BESIII

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This report is dedicated to the memory of our friend and colleague Rinaldo Baldini Ferroli whose left us few weeks ago. His contribution to the BESIII experiment in general and to the BESIII LNF group in particular is highly valuable and of great inspiration. Thank you Rinaldo !

1 The BESIII experiment

In 2025 the BESIII experiment [1] reached 16 years of data taking at the BEPCII electron-positron collider at IHEP, Beijing. The center-of-mass energy region, now ranging from 1.84 GeV to 4.95 GeV, offers vast and diverse physics opportunities at the boundary between the perturbative and non-perturbative regimes of QCD. Results from BESIII are playing an important role in the understanding of the Standard Model and will also provide important calibrations for the Lattice Gage community. Studies of tau-charm physics can reveal or indicate the possible presence of new physics in the low energy region.

BESIII is a multi-purpose detector designed to study physics in the tau-charm energy region of BEPCII double ring electron-positron collider. The rich physics program includes [2]:

- tests of electroweak interactions with high precision in both the quark and lepton sectors
- high statistics study of light hadron spectroscopy and decay properties
- study of the production and decay properties of J/ψ, $\psi(3686)$, $\psi(3770)$ states with large data samples and search for glueballs, quark-hybrids, multi-quark states and other exotic states via charmonium hadronic and radiative decays
- studies of XYZ states
- studies ot tau-physics
- precision measurements of QCD parameters and CKM parameters
- barion form factors measurements via ISR process and via energy scan
- search for new physics by studying rare and forbidden decays, oscillations, and CP violations in c-hadron and tau-lepton sectors.

The LNF group is involved in the upgrade of the BESIII Inner tracker (IT) with a new Cylindrical GEM (CGEM) detector. The project [3], among Ferrara and Turin INFN sections, also includes groups from Mainz, Uppsala and IHEP, and has been recognized as a Great Relevance Project within the Executive Program for Scientific and Technological Cooperation between Italy and P.R.C. for the years 2013-2015, it has been funded by the European Commission within the BESIIICGEM RISE-MSCA-H2020-2014 project which lasted until 2018,

while in 2019 it received funding within the FEST RISE-MSCA-H2020-2020 project, which started in 2021 due to Covid-19 delays and will end in 2026.
The group is also involved in the analysis of several physics processes involving baryons and light hadrons among the "Comitato Italiano di Fisica di BESIII".

2 The BEPCII and BESIII 2024-2025 Upgrade Program

The design luminosity of the accelerator is $10^{33} cm^{-2} s^{-1}$ (at c.m. energy of 4.7 GeV) has been reached and exceeded while the energy in the center of mass, which by design used to be in the range [2.0, 4.6] GeV, now has a lower limit of 1.84 GeV and an upper limit of 4.95 GeV, reached through accelerator machine upgrades during the years. Two major BEPCII Upgrades (BEPCII-U) aim to extend the c.m. energy to 5.6 GeV and to enhance the luminosity by a factor of three ($3 \cdot 10^{33} cm^{-2} s^{-1}$) at c.m. energy of 4.7 GeV. It requires the development of combined superconducting (SCQ) magnets with higher magnetic field gradients for the interaction region.The challenge lies in producing combined superconducting magnets that meet high magnetic field precision requirements, essential to ensure that the coil winding process is both stable and precise. The new magnets met the required conditions to be installed on BEPCII during the major shutdown in the summer 2024. New RF modules were also installed, the Inner Drift Chamber has been extracted and on its place the CGEM-IT was installed.

During the period from year 2025 to 2028 it is foreseen the increase of the luminosity (phase I upgrade), while from year 2028 to 2030 the maximum beam energy will be increased from c.m. 4.95 GeV to 5.6 GeV (phase II upgrade).

