The new BESIII inner tracker: CGEM-IT

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Summary. — The extension of the BESIII (IHEP, Beijing) experiment's data taking until 2030 has initiated a program to improve both the accelerator and detector, which includes the replacement of the internal drift chamber with a Cylindrical GEM Inner Tracker (CGEM-IT). The CGEM-IT consists of three coaxial layers of triple GEMs and aims to restore efficiency, improve z-coordinate determination and refine the reconstruction of secondary vertex positions, with a resolution of 130 µm in the xy plane and less than 500 µm along the beam direction.
A dedicated system based on TIGER, a 64-channel ASIC, was developed to read out the signal, providing an analogue reading of charge and time and digital transmission of the information to the CGEM-IT acquisition board. The assembly of the three layers was completed in October 2023 and the detector was installed in BESIII in October 2024, after a year of commissioning on cosmic ray stands. A second cosmic ray data acquisition campaign is currently underway to evaluate the performance after installation in BESIII.
The general status of the CGEM-IT project will be presented, with a focus on the results obtained from cosmic ray detection.

1. – BEPCII and BESIII

The Beijing Electron Positron Collider II (BEPCII) is an e^+e^- collider, located at the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences in Beijing. Since the energy at the center of mass is in the range of 2.0 - 4.95 GeV, BEPCII is a unique machine operating in the τ-charm energy range [1].

BESIII is a cylindrical spectrometer that has been operating at the BEPCII interaction point since 2008 [2]. Its components are a Main Drift Chamber (MDC) for tracking charged particles, a Time-Of-Flight system (TOF) for particle identification and an Electro-Magnetic Calorimeter (EMC) for measuring the energy of both photons and electrons, all maintained in a 1 T magnetic field generated from a SuperConducting solenoid magnet (SC solenoid). Multiple layers of Resistive Plate Chambers (RPC) are attached to the outside of the SC solenoid for counting muons.

The experiment holds the record for the world's largest data sample of J/ψ states, counting more than 10 billion events.

An upgrade of both BEPCII and BESIII has been underway since 2017 to extend the experiment's data taking at least until 2030, while improving its performance to contribute to cutting-edge physics research. Once this upgrade is completed, the experiment will actually be able to study the universality of the lepton flavor, the unitarity of the Cabibbo–Kobayashi–Maskawa matrix and the validity of the lattice QCD [3].

The BEPCII modifications were developed to improve both the energy at the center of mass and the luminosity. The initial maximum energy value of 4.6 GeV was raised to 4.95 GeV in 2021, and will be increased to 5.6 GeV during a further update scheduled for 2028. The integrated luminosity has been increased by about 30 % for long runs with the introduction of a top-up injection scheme in 2019, while the latest upgrade will grant a factor three improvement in the peak luminosity at 2.35 GeV, reaching a maximum value of $11 \times 10^{32}\,\mathrm{cm^{-2}s^{-1}}$ [4].

The upgrade of the BESIII spectrometer, on the other hand, consisted in the replacement of the 8 inner layers of the MDC, dubbed Inner Drift Chamber (IDC), which have shown a gain loss per year of about 4 % since 2009, due to the high rate to which they are subjected [5].

2. – The CGEM-IT

Designed by the Italian group with the experience acquired in the Gas Electron Multiplier (GEM) technology [6] for the KLOE-2 experiment [7], the Cylindrical GEM Inner Tracker (CGEM-IT) is composed of three independent cylindrical triple GEM layers. The use of three amplification stages for each layer allows higher effective gain at lower potentials while keeping the discharge probability low. Furthermore, the triple GEM achieves a higher operation rate and have a better aging resitance in comparison to wire chambers.

The spatial resolution along the beam direction of less than 500 μm given by the overlapping of the two sets of strips (X-strips parallel to the axis of the cylinder, and V-strips at an angle to the X-strips, 570 μm and 130 μm wide respectively) will be better than that of the inner drift chamber.

2˙1. *Readout electronics*. – Figure 1 shows a schematic representation of the readout chain developed for the CGEM-IT [8]. Each strip of the detector is read by one of the 64 channels of the 160 TIGER chips (Torino Integrated GEM Electronics for Readout) [9], which are hosted in pairs on 80 Front End Boards (FEBs) installed on-detector. These ASICs amplify and process the incoming signal through an analog front-end and transmit the digitized information about the time and charge of each event to the off-detector electronics through a digital back-end.

Power supply, configuration and readout of the TIGERs are handled by 22 GEMROC (GEM Read-Out Card) modules, each consisting of an interface card connected via a board-to-board HSMC (High Speed Mezzanine Card) connector to a development kit hosting an Arria V GX FPGA board. A single GEMROC can manage up to 4 FEBs, for a total of 8 TIGERs.

