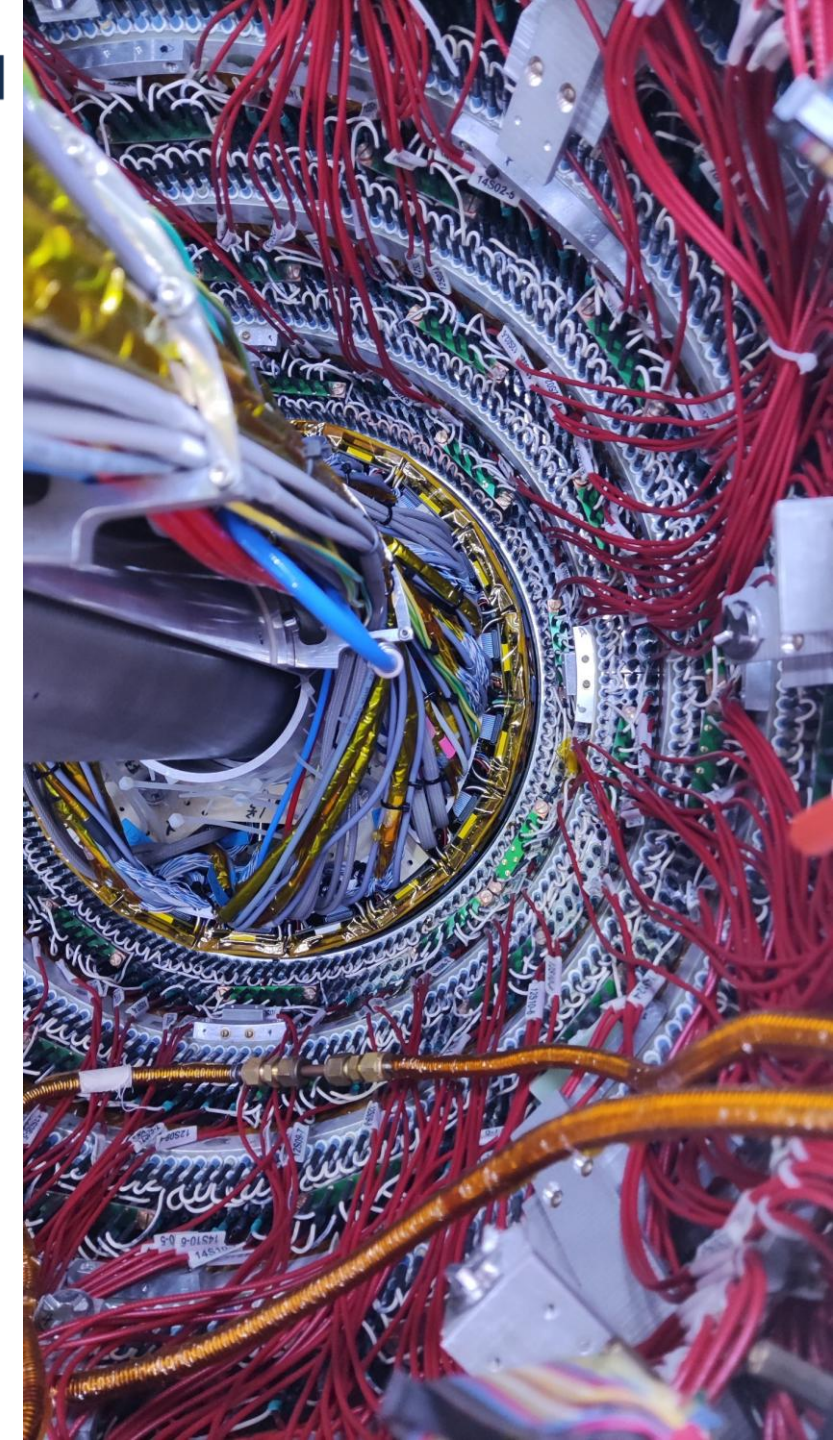


Operation of the CGEM-IT at BESIII

Overview of the Cylindrical GEM Inner Tracker detector of BESIII experiment at BEPCII

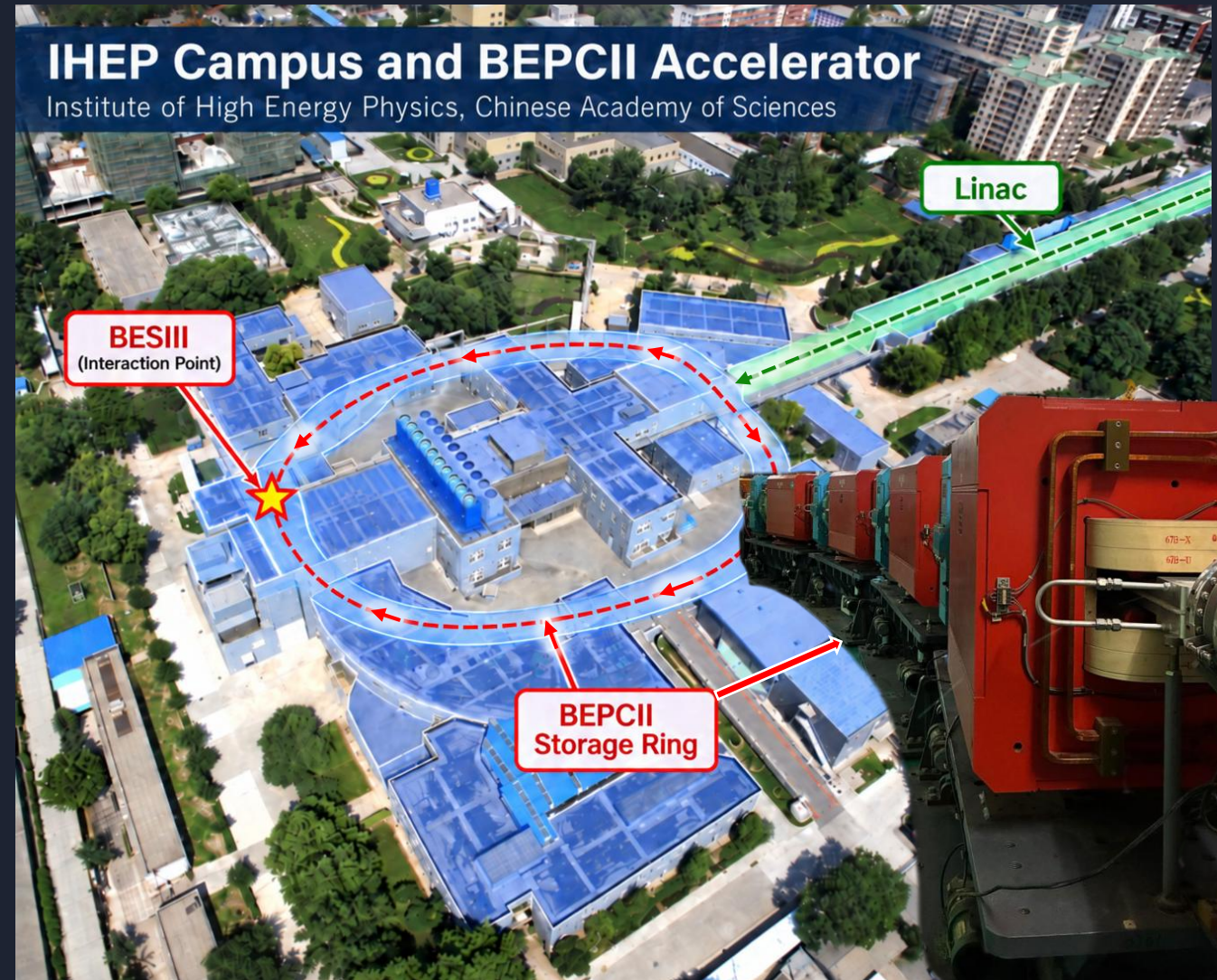
Chiara Alice - on behalf of the CGEM-IT working group
INFN – Laboratori Nazionali di Frascati
chiara.alice@lnf.infn.it



BESIII experiment at BEPCII accelerator

The **BE**ijing **S**pectrometer **III** is located at the **BE**ijing **E**lectron **P**ositron **C**ollider **II** interaction point.

- **BESIII** is optimized for high accuracy hadron physics and τ -charm physics measurements.
- symmetric e^+e^- collisions provided by the **BEPCII storage ring** center-of-mass energy range from 2.0 to 4.95 GeV
- **BEPCII** peak luminosity of $1.1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ achieved at $E_{\text{cm}} = 3.773 \text{ GeV}$ in 2023



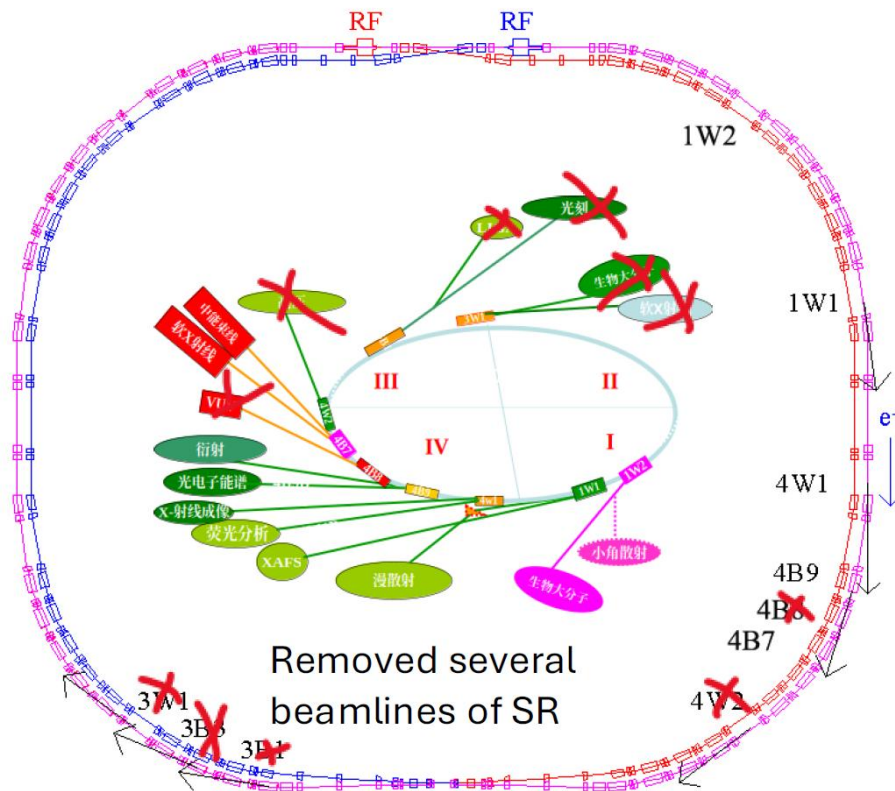
BEP-CII-U : upgrade program

Upgrade program

- First phase focusing at **increasing the luminosity** by factor 3 @ 2.35 GeV
- Second phase (after 2028) **to increase the beam energy** up to 2.8 GeV

Key technologies

- Double beam power
- Optics upgrades
- New high gradient of magnets
- Additional superconducting RF cavities



	BEPCII @ 2.35GeV	BEPCII-U @ 2.35GeV	BEPCII-U @ 2.8GeV
L [$10^{32}\text{cm}^{-2}\text{s}^{-1}$]	3.5	11	3.7
β_y^* [cm]	1.5	1.35	3.0
Beam current [mA]	400	900	450
SR Power [kW]	110	250	250
$\xi_{y,\text{lum}}$	0.029	0.033	0.043
Emittance [nmrad]	147	152	200
Coupling [%]	0.53	0.35	0.5
Bucket Height	0.0069	0.011	0.009
$\sigma_{z,0}$ [cm]	1.54	1.07	1.4
σ_z [cm]	1.69	1.22	1.6
RF Voltage [MV]	1.6	3.3	3.3

Peak luminosity ($\text{cm}^{-2}\text{s}^{-1}$)

BESIII spectrometer architecture

Inner Tracking system

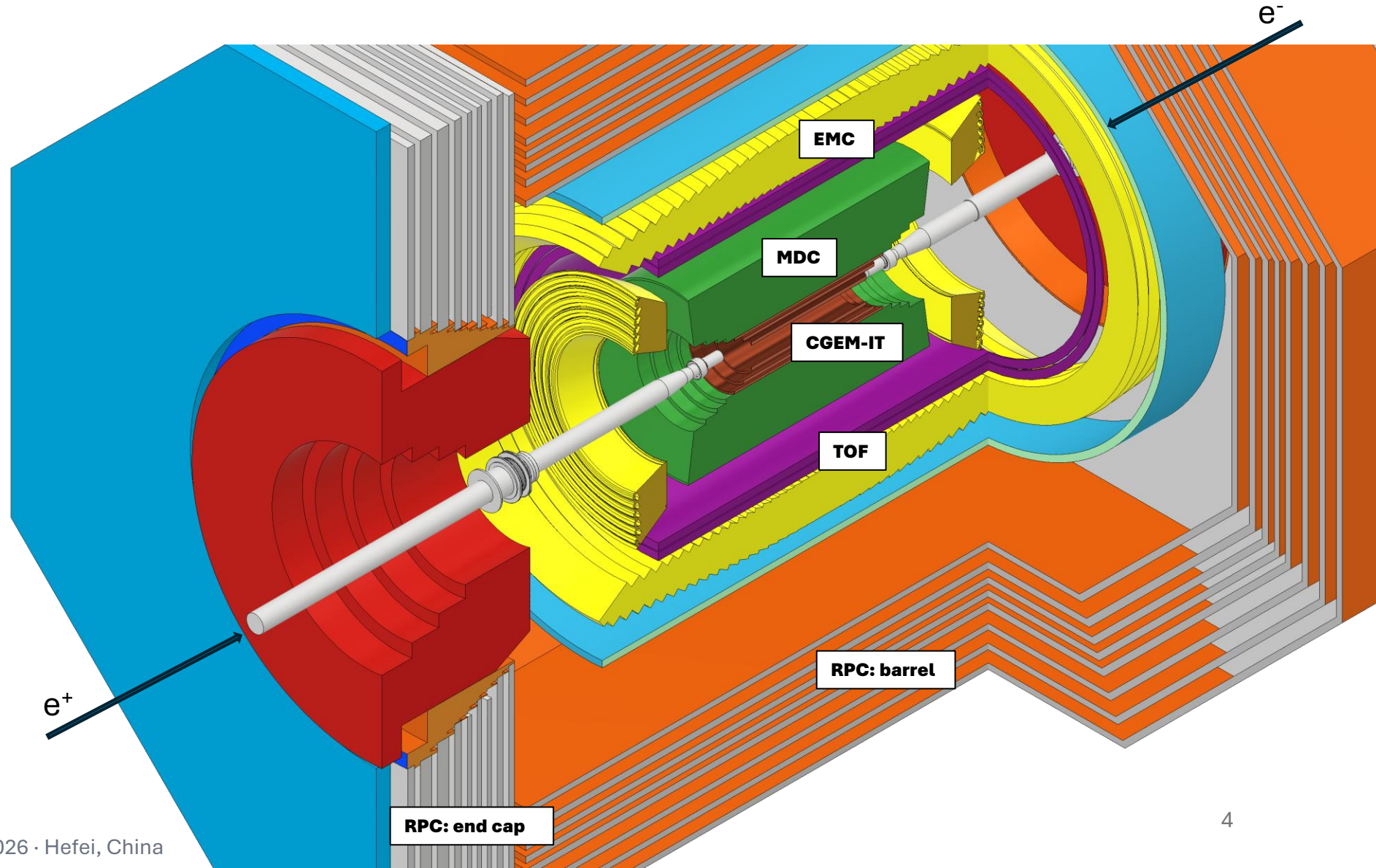
- Cylindrical GEM-Inner Tracker (**CGEM-IT**)
- Main Drift Chamber (**MDC**)

