Investigation of the charge transport in a GEM system within the MarlinTPC simulation framework

DESY Summer Student Program 2016 – Work report

Dmytro Dmytriiev

Taras Shevchenko National University of Kiev

ILC TPC Group

Supervised by Dr. Ties Behnke and Uli Einhaus

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Abstract

In this Summer Student Project charge transport in a GEM system within the MarlinTPC simulation framework has been investigated. The main idea of the investigation is to fix the simulation that gives us different results than the TPC prototype. DriftProcessor, GEMProcessor and ChargeDistributionProcessor were checked. We also made new processor for data acquiring which made our troubleshooting much more easily. Due to the geometry of TPC, we create NewChargeDistributionProcessor where we add two more GEM grids, because old processor have just one.

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1. Introduction

The ILC is a proposed linear particle accelerator. It is planned to have a collision energy of 500 GeV initially, with the possibility for a later upgrade to 1000 GeV (1 TeV). The ILC would collide electrons with positrons. It will be between 30 km and 50 km long, more than 10 times as long as the 50 GeV Stanford Linear Accelerator, the longest existing linear particle accelerator. The proposal is based on previous similar proposals from Europe, the U.S., and Japan. It is widely expected that effects of physics beyond that described in the current Standard Model will be detected by experiments at the proposed ILC. In addition, particles and interactions described by the Standard Model are expected to be discovered and measured. At the ILC physicists want to be able to:

- Measure the mass, spin, and interaction strengths of the Higgs boson.
- If existing, measure the number, size, and shape of any TeV-scale extra dimensions.
- Investigate the lightest supersymmetric particles, possible candidates for dark. matter

To achieve these goals, new generation particle detectors are necessary, and the new TPC is believed to become one.

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 high 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 4π-detectors (detectors that cover nearly the whole solid angle) at high-energy physics 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. A charged particle traversing the gas volume of the TPC will ionizes the atoms of the gas mixture (usually around 90% noble gas and 10% quencher gas) along its trajectory, see Figure 1. A high electric field is applied between the endplates of the chamber. The released electrons drift in this field towards the anode.

To be able to measure the position of the particle trajectory as accurately as possible, the electric field has to be very homogeneous. This can be achieved by a field cage, which usually consists of conducting rings around the cylinder. These rings divide the potential from the cathode stepwise down to the anode. Additionally, a high magnetic field parallel to the electric field is used to "bend" the trajectory of the particle on a spiral track due to the Lorentz force. This gives the possibility to calculate the momentum of the particle from the knowledge of the curvature and the B-field.

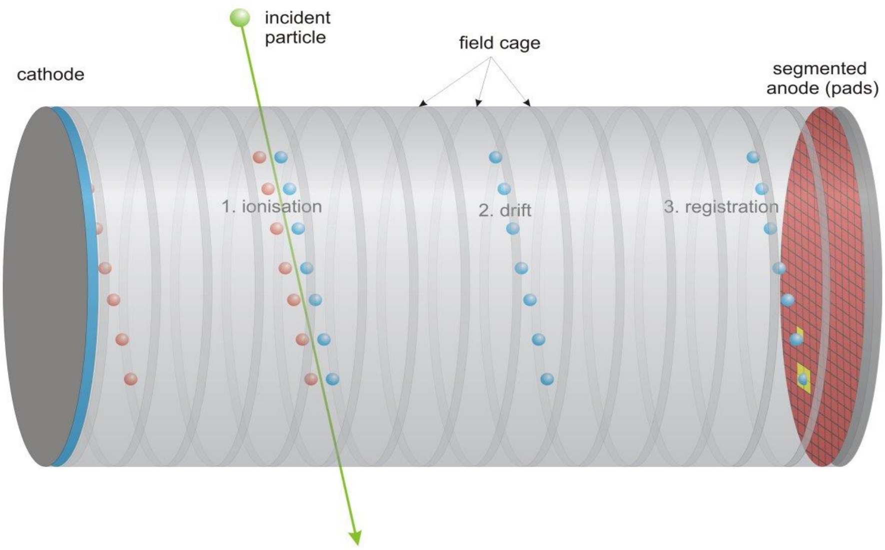

Figure 1. Working principle of the TPC

At the anode plane, the electrons can be detected on the readout plane that is segmented in the directions perpendicular to the drift direction, see point 3 in Figure 1. 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. Traditionally this has been done within 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 (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.

