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LC TPC R&D in Aachen
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1 Measurements in High Magnetic Fields

For the measurements described below small test chambers were used. The mechanical and electric setup of these test chambers has been described in detail in Reference [4]. In case of the current measurements the anode plane consists of a solid copper electrode of the same size as the GEM structures [6]. 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 [10]. The signal pulse of each strip is read out via a preamplifier and digitised using a 100 MHz Flash ADC.

For the measurements in high magnetic fields 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 [12]. The gas volume consists of a composite frame enclosing a stack of three standard 10×10 cm^2 GEM foils [1]. Using thin absorbers the radiation from an ^{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 [3]. Further details of the experimental setup can be found in Reference [5]. Figure 1 shows one of the chambers just before insertion into the aperture of the superconducting magnet.

As first result, an increase in anode current is seen with rising magnetic fields up to 5 T. According to the Langevin formula high magnetic fields would cause the charge carriers to travel along the magnetic instead of the electric field lines. Due to this effect the extraction efficiency out of the GEM holes

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Fig. 1. Insertion of the test chamber into the magnet

increases whereas no significant drop of the collection efficiency into the holes is observed.

2 Charge Transfer and Ion Back Drift

From the current measurements 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 [8,9]. Good agreement between the measurements and the parametrisation of the charge transfer coefficients is observed.

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 back drift. Using the parametrisation of the charge transfer coefficients as a function of the electric fields, the ion back drift is calculated as a product of charge transfer coefficients and single GEM gain factors. By scanning the whole parameter space and calculating the ion back drift at every point, minima in ion back drift can be found. Using this method, an ion back drift of only 2.5 permille has been achieved in a magnetic field of 4 T.

An important charge transfer quantity of the whole triple GEM setup is the ion

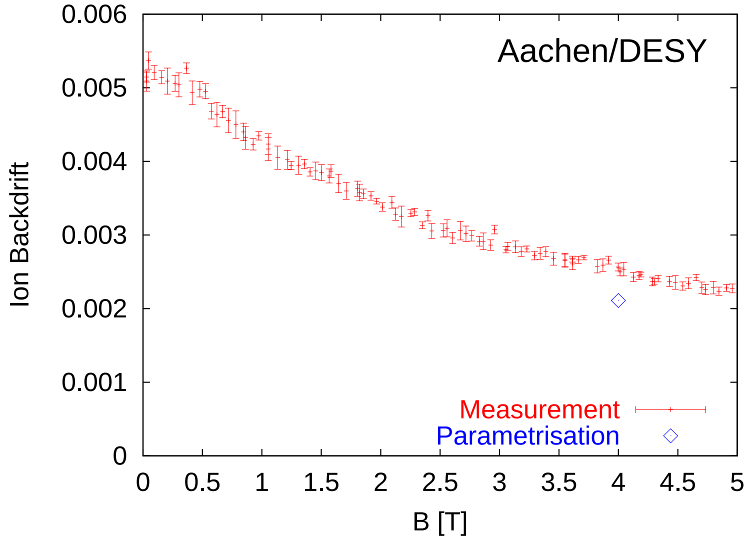

Fig. 2. Suppression of ion back drift versus magnetic field

back drift, 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 back drift 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 the cathode and releasing new electrons. 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 back drift suppression. Moreover, the ion back drift can be minimised by the variation of the electrical fields within the GEM structure.

Figure 2 shows the ion back drift for constant effective gas amplification. It 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 back drift at 4 T from the parametrisation model. The offset from the measurement is due to the error propagation as the ion back drift is a product of many charge transfer coefficients.

Fig. 3 shows the dependence of the minimum reachable ion back drift on the effective gain of the triple GEM structure. For each data point, all GEM voltages and fields were optimised and the resulting ion back drift was plotted. The ion back drift is almost independent on the gain. Therefore, the choice of a low gain factor (if the signal to noise ratio is acceptable) would lead to a low absolute ion charge drifting back into the drift volume. At an effective gain of 1000, this charge would be only 2.5 times the charge from primary ionisation.

As a possibility to further suppress ion back drift we tried to use a GEM foil with a strip pattern etched onto one side, the so called MHSP (Micro Hole Strip Plate) [2]. 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 4 shows the measured ion back drift versus the inter-strip voltage applied. A suppression of the ion back drift 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 back drift in comparison to Figure 2.

