Prototype Development and Simulation Studies for a GEM Based TPC

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We report on the development of a large time projection chamber (TPC) for the $e^+ e^-$ International Linear Collider. Our studies concentrate on the use of Gas Electron Multiplier (GEM [1]) foils for the gas amplification in the TPC. A TPC prototype has been designed and constructed for operation in a 5 T magnet at DESY Hamburg and for test beam measurements. To obtain an independent reference measurement of the particle tracks, a hodoscope made up of silicon strip sensors has been integrated into the test stand. To study the single and double track resolution in the z-coordinate (time coordinate), new fast readout electronics is under development. To gain a better understanding of the influence of the GEM structure and the readout geometry on the spatial resolution, a modular simulation of a TPC has been developed.

1. THE TPC PROTOTYPE

1.1. Design of the Field Cage

The prototype has been designed to fit into a 5 T magnet with a bore of 28 cm in diameter located at DESY Hamburg. It has a drift length of 26 cm. By minimizing the material budget of the field cage, 1% of a radiation length has been achieved. The design goal stated in the TESLA TDR [2] of 3% of a radiation length for the ILC TPC seems achievable with a similar design. On the left side of figure 1 the prototype is shown. Inside the field cage, the first layer of the amplification structure consisting of three quadratic GEMs can be seen. A shield at the level of the upper GEM prevents field inhomogeneities at the edges of the GEM stack.

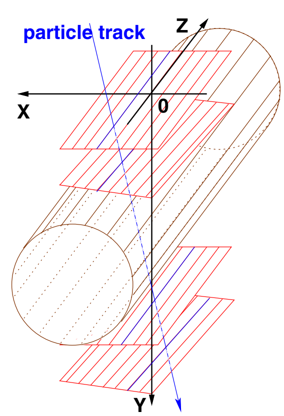

Figure 1: TPC prototype (left) and setup of the hodoscope (right)

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1.2. Electronics

To take full advantage of the fast electron signals of a GEM amplification structure, new electronics is being developed. As a first step the Preshape 32 [3] has been chosen as a preamplifier. It is an integrated, charge sensitive amplifier/shaper with 32 channels and a nominal peaking time of 45 ns. This preamplifier is currently in use together with 12.5 MHz, 8 bits ALEPH ADCs. The next step in the electronics development will be the choice of a new ADC. The minimum requirements are 10 bits resolution and a sampling rate of 40 MHz. Several prototypes are being tested to determine the best system.

2. OPERATION OF THE TPC IN A HODOSCOPE

The hodoscope allows an independent measurement of the particle track and therefore the study of the TPC properties. Four silicon strip modules are used to obtain two independent reference points of the particle track. Two silicon strip modules are placed below and two above the TPC (right side of figure 1). Each pair of modules is arranged with a stereo angle of 5 degrees to allow a two dimensional measurement. Each module consists of two 500 μm thick sensors with 768 strips at a pitch of 122 μm. The hodoscope achieves a resolution of 58 μm in x.

The left plot of figure 2 shows the single point resolution of the TPC in x, given by the distance of a reconstructed point in the TPC to the corresponding track measured with the hodoscope.

3. SIMULATION STUDIES

The goal of this simulation framework is to obtain a better understanding of the influence of electric and magnetic fields on the performance of a GEM TPC. To allow flexibility and minimize data overhead, the simulation is divided into four modules corresponding to the actual processes in a TPC:

1. **Primary Ionization:** The program HEED [4] is used to obtain information about the process of primary ionisiation, but is not used in the simulation itself. The simulation randomly calculates the distance to the next cluster and deposits electrons on the track according to the results attained from HEED. Without magnetic field the electrons are placed along a straight line, while with magnetic field a helix is used. Currently the simulation does not include multiple scattering and the spatial propagation of δ-electrons.

2. **Drifting of Electrons:** Gas properties obtained using MAGBOLTZ [5] are parameterized and this parameterization is used in the simulation. The drift time is calculated from the z position of the primary electron, the drift velocity and a Gaussian distribution with the longitudinal diffusion as width. Accordingly, a Gaussian distribution with the transverse diffusion as width is used to determine the position of the drifted electron in the xy plane.