PID and Calorimetry

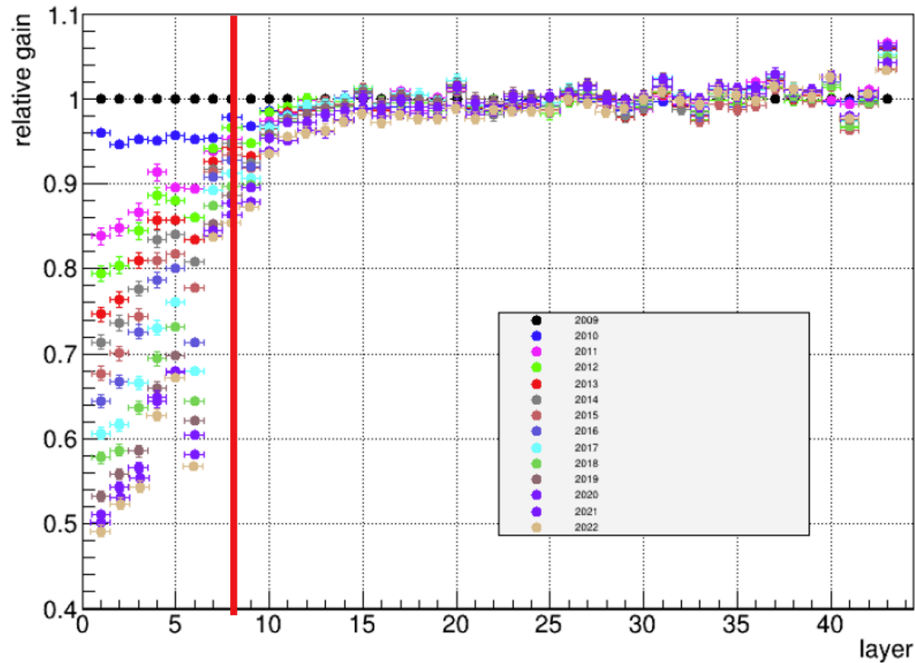
- **MDC** dE/dx measurement
- Time-Of-Flight (**TOF**): barrel + end cap
- Electro-magnetic Calorimeter (**EMC**)

Muon Counters (MUC)

- Resistive Plate Chambers (**RPC**): barrel + end cap



BESIII inner tracker : CGEM-IT development motivation



MDC

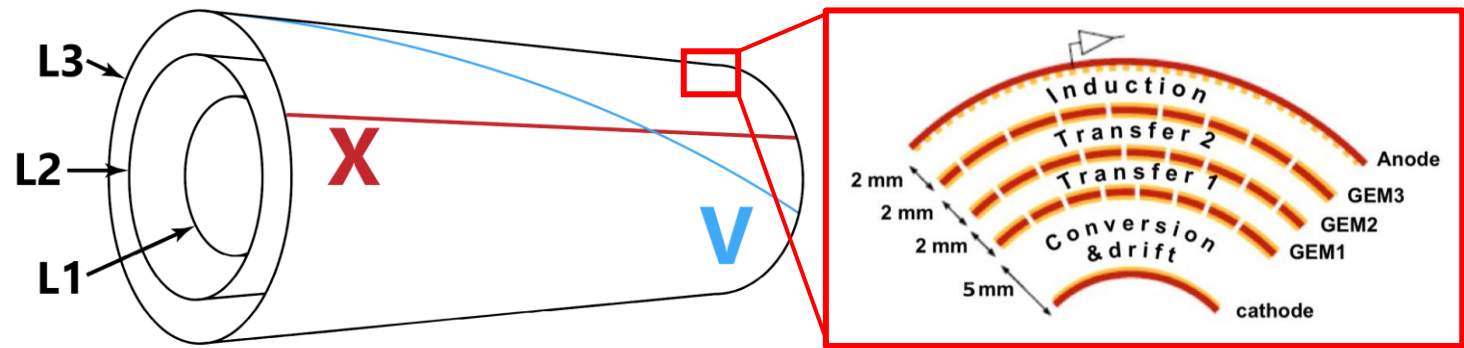
- The **Main Drift Chamber** of BESIII was composed of an inner and outer part, sharing the same gas volume.
- The **Inner part** had a gain drop of about 51% in 2022 due to the aging effect caused by beam-induced background. [1]
- The gain loss led to the decision to replace the inner chamber of MDC with a new **Cylindrical GEM detector**

CGEM-IT requirements

- Keep the tracking performances of MDC
- Low material budget
- Higher rate capability
- Lower aging
- Better Z resolution
- Better secondary vertex reconstruction
- Better time resolution

BESIII inner tracker : CGEM detector

The **CGEM-IT** consists of 3 independent cylindrical triple GEM layers, called **Layer1 (L1)**, **Layer2 (L2)** and **Layer3 (L3)**



Layer	Inner Diameter	Active Area Length	Strips Stereo Angle
L1	153.8 mm	532 mm	46.7°
L2	242.8 mm	690 mm	-31.0°
L3	323.8 mm	847 mm	32.9°

- GAS**

Active volume ~ 5.2 l

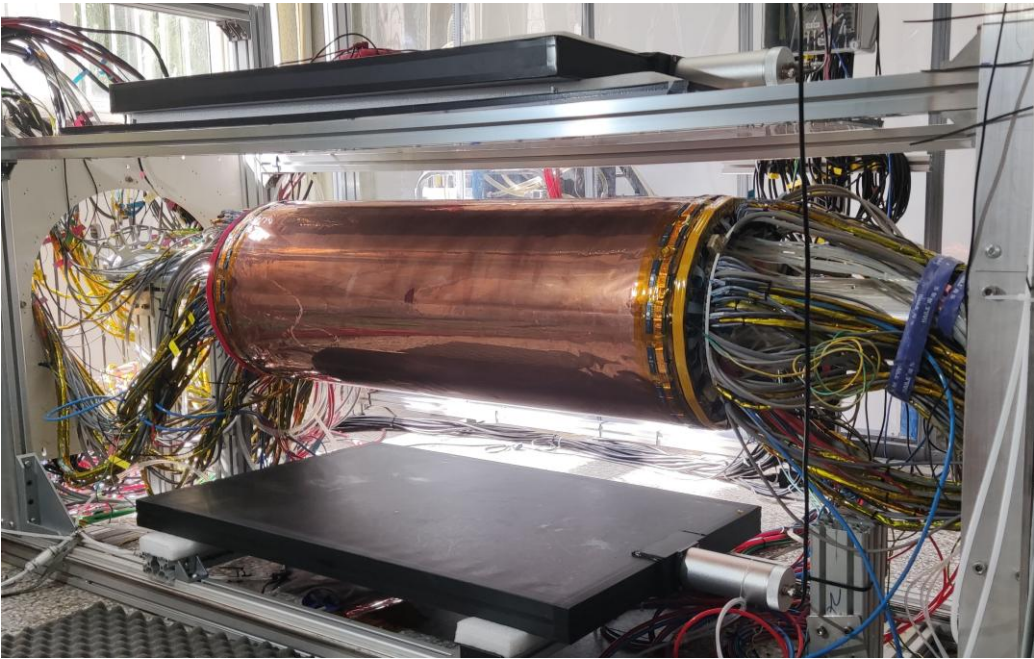
Ar –iC₄H₁₀ (90% –10%)
- HV**

GEM 1/2/3 280/280/275 V

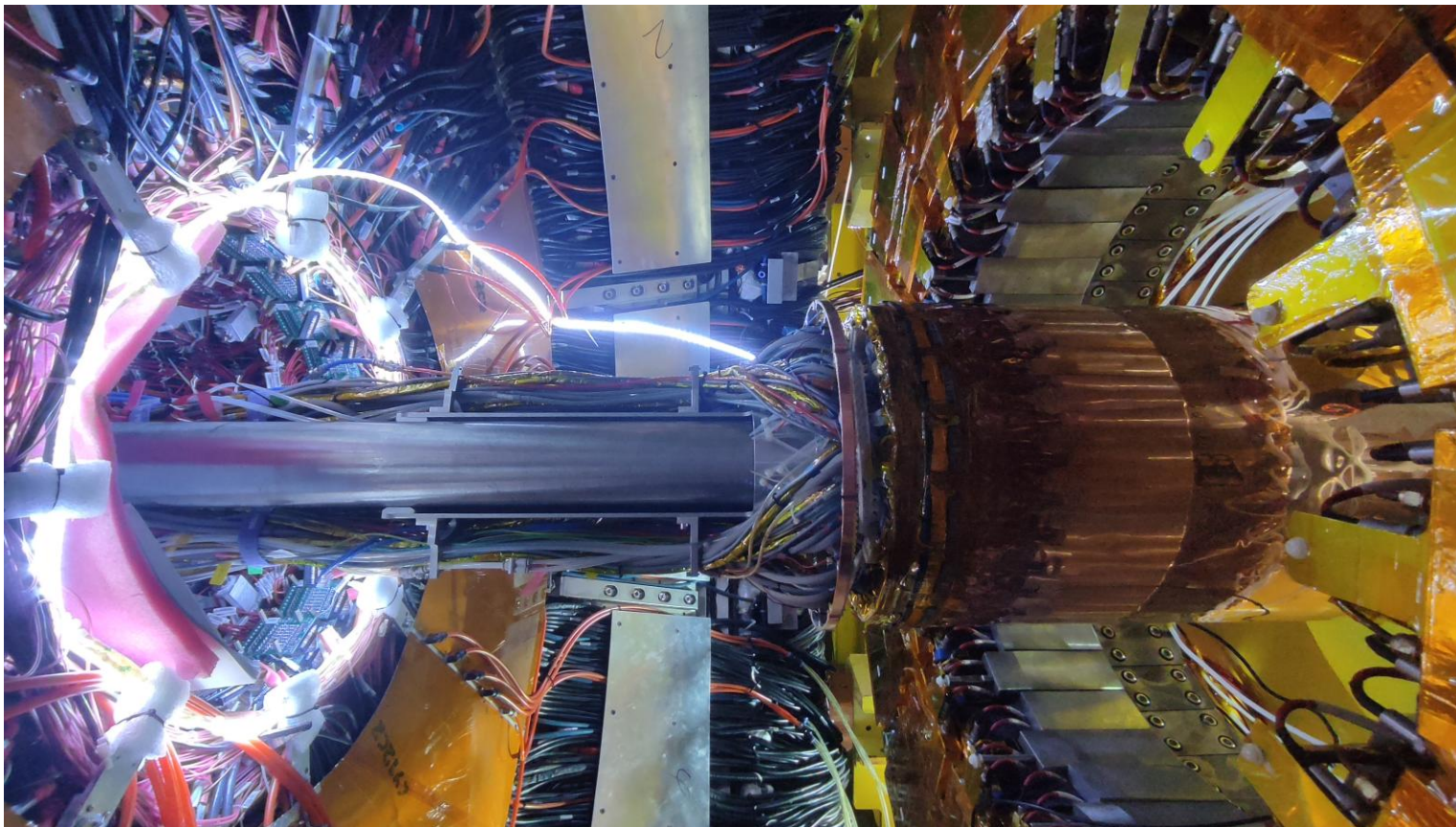
Electric field 1.5/3/3/5 kV/cm
- Read Out**

About 10⁴ X and V strips

- X strips parallel to the beam axis providing the azimuthal coordinate.
 - V strips for each layer are oriented with a different stereo angle.

