PROCEEDINGS OF SCIENCE

The CGEM-IT of the BESIII experiment

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BESIII is a spectrometer hosted at the leptonic collider BEPCII, at the Institute of High Energy Physics, in Beijing, since 2009. Its program covers charmonium(-like), charmed, and light hadrons spectroscopy, new physics, and QCD studies. The physics program has recently been extended up to 2030. In 2024, both the accelerator and the spectrometer underwent an upgrade program. The inner drift chamber, which was showing aging effects, has been replaced with a new inner tracker based on the cylindrical GEM technology. The CGEM-IT deploys three coaxial layers of cylindrical triple-GEM detectors. A dedicated electronic readout chain, based on the TIGER ASIC, and the FPGA-based GEMROC readout cards, has been thoroughly developed and tested with the final detectors. Studies with cosmic-ray data taken during a standalone commissioning show a spatial resolution better than 200 μm with orthogonal tracks and a tracking efficiency of 95% in each layer. The system was installed at the beginning of October 2024. This presentation will cover the project details, the results from the standalone commissioning with cosmic rays, and the most interesting parts of the installation.

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1. The CGEM-IT at BESIII experiment

The BESIII experiment is the third upgrade of the BES (Beijing Spectrometer) experimental program started in the late 80s, hosted by the Institute of High Energy Physics of the Chinese Academy of Sciences, in Beijing, PRC. Since 2009, the BESIII spectrometer is taking data from the collisions provided by the BEPCII (Beijing Electron Positron Collider II), a circular e^+e^- machine capable of operating between 2 and 4.9 GeV with a peak luminosity of $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The spectrometer is a central detector divided into a barrel and two endcaps to cover 93% of the solid angle. It consists of several subsystems, including the Main Drift Chamber (MDC), which comprises two chambers sharing the same gas volume. More details about the spectrometer can be found in Ref. [1]. BESIII has a rich physics program; details can be found in Refs.[2, 3].

An upgrade program was approved and performed in the second half of 2024. It consists of both accelerator and detector upgrades: the luminosity at 2.35 GeV beam energy has been increased by three times with respect to the present status, and from 2028 it will also be possible to access center-of-mass energies up to 5.6 GeV; the innermost part of the MDC, which was showing aging effects, has been replaced with a new inner tracker based on cylindrical triple GEM technology, the CGEM-IT.

The CGEM-IT project deploys three concentric layers of cylindrical triple-GEM, based on the original idea of the KLOE2-IT CGEM [4]. The CGEM-IT will match the momentum and azimuthal spatial resolutions of the present detector ($\sigma_{xy} \sim 150\,\mu$m) but will improve the spatial resolution ($\sigma_z \sim 300\,\mu$m) along the beam direction, rate capabilities, and radiation hardness. A light structure is guaranteed by a Honeycomb-carbon fiber-based cathode and anode, with permaglass rings outside the active area.

The CGEM-IT signals are read out by a dedicated ASIC, called TIGER (Turin Integrated GEM Electronics for Readout). TIGER [5, 6] is a triggerless 64-channel mixed signal ASIC capable of simultaneous readout of time and charge, to allow for μTPC [7] reconstruction. The signal from each TIGER is read out by the GEMROC modules; it is also designed to provide the power supply and to configure the FEBs. A dedicated standalone tool, called GUFI [8], allows controlling the GEMROCs and performing complex procedures with ease. More details about the system can be found in Ref.[9].

2. Standalone cosmic commissioning

Before its installation inside the spectrometer, the CGEM-IT required a full standalone commissioning with cosmic rays to assess its performance and operation stability, and to be evaluated by an external review committee.

The CGEM-IT was installed in a cosmic stand inside one of the laboratories at IHEP. Two plastic scintillators read out by PMTs placed above and below the CGEM-IT provided triggers. The full final readout chain was used. The CGEM-IT will operate in Ar:ISO (91:9) gas mixture. During the commissioning, the three detectors were connected in series. A parallel connection was tested, and a general improvement was observed. In the experimental environment, each detector will run at a 4 vol/h gas flow. Small oscillations in the current absorption of the electrodes are observed due to humidity cycles, with no registered impact on detector performance. Overall, very

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good electrical stability is observed, with only a few trips during the entire data-taking period. A Sr-90 radioactive source has also been used to measure the current absorption, with no discharge observed. An optimal grounding scheme was found to operate with thresholds in the range of 1 to 4 fC.

The data analysis had three different levels. The first is the strip level, performed (almost) online during data taking, to promptly identify any issues with the detector status. Figure 1 shows the typical plot, of the strip charge as a function of the strip number. The difference in the maximum charge between different strips is due to the ASIC charge saturation. Similar plots over time are available.

