DESY Summer Student Program 2009

Work Report

Measurement and simulation of signals from a GEM detector

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Contents

Abstract

This work deals with simulation and measurement signals from a GEM TPC. First stage of work was simulation of experimental model in CST- Studio Program. Second stage was measurement signal and keeping data with developed scripts. Third was comparison of results and conclusion of performed work.

Introduction

The International Linear Collider (ILC) is an electron – positron collider with high precision, energy and luminosity which is designed to answer questions about what the universe is made of and provide exciting new insights into how it works. Time Projection Chamber (TPC) is a main particle tracking detector for the International Linear Collider. The TPC allows a three-dimensional reconstruction of trajectories of charged particles.

1. Working principle of a Time Projection Chamber

A Time Projection Chamber [1] is a charged particles detector. TPC consists of a gas-filled cylindrical chamber with a set of independent electrodes - pads. A high voltage potential applied to cathode (Fig. 1) and segmented anode at zero potential form electric field inside of the volume of a TPC.

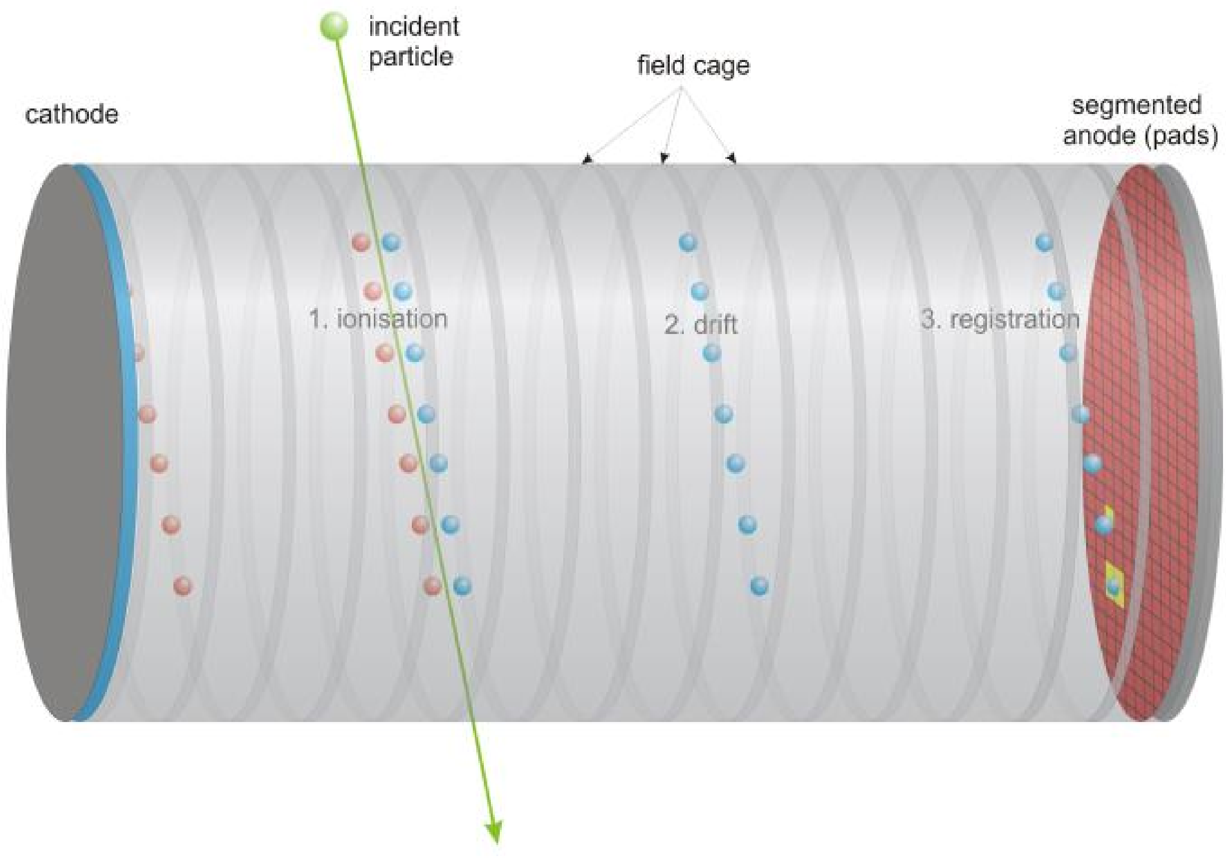

Figure 1: Working principle of a TPC

A charged particle passing the gas volume of the TPC ionizes neutral atoms of the gas, leaves a trail of electron-ions pair *(primary ionization)* along its track . By the force of electric filed ions and electrons drift toward cathode and anode respectively.

