BESIII CGEM 内径迹探测器

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On hehalf of CGEM IT group

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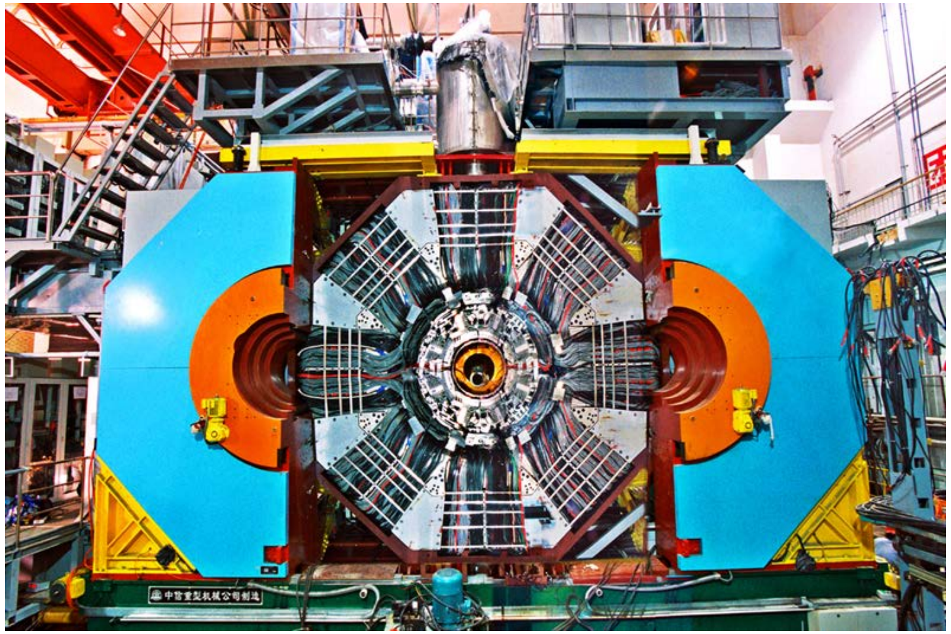
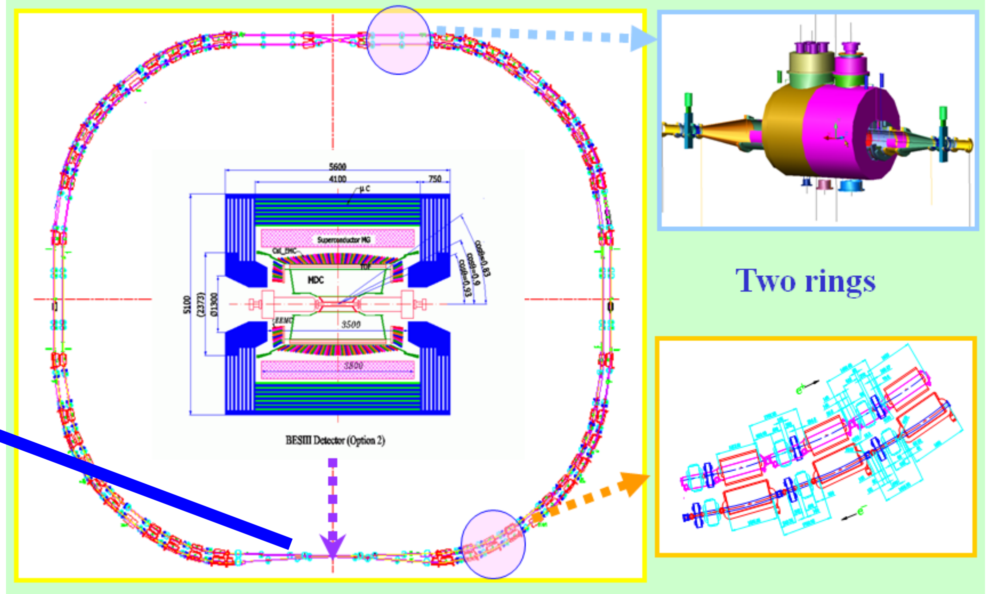
Outline

- **Introduction of BESIII and MDC aging**
- **CGEM design, construction, installation and operation**
- **Preliminary performance**
- **Summary**

The BESIII experiment

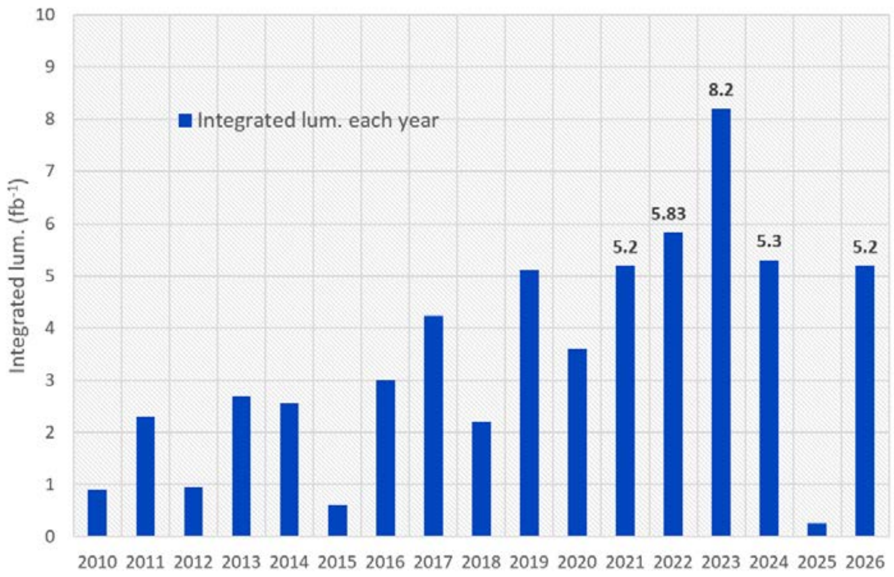
- Beijing Spectrometer(BESIII) is a general purpose detector at Beijing Electron-positron Collider (BEPCII), $E_{cm} \approx$ 2-5 GeV, $L_{peak} \approx 10^{33}/cm^2/s$
- Versatile researches in τ-charm physics
- BESIII collaboration has >700 members from 93 institutes in 15 countries and regions



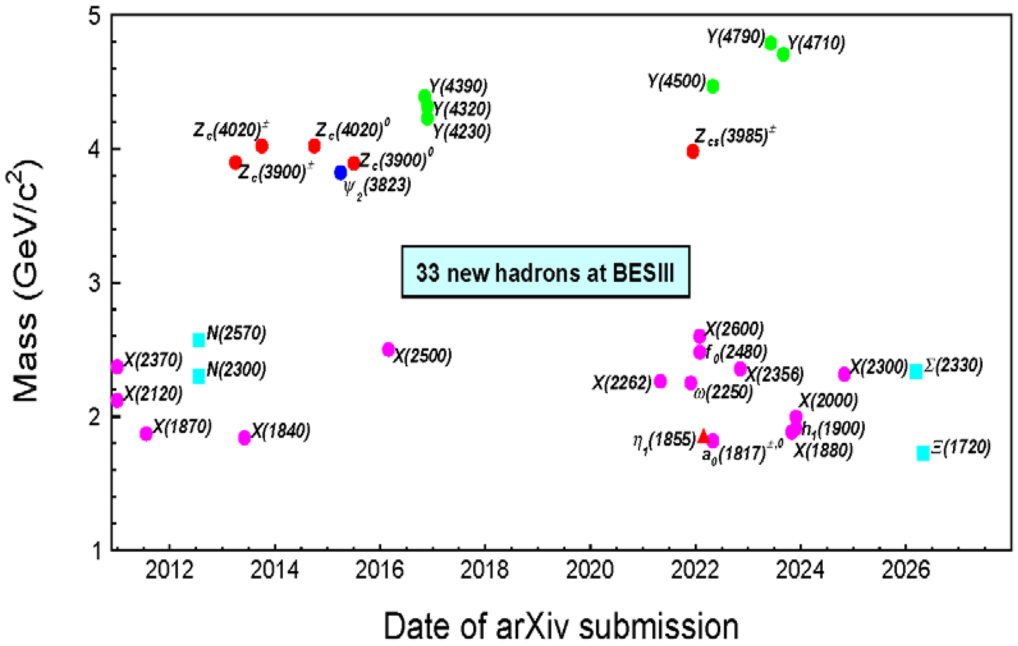


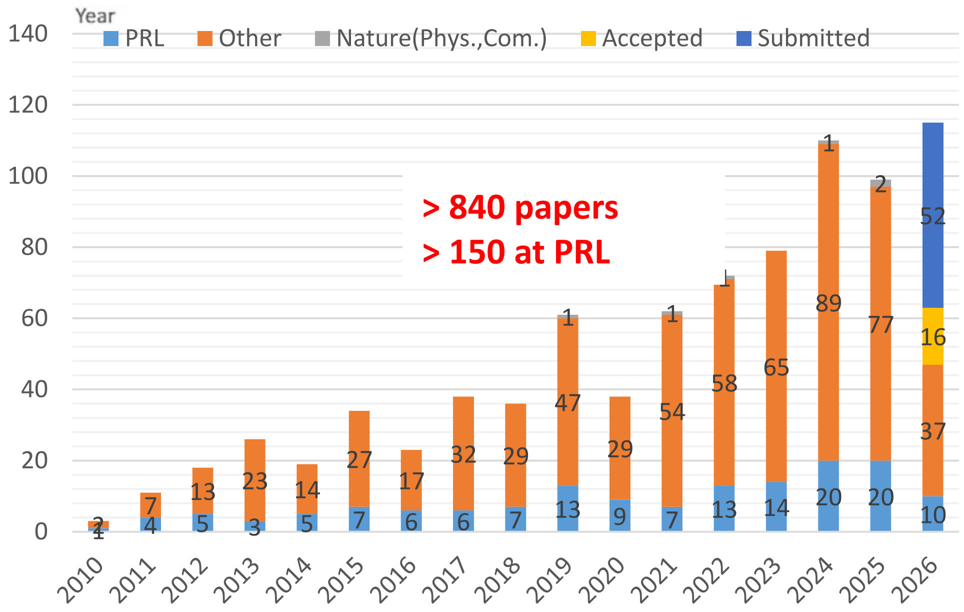
The BESIII experiment

- Started commissioning run in July, 2008
- Started data collection in 2009
- More than 17 years operation
- BEPC and inner tracker of BESIII were upgraded in 2024-2025



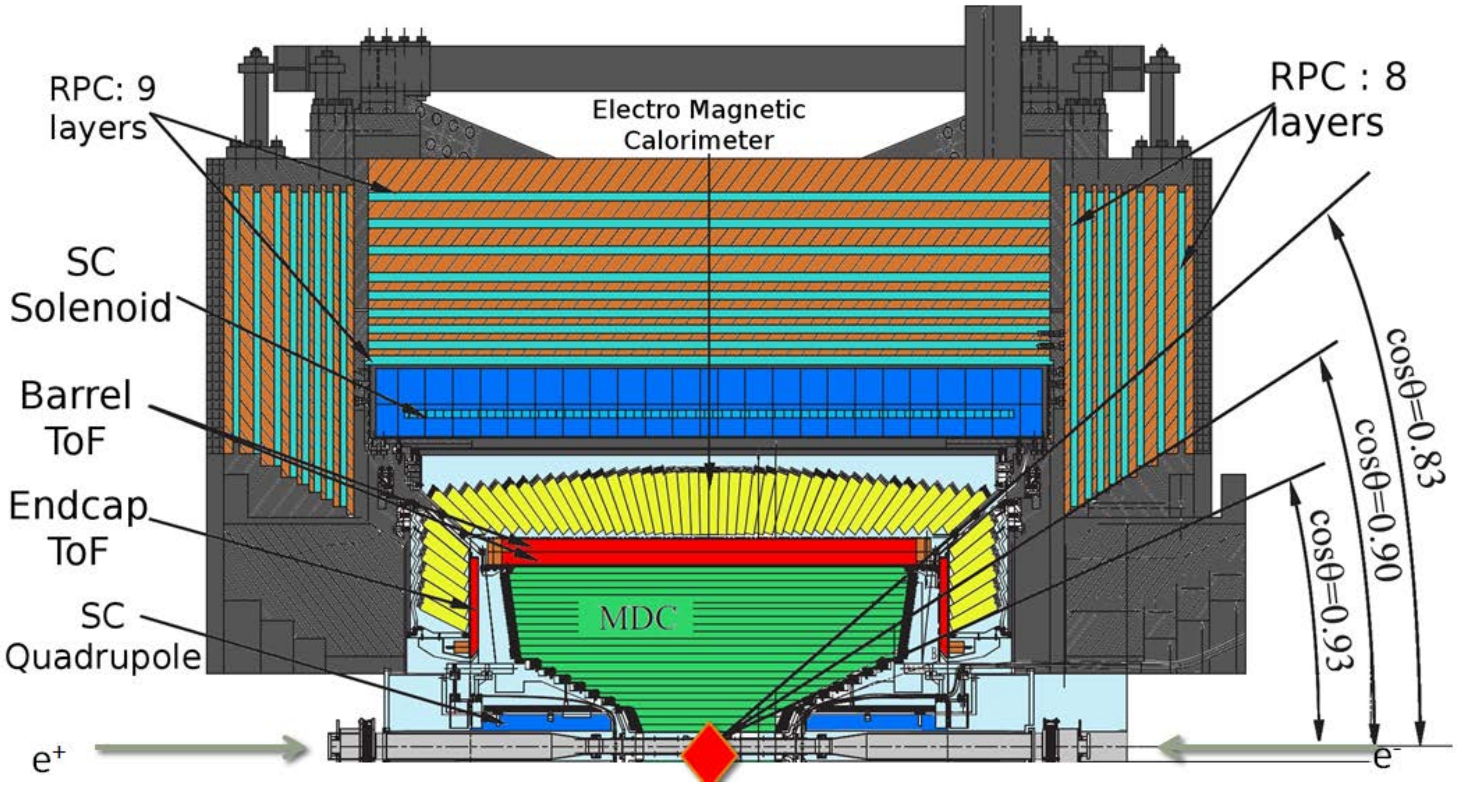
- Total integrated lum. : 58.2 fb^{-1}
  - 10 B J/ψ events
  - 4 B ψ(2S)events
  - 20 fb^{-1} ψ(3770)
  - 3.2 fb^{-1} Ds
  - 27.1 fb^{-1} E_{cm} > 4GeV data
  - ……
- Most of them are the largest events in the world





BESIII detector

- He-based gas drift chamber (MDC):
  single-wire resolution < 130 μm
- CsI (Tl) crystal electromagnetic calorimeter (EMC) :
  energy resolution < 2.5% at 1 GeV
- Time of Flight (TOF):
  time resolution <100 ps
- Superconducting solenoid magnet(SSM) :
  1 T magnetic field
- RPC-based muon detector (MUC)



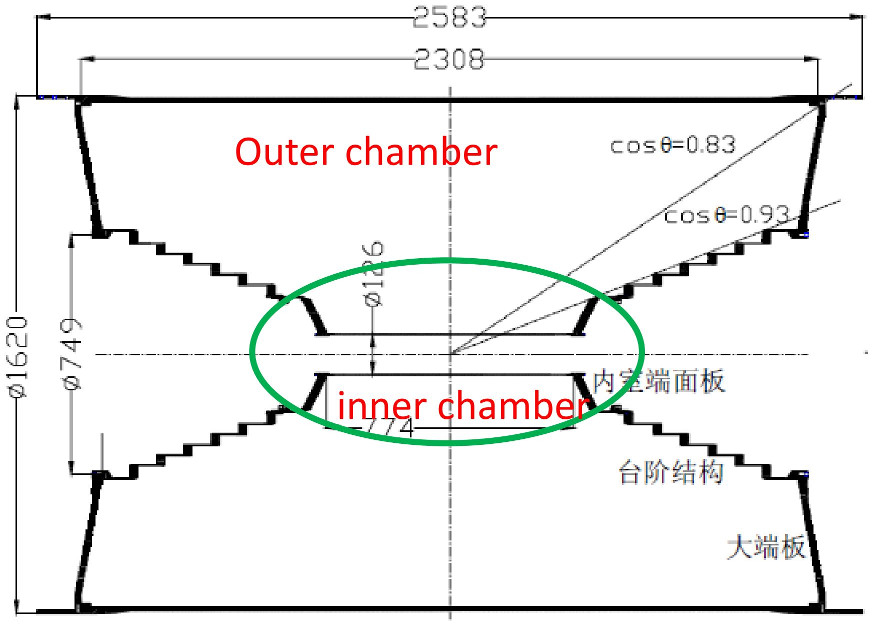
BESIII Main drift chamber (MDC)

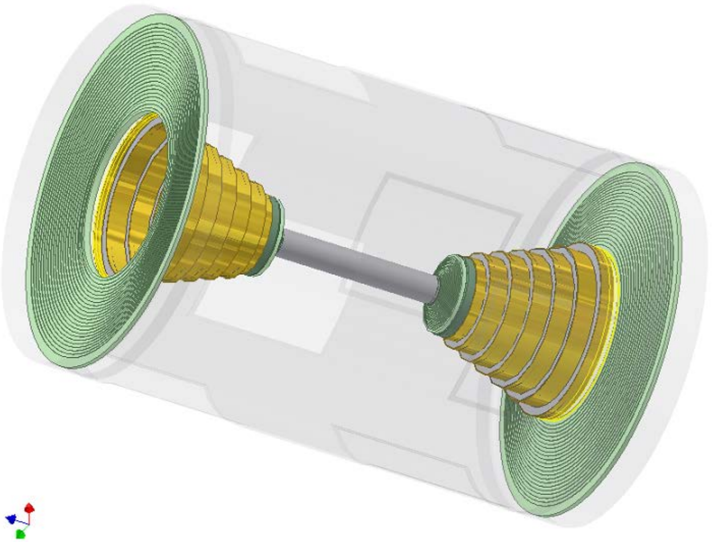
- Main tracking detector for the charged particles