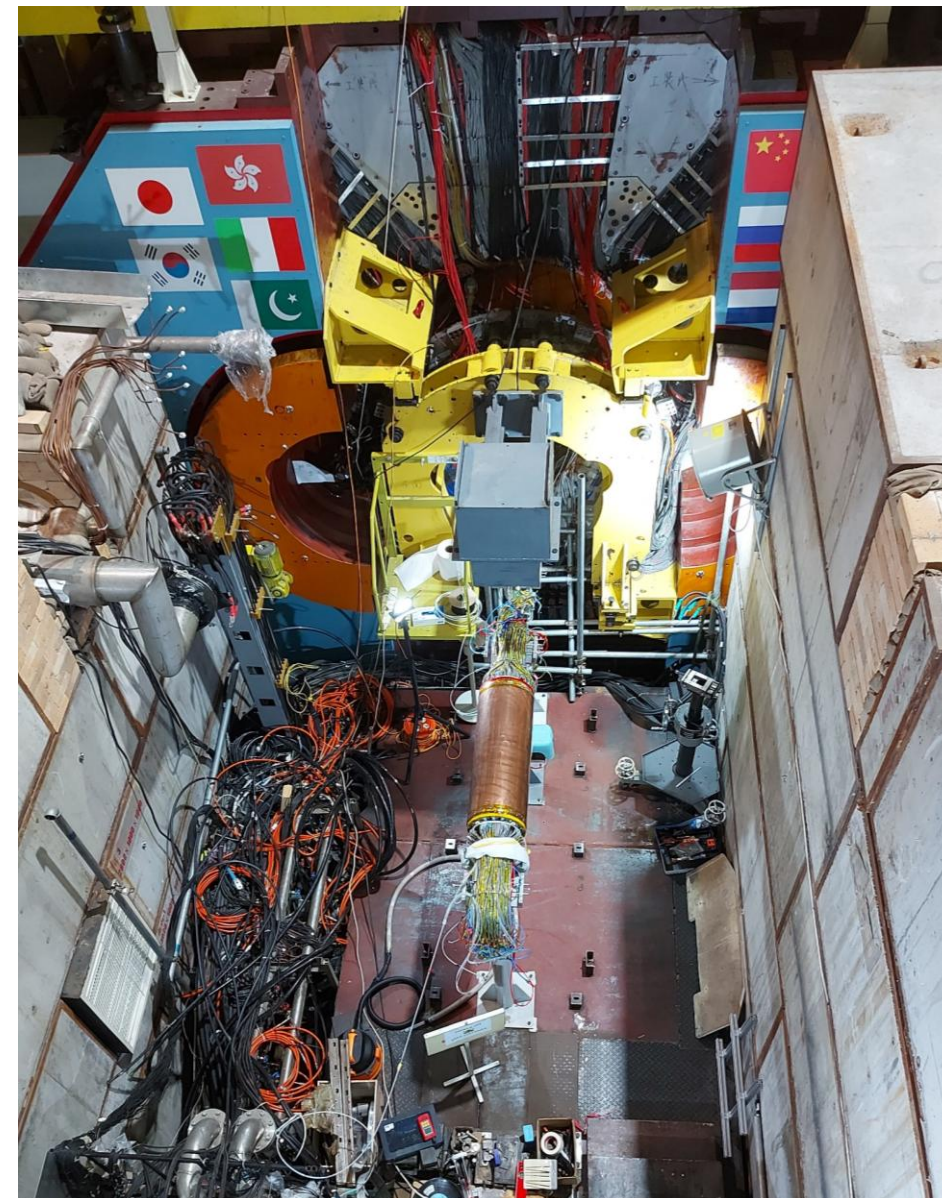


BESIII inner tracker : CGEM installation

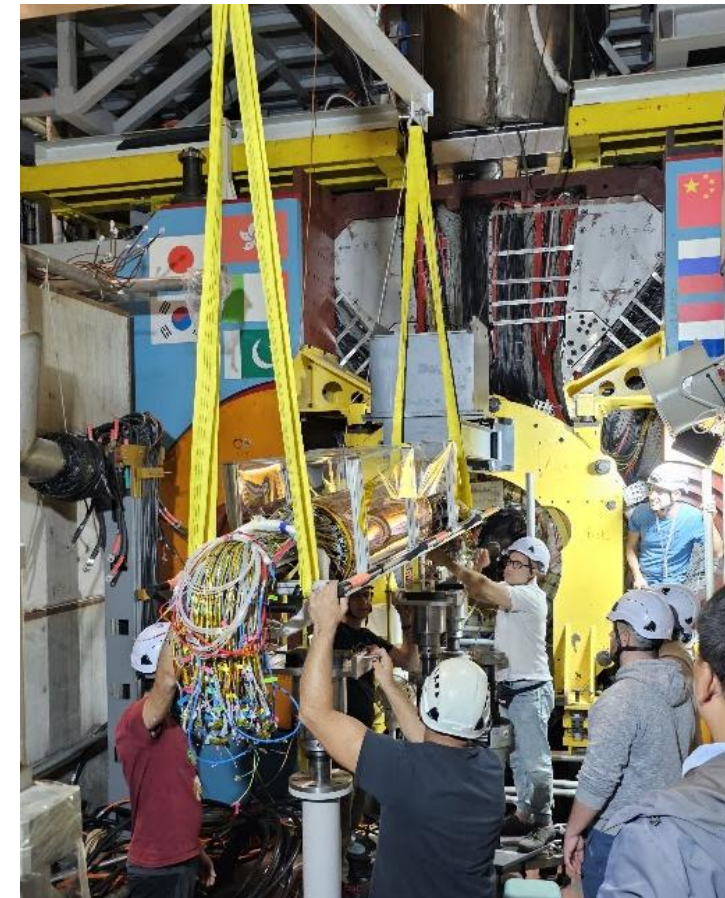
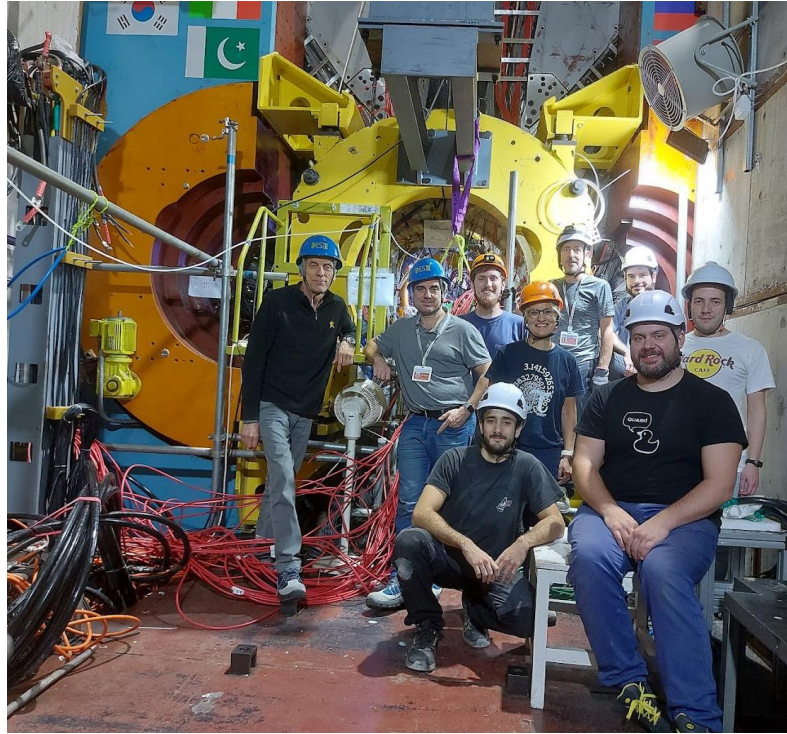


The CGEM-IT installation inside BESIII was the result of extensive preparation and dedicated validation studies [2]

- Full-scale mock-up tests
- Risk assessment
- Optimization of both tooling and operations.

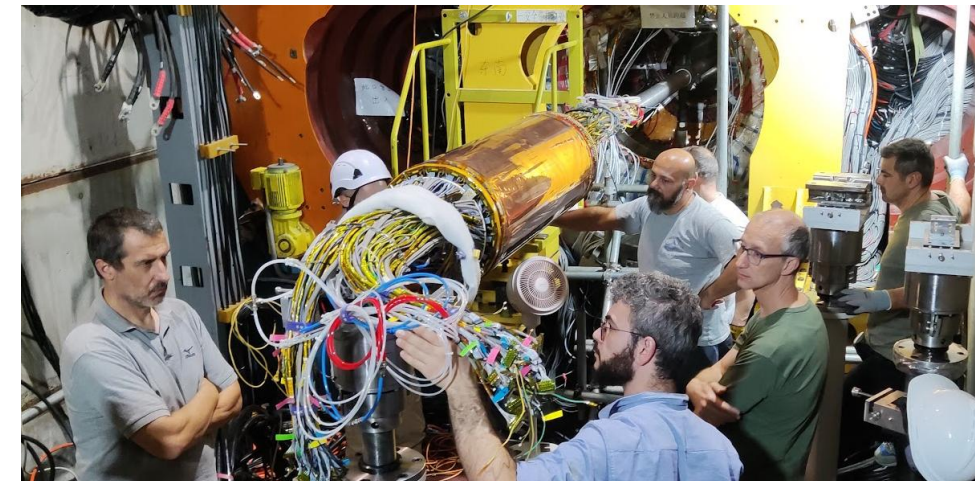


BESIII inner tracker : CGEM installation



The CGEM-IT installation was the result of a major collaborative effort

- Collaboration with Mainz and Uppsala University for the hardware and the software
- Core activity of one MAECI-MOST project, two RISE projects, four Ph.D. theses between INFN Torino and Ferrara.
- Within the IJ2L framework, postdoctoral fellows played a key role in strengthening the connection between IHEP and INFN



The **CGEM-IT** readout chain has been mainly developed by INFN-To and INFN-Fe [3]

160 TIGER ASICs wire bonded on **80 FEBs**

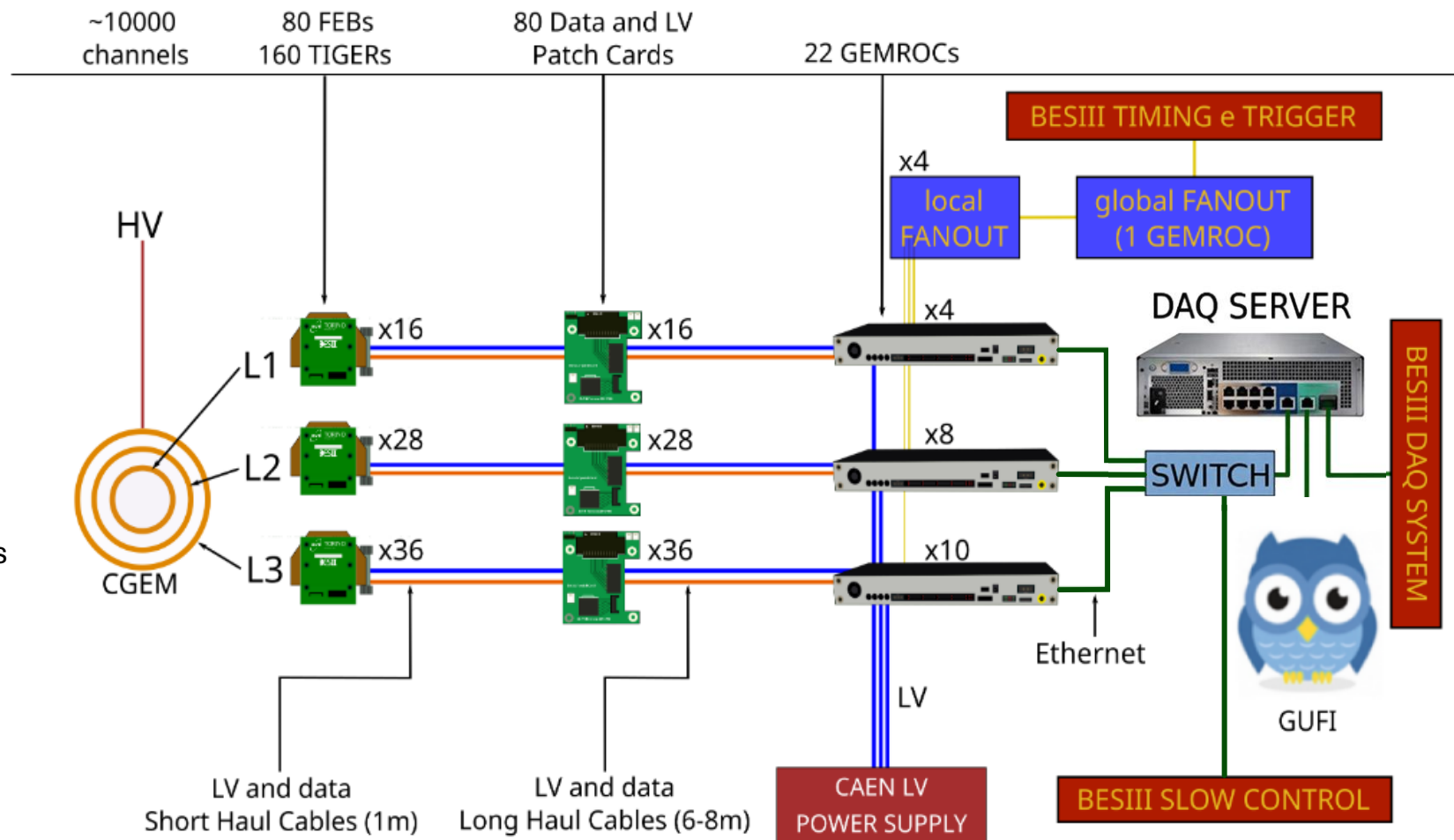
- 16 L1 FEBs
- 28 L2 FEBs
- 36 L3 FEBs

80 **DLVPC boards** which serve as mezzanine cards between the FEBs and the GEMROC modules

- 4 GEMROCs reading out L1 FEBs
- 8 GEMROCs reading out L2 FEBs
- 10 GEMROCs reading out L3 FEBs

22 GEMROCs collect the data from the three CGEM-IT layers

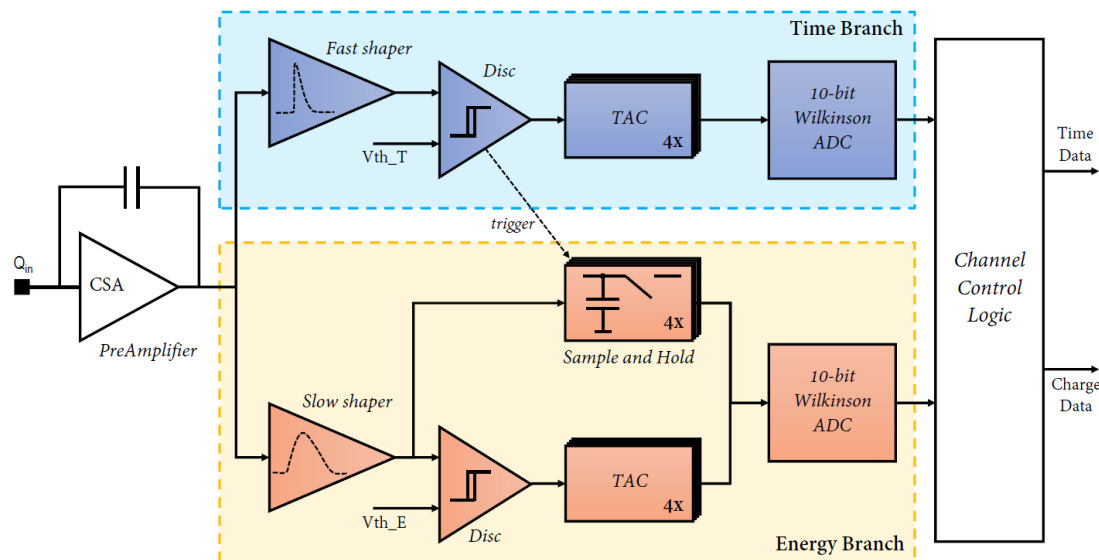
- Data are sent via **Ethernet to the DAQ server** and integrated into the **BESIII DAQ** and **GUF** [4], the latest providing the expert interface
- Data acquisition is synchronized with the **BESIII Timing & Trigger system**



CGEM-IT Readout: TIGER ASIC

TIGER (Torino Integrated Gem Electronics for Readout) is a 64-channel mixed-signal ASIC. [5]

- 5 x 5 mm² **110nm CMOS technology**
- **Digital backend from TOFPET2 ASIC** (SEU protected)
- Analog frontend architecture: CSA, shapers, TDC/ADC, local controller
- On-chip bias and power management
- On-chip calibration circuitry

