Commissioning of the CGEM Inner Tracker

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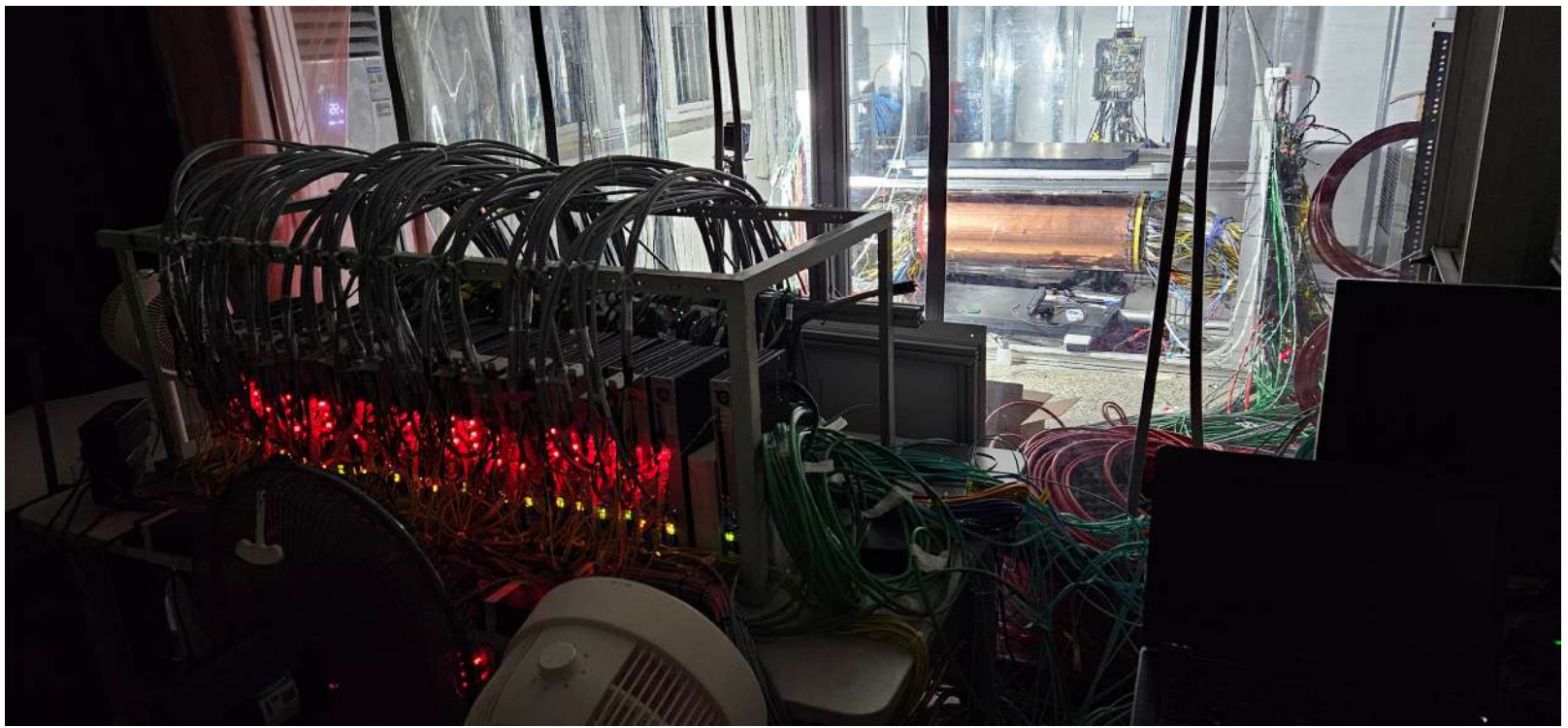
MPDG 2024 – USTC, Hefei – 2024/10/17