Therefore the electrons are projected onto the segmented anode, where two dimensional coordinate of a track segment is given by an individual pad. If time of appearance of an incident particle is known, one can measure drift time Δt of electrons from the track to the anode. With the known drift velocity of electrons in gas, can measure the drift path of electrons and therefore third coordinate of a track segment:

$$\Delta z = v_{drift} \Delta t$$

Because signals on anode are too weak to be readout, they should be multiplied.
On of the possible solutions: a GEM amplification system.

Gas Electron Multiplier

A Gas Electron Multiplier (GEM) [2] constructed of 50 micrometer thick kapton foil clad in copper foils (5 μm) on both side. By means of electro-chemical etching unified sets of 55-70 micrometer through-holes are perforated (Fig. 2) A potential of the order of 300 V is placed across the two electrodes, producing high electric fields inside the holes.

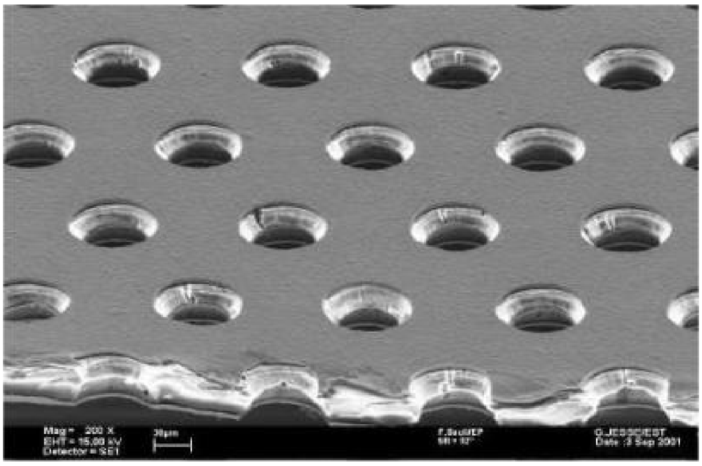

Figure 2: Micro-photograph of a Gas Electron Multiplier

Under these conditions, in the presence of appropriate gases, electrons entering any hole will cause avalanche multiplication of number of electrons. Typical multiplication factor (also called *gas gain factor*) is of the order of 50.

In order to achieve higher gas gain factors one can increase potential on the GEM up to certain limit. Another possibility is to stack one or more GEM foils. Often triple GEM system (GEM detector) is used (Fig .3).

The major advantage of the GEM detector is the separation of gas amplification and readout stage. This separation results in a fast readout signal (only electrons are collected by the readout structure). After amplification electrons moving in the induction gap of a GEM system will induce signal on the pads, which can be recorded by the readout electronics.