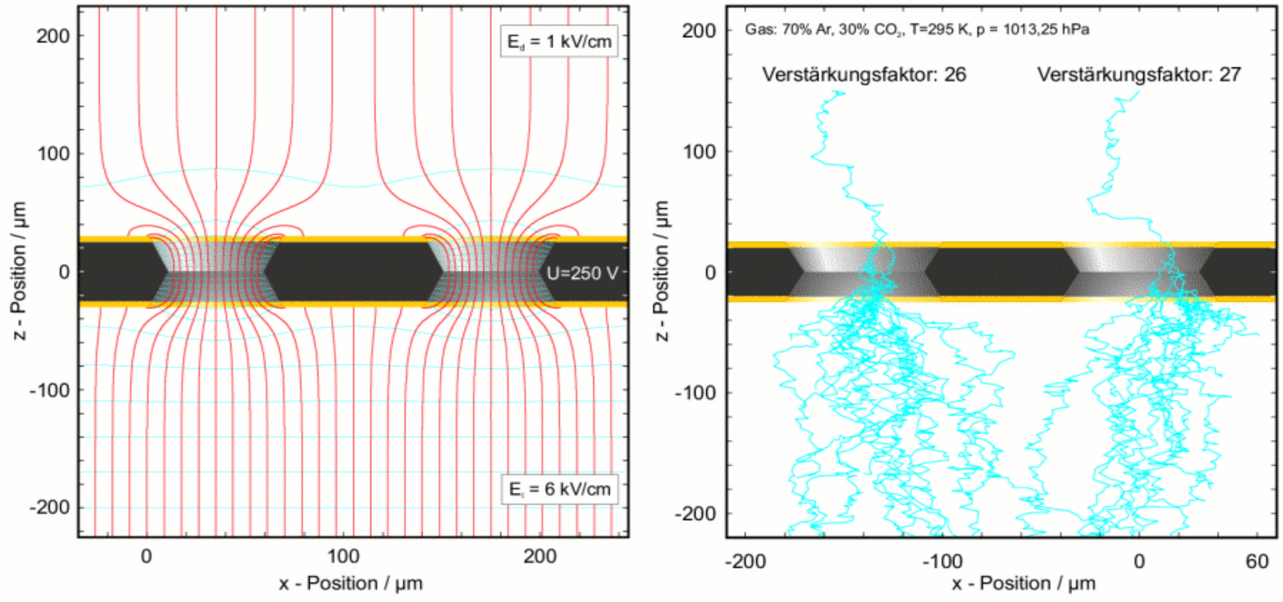

Figure 2 Amplification system of the TPC

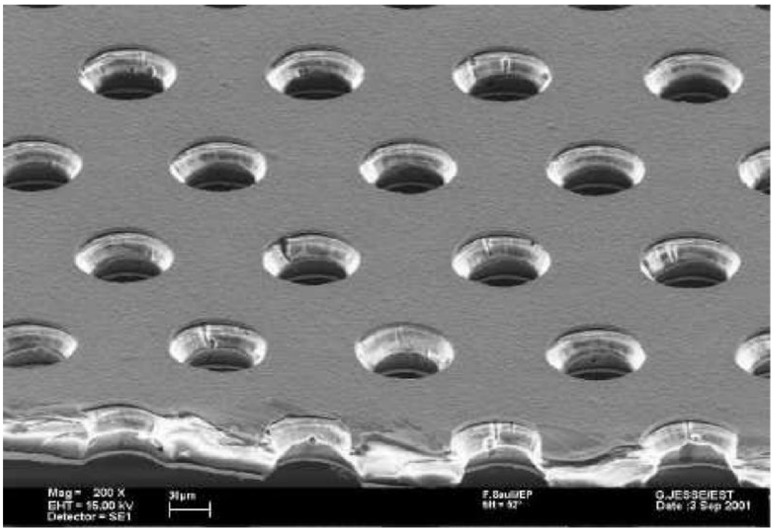

Figure 3 How does the amplifier looks

2.MarlinTPC framework description

The goal of this project is to get a highly modular simulation, digitisation, reconstruction and analysis framework for TPC R&D with standardised interfaces between its modules. This ensures that despite of the large diversity of readout structures, electronics, amplification system, etc. Much code can be shared among the groups and that different algorithms developed by different people or data taken by different groups can be easily compared.

The idea is that every computing task is implemented as a processor (module) that analyzes data in an LCEvent and creates additional output collections that are added to the event. The framework allows to define the processors (and their order) that are executed at runtime in a simple steering file. Via the steering file you can also define named parameters (string, float, int - single and arrays) for every processor as well as for the global scope. By using the framework users don't have to write any code that deals with the IO they simply write processors with defined callbacks, i.e. init(), processRunHeader(), processEvent(), end().