  Position, momentum and dE/dx measurements

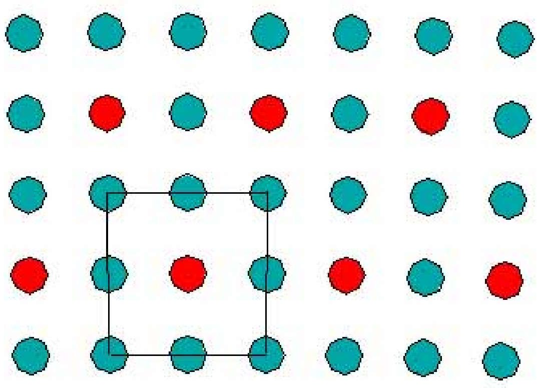
- Consists of inner chamber and outer chamber

Parameters	Specification
Number of layer	43 (inner chamber: 8 layers+ outer chamber: 35 layers) 19 axis layers， 24 stereo layers
Number of cell	6796
R extension	63 mm → 810 mm
Length	2308 mm
Inner cylinder	1.2mm- thick CF
Outer cylinder	11.5mm- thick CF
End plates	18mm-thick Al （6 stepped parts， inner end plate）

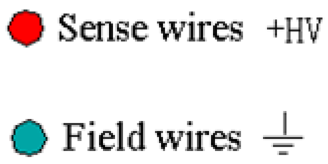




Small cell design and He based gas mixture



Field to sense
wire ratio: 3:1



- cell size：
  inner chamber: 12mm×12mm
  outer chamber: 16.2mm×16.2mm

- Sense wires: ϕ25μm W (Au)
- field wires: ϕ110μm Al (Au)
- 28680 wires in total

- **Gas**
  - He based gas mixture , He : C_3H_8 = 60％ : 40％
  - low material budget to reduce multiple scattering
  - v_e=3.8 cm/μs
- **High Voltage**
  - About 2200 V, little difference between each layer
  - The first four layers: 98%, 98.5%, 99%, and 99.5% of the nominal value, respectively, due to beam background
  - Gas gain：~2×10^4 @2200V

Anode aging in MDC

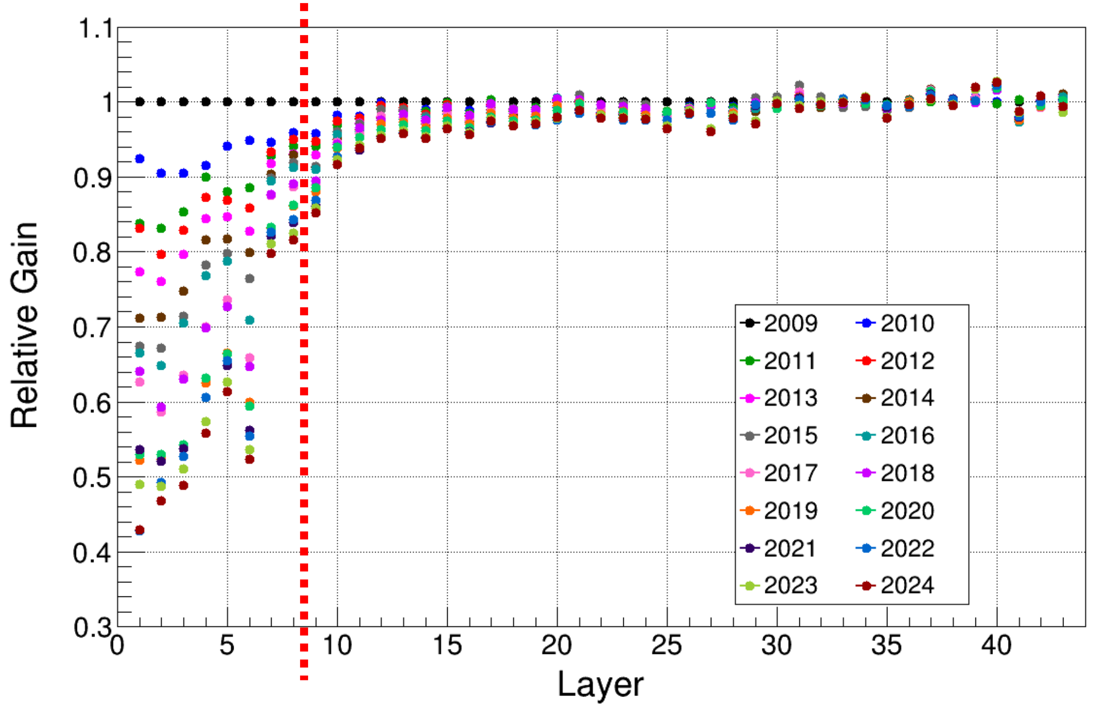
- After >17 years operation, gains of inner chamber dropped by >50% for the first layer cells
- No significant change in gain for outer layers

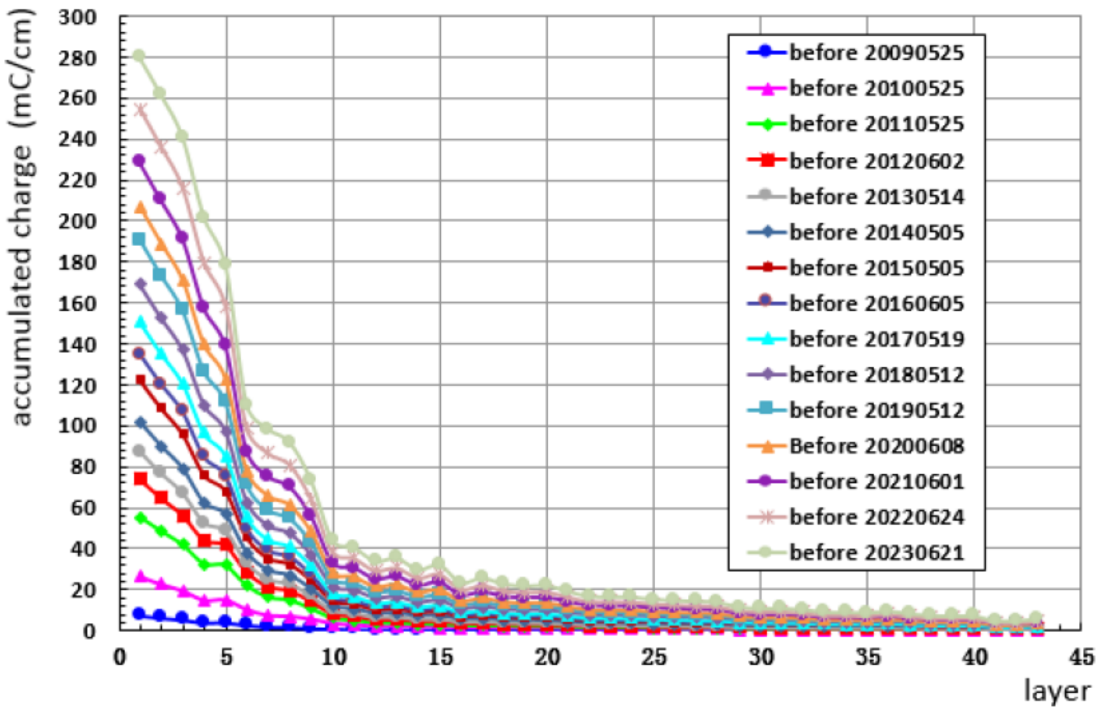
- Aging ratio: $R = -\frac{1}{Q} \cdot \frac{\Delta G}{G} \% \Big/ (mC/cm)$

Aging ratio is not a constant, which depends on correlated parameters, such as gas gain, radiation intensity…

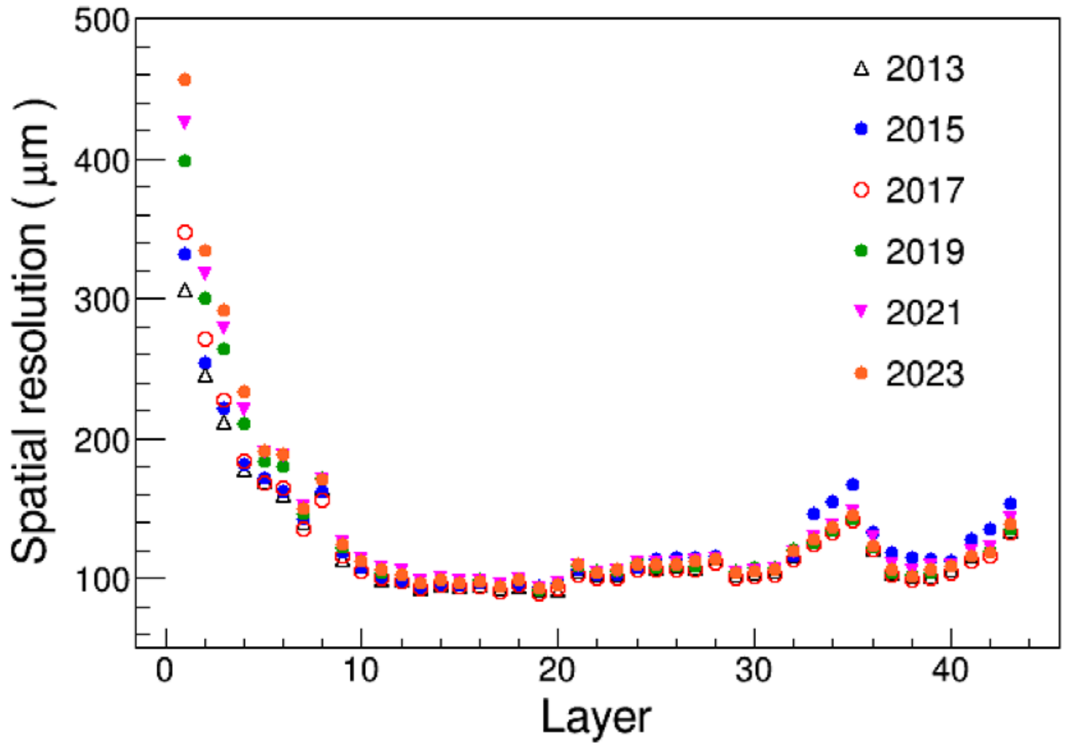
Inner chamber

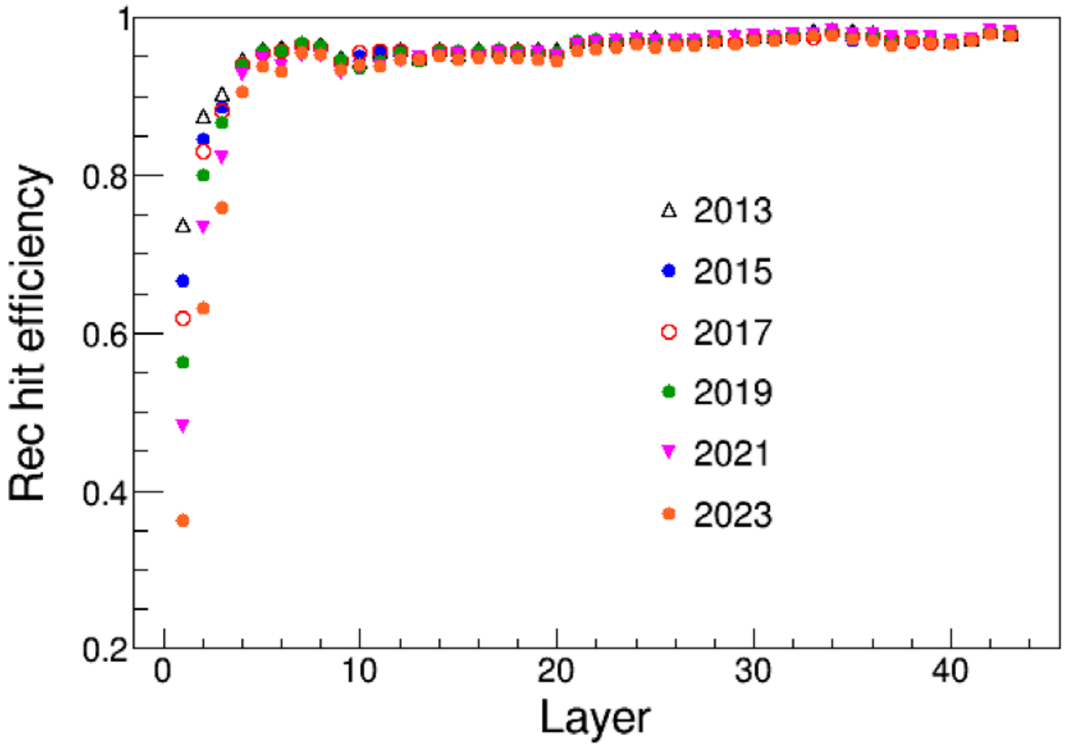
Inner chamber





MDC spatial resolution and efficiency

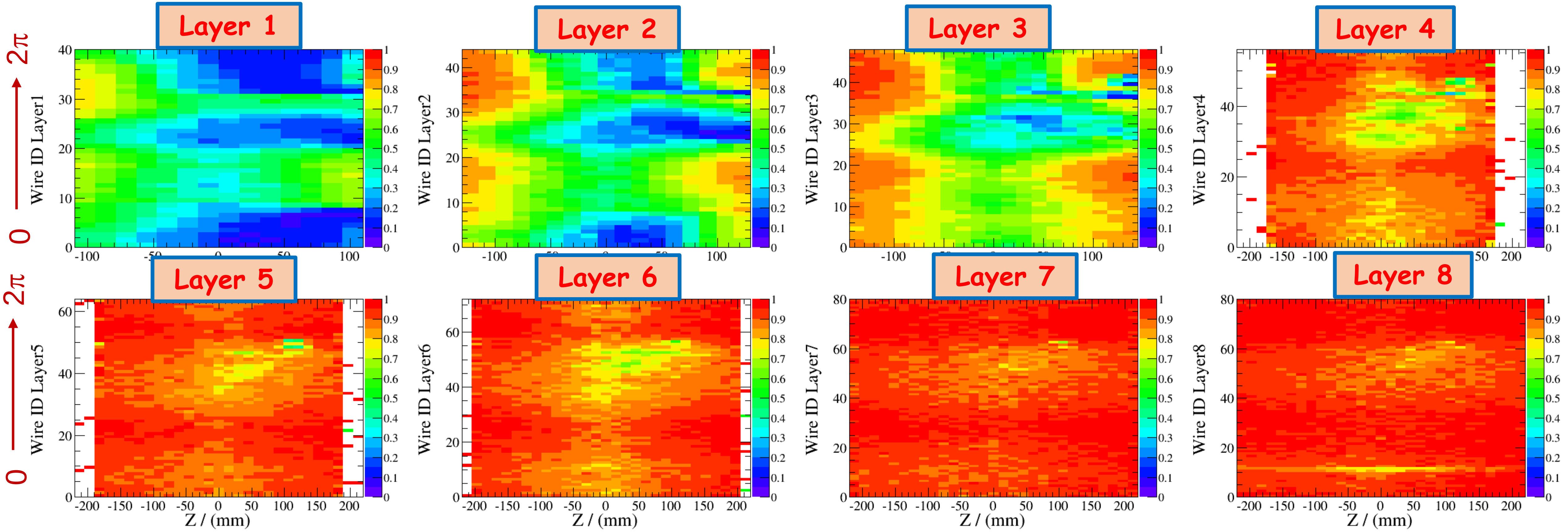




- The resolution of the inner chamber has significantly decreased
  - Decrease in gain caused by aging
  - Low voltage setting leads to low gain for the first four layers
- Almost no changes for the outer chamber

