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The field cage for a large TPC prototype

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Abstract

Within the EUDET Programme, the FLC TPC Group at DESY in collaboration with the Department of Physics of the University of Hamburg will develop and construct a field cage for a large TPC prototype. This field cage will fit into the PCMAG, a superconducting magnet which will be installed in the electron test beam at DESY. This setup will be available for development work towards a TPC for a detector at the International Linear Collider (ILC).

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1 Introduction

The EUDET Programme is an EU co-financed project to provide an infrastructure to support research and development work on detectors for the International Linear Collider. In line with this programme the FLC TPC Group at DESY in collaboration with the Department of Physics of the University of Hamburg will construct the field cage for a large prototype (LP) of a time projection chamber (TPC), which is proposed as the central tracking detector for detectors at the ILC. The construction of the LP will be performed in combination with the installation of a superconducting magnet (PCMAG) which will host the LP in the electron test beam at DESY.

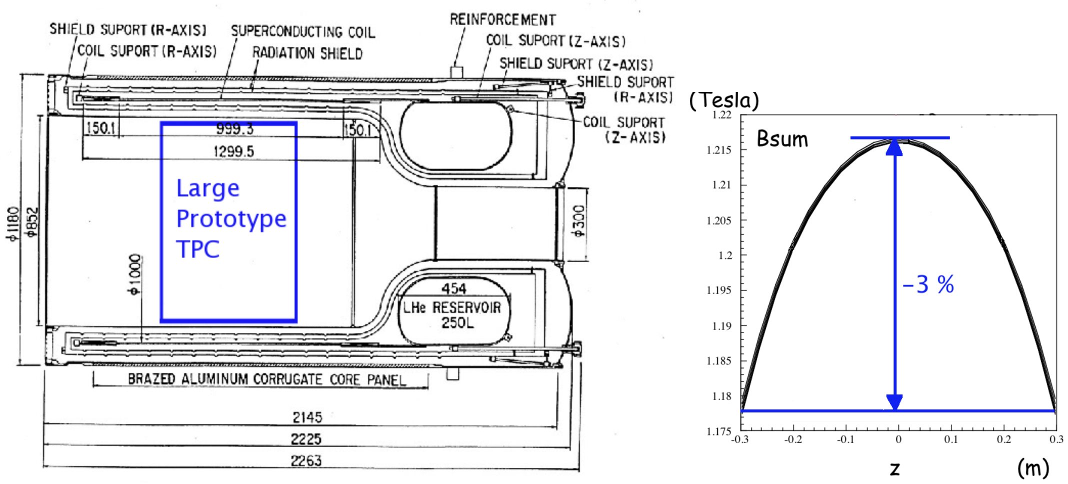

Figure 1: Technical drawing of the PCMAG (from [KEK]) and the result of a magnetic field calculation on the axis of the magnet (from [PCM])

Figure 1 shows a technical drawing of the magnet and the result of a magnetic field calculation on the axis of the magnet. Since the LP is foreseen to fit into the PCMAG, the dimensions of its field cage are restricted by the magnet's geometry and field.
The outer diameter of the field cage is foreseen to be 80 cm leaving a gap of 2.5 cm to the inner wall of the magnet, which has a diameter of 85 cm. This space will eventually be used for the installation of silicon strip detectors to perform combined studies with the LP and the silicon strips as external tracking detectors.
The length of the field cage will be 60 cm. This is driven by the fact, that the magnetic field on the axis in the centre of the magnet is homogeneous within 3 % only in a range of ±30 cm.
The field cage should be very lightweight but nevertheless stable and flexible to use. Therefore its structure will be made of composite materials which have already been used for the construction of smaller prototypes (see e.g. [Lux]).
The LP cage is foreseen to be available by mid 2007.

2 Construction issues of the field cage

The construction of the field cage is split up into three main steps. In the preproduction phase, the barrel and two endplates will be built. In parallel a special foil carrying field strips (see below) and the cathode are prepared and will be ready when the barrel and the endplate are available. In the final step, the foil carrying the field strips will be mounted on the inside of the barrel and the cathode will be attached to one endplate.