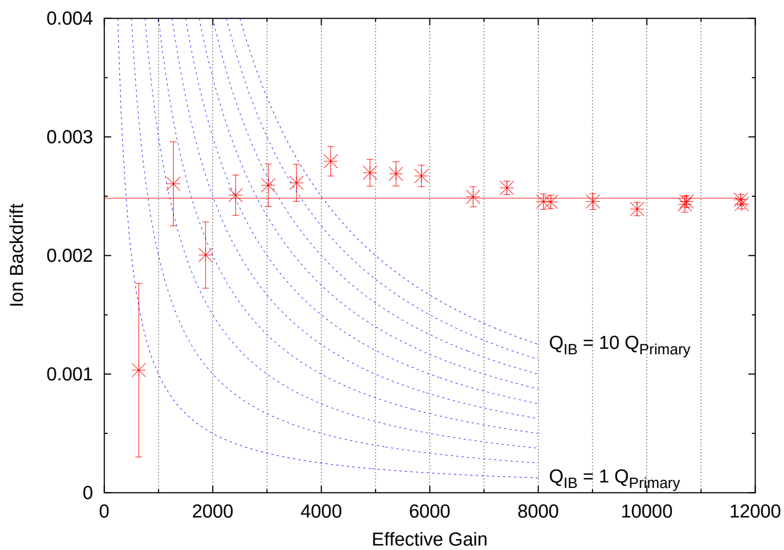

Fig. 3. Relative ion back drift versus effective gain

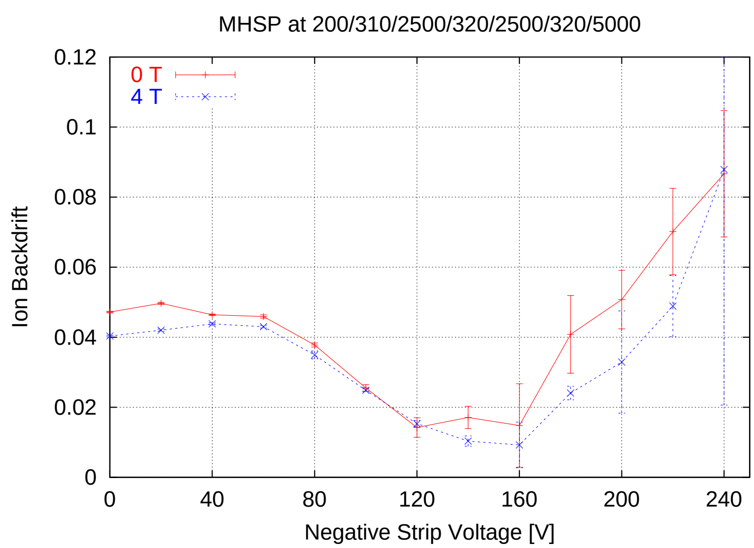

Fig. 4. Suppression of ion back drift versus the inter-strip voltage of the MHSP

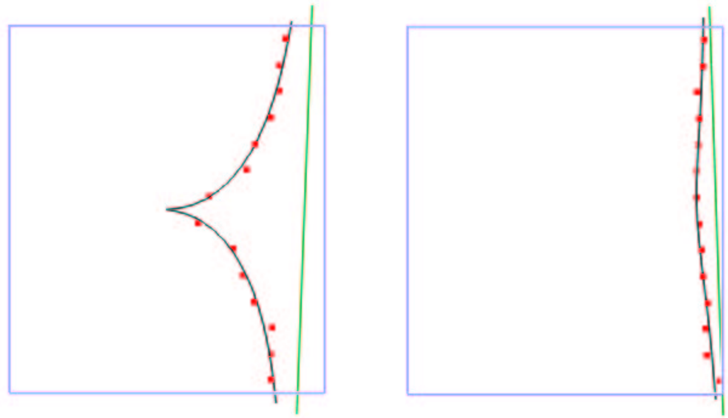

Fig. 5. Distortion of tracks from cosmic ray muons with normal settings (left) and settings optimised for minimum ion back drift (right)

To see the influence of located ion charges on the drift of electrons we mounted an ionising ^{55}Fe-Source onto the cathode plane of our test TPC. This leads to a continuous flow of ions drifting from the readout to the cathode, forming an ion tube. Fig. 5 shows the distortions caused by this ion charge. On the right hand side the GEMs have been operated with settings to minimize the ion backdrift and the distortions are diminished. We have developed a parametrisation to describe the distortions and are currently working on a quantitative analysis of the effect.

3 Measurement of Charge Width

Information about the charge spread within a GEM structure is important to estimate the optimum pad size for the GEM TPC. We present 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 6 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, we observe an almost identical shape of the two curves. This is a hint that the charge spreading in the triple GEM is dominated by the diffusion between the GEM foils and not by effects specific to GEMs.

