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An ultra-light cylindrical GEM detector as inner tracker at KLOE-2

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Abstract

We are developing a low-mass, fully cylindrical and dead-zone-free GEM detector as inner tracker for the KLOE experiment upgrade at the DA*Φ*NE*Φ* factory. The inner tracker will be composed of five concentric layers of cylindrical triple-GEM detectors (C-GEM), completely realized with very thin polyimide foils. The final result is a very light detector: only 0.2% of X_0 per layer inside the active area. We successfully built and tested with an X-ray gun a small-size prototype operated in current mode with an $Ar/CO_2 = 70/30$ gas mixture. The very positive results obtained with the prototype open the way for a completely new and competitive category of ultra-light fully sensitive vertex detectors for high-energy physics experiments.

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Keywords: GEM; Tracking; Vertex

1. Introduction

In the framework of the R&D for the upgrade of the KLOE experiment we present a novel idea for an ultra-light cylindrical triple-GEM (C-GEM) detector [1,2], for vertex and inner tracking purposes.

The proposed detector will play a crucial role in the study of rare K_S decays and measurements for neutral kaon interferometry. The main physics requirements are moderate spatial detector resolution of $\sigma_{r\phi} \sim 200\,\mu m$ and $\sigma_z \sim 500\,\mu m$ but very low material budget inside the active area: 1.5% of X_0 for the whole sub-detector. The inner tracker will be composed of five layers of C-GEM detectors. Each C-GEM is realized by inserting into one another the required five cylindrical structures made of thin (50–100 μm) polyimide foils: the cathode, the three GEMs and the anode readout. Due to the overall detector dimensions, layer diameters in the range 300–500 mm with corresponding lengths of about 400–600 mm, corresponding to very large GEM foils of up to $600 \times 1500\,mm^2$, are required. The idea is to realize such large GEMs by patching together three relatively small foils ($600 \times 500\,mm^2$), which is still well above present technological limits ($\sim 400 \times 400\,mm^2$). For this, contacts with the Printed Circuits Boards Workshop at CERN, and 3M Company in USA are in progress in order to solve this very challenging problem.

The readout of the detector will be performed with stereo U–V (or X–V) strips engraved on a 50-μm polyimide substrate, with different widths for equal charge sharing. Considering a strip pitch of the order of 650 μm and digital readout, the tracking performance required by the KLOE experiment can be easily fulfilled. Of course, a better spatial resolution down to ∼50 μm could be achieved by using a reduced strip pitch and a center-of-gravity technique with analog readout.

In the following we first describe the basic idea to realize a cylindrical GEM. Then we will discuss the preliminary results from Garfield simulations and the results from tests with an X-ray gun of a small-size prototype operated in current mode using an $Ar/CO_2 = 70/30$ gas mixture.

2. Construction of a small-size C-GEM prototype

The basic components of a C-GEM are the generic cylindrical electrodes: the GEMs, the cathode and the anode. Such electrodes are obtained by exploiting the

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vacuum bag technique and rolling the polyimide circuits onto machined PTFE cylinders that act as molds. The electrodes are glued together with bi-component epoxy along the axial millimetric overlap (2–3 mm wide), where, in case of the GEM foil, there will necessarily be no holes. The effect of this junction line has been simulated and the results are discussed in the next section.

The whole construction procedure of a C-GEM has been tuned while building a small-size prototype: ~90 mm diameter and ~250 mm active length. For this prototype we used GEMs designed for the LHCb experiment and a 50-μm thick Kapton foil, with a 5-μm thick copper deposition, for the anode and cathode. The geometrical configuration of the detector gaps is the standard one: drift/transfer1/transfer2/induction = 3/2/2/2 mm.

The main construction steps are the following:

- the GEM foil is rolled onto the cylindrical mold;
- the GEM foil is glued together with Araldite 2011 along a 2–3 mm overlap junction;
- the cylinder is enveloped in a vacuum bag, and vacuum is established by using a Venturi system (see Fig. 1);
- after the curing cycle (~12 h at room temperature) the GEM foil is easily removed from the cylindrical mold: the results are perfectly cylindrical GEMs, cathodes and anodes;
- on each cylindrical GEM foil 1-MΩ HV-limiting resistors are soldered onto the corresponding six GEM HV sectors;
- the cylindrical electrodes are inserted into one another (cathode, GEM-1, 2, 3, anode, see Fig. 2) and then fiber-glass flanges used as mechanical support are glued onto one another with Araldite 2011.