2.1 Field cage barrel

Based on the proposed dimensions, a preliminary technical drawing of the field cage barrel has been prepared as shown in Figure 2.
The wall of the barrel will consist of a honeycomb structure sandwiched between two layers of glass-fibre reinforced plastic (GRP), which give stability to the structure. The wall thickness is planned to be 2 cm, the thickness of the GRP layers is currently being optimised, but will be less than 1 mm.
At the anode and the cathode side, the walls will be terminated by flanges made of G10[1] (cathode), respectively aluminium (anode). These flanges carry an o-ring groove. A circle of threaded holes will allow the mounting of the cathode and anode endplates. Before the construction starts, the following design plans (Figure 2) will be reviewed:

- The thickness of the GRP layers will be minimised to a reasonable value to reduce the total weight and the radiation length of the walls. For this mechanical calculations of the structure are ongoing.
- The anode and cathode interfaces have to be finalised. The latest version is shown in Figure 2. The anode interface needs further considerations, as it should be possible to operate the chamber with GEM and MICROMEGAS based readout structures. Detailed designs of the anode are currently under discussion between the research groups involved.

Once the design plans are fixed by February 2007, they will be available for the construction of anode plates for the field cage.

2.2 Cathode

Along with the construction of the field cage barrel, two 5 mm thick G10 endplates will be prepared. One of these will support the cathode. In the first iteration, the cathode will be a simple circular disc with a copper surface. On the cathode side, it will seal the drift volume and be connected to the high voltage (HV) supply. As sketched in Figure 3, the cathode will be equipped with special tabs at its margin which are in contact to the last field strip (see below) to supply the HV to the field cage potential strips.
The cathode will be mounted with some $1-2$ cm distance to the endplate. This space will allow modifications, for example the installation of a device to carry a radioactive