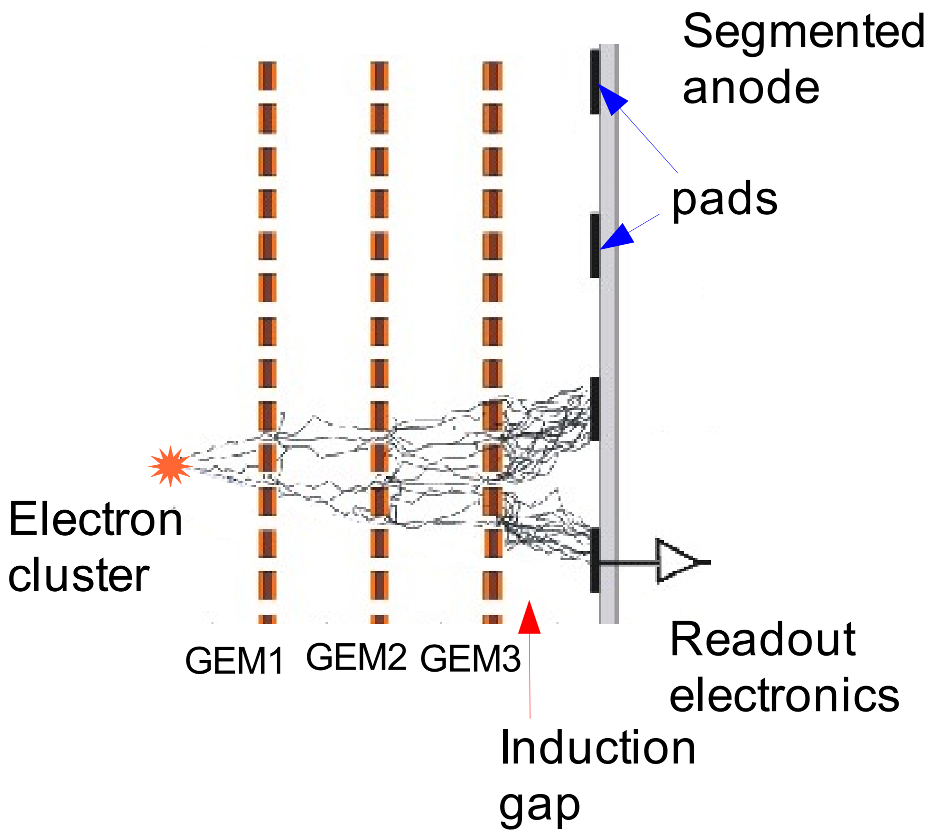

Figure 3: Triple GEM detector

2. Signal Formation and Ramo's Theorem

The motion of electrical charges induces current in corresponding pads which are readout by a separate set of amplifiers.

Induced current of an electrode is calculated by using *Ramo's theorem:*

Current i flows into a particular electrode under the influence of charge q moving with velocity $\vec{v}$.

$\vec{E}_w$ is the weighting field defined by rising this electrode to unit potential and grounding all others, in the absence of the charge.

The weighting field shows the electrostatic coupling of a charge to the specified electrode.

Only in the case of two electrodes configuration, like a cylindrical drift chamber, the shape of the weighting field will coincide with the shape of electric field. In case of many electrode system like pads on the pad-plane, the weighting field will have a sophisticated shape (Fig. 4).