Fig. 1. A cylindrical GEM foil realized with vacuum bag technology.

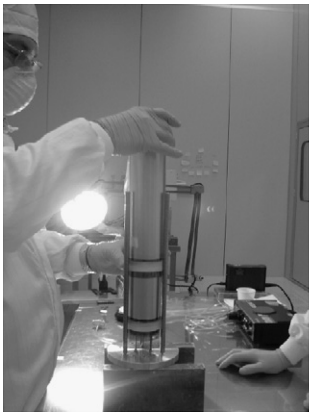

Fig. 2. Assembly of cylindrical GEM electrodes.

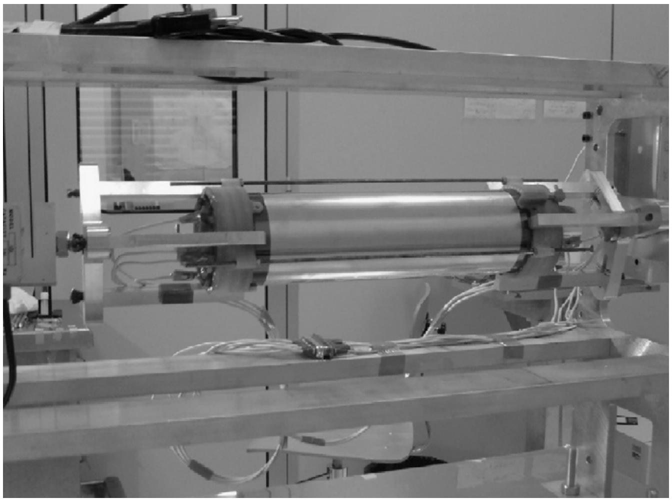

Fig. 3. The C-GEM prototype installed in the stretching system.

After the assembly, the C-GEM prototype was installed in a stretching system equipped with a gauge meter allowing the monitoring and control of the mechanical tension applied to the prototype (see Fig. 3).

3. Simulation of the C-GEM gluing junction line

The construction procedure of cylindrical GEM electrodes implies the presence of a singularity along the gluing junction line made of bare Kapton: neither copper nor holes are present in this region. The effect of this singularity is to create distortions of the transfer field lines above and below the singularity itself, without generating dead zones.

A preliminary simulation study of the effect of such a singularity for the first GEM shows that electrons generated in the conversion gap by a track drift along the distorted field lines and are efficiently driven and focused into the multiplication holes of the GEM, from where they are subsequently transferred to the next gap (see Fig. 4).

The track detection efficiency for MIPs (see Fig. 5), which is practically 100% all over the GEM foil, slightly

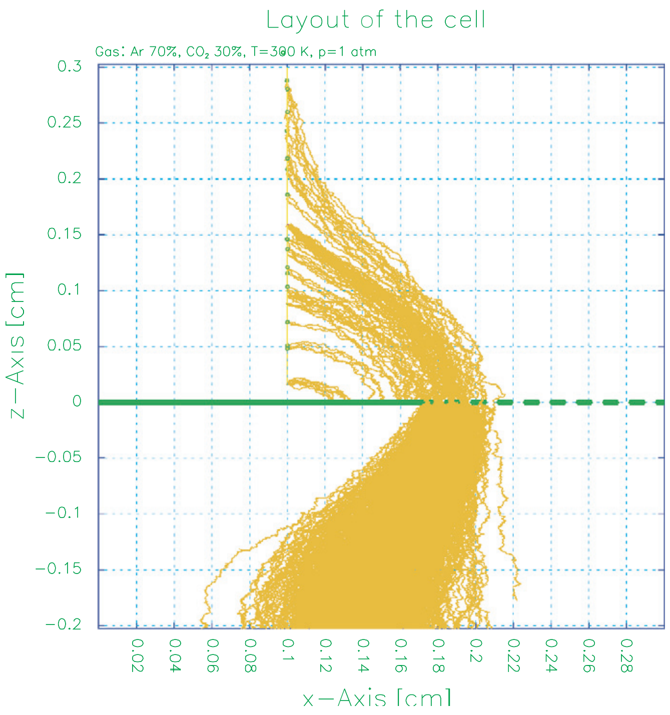

Fig. 4. Garfield simulation of a track crossing the gluing junction line perpendicularly.