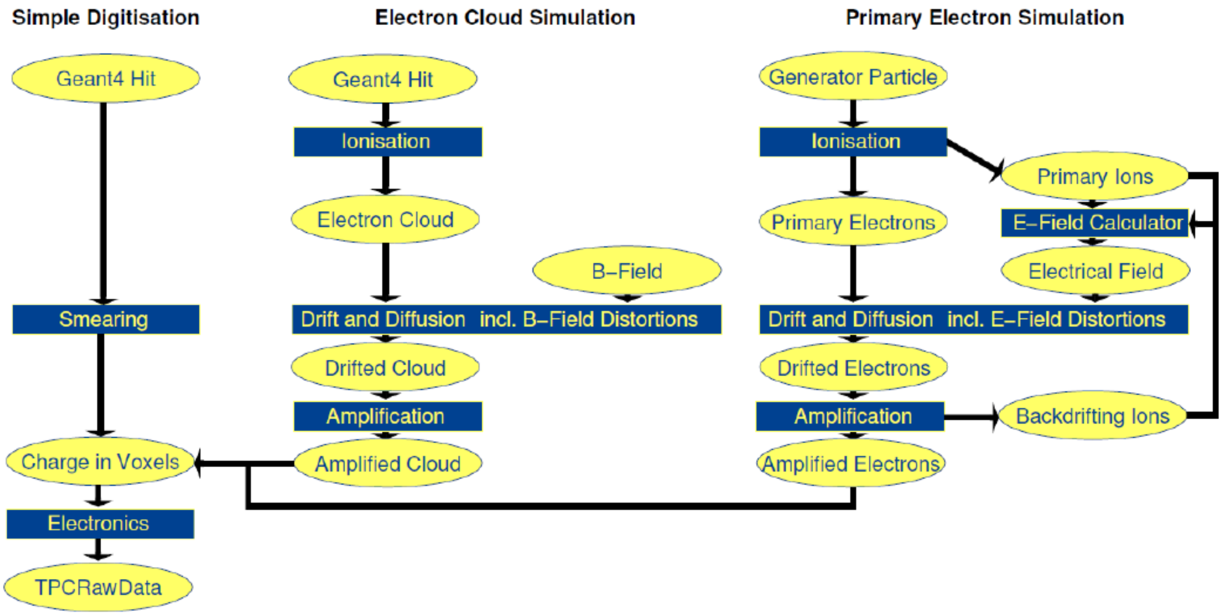

Figure 4 Different simulation approaches with different detail level

3.Problems and bugs

Simulation differs from experimental results from the TPC prototype → width of the charge cloud is smaller in the simulation than in data. So, we can`t use the simulation for calculations because it is incorrect.

ChargeDistributionprocessor has just one amplification grid, when our TPC has three of them. That`s why we should change existing processor or write our own with correct geometry.

For better troubleshooting and data acquiring we need processor which can take data after work of each processor and in working process.

4. Results and discussing

At first we create ElectronPositionCollectorProcessor, which can take data from any part of program. In comparison with “dumpevent” utility it gives us much more precise data.

