THE FIRST CYLINDRICAL GEM DETECTOR: THE KLOE-2 INNER TRACKER*

E. De Lucia

on behalf of the KLOE-2 Collaboration

Laboratori Nazionali di Frascati dell'INFN
via E. Fermi 40, 00044 Frascati, Italy
erika.delucia@lnf.infn.it

(Received September 6, 2017)

The KLOE-2 experiment is presently running at the e^+e^- DAΦNE Φ-factory of the INFN Laboratori Nazionali di Frascati (LNF) exploiting GEM technology with a cylindrical geometry for the first time in high-energy physics. This novel idea was developed at LNF exploiting kapton properties to build a light and compact tracking system with four concentric cylindrical triple-GEM detectors, inserted around the interaction region and before the inner wall of the pre-existing KLOE Drift Chamber to improve vertex reconstruction capabilities near the interaction region. Single-mask GEM etching, multi-layer XV patterned readout circuit, GASTONE front–end board a custom 64-channel ASIC with digital output, and the Global Interface Board with a configurable FPGA architecture and Gigabit Ethernet, are some of the state-of-the-art solutions of this project. Detector operation, alignment and calibration, never done before for a cylindrical GEM detector, and performance will be reported together with first results from the integrated tracking and vertexing obtained with $\phi \to \pi^+\pi^-\pi^0$ and $K_{\rm S} \to \pi^+\pi^-$ decays.

DOI:10.5506/APhysPolB.48.1701

1. Introduction

KLOE-2 at the e^+e^- DAΦNE Φ-factory of INFN Laboratori Nazionali di Frascati (LNF) is the continuation of the KLOE experiment [1], upgraded with state-of-the-art technology to improve its discovery potential over a broad physics program [2], which includes CPT symmetry and quantum coherence tests with neutral kaons with an unprecedented precision, high

* Presented at the 2nd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland, June 3–11, 2017.

precision studies of $\gamma\gamma$-physics processes and the search for new exotic particles that could constitute the dark matter. The general purpose original KLOE setup consisting of a huge Drift Chamber (DC) [3] and an Electromagnetic Calorimeter (EMC) [4], both immersed in a 0.5 T axial magnetic field, underwent several upgrades through the installation of new sub-detectors: *(i)* state-of-the-art cylindrical GEM detector, the Inner Tracker (IT), to improve vertex reconstruction capabilities near the interaction region, *(ii)* e^+e^- taggers for $\gamma\gamma$-physics the LET [5] and HET [6], *(iii)* CCALT and QCALT detectors [7], crystal and tile calorimeters positioned near the interaction point and along the beam pipe with the goal of improving multi-photon detection in rare decays and background rejection power.

Starting from November 2014, KLOE-2 acquired 3.7 fb^{-1} by June 2017 with the aim of collecting at least 5 fb^{-1} by the end of March 2018.

2. The Inner Tracker

Figure 1 shows the detector composed of four concentric cylindrical triple-GEM (CGEM) with 70 cm total active length and at radii from 13 to 20.5 cm, the first value to preserve the $K_{\rm S}$–$K_{\rm L}$ quantum interference region and the second due to the constraints from DC inner wall. Each CGEM [8] is a triple-GEM detector composed of five concentric cylindrical electrodes (Fig. 2): the cathode, to set the drift field, 3 GEM foils for the electron multiplication and the anode, acting also as a readout circuit.

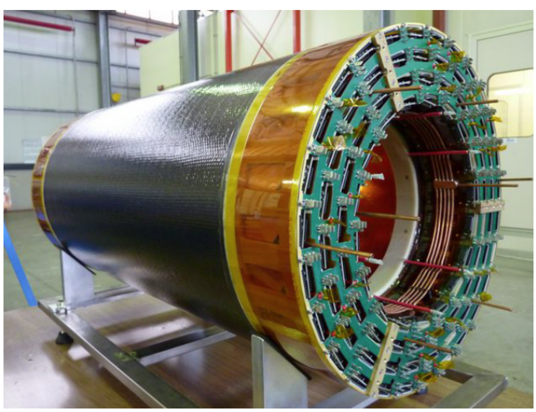

Fig. 1. The Inner Tracker detector.

