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TPC Simulation

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A framework to simulate the specific properties of a TPC is presented. The simulation includes primary ionisation, drifting in gases and amplification in a triple GEM structure. First results and a comparison with measurements are shown.

1. GOAL

The goal of this simulation framework is to obtain a better understanding of the influence of electric and magnetic fields on the charge transfer in a TPC. This includes studies on the effect of ion backdrift with a triple GEM structure and finding optimised settings for a TPC at the Linear Collider. Tuning the parameters of the detector, like pad geometry or GEM setting for energy and momentum resolution is another tasks. The simulation should be straight forward, fast and therefore independent of big simulation packages.

2. METHODS

To allow flexibility and minimize data overhead, the simulation is divided into three modules which follow the actual events in a TPC:

2.1. Primary Ionisation

The program HEED [1] is used to obtain information about the process of primary ionisiation. For the simulation one needs to know the number of clusters on a certain length of the track and the number of electrons in each individual cluster. Figure 1 shows the corresponding distributions. HEED is not used in the simulation itself because it neither includes magnetic fields nor a three-dimensional processing of the track. Instead, the cluster distribution is parametrised and the electron probability is written to a file which is directly used in the simulation. From the parametrisation of the number of clusters per cm the distance to the next cluster is calculated using the assumption that it is exponentially distributed. The number of electrons in the cluster is randomly chosen according to its probability distribution. Repeating this procedure, the simulation deposits the electrons along the track of the primary particle. Using this method, magnetic fields can be simulated by placing the primary electrons along a helix. Currently the simulation does not include the spatial propagation of δ-electrons. The energy loss due to the ionisation is accounted for. Figure 2 shows the primary electrons of an event generated with PYTHIA and simulated for a magnetic field of 4T.

2.2. Drifting of Electrons

To drift the produced electrons through the gas volume, information about the gas properties like drift velocity, longitudinal and transverse diffusion is needed. It is obtained by using the program MAGBOLTZ [2]. The gas properties are then parametrised and this parametrisation is used in the simulation. The left plot in figure 3 shows this for the drift velocity. Using this quantity, the time coordinate of the drifted electron can be calculated using a gaussian distribution with the longitudinal diffusion as width. Accordingly, a gaussian distribution with the transverse

