is from Run 0095-01.

Measurements were done with two sets of parameters as in table 1.

Table 1

Parameter	Set 1	Set 2
Gas mixture	T2K	P5
Drift field	250 V/cm	90 V/cm
Transfer field	1500 V/cm	1500 V/cm
Induction field	3000 V/cm	3000 V/cm
Voltage per first GEM	250 V	325 V
Voltage per other GEMs	250 V	320 V

3. Field calculation

Field calculations were done in CST Electrostatics 2012/2013. The following model of drift chamber was developed for this purpose:

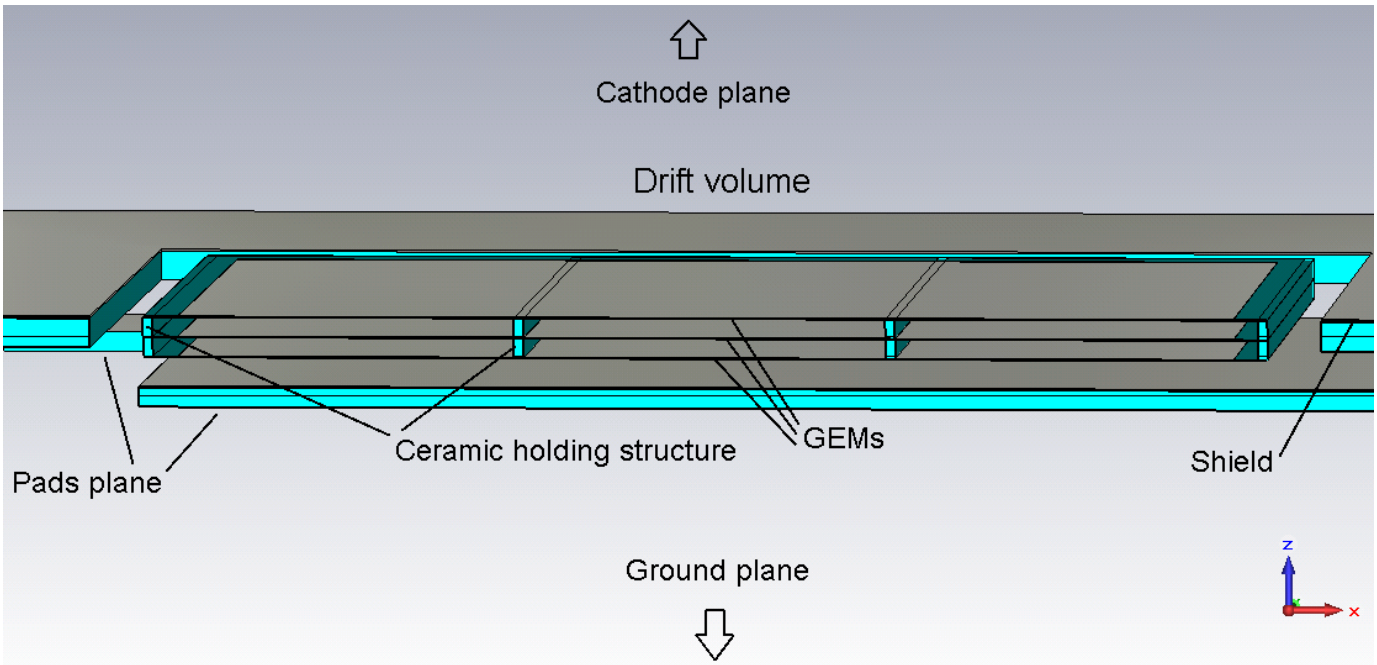

Figure 3.1: Sketch of the model for field simulation.

Volume which was simulated has box shape when prototype was circle like. That doesn't matter because tangential boundary conditions were set for sides to get uniform field above GEMs. Ground and pads plane have the same zero potential. Shield and upper copper plane of first GEM also have equal potentials which as potentials of the rest of electrodes were calculated to reach predefined field strengths.

Results of calculations you can see on Figures 3.2-4:

