Charge Transfer of GEM Structures in High Magnetic Fields

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We report on measurements of a triple GEM (Gas Electron Multiplier) structure in high magnetic fields up to 5 T which were performed in the framework of the R&D work for a Time Projection Chamber at a future Linear Collider.

The determination of charge transfer is performed using a triple GEM structure installed into a small test chamber which is irradiated with a $^{55}$Fe source. The measurements are parametrised using a functional dependence on the electric setup which was motivated by detailed numerical simulations of a GEM using the programs MAXWELL and GARFIELD. This parametrisation of a single GEM foil is extended to a model which describes the performance of the triple GEM structure and allows to predict the parameter setup leading to minimum ion backdrift. Applying this setup, ion backdrift of only 2.5 permille is achieved. Also the use of MHSPs (Micro Hole Strip Plates) for ion backdrift reduction is investigated. Setting an optimised negative strip voltage, a suppression factor of approximately 4 is reached at 4 T magnetic field.

Additionally, the width of the charge cloud of individual $^{55}$Fe photons is measured using a fine segmented strip readout after the triple GEM structure. Charge widths between 0.2 and 0.3 mm RMS are observed, which appear to be dominated by the diffusion in the space between the individual GEMs. This charge broadening is partly suppressed at high magnetic fields.

1. Experimental Setup

For the measurements described below the chambers were mounted in a 5 T superconducting magnet at DESY such that the magnetic field was perpendicular to the GEM foils, as it will be in a TPC. More information on the magnet facility is presented in [1]. The mechanical and electric setup of our test chambers has been described in detail in reference [2]. The gas volume consists of a composite frame enclosing a stack of three standard 10 $\times$ 10 cm$^2$ GEM foils [3]. Using thin absorbers the radiation from a $^{55}$Fe source of 1 GBq activity is diminished such that about $2 \cdot 10^6$ photons per second penetrate into the chamber. The chambers were operated with a gas mixture consisting of Ar(93%), CH$_4$(5%), CO$_2$(2%) as it is proposed in the TESLA Technical Design Report [4].

For the current measurements the anode plane consists of a solid copper electrode of the same size as the GEM structures [5]. Every electrode is connected to an individual HV channel via a current monitor with a resolution of about 0.1 nA. To measure the anode current, the anode plane is connected to ground via an additional current monitor. For the measurement of individual pulses an anode with a finely segmented area with 8 strips of 0.3 mm pitch is used [6]. The signal pulse of each strip is read out via a preamplifier and digitised using a 100 MHz Flash ADC.

Figure 1 shows one of the chambers just before insertion into the aperture of the superconducting magnet.

2. Measurements

From the measured currents one determines the charge transfer coefficients of a single GEM. These are the collection efficiency into and extraction efficiency out of the GEMs holes for electrons.
and ions, respectively. Additionally, the electron gain of a single GEM is derived. The measurements are parametrised using a functional dependence on the electric setup which was motivated by detailed numerical simulations of a GEM using the programs MAXWELL and GARFIELD [7]. Good agreement between the measurements and the parametrisation of the charge transfer coefficients is observed.

As a first result, no significant drop in the collection efficiency is seen at magnetic fields up to 5 T. The Langevin formula suggests such a behavior for high magnetic fields where the charge carriers travel along the magnetic instead of the electric field lines.

An important charge transfer quantity of the whole triple GEM setup is the ion backdrift, which describes how much ion charge is transferred into the drift volume per electron charge collected on the anode plane. Ions reaching the TPC drift volume would represent a positive space charge and deteriorate the homogeneous electric drift field thus leading to track distortions. The ion backdrift can be derived from the measurements by dividing the cathode current by the anode current. It has also misleadingly been called ion feedback, a term which should only be used for the feedback loop caused by ions hitting a photo cathode and releasing new photo electrons in a GEM based photomultiplier.

The small electric field in the drift volume causes many of the drift lines from the amplification region inside the GEM hole to end on the copper plane facing the TPC drift volume. Therefore, the relatively small drift field typical of a TPC automatically leads to ion backdrift suppression. Moreover, the ion backdrift can be minimised by the variation of the electrical fields within the GEM structure.

The parametrisation of a single GEM foil is extended to a model which describes the performance of the triple GEM structure and allows to predict the parameter setup leading to minimum ion backdrift. Using the parametrisation of the charge transfer coefficients as a function of the electric fields, the ion backdrift is calculated as a product of charge transfer coefficients and single GEM gain factors. By scanning the whole parameter space and calculating the ion backdrift at every point, minima in ion backdrift can be found.

Using this method, an ion backdrift of only 2.5 permille has been achieved in a magnetic field of 4 T. Figure 2 shows that the ion backdrift decreases for increasing magnetic fields. This behavior is mostly due to an enhanced electron extraction efficiency. The plot also contains the
prediction of the ion backdrift at 4 T from the parametrisation model. The offset from the measurement is due to the error propagation as the ion backdrift is a product of many charge transfer coefficients.

As a possibility to further suppress ion backdrift we tried to use a GEM foil with a strip pattern etched onto one side, the so called MHSP (Micro Hole Strip Plate) [8]. The MHSP is mounted into the chamber replacing the first GEM after the drift volume and the strip pattern pointing in direction of the anode. Then the strips between the GEM holes are supplied with a negative voltage with respect to the rest of the electrode, thus serving as a cathode, catching back-drifting ions from the lower GEMs. Figure 3 shows the measured ion backdrift versus the inter-strip voltage applied. A suppression of the ion backdrift by a factor of 4 has been achieved. In this measurement the settings of the other GEMs are not optimised which leads to the higher absolute ion backdrift in comparison to Figure 2.

Information about the charge spread within a GEM structure is important to estimate the optimum pad size for the GEM TPC. We present new measurements of the charge spread by GEM structures in high magnetic fields. The cluster width distribution for individual events has been analysed using a segmented strip anode with a pitch of 0.3 mm. The width of the charge cloud originating from a photon emitted by the $^{55}$Fe source is determined by fitting a gaussian to the charge distribution across the eight strips.

Figure 4 shows the results of this measurement. The RMS width of the charge cloud is reduced from 0.3 mm without magnetic field to 0.2 mm at 4 T. A MAGBOLTZ simulation of the total transverse diffusion for electrons drifting through the spaces between the three GEM foils suggests that even higher values than those measured are expected even if not taking any additional effects into account. Even though MAGBOLTZ generally overestimates transverse diffusion somewhat, this is a hint that the charge spreading in the triple GEM is dominated by the diffusion between the GEM foils. This is also supported by the almost identical shape of the two curves.

REFERENCES

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