Outline

1) Project overview

2) Commissioning results

3) CGEM-IT installation

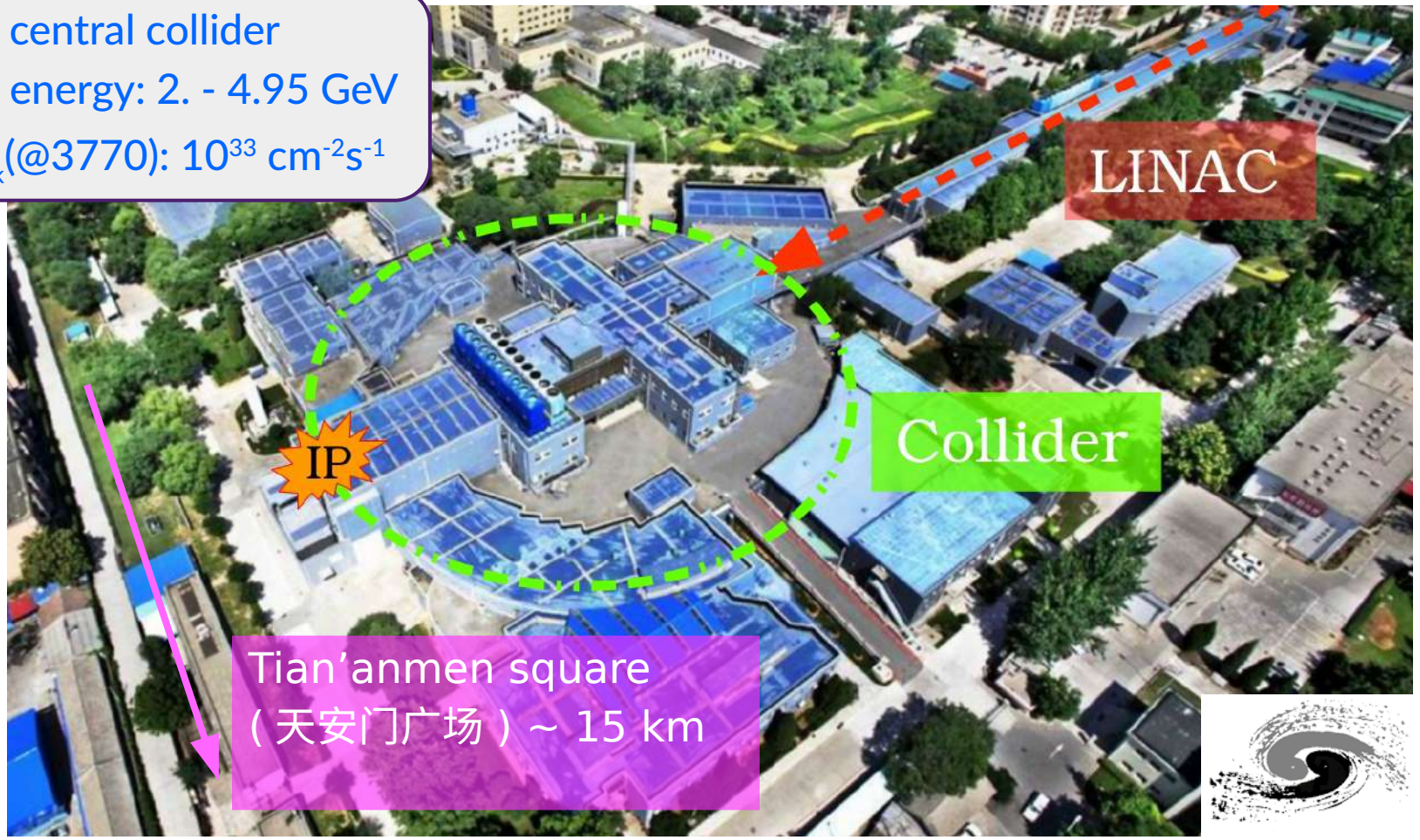


BEPCII @ IHEP (Beijing)

