Journal of Instrumentation

The cylindrical GEM detector of the KLOE-2 experiment

To cite this article: G. Bencivenni *et al* 2017 *JINST* **12** C07016

Published by IOP Publishing for Sissa Medialab

Received: *May 27, 2017*
Accepted: *June 26, 2017*
Published: *July 11, 2017*

International Conference on Instrumentation for Colliding Beam Physics
Budker Institute of Nuclear Physics, Novosibirsk, Russia
27 February – 3 March 2017

The cylindrical GEM detector of the KLOE-2 experiment

G. Bencivenni,[a] P. Branchini,[b] P. Ciambrone,[a] E. Czerwinski,[c] E. De Lucia,[a] A. Di Cicco,[b,d,1] D. Domenici,[a] G. Felici,[a] P. Fermani[a] and G. Morello,[a]

[a] *Laboratori Nazionali di Frascati dell'INFN,*
Via Enrico Fermi 40, Frascati, Rome, Italy
[b] *INFN Sezione di Roma Tre,*
Via della Vasca Navale 84, Rome, Italy
[c] *Department of Nuclear Physics, Jagiellonian University,*
Street 11, 30-348 Cracow, Poland
[d] *Dipartimento di Matematica e Fisica, Università Roma Tre,*
Via della Vasca Navale 84, Rome, Italy

E-mail: alessandro.dicicco@roma3.infn.it

Abstract: The KLOE-2 experiment started its data taking campaign in November 2014 with an upgraded tracking system at the DAΦNE electron-positron collider at the Frascati National Laboratory of INFN. The new tracking device, the Inner Tracker, operated together with the KLOE-2 Drift Chamber, has been installed to improve track and vertex reconstruction capabilities of the experimental apparatus.

The Inner Tracker is a cylindrical GEM detector composed of four cylindrical triple-GEM detectors, each provided with an X-V strips-pads stereo readout. Although GEM detectors are already used in high energy physics experiments, this device is considered a frontier detector due to its fully-cylindrical geometry: KLOE-2 is the first experiment benefiting of this novel detector technology.

Alignment and calibration of this detector will be presented together with its operating performance and reconstruction capabilities.

Keywords: Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Particle tracking detectors; Performance of High Energy Physics Detectors

---

[1] Corresponding author.

https://doi.org/10.1088/1748-0221/12/07/C07016

2017 JINST 12 C07016

Contents

2017 JINST 12 C07016

1 The KLOE-2 experiment

The KLOE-2 experiment represents the continuation of KLOE and started its data taking campaign in November 2014 at the DAΦNE electron-positron collider at the Frascati National Laboratory of INFN. In order to confront a rich physics program, based on tests of discrete symmetries and quantum mechanics, measurement of light hadron decays, γ-γ physics processes and search of dark forces mediators [1], the Drift Chamber (DC) and the Electromagnetic Calorimeter (EMC) of the forerunner KLOE apparatus have been upgraded with new calorimeter systems and a tracker, Inner Tracker (IT), all immersed in a 0.52 T axial magnetic field. This novel fully-cylindrical GEM detector has been installed between the inner wall of the DC and the beam pipe with the aim of reducing track extrapolation length, therefore improving the resolution on the decay vertices close to the interaction point (IP), which are reconstructed from low-momentum secondaries. Although GEM detectors are used in high energy physics experiments at hadron colliders, KLOE-2 is indeed the first experiment profiting of novel cylindrical GEM chambers equipped with an X-V strips-pads kapton/copper flexible readout circuit.

2 The Inner Tracker detector

The Inner Tracker, shown in figure 1, upgrades the KLOE tracking system operating together with the DC [2], which inner radius is 25 cm. The chamber volume is 3.3 m length ×4 m diameter and is filled with a He:iC_4H_{10} 90:10 gas mixture. The DC provides $\sigma_{xy} \sim 150\,\mu$m spatial resolution in the bending plane, $\sigma_z \sim 2$ mm along the beam line, ∼ 3 mm on decay vertices reconstructed inside the DC fiducial volume and ∼ 6 mm on decay vertices close to the IP. The new ultra-light IT, with its total material budget below 2 % of the radiation length X_0, allows to limit the multiple scattering of low-momentum tracks and the photon-conversion probability at KLOE-2. The resolution on vertices close to the IP is expected to improve by a factor of ∼ 3 [3].