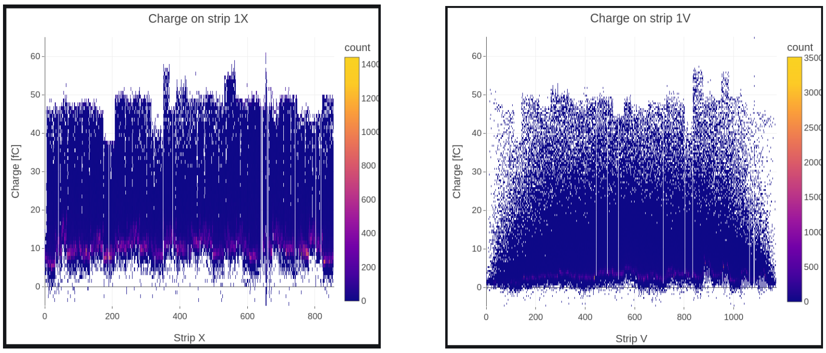

Figure 1: Charge as a function of the strip number for L1. (left) X strip. (right) V strip.

The second level is the cluster analysis, where contiguous strips of the same event are joined to form a cluster. Cluster size and charge provide insight into detector performance. The third and last level, performed offline, is done with tracking and alignment, where the good clusters are selected to extract performance metrics like residual and efficiency. To increase the number of points available for the metrics, each layer is divided into two halves. For both residual distribution and efficiency, the half-layer under investigation is excluded from tracking, and if a cluster is found within 20σ of the residual distribution, the event is considered. Figure 2 (left) shows the charge distribution for these good clusters. The three layers show similar behavior with L2 with slightly less charge, since it was operated at 2 kV/cm on the transfer field, and L1 with a larger cluster size, being the smallest one, and so hit with the largest incident angles.

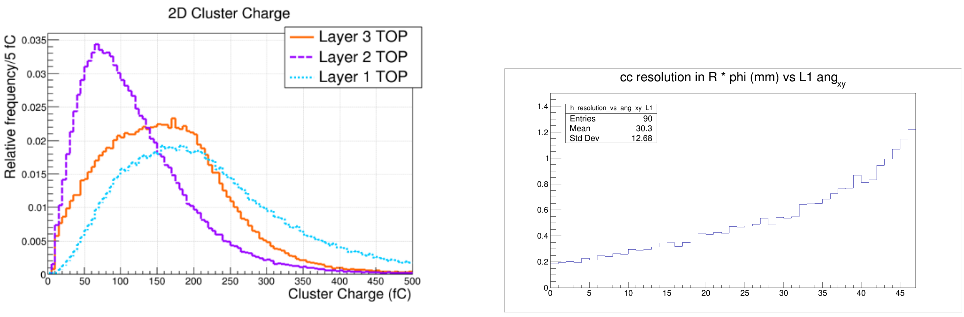

Figure 2: Typical performance of the detector (Left) 2D cluster charge distribution for the three layers. (Right) Measured residual distribution (not corrected for the tracking contribution) as a function of the track incident angle.

Figure 2 (right) shows the residual distribution for the charge centroid as a function of the incident angle of the track. For tracks with incident angles below 5°, the residual is about 200 μm. Given that the tracking contribution will be removed from this data, the final resolution will be compatible with the design specification. Moreover, the μTPC algorithm will also be implemented to extend these results to other incident angles.

Figure 3 shows the efficiency distribution of the different layers for both azimuthal angle ϕ and beam direction z. The efficiency is flat and about 95%. The small regular drops that can be seen in the ϕ plot are due to the microsectors, a small separation in the HV distribution to reduce the power in case of a discharge [9]. This creates a small area where there is less multiplication. The effect is largely diminished with non-orthogonal tracks and the presence of the magnetic field.

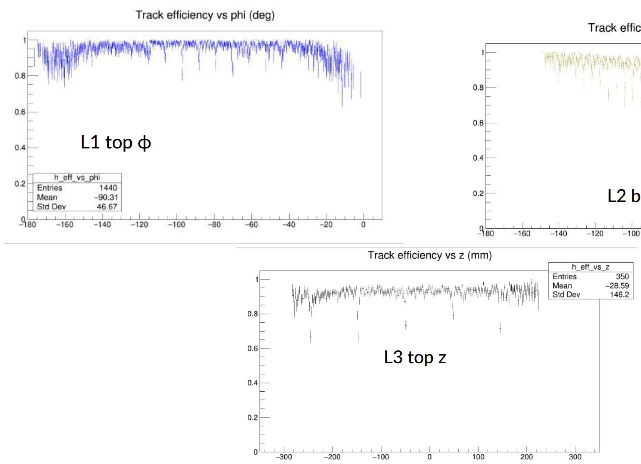

Figure 3: Typical plots of efficiency distribution as a function of a spatial coordinate for the three layers. They contain roughly 2M muon triggers.