3 The BESIII CGEM-IT Project

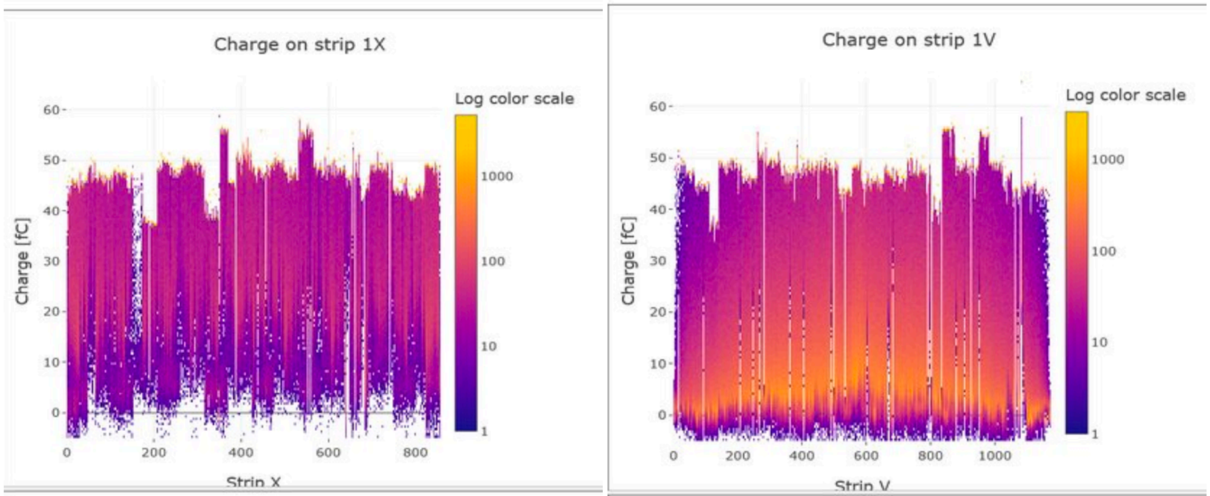
The Cylindrical GEM Inner Tracker (CGEM-IT) is the detector designed and built to replace the innermost part of the Multilayer Drift Chamber (MDC) of BESIII experiment, which was experiencing relative gain losses due to aging reaching up to 50% in the first eight layers.

The CGEM-IT consists of three coaxial layers of triple GEM. The tracker is expected to restore efficiency, improve z-determination and secondary vertex position reconstruction compared to the current inner tracker, with a resolution of 130 m in the xy-plane and better than 300 m along the beam direction. A special readout system was developed for data acquisition: the signals from the detector strips are processed by TIGER, a custom 64-channel ASIC developed in CMOS 110 nm UMC technology, providing analog charge readout via a fully digital output with linear charge readout up to about 50 fC and less than 3ns jitter. TIGER continuously transmits data across the threshold in triggerless mode to an FPGA-based readout module, the GEM Read Out Card (GEMROC), designed specifically for this system. The module configures the ASICs and organizes the incoming data by creating the event packets when the trigger arrives.

3.1 Integration of the CGEM-IT detector in the BESIII spectrometer

As reported last year, by the end of 2024 the whole CGEM-IT was inserted inside the BESIII spectrometer, after extraction of the Inner Drift chamber. During the first months of 2025 the activity was focused on commissioning and integration of the whole detector inside the spectrometer [4]. First of all an operational phase to optimize the integration, during which additional copper shields were added to better isolate the MDC and CGEM readout.

On 27 February 2025, the spectrometer was closed and the integration of the BEPCII update began, while the Italian team completed the integration of the CGEM-IT handling and monitoring into the BESIII Slow Control system. The timing and trigger signals coming from BESIII are distributed by another GEM- ROC 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), 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.



(a) CGEM-IT strip X vs collected charge [fC]

(b) CGEM-IT strip V vs collected charge [fC]

3.2 Commissionig of the CGEM-IT detector with e+e- colliding beams

Following the completion of the accelerator commissioning in June 2025, the CGEM-IT was gradually powered on with the electron and positron beams. During this phase, all three layers exhibited excellent electrical stability,operating successfully at nominal values with BEPCII in run mode. The data sets collected during the summer 2025 demonstrated that all layers are collecting charge and are correctly read by the electronics, as shown in Figures 1(a) and 1(b).
During the scheduled summer2025 shutdown, several maintenance and upgrade interventions were performed to optimize the system, including the installation of additional cooling monitoring sensors and the refinement of external cable routing. These results, combined with the continuous system enhancements, provide a solid foundation for the upcoming detailed performance characterization.

3.3 Conclusions

The installation and the commissioning of the CGEM-IT detector marked an important milestone for the BESIII experiment upgrade. Extensive standalone testing with cosmic rays has validated the performance of the detector, demonstrating an excellent tracking efficiency and spatial resolution. Despite the mechanical challenges and strict spatial constraints encountered during installation,the system was successfully integrated into the spectrometer, and initial operations with electron and positron beams have confirmed excellent electrical stability and correct data acquisition. These promising preliminary results,combined with ongoing optimization of software and hardware, will ensure an important contribute to the BESIII physics program till the 2030.

We would like to thank Rinaldo Baldini Ferroli for being the first to believe in the success of this project.

References

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