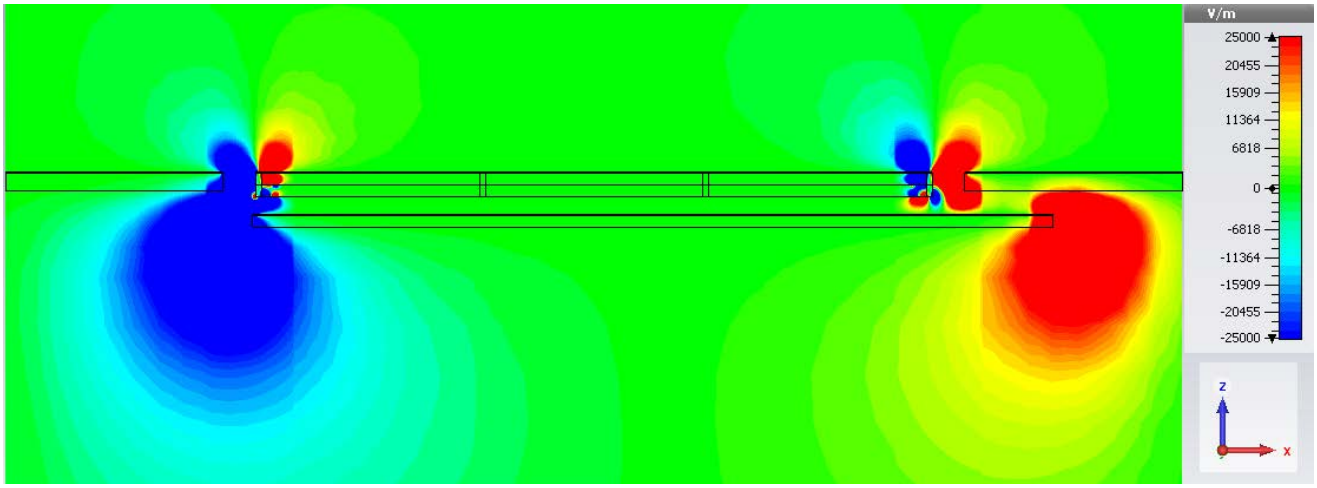

Figure 3.2: E_x component of the field with high drift field.

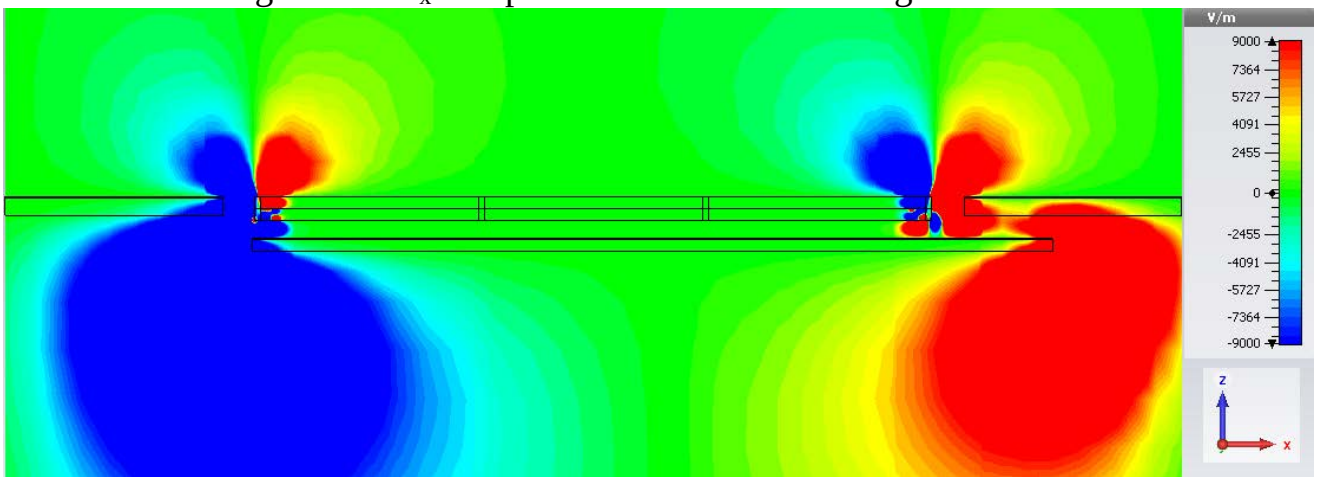

Figure 3.3: E_x component of the field with low drift field.

