R&D for a TPC with GEM Readout

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Recent results of our R&D for a TPC with GEM readout are presented. Measurements with a new TPC prototype have been performed within a hodoscope. The hodoscope allows to study systematic effects of the spatial resolution and field homogeneity of the TPC. New readout electronics is under development. A detailed simulation program for the TPC has been developed. First results of this program are compared to measurements.

1. CONSTRUCTION OF A TPC PROTOTYPE

The prototype has been designed to fit into a 5 T magnet with a bore of 28 cm located at DESY Hamburg. The material budget of the fieldcage has been minimised, achieving 1% of a radiation length. Figure 1 shows the different layers of the fiedcage on the left and the fraction of the radiation length of the different materials on the right. The design goal in the TDR [1] of 3% of a radiation length for the ILC TPC seems reachable with a similar design.

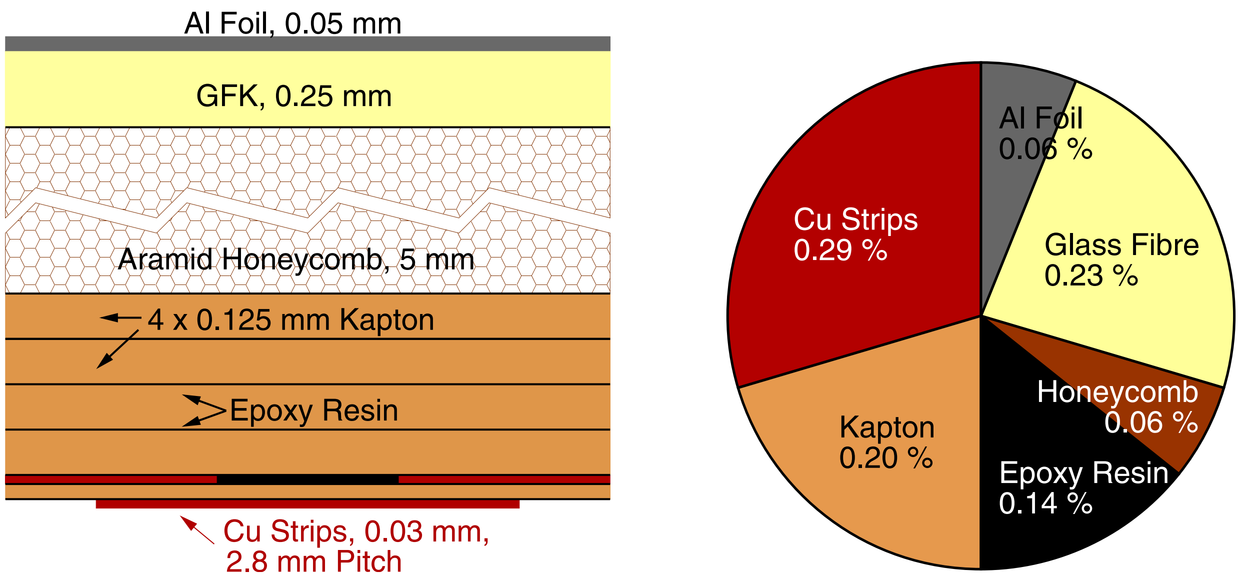

Figure 1: Design and material budget of the fieldcage.

With a drift length of 26 cm and a voltage supply of 26 kV drift fields up to 1000 V/cm can be reached. The strips of the fieldcage have a pitch of 2.8 mm. The prototype is working stable and the first measurement of the drift velocity in TDR gas ($Ar/CH_4/CO_2$ 93/5/2) gives a value of $4.53 \pm 0.03\ \frac{cm}{\mu s}$ which is in good agreement with simulations conducted with MAGBOLTZ [2]. The left picture of figure 2 shows the prototype. Inside the fieldcage, the amplification structure consisting of three GEMs can be seen. A shield at the level of the upper GEM prevents field inhomogeneities at the edges of the GEM stack. On the right hand side a cosmic event is depicted with an event display illustrating on the upper view the sensitive area in the middle of the chamber and on the bottom picture the charge deposition on the pad plane with 2.4 times 6.4 cm^2 pads.