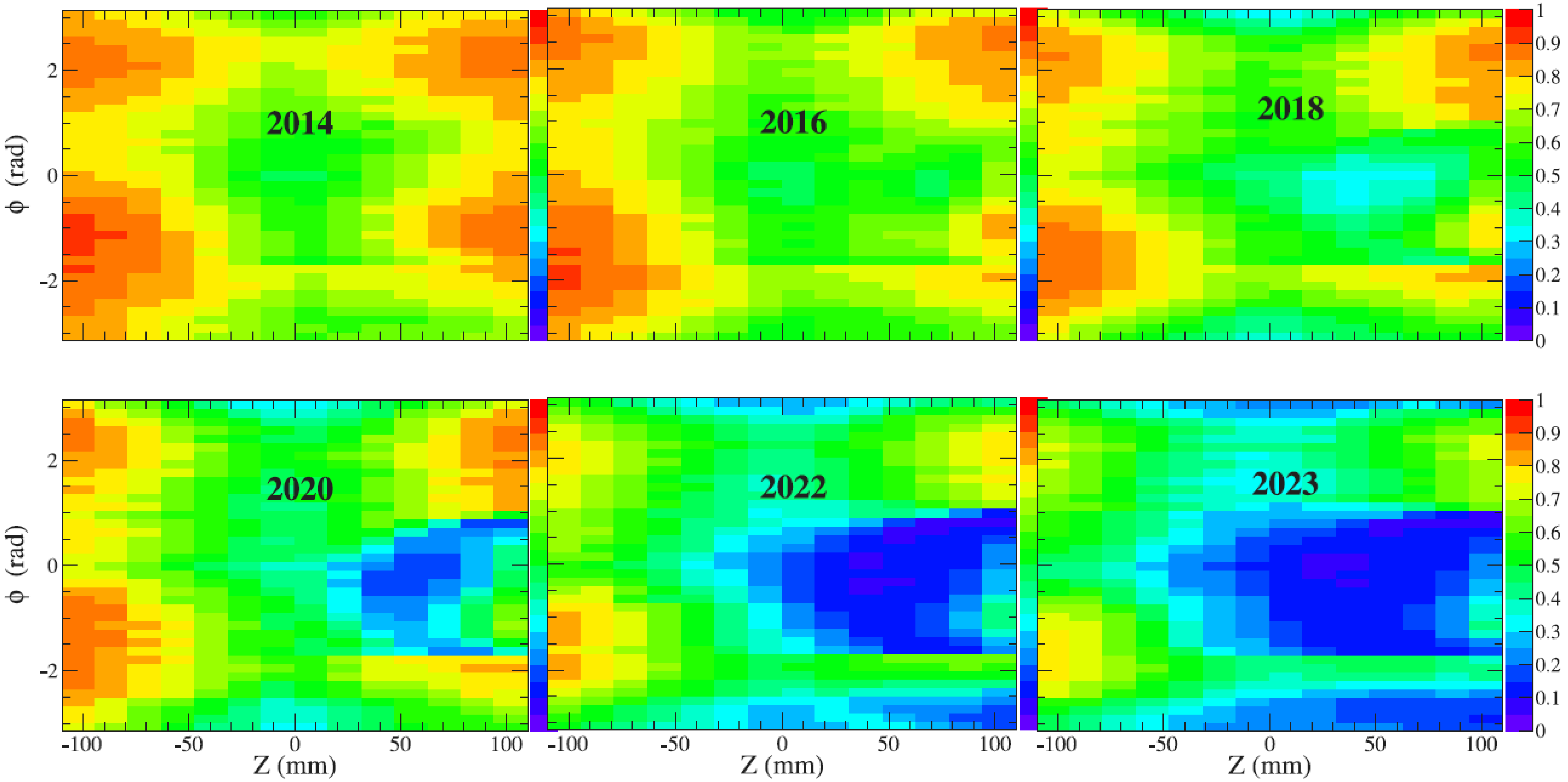
- Hit efficiency of the first three layers decreased year by year
- No significant decrease for most layers

Rec hit efficiency of inner chamber



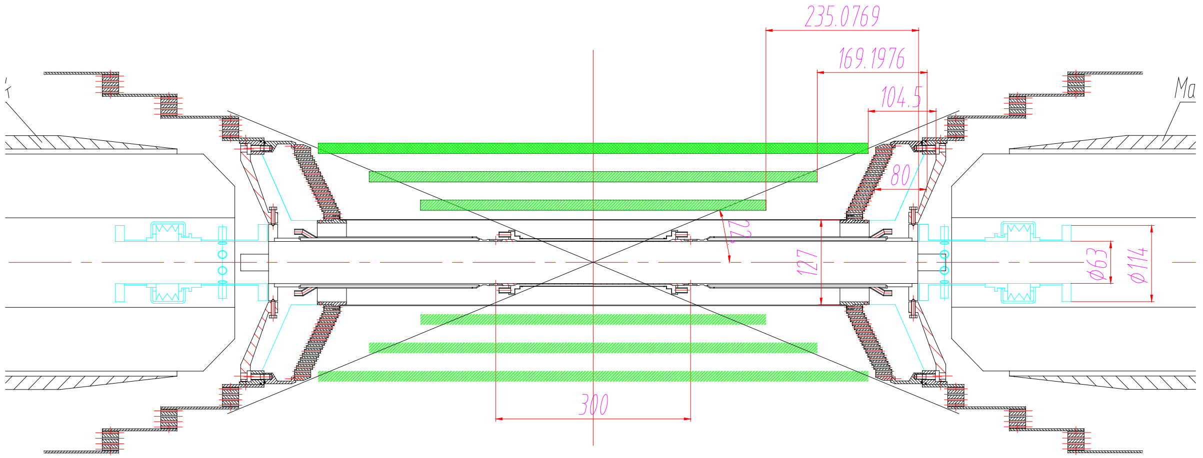
- The efficiency of the first three layers are nonuniform
- Some region is quite low (~*20%*) , Signals are lower than threshold

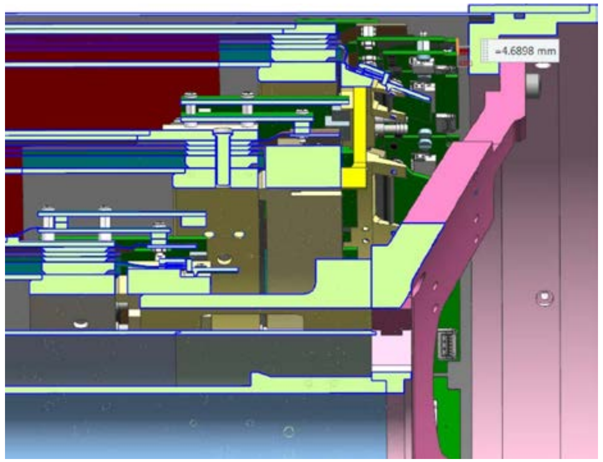
Rec hit efficiency of L1 in each year

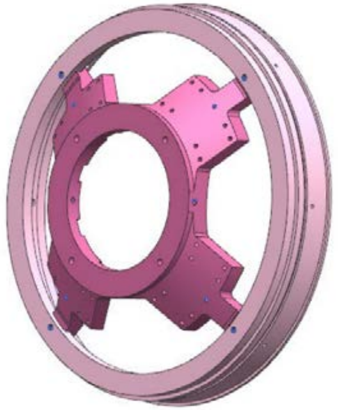


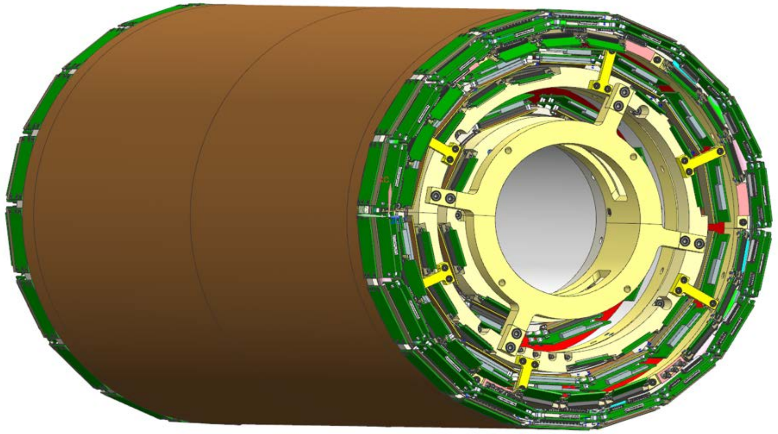
Cylindrical GEM inner tracker (CGEM-IT)

- A 3-layer cylindrical GEM inner tracker is designed for inner drift chamber upgrade (INFN and IHEP)
  - Higher particle rates capability (>10^4 Hz/cm^2)
  - Less sensitive to the aging
  - Significantly improvement of σ_z (~1.5 mm →~0.5 mm)
  - Improvements from Micro-TPC reconstruction







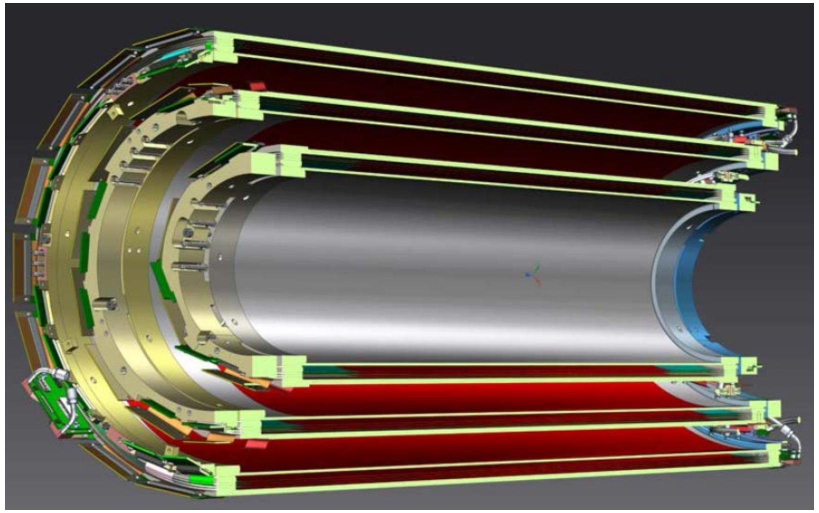


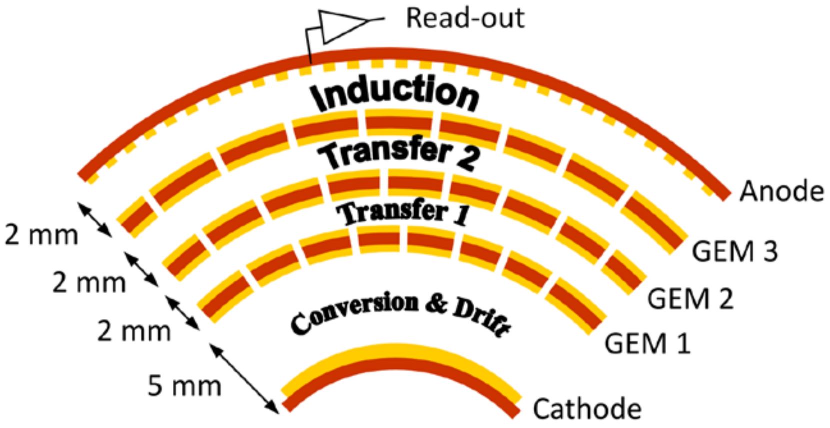
CGEM-IT

CGEM- inner tracker , new technology
In BESIII, first used
- Analogy readout, charge +time

Design of CGEM-IT

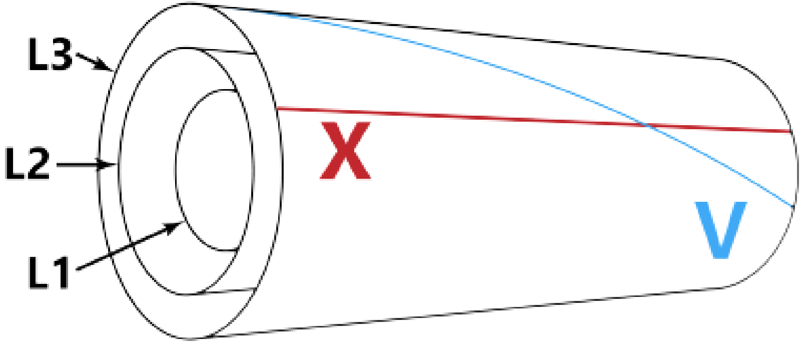
- Three layers
- Triple GEMs /each layer
- X-V 2D readout strips



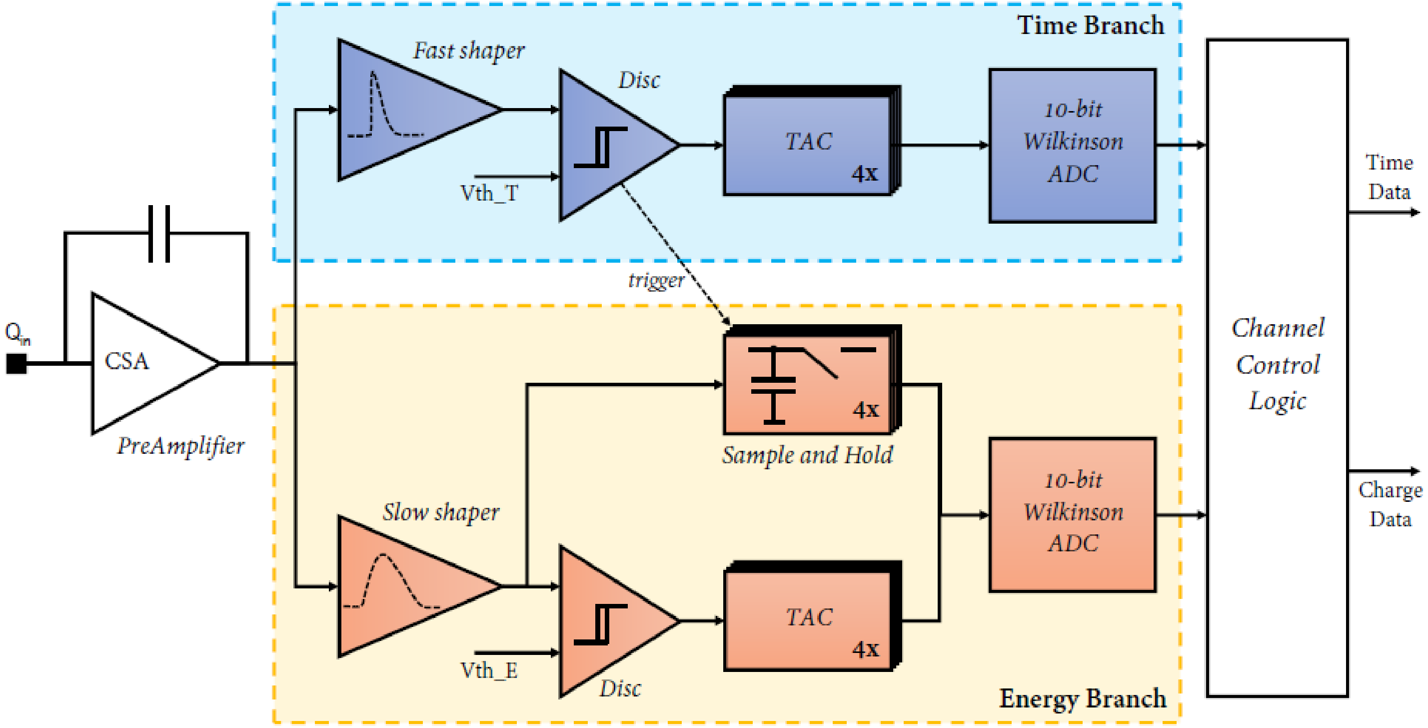


Characteristic	Goal
$\sigma_{r\phi}$	$\leq 130\,\mu m$
σ_z	$\leq 1\,mm$
dp/p @ 1 GeV/c	0.5 %
Material Budget	$\leq 1.5\,\%X_0$
Angular Coverage	$93\,\% \times 4\pi$
Rate Capability	$10^4\,Hz/cm^2$

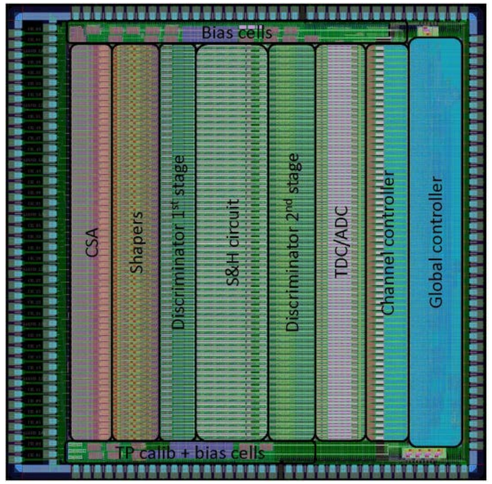
Detector	Inner Diameter	Active Area Length	Strips Stereo Angle
Inner	153.8 mm	532 mm	46.7°
Middle	242.8 mm	690 mm	–31.0°
Outer	323.8 mm	847 mm	32.9°



