BESIII

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1 The BESIII experiment

In 2004 the BESIII experiment [1] reached 15 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]:

- 1) tests of electroweak interactions with high precision in both the quark and lepton sectors
- 2) high statistics study of light hadron spectroscopy and decay properties
- 3) 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
- 4) studies of XYZ states
- 5) studies ot tau-physics
- 6) precision measurements of QCD parameters and CKM parameters
- 7) barion form factors measurements via ISR process and via energy scan
- 8) 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, 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, designed specifically for this system. The module configures the ASICs and organizes the incoming data by creating the event packets when the trigger arrives.
As reported last year, by the end of 2023 the whole CGEM-IT was assembled in a clean room at IHEP, tested for gas leaks, equipped with front end electronics, HV/LV cables connected and ready to take cosmic data for commissioning and calibration. The cosmic ray data collection campaign started right after, at the beginning of 2024, to evaluate the performance of the CGEM-IT before installation.

3.1 Standalone Commissioning of the CGEM-IT detector at IHEP

During the first part of 2024 the system was validated with cosmic rays and also the first figures of merit were extracted for the internal review committee, called to evaluate the projectś readiness before installation.

For the analysis of cosmic ray data, the detector is treated as two halves, separated along the horizontal plane, and thus as six separate detection surfaces. The results [4] shown in fig. 1 refer solely to the top half of the detector: the left picture shows the charge distribution of 2D clusters (ayer 2 collects on average less charge due to the fact that it is being operated at lower transfer fields); the right picture shows the exclusive residuals of almost perpendicular tracks reconstructed through the Charge Centroid algorithm. Overall the three layers perform similarly.

Early results show promising steps towards the upgrade requirements for perpendicular tracks, while TPC is currently being fine-tuned for better reconstructing angled tracks, track efficiency is flat about 95% for all the layers on both views.

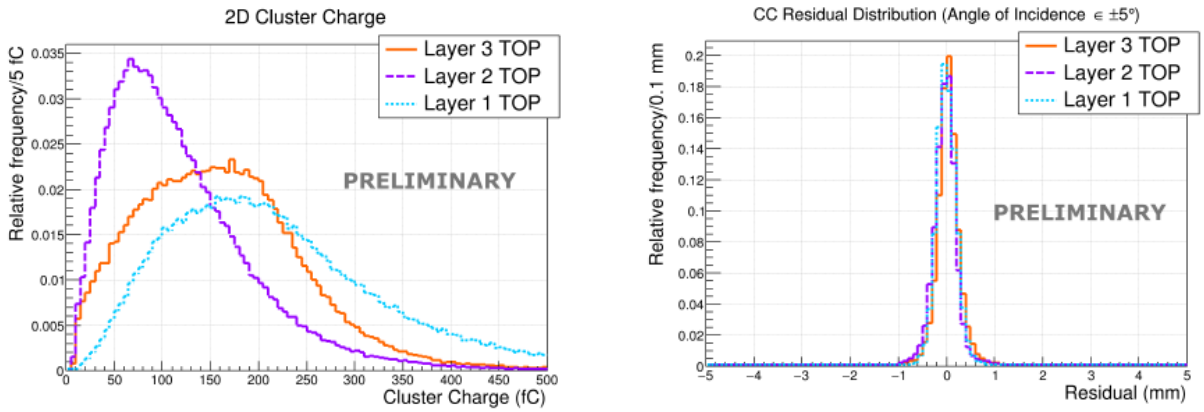

Figure 1: Preliminary results on cosmic ray data: on the left the charge of 2D clusters obtained combining neighboring hits in both viwes, on the right the exclusive residuals distribution for almost perpendicular tracks.

The project passed three stages of review and received the green light to be installed from the review committeee and from IHEP management.

3.2 Final installation of the detector inside BESIII

Several installation tests with a mockup (fig.2-left) and risk assessment tests were performed in the second half of the year, in order to ensure a safe and secure installation inside the BESIII detector. In parallel, IHEP people were testing the extraction of the inner drif chamber,that was successfully removed at the end of September 2024 (fig.2-right).

On October 2^{nd} the CGEM-IT was un-cabled and moved to the experimental hall were it was successfully inserted (fig. 3) inside BESIII reaching the final position on October 5^{th}. The major task of cabling the detector was also completed. By December the CGEM-IT was finally powered on at operating values inside BESIII.

References

1. BESIII Collaboration (M. Ablikim et al.) " Design and Construction of the BESIII Detector" Nucl. Inst. Meth. Phys. Res. Sect. A 2010, 614, 345.

2. White Paper on the Future Physics Programme of BESIII BESIII Collaboration (M. Ablikim et al.). Chin.Phys. C44(2020) no. 4, 040001 e-Print: arXiv:1912.05983 [hep-ex].