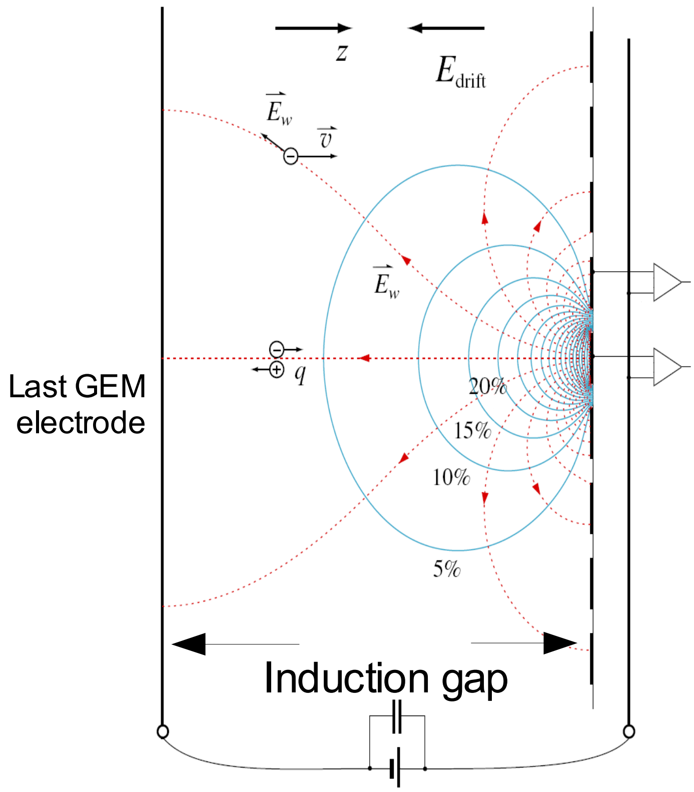

Figure 4: Induction gap of a GEM detector

3. Signal simulation with *CST Studio*

In general case calculation of electric field for arbitrary electrode shapes can be done with the *Finite Elements Method*. Technically it is carried out in *CST-Studio Program*.

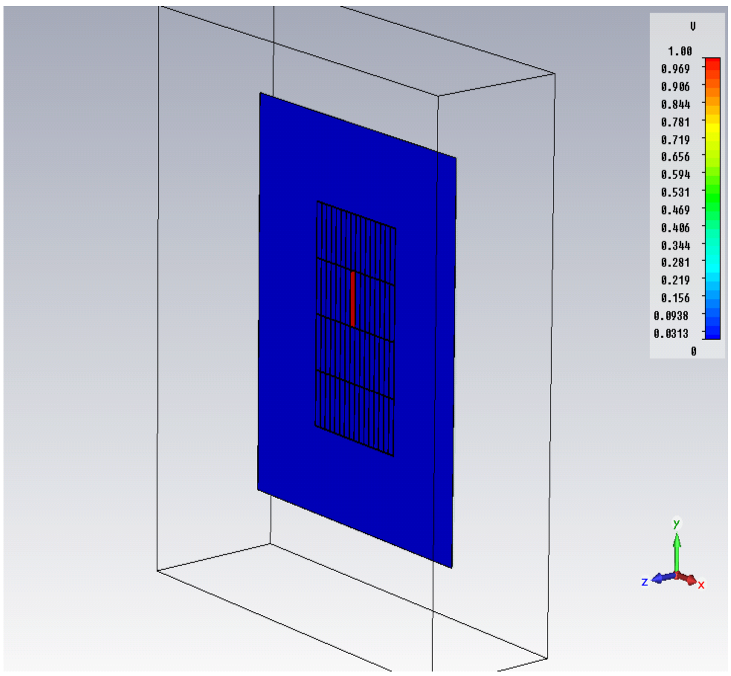

Figure 5: Definition of weighting Field in CST studio Program.

Determination of a weighting field for a pad plane is presented on Fig. 5. Here pads have size of 14 mm * 2.5 mm. These geometrical sizes correspond to parameters of real detector, which will be described later. The pad of interest has potential of 1 volt, all others are at zero potential.

Calculation of weighting field was performed with the *CST - Studio*

Electrostatic Solver. The result of calculation is shown on Fig. 6. Here equipotential lines of the weighting field are shown on the YZ-plane. The highest potential, by definition, is on the pad of interest,

If one assumes no diffusion, a single electron would drift strictly along the z-axis toward the pads. Assume constant drift velocity of the electron in the induction gap.

This makes calculation of the signal shape easier:

$$i = -q(E_w)_z v_z$$

Then, the shape of the signal will be given by the shape of the z component of the weighting field. The strength of the weighting field was taken at the center of the pad of interest, Fig. 7. At other places on the pad, shape of the weighting field will be different, and so the shape of the