[1] a special GRP material

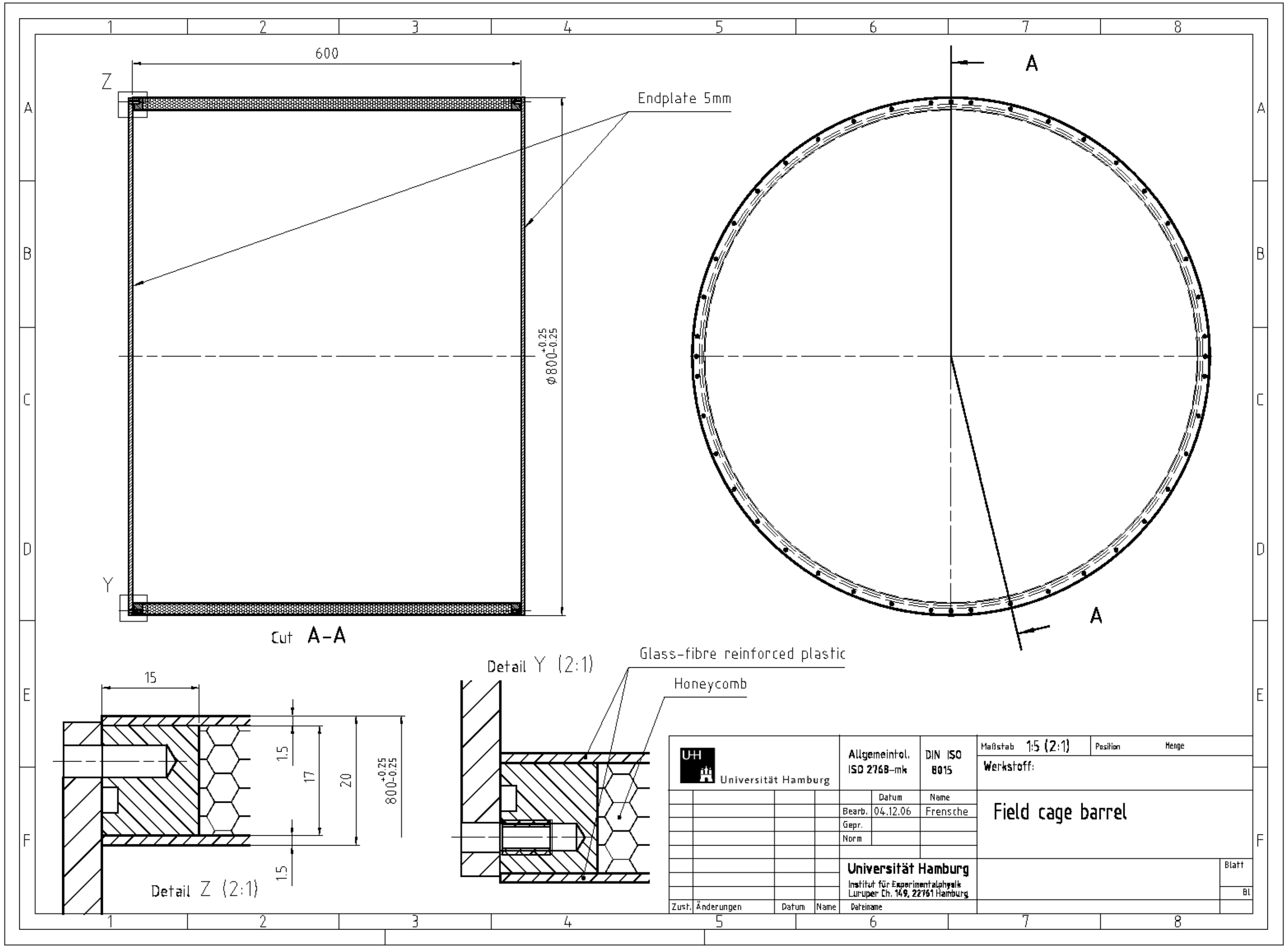

Figure 2: First iteration of construction plans for the field cage barrel

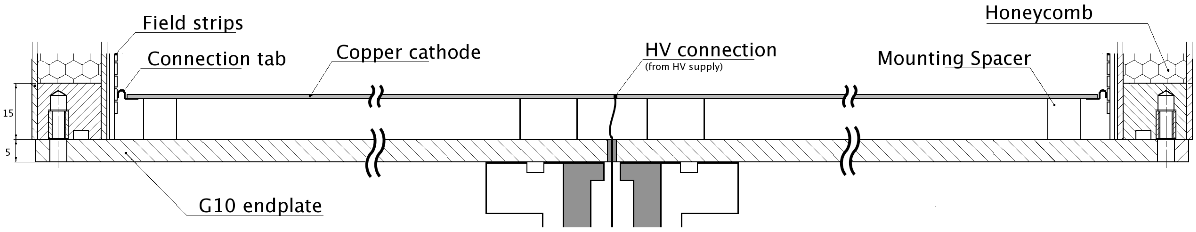

Figure 3: Cathode mounted to the endplate

source behind the cathode disc which radiates into the drift volume through a small hole.

2.3 Electrostatics of the field cage

The outside of the field cage barrel will be coated with an aluminium or a copper foil. In operation this layer will be at ground potential and act as an electrical shielding to prevent the internal drift field from influencing external devices like the silicon strip detectors. This shielding has the drawback that it will influence the internal drift field. To ensure the drift field quality, the inner layer of the field cage's wall will be a foil carrying field strips. These field strips are parallel rings that lie on potentials that are incrementally falling from the anode towards the cathode. This is schematically shown in Figure 4 (see for example [Lux] or [AHB]).

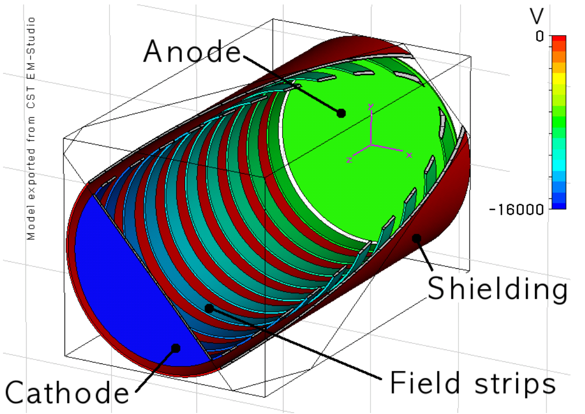

Figure 4: Schematic design of a cylindrical TPC

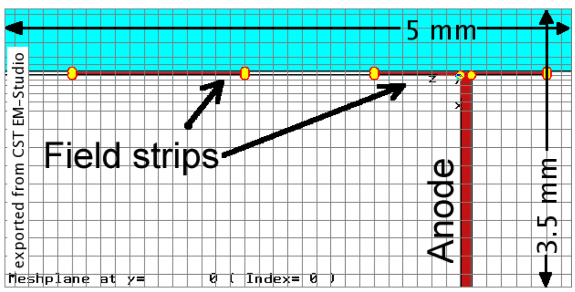

Figure 5: Cutout of the model set up for the drift field calculations

2.3.1 Calculations to optimise the field strip layout

The field strips at the inside of the field cage barrel will ensure the drift field quality in the sensitive volume. To find the optimal layout for the field strips, electrostatic calculations with different possible geometries were performed. For this a computer