3. The BESIII Collaboration, "Conceptual Design Report: BESIII Cylindrical GEM Inner Tracker" (2014).

4. "Commissioning of the CGEM inner tracker" to be published in the "16th Pisa Meeting on Advanced Detectors" proceedings, Nucl. Inst. Meth. Phys. Res.A(2024)

Figure 2: Left picture: the mechanical team with a CGEM mockup after a successful insertion test. Right picture: the inner drift chamber extracted from BESIII, to leave space for the CGEM-IT.

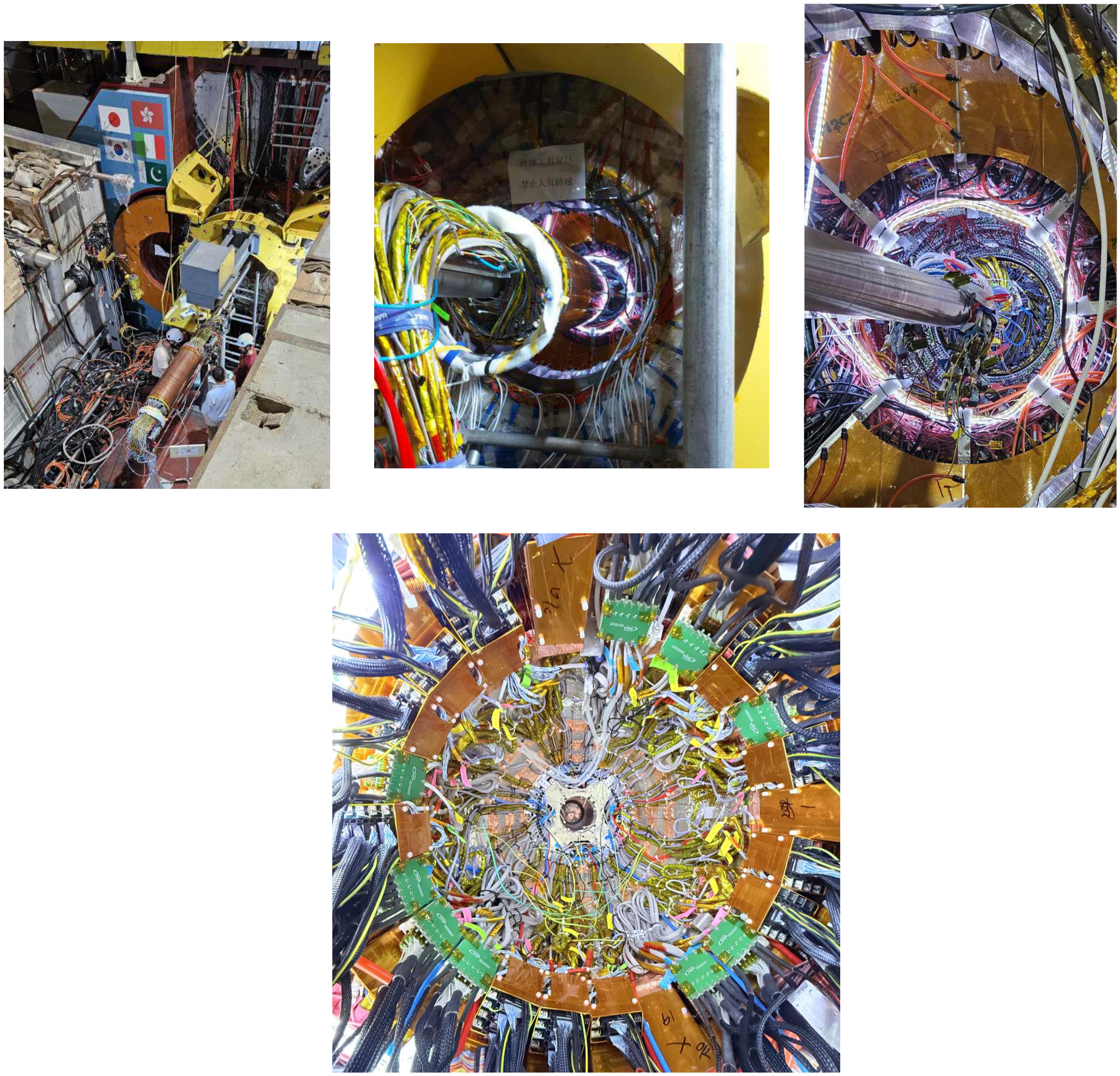

Figure 3: Some pictures of the CGEM istallation inside BESIII: positioning in front of the insertion hole (top left), slowly going inside (top middle), reaching the final position, front view with electronics and cabling (bottom).