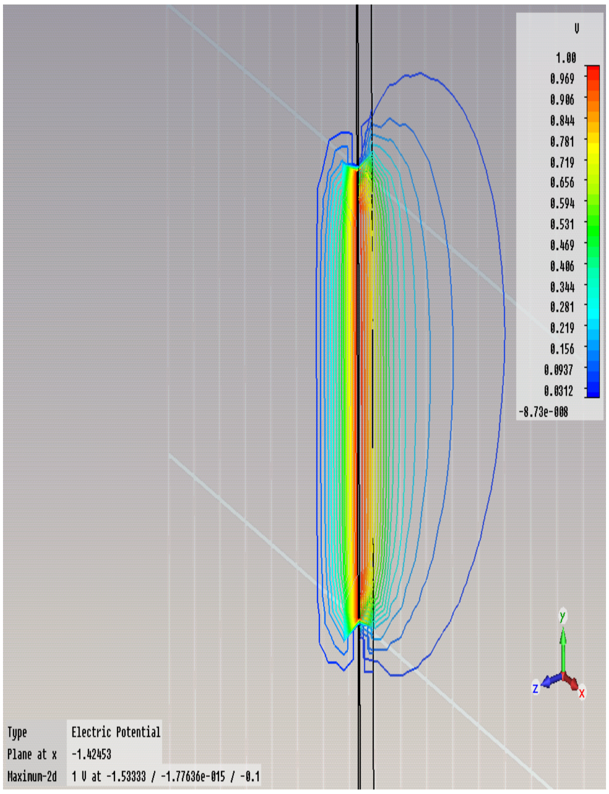

Figure 6: Equipotential lines of the weighting field shown on YZ-plane.

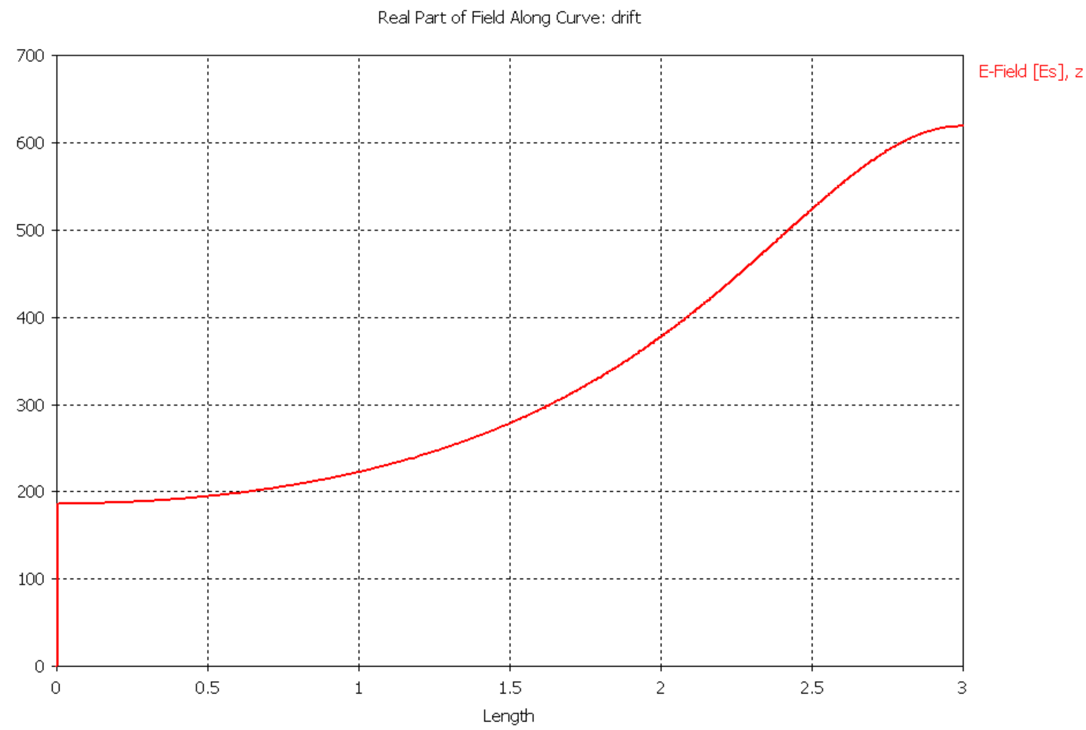

Figure 7: Strength of the z-component of the Weighting Field

induced signal. The shape of the signal, namely timing features, is helpful in the optimization of timing performance of the readout electronics.

