The Full Scale Prototype of the Cylindrical-GEM Detector as Inner Tracker in KLOE2

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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 DAFNE Φ-factory.**

The proposed detector will play a crucial role in the study of the K_S rare decays and in the measurement of the neutral kaon interferometry. The main physics requirements are: a good detector spatial resolutions, ($\sigma_{r\phi} \simeq 200\ \mu\mathrm{m}$ and $\sigma_Z \simeq 500\ \mu\mathrm{m}$) and a very low material budget inside the active area (1.5% of X_0 for the whole sub-detector).

The Inner Tracker will be composed by five layers of cylindrical triple-GEM detectors (C-GEM), covering the space from the beam pipe to the inner cylinder of the KLOE main Drift Chamber (from 150 mm to 250 mm radius). Each C-GEM is realized inserting one into the other the required five cylindrical structures made of thin (50 μm) polyimide foils: the cathode, the three GEMs and the anode readout. The final result is a very light detector: only 0.2% of X_0 per tracking layer inside the active area.

After the successful construction and test of a small size prototype (90 mm diameter, 250 mm length), a full scale prototype (300 mm diameter, 352 mm length) of the first layer of the Inner Tracker has been designed in all details, namely mechanics, readout and front-end electronics, exploiting many of the technical solutions we studied and implemented for the planar GEMs of the LHCb experiment, adapted for the cylindrical geometry.

We report about the design, the construction and some preliminary test of such a large prototype that opens the way for a new and competitive category of ultra-light micro-pattern gas vertex detectors.

I. INTRODUCTION

THE KLOE experimental activity is planned to continue at the DAFNE e^+e^- machine upgraded in luminosity and energy. The challenge is to improve the systematics at the level demanded by the increase of the integrated luminosity to 50 fb^{-1} in 3-4 years of running.

The vast physics program, mainly concerning K_S, η, kaon interferometry, charged kaon decays, is focused on events produced close to the interaction point (IP), requiring an optimization of the detection for low momentum tracks coming from the IP and from the K^+K^- decays.

Besides a normal revision of some subsystem (Drift Chamber, FEE, DAQ, online/offline systems) the evolution of the KLOE apparatus foresees the upgrade of the scintillating fiber calorimeter and the insertions of three new devices: a crystal calorimeter placed in front of the Quads, a $\gamma\gamma$ tagger and an Inner Tracker (IT). Concerning the calorimeter the plan is to substitute the present photodetectors with higher granularity or higher Quantum Efficiency devices. The crystal calorimeter is needed to increase the acceptance for photons. The $\gamma\gamma$ tagger is devoted to detect small angles interactions with a technology of Si micro-strips and a plastic scintillator hodoscope.

TABLE I
RECONSTRUCTION PARAMETERS FOR A π TRACK WITH AND WITHOUT THE CONTRIBUTION OF THE INNER TRACKER

	$\Delta x@pca$	$\Delta z@pca$	$\Delta p_x@pca$	$\Delta x@vtx$
IT	0.6 mm	0.9 mm	1.2 MeV/c	1.9 mm
No IT	1.7 mm	2.2 mm	1.6 MeV/c	4.9 mm

The Inner Tracker exploits a novel technology of fully cylindrical GEM (Gas Electron Multiplier [1]) detectors. It is composed by five concentric layers providing a point space 2-D measurement of the track. Each layer is a triple-GEM chamber with cathode and anode made of thin polyimide foils, in order to reduce the material budget. The result is an ultra-light and dead-zone free detector representing a completely new step in the development of tracking devices with gas detectors.

II. THE KLOE INNER TRACKER

The Inner Tracker is composed by five independent tracking layers (L1-L5), in order to achieve a good track reconstruction. The innermost layer will be placed at 15 cm from the beam line, corresponding to 20 τ_S in order not to spoil the K_LK_S interference. The outermost layer will be placed at 25 cm from the beam line, just inside the internal wall of the Drift Chamber.

A. Preliminary simulation results

The Inner Tracker contribution to the overall tracking capability has been simulated implementing the new device in the existing reconstruction algorithm of KLOE. Preliminary results for a π track from a $K_S \to \pi\pi$ decay are shown in Table I.