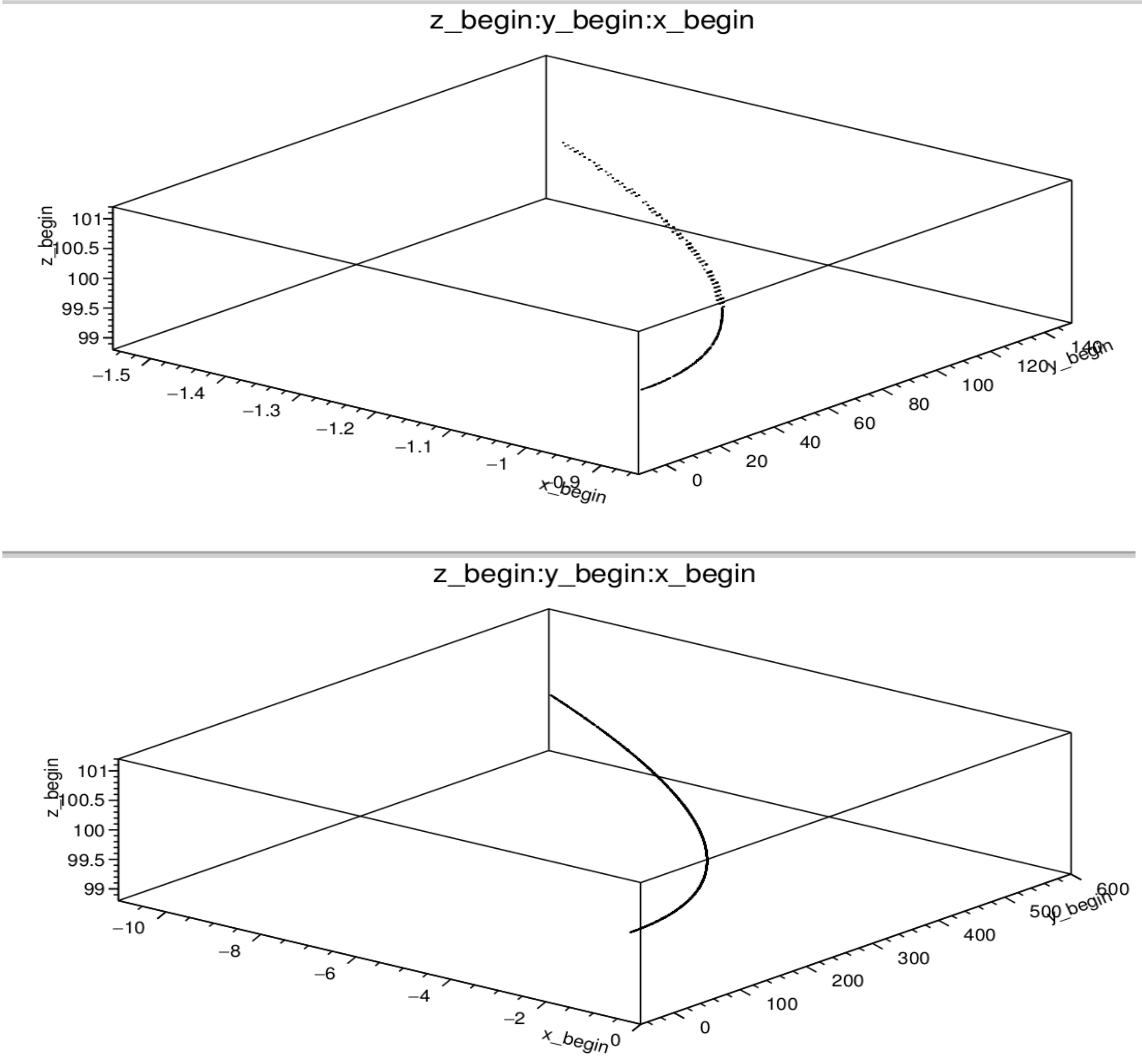

Figure 5 Results after “dumpevent” utility and the new processor

Then we checked the DriftProcessor. We put a transverse diffusion as a parameter and compared transversal diffusion that we obtained from the data using formula below with that parameter. Transverse diffusion was equal to **95.5704 µm/cm$^{1/2}$**.

$$D_T = \frac{RMS}{\sqrt{12}}$$

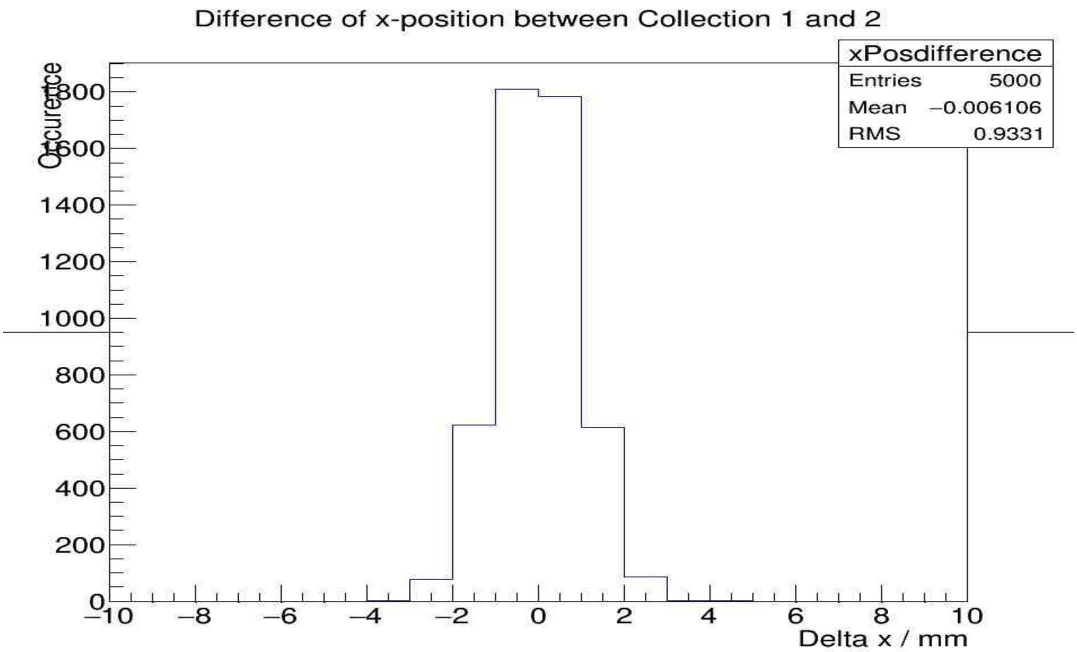

Figure 6 Difference of X-position between electrons before ionization and after the drift

In the table 1 one can see, that data and expectations are in agreement for different drift length. So, now we sure, that the DriftProcessor works as we expect.

Table 1. Comparison of diffusion constant for different drift lengths

Z (drift length) / cm	RMS(Δx / mm)	D_T / µm/cm$^{1/2}$
95	0.9313	95.5494
90	0.9065	95.5535
80	0.8547	95.5584
70	0.7995	95.5585
60	0.7402	95.5594
50	0.6757	95.5584
45	0.641	95.5546

After DriftProcessor we worked on the GEMProcessor. We obtained difference in positions between drifted electrons and amplified electrons. GEMProcessor gave us data what we expect and it is shown in Figure 7