4. Signals from a GEM detector

The experimental setup (Fig. 8) consist of a *UNIMOCS* detector with a triple GEM setup (applied voltage is 290 V); γ-source Fe^{55}. The pad plane has pads of the same size as was used in simulation: 14 mm * 2.5 mm. Signals from a pad were amplified with "HERMES" amplifier and digitized with a digital oscilloscope Tektronix TDS 3054B.

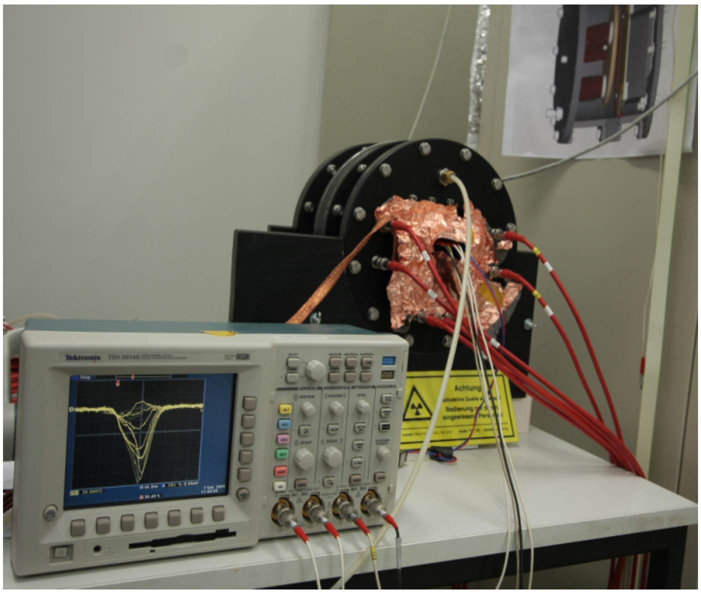

Figure 8: The experimental setup

A shell script "*Script_for_data_acquisition.sh*" (Appendix 1) was written to communicate with the oscilloscope. This script set the oscilloscope up, acquires and writes data to an ASCII file. The script runs on a Linux PC.

In order to display collected data a ROOT script "*show_waveforms.C*" was written (Appendix 2). One can easily check recorded signals visually. Another advantage is that for ROOT can be used for analysis of data.

5. Comparison of simulation and measurement

In framework of this project first attempt to analyze measurement and simulation data was made.
An example of measured signal from a triple GEM setup is shown in red on Fig. 9.
The pulse duration is ~150 ns. The signal from simulation (in blue on Fig. 9) was inverted and scaled. The scaling included matching of amplitude peaks for both measured and simulated signals, as well as zero levels.
The induction of signal takes time Δt:

$$\Delta t = \frac{\Delta z_{ind.\,gap}}{v_{drift}}$$

With the thickness of the induction gap of 3 mm and drift velocity of 2.9 cm/μs, one obtains total time of about 100 ns.
Taking this into account, the simulated signal was scaled in time as well.

The signals do not match perfectly, but still in a good agreement. The mismatch is due to assumptions in the simulation and features of the experimental setup, which were not taking into account:

1. Only single electron was considered, not a real charged cluster
2. Fixed position (x,y) of the drift path
3. No diffusion of an electron
4. Uncollimated γ-source.
5. Finite response time of the amplifier.

It is not clear, however, whether those limitation, in combination, can explain the fact, that the amplitude of the simulated signals starts at the level of about 1/3 of the maximum.