The reconstruction variables in the first three columns indicate the difference respectively of the x coordinate, z coordinate and x momentum component between the point of closest approach (pca) of the track with respect to the vertex and the vertex itself; the fourth column indicates the sigma of

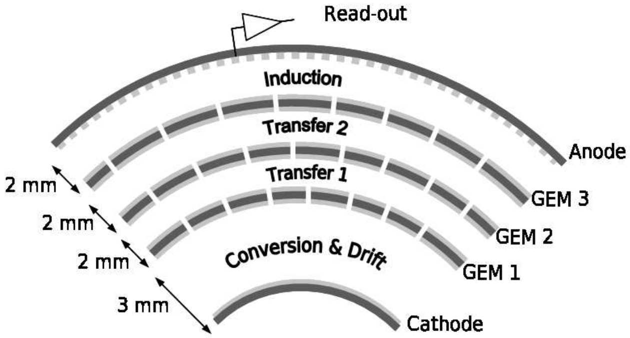

Fig. 1. Scheme of a cylindrical triple-GEM detector.

the difference between the x coordinate of the reconstructed and Monte Carlo vertex.

Although the algorithm is not yet optimized for the new geometry, it is clear how the information from the IT noticeably improve the reconstruction capability of the detector.

B. Inner Tracker motivations and requirements

The insertion of an Inner Tracker in the present KLOE configuration is requested for the optimization of the reconstruction for the physics coming from the interaction region, namely for a fine vertex reconstruction of the K_S, η and η' decay products.

The detector requirements are:

1) $\sigma_{r\phi} \simeq 200$ μm spatial resolution;
2) 5 kHz/cm^2 rate capability;
3) $\leq 1.5\%$ X_0 overall material budget.

While the first two requirements can be easily accomplished by a standard GEM detector, we have developed the technology of fully cylindrical GEM in order to fulfill the very stringent requirement on the material budget, needed to minimize the multiple scattering effect for low-momentum tracks.

A cylindrical triple-GEM detector (C-GEM) is thus obtained inserting one into the other the five cylindrical electrodes defining the gaps with a pattern of 3/2/2/2 mm respectively for the Drift/Transfer1/Transfer2/Induction (see Fig.1).

All the electrodes are realized with thin polyimide foils with a copper clad, resulting in an ultra-light detector. Moreover all the support mechanics is placed outside from the active area, at the edges of the cylinder, permitting the construction of a detector practically free of dead zones. In fact the structural rigidity and the tension of the GEMs is achieved by stretching the detector along its longitudinal axis.

III. THE SMALL SIZE PROTOTYPE

In 2006 ([2], [3]) a small size prototype of cylindrical GEM has been built recycling GEM foils designed for the LHCb Muon System ([4], [5]). Due to the dimensions of the foils (20x24 cm^2 active area) the chamber had a diameter of only 9 cm. This prototype represented the very first test of the novel idea of fully cylindrical GEM detectors, and several construction solutions have been successfully exploited, as the vacuum-bag technique for the gluing of the electrodes.

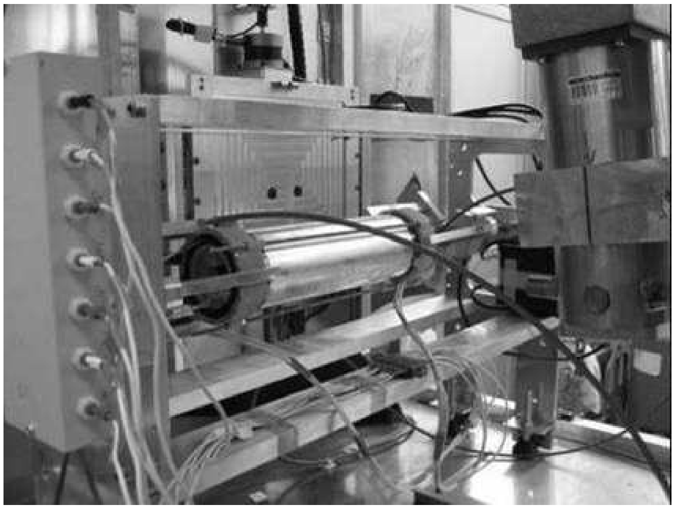

Fig. 2. The small size prototype built in 2006 under the X-ray irradiation facility.

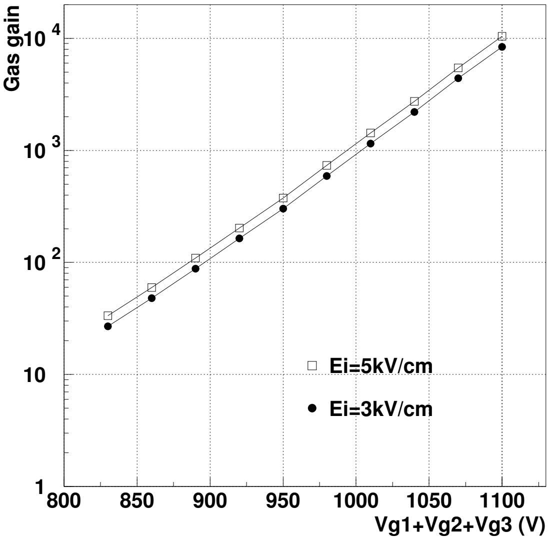

Fig. 3. The gas gain measured for a Ar/CO$_2$ gas mixture at two different values of the Induction field.