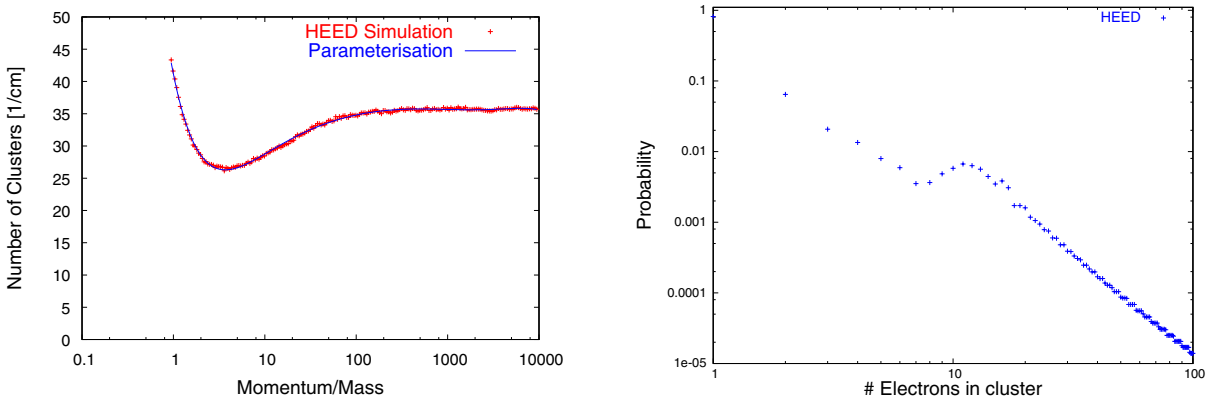

Figure 1: Information about primary ionisation obtained from HEED

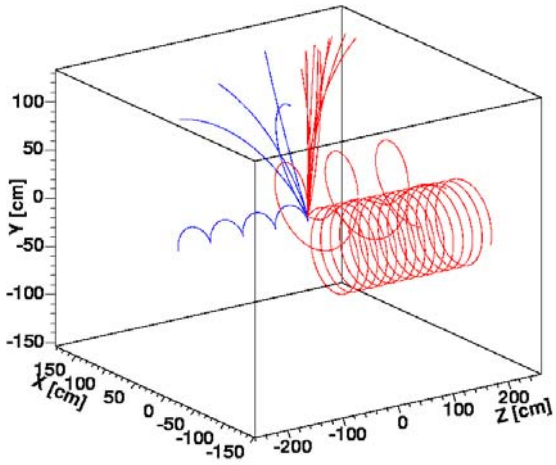

Figure 2: Primary ionisation for a pythia event.

diffusion as width is used to determine the position of the drifted electron in the xy plane. The right plot of figure 3 shows the primary electrons after drift and diffusion compared to their position neglecting diffusion.

2.3. Amplification with GEMs

The electrons are drifted to the amplification structure which consists of three Gas Electron Multipliers (GEMs [3]). A GEM is a 50 μm thin kapton foil coated with 5 μm copper on both sides. Holes with a diameter of 70 μm and a pitch of 140 μm are etched into the foil. By applying a voltage across the GEM a high electric field is created inside the holes where gas amplification is possible.

The charge transfer through such a structure has been studied by our group in detail [4]. There are three important parameters: The *collection efficiency* describes how many electrons are collected into the GEM holes, the *gain* gives the number of electrons produced in a GEM and the *extraction efficiency* determines how many electrons can be extracted from the GEM. These charge transfer coefficients depend on the fields and voltages applied and have been measured and parametrised. This knowledge is used as input for the simulation.

The charge broadening in the GEM structure is caused by diffusion in the gaps between the GEMs and not due to an effect originating from amplification in the GEMs. This result was obtained by a measurement of the charge width in dependence on the magnetic field [5]. The charge width was found to be in agreement with diffusion values

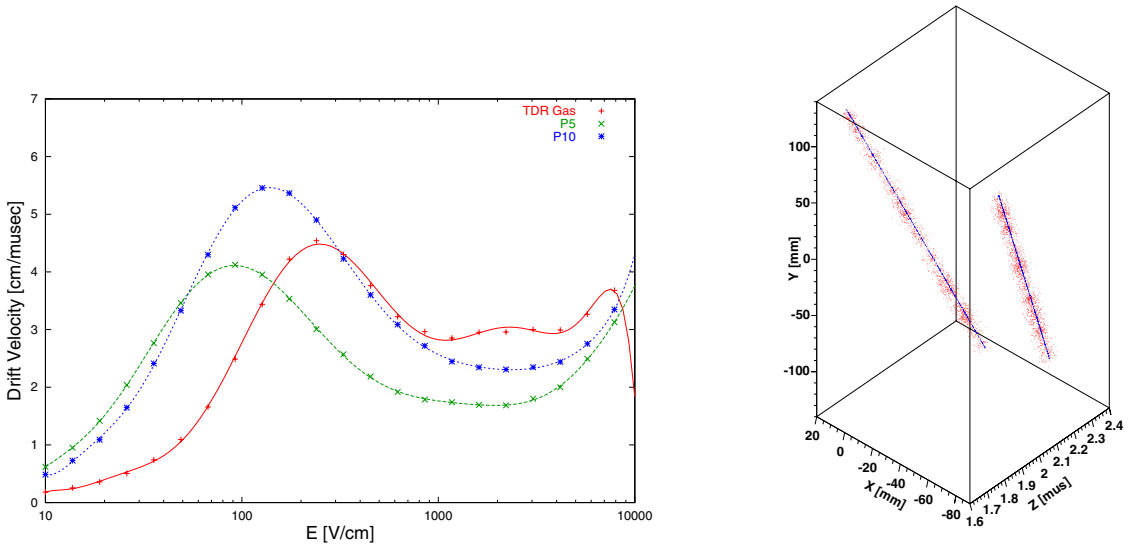

Figure 3: Parametrisation of drift velocity and drifted muon tracks

simulated with MAGBOLTZ.