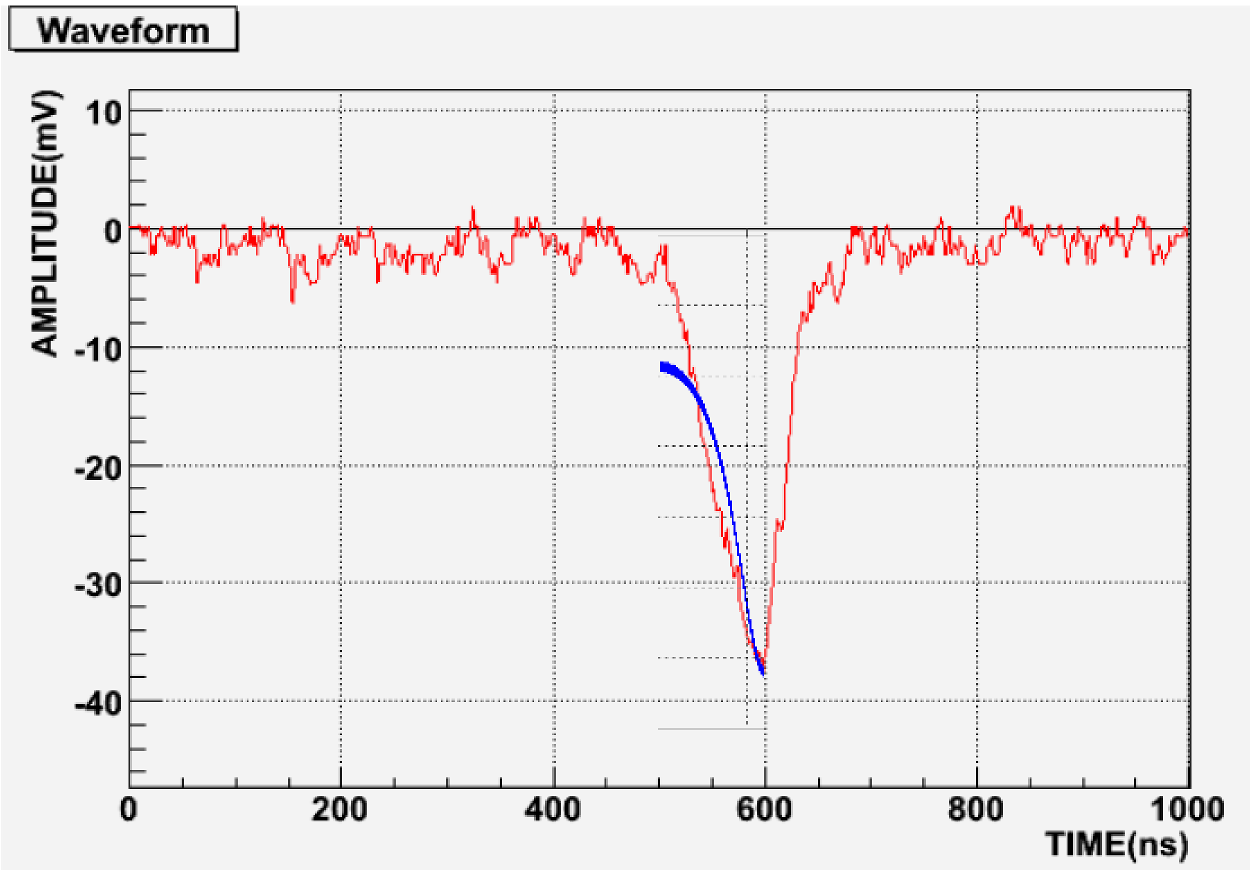

Figure 9: Red - measured signal; blue – scaled and inverted signal from simulation.

6. Summary

In term of this work signal induction mechanism was studied. Signals were simulated using several assumptions with the help of CST-Studio Program and measured with a triple GEM setup. First attempt to compare signals was performed and results are in good agreement.

Further steps could include development of detailed simulation and dedicated experimental setup.

Development of a GEM signal model can help not only in optimization of readout electronics, but also in improvement of overall TPC performance.

Acknowledgments

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And also Vadim Kantserov, who helped organize such possibility.

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