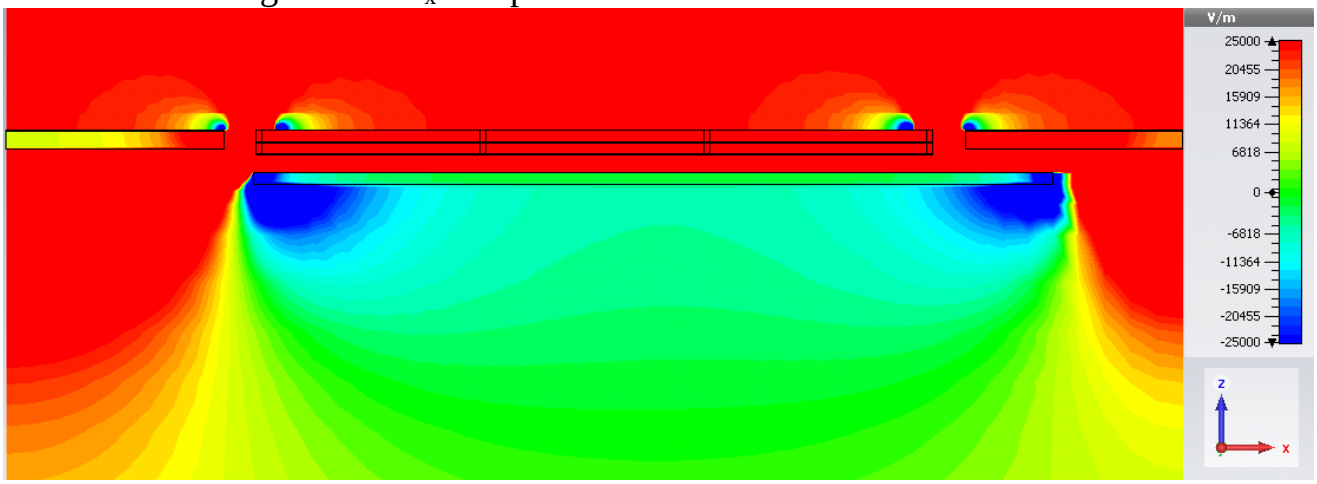

Figure 3.4: E_z component of the field with high drift field.

Project for simulation of GEM field was provided for me by my supervisor Klaus Zenker. GEM pattern and example of simulation with drift field 90 V/cm and transfer field 1500 V/cm you can find on Figures 3.5-6:

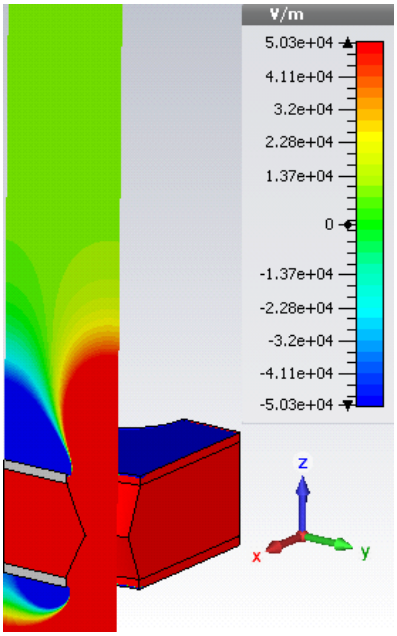

Figure 3.5: E_z component of GEM field.

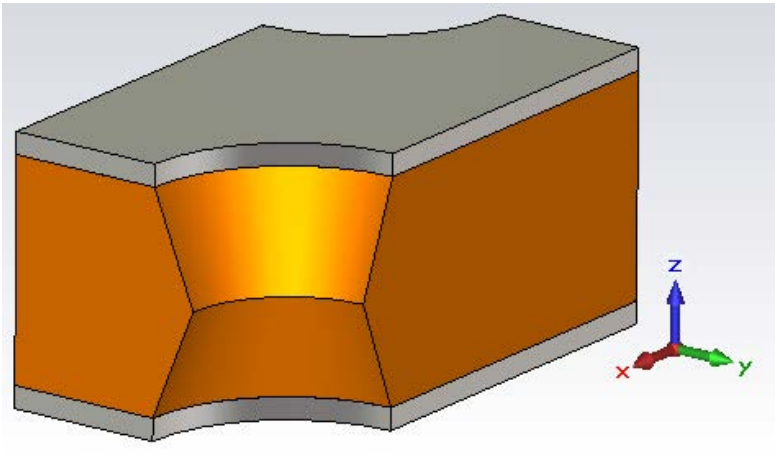

Figure 3.6: GEM pattern.

Here tangential boundary conditions are also applied, so we can use mirror periodicity to create whole GEM. Another point is optimization of potential value on top and bottom sides. Because of influence of holes on field in drift region we get higher field than expect, so we need to find optimal value by several iterations what can be done by using of corresponding function in CST. It can't be managed with too small additional drift volume, so 1 mm above and 440 μm under GEM were chosen (such sizes are necessary for first GEM only where we have low drift field but for simplicity they were used for all GEMs).

4. Garfield simulation

Before starting to simulate drift of electrons I decided to create as realistic field map as possible. Two classes were developed for this purpose.

Class ViewFieldInterectively : public ViewField_Copy

It is derived from slightly modified standard class ViewField. It was necessary to make some private members protected and change following line in every PlotXXX function:

```
//Changed: if (fPot == 0) {CreateFunction();} => following two lines:
if (fPot != 0) {delete fPot;}
CreateFunction();
```

This class adds only one method named EnterInteractiveMode in which you can type commands in console to change presentation of the plot as on Figure 4.1. Help command is available.