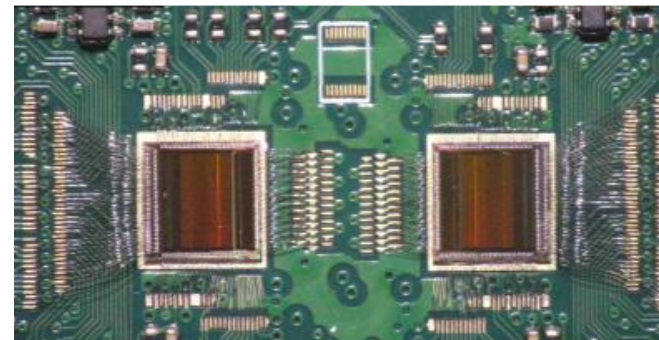


Analog frontend features:

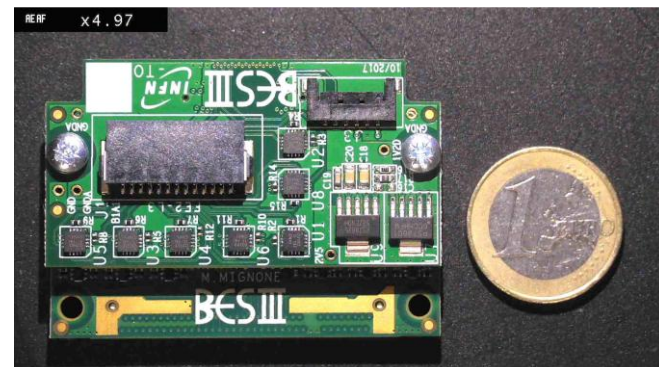
- input charge: 2 - 50 fC
- up to 100 pF sensor capacitance
- 4-5 ns time resolution
- Sustained event rate > 100 kHz/ch

- **Trigger-less operation, fully digital output** sent via 4 TX SDR/DDR LVDS links, 8B/10B encoding
- 160-200 MHz system clock
- Power consumption < 12 mW/ch

TIGERs wire-bonded on a FEB



L3 FEBs form-factor



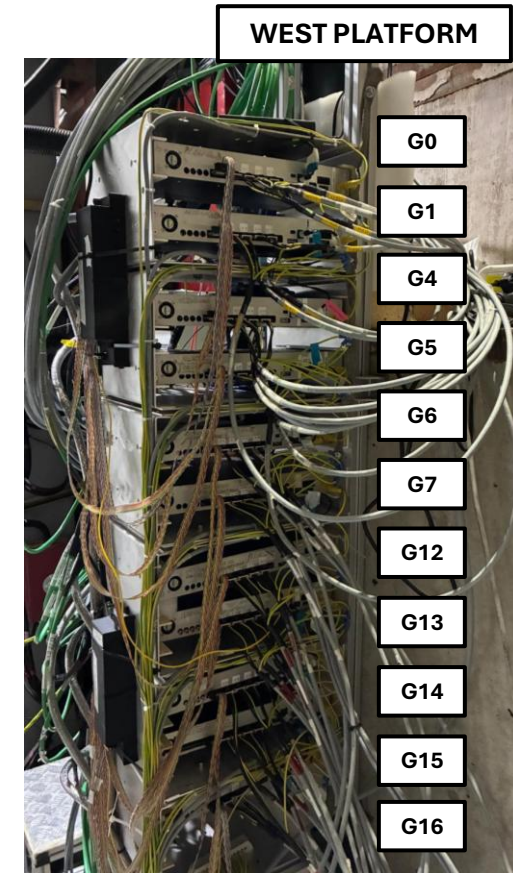
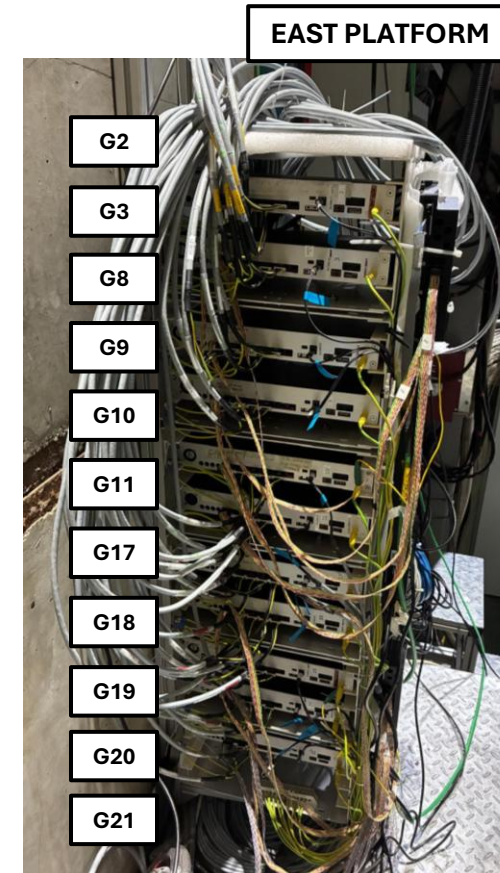
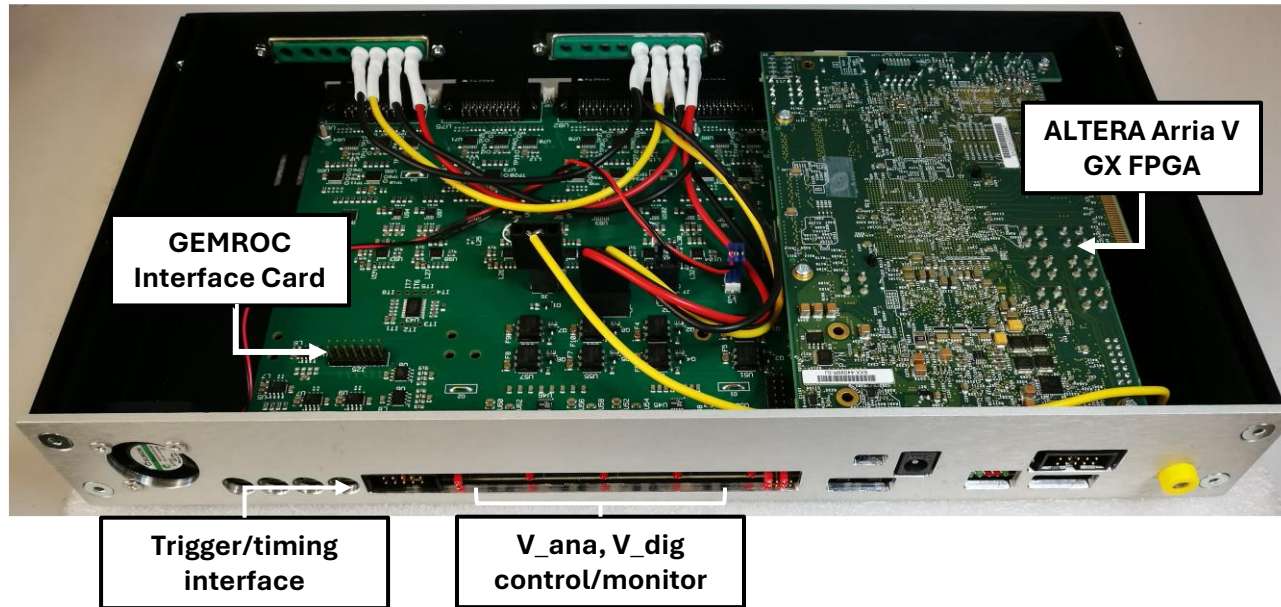
L1/L2 FEBs form-factor



CGEM-IT Readout: GEMROC modules

The off-detector electronics is mainly composed of the **GEMROC (GEM Read-Out Card)** module.

- Interface with the ON-detector electronics
- Data handling
- Configuration and monitoring through LVDS links
- Providing Low-Voltage to the distribution system toward the FEBs



- Each GEMROC module can handle up to four FEBs (8 chips, 512 channels)
- Based on an ALTERA Arria V GX FPGA development board + custom Interface Card (GEMROC_IFC)
- The Interface Card manages the electrical and physical interfaces

CGEM-IT DAQ

BESIII Main DAQ

- Central **run control, trigger synchronization and event acquisition**
- ~39 VME readout crates (~30k channels)
- L1 trigger rate: 4 kHz
- Average event size: ~14 kB
- DAQ readout bandwidth: 80 MB/s

CGEM-IT DAQ Server

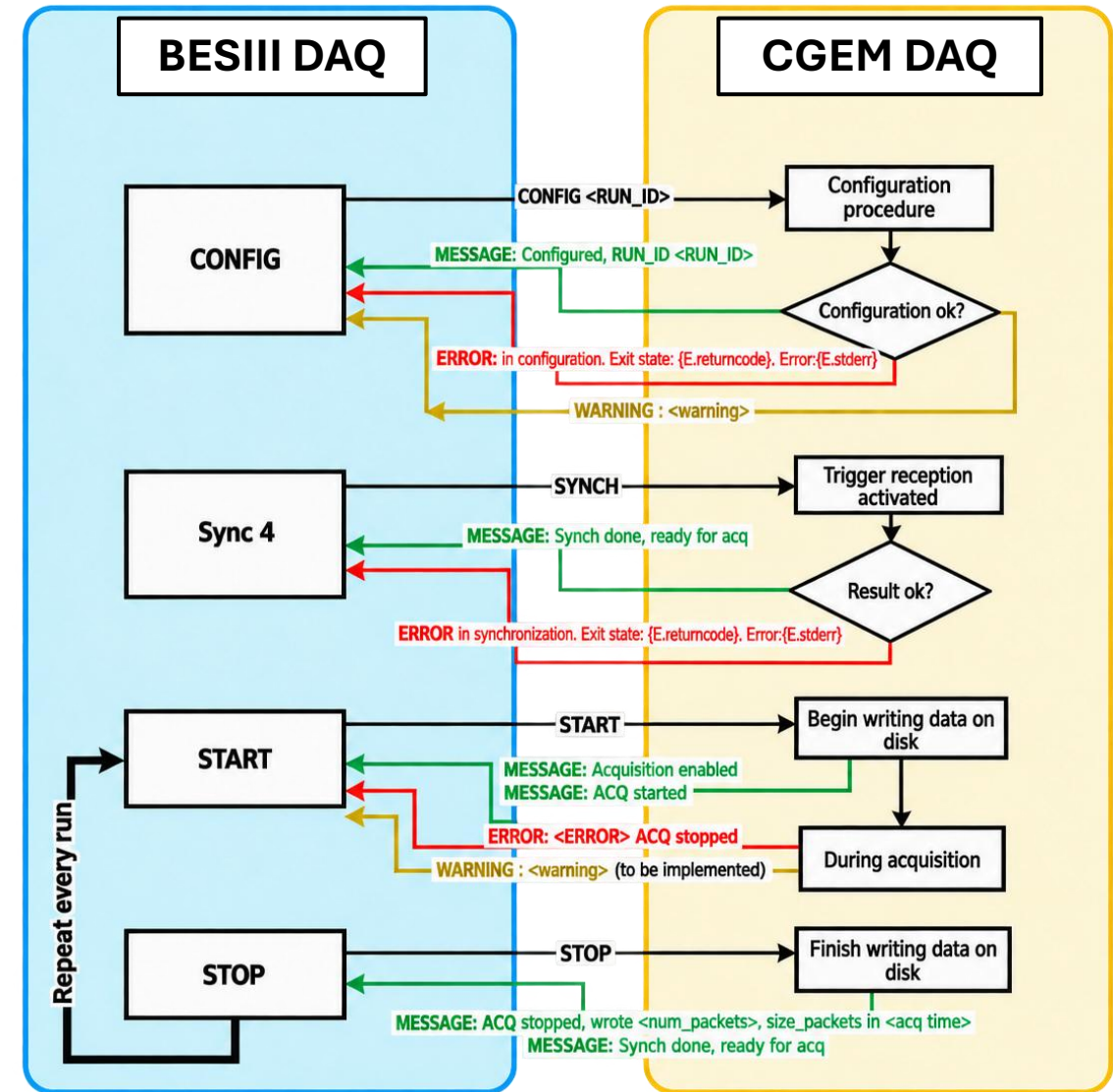


- Dedicated **Dell PowerEdge R7525**
- **2 × AMD EPYC 7313**, 64 GB RAM, 10/25 GbE
- Parallel acquisition from **22 GEMROCs**
- Performs **event building using the L1 trigger ID**
- Data sent to **BESIII DAQ via TCP**, while keeping a local copy

GUFI – CGEM expert interface



- Graphical **User Frontend Interface** for all **GEMROC** configuration, synchronization, and initialization procedures within the CGEM-IT DAQ system
- Used for **expert operations**
- GUFI scripts are also called automatically by the **CGEM Acquisition Service**



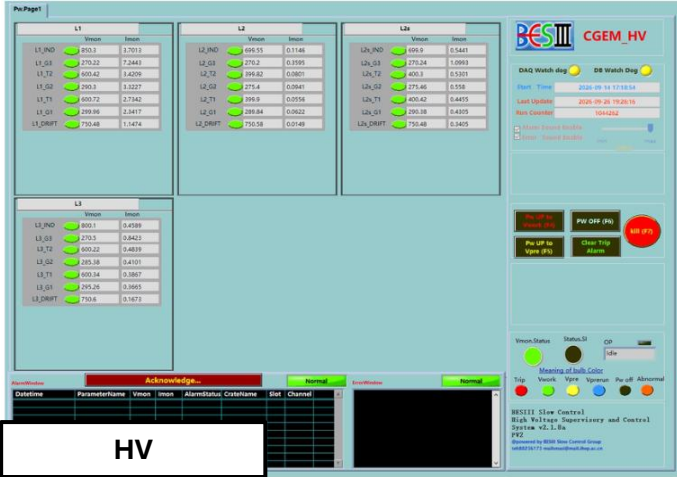
CGEM-IT Slow Control

CGEM-IT is fully integrated into the BESIII Slow Control Global Control System (GSC)

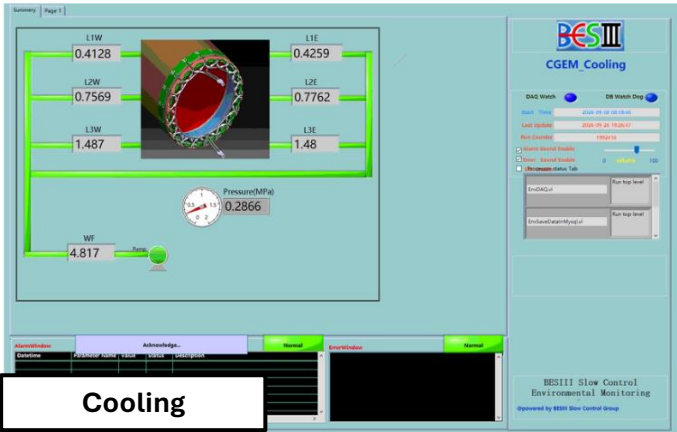


Each BESIII subsystem has its own Slow Control system which allows shifters and experts to operate the detectors.