Readout ASIC

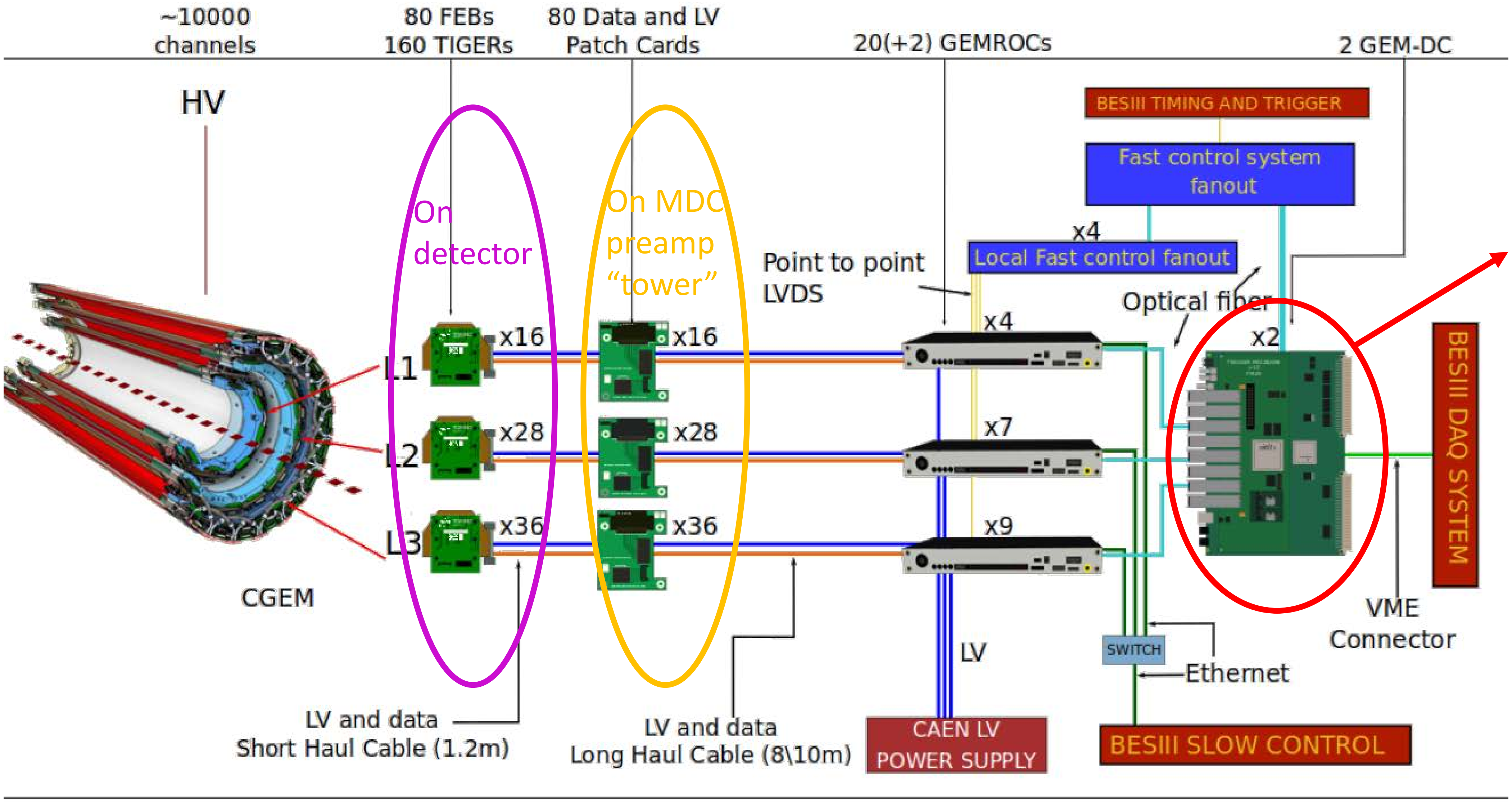


Parameters	Value
Number of channels	64
Clock frequency	160-200 MHz
Input capacitance	Up to 100 pF
Input dynamic range	2-50 fC
Front-end gain	12 mV/fC
Non-linearity	<2%
ENC	<2000 e^-
TDC time binning	50 ps
Maximum event rate	60 kHz/ch
Readout mode	Trigger-less
Charge Collection Time	60 ns
Time resolution	<5 ns
Power Consumption	<12 mW/ch
Technology	CMOS 110 nm



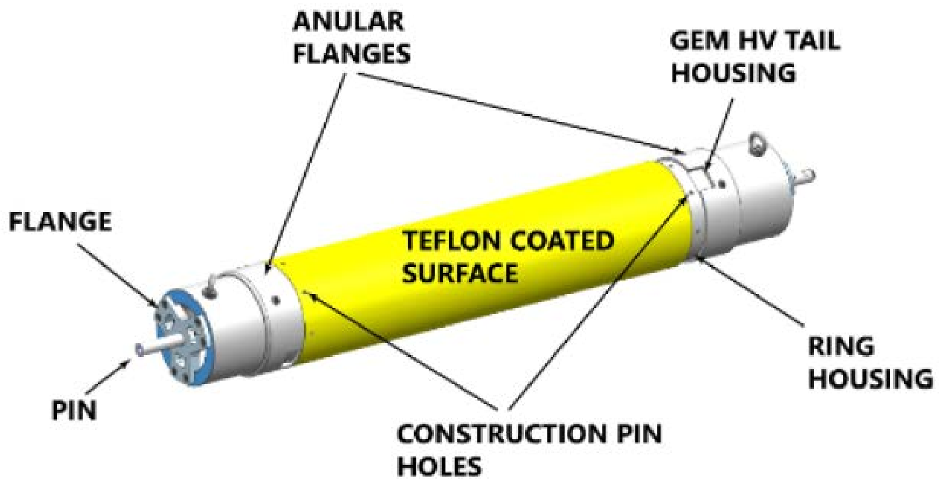
- A charge sensitive amplifier
- Time measurement and Charge measurement
  - Time resolution < 5 ns
  - Charge measurement: slow shaper output sampled and digitized with a 10-bit Wilkinson ADC

CGEM readout



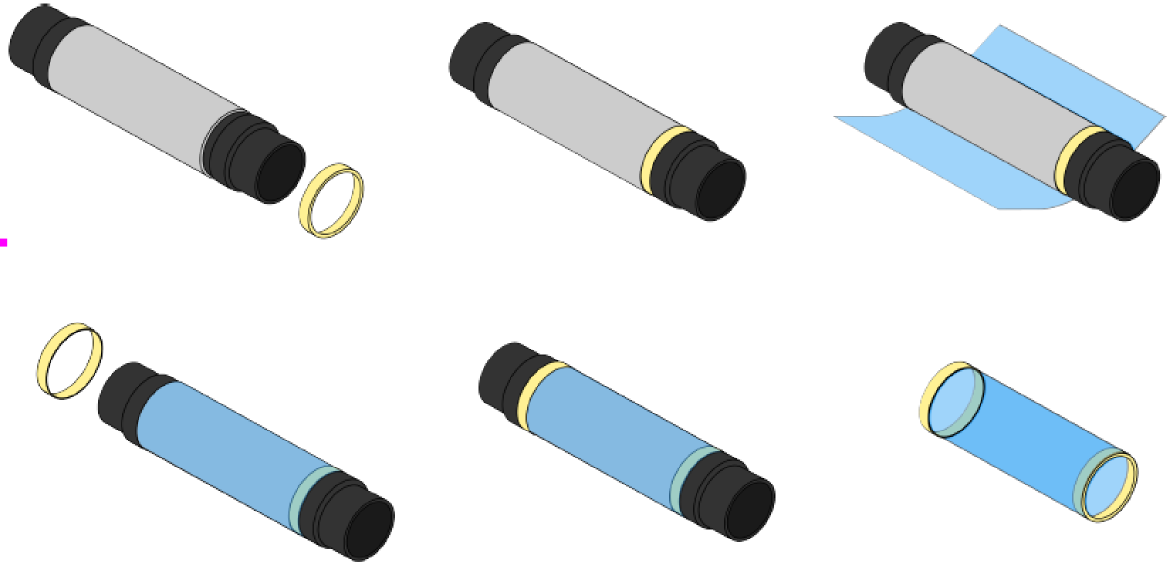
were
not used

Construction of CGEM

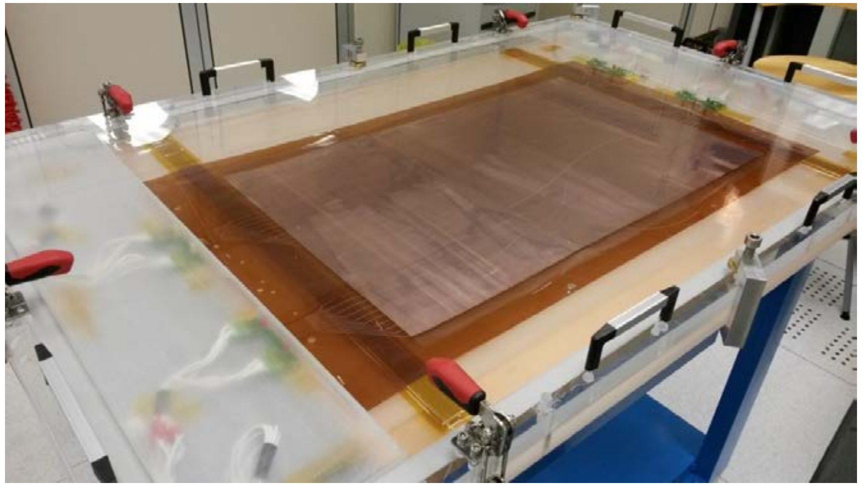


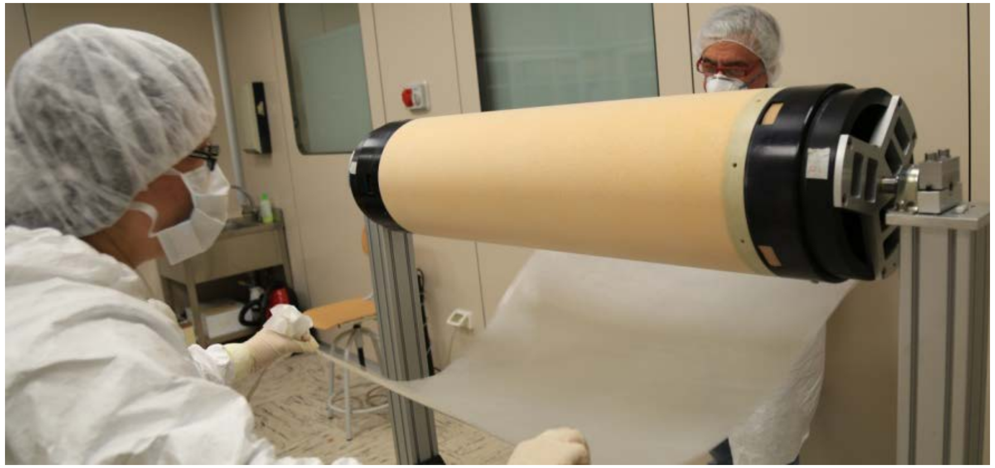
- A Teflon coated surface in the middle part
- Aluminum for the other parts
- An easy release of the sub-layer during the assembly without any residual glue.
- Can be rotated around its axis

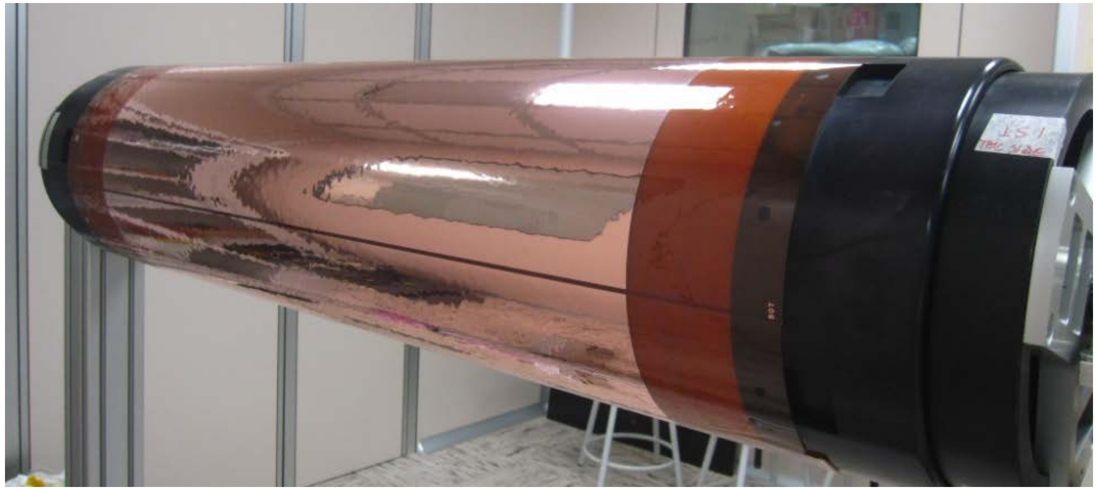
- Inner-ring placed on the mold;
- Wrapping of the GEM foil;
- Installation of the outer-ring;
- Final gluing;
- Sub-layer ready



Construction of CGEM

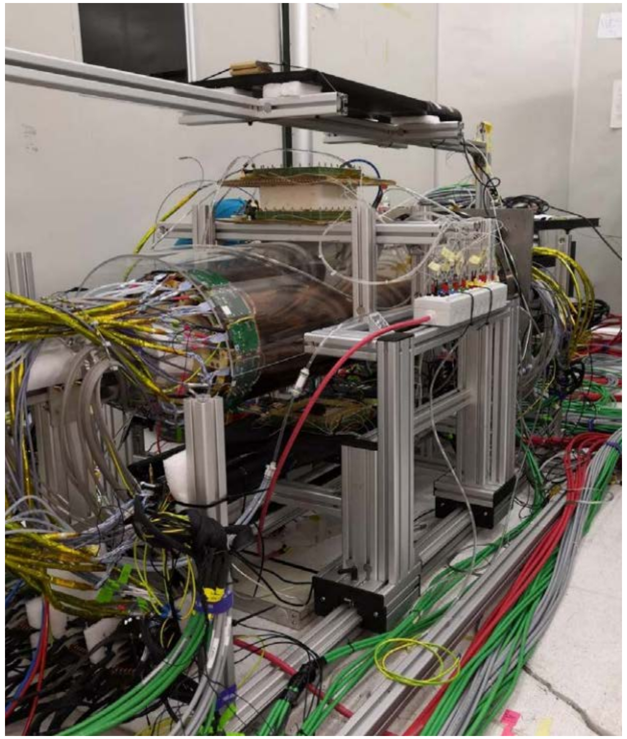






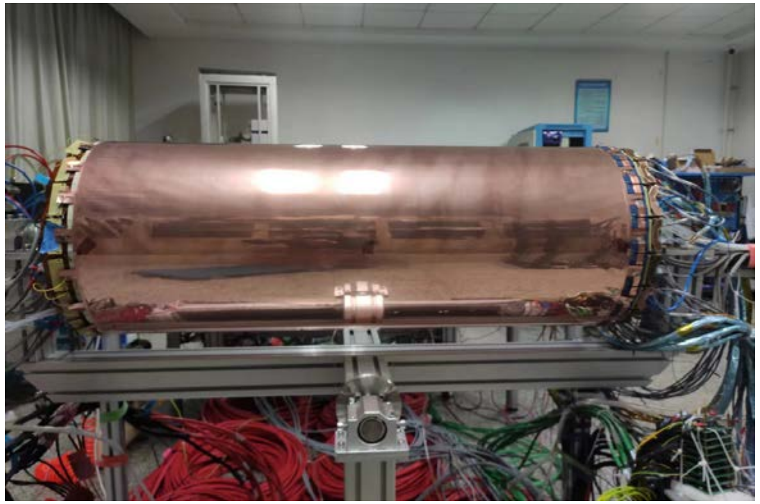
Construction of CGEM-IT

- Layer1 and Layer2 were completed in Italy, and system debugging and cosmic ray testing were carried out at IHEP
- Layer3 was constructed at IHEP, and then the three layers were assembled together for cosmic ray testing