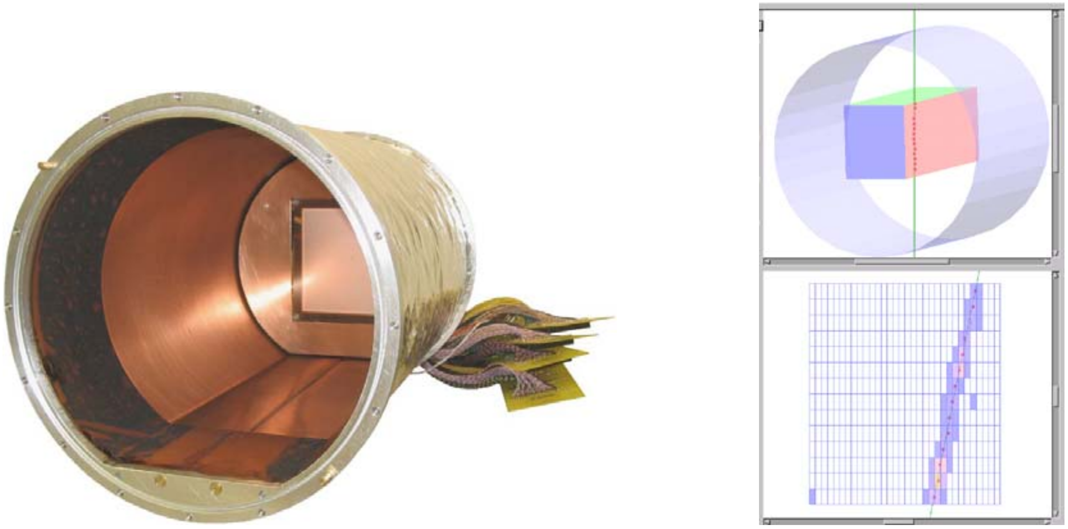

Figure 2: Prototype and event display of cosmic track.

2. OPERATION OF THE TPC IN A HODOSCOPE

To have an independent measurement of the particle track, a hodoscope has been built to study the properties of the TPC. The hodoscope consists of four silicon strip modules. Each module consists of two 500 μm thin sensors with 768 strips and a pitch of 122 μm. Two silicon strip modules are placed under and two on top of the TPC (see figure 3 left). The two modules are rotated by an angle of 5 mrad to allow a two dimensional measurement. This gives two indepent reference points of the particle track. The hodoscope reaches a resolution of 58 μm in x and 624 μm in z. The system of TPC and hodoscope has to be calibrated to account for mechanical offsets and rotations. Once both systems are transformed into the same coordinate system, comparisons can be made. The average single point resolution of the TPC within the hodoscope has been measured to 266 μm. Using the hodoscope the homogeneity of the drift field can be measured. Comparing the z positions of reconstucted track points in TPC and hodoscope (figure 3 right), a variation of their difference Δz from zero near the anode is visible. This can be explained by an offset of the anode relative to the first strip of the fieldcage due to the inaccuracy occuring when inserting the readout module into the chamber. This results in field distortions because the voltages of the strips do not match the voltage of the GEM stack anymore. Simulations with FEMLAB [3] have shown exactly this behaviour, assuming an anode offset of 0.5 mm. This can be corrected by either improving the mechanical precision or by adjusting the voltage of the shielding.

3. DEVELOPMENT OF ELECTRONICS

Our group is currently using ALEPH electronics to read out the TPC. Our first goal is to replace the ALEPH preamplifiers with a faster and smaller model. For this purpose, the Preshape 32 has been chosen. It has 32 channels and a nominal peaking time of 45 ns. This is about a factor of 10 faster than the ALEPH preamplifier. A cable driver was developed to transport the signal over a reasonable distance to the ADCs. First test of the preshape with an ^{55}Fe source show a good spectrum and pulse widths of about 100 ns shown on figure 4.

No ADC has been choosen so far to replace the ALEPH TPDs, but there are three candidates we are planning to test. All are VME based ADCs with high channel density per module, sampling frequencies of 40 to 100 MHz and a resolution of 10 bit.

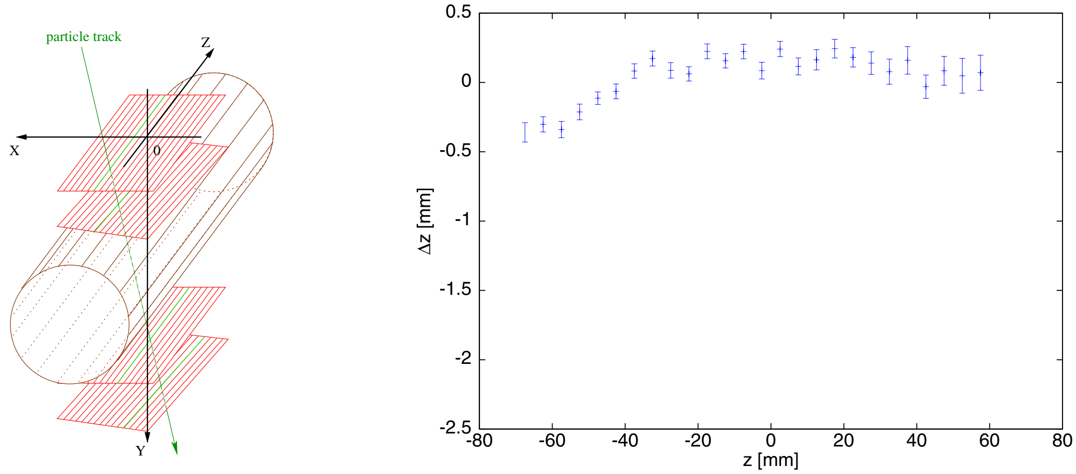

Figure 3: Schematic setup of hodoscope and measurement of field inhomogeneities.