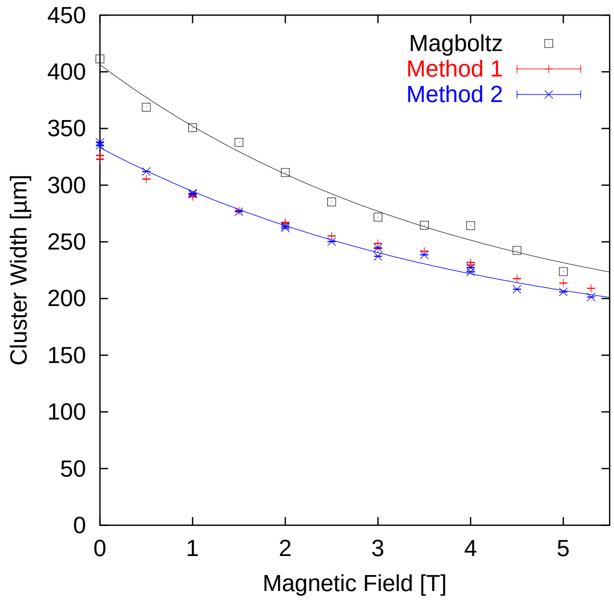

Fig. 6. Charge width vs. magnetic field

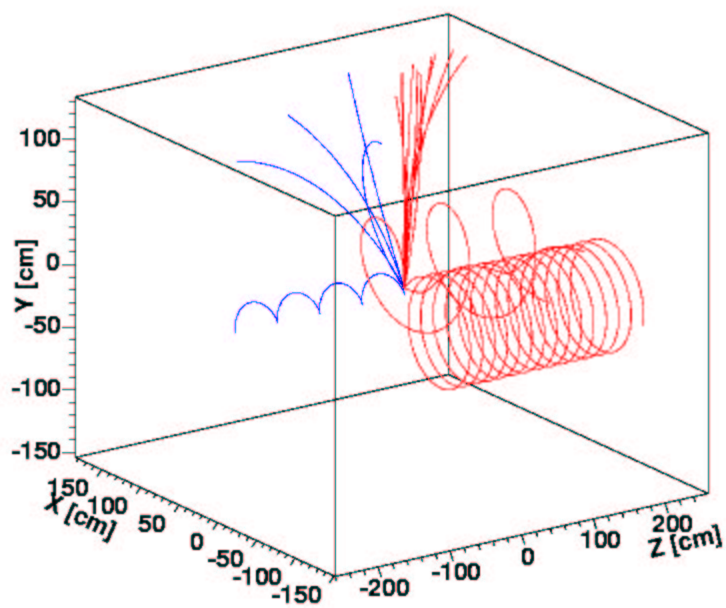

Fig. 7. Simulation of primary electrons produced by one LC event inside the TPC

4 Simulation of a TPC

The goal is to create a simple and efficient tool to simulate specific properties of a TPC. It should include production, transfer and amplification of charge, which are governed by the gas choice and the pad response and geometry.

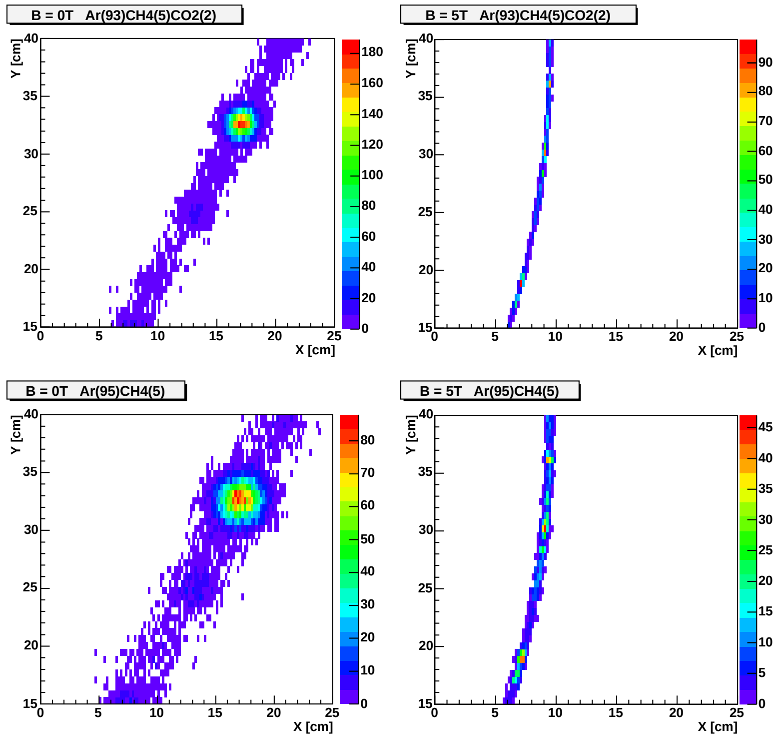

Fig. 8. Simulation of total charge deposited on pad plane for two gas choices (TDR upper row, P5 lower row) and two magnetic fields (0 T left column, 5 T right column)