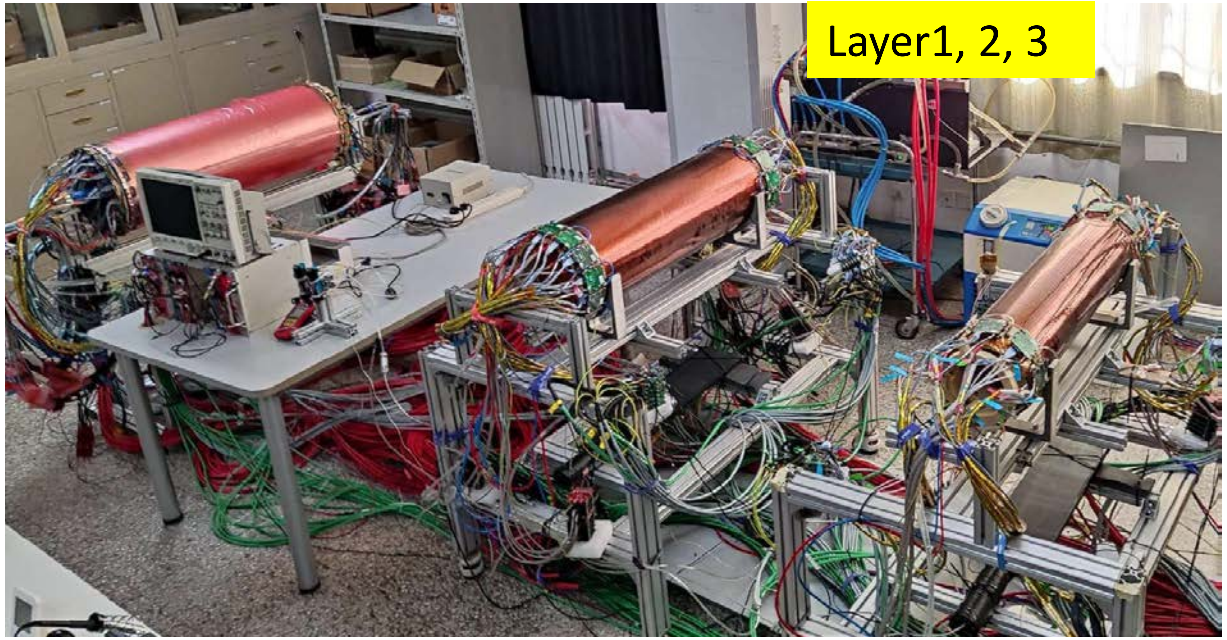
Cosmic-ray test of layer1 & layer2

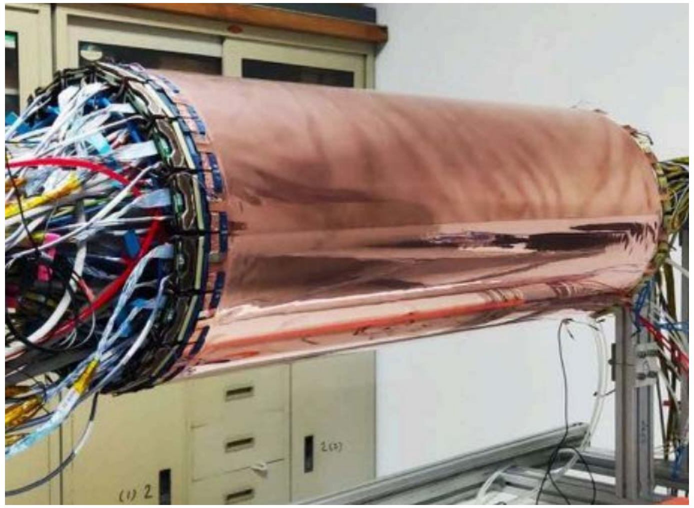


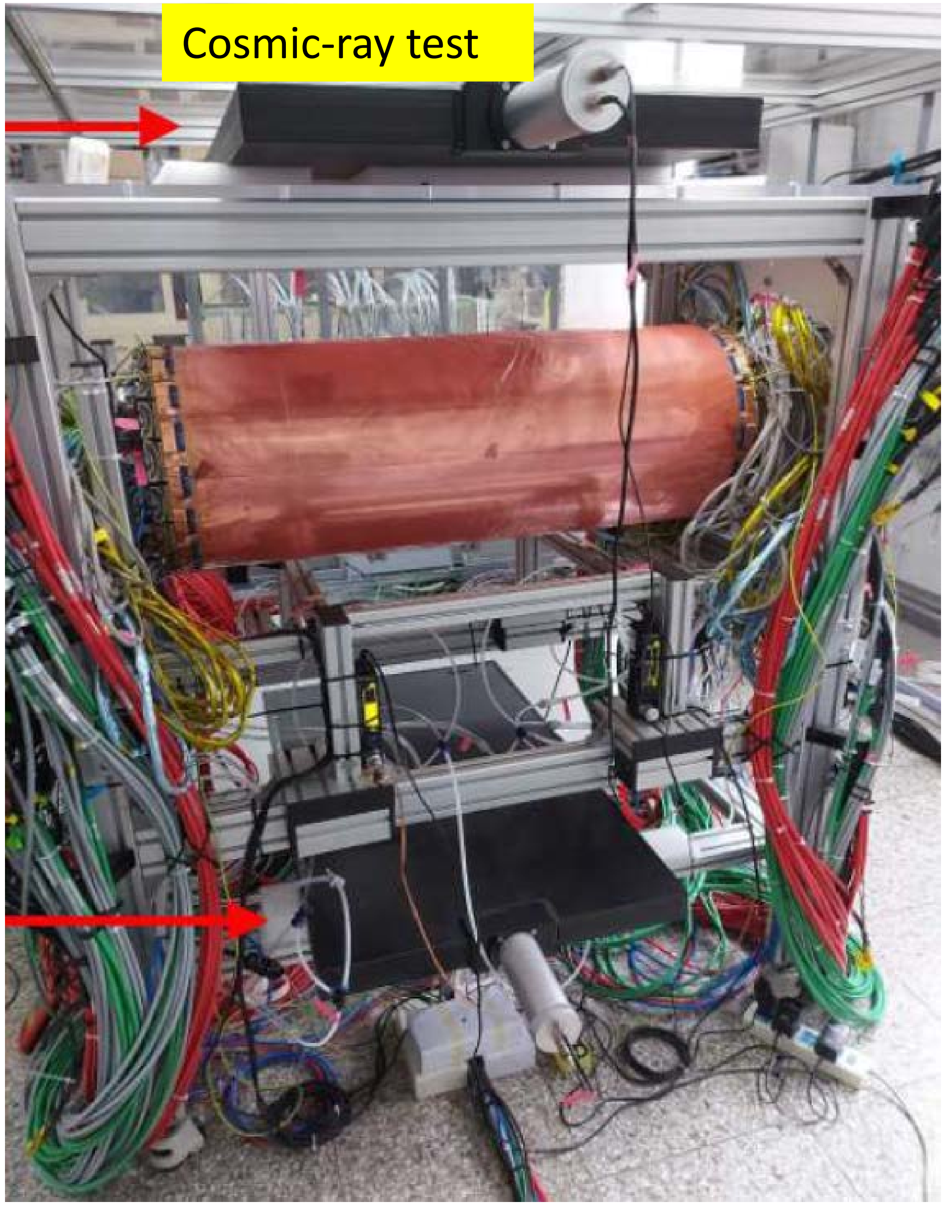


Construction and test of layer2

Assembly and cosmic-ray test

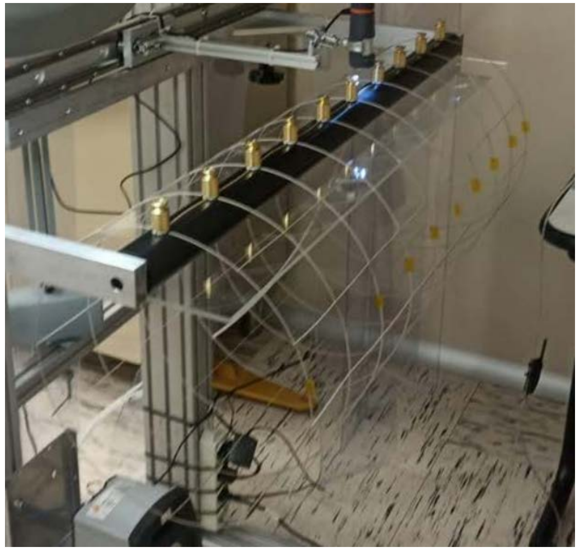


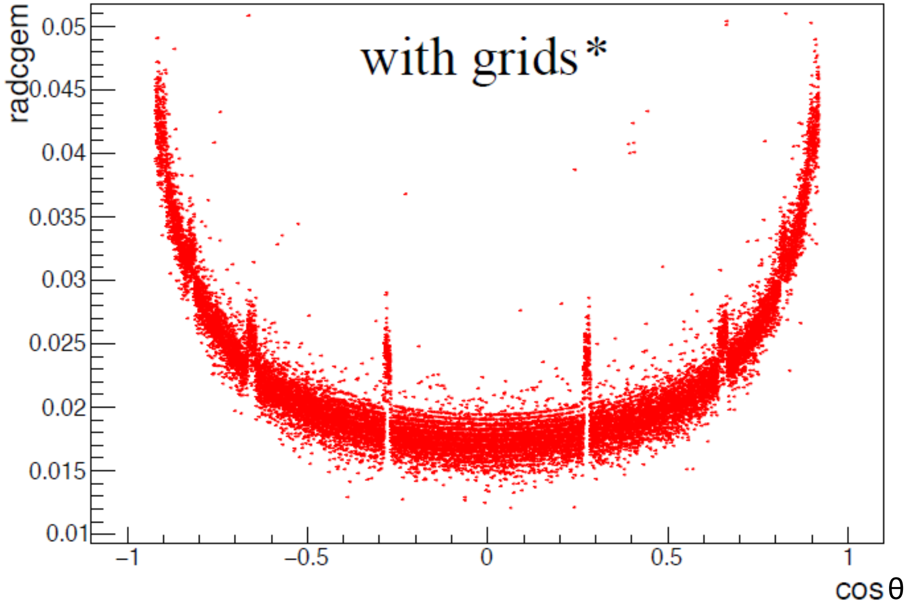




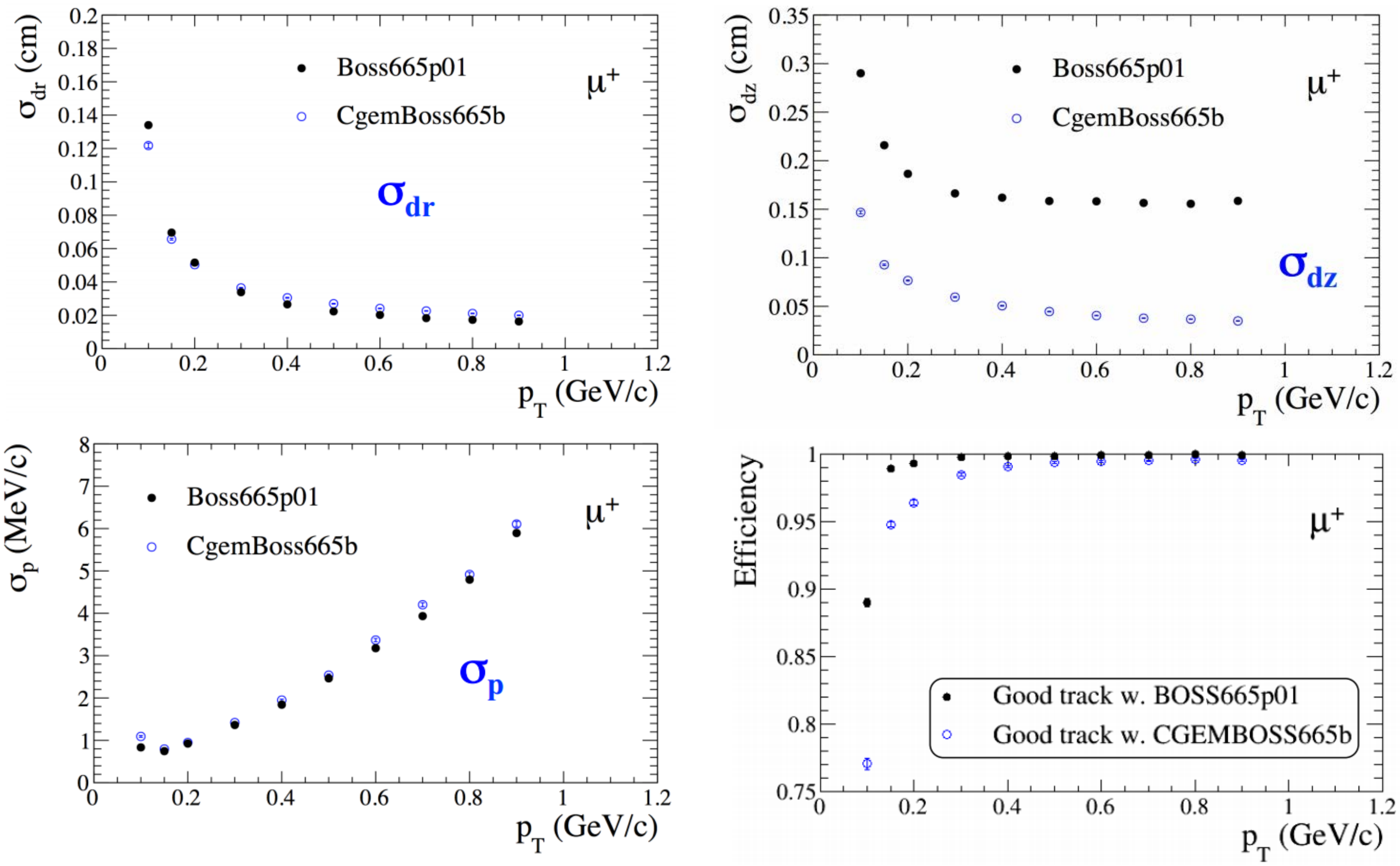
Material budget

Layer	Cathode support	Anode support	Grid between each electrode	Material budget (X_0)
Layer1	Honeycomb (1.9mm), Kapton	Honeycomb (3.9mm) , Carbon fiber	no	0.50%
Layer2	Rohacel (1mm+1mm), Kapton	Rohacel (2mm+2mm), kapton	no	0.45%
layer3	Honeycomb (1.9mm), Carbon fiber	Honeycomb (3.9mm), Carbon fiber	4 layers（4.75mm+3×1.75mm） Fill factor: 0.00634	0.60%





Simulation study of CGEM-IT



- Spatial resolution in $r\phi$ & momentum resolution with CGEM is comparable to Boss665p01 (without CGEM)
- Spatial resolution in z is significantly improved with CGEM
- The efficiency for tracks with low transverse momenta is little worse

Simulation study of CGEM-IT

- Different single track : e, μ, π, K, P
- Different reconstruction (benchmark channels studies):

$K^0_s \rightarrow \pi^+\pi^-$ reconstruction

$\psi(3686) \rightarrow \pi+\pi-J/\psi \rightarrow \pi+\pi-e+e-$

$ee \rightarrow \mu\mu\gamma$ @ 3.773 GeV

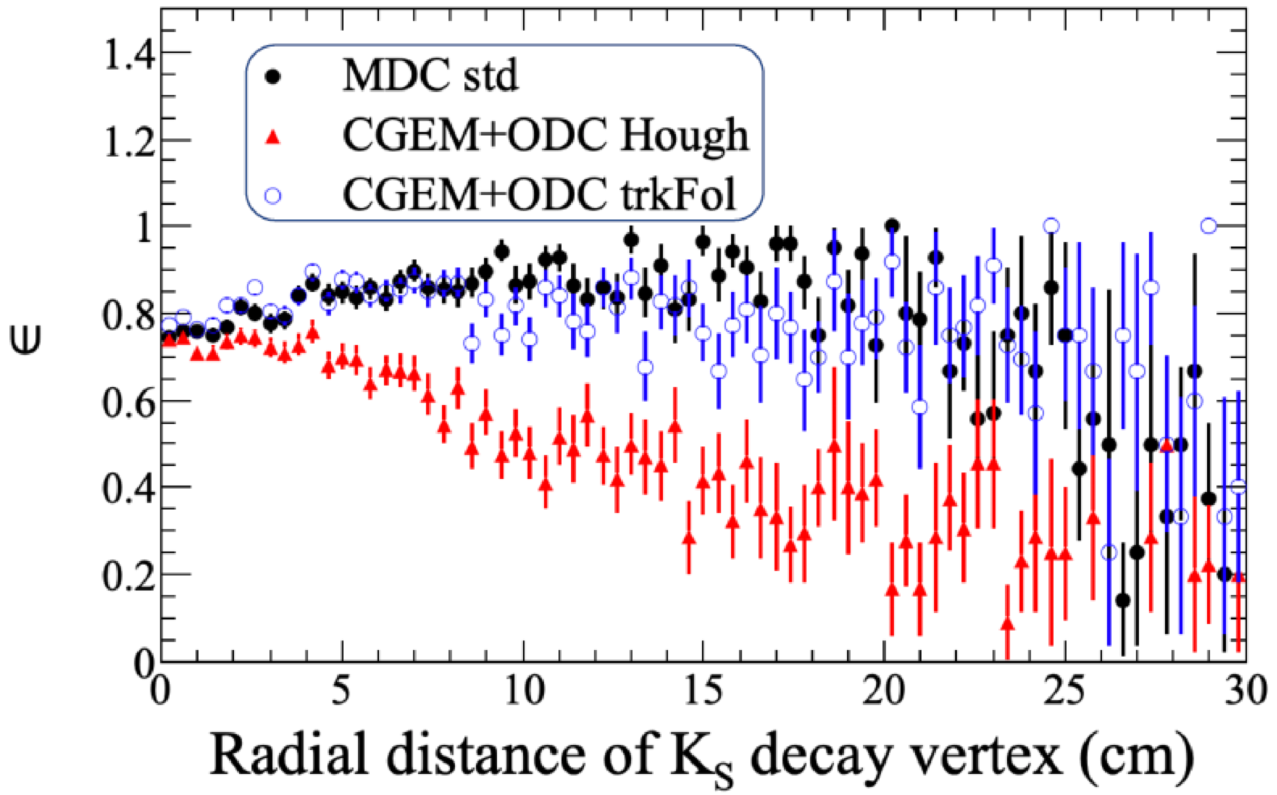
$ee \rightarrow$ ppbar

$ee \rightarrow Y \rightarrow D^{*-}D^0\pi^+$ @ 4.42GeV

Tag $D^0 \rightarrow K_s K^+ K^-$ in $ee \rightarrow \bar{D}^0 D^0$ @ 3.773 GeV

$ee \rightarrow \Lambda\bar{\Lambda} \rightarrow p\pi^-\bar{p}\pi^+$

……

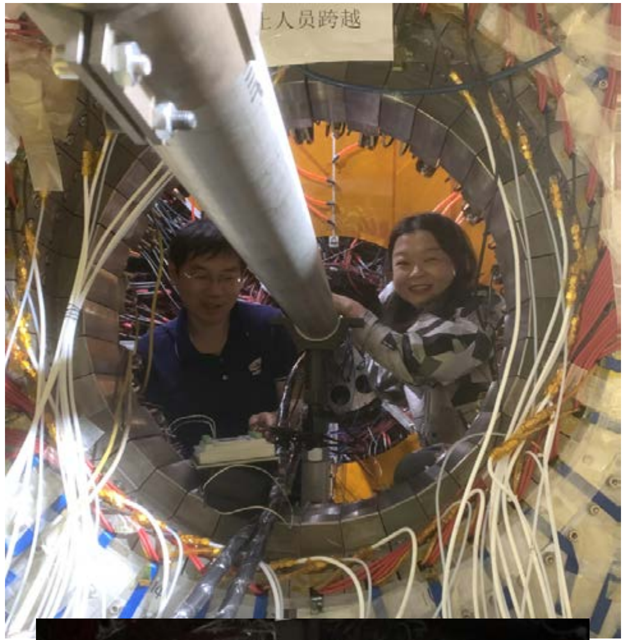


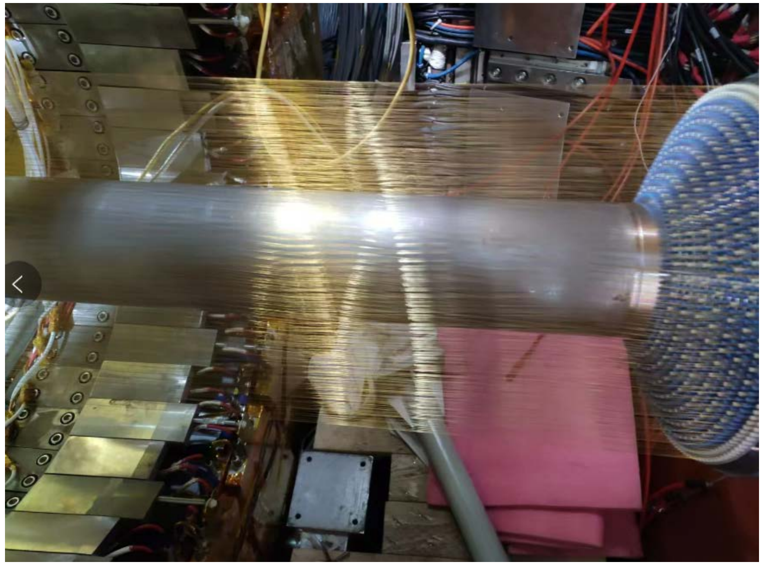
'Track Following' (TrkFol) result for CGEM+ODC **comparable with MDC**