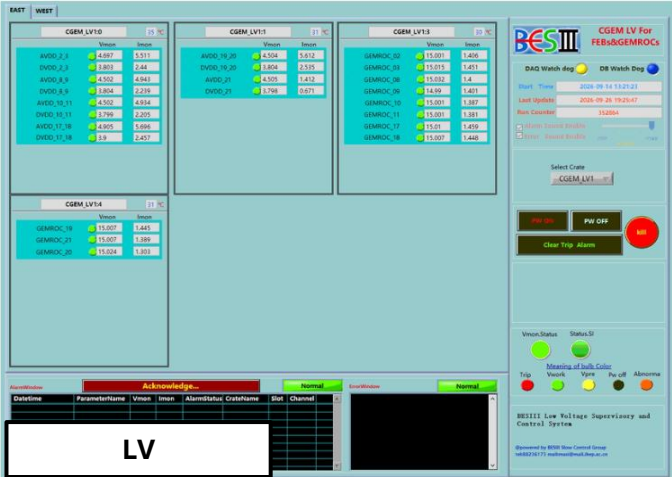
All the gaseous detector systems monitored via the BESIII gas monitor.



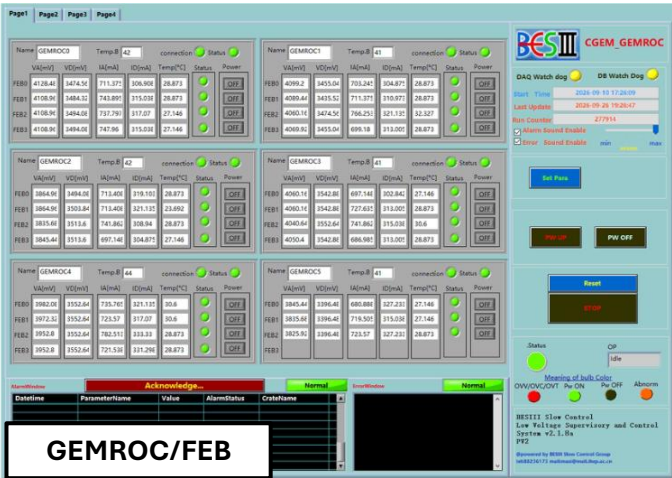
HV



Cooling



LV



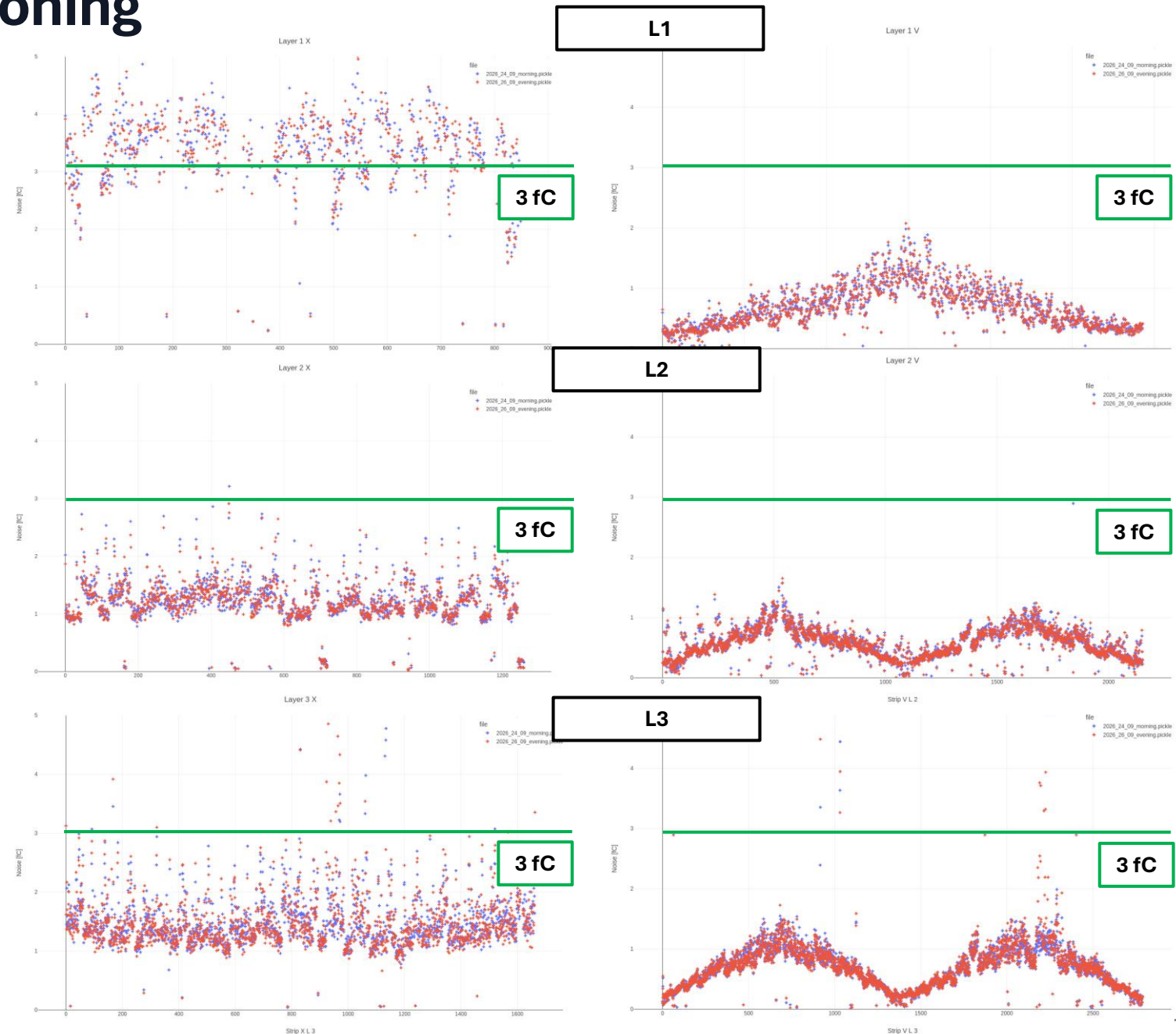
GEMROC/FEB

CGEM-IT LabView VIs for **HV, LV, GEMROC/FEB status and cooling**

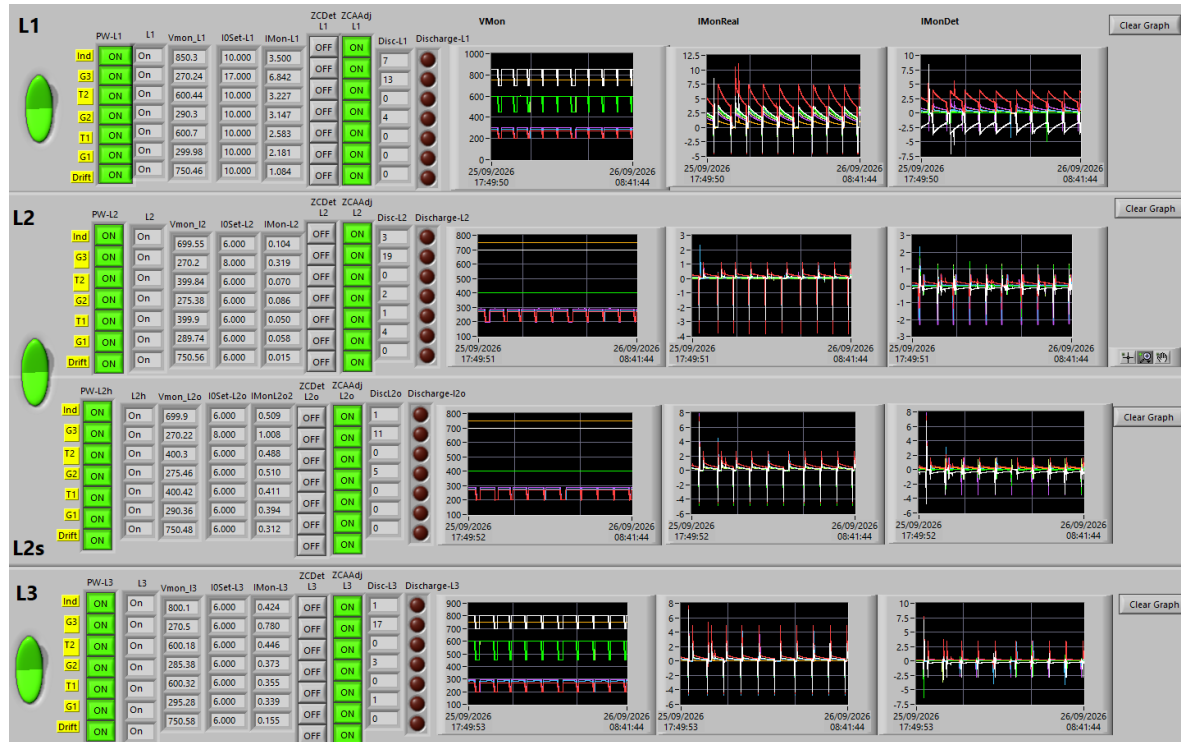
Alarm and interlock logic protects the detector and automatically acts in unsafe conditions

CGEM-IT detector commissioning

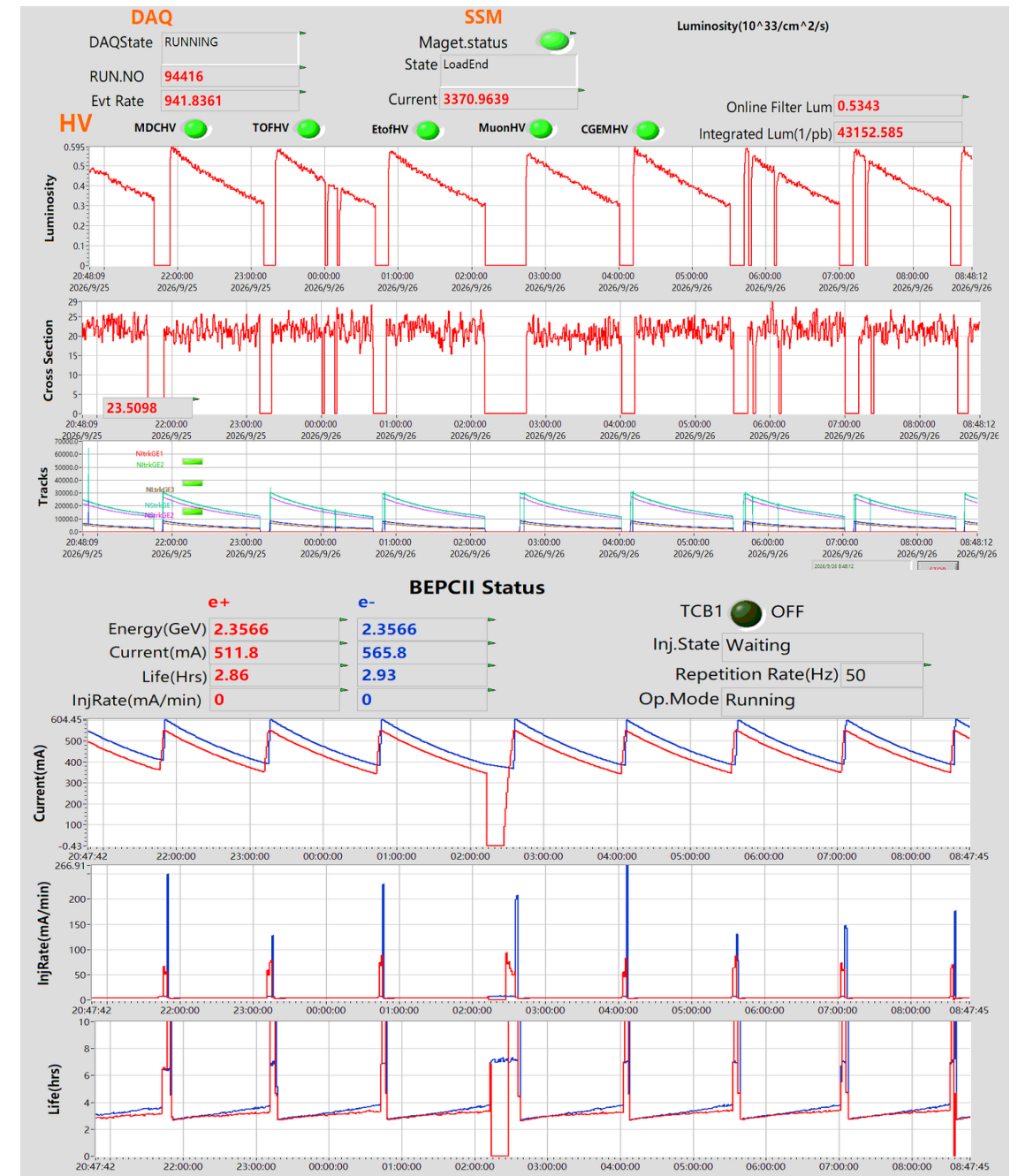
- 19/10/2024 first power ON at nominal values inside BESIII.
- Noise level interventions summary
 - CGEM detector noise compatible with standalone setup
 - Large pick-up noise on the first layer of the MDC even with CGEM disconnected
 - All DLVPCs were shielded
- Noise level stable over the years
 - Almost all channels have a noise level below 3fC with **magnetic field ON**
 - Higher but stable noise level on L1 X