Finally, for example the effect of ion back drift on field homogenity should be calculable using this tool. As first approach electrons are generated along small track parts according to a parametrisation gained from HEED. This allows to simulate the primary electrons produced in one LC event as shown in Fig. 7. Fig. 8 shows the collected charge on a part of the pad plane (2×6 mm^2 pads) after transfer of the primary electrons. The effect of the gas type and the magnetic field on the diffusion can be seen.

5 Design of a Field Cage

The field cage has to provide a homogeneous electric field in order to avoid track distortions. Also, a stable mechanical support structure is needed to ensure a precise mutual alignment of the various TPC components. At the same time the material budget in terms of radiation lengths has to be kept small in order to minimize a degradation of the calorimeter performance. The resistor chain needed to gradually degrade the potential from the cathode to the anode potential should dissipate as little heat as possible into the chamber gas because local temperature fluctuations change the drift velocity and various other gas parameters. Finally, the field cage of a large-scale TPC as proposed

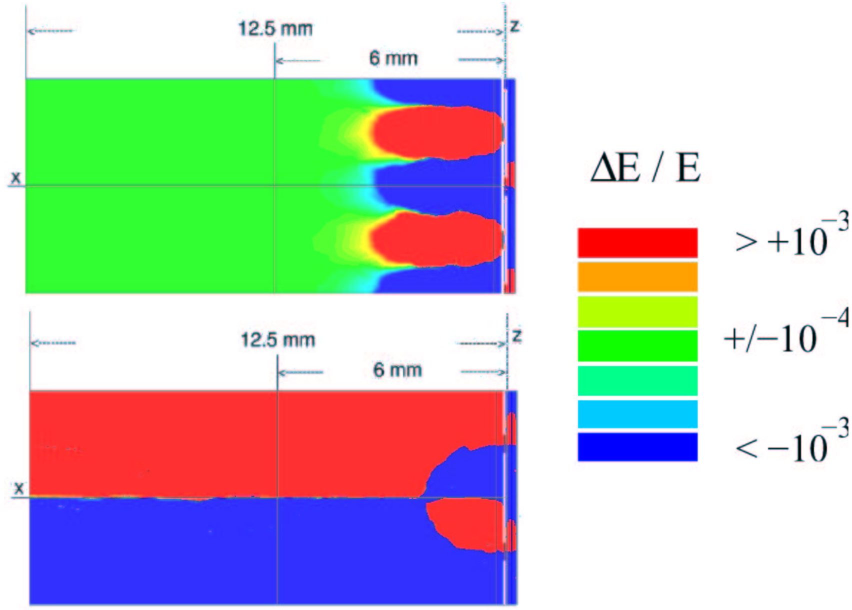

Fig. 9. The simulated electric field homogeneities for field cages with (top) and without (bottom) mirror strips on the outer side of the field cage.