The IT is composed of four concentric Cylindrical triple-GEM detectors [4], wiht radii 13.0, 15.5, 18.0, 20.5 cm from the inner to the outer layer (figure 1, right). Each layer, with a total active length of 70 cm, is a triple-GEM detector with 5 concentric cylindrical electrodes: a cathode, to set the drift field, 3 GEM foils acting as multiplication stages, and an anode/readout plane. In order to produce foils of unprecedented size ($50 \times 100\,\mathrm{cm}^2$) to build the IT, the R&D phase included the development of a new GEM manufacturing procedure with the TE-MPE-EM CERN group, a single-mask electro-chemical etching of the GEM foils micro-holes. Thanks to the lightness and the flexibility of the GEM foils (50 μm kapton layers clad on both sides with 5 μm copper films) it has been possible to build cylindrical GEM foils with a 3 mm-wide superposition gluing zone only. This activity has been followed and supported within the RD51 Collaboration [5].

The anode plane is a multi-layer kapton/copper flexible circuit: longitudinal X strips, with a 650 μm pitch, and V pads are patterned at the same level on the same substrate; V pads are then connected through internal vias to form V strips, with a pitch of about 650 μm, at an angle in the range $25^\circ \div 27^\circ$, for a total amount of some 30000 front-end channels. Strip signals are read out by front-end 64-channel GASTONE ASIC chips, with digital output, expressively developed for KLOE-2 [6] and then collected by FPGA-based boards and then acquired [7].

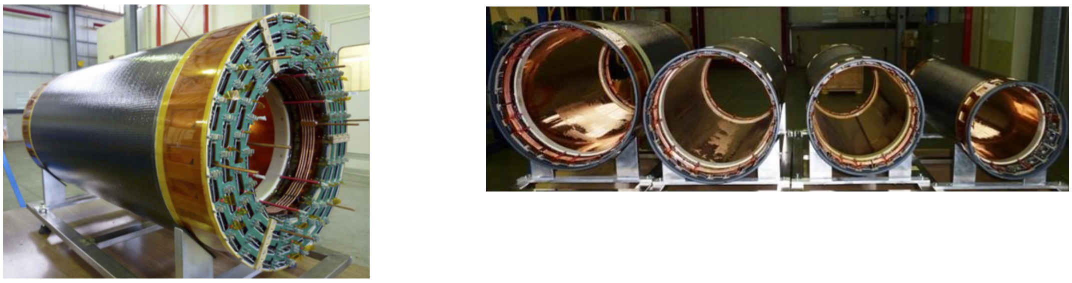

Figure 1. The Inner Tracker detector before its installation in the KLOE-2 interaction region is shown in the left panel. All the four layers before assembling them to build the Inner Tracker are shown in the right panel.

3 Detector operation

The IT is operated with a Ar:iC_4H_{10} 90:10 gas mixture to account for important operating parameters and also to limit the discharge probability measured with α-particles. Since late November 2014, IT efficiency measurements have driven the activities devoted to optimize detector operation with colliding beams, whose working point is presently set at a nominal effective gain of about 1.0×10^4, corresponding to GEM1/GEM2/GEM3 voltages of 280/280/270 V with electric fields set at 1.5/3/3/6 kV/cm for drift/transfer1/transfer2/induction gaps respectively.