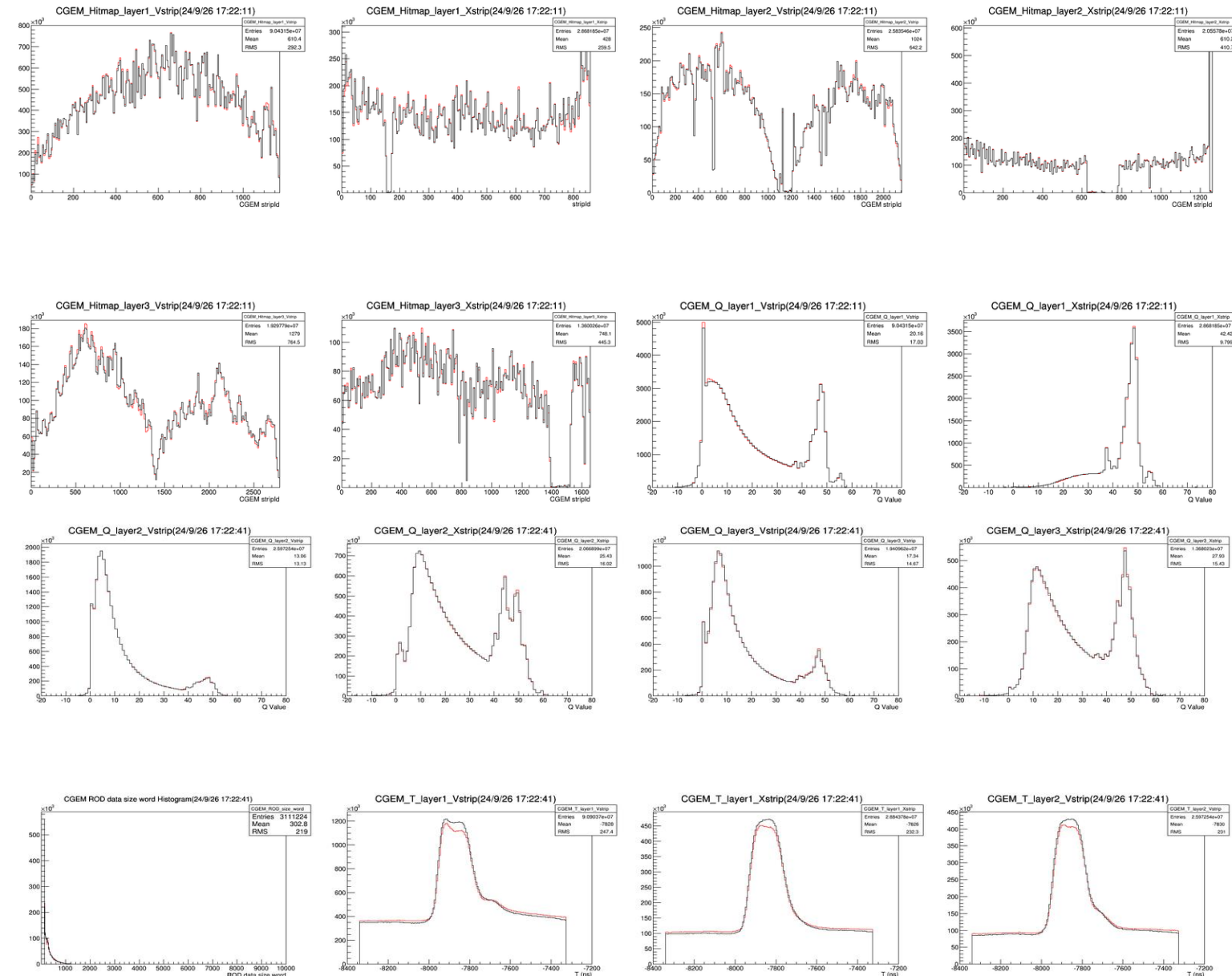
CGEM-IT detector commissioning



- Mid-2025 beam commissioning completed and BESIII started running with the CGEM-IT system integrated. The CGEM-IT is running stably.
- Target luminosity of $1 \times 10^{33} \text{ cm}^2/\text{s}^{-1}$ @BEPcII achieved on 17/04/2026.
- The data taking restarted on 19/09/2026 reaching almost $0.6 \times 10^{33} \text{ cm}^2/\text{s}^{-1}$ luminosity in a week.



CGEM-IT detector integration within BESIII



Online data quality plot of each layer of the CGEM-IT added to the BESIII DAQ monitor in 2026

- Hitmaps
- Charge distributions
- Time distributions

Known issues in the distributions due to disconnected HV sectors.

Easier hot strips identification.

Per-strip charge distributions are still to be implemented to better identify local inefficiencies.

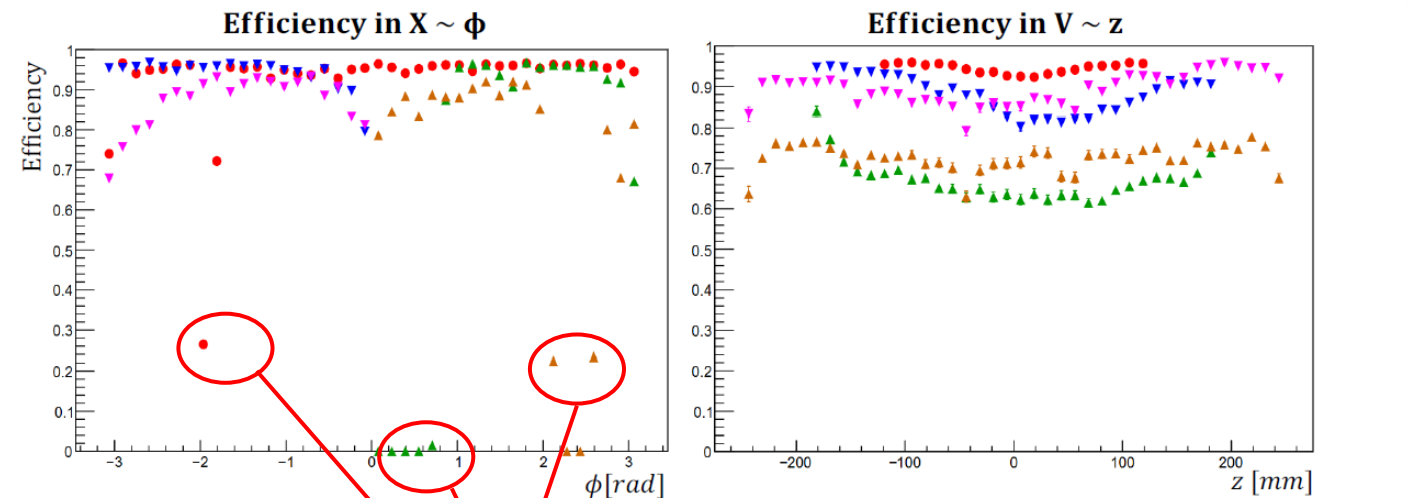
CGEM-IT detector preliminary performances within BESIII

CGEM-IT detector performances study
using **BhaBha events** [6]:

- **1D-cluster efficiency** after removing some disconnected HV sectors are all above 75%
- **Stability over the analyzed RUNs** observed
- **Spatial and Momentum resolutions** showing promising results

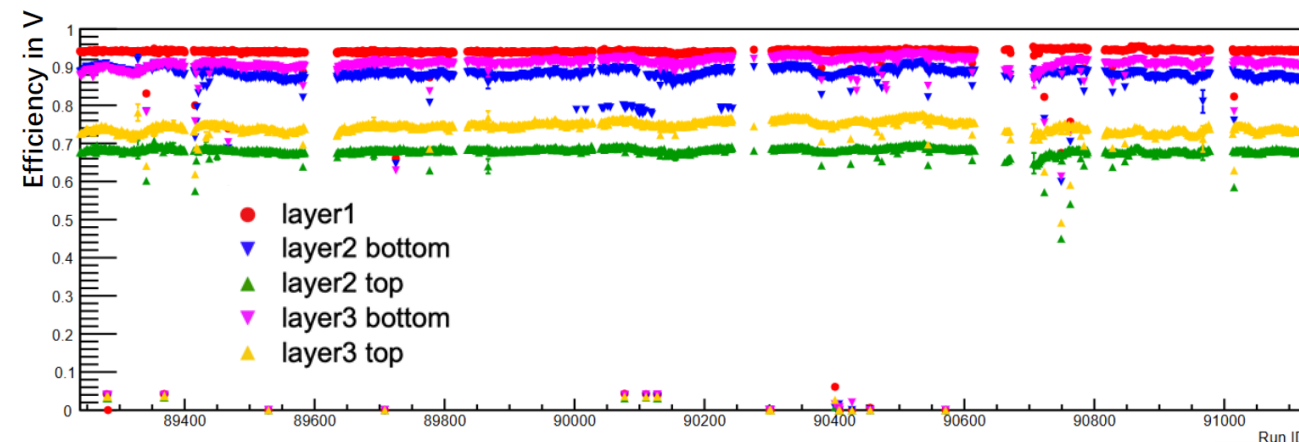
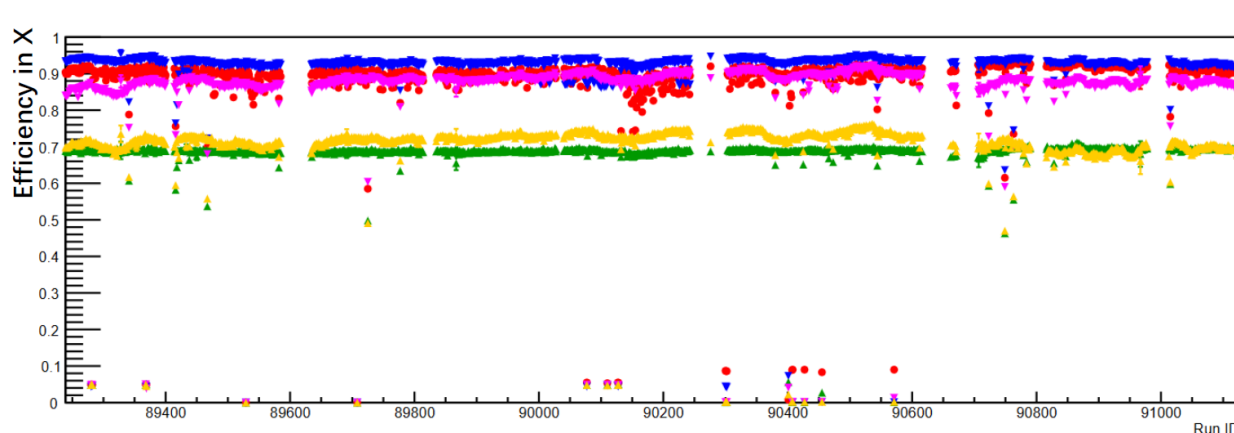
See next talk by Yaxuan

Courtesy of Li Yaxuan



Inefficiencies due to disconnected HV sector

Courtesy of Li Yaxuan



Summary and Outlook

- BESIII Spectrometer and BEPCII accelerator upgrades successfully completed
 - CGEM-IT running within BESIII environment since 2025
 - BEPCII operations resumed in December 2025 (delay due to cryogenic system failure) and the **target luminosity goal** was **achieved** on 17/04/2026.
 - 2026 summer shutdown plans completed and operations successfully restarted on 19/09/2026
- CGEM efficiency and noise status remained stable over the years.
- CGEM-IT tracking and reconstruction optimizations is currently ongoing.

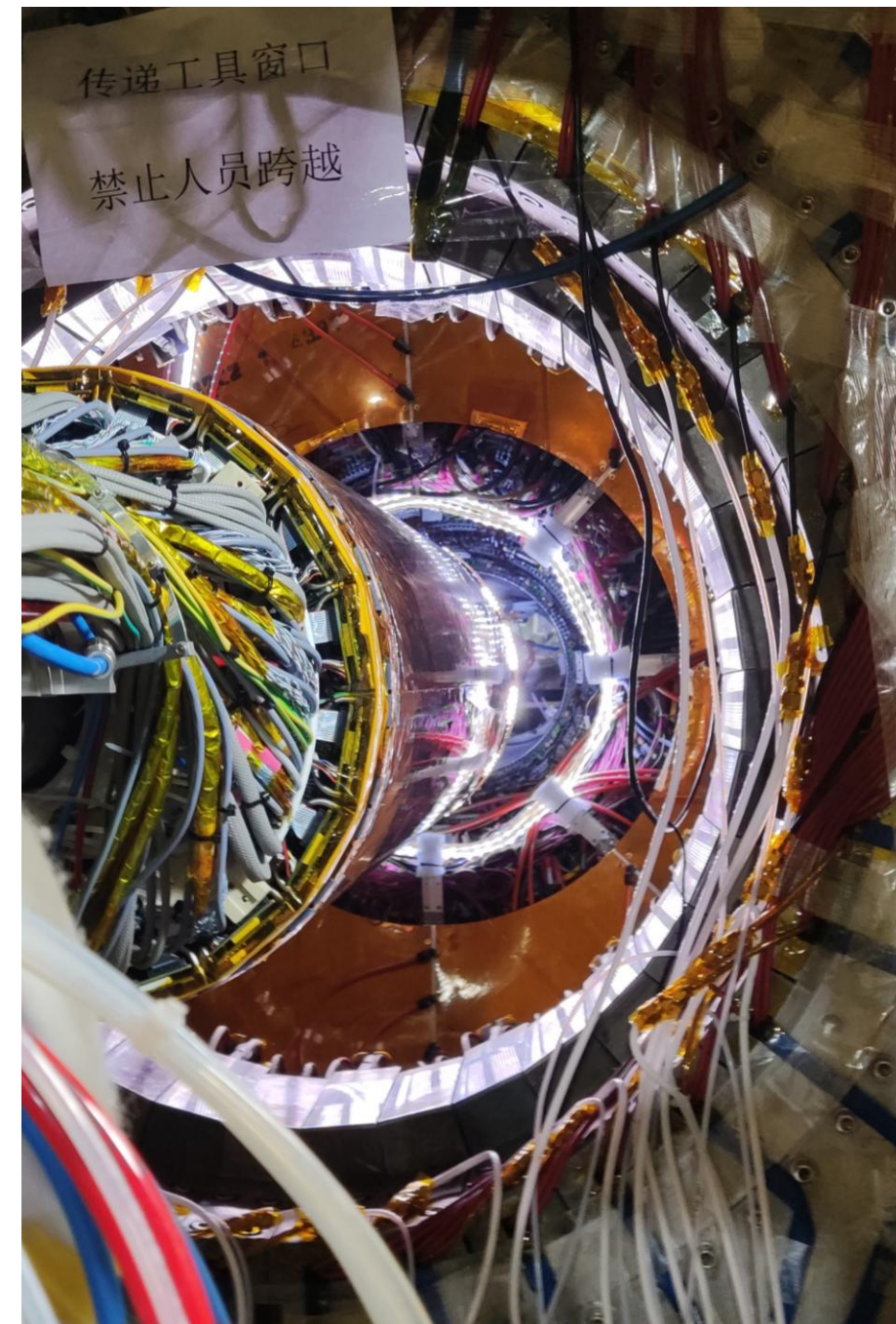
Thank you! 谢谢!

