IL NUOVO CIMENTO **45 C** (2022) 109
DOI 10.1393/ncc/i2022-22109-5

Communications: SIF Congress 2021

Construction and assembly of the CGEM-IT innermost layer

S. Gramigna(1)(2)(*)

(1) *Department of Physics and Earth Science, University of Ferrara - Ferrara, Italy*
(2) *INFN Ferrara - Ferrara, Italy*

received 30 January 2022

Summary. — The CGEM-IT, an innovative Cylindrical GEM Inner Tracker, is the Italian proposal for the upgrade of the inner multilayer drift chamber of the BESIII experiment. The tracker consists of three independent layers, each with three multiplication stages. The strict requirements for resolution, size, and radiation length, as well as the need to withstand intercontinental shipping, require the use of advanced lightweight materials and state-of-the-art construction techniques. The construction of the innermost layer of the tracker is described in its entirety: from quality controls of the materials to assembly, which is accomplished with a custom vertical insertion machine.

1. – Introduction

The Cylindrical Gas Electron Multiplier Inner Tracker (CGEM-IT) project aims to develop a new and improved inner tracker for the Beijing Spectrometer III (BESIII) experiment, as its inner Multilayer Drift Chamber (MDC) is experiencing performance degradation due to ageing phenomena [1]. BESIII is located at the Institute of High Energy Physics (IHEP) in Beijing, at the southern interaction point of the Beijing Electron Positron Collider II (BEPCII). BEPCII operates in the tau-charm mass region, more specifically between 2 and 4.95 GeV, and reached its design luminosity of $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [2] in 2016. The configuration of BESIII, described in refs. [3, 4], is optimised for flavour studies. The BESIII collaboration studies a broad physics programme [5, 6] and has observed both the first charged tetraquark candidate, the $\mathrm{Z}_c(3900)^{\pm}$ in 2013 [7], and the first tetraquark candidate with strangeness, the $\mathrm{Z}_{cs}(3985)^{\pm}$ in 2021 [8].

This paper reviews the design choices adopted in the development of the CGEM-IT, with particular focus on the construction and assembly of the innermost layer and describing materials and techniques used for the construction of the detector in order to meet the strict requirements of the upgrade, which are reported in table I.

(*) On behalf of the CGEM-IT Working Group.

TABLE I. – *A list of the CGEM-IT upgrade requirements* [6].

$\sigma_{r\phi}$	$\leq$130 μm
σ_z	$\leq$1 mm
dp/p (1 GeV)	0.5%
Material budget	$\leq$1.5% X_0
Angular coverage	93% $\times$ 4π
Rate capability	10^4 Hz/cm^2
Minimum radius	65.5 mm
Maximum radius	180.7 mm

2. – The CGEM-IT

The CGEM-IT is based on the application of the Gas Electron Multiplier (GEM), first introduced in 1997 by Sauli [9], to a cylindrical configuration. The operation principles of this kind of micro-pattern gaseous detectors are described in detail in ref. [10]. The CGEM-IT will consist of three cylindrical tracking layers, each of which is an independent triple GEM detector with a cathode, a readout anode and three GEM foils. Figure 1 schematically shows the relative positions of the three layers and the spacings that separate the electrodes in each layer. The GEM foils used to build the CGEM-IT consist of 50 μm thick polyimide foils coated with 5 μm of copper on each side, etched to produce 70 μm wide holes with a 140 μm pitch. Cathodes and anodes are also produced on similar substrates; the cathode is copper clad on a single face without holes while the anode is segmented with X strips, running parallel to the beam direction, and V strips, forming a stereo angle with the X strips. The stereo angles of the first, second, and third layer of the detector are 43.3°, −31.1°, and 33.0° respectively.