Efficiency measurements have been performed by using cosmic-ray muon tracks reconstructed by the DC in the KLOE-2 B-field, selecting tracks crossing the IT at two points and retaining IT clusters closest to the expected positions given by the extrapolated tracks. Single-view and two-view efficiencies up to 98% and 95%, respectively, have been measured at a gain of $\sim 2.0{\times}10^4$, which has been tuned to $1.0{\times}10^4$ in order to safely operate the detector with DAΦNE providing collisions while keeping a good IT clustering efficiency. The single-view efficiency is measured by reconstructing IT clusters with longitudinal X strips only, while the two-view efficiency is measured by reconstructing

IT clusters profiting of both X and V strips. The single-view efficiency as a function of the effective gain of one of the IT layers, measured with cosmic-ray muon data, is shown in figure 2 left: a Fermi-Dirac function has been used to fit data points and to obtain the efficiency curve parametrizing the performance of the detector, which is similar also to all other layers, as measured using the same technique. Setting the effective gain of the IT at 12000 the measured single-view efficiency is $\sim 92\%$ as can be obtained by knowing the parametrization function. The two-view efficiency as a function of the longitudinal z-coordinate, obtained by analyzing a sample of Bhabha scattering events and following the same strategy as for cosmic-ray muon data analysis, is shown on the right in figure 2: the average efficiency value of $\sim 84\%$, obtained by setting the IT effective gain at 12000, is in agreement with measurements performed with cosmic-ray muon data.

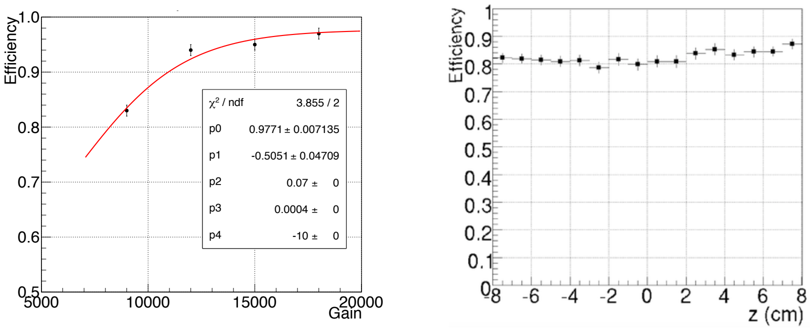

Figure 2. Single-view ffficiency as a function of the gain for IT Layer#1 as measured using cosmic-ray muon data is shown on the left. The red solid line is the efficiency curve obtained by fitting data points (black dots) using a Fermi-Dirac function. The two-view efficiency as a function of the longitudinal z-coordinate measured using Bhabha scattering events is shown on the right for the same IT layer.

Detector operation must be continuously monitored in time and during the data acquisition. Software procedures for identifying *noisy* and *dead* channels [8] have been developed to check the IT status and performance on a run-by-run basis. These pieces of information are stored in the database and then accessed to mask the noisy and dead channels for correctly evaluating efficiency and knowing the detector status run-by-run at the analysis stage. Dedicated runs, including cosmic-ray muon samples, are acquired every three days for detector calibration and status monitoring purposes. From a reference cosmic-ray muon run only few % of noisy and some % of dead channels have been found, considering both X- and V-view strips for all the four IT layers.

The presence of noisy channels is due to the onset of unfavorable running conditions connected to electron and positron anomalous injections or beam losses, causing drops of voltages and fields values in the IT layers, which may in turn induce discharges propagating through GEM amplification stages. A new HV scheme has been developed together with CAEN and a new board with independent floating channels and single voltages adjustment has been successfully tested and installed since September 2016. This new HV configuration, together with DAΦNE beam injection optimization, allows to safely operate the IT. As shown in figure 3, GEM voltages decrease when currents values exceed a 5000 nA limit at beams injection, without affecting electric field values, thus preventing discharges propagation through the GEM stages. Other important parameters of the IT, such as voltages, temperatures, occupancy distributions and clustering performance are kept