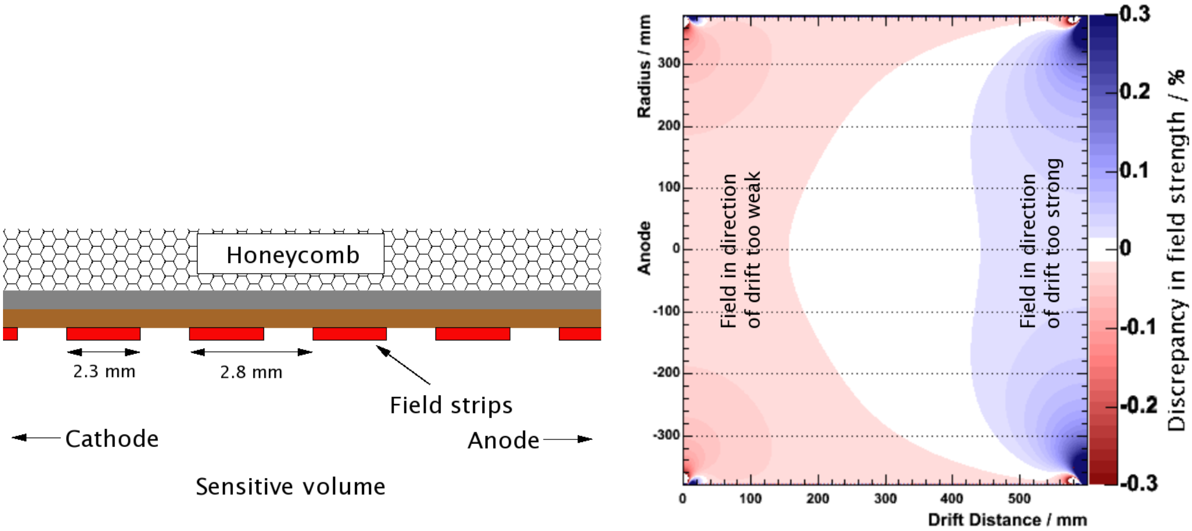

Figure 6: Layout and field map for one-sided field strips of 2.3 mm width and 0.5 mm gaps

model in an electrostatic calculation program[2] based on the proposed dimensions of the field cage was used. As an example Figure 5 shows a cutout of the model at the corner where the anode adjoins the field cage wall. Because of the rotational symmetry of the barrel, it is sufficient to calculate the electric field in a two dimensional plane ranging from the axis of the chamber to the outside wall. The model covers the full length of the LP (60 cm) and allows to vary the design of the field strips, meaning for example the pitch and the ratio between the width of the strips and the gaps. To get a precise result within acceptable computing time, the mesh used to do a finite element calculation of the electric field was chosen to be as narrow as reasonable possible. As shown in Figure 5 depending on the width between 10 up to 20 mesh cells cover one field strip. The total mesh of the model has typically $5 \cdot 10^6$ cells.

2.3.2 One-sided field strips

A smaller TPC-prototype operated at DESY (MediTPC, see [Lux]) has one layer of field strips (width of the strips 1.6 mm, pitch 2.8 mm). The pitch of 2.8 mm allows the connecting of two neighbouring strips by surface-mounted (SMD) resistors inside the chamber. For the LP it is planned to have a similar setup with SMD-resistors, therefore it is advantageous to stick to the 2.8 mm pitch.
The field map calculated for the LP with one-sided field strips shows large distortions over the drift volume, especially in the corners of the chamber. These distortions can be minimised by increasing the width of the field strips and decreasing the size of the gaps keeping the 2.8 mm pitch. Due to fabrication and electrostatic operation issues[3] the gaps cannot be made narrower than 0.5 mm. Therefore minimal field distortions in

[2] CST^{TM}EM-Studio
[3] the potential difference between two neighbouring field strips can have a magnitude of up to 100 V

