Performance of the Cylindrical-GEM prototype for the Inner Tracker of KLOE-2

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***Abstract*—We developed 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, that opens the way for a new and competitive category of ultra-light, full sensitive vertex detectors for high energy physics experiments, will play a crucial role in the study of the K$_S$ and η rare decays and in the measurement of the neutral kaon interferometry. The main physics requirements are: good spatial resolutions, $\sigma(r\phi) = 200\ \mu m$ and $\sigma(z) = 500\ \mu m$ and a very low material budget, 2% of X$_0$ for the whole detector. The inner tracker will be composed by five layers of cylindrical triple-GEM detectors (CGEM), covering the space from the beam pipe to the inner wall of the KLOE Drift Chamber (from 150 mm to 250 mm radius). Each CGEM is realized inserting one into the other the required five cylindrical structures made of thin (50 μ m) polyimide foils: the cathode, the three GEMs and the anode readout. In order to avoid the use of support frames inside the sensitive volume, the cylindrical GEMs are mechanically stretched from their ends where annular fiberglass frames are glued. The final result is a very light detector: only 0.2% of X$_0$ per layer inside the active area. A full scale prototype (300 mm diameter, 360 mm length) of the first layer of the inner tracker has been successfully built and characterized under different experimental conditions. After a brief description of the construction procedure, the results of the extensive tests are presented.**

I. KLOE-2 AT DAFNE

IN 2010 the KLOE experiment will start a new data taking with the upgraded DAFNE machine delivering a factor of 5 more luminosity. The KLOE apparatus will be upgraded with a new Inner Tracker (IT) placed inside the present Drift Chamber, aimed to improve the reconstruction of low momentum tracks near the Interaction Region, mainly K$_S$ and η decay products.

The IT will be composed by five independent tracking layers of Cylindrical-GEM detectors (CGEM). The diameters will range from 150 mm (closer to the beam pipe) to 250 mm (closer to the inner wall of the Drift Chamber), with an active length of 700 mm. The idea is to realize the very large GEM foils required (up to 1600x700 mm^2) as a join of three smaller foils (about 550x700 mm^2).

The requirements of the experiment are a spatial resolution of $\sigma(r\phi) = 200\ \mu m$ and $\sigma(z) = 500\ \mu m$ and an overall material budget below 2% of X$_0$ to minimize the multiple scattering before the Drift Chamber. The readout will be performed with a XV pattern of readout strips engraved on the anode foil [1].

II. THE CGEM PROTOTYPE

In 2007 a CGEM prototype has been built with the same diameter of the innermost IT layer (300 mm) and a reduced length of 360 mm. For sake of simplicity the anode has been segmented only with longitudinal strips, with a pitch of 650 μm, providing the $r\phi$ coordinate. About 320 strips over the 1500 have been connected to FEE and readout.

Each CGEM is a Triple-GEM detector with a geometrical configuration of the gaps of 3/2/2/2 mm, respectively for drift/transfer1/transfer2/induction. The cathode is inner to the anode.

A. Prototype construction

At first three GEM foils are glued together to obtain the single large foil needed to make a cylindrical electrode. We used an epoxy (Araldite), distributed along an edge of the GEM, on a 3 mm wide region. Then the foil is rolled on an aluminum mould coated with a machined Teflon film providing a non-stick, low friction surface. The mould is then enveloped in a vacuum bag and vacuum is applied with a Venturi system, resulting in a uniform pressure of 0.8 Kg/cm^2 throughout the whole surface. At this step two fiberglass annular rings are also glued at the edges of the electrode, representing all the mechanical frames needed to support the detector. After the curing cycle of the glue the cylindrical electrode is extracted from the mould. Cathode and anode are obtained with the same procedure as well. At the end the five electrodes are inserted one into the other and the detector is sealed with epoxy on both sides [2].

B. X-ray test

The prototype has been flushed with a $Ar/iC_4H_{10}/CF_4 = 65/7/28$ and tested in current mode with a 6 keV X-ray gun. A 10x10 cm^2 planar GEM has been placed in the same gas line and used as a reference in order to normalize the gain for changes of atmospheric variables. The gas gain has been measured up to a value of 2x10^4 and no discharge has been observed. The electron transparencies have also measured as a function of the various fields, resulting in a good agreement with the measurements found in literature. The fluctuations of the gain throughout the 940 mm of circumference were within 9%, showing a good uniformity on such a large surface.