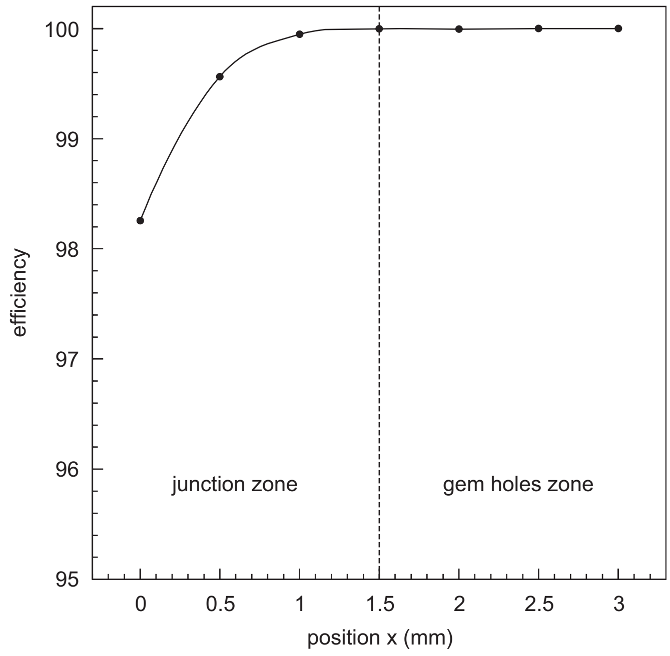

Fig. 5. Track detection efficiency around the gluing junction line of the first GEM.

drops to ~98% for the pessimistic case of tracks crossing perpendicularly in the middle of the junction line. More detailed simulation studies of this effect are in progress.

4. Test of the small-size C-GEM prototype

A C-GEM operated with an Ar/CO$_2$ = 70/30 gas mixture has been studied using an X-ray gun (~6 keV). During the test several gas parameters such as T, P and RH as well as the mechanical stretching tension applied to the prototype have been monitored. In this respect, no critical effect on the detector performance has been observed over a wide range of stretching tensions (10–60 kg for the whole chamber), which was in all cases well below the elastic limit of the Kapton (~1 kg/cm). This means that only quite a

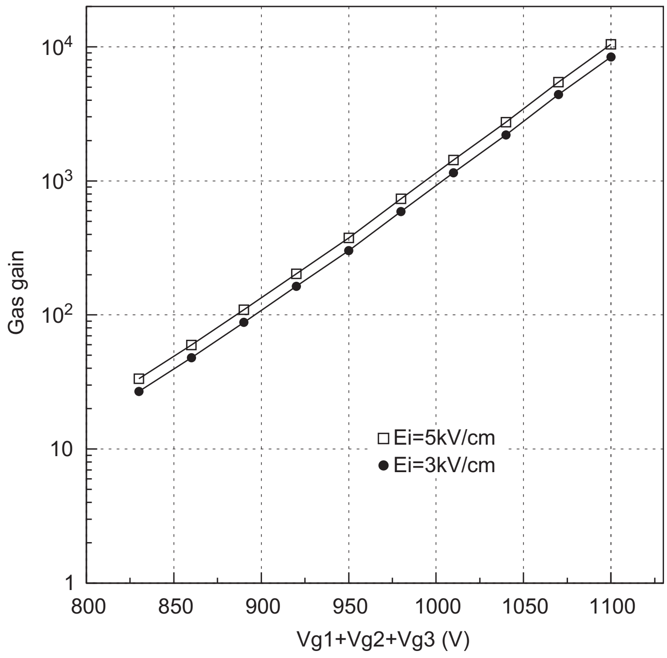

Fig. 6. Gain of the C-GEM operated with an Ar/CO$_2$ = 70/30 gas mixture as a function of the sum of the voltages applied to the three GEMs.