The timing and trigger signals coming from BESIII are distributed by another GEMROC with a different firmware (global FANOUT) via 4 local FANOUT modules.

The data acquisition is done via a single Python software called GUFI (Graphical User Frontend Interface [10]), which communicates with the system via Ethernet connections and stores the collected data on a server for offline integration with the outputs of the other BESIII sub-detectors.

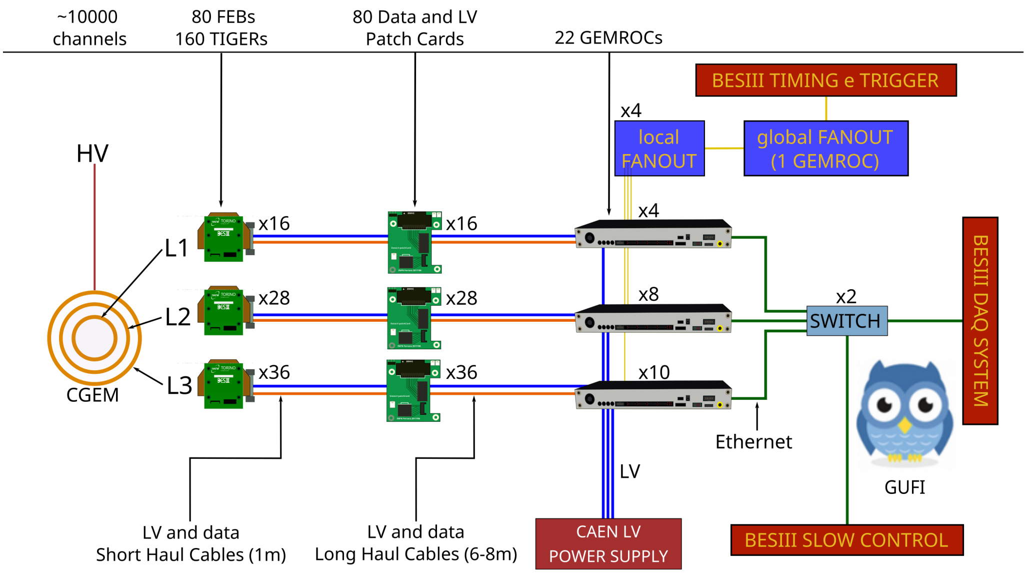

Fig. 1. – Layout of CGEM-IT readout chain.

3. – Integration and commissioning

The two inner layers (L1 and L2) were fully assembled in 2019 and taking data since 2020 [4], but due to the COVID-19 pandemic they were operated remotely until November 2022. The outer layer (L3) was assembled in July 2023 in a class 1000 clean room at IHEP, combining the electrodes prepared in Ferrara and then shipped on mandrels to Beijing [11]. After the three layers were joined, the commissioning of CGEM-IT was performed with the detection of cosmic rays from December 2023 to September 2024.

The detector was mounted on a stand with one scintillator plate at the top and one at the bottom as shown in fig. 2. The coincidence of the signals generated by these scintillators was used as the trigger signal. The collected data was used to evaluate the performance of the detector with the following results.

The noise levels differ between the layers, as expected due to their different mechanical features. In particular, the X-strips of Layer 1 have higher noise levels, which is due to the carbon fiber structure they are close to.

Using a Charge Centroid (CC) algorithm to determine the position of an event has yielded a spatial resolution of about 200 µm for tracks with an incidence angle of less than 5°. Since the CC resolution deteriorates at higher angles as shown in fig. 3, a micro-Time Projection Chamber (μTPC) algorithm is underway for these tracks, since it has been showed to have the capability to guarantee the expected performance [12]. All three layers have shown a tracking efficiency of more than 95%. These results were presented to the IHEP executive board and the BESIII collaboration, which granted approval for the installation of the CGEM-IT in BESIII at the end of June 2024.

4. – Installation

In September 2024, the Chinese team removed the IDC and then sealed the Outer Drift Chamber (ODC) by inserting an aluminum cylinder. It was then possible to proceed