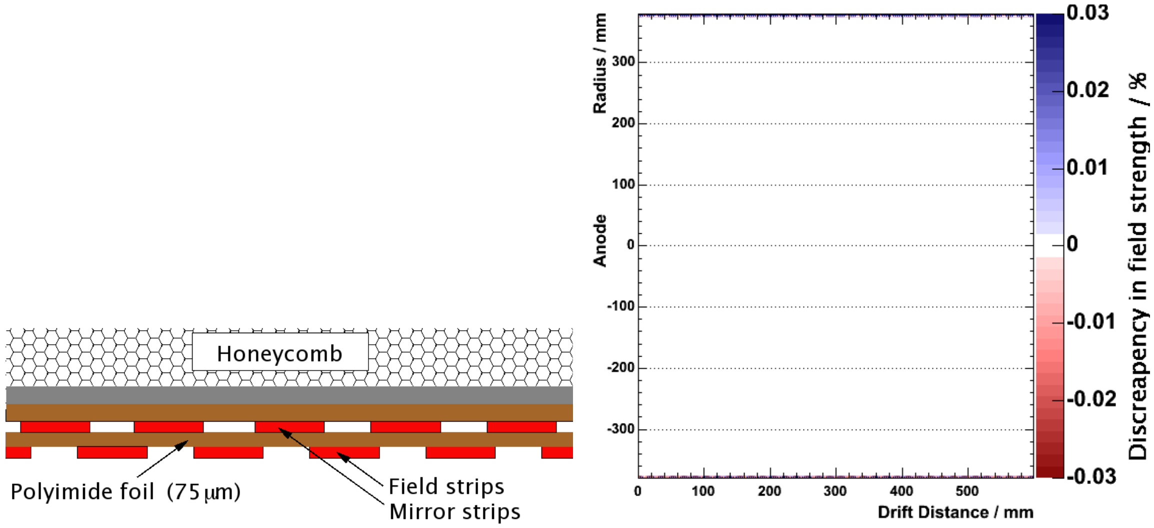

Figure 7: Layout and field map for a design with two layers of field strips (width of the strips 2.3 mm and of the gaps 0.5 mm) for the LP

a feasible layout with one-sided field strips are achieved with strips of 2.3 mm width and 0.5 mm gaps. The corresponding field map is show in Figure 6.
Additional distortions will occur due to effects that are not taken into account in this calculation and that worsen the field quality (for example holes in the cathode for the gas inlet). Therefore this result is an lower limit for the magnitude of field distortions in the drift volume. The field quality cannot be improved without introducing an additional layer of field strips.

2.3.3 Double-sided field strips

Figure 7 shows a modified layout of the field strip foil. In addition to the strips on the inside of the chamber, a second set of strips is located on the other side of a polyimide foil (mirror strips). Each of these mirror strips has the intermediate potential of the two strips opposite from it. The foil separating the field strips from the mirror strips has a thickness of $75 - 100\,\mu$m.
The calculated field map, shown in Figure 7 shows no distortions down to a per mill regime. With this design, field distortions coming from the geometry of the field strips are nearly completely avoided. Other geometries with mirror strips were also investigated, however the results show that once a design including mirror strips is chosen the optimal field quality is achieved with the layout as sketched in Figure 7.
To get an estimate on the final field quality in the chamber, distortion from systematic effects for example coming from non perfect resistors and deformations in the volume have to be taken into account. Once these numbers are known within a final design, calculations to make an estimate on the final drift quality can be performed.