Three years of R&D demonstrated the feasibility of a cylindrical triple-GEM detector with an XV readout [9–11] and included the tuning and development of a new manufacturing procedure of GEM foils of unprecedented size (up to 50×100 cm^2) with a single-mask electro-chemical etching

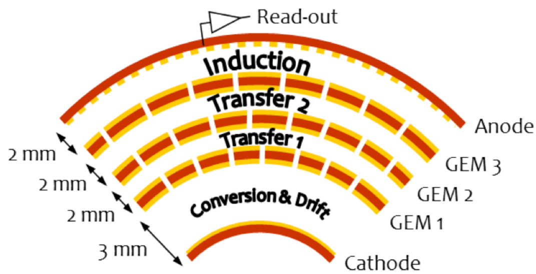

Fig. 2. Schematic cross section of the triple-GEM detector.

of the micro-holes, produced with the TE-MPE-EM CERN group and followed and supported within the RD51 Collaboration [12]. A state-of-the-art multi-layer XV patterned anode readout circuit has been expressly developed with TE-MPE-EM CERN group: longitudinal X strips with 650 μm pitch are interleaved, on the same substrate and at the same level, with pads connected through internal vias to form V strips at an angle within $25^\circ \div 27^\circ$ and with 600 μm pitch, for a total of about 30,000 FEE channels. Space coordinates are reconstructed coupling the anode readout to custom on- and off-detector electronics developed for KLOE-2: the GASTONE front-end, a 64-channel ASIC with digital output [13] and the General Interface Board (GIB) for data collection with a configurable FPGA architecture, Gigabit Ethernet and the readout driver (ROD) [14]. The detector is operated with an $\mathrm{Ar} : \mathrm{iC_4H_{10}}$ 90:10 gas mixture at a nominal effective gain of about 10^4, with electric fields set at 1.5/3/3/6 kV/cm for drift/transfer1/transfer2/induction gaps and GEM1/GEM2/GEM3 voltages set at 280/280/270 V, respectively. The operational parameters have been optimized as a function of the DAΦNE e^+e^- beam currents and machine background conditions. Dedicated on-line procedures are used to monitor IT temperature, currents and voltages, together with occupancy and clustering performance [15] with DAΦNE delivering collision data.

At the IT working point, a satisfactory single-view efficiency of $\sim 92\%$ and a two-view efficiency of $\sim 84\%$ have been measured with cosmic-ray muon tracks reconstructed with DC information [16]. The two-view efficiency is confirmed with collision data using Bhabha scattering events [17].

The IT has been inserted in the free space between the beam pipe and the inner wall of KLOE DC [3] providing $\simeq 150$ μm spatial resolution in the bending plane, $\sigma_z \simeq 2$ mm along the beam line and $\simeq 6$ mm on K_S decay vertices close to the IP. With the IT+DC integrated tracking, this resolution is expected to improve of about a factor 2 [18].

3. Detector alignment and calibration

Alignment and calibration of a novel detector as the CGEM have been among the challenging activities of the KLOE-2 project and, to this extent, the DC excellent track reconstruction has been exploited. In order to evaluate the first set of alignment and calibration parameters, cosmic-ray muon data samples with and without magnetic field have been acquired and then Bhabha scattering events have been used as a cross-check.

The IT–DC residual distributions with Bhabha scattering events using the first alignment and calibration exhibit average widths along the x-axis $\mathrm{Res}(x) \sim 400\ \mu\mathrm{m}$ for all layers, to be compared with the starting value of 1.5 mm without any alignment and calibration, and are all centered around zero within 50 μm [17]. These results are very close to expectations and will improve with presently ongoing refinements of the alignment and calibration procedure.

4. Detector performance

Starting from DC hits and track parameters, IT clusters are included in the reconstruction by using the Kalman filter technique and then track parameters are updated. The vertexing algorithm has been updated as well accounting for the additional IT information. Benchmark studies of the newly IT+DC integrated tracking and vertexing algorithms have been performed using both Bhabha scattering events and data samples of decays close to the IP, seen by both DC and IT detectors. Preliminary results have been obtained using the first set of alignment and calibration parameters. A good figure of merit of the vertex resolution close to the IP is represented by the YV distribution of the y coordinate of the reconstructed vertex position of $\phi \to \pi^+\pi^-\pi^0$ decays, due to the negligible beam size contribution (tens of μm). Figure 3, left shows the improvement on vertex performance in the YV distribution of $\phi \to \pi^+\pi^-\pi^0$ decays, using the integrated tracking. Fitting the distribution with a double Gaussian function, the 3 mm sigma of the narrow component obtained with DC-only reconstruction is reduced to about 2 mm with the integrated reconstruction.

Similar results have been obtained with $K_{\mathrm{S}} \to \pi^+\pi^-$ decays (Fig. 3, right) in which the YV distribution is the convolution of beam size, vertex resolution and K_{S} lifetime. The total sigma $\sigma_{\mathrm{DC}} \sim 1$ cm of the double Gaussian fit to the YV distribution obtained with DC-only reconstruction is reduced to $\sigma_{\mathrm{IT+DC}} \sim 0.7$ cm using the integrated reconstruction.