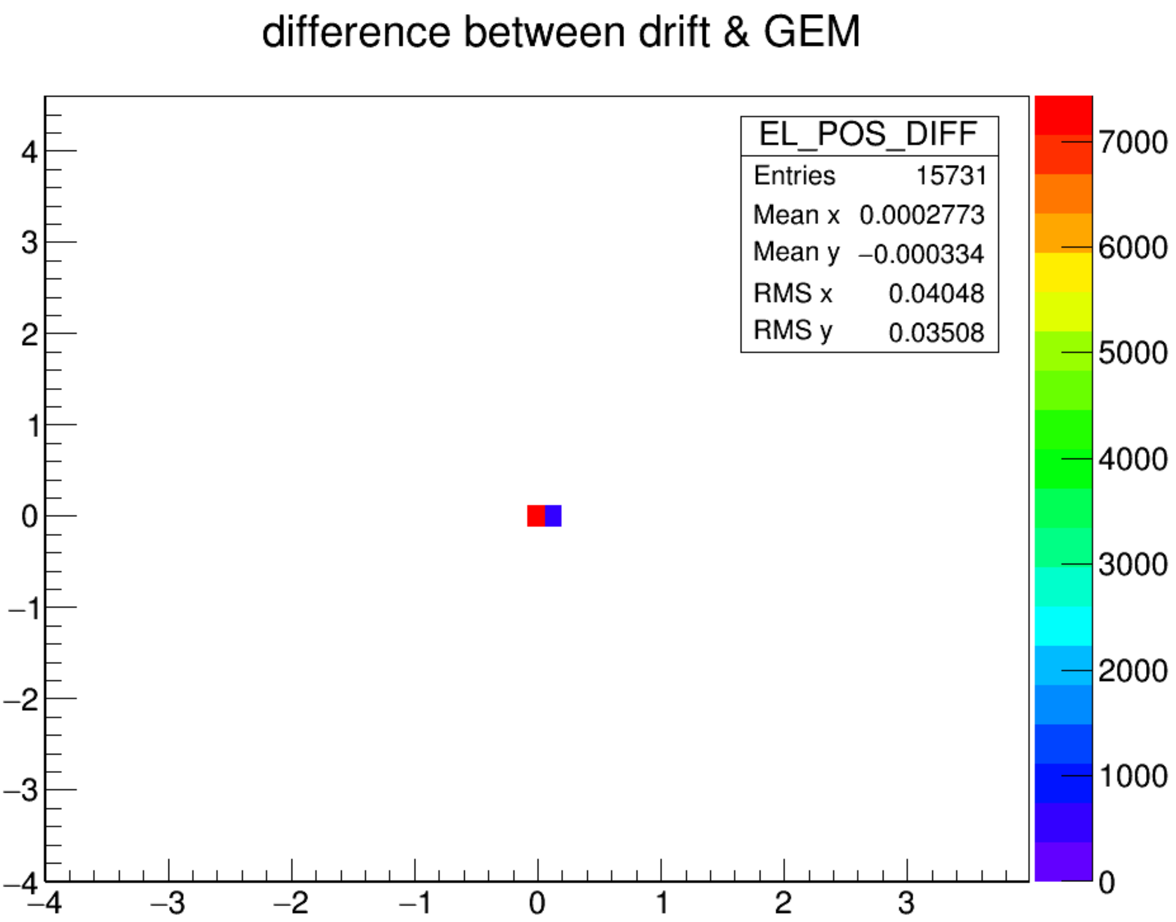

Figure 7 Difference between drifted and amplified electrons (all dimensions in mm)

Due to the structure of the GEM grids, we have binning effect. To take this into account we should choose right size of the bin to see real difference and charge distribution. As one can see on the Figure 8 the distance between centers of holes is 140µm in one direction and 121 µm in second. Direction, where the distance is 140 µm was named X, the second one was named Y. Point “0” - it is XY position of drifted electron.