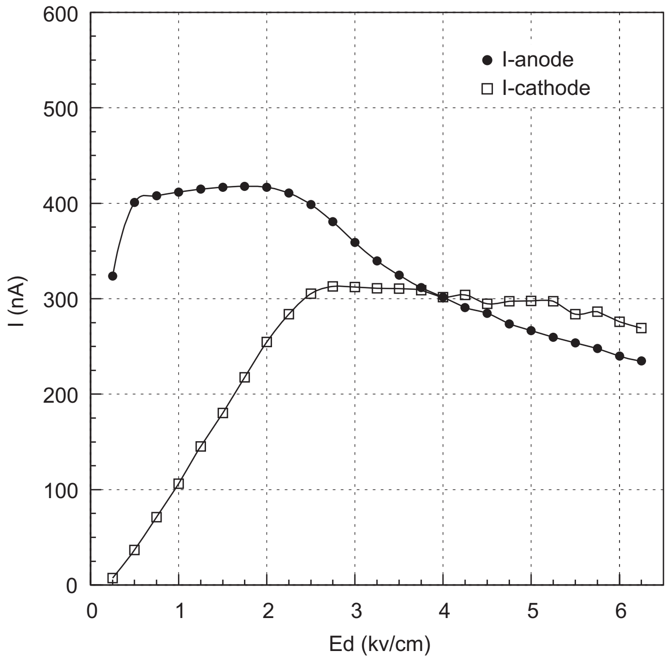

Fig. 7. Electron transparency as a function of the drift field.

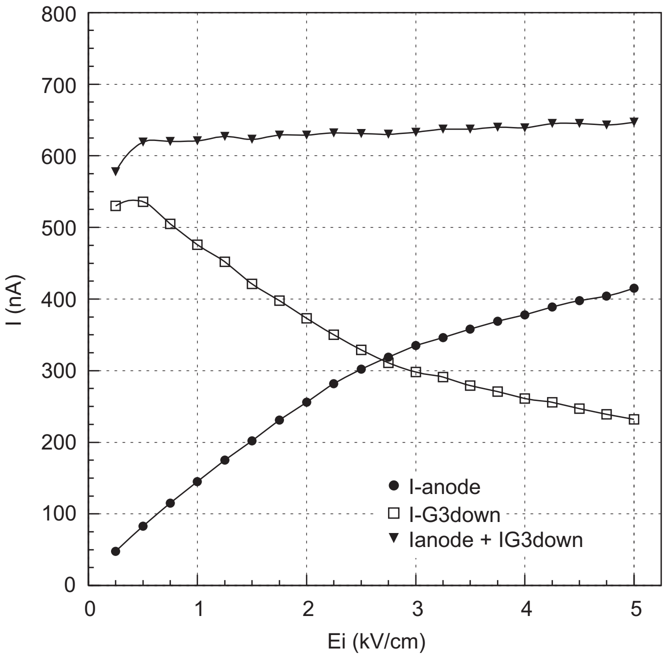

Fig. 8. Electron transparency as a function of induction field.

moderate stretching tension is required to guarantee the good operation of a C-GEM detector.

The main goal of the tests performed on the prototype was to check its general stability: neither dark current nor spurious sparks up to a gain of 10^4 have been observed (see Fig. 6).

In addition, we also measured the typical electron transparency as a function of the drift and induction fields. The results shown in Figs. 7 and 8 are in good agreement with those obtained with planar triple-GEM detectors with the same gas mixture [3].

5. Conclusions

The first working prototype of a low-mass, dead-zone-free C-GEM has been successfully built and tested. The results of the tests performed in current mode with X-rays demonstrate that the C-GEM does not show any difference with respect to a standard planar GEM detector. The stretching tension needed for good detector operation does not seem to be a critical parameter. The simulation of the effects of the singularity due to the gluing junction line of the GEM indicates that only negligible loss of efficiency is expected.

The very positive results obtained with the small-size C-GEM open the way for the construction of a full-scale prototype for the first layer of the inner tracker.

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