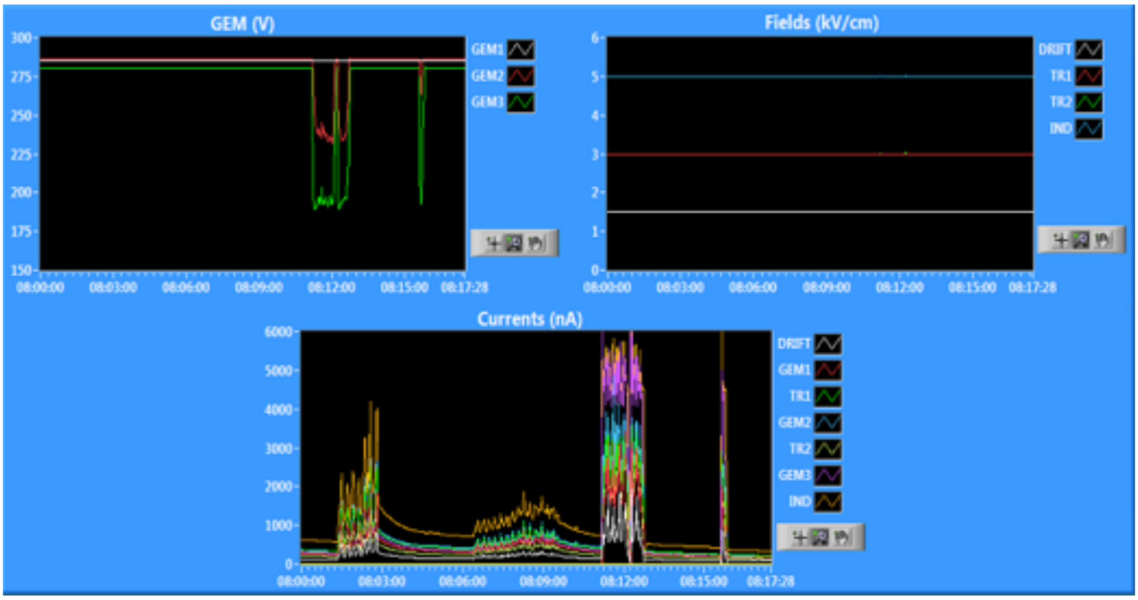

Figure 3. IT Layer#3 currents, voltages and electric field values as measured for each electrode during the tests performed on the new HV-system configuration.

under observation and tracked in time as well by exploiting software tools embedded in the KLOE-2 monitoring environment.

4 Detector alignment and calibration

To achieve the optimal IT reconstruction performance, two effects must be taken into account: a non-radial track effect and the presence of the KLOE-2 magnetic field. The first, due to a non-zero angle between the impinging track and the radial direction of ionization electrons motion, induces a shift and a spread of the reconstructed hit position on the readout plane. The second is due to the Lorentz force acting on the signal electron cloud which is further shifted and spread. The combination of those two effects results in a focusing or a defocusing of the electron cloud, depending on the impact parameter of the track on the cylindrical IT layers. These effects must be studied and measured independently: cosmic-ray muon runs acquired without magnetic field have been used to evaluate the non-radial correction, while the magnetic field influence has been investigated using cosmic-ray muon data.

DC reconstructed tracks, crossing IT at two points and extrapolated backward to the IP, are used as reference for the alignment and calibration studies, providing us with the expected positions on the IT layers. Looking for the three-dimensional IT clusters closest to the expected positions, distributions of *residuals* between the expected positions and the IT measured clusters along the three space coordinates are studied to produce a set of alignment and calibration parameters. Bhabha scattering events are then used to validate the alignment and calibration parameters obtained with cosmic-ray muon data samples. A big improvement is achieved by inserting a first set of alignment and calibration constants in the IT reconstruction, obtaining residual distributions centered around zero within $\sim 50\,\mu$m and with an average width of $\sigma_x \sim 400\,\mu$m along the x-coordinate, to be compared with the starting point value of ~ 1.5 mm. Similar results holds for residuals along y and z coordinates. In figure 4 residual distributions along the x-coordinate for one of the IT layers are shown for the starting point (top left), for cosmic-ray muon data acquired without magnetic field (top right), for cosmic-ray muon data acquired with magnetic field (bottom left) and for Bhabha scattering events (bottom, right). Though present achievements are very close to expectations, the validation of the first set of alignment and calibration constants suggests how to improve and studies for producing more refined alignment and calibration parameters are ongoing.