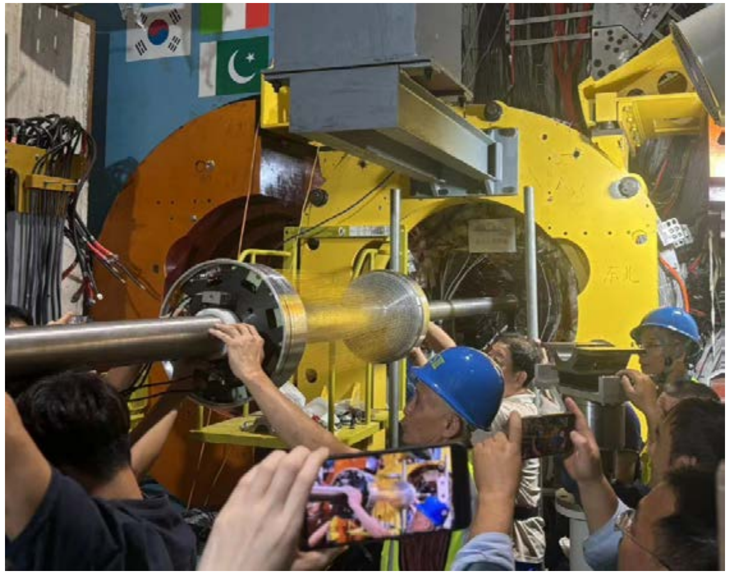
Removal of BESIII inner chamber

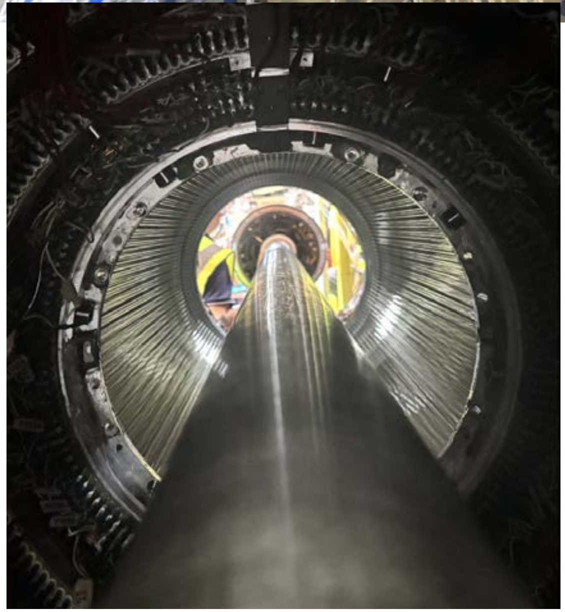
◘ 内室拆卸

- MDC内外室公用同一个腔室，在端板处紧密配合以及加胶密封，内室拆卸风险极大
- 多种拆卸方案，充分的实验，确定了最可靠的方案以及可能出现问题的预案
- 拆卸过程中，位移监测、丝张力检测，温度监测等





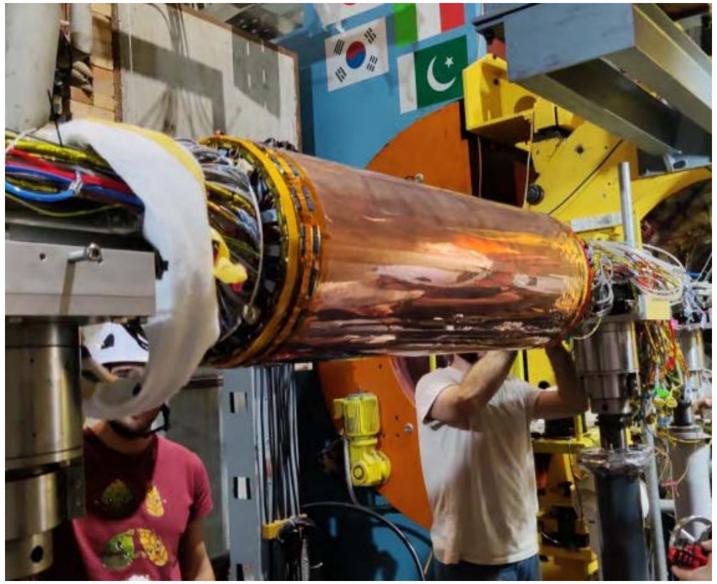


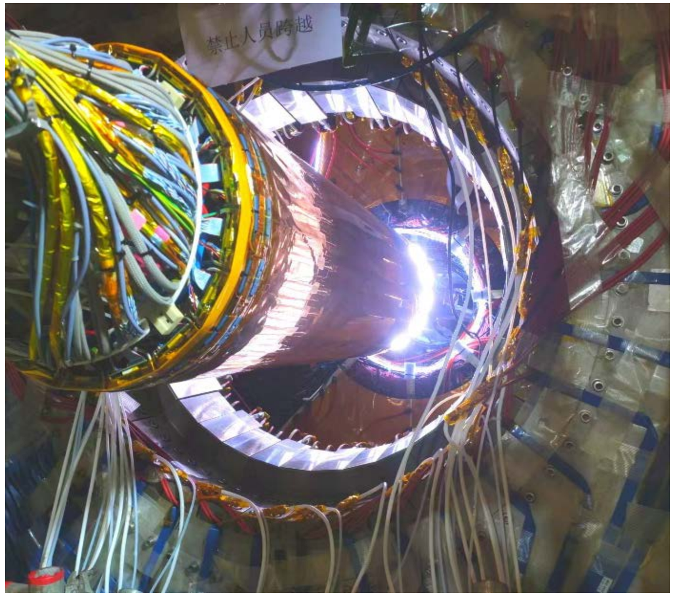


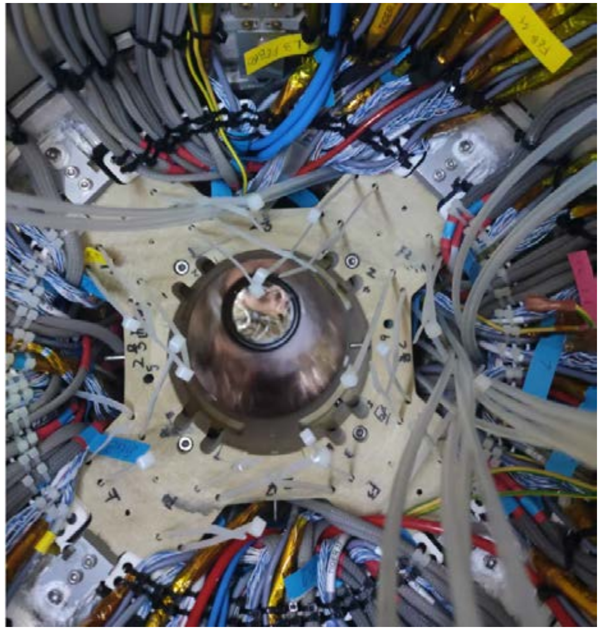
Installation of CGEM-IT

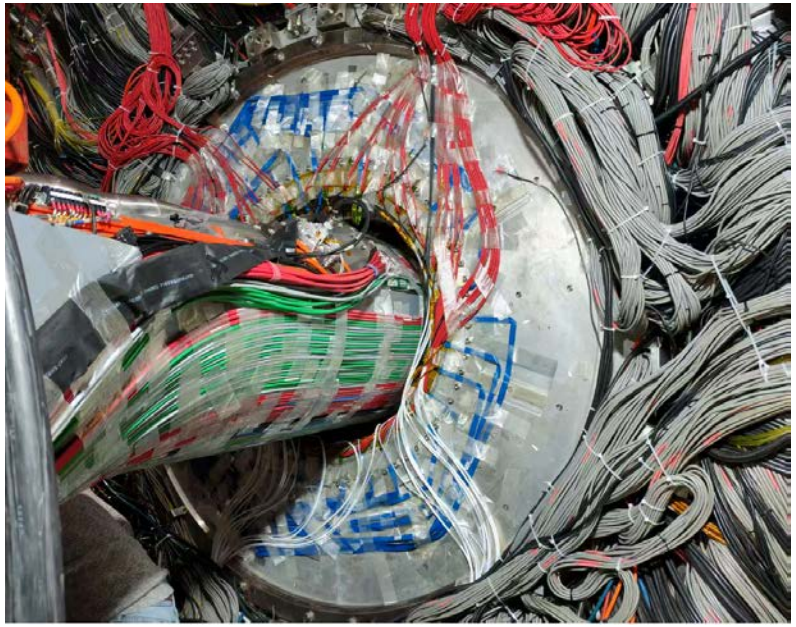
◘ CGEM的安装

- 通道数：484—>约10000
- 电缆数：增加3倍，且电缆直径大
- 安装空间非常紧张
- 顺利对接及联合测试
- 经过测试，CGEM可以在正常高压下工作。



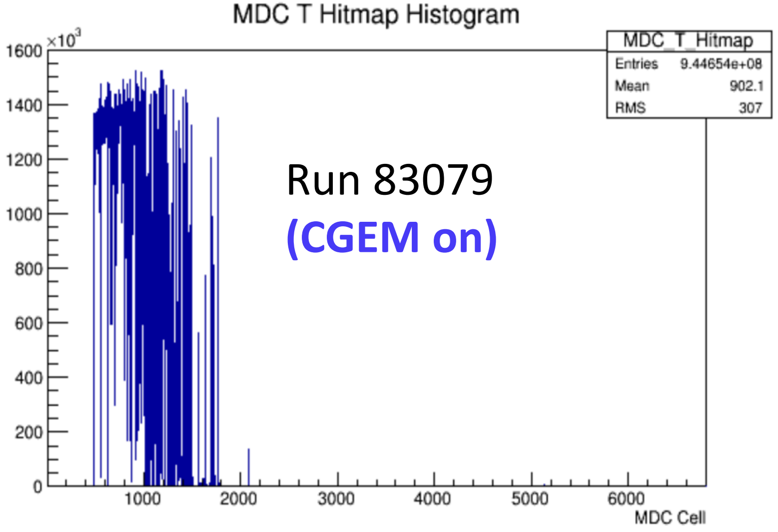




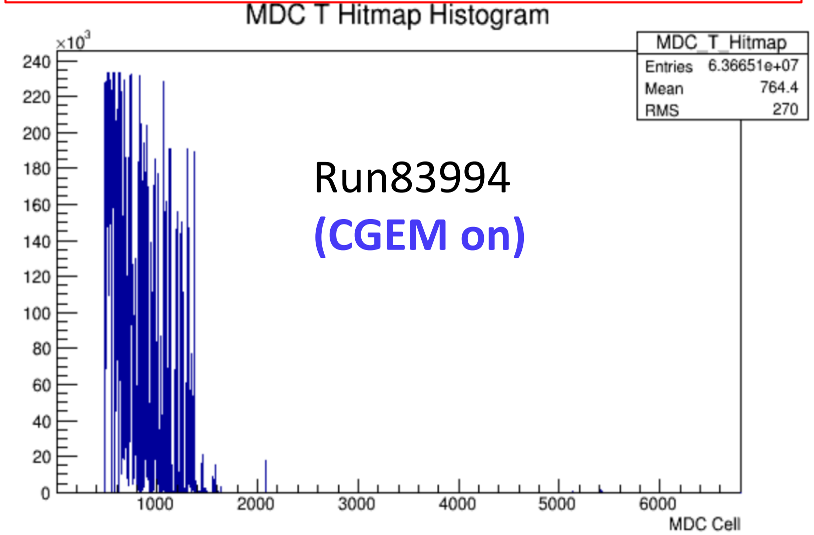


CGEM related noise in MDC

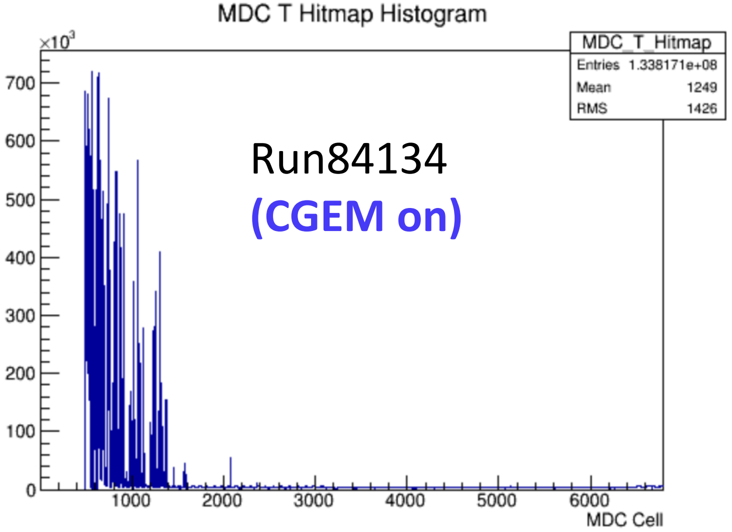
After installation of CGEM

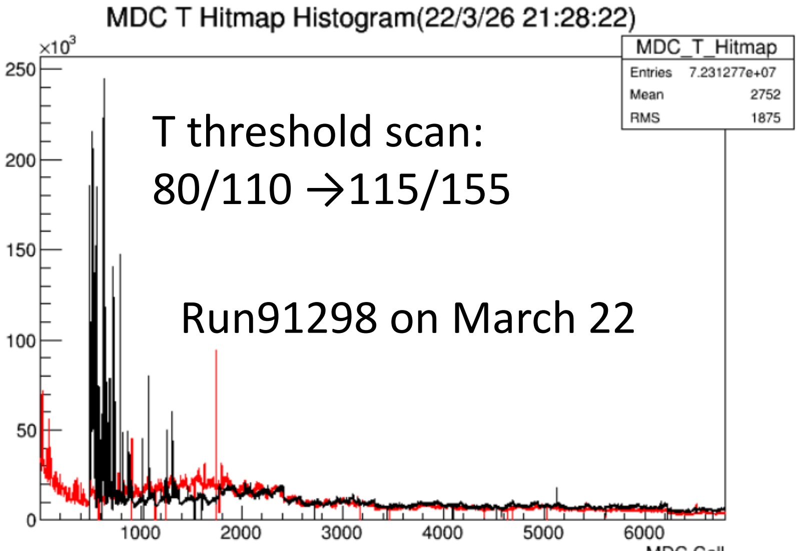


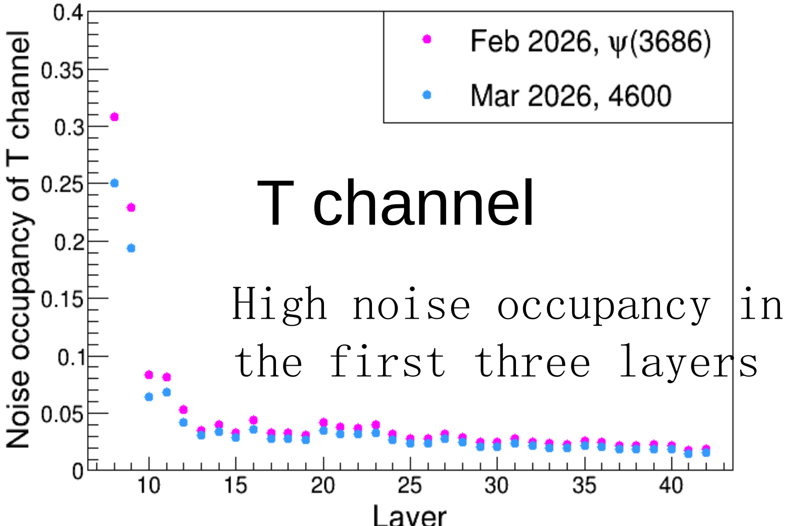
After installation of shielding boxes for CGEM patch cards and MDC preamp