In the simulation, each electron that drifted to the first GEM is transfered through the structure according to the charge transfer coefficients. The parametrisation of the coefficients is combined with binomial statistics. This statistical consideration is necessary because the parametrisation applies to charge currents. A single electron, however, has a certain probability to be collected into a GEM hole. The secondary electrons produced in the amplification process are assumed to be distributed on the pad plane according to a two dimensional gaussian. Its width is given by the diffusion between the GEMs. The gaussian is integrated for each pad within a four sigma radius. This gives the charge for each channel in a certain timeslice which corresponds to the information a TPC would measure.

The left plot in figure 4 shows a projection of two muon tracks onto the pad plane with a pad size of 2.4x6.4 mm^2 at 0 T whereas the right plot shows the time projection of a PYTHIA generated event at 4 T with a particle curling through the chamber. The effect of the longitudinal diffusion is clearly visible, resulting in a broader distribution of the charge in time for longer drift times. The color scale corresponds to the number of electrons collected in each volume element (voxel) shown in the projection.

2.4. Inputs for the Simulation

This simulation framework has several input parameters which can be controlled by the graphical user interface shown in figure 5. For example, the first module needs the radius and length of the TPC as well as the magnetic field. For drifting the electrons one has to choose the gas mixture and the drift field. For the amplification a few more parameters are needed. The user can choose the readout frequency, pad size, a cut for the sensitvity of the electronics and the electric fields and voltages for the GEM setting. This allows systematic studies of their influence on the charge deposition, resolution and many other important properties of such a detector. Because of the very detailed simulation of the GEM structure, one can even study the influence of the GEM setting on energy and spatial resolution.

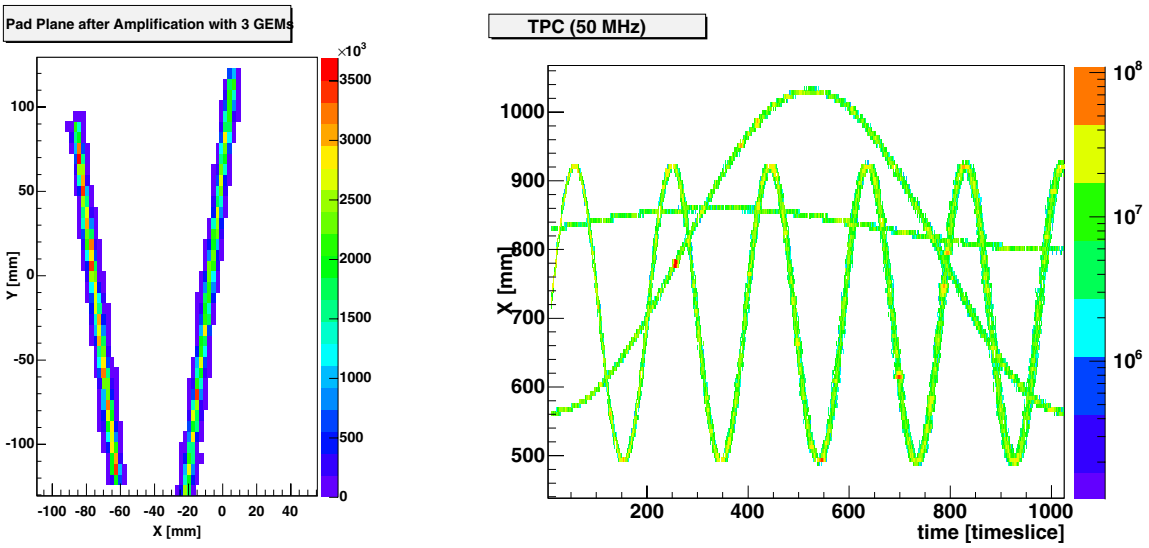

Figure 4: Pad plane with muon tracks and time plane with pythia event.