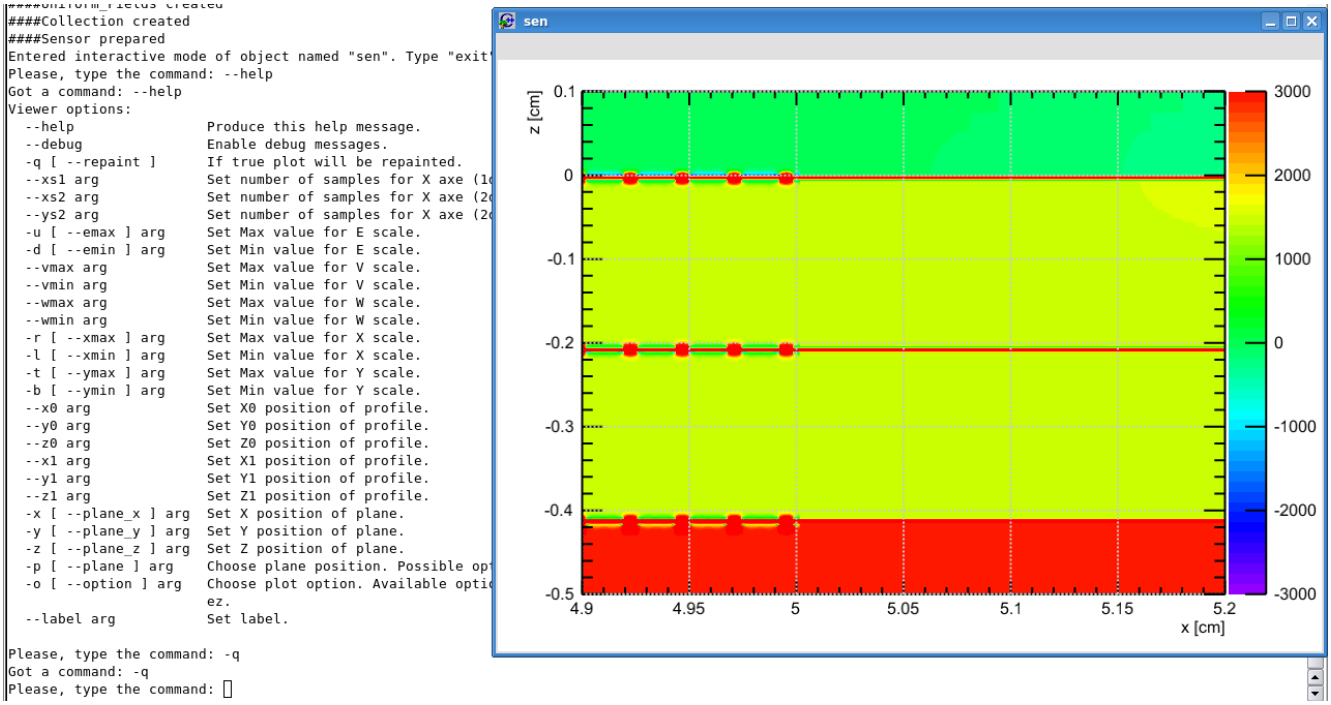

Figure 4.1: Example of usage of interactive field viewing mode.

Another class is ComponentCollection:

Class ComponentCollection : public ComponentBase

As derived from ComponentBase it can be added to the sensor as ComponentUser or ComponentCST etc. It's a container of ComponentBase derived classes and provides some additional control over them. You can disable/enable E or B fields or only one component of field, invert fields, shift them, disable component, set bounding box or user defined medium function. Several points have to be clarified.

Every contained object and whole collection has shift vector and bounding box option. Lets look how they refer to each other. First you have to understand that bounding box has nothing common with object that owns it. It just defines the plane were you want the field can be. Then maybe you need to shift the field of this object to the desired place. Second point is that in spite of what kind of object you have added to the collection you can define you own medium function and it will interact with object's GetMedium (GM) method as set in object's MediumMode (MM).

Every object (and also whole collection) has its own frame of references (FoR) and bounding box (BB) set in this FoR. Outside BB there is no field and medium. With Shift vector of object you can shift field inside this object with respect to its BB and its FoR. In this case BB and FoR left on the same position. Then with Shift vector of collection you can shift all objects together with their fields and BBs (this means that FoRs of objects are shifted) with respect to global FoR and BB. At the beginning when all Shift vector are

zero all FoRs are equal (have the same origin and axes' directions). The same rules are applied to medium.

Every object has MediumMode (MM), GetMedium method (GM) and can has MediumFunction (MF, in object's FoR). There are also global MF, global MM and collectionMM. Medium mode can be "or" (default), "and" or "xor". Result of collection's GM method calculates like if statement:

Result of collection's GM method = globalMF globalMM ((obj1GM obj1MM obj1MF) collectionMM (obj2GM obj2MM obj2MF) collectionMM … (objnGM objnMM objnMF))

Disabled component means that it won't be taken into account and ComponentCollection won't touch its pointer. So if some object added to collection has been deleted (its pointer isn't valid any more) you should disable it in ComponentCollection because there is no way to deleted object from collection. Reason of this you will understand after the following example of usage. More advanced example with comments you can see in script for Garfield simulation.