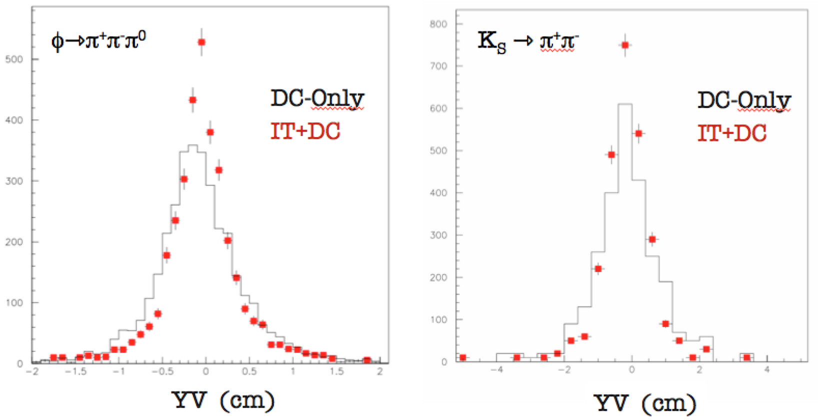

Fig. 3. The distribution of the y coordinate of the reconstructed vertex position of $\phi \to \pi^+\pi^-\pi^0$ (left) and $K_S \to \pi^+\pi^-$ (right) decays: comparison between DC-only (solid line) and integrated IT+DC reconstruction (black points).

5. Conclusions

The KLOE detector has been upgraded with several new sub-detectors for the new data taking campaign within the KLOE-2 project. As of June 2017, the integrated luminosity is 3.7 fb^{-1} with the goal of acquiring at least 5 fb^{-1} by the end of March 2018. The KLOE-2 Inner Tracker is the first CGEM detector used in high-energy physics experiment which has been operated, aligned and calibrated. Good results from the integrated tracking and vertexing obtained with samples $\phi \to \pi^+\pi^-\pi^0$ and $K_S \to \pi^+\pi^-$ have been shown already with the first set of alignment and calibration parameters. Improvements are expected with the refined procedure.

We warmly thank our former KLOE colleagues for the access to the data collected during the KLOE data taking campaign. We thank the DAΦNE team for their efforts in maintaining low-background running conditions and their collaboration during all data taking. We want to thank our technical staff: G.F. Fortugno and F. Sborzacchi for their dedication in ensuring efficient operation of the KLOE computing facilities; M. Anelli for his continuous attention to the gas system and detector safety; A. Balla, M. Gatta, G. Corradi and G. Papalino for electronics maintenance; C. Piscitelli for his help during major maintenance periods. This work was supported in part by the National Science Centre, Poland (NCN) through the grants Nos. 2013/08/M/ST2/00323, 2013/11/B/ST2/04245, 2014/14/E/ST2/00262, 2014/12/S/ST2/00459.

REFERENCES

[1] F. Bossi *et al.* [KLOE Collaboration], *Riv. Nuovo Cim.* **031**, 531 (2008).

[2] G. Amelino Camelia *et al.*, *Eur. Phys. J. C* **68**, 619 (2010).

[3] M. Adinolfi *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **488**, 51 (2002).

[4] M. Adinolfi *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **482**, 51 (2002).

[5] D. Babusci *et al.*, *Acta Phys. Pol. B* **46**, 87 (2015).

[6] D. Babusci *et al.*, *Acta Phys. Pol. B* **46**, 81 (2015).

[7] F. Happacher, M. Martini, *Acta Phys. Pol. B* **46**, 87 (2015).

[8] G. Bencivenni, D. Domenici, *Nucl. Instrum. Methods Phys. Res. A* **581**, 221 (2007).

[9] G. Bencivenni *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **698**, 185 (2013).

[10] A. Balla *et al.*, *JINST* **9**, C01014 (2014).

[11] A. Balla *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **628**, 194 (2011).

[12] M. Alfonsi *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **617**, 151 (2010).

[13] A. Balla *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **732**, 523 (2013).

[14] P. Branchini *et al.*, *JINST* **8**, T04004 (2013).

[15] A. Di Cicco, G. Morello, *Acta Phys. Pol. B* **46**, 73 (2015).

[16] A. Balla *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **845**, 266 (2017).

[17] G. Bencivenni *et al.*, *JINST* **12**, C07016 (2017).

[18] F. Archilli *et al.*, `arXiv:1002.2572 [physics.ins-det]`.