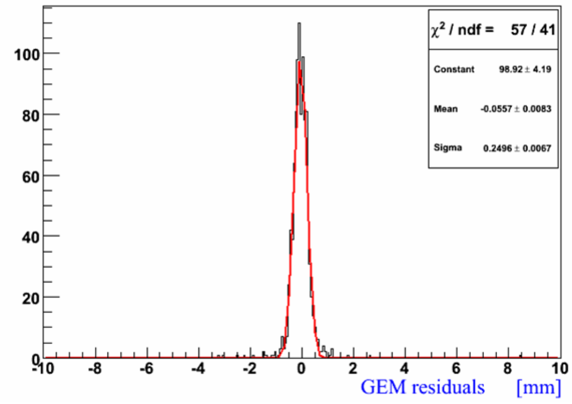

Fig. 1. Distribution of the residuals showing $\sigma_{res} = 250 \mu m$

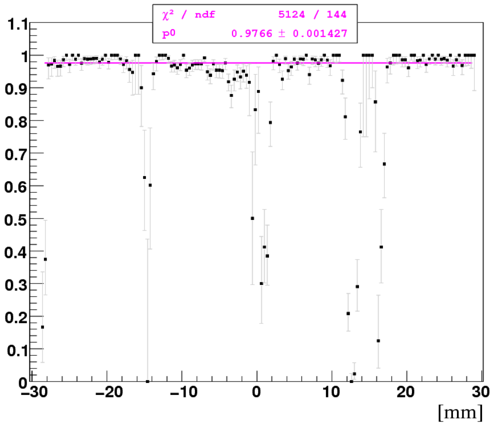

Fig. 2. Distribution of the residuals showing $\sigma_{res} = 250 \mu m$

C. Beam test

The prototype has been extensively tested with the 10 GeV pion beam at the T9 area of CERN PS. Here 128 channels have been equipped with the new GASTONE ASIC, which is being developed for the KLOE-2 experiment, in order to fulfill the low-power consumption and high integration requirements. It is composed of four different blocks: a charge sensitive preamplifier (20 mV/fC sensitivity), a shaper, a leading edge discriminator and a monostable circuit to stretch the digital signal waiting for the KLOE L1 trigger. We mounted on the detector the first release with 16 channels, while 64 channels are foreseen in the final chip [3].

The detector was flushed with a $Ar/CO_2 = 70/30$ gas mixture and operated at a gain of 4x10^4. Figure 1 shows the residuals of the clusters with respect to the reconstructed position of the track. The own spatial resolution of the tracker has been previously measured to be $\sigma_{trk} = 140 \mu m$. If this contribution is subtracted the GEM spatial resolution is found:

$$\sigma_{GEM} = \sqrt{\sigma_{res}^2 - \sigma_{trk}^2} \simeq 200 \mu m \qquad (1)$$

which is exactly what is expected from a digital readout of 650 μm pitch strips.

Figure 2 shows the efficiency of the chamber measured for different positions of the impact track. The average through the whole equipped region is 97.7%. The low efficiency and low statistics points are due to a lack of reconstructed tracks in proximity of the walls of the drift tubes (30 mm diameter). Should not these points be taken into account a very high efficiency of 99.6% is obtained.

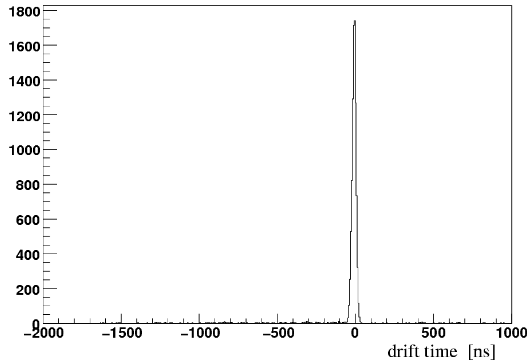

Fig. 3. Time distribution in a regular region showing RMS=13 ns

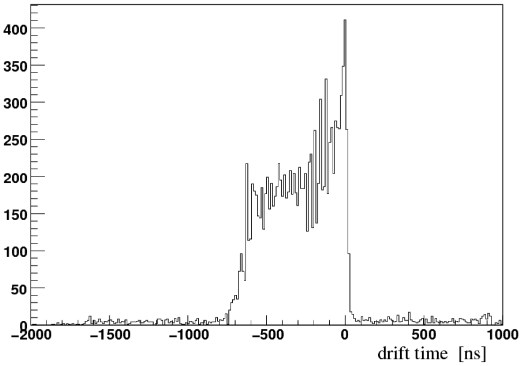

Fig. 4. Time distribution in a joint region showing RMS=200 ns

Time distributions in regular regions and on the joint zone are shown respectively in Figures 3 and 4. In the first case a 13 ns RMS is obtained, in agreement with the performance of the gas mixture. In the second (representing less than 0.4% of the surface) the spectrum is much broader, with a 200 ns RMS. In particular the signals are delayed up to 700 ns, suggesting a longer drift path followed to reach the anode. Such hypothesis has been confirmed by simulations with ANSYS and GARFIELD, showing a distortion of the field lines in the gluing regions, due to a space charge on the dielectric.

III. SIMULATION STUDIES

The mechanical tension needed by the GEM foil in order to avoid oscillations and instability is given by hanging the protype and applying a traction along its axis. A detailed simulation has been performed with the ANSYS program in order to evaluate the static and dynamic behavior of the detector. In particular we found that for a 100 N longitudinal traction the elongation is about 0.03 mm, and the sagitta due the gravity is only 6 μm. We have experimentally verified that such a traction is enough to obtain a proper operation of the chamber.

The final IT detector will require GEM foils with an active area as large as 700x500 cm^2. The ST-DEM-PMT laboratory at CERN, where our GEMs are produced, is planning a change of technology in order to realize such large area foils, leading to a different shape of the holes. We are simulating the new GEM as well, to determine the operating parameters, such as gain, electron transparencies, ion feedback.

IV. CONCLUSIONS

The KLOE-2 experiment is planned to exploit the high luminosity of the upgraded DAFNE machine. A completely new Inner Tracker is crucial to improve the reconstruction capability for physics close to interaction region. A total material budget of $\leq$ 2% of X_0 is needed to preserve the momentum measurement in the outer Drift Chamber.

We proposed a very light detector made of cylindrical GEMs. A prototype with a diameter of 300 mm and an active length of 360 mm has been built. The vacuum bag technique has been exploited to obtain the cylindrical electrodes.

A dedicated front-end electronics is being developed to fulfill the low-power consumption and high-integration requirements of the experiment. It is based on the GASTONE chip performing an amplification, shaping and discrimination of the signal with a serial LVDS output.

The detector and the readout electronics have been extensively tested in several different conditions and the results confirm the effectiveness of the project.

REFERENCES

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