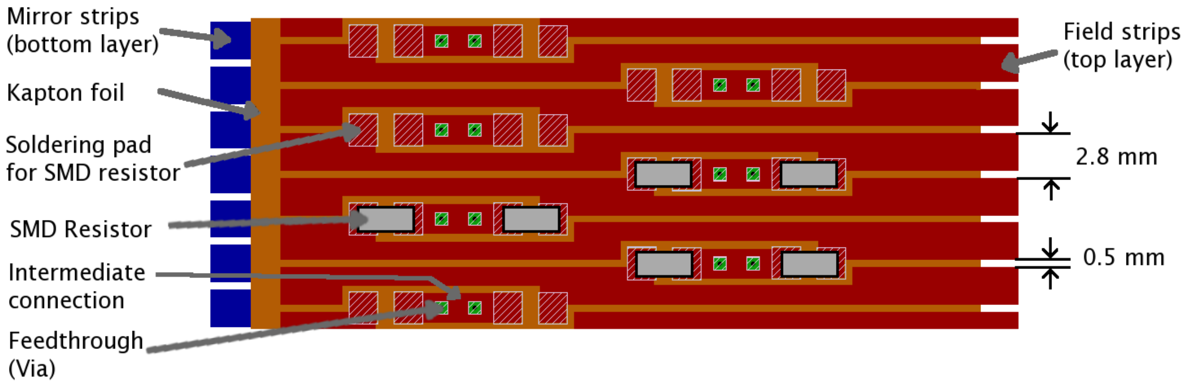

Figure 8: Design of the foil field-strip foil

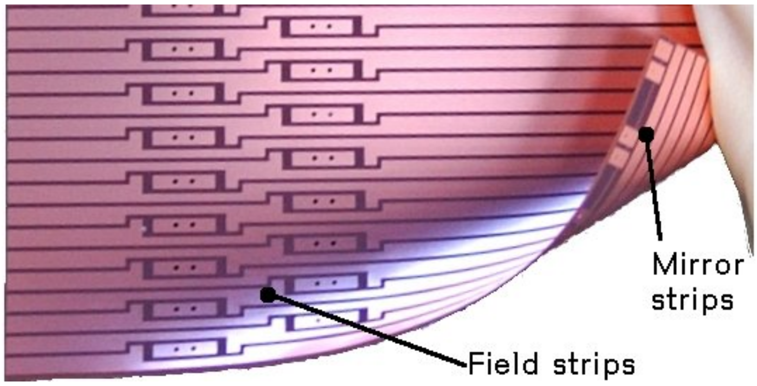

Figure 9: Photo of a sample piece of the field-strip foil

2.3.4 Circuit board carrying the field strips

To achieve the optimal drift field quality for the LP, it is foreseen to equip the inner wall of the drift volume with two layers of field strips, as discussed above. Therefore a flexible circuit board of $2.4\,\mathrm{m} \times 0.6\,\mathrm{m}$ size[4] which carries the field strips (field-strip foil) has to be produced.

The layout of this board is shown in Figure 8. The field strips are arranged with a pitch of 2.8 mm and are separated by gaps of 0.5 mm width. On the top side of the foil[5] - the side which will be in the inside of the drift volume - SMD-resistors of equal resistivity are mounted in the illustrated scheme.

Two resistors connect two neighbouring field strips via an intermediate piece of conducting path. This intermediate piece automatically lies on the intermediate potential of the two adjacent field strips which is the potential for the mirror strip on the opposite side. Two vias[6] transfer the potential to the mirror strip.

The resistivity of the SMD-resistors will be in the mega ohm regime ($1 - 2\,\mathrm{M}\Omega$). For

[4]2.4 m is the inner circumference of the field cage
[5]Dupont$^{\mathrm{TM}}$Kapton
[6]connections through the foil

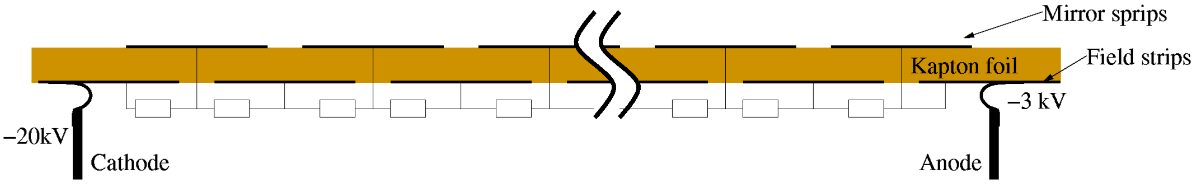

Figure 10: Circuit plan for the connection of the field strips

redundancy there will be two parallel resistor chains.
The field-strip foil will be produced and shipped to DESY in parallel to the field cage's construction. As a first step, smaller sample pieces ($10 \times 8\,\text{cm}^2$) have already been made (see photo in Figure 9). They will be used for mechanical and electrical tests which will eventually result in modifications of the design.
Figure 10 shows the circuit diagram belonging to the discussed electrical connections. The anode could be directly connected to the last field strip on the anode side similar to the cathode, however the layout of the anode interface is currently under discussion with other groups.

2.3.5 High voltage stability of the field cage walls

The field strength in the drift volume of the field cage will be up to $300\,\frac{\text{V}}{\text{cm}}$ which will make it necessary to apply up to 21 kV to the cathode. The walls of the chamber being covered with the grounded shielding layer on the outside and the field strips being connected to the HV on the inside must have a dielectric strength high enough to stand this potential difference.