3. Installation of the CGEM-IT: a first look

After the approval from the experiment board and the removal of the previous inner drift chamber, by the IHEP experts, the CGEM-IT installation began on October 1st, 2024. The operation of the installation involved sliding the detector inside the central part of the detector, finalizing the cabling by connecting the short part of the cables (already installed in the detector) to the long part extending outside the spectrometer volume, and testing the grounding schemes. Figure 4 shows some photos of the detector installation. The CGEM-IT was successfully powered on on October 19th, after two weeks of work. Detailed discussion can be found in Ref. [10].

Finding an optimal configuration for the integration between the CGEM-IT and the outer drift chamber required a couple of months and was completed by the end of February. The present situation shows a noise level of the order of a few (1-3) fC for all the strips except the X (azimuthal coordinate) of the innermost layer. Given the flexibility of the TIGER ASIC, a configuration has been found to set thresholds to all the channels.

From March to May, a cosmic commissioning has been performed to check the CGEM-IT operation stability and preliminary alignment. Since June, the beam commissioning has started

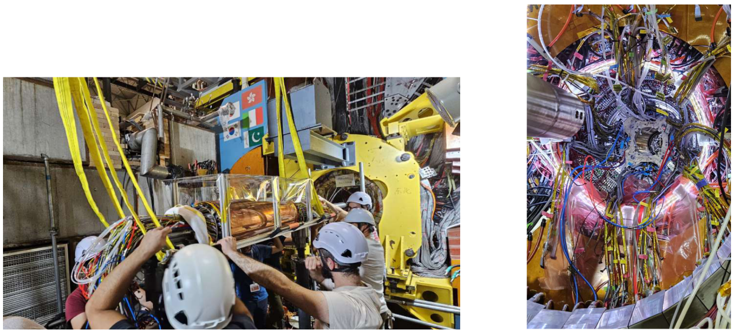

Figure 4: Some photos from the detector installation. (Left) The detector is placed on the rail to slide inside the BESIII spectrometer core. (Right) The CGEM-IT is in its final position, ready to start the cabling.

with the goal to collect $\sim 500\,\mathrm{pb}^{-1}$ at $\psi(2S)$ peak to characterize the detector performance. The first results, shown in Fig. 5, are promising, and detailed analyses are ongoing.

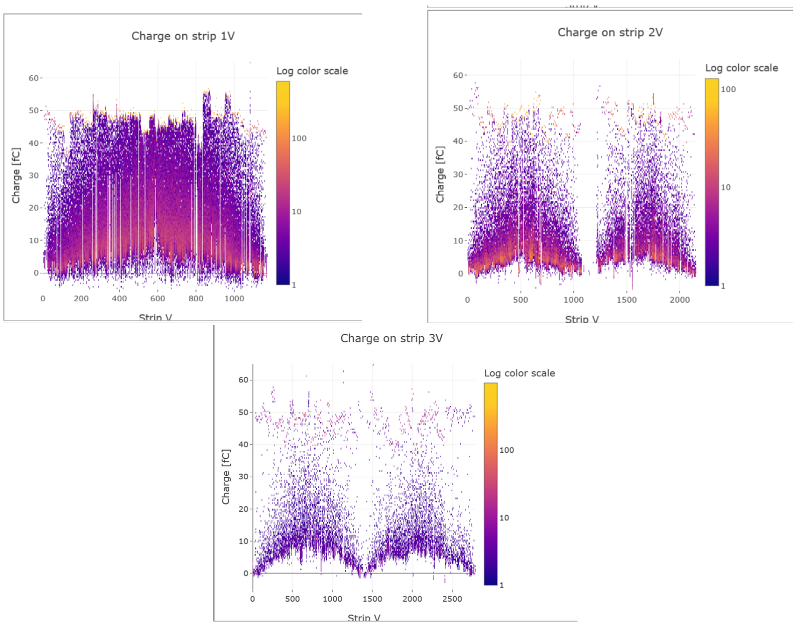

Figure 5: Collected charge with respect to the V strips for L1, L2, and L3. The typical shape of the distribution is given by the strip configuration and detector geometry

4. Summary and acknowledgments

The CGEM-IT has been successfully installed, and it will operate as the new inner tracker of the BESIII experiment, employing innovative solutions to ensure BESIII competitiveness until the 2030s. The standalone commissioning with cosmic rays showed that the design performance is achieved. Beam commissioning is ongoing to fully validate its performance with the beam.

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