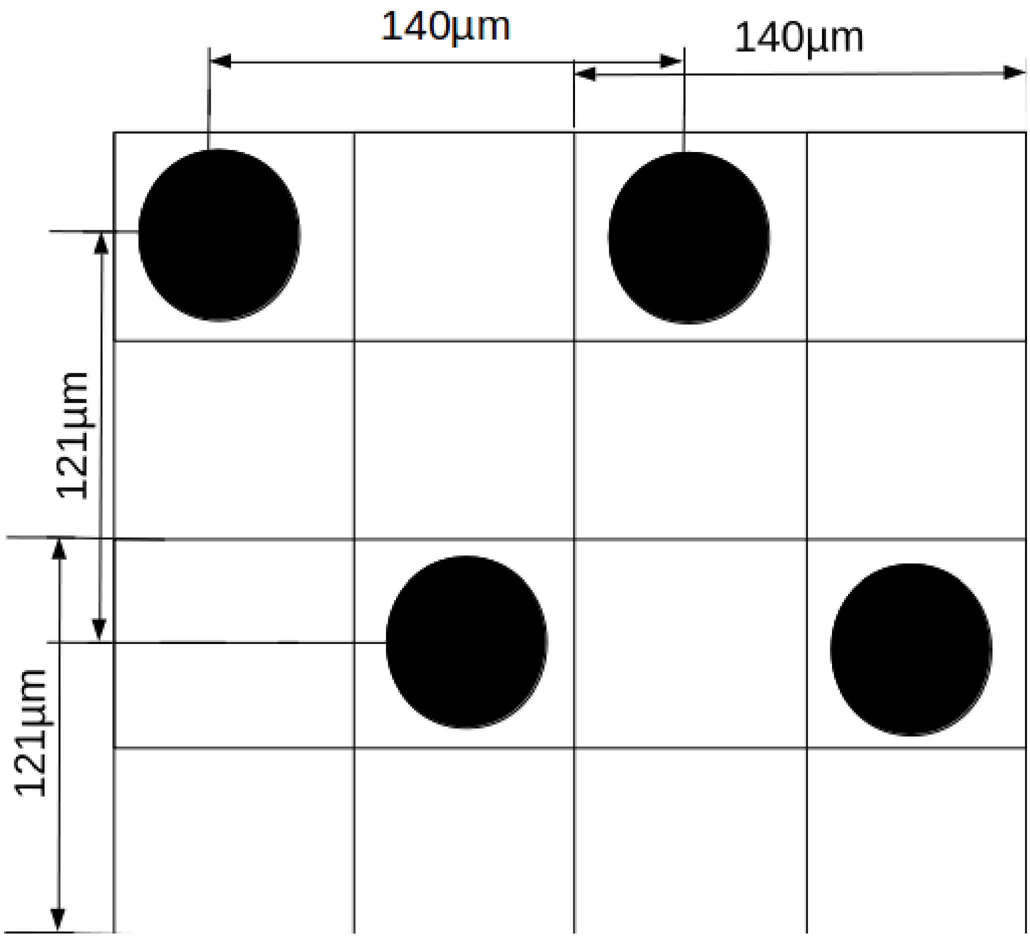

Figure 8 Scheme of the GEM structure

After the GEMProcessor we have the ChargeDistributionProcessor. Old version of this processor has just one GEM grid and distribute electrons once. But real TPC has three GEM grids, so we made NewChargeDistributionProcessor with two more grids. However, our new processor gives us less diffusion, than it must be from theoretical expectations and even smaller, than the diffusion from the old ChargeDistribution processor. Formula, which we put in the new processor, takes into account diffusion between grids, binning effect on the each grid and pad layout. Here it is:

$$f_3(x) = \sqrt{\left(dt_1^2 + \frac{dx_1^2}{12} + dt_2^2 + \frac{dx_2^2}{12} + d_I^2 + \frac{p^2}{12}\right)}$$

dt_n – transversal diffusion between n and n+1 grids

d_I – diffusion between last grid and anode

dx_n – bin size of n-grid in X-direction. For Y-direction we use the same formula, just with a smaller bin size.

p – bin size of pad layout (220 μm)

Results for different sizes of pad bin are shown in the Table 2. All dimensions are in μm.

Table 2. Results for different sizes of pad bin

Bin size of the GEM grids	140	220	300
1 grid theory diffusion	187.3	193.6	202.4
1 grid RMS	187.2	193.5	202.5
2 grids theory	264.9	273.8	286.2
2 grids RMS	249.9	271.2	285.1
3 grids theory	368.2	374.7	383.8
3 grids RMS	355.5	362.3	375.0
Old processor	367.7	374.2	383.3

Diffusion and charge distribution on the each grid are shown on the Figures 9-11. All sizes in mm, binning is 0.140 x 0.121 mm. Colour shows charge in bin in charges of electron.