e^+e^- central collider

CM energy: 2. - 4.95 GeV

L_{peak}(@3770): 10^{33} $cm^{-2}s^{-1}$

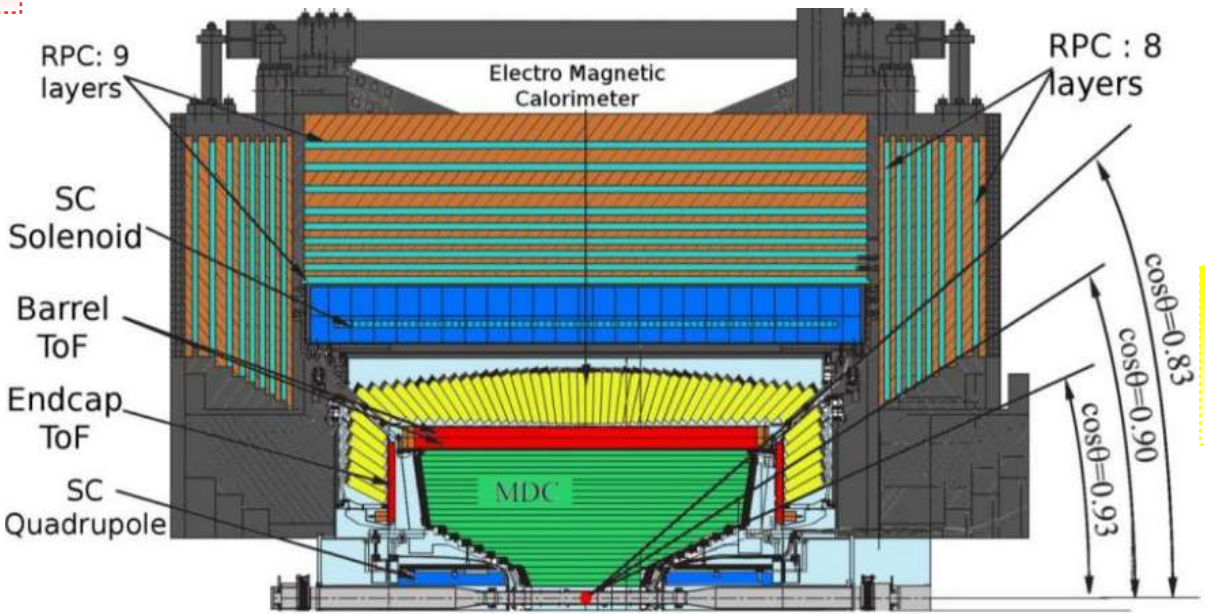


BESIII @ BEPCII

Time Of Flight:
σ_t (barrel) = 90 ps
σ_t (endcap) = 58 ps

1 Tesla Magnetic field

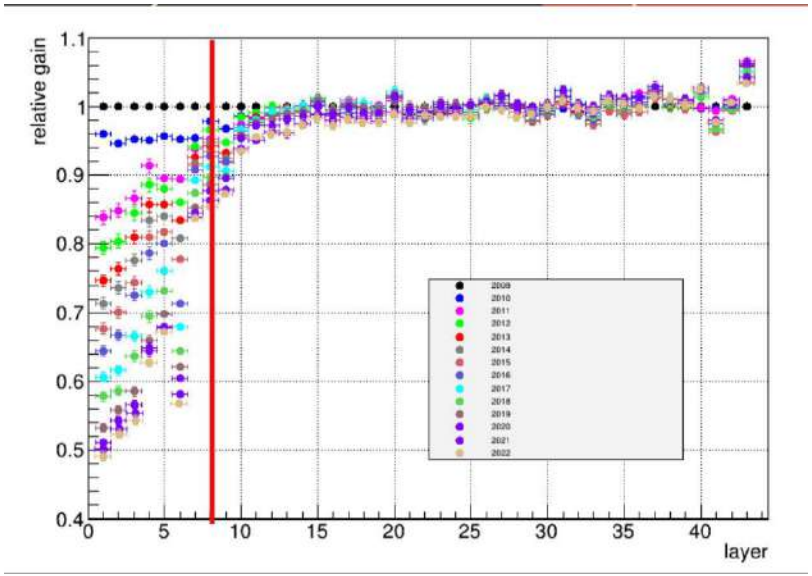
Muon counters:
$\delta_{r\varphi}$ = 1.4 cmv – 1.7 cm



Electromagnetic Calorimeter:
dE/√E (1 GeV) = 2.5 %

Main Drift Chamber:
σ_x (1 GeV/c) ~ 130 μm
dp/p (1 GeV/c) = 0.5 %

Upgrade program



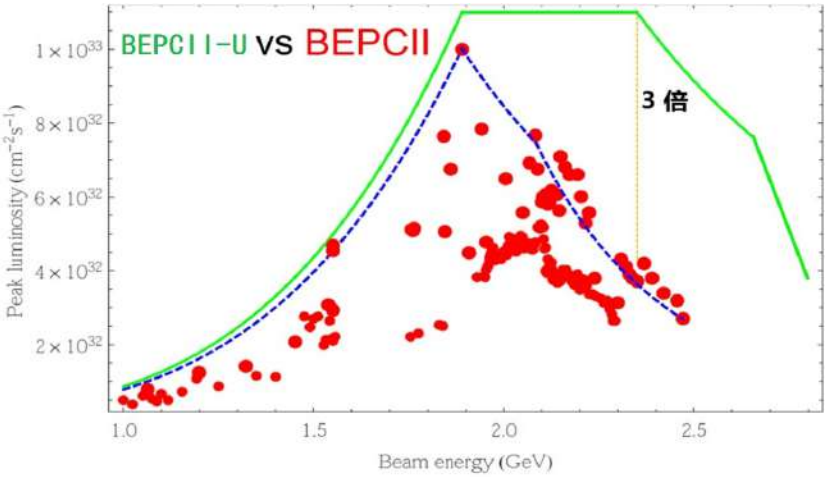
Inner Outer

Replace the aging innermost layers with a new inner tracker: the CGEM-IT

Two steps accelerator upgrade:

1) 3x Increase luminosity at 4.7 GeV (now)

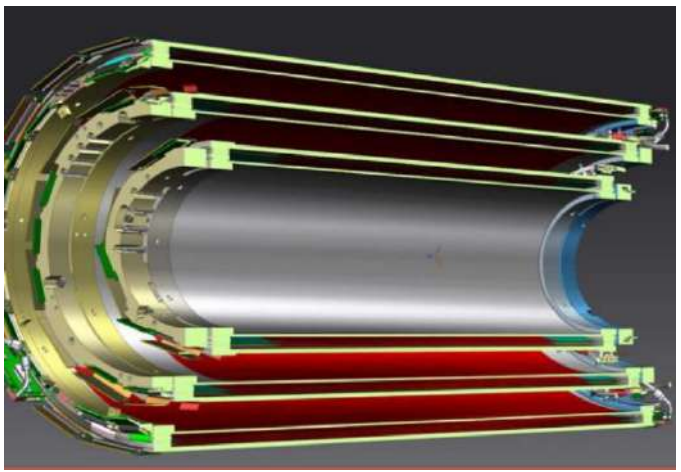
2) Extend the center of mass energy up to 5.6 GeV (in 2028)



The CGEM-IT: detector

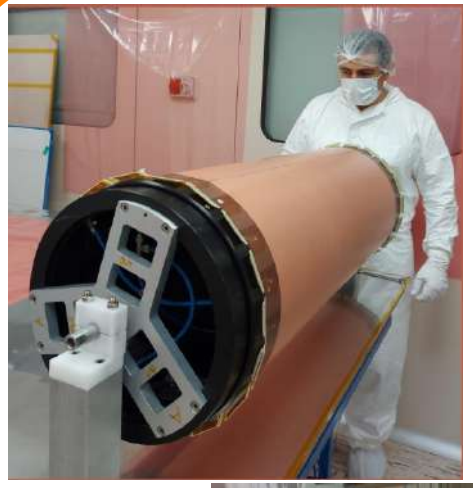
The CGEM-IT info:

- three layers of cylindrical triple-GEM
- improve spatial resolution along the beam axis (< 300 μm), rate capability, and radiation hardness
- keep momentum and azimuthal spatial resolution (~150 μm and 0.5% at 1 GeV/c)
- 0.5% X_0 per layer material budget:
    - cathode and anode are the supporting structure, made by a sandwich of Rohacell-Kapton (L2), Honeycomb-carbon fiber (L1 and L3)
    - supporting permaglass rings at the two ends outside the active area

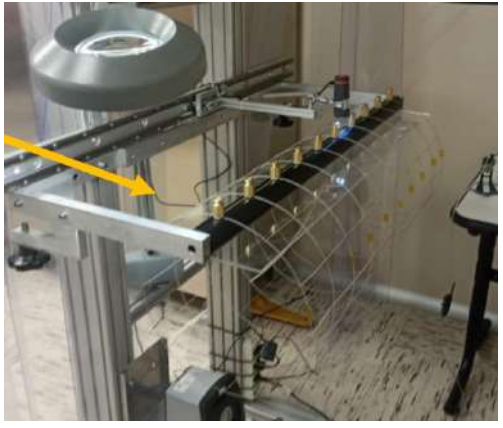


The CGEM-IT: layer 3 construction

Ferrara



The electrodes on the mandrels

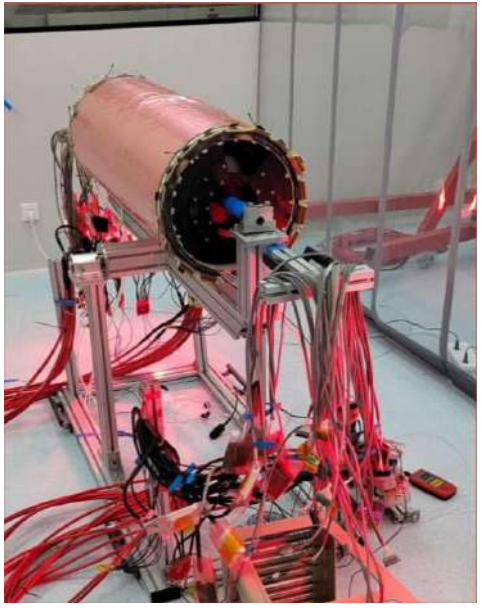


Peek grids to prevent buckling

Beijing (北京)