Example of usage:

```
#include < ComponentCollection.hh>
…
// Assume
ComponentCST* chamber = … // load chamber field
ComponentCST* gem = … // load gem field
ComponentConstant* up = … // create constant field above gem
ComponentConstant* down = … // create constant field under gem
// Then
ComponentCollection* collection = new ComponentCollection();
collection ->SetCollectionMediumMode("or"); // just for illustration because “or” is
       default mode
// You MUST set bounds for collection
collection->SetGlobalBounds(-10, -10, -10, 10, 10, 10); // set bounds for whole
      collection
collection->EnableVforMedium(); // this function will be explained later
// Adding chamber to collection
// We will use result of calling AddComponent method to get access to this object in
      future
int i_chamber = collection->AddComponent(chamber); // bounding box is automatically
      set by chamber->GetBoundingBox method
// we need to delete field in the place where gem will be placed
int i_gem_place = collection->AddComponent(chamber);
collection->SetBounds(i_gem_place, gem_left, gem_rear, gem_bottom, gem_right,
      gem_front, gem_top);
collection->EnableEfieldInversion(i_gem_place); // in superposition two fields will
      cancel
collection->DisableBfield(i_gem_place); // we need to delete only E field
// And put gem at that place
int i_gem = collection->AddComponent(gem);
collection->SetBounds(i_gem, gem_left, gem_rear, gem_bottom -
      additional_space_under, gem_right, gem_front, gem_top +
additional_space_above);
collection->SetShift(i_gem, 0, 0, necessary_field_shift_z); // align gem field with
      respect to its bounding box if necessary
// We will have uniform field above and under gem twice (from chamber and gem
      objects). So we need to substruct it once
int i_up = collection->AddComponent(up);
```

```
collection->SetBounds(i_up, gem_left, gem_rear, gem_top, gem_right, gem_front,
      gem_top + additional_space_above);
int i_down = collection->AddComponent(down);
collection->SetBounds(i_down, gem_left, gem_rear, gem_bottom -
      additional_space_under, gem_right, gem_front, gem_bottom);

sensor->AddComponent(collection);
```

In this example collection->EnableVforMedium(); method was mentioned. If this function is turned on then instead of potential value two constants will be assigned to v parameter in collection->ElectricField method, one in case there is medium at given point or another if not. This won't influence on simulation results because Avalanche methods use another version of ElectricField without this parameter. But now if you switch in interactive mode with command "-o v" from field view to potential view you will see plot of medium instead of potential as on Figure 4.3 where orange means medium and green no medium.

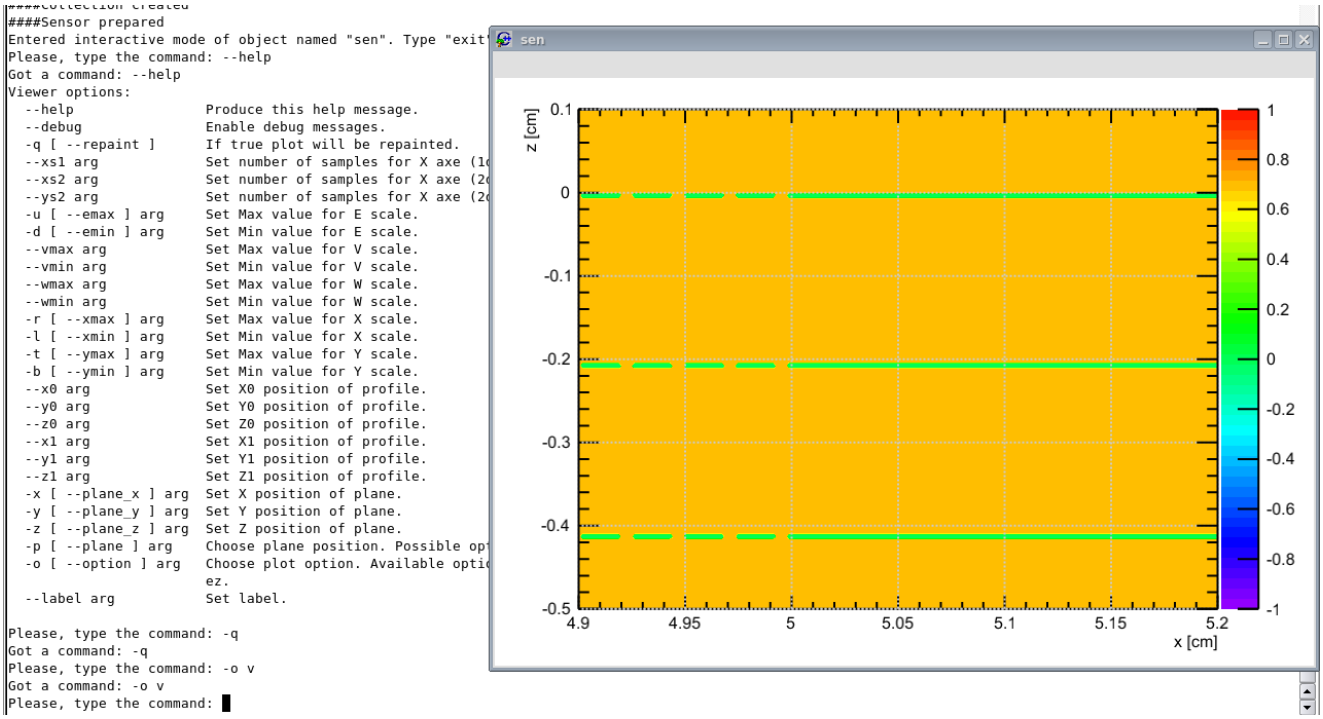

Figure 4.3: Plot of the medium.