The detector is designed to fit the tight volume currently occupied by the innermost part of the MDC and to provide a 93% angular coverage without endcaps. To keep the material budget within the upgrade requirements and to be able to withstand intercontinental transport, the cylindrical structural elements supporting cathodes and anodes are built using advanced lightweight materials such as honeycomb, Kapton, and laminated carbon fibre sheets. Permaglass rings, located at both ends of the detector, serve both as spacers, maintaining the gaps between the electrodes, and as structural elements located outside the active area of the detector.

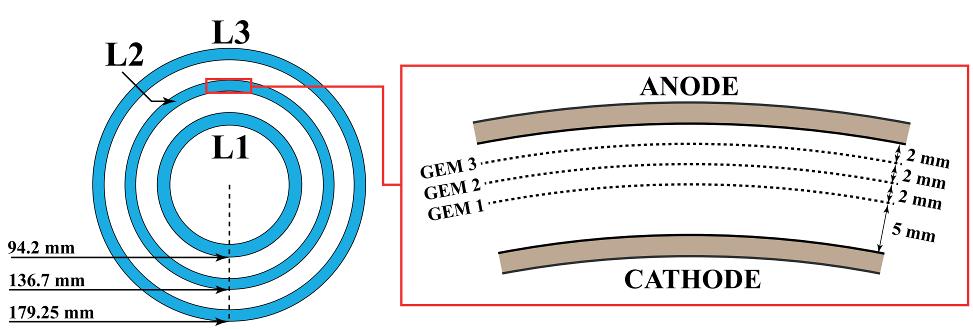

Fig. 1. – Schematic drawing of the structure of the CGEM-IT and its layers. The outer radii of the three layers and the size of the gaps that separate the electrodes in each layer are reported.

A full readout chain based on the Torino Integrated GEM Electronics for Readout (TIGER) chip has been developed alongside the detector. Each TIGER chip can perform simultaneous charge and time measurements on up to 64 channels and does not require an external trigger to operate thanks to the presence of two discriminators for each channel. More information about TIGER and the complete CGEM-IT readout chain can be found in ref. [11] and ref. [12] respectively.

3. – Construction of the innermost layer

Most of the construction of the CGEM-IT takes place in a class 1000 cleanroom at the National Laboratory of Frascati. The construction process of a layer can be divided into three main phases: an initial preparatory phase, the construction of the detector components, and finally the assembly and sealing.

3˙1. *Preparatory phase.* – The cathode, the anodic circuit, and the GEM foils are visually inspected before being resized using a precision cutting machine. This machine consists of an adjustable rectified ruler and a pair of microscopes, used to align the foil before cutting. Each GEM foil undergoes a HV test, in which the sectors of the foil are gradually powered to assess the number of discharges that occur. The structural Permaglass rings undergo a geometric inspection performed using a coordinate measuring machine to measure several points on the inner and outer circumferences of the rings and extract their diameters through a fit. Finally, the Vertical Insertion Machine (VIM), used for the assembly of the detector, is aligned using as reference each of the aluminium moulds that will later be employed in the construction of the detector components.

3˙2. *Construction of the components.* – Each component of the CGEM-IT is built on top of a rectified Teflon-coated aluminium mould, which gives them their cylindrical shape. The building of the cylindrical GEMs for the innermost layer requires glueing a single GEM foil to an inner ring on one end and to an outer ring on the other. A groove on the mould houses the inner Permaglass ring, on top of which Araldite 2011 epoxy adhesive is deposited using a glue transfer. The foil is then wrapped around the mould forming a 3 mm wide overlap, also glued with Araldite 2011, which provides longitudinal closure of the foil. A vacuum bag is used to apply pressure while the glue cures for at least 7 hours. After freeing the mould from the bag, the second ring can be glued at the opposite end of the GEM foil. The outer ring is cut, allowing it to be forced open and placed in position. Glueing is completed through the preparation of a second vacuum bag. Once the glue has cured, the cut on the outer ring is filled using Araldite 103 epoxy glue. The cathodes and the anodes of the detector require a more complex construction procedure due to the presence of cylindrical structural elements. These are sandwiches, consisting of a honeycomb core enclosed between Kapton or laminated carbon fibre skins, which are also built around the moulds by layering the materials and glueing them together with similar techniques. A detailed description of the construction of these components, and of the entire layer, can be found in ref. [13].