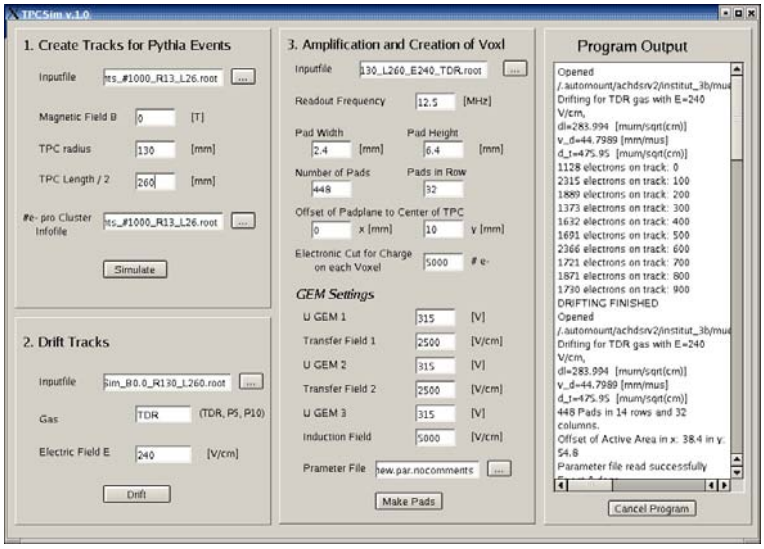

Figure 5: User interface for the TPC simulation.

3. RESULTS

The first step is to compare the results from the simulation to the measurement. For this purpose, simulated and measured data are analysed with the same software applying the same cuts and algorithms. This has been done for the drift velocity shown in the left plot of figure 6. The values marked as crosses ("x") are obtained directly with MAGBOLTZ, the plusses ("+") are the results from the simulation and the star ("∗") correspond to the measured drift velocity. Good agreement is observed. The right plot of figure 6 shows the same comparison for the transverse diffusion. The values resulting from the simulation are slightly below the predicted values from MAGBOLTZ. The measured value, however, is far smaller than the simulated ones. The cause of this effect is under investigation.

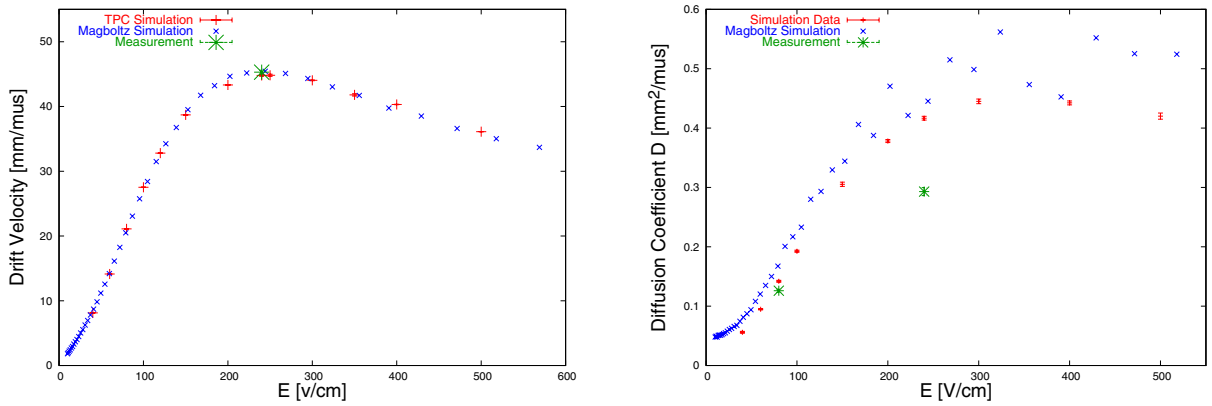

Figure 6: Comparison between measurement and simulation for drift velocity and diffusion.

4. CONCLUSION

A simulation framework has been developed to create, drift and amplify primary electrons. The variation of the input parameters allows for systematic studies. Currently the simulation does not include the spatial propagation of δ-electrons. The implementation of electronic shaping is planed.
As soon as the simulation has been compared in detail with corresponding measurements, systematic studies of the TPC parameters will be done.
The implementation of the new data format LCIO [6] in the software is in progress.

References

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