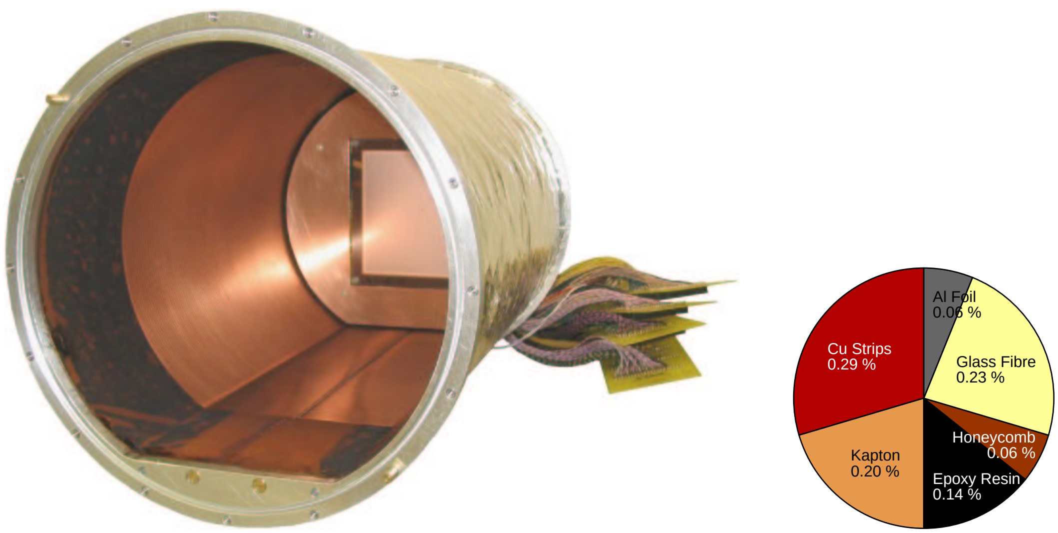

Fig. 10. Photograph of the prototype field cage (right) and contribution of the various field-cage components to the radiation length (left).

for the TESLA detector [3] has to stand cathode voltages of the order of 50 kV to 100 kV.

The electric field homogeneity is mainly determined by the chosen strip layout. In order to find an optimal setup, simulations have been performed with the MAXWELL finite element package. Details of the numerical simulation can be found in Reference [11]. Fig. 9 shows the simulated relative E field homogeneity for field cage designs with and without interlaced strips on the outer side of the field cage. The double-sided strip layout provides a field homogeneity better than 10^{-4} starting at a distance which corresponds to about two strip pitches. This is an order of magnitude better than obtained without outside strips.

The findings from the simulation study lead to the construction of a TPC prototype with a double-sided strip field cage. It has a diameter of 28 cm and provides a driftlength of 26 cm. Its mechanical support structure is composed of honeycomb and glass fiber reinforced plastic. Electrical insulation is provided by four layers of Kapton. In total the field cage represents only about 1 % of a radiation length and the contributions of the different components to the total radiation length is shown in Fig. 10. It has proven to stand at least 30 kV. To reduce the heat emission of the resistor chain into the chamber gas, the resistor chain has been placed outside the gas volume. It is covered by a ceramics plate conducting the produced heat to the outside and, at the same time, providing good electric insulation. Following the careful design and test phase, the prototpye performance is currently checked in first measurements with cosmic muons and a ^{90}Sr source.

6 Development of Readout Electronics

To take advantage of the fast GEM signals and to allow reasonable operation in testbeams a new, fast readout has to be developed. In addition the preamplifiers of this readout should be as small as possible, to allow small pad sizes. As a starting point the Preshape 32 chip has been chosen, which is a 32 channel parallel in/out preamplifier/shaper with a nominal peaking time of 45 ns and a size of $4.5 \times 4.4\,\mathrm{mm}^2$ (see Fig.11). First successful tests have been performed in a test chamber with GEMs, irradiated by an ^{55}Fe source.

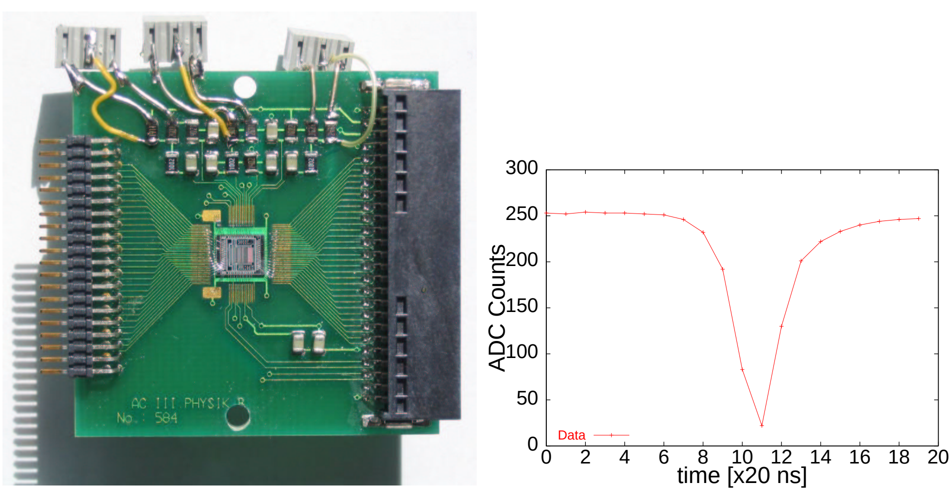

Fig. 11. Photograph of the Preshape 32 chip bonded to a test board (left) and a first signal recorded with this setup

It is planned to equip our TPC prototype with these preamplifiers read out by suitable Flash-ADC's. A total of 512 channels with 10 bit resolution and at least 40 MHz sampling rate is foreseen.

References

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