The scheme of the detector was that of a standard triple-GEM with 3/2/2/2 mm gaps (respectively for the Drift/Transfer1/Transfer2/Induction). Both the cathode and the anode have been obtained as single polyimide foils (50 μm thickness). Hence the readout had no segmentation and the chamber could only be tested in current mode. Nevertheless it has been operated with a Ar/CO$_2$ (70/30) gas mixture, and tested with a X-ray gun of 6 keV energy (see Fig.2).

The basic idea of the detector has been proved valid and the characteristic plots of the electron transparency as a function of the various fields have been obtained, resulting in good agreement with the reference values found in literature.

A gain plot has been achieved as well, reaching a value of 10000 without any discharge or leakage currents (see Fig.3).

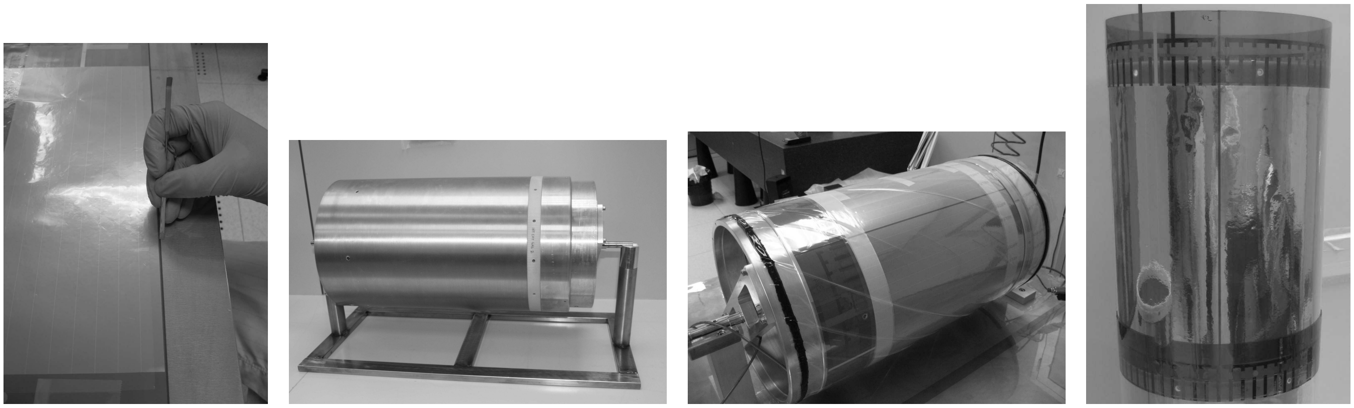

Fig. 4. The various steps of the construction of a cylindrical GEM. See the text for the description.

IV. THE FULL SCALE PROTOTYPE

Supported by the positive, though not exhaustive, results reached with the small size prototype, in 2007 we started the construction of a new prototype with larger dimensions, similar to those of the Layer1 of the final KLOE Inner Tracker: it has the same diameter of 300 mm but a reduced active length of 352 mm (instead of the foreseen 600 mm), due to the present limitation on the GEM foil production technique. For the same reason a single cylindrical electrode (352x960 mm) has been obtained as a join of three identical GEM foils (352x320 mm). The foils have been glued with an overlap region 3 mm wide where the copper has been completely etched.

The cathode is realized as a unique polyimide foil (100 μm) with a copper clad (18 μm) on the internal face.

The anode is realized as a join of 3 foils, made of polyimide, with a read-out segmentation composed by a 1-dimensional set of strips along the axis of the cylinder, for the $r\phi$ coordinate read-out. The 1538 strips have a 650 μm pitch.

A. The C-GEM building procedure

The following are the steps performed to obtain a cylindrical GEM foil (see Fig.4):

1) an epoxy adhesive (typically Araldite) is distributed along one edge (3 mm wide) of the foil;
2) the foil is rolled on an Aluminum mould coated with a very precise 400 μm thick machined Teflon film, to have a non-stick, low-friction surface;
3) the cylinder is enveloped in a vacuum bag and the vacuum is obtained with a Venturi system, providing a high ($\simeq$ 1 kg/cm^2) and uniform pressure throughout the surface of the cylinder;
4) the foil is easily extracted from the mould, thanks to its Teflon surface, and a cylindrical GEM is obtained;
5) with the same technique the cathode and anode foils are obtained as well.