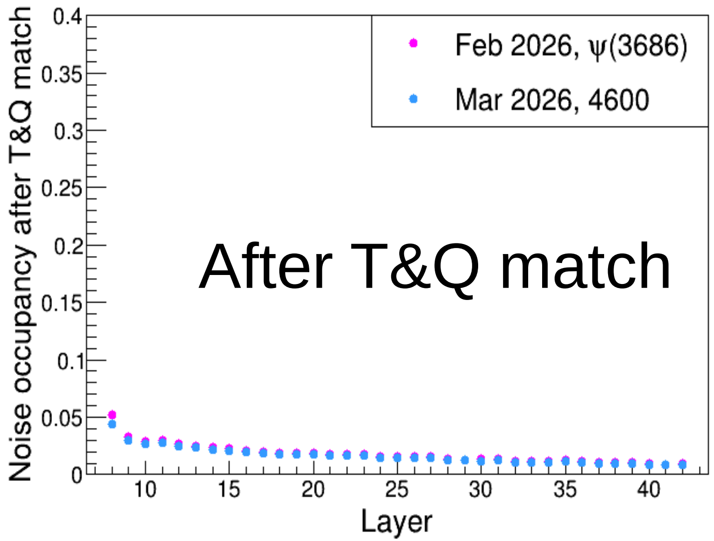


After installation of final shielding plates







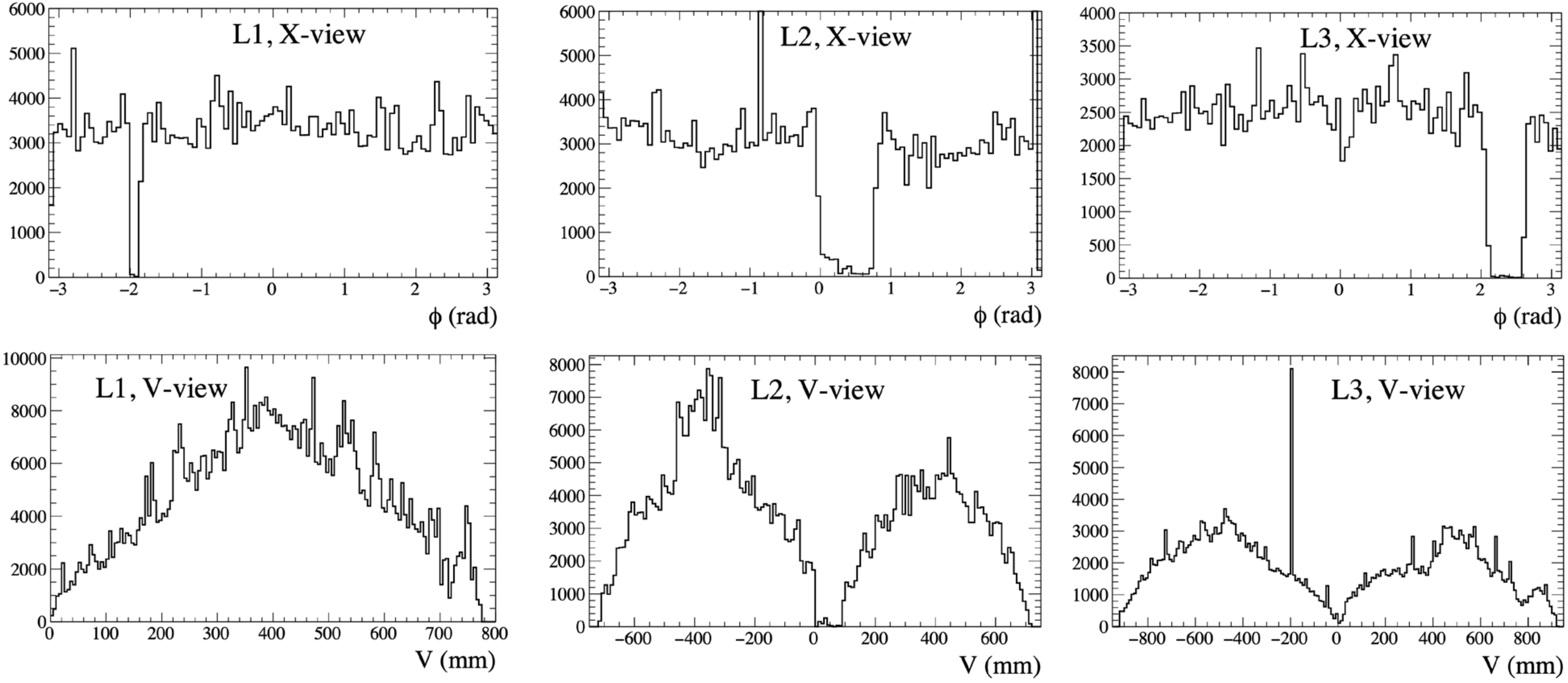


CGEM DAQ issues

- CGEM data concentrator (DC) board issues encountered during CGEM DAQ debugging process
- Very limited time before physics data taking
- Risk that CGEM DAQ may not be able to function properly with the DC boards when starting data taking

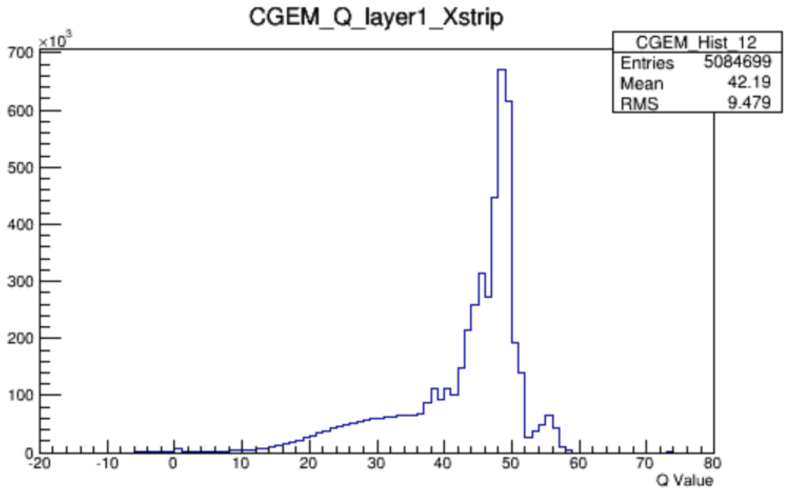
- Dedicated meeting about CGEM DAQ on Feb.14, 2025
    - Decided to use GUFI as CGEM DAQ solution and do not use DC board
    - CGEM GUFI is controlled by BESIII DAQ, CGEM data is merged offline with other detector data
    - Next plan for 2026-2027 run period: update DAQ, and CGEM data will be merged online with other detector data

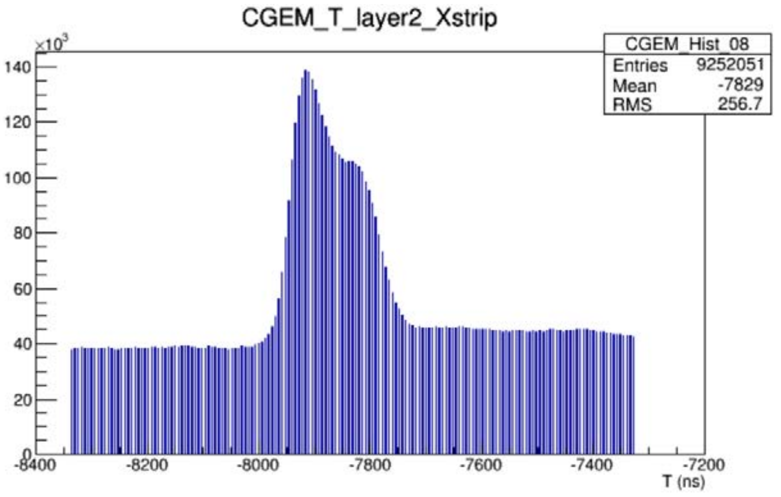
CGEM commissioning

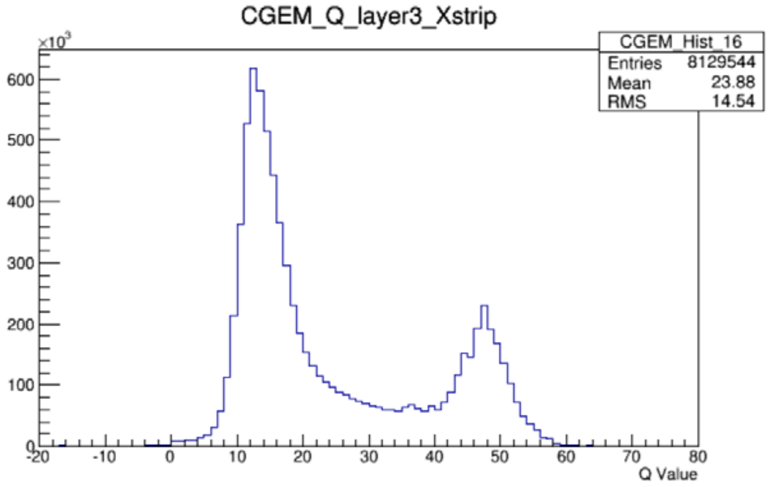


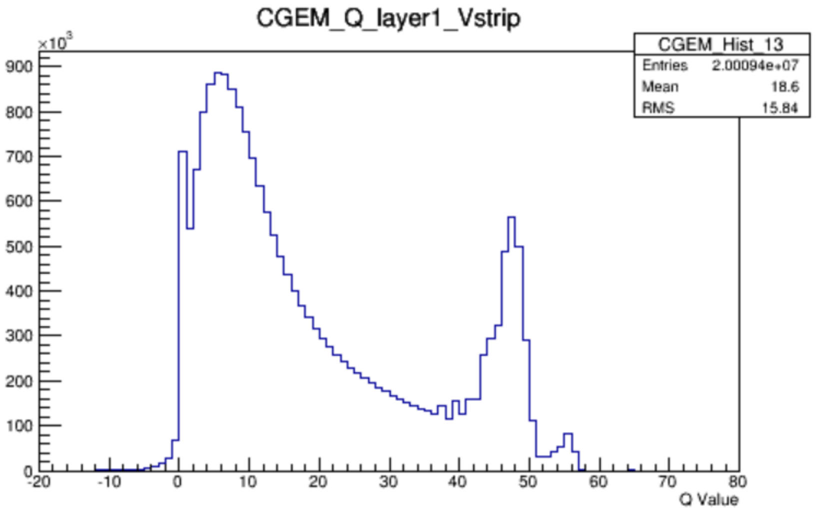
- Dead regions associated with HV connections will be repaired during this summer maintenance