Garfield++ is a cross section based simulation toolkit for the detailed simulation of particle detectors which use a gas mixture or a semiconductor material as sensitive medium. Two methods of simulation are available: AvalancheMicroscopic and AvalancheMC (Monte Carlo). In our case for simulation of electron transfer for long distances second method is more suitable. It requires previously calculated gastable with parameters of the gas and as I have proper one for T2K gas only further analysis will be done for first set of parameters.

Scan was done with step 0.5 mm over GEM area with holes (200 points in total) along X direction by starting 100 electrons from each point. You can also see visualization of electrons behavior near the gap on figure 4.4. Part of electrons above GEM's copper plane

is sucked to the gap but hopefully it is observed above the 4 mm copper frame (without holes) only and we don't have charge loss as shown on figure 4.5.

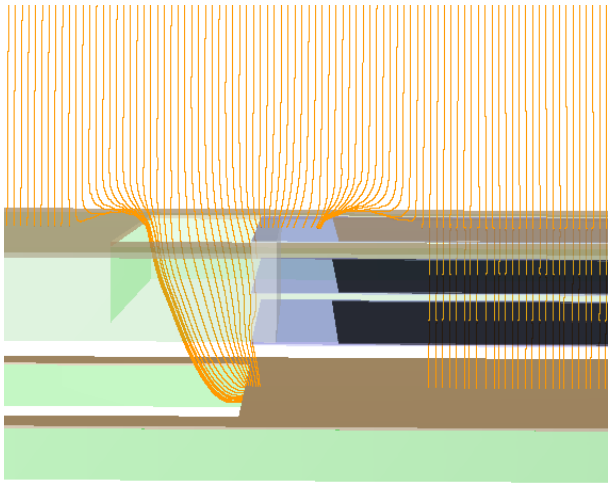

Figure 4.4: Electrons behavior near the gap.

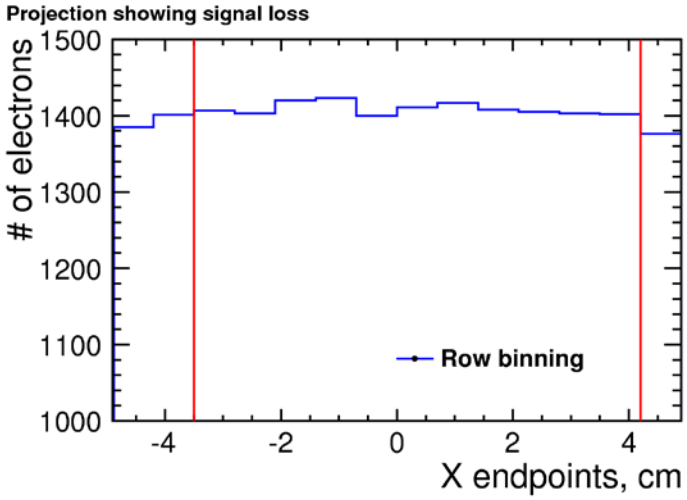

Figure 4.5: Charge loss with row binning. Vertical lines mark readout area.

Due to E cross B effect electrons are bended in Y direction as you can see on figure 4.6. From plot 4.7 we can conclude that it's not necessary to do simulation with high statistic because fields are smooth and we can just turn off the diffusion and make one scan.

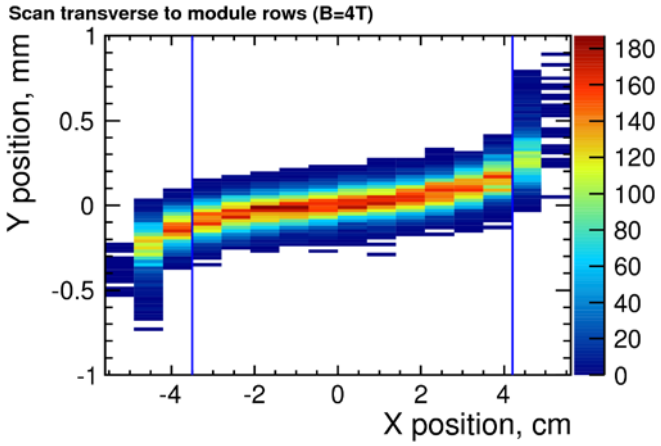

Figure 4.6: Endpoints of electrons stopped just before the first GEM.