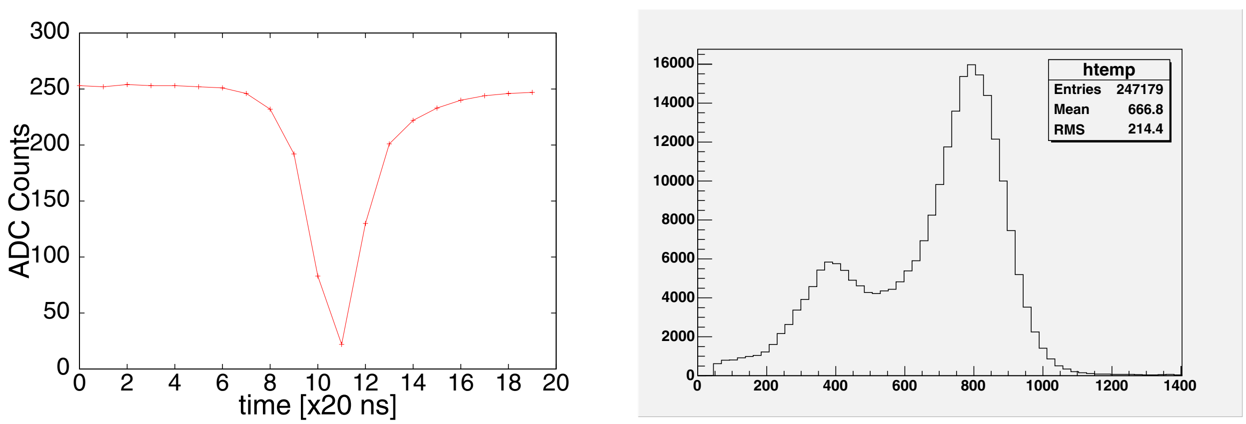

Figure 4: ^{55}Fe pulse and spectrum with Preshape 32.

4. SIMULATION OF A TPC WITH A GEM READOUT

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.

To allow flexibility and minimize data overhead, the simulation is divided into three modules following the actual processes in a TPC: The first module creates primary ionisation along the particle track, the second drifts the produced electrons through the chosen gas to the amplification structure including the diffusion process. In a third step, the electrons are transfered through a triple GEM structure where they are amplified. This module uses information about the charge transfer through the GEMs from measurements performed by our group [4, 5]. They describe the collection efficiency, gain and extraction efficiency so that the actual GEM setting is accounted for.

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

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 5. 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 5 shows the same comparison for the transverse diffusion. The values resulting from the simulation are slightly below the prediction from MAGBOLTZ. The measured value, however, is far smaller than the simulated ones. The cause of this effect is under investigation.

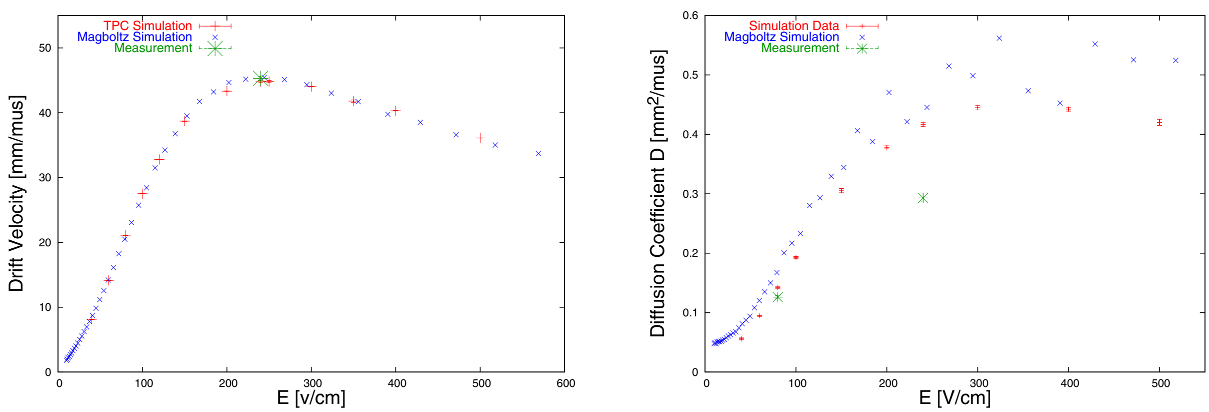

Figure 5: Comparison between simulation and measurement for drift velocity and diffusion.

5. CONCLUSION

Our prototype TPC and our hosdoscope are working synchronously and stable. Systematic studies of the TPC properties are planned as well as test beam measurements within this year. The preamplifiers for the new readout electronics have been chosen, the cable drivers have been designed and the production is in progress. Measurements with a new readout plane will follow soon. Systematic studies of the various TPC parameters with the simulation are planned. The implementation of the new data format LCIO [6] in the software is in progress.

References

[1] TESLA Technical Design Report, DESY-01-011, ECFA 2001-209 (2001)

[2] S.Biagi "MAGBOLTZ: Transport of electrons in gas mixtures", http://consult.cern.ch/writeup/magboltz/

[3] FEMLAB - Multiphysics Modeling , www.comsol.com

[4] M. Killenberg et al., Nucl. Instr. Meth. A498 (2003) 369

[5] M. Killenberg et al., Nucl. Instr. Meth. A530 (2004) 251-257

[6] LCIO, http://lcio.desy.de/