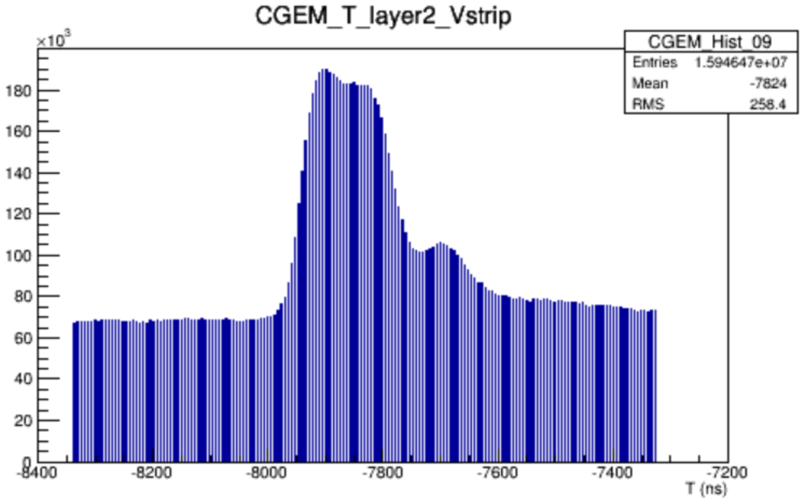
CGEM commissioning

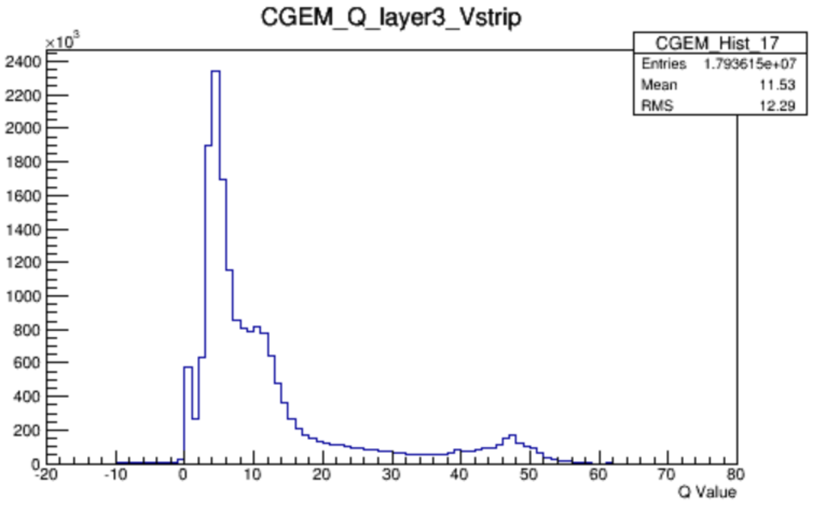




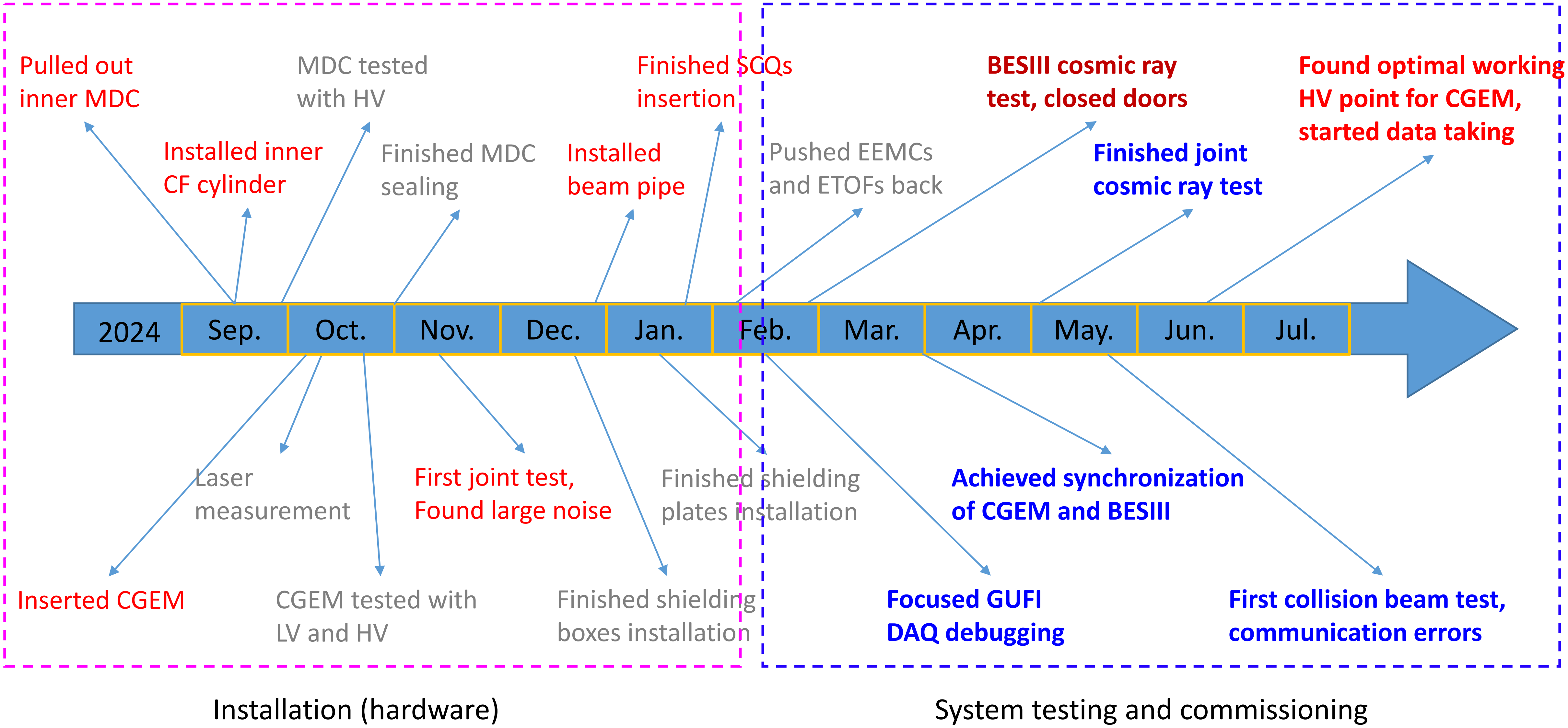






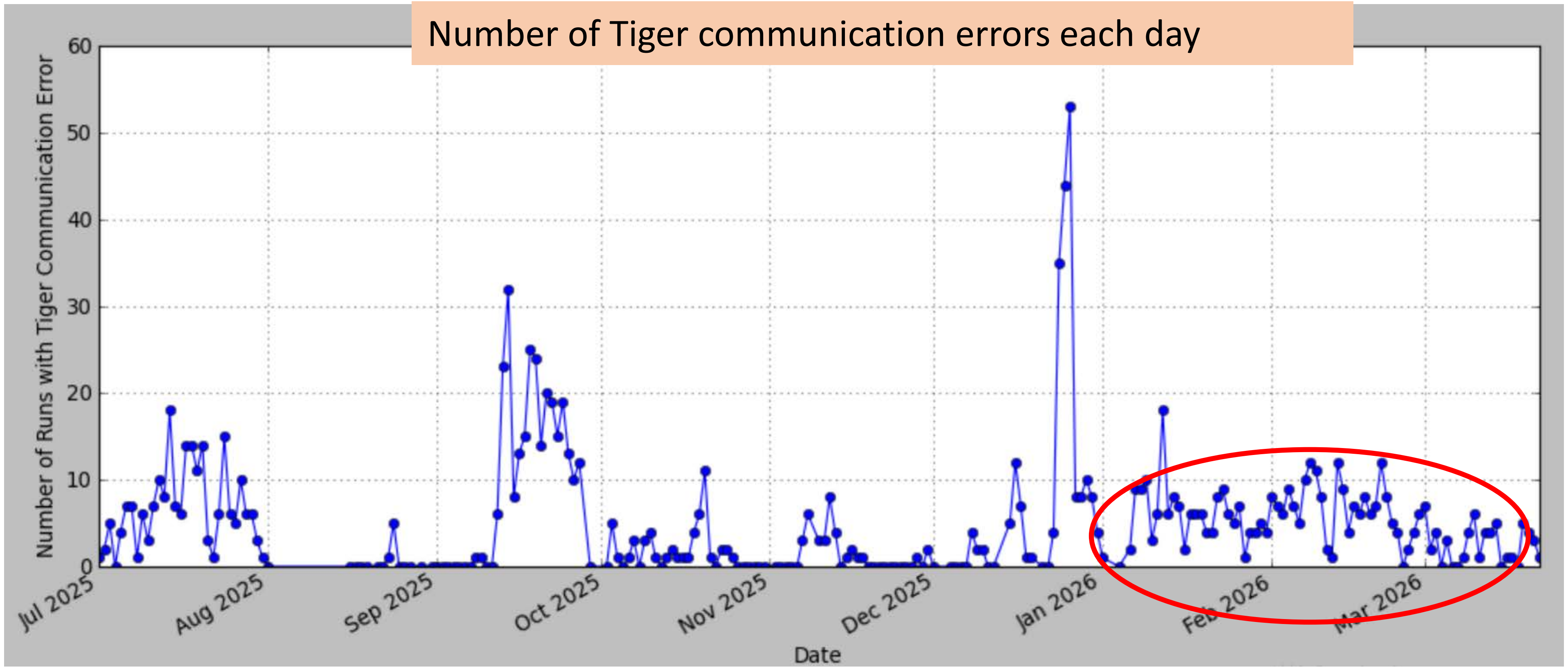


Milestones of Inner tracker upgrade



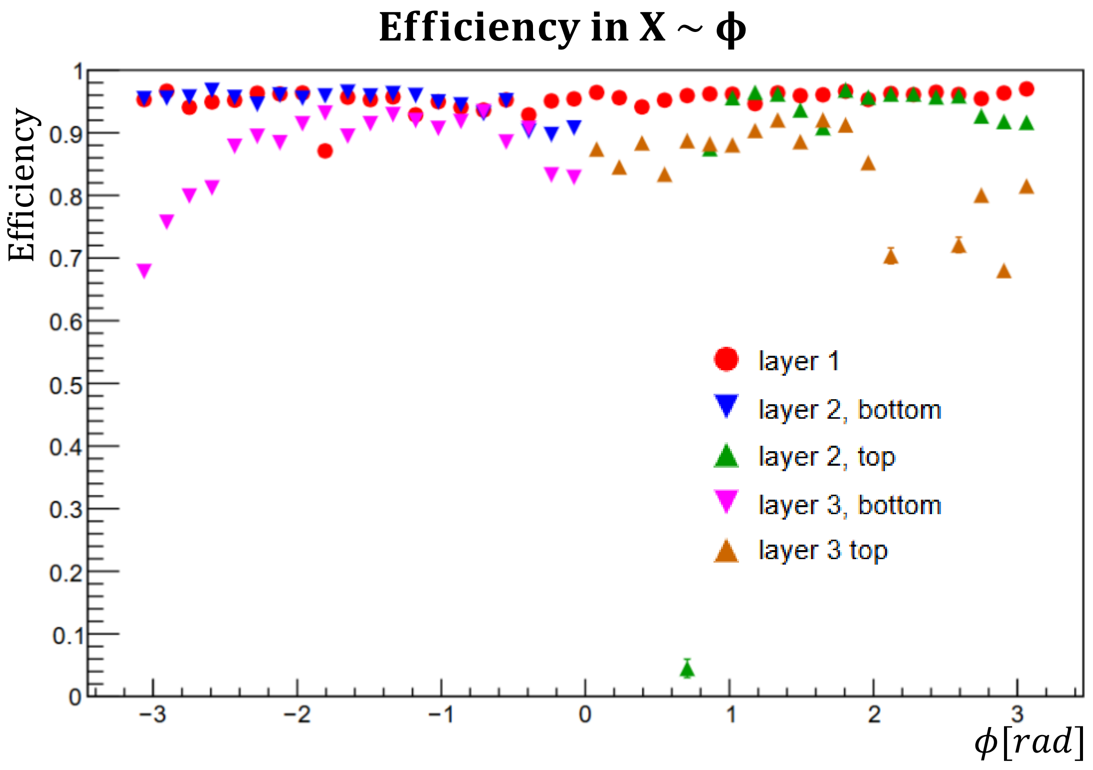
CGEM operation

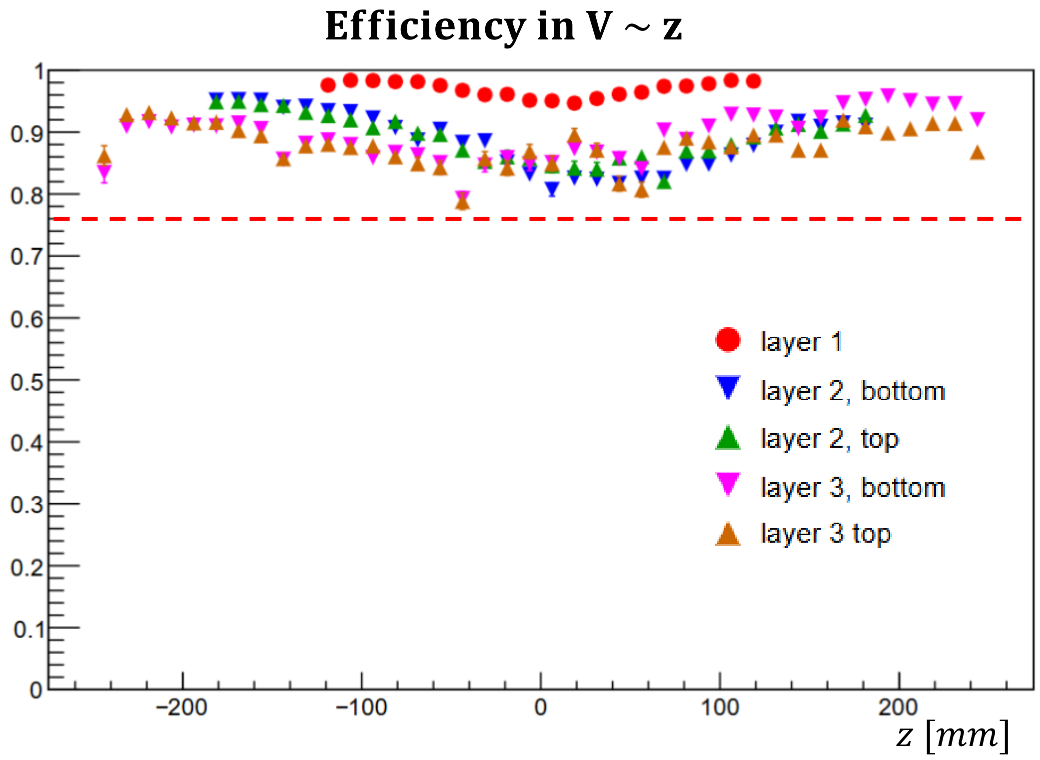
- CGEM participated in data taking normally
- "Communication errors" frequently occurred at the beginning of data taking
- Optimized (lowered) the high voltage setting and replaced GEMROC modules of L2, the communication errors was reduced to less than 5 times/day at the energy point of 4.68GeV



1D-Cluster Efficiency

Data sample: run 90730
(online barrel Bhabha @4680 on 2026.03.01)





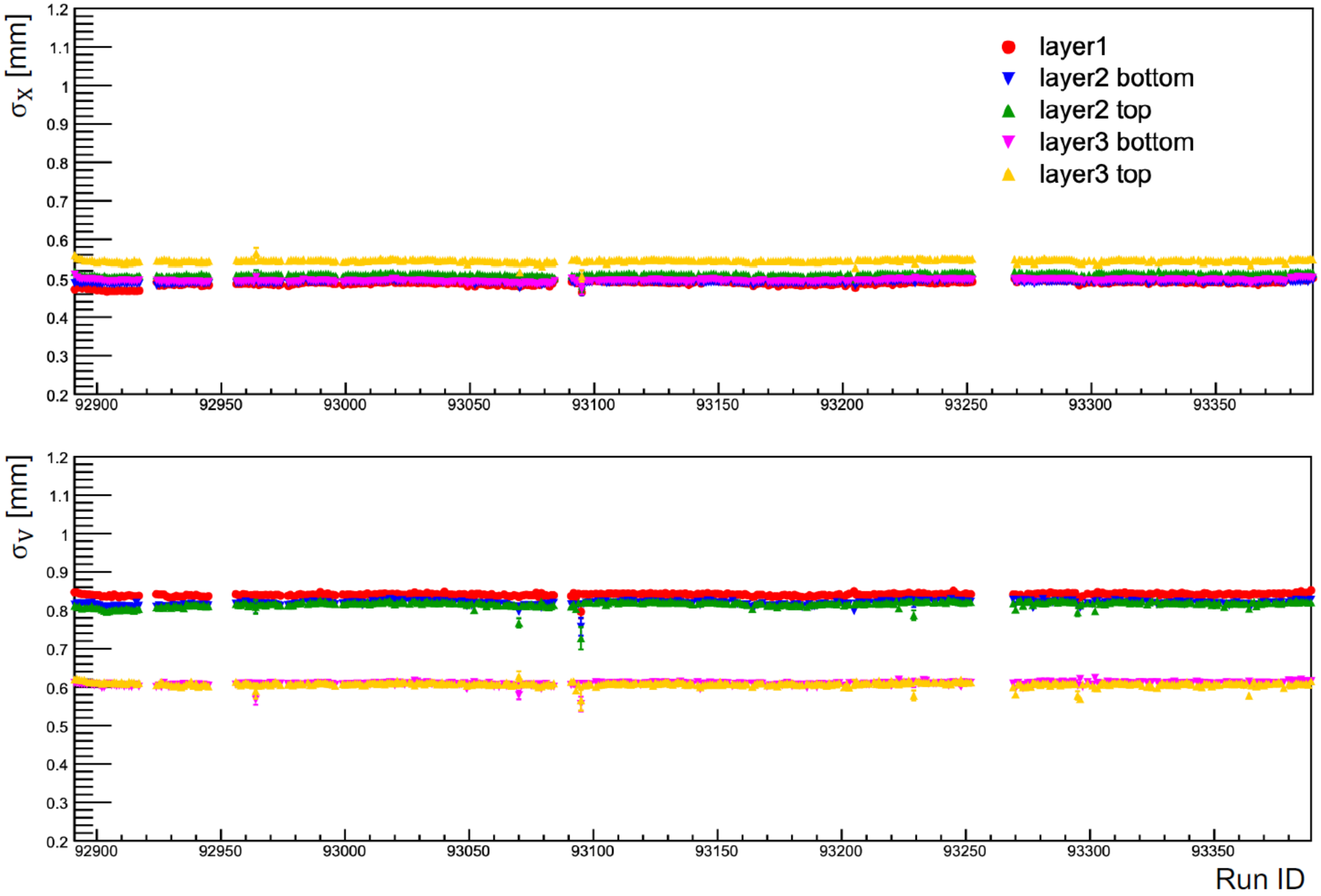
Spatial Resolution in X, V

Data sample:
online barrel Bhabha
@4680 on 2026.03.01

	Layer1	Layer2	Layer3
$\boldsymbol{\sigma_X}$ **[mm]**	0.50	0.52 (top)	0.55 (top)
		0.49 (bottom)	0.52 (bottom)
$\boldsymbol{\sigma_V}$ **[mm]**	0.90	0.83 (top)	0.65 (top)
		0.83 (bottom)	0.66 (bottom)

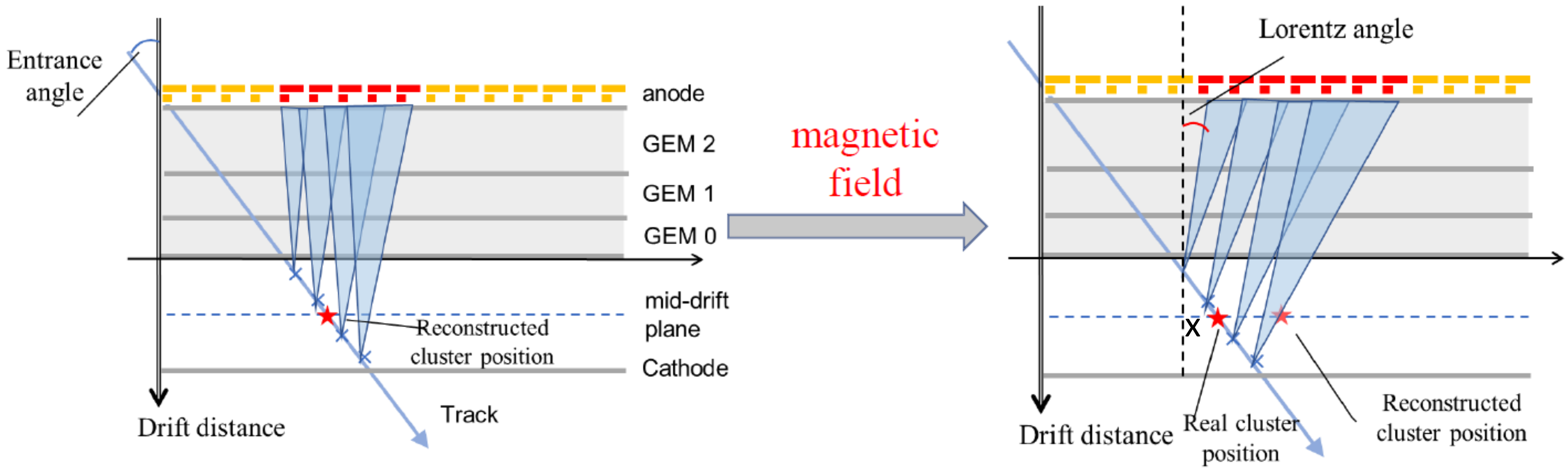
Resolution variation with layers, preliminary results

Spatial Resolution vs. Run



Data sample:
online barrel
Bhabha @4680
from 2026.06.01
to 2026.06.21

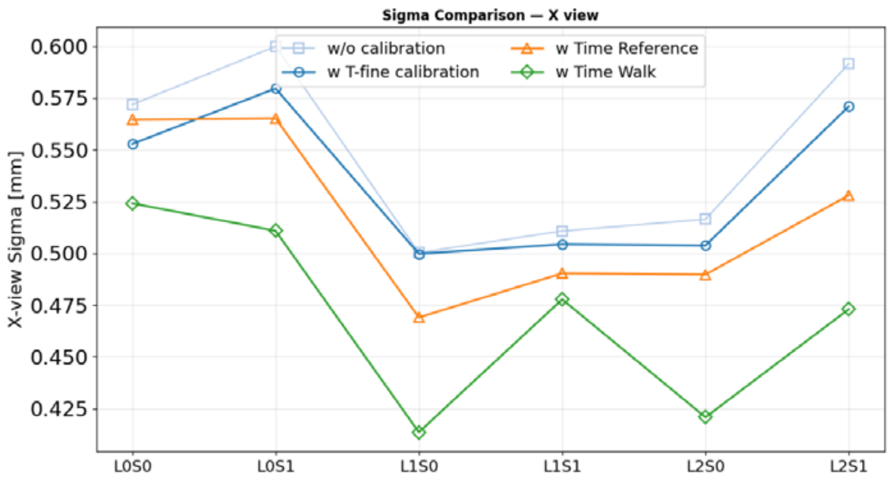
µTPC method



For track direction very different from the ionization electrons drifting=> Time measurement needs calibration

$d = a \cdot x + b$ by fitting $(x_i, d_i = v \cdot t_i)$

- Comparison of the difference between the µTPC-reconstructed clusters and the ODC reconstructed tracks(without CGEM) extrapolated to the CGEM
- Significant improvement in sigma at all levels of calibration
- Sigma of residual ~0.46mm(X view)



Summary

- The inner drift chamber of BESIII was upgraded with CGEM-IT in 2024-2025.
- CGEM-IT has participated in physics data taking after the upgrade and operates steadily following parameter optimization.
- Preliminary results demonstrate that the CGEM functions properly. Further improvements of calibration and alignment are needed to enhance its performance.

Thanks for your attention !