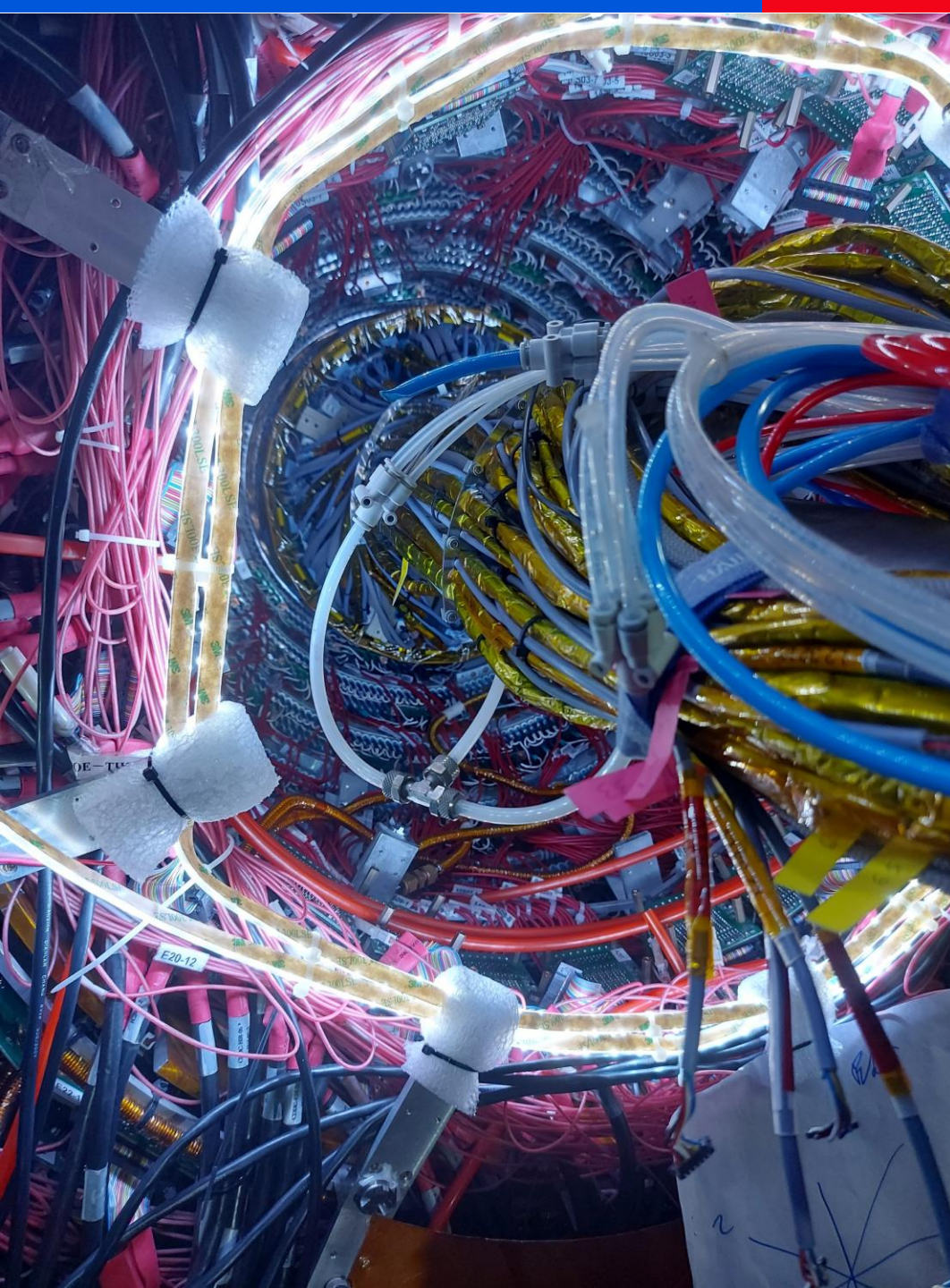


European
Commission

Horizon 2020
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for Research & Innovation

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BESIII CGEM Project (645664) H2020-MSCA-RISE-2014





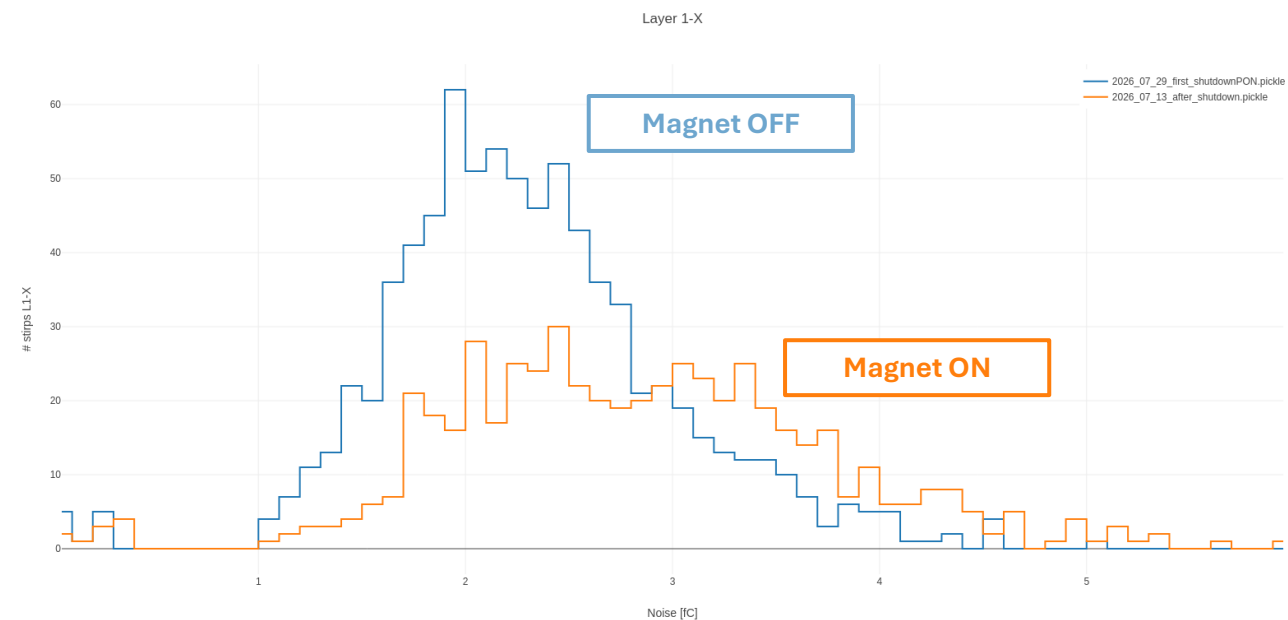
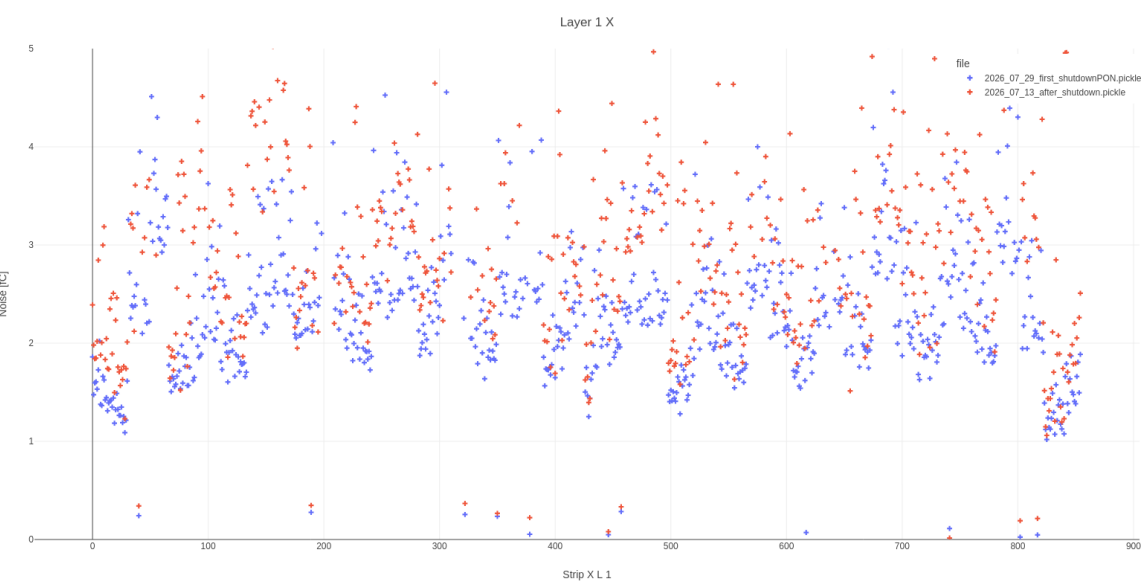
Backup slides

CGEM-IT noise levels

Layer 1 X shows the highest noise level: this could be due to the presence of a carbon fiber layer just below its anode, which may be the source of parasitic capacitive coupling.

Layer 1 V strips, facing the gas volume could be less affected.

This is also the layer whose noise level is most affected by the presence of the magnetic field

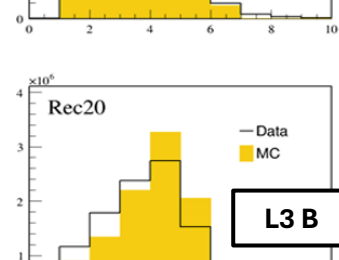
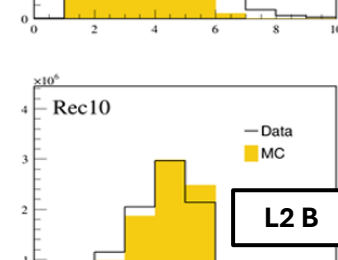
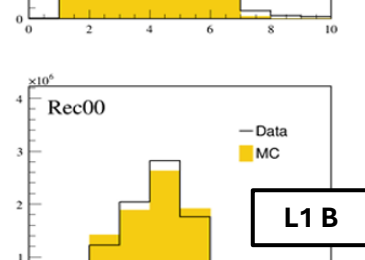
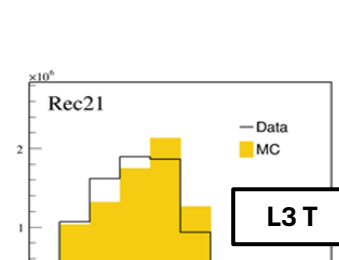
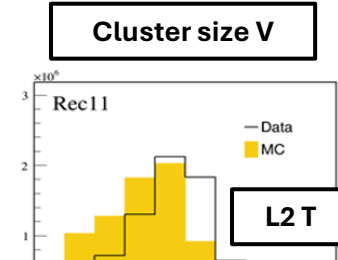
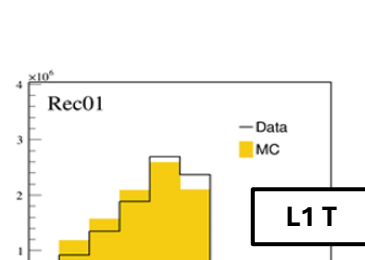
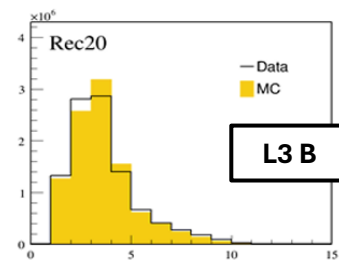
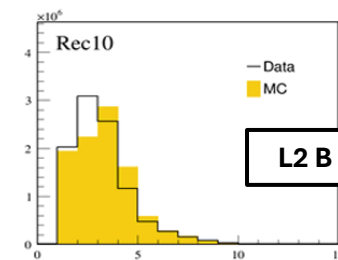
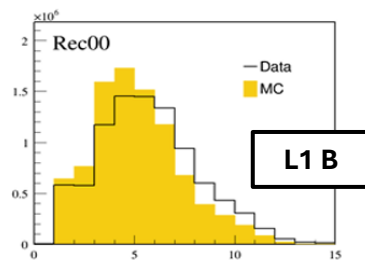
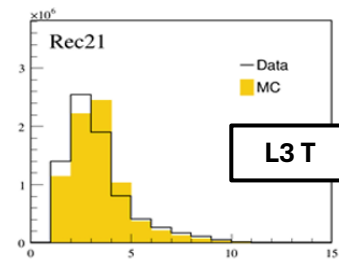
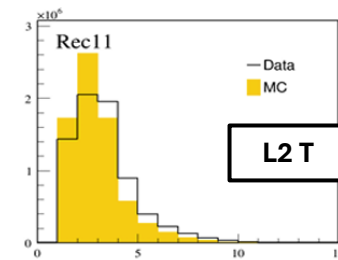
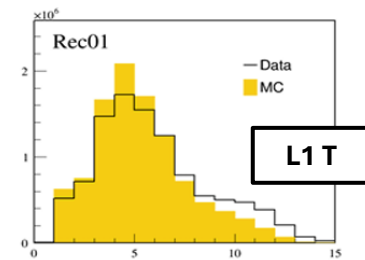
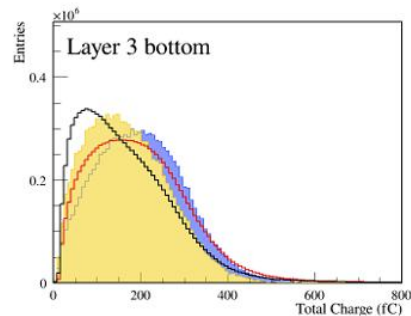
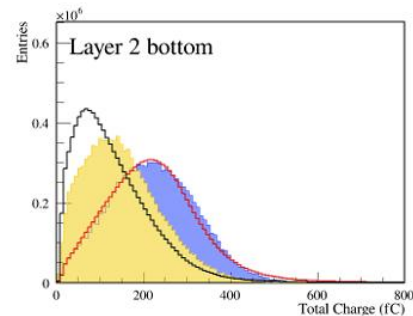
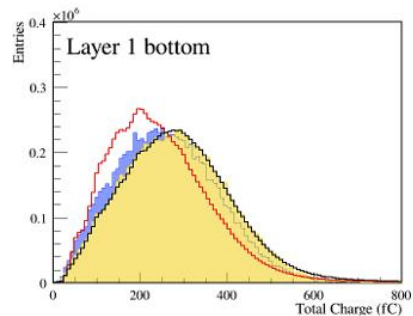
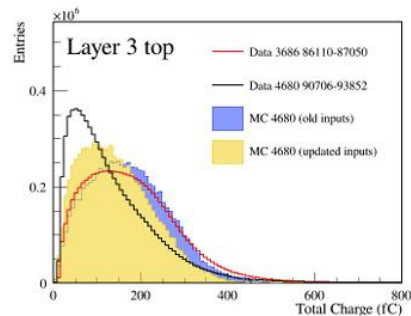
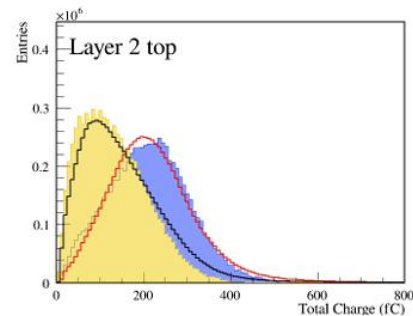
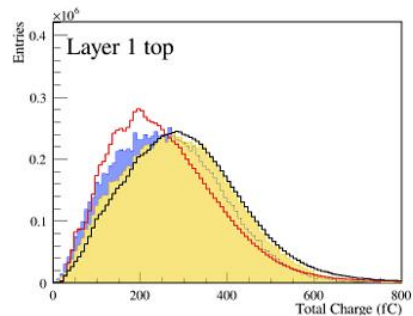