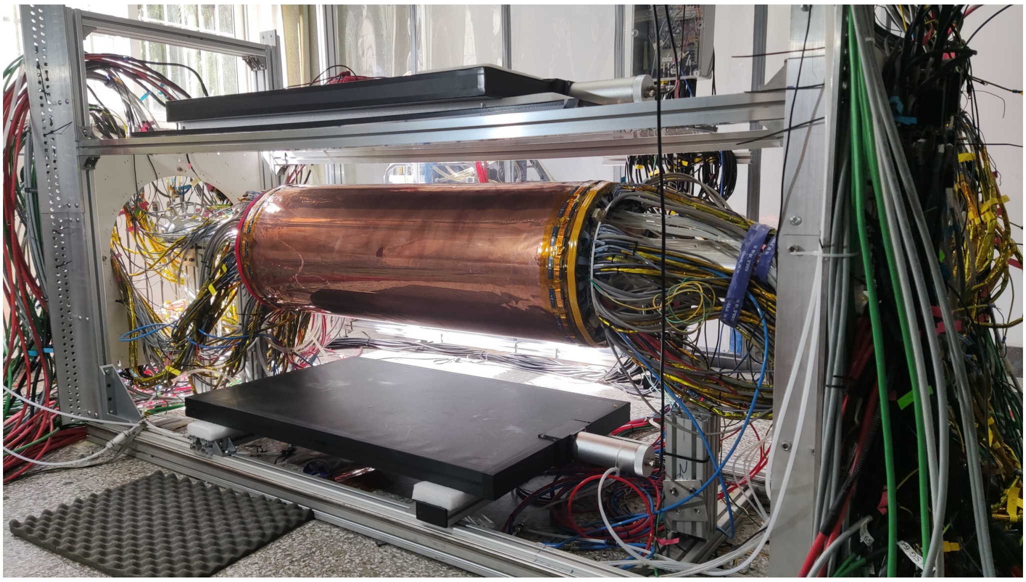

Fig. 2. – The CGEM-IT on its cosmic stand.

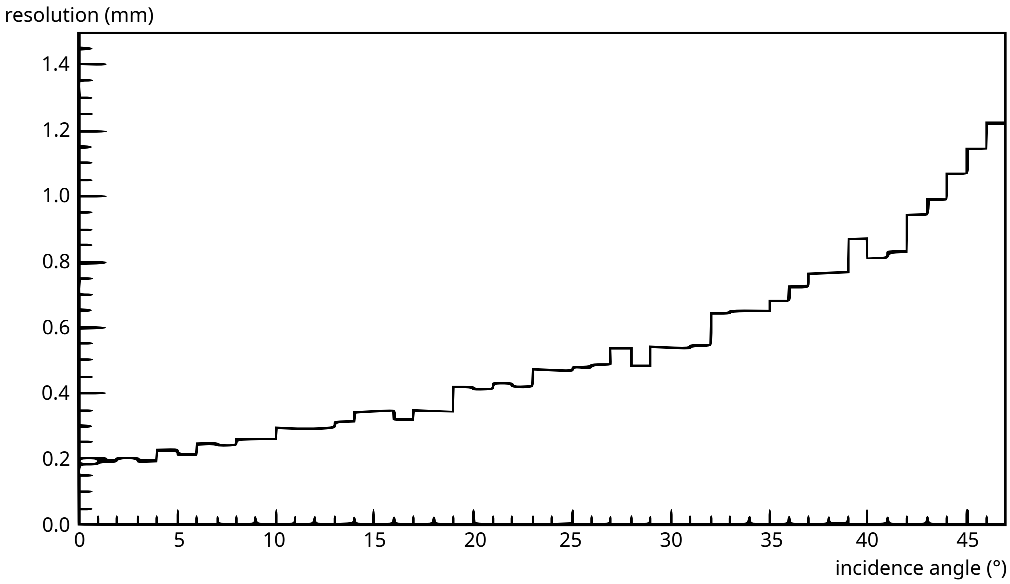

Fig. 3. – Spatial resolution for tracks with different incidence angles obtained using a Charge Centroid algorithm.

with the installation of the CGEM-IT.

The detector was brought into the experimental hall on October 2, 2024. It was mounted on a trolley that was slowly pushed by hand on a rail leading inside the spectrometer and reached its final position on October 5.

All connections were installed: the water cooling system for the detector electronics, the gas system for distributing the argon-isobutane mixture (91:9) to the three layers volumes, the high voltage for generating the fields and the low voltage supply for the FEBs. On October 19, the CGEM-IT was switched on inside the spectrometer for the first time and achieved stability with operating values for the fields.

This was followed by an operational phase to optimize the integration, during which additional copper shields were added to better isolate the MDC and CGEM-IT readout.

On 27 February 2025, the spectrometer was closed and the integration of the BEPCII upgrade began, while the Italian team completed the integration of the CGEM-IT handling and monitoring into the BESIII Slow Control system. The original readout chain design, which included two VME modules for online data integration into the BESIII DAQ data stream [8], was replaced by the design presented above, where a server with a dedicated GUFI installation took over the data acquisition.

5. – Conclusions

After 10 years of work, the CGEM-IT has finally been completed. The performance demonstrated in the 10 months of cosmic rays commissioning led to approval in June 2024 for its installation inside the BESIII spectrometer, which was completed in October 2024. Following the completion of its integration into the BESIII systems, a new phase of cosmic rays commissioning inside the spectrometer has begun and continued until the BEPCII beams were switched on in May 2025.

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