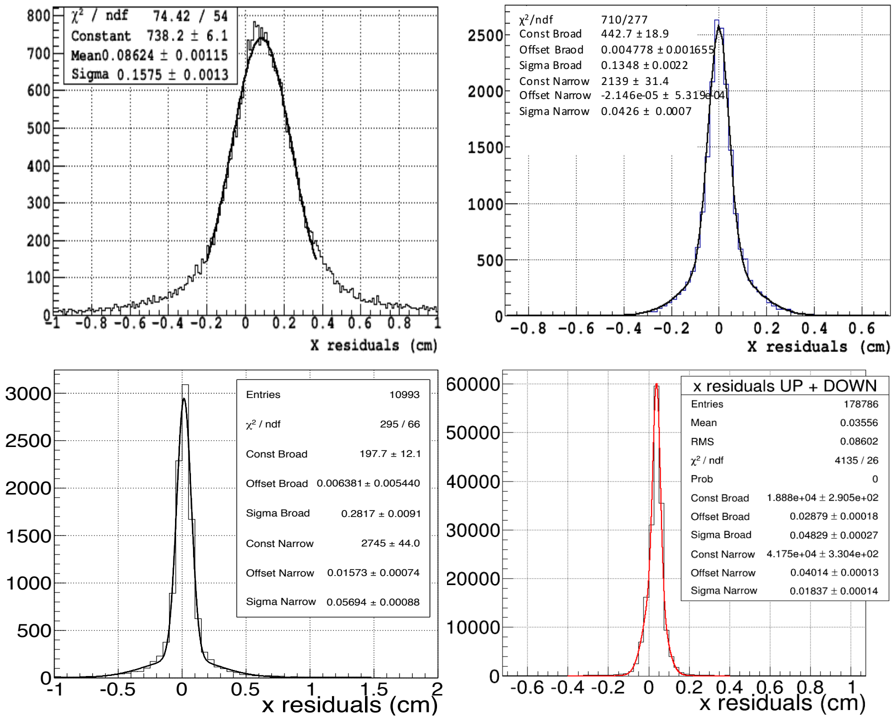

Figure 4. Residual distributions along the x-coordinate for IT Layer#4 for the starting point (top left), for cosmic-ray muon data acquired without magnetic field (top right), for cosmic-ray muon data acquired with magnetic field (bottom left) and for Bhabha scattering events (bottom, right).

5 Track reconstruction with the Inner Tracker

Track and vertex reconstruction at KLOE-2 will benefit of the presence of the novel IT detector, whose installation close to the IP allows to equip the space between the beam pipe and the DC. IT clusters are added to the DC reconstructed tracks by using the Kalman filter algorithm and then track parameters are updated considering both DC and IT information. Bhabha scattering events, selected as for the alignment and calibration studies, are used as benchmark for testing the integrated IT+DC track and vertex reconstruction. The first set of alignment and calibration parameters, obtained as described in the previous section, are inserted to account for non-radial track and B-field effects.

A first version of the track reconstruction, using both IT and DC information, has been implemented and is being validated, using also $\phi \rightarrow \pi^+\pi^-\pi^0$ and $K_S \rightarrow \pi^+\pi^-$ decays — physics processes occurring at and nearby the IP — whose decay vertices are presently reconstructed with a simple vertex finder base on the minimum distance between extrapolated tracks. A very preliminary comparison between DC only and IT+DC integrated tracking, performed using two-pion K_S decays data samples, is shown in figure 5: the minimum distance between the two track helixes is shown on the left, as obtained by using DC only (red) and IT+DC (black) information and the simple vertex finder routine; the correlation plot between z-coordinate and radius in the transverse plane for the reconstructed vertices is shown on the right with the same color code.