CGEM-IT charge distributions

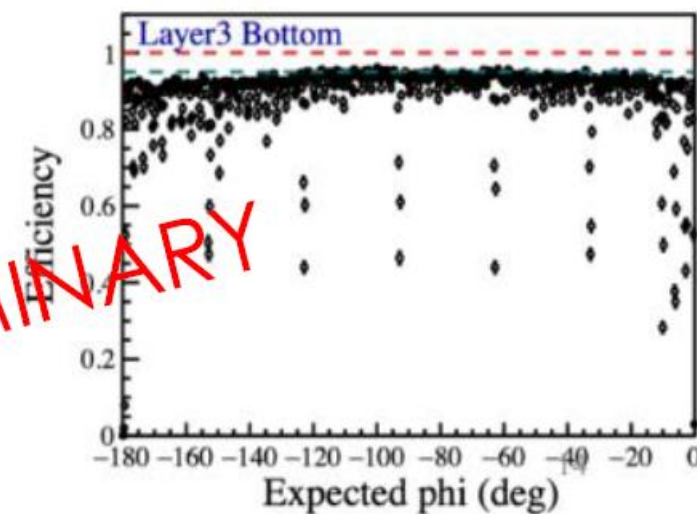
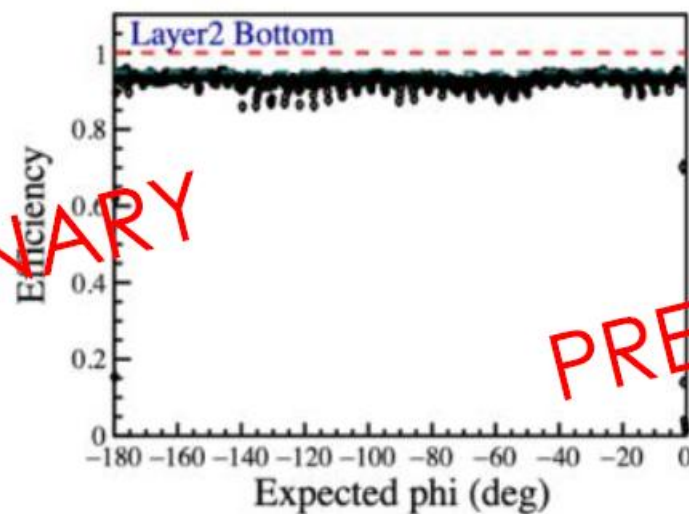
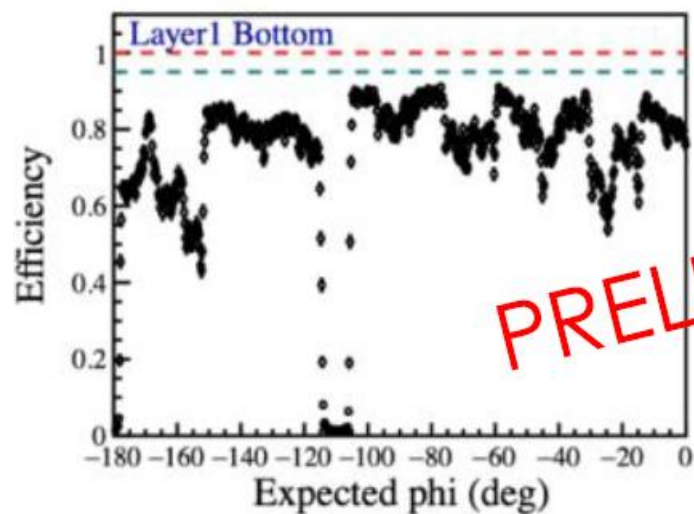
Each layer is divided into halves along the horizontal plane: TOP and BOTTOM

Layer 1 collects more charge and has larger clusters.

- Gas distribution
- Capacitive coupling between the anode and the carbon layer, leading to higher noise
- Reduced defocusing due to the smaller radius of curvature



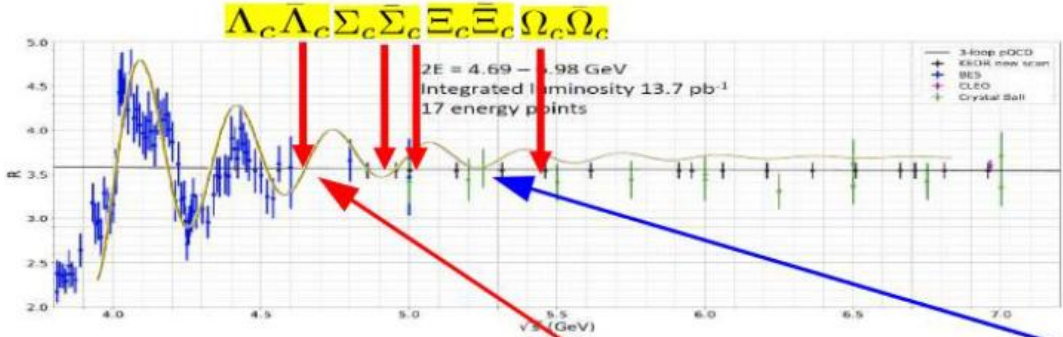
CGEM-IT efficiencies cosmic rays



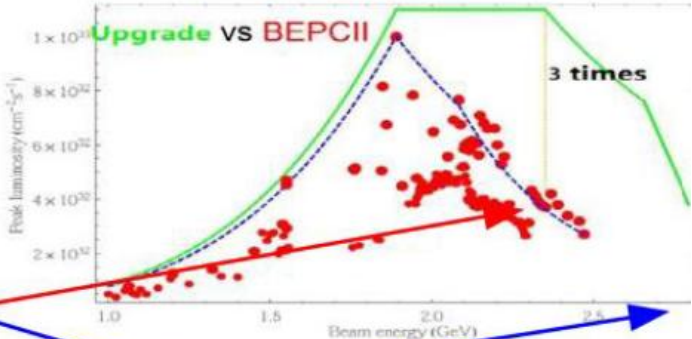
PRELIMINARY

PRELIMINARY

BEPCII upgrade program



* KEDR new scan points positions are fixed at pQCD predictions
Expected total uncertainty is about 3 % (systematic uncertainty about 2.5%)



BEPCII upgrade aims at: Increase luminosity by a factor of 3 & Increase beam energy to 2.8GeV

Key Technologies: Double beam power & Optics upgrade & New high gradient of magnets



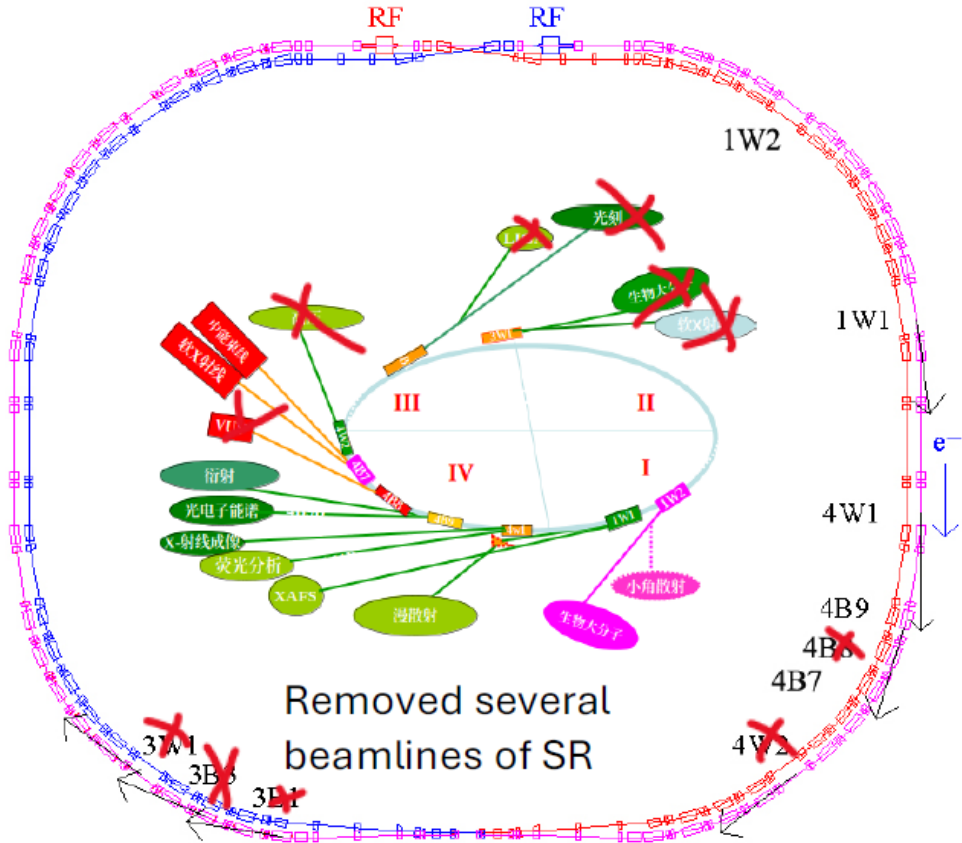
BEPCII-U program

- Key technologies:
- Double beam power
 - Optics upgrade
 - Higher gradient of magnets

Comparison of performance

	BEPCII @ 2.35GeV	BEPCII-U @ 2.35GeV	BEPCII-U @ 2.8GeV
L [10 ³² cm ⁻² s ⁻¹]	3.5	11	3.7
β_y^* [cm]	1.5	1.35	3.0
Beam current [mA]	400	900	450
SR Power [kW]	110	250	250
$\xi_{y,lum}$	0.029	0.033	0.043
Emittance [nmrad]	147	152	200
Couping [%]	0.53	0.35	0.5
Bucket Height	0.0069	0.011	0.009
$\sigma_{z,0}$ [cm]	1.54	1.07	1.4
σ_z [cm]	1.69	1.22	1.6
RF Voltage [MV]	1.6	3.3	3.3

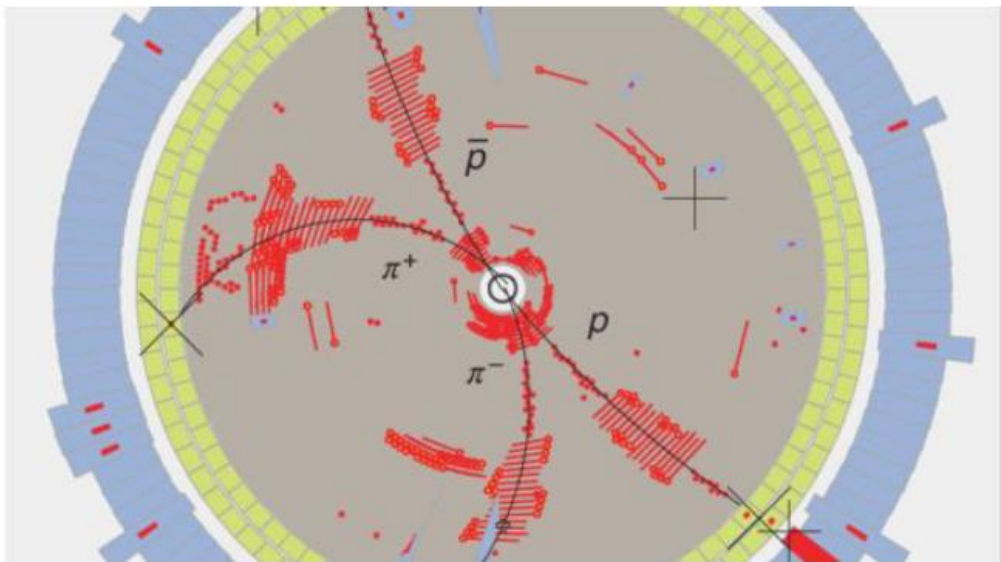
Peak luminosity (cm⁻²s⁻¹)



w/o BSRF dedicated operation, only parasitic SR experiments, 10 months/year BESIII time.

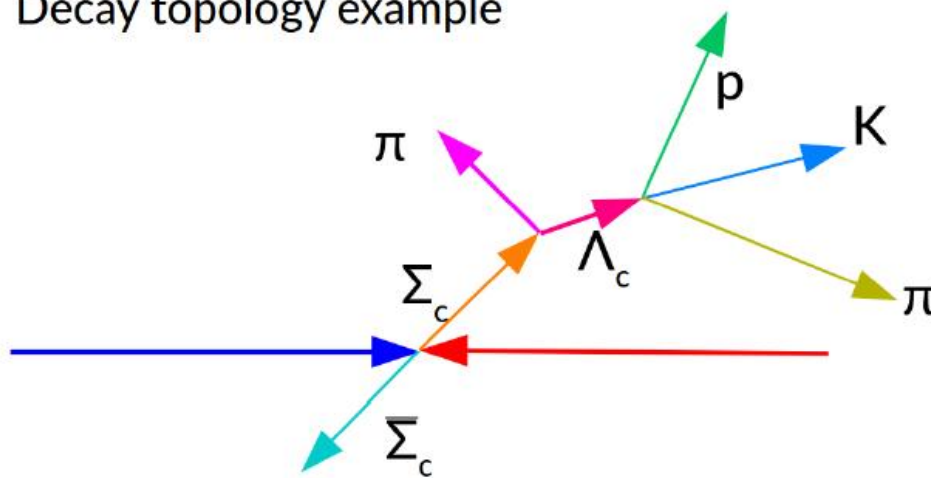
The CGEM-IT impact

- $J/\psi \rightarrow \Lambda \bar{\Lambda}$
Nature Phys. 15 (2019) 631-634



- Most relevant impact is on vertex reconstruction, radiation hardness and rate capability
- Better separation for complex topologies crucial for charmed baryon decays, central in the BESIII program
- Improvement of a factor 3 of decays with Lambda hyperon and K_s meson

Decay topology example



Strategic collaboration with industries for the hardware developments