3˙3. *Assembly.* – Once all the components are built, they are assembled using the VIM. This consists of a frame, that can rotate by 180°, and a sledge, that can move longitudinally on rails mounted at each side of the frame. First, the mould supporting the anode, which is the largest component, is inserted at the bottom of the machine. The sledge is then lowered until it is aligned with the anode ring. The two are connected together so that when the sledge is lifted it separates the anode from the mould. Once the anode has been fully extracted, the mould can be removed from the machine and replaced with the one supporting GEM3. The sledge is lowered again until the rings of the anode and GEM3 are aligned. The top rings are glued together using Araldite 103 epoxy glue, thickened with silicon microspheres in order to prevent it from dripping underneath the width of the rings. After the 23 hours required for the glue to cure, the sledge can be lifted to extract GEM3 from the mould. When GEM3 is completely pulled out, the mould is removed from the base of the machine and the whole frame is rotated by 180°, allowing access to the bottom rings. These are glued together and, after the glue has cured, the machine can be rotated back to the initial position. This process is repeated until all components are assembled. Finally, the detector is sealed at both ends using thickened Araldite 103. Once the glue has cured, the detector can be removed from the machine and positioned horizontally on a crib to allow the sealing of the pinholes present on the rings.

When the sealing process is complete, the detector is subject to the Quality Assurance and Quality Control (QA/QC) protocol, which includes the measurement of resistances and capacitances between neighbouring sectors, a gas leakage test, and the powering of all the electrodes at nominal values [14].

4. – Conclusions

This second production of the CGEM-IT innermost layer successfully passed the first round of tests following the assembly stage. It was then shipped to IHEP and showed no signs of transport damage upon arrival. After passing a second round of QA/QC tests, the detector was installed in a dedicated cosmic ray telescope setup along with the middle layer. Both detectors have now been collecting data for more than a year and, despite the lack of regular on-site maintenance due to the ongoing pandemic, they show a relatively stable behaviour.

* * *

The research leading to these results has been performed within the BESIIICGEM Project (645664), funded by the European Commission within the call H2020-MSCA-RISE-2014, and within the FEST Project (872901), funded by the European Commission within the call H2020-MSCA-RISE-2019.

REFERENCES

[1] Dong M. Y. *et al.*, *Chin. Phys. C*, **40** (2016) 016001.
[2] Zhang C. *et al.*, *Chin. Phys. C*, **33S2** (2009) 60.
[3] Ablikim M. *et al.*, *Nucl. Instrum. Methods A*, **614** (2010) 345.
[4] Cao P. *et al.*, *Nucl. Instrum. Methods A*, **953** (2020) 163053.
[5] Yuan C. Z. and Olsen S. L., *Nat. Rev. Phys.*, **1** (2019) 480.
[6] Ablikim M. *et al.*, *Chin. Phys. C*, **44** (2020) 040001.
[7] Ablikim M. *et al.*, *Phys. Rev. Lett.*, **110** (2013) 252001.
[8] Ablikim M. *et al.*, *Phys. Rev. Lett.*, **126** (2021) 102001.
[9] Sauli F., *Nucl. Instrum. Methods A*, **386** (1997) 531.
[10] Sauli F., *Nucl. Instrum. Methods A*, **805** (2016) 2.
[11] Rivetti A. *et al.*, *Nucl. Instrum. Methods A*, **924** (2019) 181.
[12] Amoroso A. *et al.*, *JINST*, **16** (2021) P08065.
[13] Gramigna S., Master Thesis, University of Ferrara (2021) `https://jinst.sissa.it/jinst/theses/2021_JINST_TH_004.pdf`.
[14] Balossino I., *JINST*, **15** (2020) C08013.