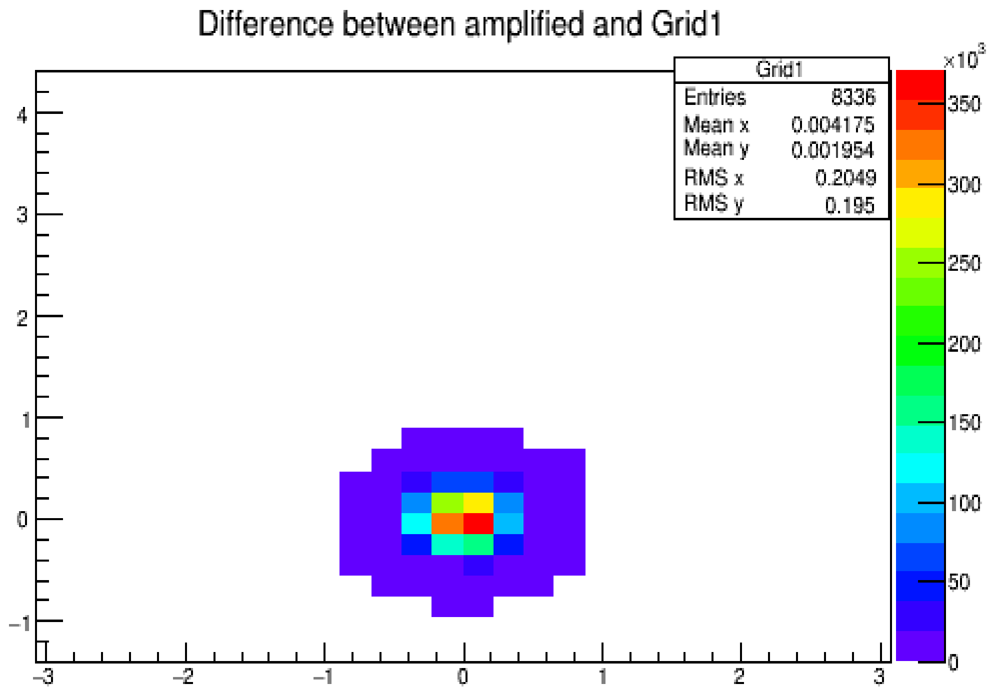

Figure 9. The charge distribution on the first GEM grid after amplification

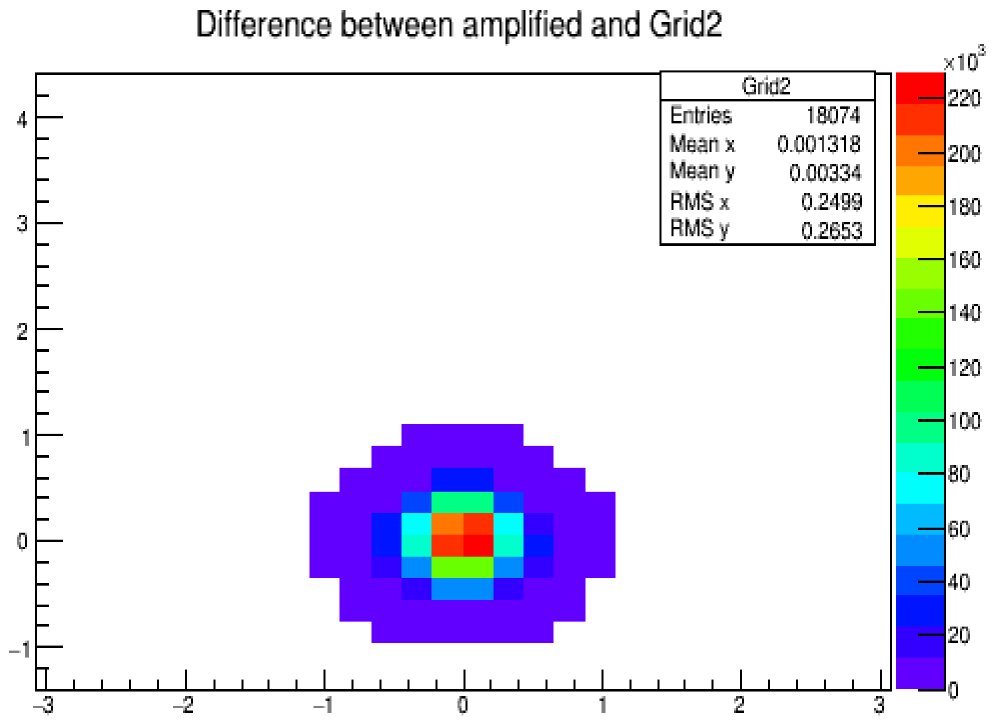

Figure 10. The charge distribution on the second GEM grid

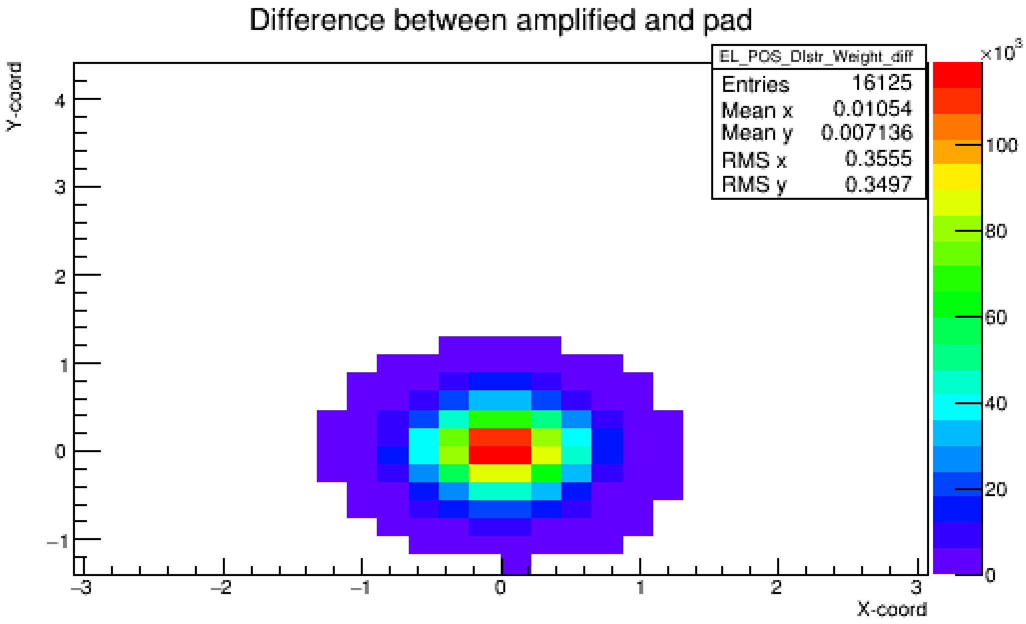

Figure 11. The charge distribution on the pad

Problem with the NewChargeDistributionProcessor happens due to the rounding. When the GEMProcessor finish its work we have O(1k) of electrons and the ChargeDistributionProcessor distribute them in a gaussian. When the hole situated in place where probability of catching electron is smaller, than 0,005 – the program rounds this number to a 0 and counts, that electrons will not reach this hole. But physically electron can be caught by this hole and amplified after this. When we have O(1k) of electrons (just after amplification by the GEMProcessor)– we can lose some of them and it is not important for us, but when we distributed electrons which were in the same hole on the previous GEM grid – we have just 20-30 electrons, and each of them is important. In this case rounding problem