B. The cylindrical cathode

The cathode is realized as a unique polyimide foil, 100 μm thick, with a copper clad of 18 μm on the internal side.

All the support mechanics of the chamber is composed by annular flanges made of Permaglass (G11) placed at the edges of the cylinder. They account for the gas inlets and outlets and their thickness defines the distance between the various electrodes.

C. The GEM foils

The GEM foils have an area of 352x320 mm^2, being one of the largest ever built. For a safe detector operation the foil has independent high voltage sectors, in order to limit the capacitance and hence the energy released through the GEM hole in case of a discharge. Each foil has 20 sectors, with an area of about 56 cm^2, meaning a width of 1.6 cm for the single sector.

Three foils are preliminary joined together, providing a very large foil of 960x352 mm^2. The planar gluing is executed on a table with the technique of vacuum bag. The glue is an epoxy adhesive and the overlaps regions are 3 mm wide.

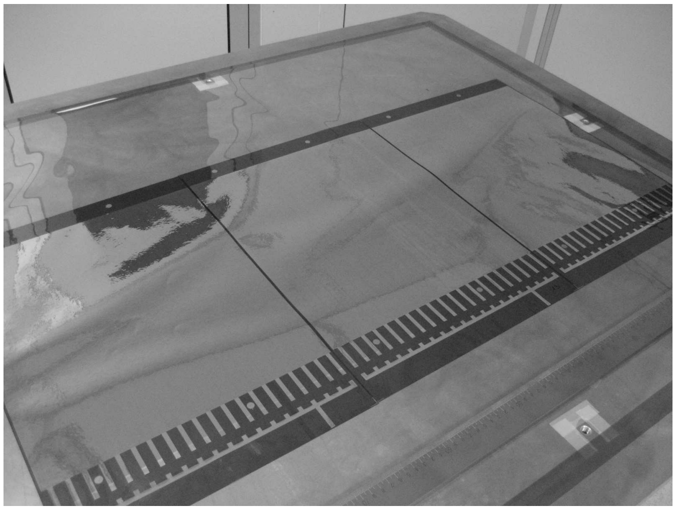

Fig. 5. The GEM obtained as a join of three foils. The dimensions are 960x352 mm^2.

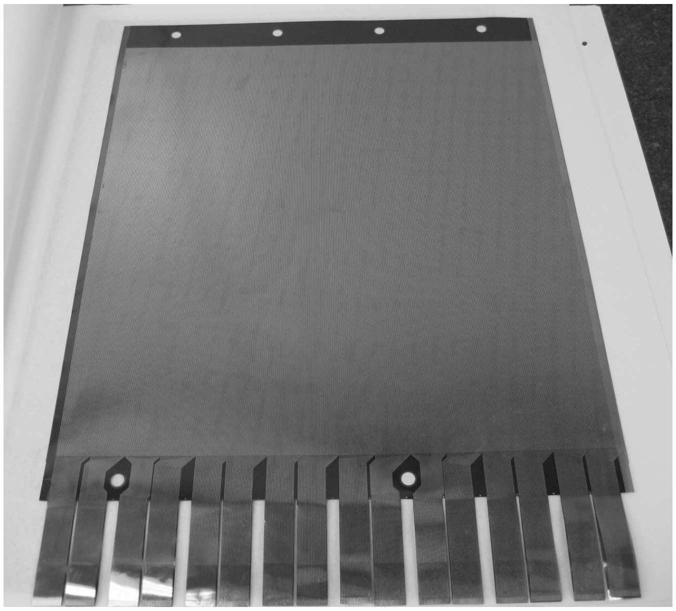

Fig. 6. The anode with the strips for the readout and the flaps for the bonding of the FEE.

D. The anode readout

Also the anode is realized as a join of three foils. Each foil hosts the readout copper strips and the ground. The copper strips side and the ground side are placed on the opposite faces of two different polyimide foils, staggered and glued together. In this way the readout strips have no discontinuity and the pitch value is preserved across the overlap region.