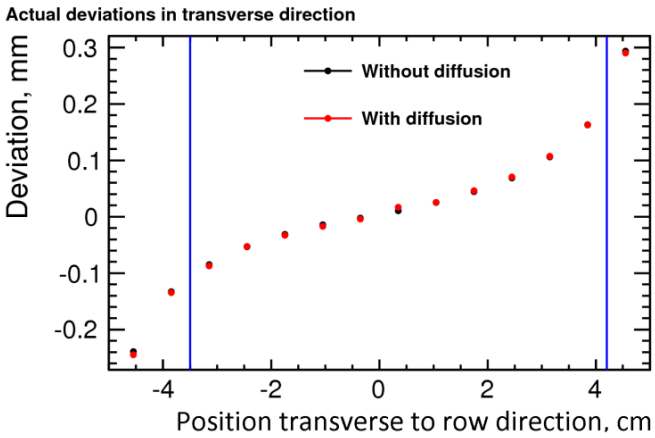

Figure 4.7: Comparison of simulations done with diffusion turned on and off.

Electron which comes to the first GEM is sucked to the hole and "forgets" where it came from. After the amplification at first GEM a cloud of electrons due to high diffusion in strong field spreads over ~1 mm in diameter circle and doesn't "feel" the discrete structure of second and third GEMs. To explore the influence of first GEM on track registration many scans with different uniformly distributed Y starting positions were done and in mean value we get the same result as expected. GEM structure is barely seen even for one track because we calculate mean value of y-endpoints of tens of electrons and they are Gausially distributed over several holes. There is also no difference whether we stop

electrons at first GEM or at pad plane because of absence of any transverse field between them.

To compare simulation results with experimental data we need to go through track reconstruction procedure. The easiest way is to approximate deviations of rows from readout area with straight line and calculate distances to it. This you can see on figure 4.8:

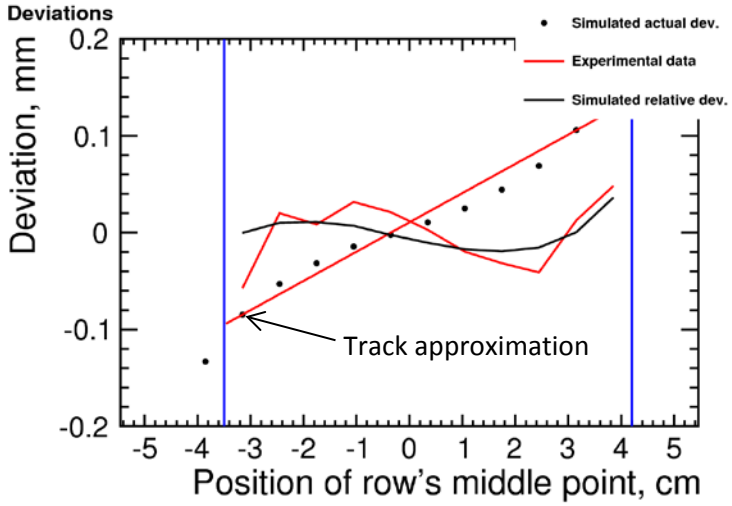

Figure 4.8: Comparison of experimental data with result of simulation when simple track reconstruction algorithm is used.

5. Reconstruction using MarlinTPC software

With simple reconstruction algorithm we got the right trend of deviations. Next step is to apply the same algorithm that was used for experimental data. So, first we need to set positions of electrons to be amplified. Assume that we have ~100 primary electrons per 1 cm and transverse diffusion coefficient for current setup accordingly to studies by Akimasa Ishikawa is ~35$\frac{\mu m}{\sqrt{cm}}$. Then throw random number of electrons (see figure 5.1) with Poisson distribution and mean value of 70 over each row and apply Gaus diffusion with sigma 200 μm that corresponds to 30 cm distance from track to registration module. These primary electrons are amplified by GEMProcessor then distributed over the pads (see figure 5.2) by ChargeDistributionProcessor, converted to pulses and so on to hits and track reconstruction.

There are two ways to calculate deviations: using residuals and using simple distances from hit to track. Residuals in contradistinction to simple distances are distances from hit to track fitted without this hit, so they are more objective.

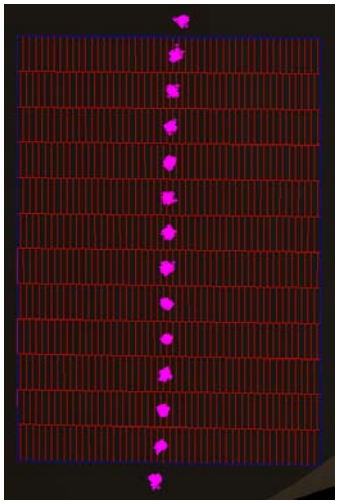

Figure 5.1: Initial positions of primary electrons.

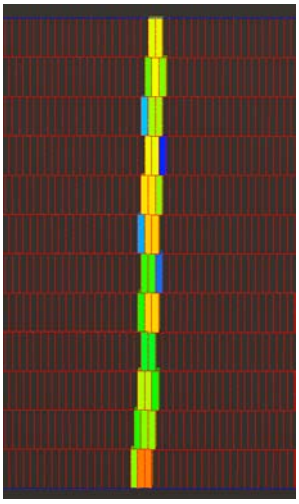

Figure 5.2: Pulses over the pads (200 μm diffusion).