can decrease RMS. But to fix this problem we need much more time, than we had during the Summer School. The Figure 12 shows filling of the bins in according to the probability distribution.

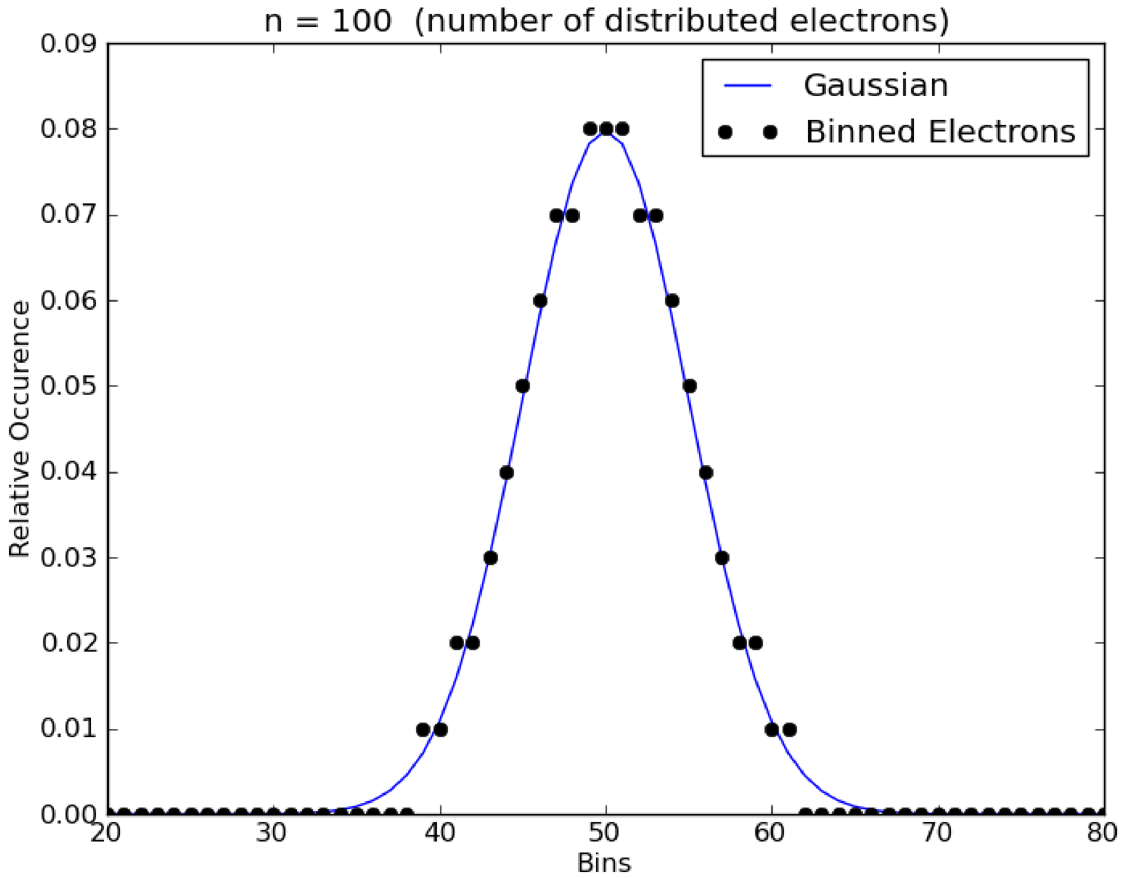

Figure 12 Probability distribution and filling of the bins

5. Summary

This summer student project investigates the charge transport in a GEM system within the MarlinTPC simulation framework. Three processors were checked and two of them (DriftProcessor, GEMProcessor) work as we expected. The ChargeDistributionProcessor had some mistakes, so we made NewChargeDistributionProcessor in which we took into account geometry of the amplification system of the TPC. In addition, ElectronPositionCollectorProcessor was developed because we needed in processor that can take data from any part of data processing. In general, we found one of problems that makes diffusion in the simulation smaller than diffusion in the data from the TPC prototype.

6. References

1. https://www.lctpc.org/
2. https://wiki-zeuthen.desy.de/MarlinTPC/
3. MarlinTPCIntro by Felix Muller