3. **Amplification in a GEM Structure:** The amplification structure consists of three GEM foils. The charge transfer through such a structure has been measured and parameterized by our group [6]. This parameterization, combined with binomial statistics, is used as input for the simulation. The consideration of statistics is necessary because the parameterization applies to charge currents. A single electron, however, has a certain probability to be e. g. collected into a GEM hole.
   Additional measurements show that the charge broadening in the GEM structure is mainly caused by diffusion in the gaps between the GEMs [7]. Therefore the parameterization of the diffusion coefficients obtained from MAGBOLTZ can be used again to calculate this effect.

4. **Shaping and Digitization:** To take into account the shaping of the electronics, a Gaussian smearing is applied. The width of the Gaussian is calculated from the shaping constant of the electronics and the time distribution caused by the diffusion of the electrons in the pulse. The center of the Gaussian corresponds to

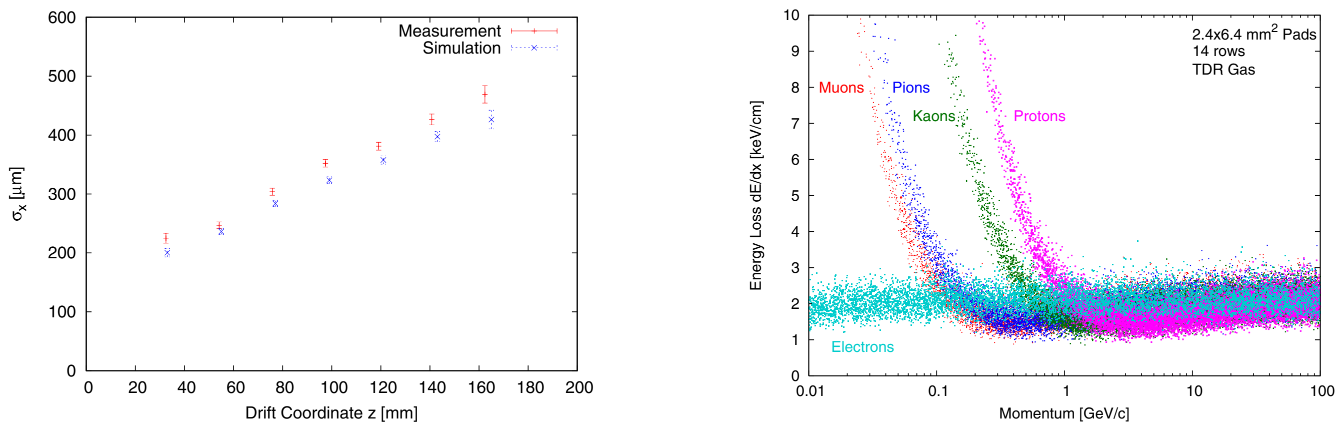

Figure 2: Spatial resolution of the TPC (left) and simulated specific energy loss (right)

the center of gravity of the electrons, its area to the number of electrons. This Gaussian is then sampled by integrating over each time bin and the charge in the bins is mapped to the ADC range.

3.1. Simulation Results

The left plot of figure 2 shows the comparison of the single point resolution in x direction between measurement and simulation. The resolution of the simulation is slightly better due to the fact that it does not include multiple scattering and spatial separation of δ-electrons from the track. However, the agreement between measurement and simulation is good, and both curves show the same degradation of the resolution due to diffusion.

Muons, pions, kaons, protons and electrons have been simulated in a momentum range from 0.01 to 100 GeV. The simulation was performed without magnetic field and for a TPC with a pad size of 2.4×6.4 mm^2 and a pad plane with 14 rows of 32 pads each. This corresponds to the pad plane used in our prototype TPC. After this the tracks have been reconstructed and dE/dx has been calculated (right plot in fig. 2). The specific energy loss is reproduced very well. Even for the small readout area in a TPC prototype the dE/dx resolution is 14% for the muons.

4. CONCLUSION

A prototype TPC has been developed and new readout electronics is under construction. A silicon strip hodoscope with a resolution of 58 μm allows studies of the field homogeneity and spatial resolution of this prototype. A modular simulation helps to understand the TPC in detail. First comparisons show a good agreement between simulation and measurement. The simulation predicts a dE/dx resolution of 14%. Test beam measurements will provide data to verify the simulation.

References

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