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Design and Construction of a TPC using GEM Foils for Gas Amplification

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We report on the development of a large Time Projection Chamber (TPC) for the e^+e^- Linear Collider (LC). Our studies concentrate on the use of Gas Electron Multiplier (GEM) foils for the gas amplification in the TPC. Charge transfer measurements are performed using a triple-GEM structure installed into a small test chamber which is irradiated with an ^{55}Fe source. This device is operated in high magnetic fields up to 5 T. No severe drop in primary ionisation statistics is observed, but an improved suppression of ion backdrift is achieved. For optimum settings the relative ion backdrift drops to only 2 per mil. Additionally, the width of the charge cloud created by individual ^{55}Fe photons is measured using a finely segmented strip readout behind the triple GEM structure. Charge widths between 0.2 and 0.5 mm RMS are observed. This charge broadening is reduced in high magnetic fields. Based on these experiments a prototype GEM-TPC has been constructed for further tests in the 5 T magnet and in test beams.

Keywords: Linear Collider; TPC; GEM

1. Ion Backdrift

A TPC is one option for the central tracker of the LC. To achieve the required momentum resolution, new technologies, e.g. GEMs[1], have to be used for the readout.

One crucial parameter of a TPC at the LC is the fraction of ions drifting back into the drift volume (Ion Backdrift, IB). Its value has to be as small as possible, since these ions degrade the quality of the drift field, and thus decrease the spatial resolution. To examine the IB of different GEM setups, a test chamber with three GEMs and a copper anode is used. The voltages of all electrodes can be adjusted separately, while all currents are monitored to sub-nA precision[2].

The IB depends on the four fields and three GEM voltages of the chamber. It is parametrised with respect to these seven parameters. To understand the dependance of the IB on these parameters and to find a parameter set with minimal IB, the parameter space can be scanned and searched for minima with a computer program. Parameter sets can then be measured automatically for confirmation of the predicted values of the IB.

The result of theese studies show that the voltages of the first and second GEM

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have little influence on the IB. They can be used to adjust the effective gain. For a minimal IB, the first transfer field and the second GEM voltage should be maximal, while the second transfer field has to be chosen minimal. As an additional result, keeping the effective gain constant, the IB drops by roughly a factor of two in a magnetic field of 4 T, as it is planned for the detector of the LC[3].

To study the influence of the IB on tracks, a large TPC (∼1 m^3) is used. A radioactive source is attached to the cathode opposite to the readout. The large amount of electrons produced by the source results in many back drifting ions, that form an ion tube between the source and the readout.

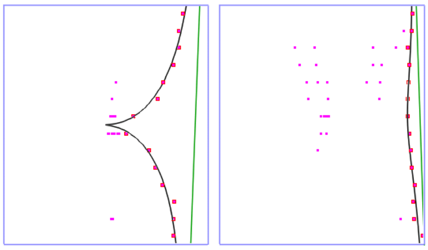

Figure 1: Track Distortions by Ion Backdrift

The impact of this ion tube on cosmic tracks is shown in Fig. 1. In the left plot a standard setting is used, while the right plot shows a comparable track with an optimized setting. The distorting effect of the ions as well as its reduction by the optimized setting are clearly visible. This is a qualitative confirmation of the parametrisations and the measurements with the small test chamber.

2. Cluster Width Studies

Another parameter that has great influence on spatial resolution is the width of the clusters that are observed on the pad plane behind the GEM setup. To study this parameter, the same test chamber as for the IB studies is used, but with a strip readout, with 300 μm pitch. Cluster widths of ∼350 μm are observed. The width drops to ∼200 μm in a 4 T magnetic field, as was expected due to the reduction of transverse diffusion[3] (Fig. 2). As a conclusion the charge broadening in GEMs is very small and permits an optimum spatial resolution.

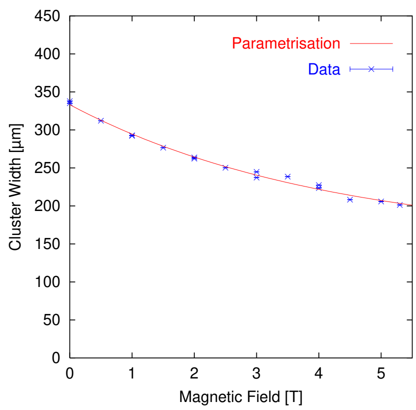

Figure 2: Cluster Widths in a Magnetic Field

3. Prototype Construction

For further studies a TPC prototype has been constructed (Fig. 3). It has a diameter of 260 mm to fit into the 5 T magnet at DESY. The total drift distance is 26 cm with a maximal drift field of $1000\frac{\text{V}}{\text{cm}}$. To test the feasibility of a low material budget for the field cage, a rigid sandwich structure with kapton, aramid honeycomb and GRP is used. A total of 1% of a radiation length is achieved (Fig. 4). This seems to be a promising design to achieve the 3%, as proposed in the TESLA TDR[4]. The field cage has a double-sided strip design to improve the quality of the field. The prototype has been tested with cosmics as well as electrons from a radioactive source. It works well and first tests of the drift field homogeneity look positive.

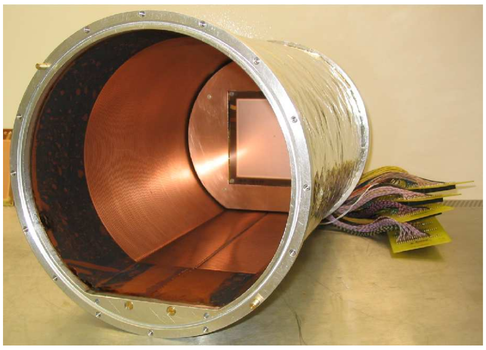

Figure 3: The Fieldcage

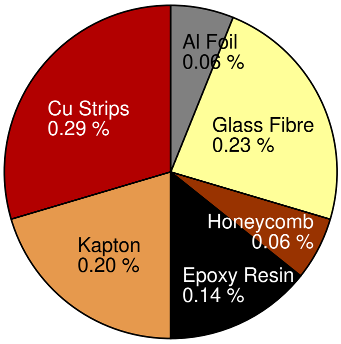

Figure 4: Fractions of Radiation Length

At the moment, the prototype uses the same readout as the large test TPC. To improve its performance and to enable reasonable test beam operation a new readout electronics with a total of 512 channels is under development. It is based on the "Preshape 32" preamplifier chip[5], with 32 channels and a nominal peaking time of 45 ns. These preamplifiers are currently being tested and first signals have been observed. The next step will be to choose suitable FADCs for this readout.

4. Conclusion

We study a multi-GEM readout for the LC TPC. The dependance of Ion Backdrift on the parameters of such a setup is well understood. The minimal IB depends strongly on the maximal reachable fields, and a magnetic field of 4 T reduces it by roughly a factor of two. A value of $2.5 \cdot 10^{-3}$ is achieved. Cluster widths of $\sim$350 μm that reduce to $\sim$200 μm in a 4 T magnetic field are observed. A TPC prototype has been constructed and a value of 1% of a radiation length is achieved for the field cage. First particle tracks have been observed and the prototype works well. For operation in a test beam a new readout electronics is now under development.

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