In order to carry out the signals, the strips end-up in polyimide flaps (see Fig.6), each grouping 32 strips, where the FEE is plugged with ZIF connectors. The pitch of the strips is 650 $\mu\mathrm{m}$ in the readout zone, thus providing, when equipped with a digital readout, a $\sigma \simeq 200$ $\mu\mathrm{m}$ spatial resolution, fulfilling the detector requirement in Sec. II-B. In the flaps the pitch is reduced to 500 $\mu\mathrm{m}$ in order to match the pitch of the connector.

E. Assembly of the detector

The extraction of the various electrodes from the moulds is made with the aid of a PVC ring, bound with pins to one of the annular flanges of the cylinder. To accomplish the insertion of the electrodes without damaging the GEMs, a tool has been properly realized (the Vertical Insertion System, see Fig.7).

The electrodes are fixed on two Aluminum plates aligned on a vertical axis, and one is pulled down with a very precise linear bearing equipment.

After the assembly of all the five electrodes the detector has been sealed on both sides and mounted on a support system. Here it has been longitudinally stretched with a tension of 200 g/cm (corresponding to 100 kg of overall tension), measured by a load cell (see Fig.8).

V. THE FRONT-END ELECTRONICS

Two different solutions are foreseen to equip the prototype and the final detector.

Fig. 7. Two electrodes fixed on the vertical insertion system used to assembly the detector.

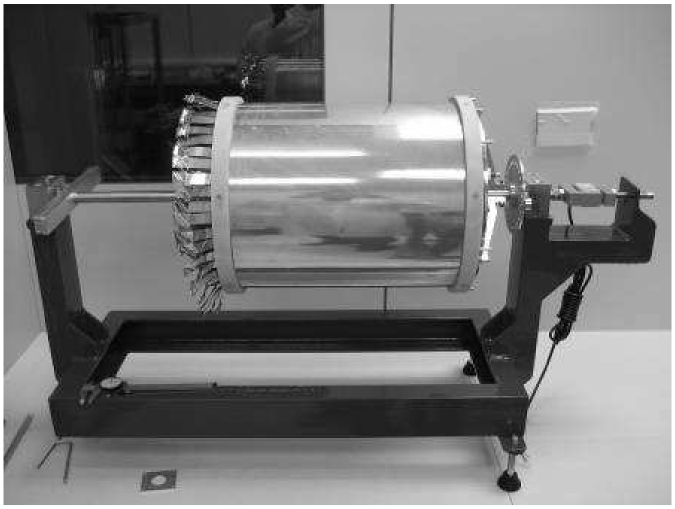

Fig. 8. The chamber mounted on the support system and stretched. The tension is measured by the load cell on the right end.

For the time being we are using a FEE based on the CARIOCA chip, initially developed for the MWPC of the LHCb Muon System, and then adapted to the GEM. It is a digital chip with 8 channels. In order to properly accomodate the chip to the prototype geometry two new boards have been designed and realized: a motherboard plugged directly to the detector with ZIF connectors, hosting the regulators and the I/O connectors; a daughterboard hosting two CARIOCA chips. Moreover 2 daughterboards are plugged on one motherboard, one on each side, for a total of 32 channels filling in a 2 cm wide space.

For the final detector we are developing, in collaboration with the INFN-Bari group, a dedicated chip (GASTONE), providing amplification/shaping/discrimination for 64 channels with serial readout.

VI. PRELIMINARY TEST RESULTS

The chamber has been flushed with a Ar/CO_2 (70/30) gas mixture and operated up to an estimated gain of 5000. No leakage current has been observed, nor discharges. In the next months an extensive test program is foreseen, both with X-rays, cosmic rays and test beams, in order to fully characterize the detector. A study on different gas mixtures (e.g. $\mathrm{Ar/i-C_4H_{10}/CF_4}$) is scheduled as well.

VII. CONCLUSIONS

The KLOE detector is ready to take up the challenge given by the next 50 fb^{-1} of integrated luminosity delivered by the upgraded DAFNE accelerator, in Frascati.

Complex hardware improvements are planned both to reduce the systematics and to open new physics channels. In order to optimize the reconstruction capability for the decays near the interaction point a new Inner Tracker will be inserted inside the Drift Chamber.

To fulfill the stringent requirement on the material budget of the IT ($\leq$1.5 X_0) we have developed a novel technique of fully cylindrical GEM detector. The mechanics has been designed so that no dead zone is present within the active area. The necessary rigidity has been obtained with a longitudinally stretch of the chamber.

A prototype with dimensions similar to those of the final IT has been successfully built, overcoming several assembling difficulties. The positive results open the way for a new and valuable category of ultra-light Micro Pattern Gas Detectors for vertexing purpose.

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