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Construction and test of the cylindrical-GEM detectors for the KLOE-2 Inner Tracker

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ABSTRACT

The upgrade of the KLOE detector at DAFNE, the Φ-factory at the Laboratori Nazionali di Frascati, foresees the insertion of an Inner Tracker around the interaction region, composed of four layers with diameters from 26 cm to 41 cm and an active length of 70 cm. Each layer is realized as a cylindrical triple-GEM detector, a solution that allows to keep the total material of the Inner Tracker below 2% of a radiation length, which is of utmost importance to limit the multiple scattering of low-momentum tracks and to minimize dead spaces, thus maximizing the detector's active area. The peculiar read-out pattern with X and V strips provides a spatial resolution of about 200 μm and 400 μm for azimuthal and longitudinal coordinates, respectively.

After 2 years, the construction of the Inner Tracker has been completed and the detector is ready to be inserted in the KLOE apparatus for a next data-taking run. The details of the manufacturing procedure as well as the results of validation tests are reported.

1. Introduction

The KLOE experiment has collected 2.5 fb^{-1} of integrated luminosity between 2001 and 2006 at DAFNE, the e^+e^- Φ-factory at the INFN Laboratori Nazionali di Frascati, fulfilling a vast program of precision kaon and hadron physics measurements [1]. KLOE-2 represents the continuation of KLOE, at an upgraded DAFNE machine, with a new physics program mainly focused on rare decays of K_S, η and η′, as well as on kaon interferometry and on the search for physics beyond the Standard Model [2,3].

To improve the resolution on decay vertices close to the interaction point, reconstructed from low-momentum charged decay secondaries, a new tracking detector will be installed in the free space between the Drift Chamber's inner wall and the beam pipe, reducing the present track extrapolation length.

This Inner Tracker (IT) will be based on the technology of the Gas Electron Multiplier (GEM) [4]. GEM detectors have been used so far to equip forward regions of experiments at hadron machines (LHCb [5], COMPASS [6], TOTEM [7]), fully exploiting their outstanding rate capability (up to 1 MHz/mm^2 [8]). At the DAFNE e^+e^- collider, the foreseen radiation flux will be well below the GEM limit. Nevertheless, the uniquely low mass of such detectors will be of utmost importance in KLOE to limit multiple scattering of low-momentum tracks, photon conversions and K_S regeneration.

2. Detector description

The IT will be inserted in the existing KLOE Drift Chamber, which is 3.3 m long and 4 m in diameter with an inner radius of 25 cm, filled with a He/iC_4H_{10} gas mixture [9].

The contribution of the IT to the overall material has to be kept as low as possible to minimize the effect of the multiple scattering on the momentum resolution of charged tracks, as well as the probability of photon conversions and of K_S regeneration from K_L. In this regard a limit on the total IT material of 2% of a radiation length (X_0) has been adopted. To fulfill such a stringent requirement we exploited the intrinsic light-weight structure of the GEM foils (50 μm

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thick polyimide bulk, double clad with 3 μm copper) and their extreme flexibility to realize a fully cylindrical triple-GEM detector, avoiding frame overlaps inside the active area [10,11].

The IT has a length of 70 cm along the beam axis and it is composed of four concentric tracking layers. Each one is a triple-GEM detector, including three GEM foils for the multiplication stage (gain $\sim 10^4$), a cathode to set the drift field and an anode acting also as read-out circuit (Fig. 1) [12]. The conversion gaps are placed at a distance of 13, 15.5, 18, and 20.5 cm from the interaction point.

A spatial resolution of $\sigma_{r\phi} \simeq 200$ μm and $\sigma_Z \simeq 400$ μm is achieved using digital electronics coupled to a read-out plane which is patterned with longitudinal X strips with 650 μm pitch, and interleaved, on the same substrate and at the same level, with pads connected through internal vias to form V strips at an angle of $\sim 25°$ (Fig. 3).

The combination of the spatial information of both X and V views provides the final $r\phi$ and Z coordinates, respectively the azimuthal angle and the distance along the beam axis.

3. The manufacturing procedure

The R&D program for this detector included the development of a novel GEM manufacturing procedure tuned together with the TE-MPE-EM CERN group to produce foils of unprecedented size (up to 50×200 cm^2) with a single-mask electro-chemical etching of the micro-holes. This activity has been followed and supported within the RD51 collaboration [13]. The GEMs used in the construction of the IT represent the very first batch of such new single-mask etched foils, exploited for the first time by the KLOE-2 experiment.