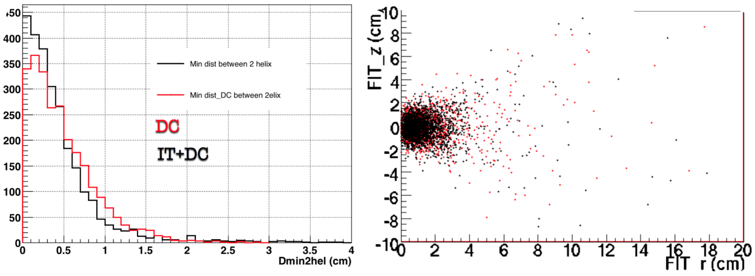

Figure 5. Very preliminary comparison between simple vertex finder positions obtained with DC only (red) and IT+DC (black) information for $K_S \to \pi^+\pi^-$ decays. The minimum distance between pion-track helixes is shown on the left; the z-coordinate vs transverse radius is shown on the right.

The present preliminary version of the integrated tracking is being included in the official reconstruction code of KLOE-2 as well as its interfacing with the vertex finder algorithm. Tests are ongoing using Bhabha scattering events, $\phi \to \pi^+\pi^-\pi^0$ and $K_S \to \pi^+\pi^-$ decays.

6 Outlook and conclusions

KLOE-2 is the first high-energy physics experiment equipped with a fully-cylindrical GEM detector. The encouraging results concerning alignment and calibration, IT+DC integrated tracking and detector operation optimization have been of interest for other experiments, which are going to use the cylindrical-GEM technology (BESIII) or are planning to use it. Operation with colliding beams has been optimized thanks to the implementation of a new HV scheme and the co-operation with DAΦNE operators, who are provided with online feedbacks concerning detector status as monitored during the data acquisition by dedicated tools.

Alignment and calibration of the IT is successfully ongoing, pointing to improve the present average residual resolutions of ~ 400 μm by using cosmic-ray muon data acquired with and without B-field. IT+DC integrated tracking and a simple vertex finder routine are being tested using benchmark physics channels: Bhabha scattering events, $\phi \to \pi^+\pi^-\pi^0$ and $K_S \to \pi^+\pi^-$ decays.

References

[1] G. Amelino-Camelia et al., *Physics with the KLOE-2 experiment at the upgraded DAϕNE*, *Eur. Phys. J.* **C 68** (2010) 619 [`arXiv:1003.3868`].

[2] M. Adinolfi et al., *The tracking detector of the KLOE experiment*, *Nucl. Instrum. Meth.* **A 488** (2002) 51.

[3] KLOE-2 collaboration, F. Archilli et al., *Technical Design Report of the Inner Tracker for the KLOE-2 experiment*, *LNF-10/3(P) INFN-LNF* [`arXiv:1002.2572`].

[4] G. Bencivenni and D. Domenici, *An ultra-light cylindrical GEM detector as inner tracker at KLOE-2*, *Nucl. Instrum. Meth.* **A 581** (2007) 221.

[5] M. Alfonsi et al., *Activity of CERN and LNF groups on large area GEM detectors*, *Nucl. Instrum. Meth.* **A 617** (2010) 151.

[6] A. Balla et al., *GASTONE64: A new front-end ASIC for the cylindrical GEM Inner Tracker of KLOE-2 experiment at DAΦNE*, *Nucl. Instrum. Meth.* **A 732** (2013) 523.

[7] P. Branchini, A. Budano, A. Balla, M. Beretta, P. Ciambrone, E. De Lucia et al., *Front-end DAQ strategy and implementation for the KLOE-2 experiment*, 2013 *JINST* **8** T04004.

[8] A. Di Cicco and G. Morello, *Commissioning of the Inner Tracker of the KLOE-2 experiment*, *Acta Phys. Polon.* **B 46** (2015) 73 [`arXiv:1501.05332`].

2017 JINST 12 C07016