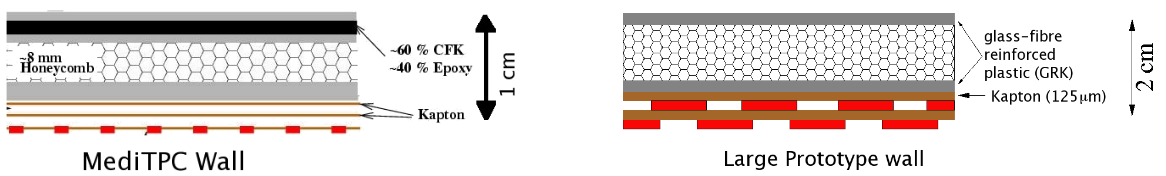

Figure 11: Comparison between the profiles of the MediTPC wall (from [Lux]) and the proposed wall of the LP

At the moment, a smaller TPC prototype, the MediTPC is in operation at DESY (see for example [Lux]). The profile of the MediTPC wall is shown in Figure 11. This chamber was also constructed using honeycomb material, but it has only 1 cm thick walls. It has three layers of 75 μm thick polyimide foil[5] as an isolating layer between the field strips and the sandwich. The chamber can stand up to 16 kV [Lux].
The walls of the LP have an increased thickness of 2 cm. Currently it is planned to have one layer of 125 μm polyimide foil[5] as an isolating layer. Because of the increased thickness of the wall, it can be assumed that the LP will be able to stand at least 21 kV. In addition the HV stability will be tested with sample pieces of the wall.

3 Completion of the field cage

Once the barrel and endplates are fabricated, the field-strip foil will be mounted to the inside of barrel. This procedure is schematically illustrated in Figure 12. The foil will be formed to a cylinder which fits into the barrel and glued to the inside of the wall. In this way, it is possible to solder the SMD-resistors and to do an electrical check of the foil before, so it can be assured that the field strips are properly connected.

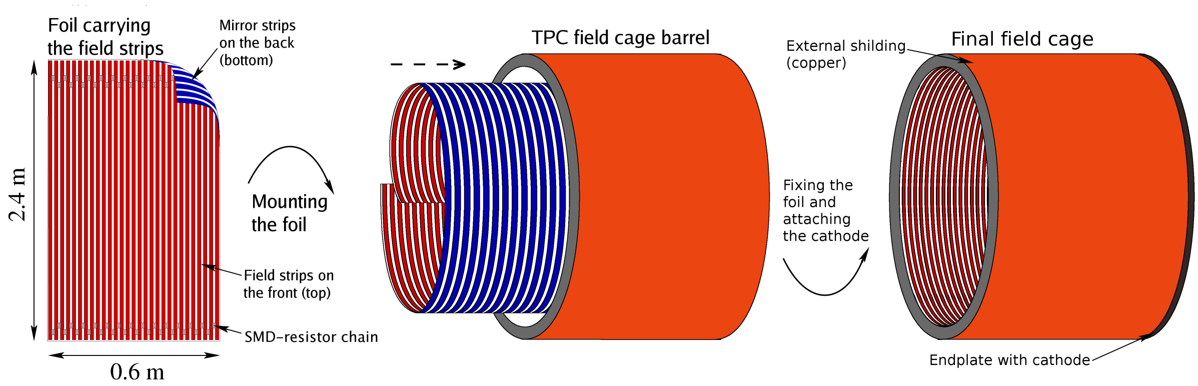

Figure 12: Mounting the field-strip foil into the field cage barrel

4 Conclusions

The field cage of the Large Prototype will have an outer diameter of 80 cm and a drift length of 60 cm. These dimensions are governed by the dimensions and the magnetic field of the PCMAG. Currently the design phase for the field cage is ongoing and a final design will be worked out by mid of January 2007. It is planned to have the field cage barrel available at DESY by June 2007.
In parallel to the construction of the barrel, a special flexible circuit board carrying field strips will be produced and shipped to DESY. This foil will have the appropriate size to be glued to the inner wall of field cage's barrel. In operation the field strips will guarantee the homogeneity of the electric field in the drift volume. Their design was optimised by electrostatic calculations and will be tested on smaller sample pieces which are already at hand.
The production of the field-strip foil, its assembly with SMD-resistors and electric checks will be done before the construction of the barrel is finished. The completion of the field cage including the construction of a cathode and its mounting onto the endplate as well as the installation of the field strips is foreseen to be finished by early July 2007.

References

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