A stringent quality check has been performed on all the GEM foils. They have been tested in a nitrogen-flushed box to keep the relative humidity below 10%. At an applied bias voltage of 600 V, each GEM sector (about 80 cm^2) must draw a current of less than 1 nA in order to accept the foil. The discharge rate has also been measured, counting at most 3 discharges per hour on an average. In the end, approximately 25% of the foils have been rejected, mostly due to the presence of dust that finally could be removed with a high-pressure washing performed at CERN. Only a few foils showed serious manufacturing defects and could not be recovered.

We used GEM foils with a length of 70 cm and with a width going from 30 to 43 cm. A single cylindrical electrode is realized according to a procedure specifically developed and tuned for this detector (Fig. 2). At first, three GEM foils are positioned on a flat table provided with reference pins, and are spliced together along their long dimension by depositing an adhesive along 3 mm wide overlap regions, thus obtaining foils that are from 90 to 129 cm wide. These are then rolled around a PTFE-clad cylindrical mold, closed with glue, and then enveloped in a tight bag with a ~0.9 bar vacuum. The pressure, uniformly distributed over the whole surface, allows to obtain a perfectly cylindrical shape. During this procedure two fiberglass rings are also glued at the two ends of the cylinder, on the available polyimide just aside of the active region, acting as spacers defining the gas gap and as support mechanics.

The cathode, that is the innermost electrode, is manufactured in a similar fashion, and then reinforced with a 3 mm thick Nomex honeycomb [14] external to the detector. The outermost plane is the read-out plane, a 350 μm thick multi-layer polyimide flexible circuit with a pattern of X and V strips. The quality tests of the electrical connections for the huge number of lines (more than 10,000 per foil) are performed with a custom-made reflectometer [15]. Once three anode foils are spliced together, the electrode is cylindrically glued on the mold and then externally laminated with a composite sandwich made of two foils of 90 μm thick carbon fiber interleaved by a 5 mm thick Nomex honeycomb. This shell contributes to give an excellent rigidity and robustness to the detector while introducing material equivalent to less than 1‰ of a radiation length.

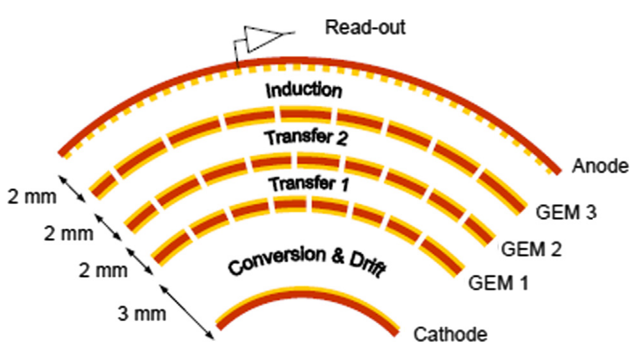

Fig. 1. A sketch of the layout of a cylindrical triple-GEM.

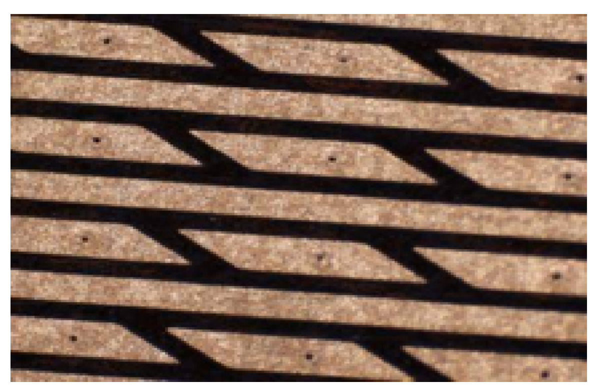

Fig. 3. The X–V patterned read-out plane with straight longitudinal X strips interleaved by parallelogram-shaped pads connected through vias to form V strips at $\sim 25°$.

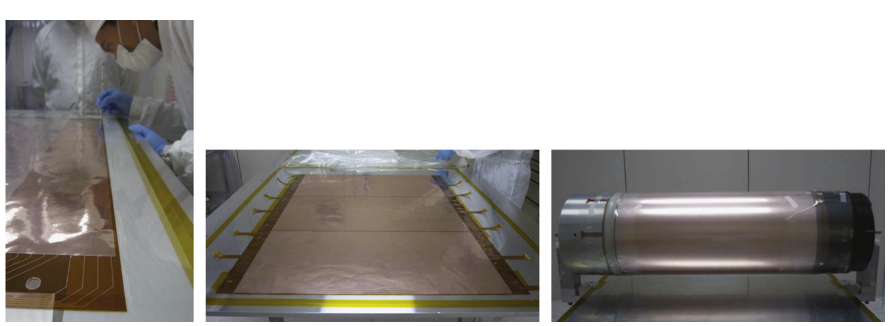

Fig. 2. Three steps of the construction of a cylindrical GEM.