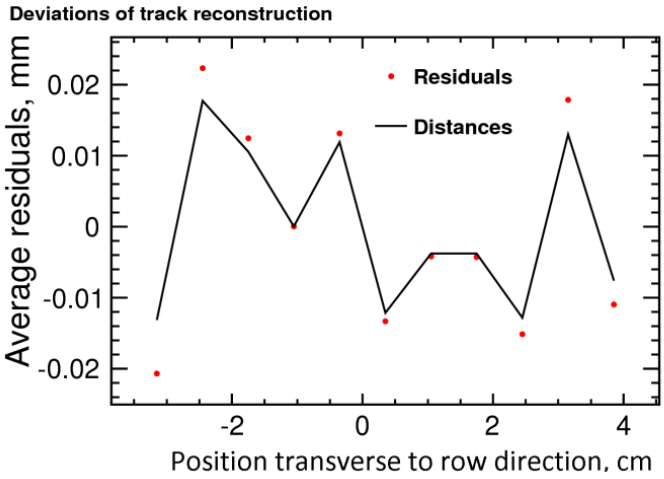

Figure 5.3: Mean deviations for 200 μm diffusion.

But we can see a kind of mess on figure 5.3 as residual deviations. It's because of not wide enough charge distribution over the pads and hits can't be reconstructed properly, track looks straighter. But on experiment registration system is always adjusted to be able to reconstruct tracks in whole active volume. Probably problem is in using of GEMProcessor optimized for TDR gas because T2K gas wasn't parameterized yet. We can manually increase diffusion to 500 μm, so now 3-4 pads per row are affected instead of 2-3 and correct shape appears (see figure 5.4). Final comparison experimental data and simulated data reconstructed with two algorithms is shown on figure 5.5. You see that after Marlin reconstruction deviations curve got the same "style" but still doesn't match experimental curve ideally.

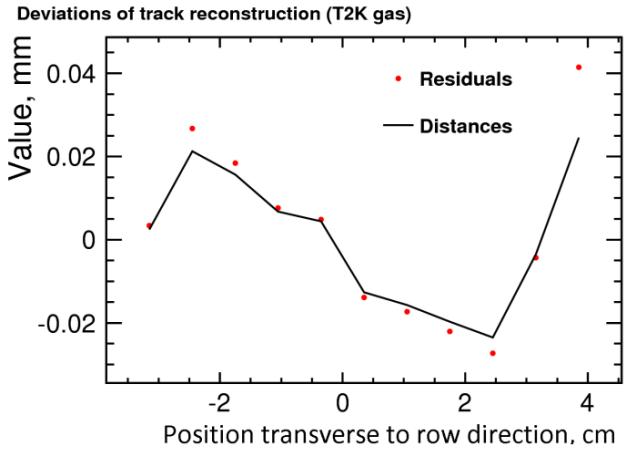

Figure 5.4: Mean deviations for 500 μm diffusion.

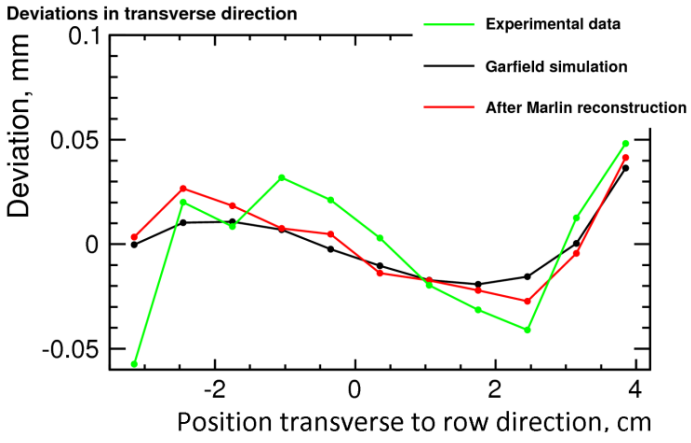

Figure 5.5: Final comparison of simulated and experimental data.

6. Summary

Physics of hits displacement is understood now at least on qualitative level. Simulation and experimental data are in good agreement with simple approach but in order to achieve better quantitative results further analysis should be done. There is a potential to improve result by using of updated GEMProcessor and more detailed field map. All chain from simulation to reconstruction was managed to be running and some new tools were developed which can facilitate certain procedures for colleagues.

7. Acknowledgements

I would like to thank DESY summer student program and guys from flc tpc group at DESY for this opportunity to get useful experience and have fun. I would specially like to thank my supervisors Klaus Zenker and Ralf Diener all their help and advices.

References

[1] International Linear Collider DBD. Chapter 4 ILD, 2012

[2] http://www-flc.desy.de/tpc/projects/medi_tpc/index.php

[3] http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/