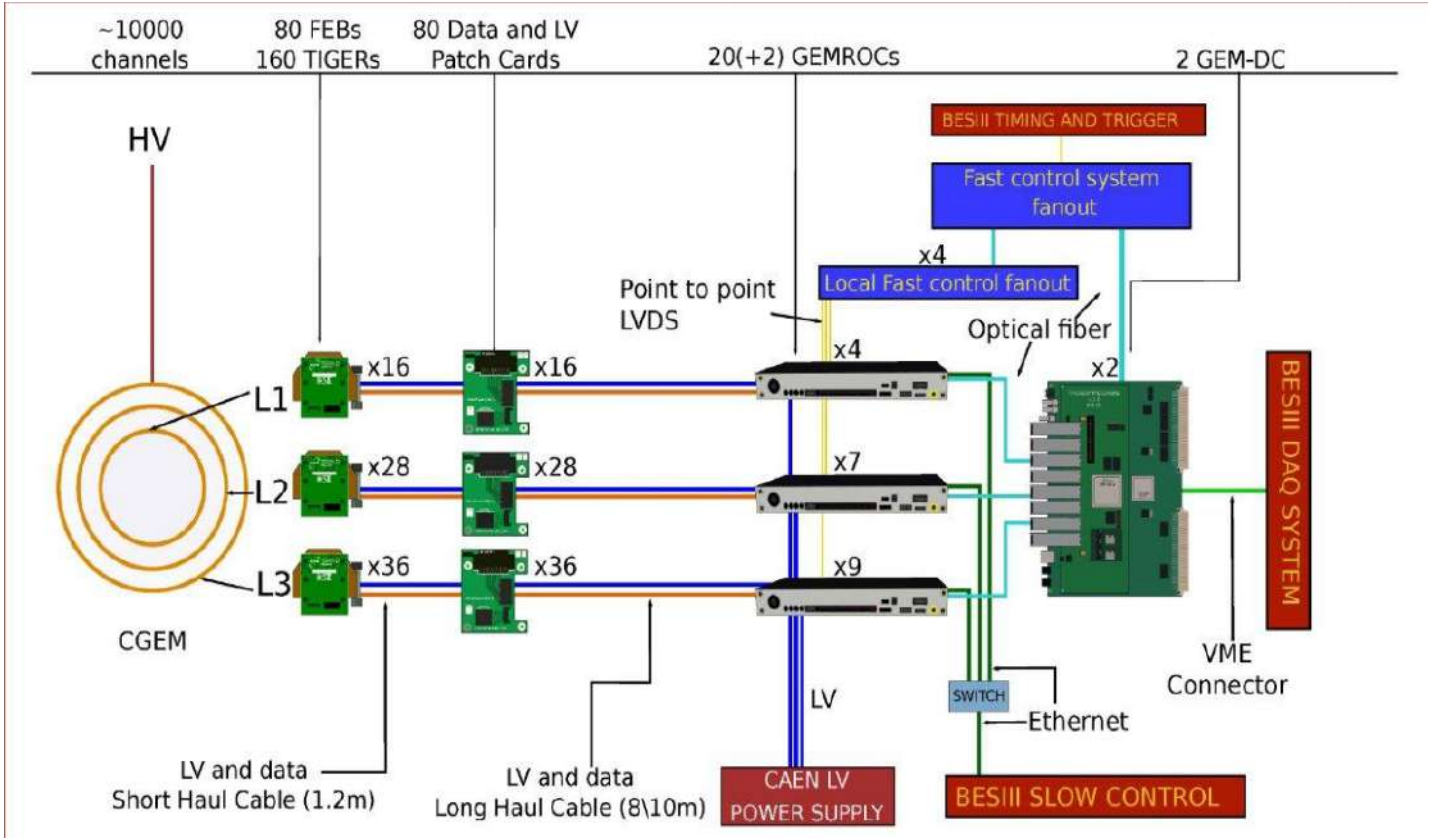
Assembly of the electrods with VIM

Gas and HV tests



JINST 16 (2021) 08, P08065

The CGEM-IT: readout chain



On detector

Off detector

The CGEM-IT: TIGER and GUFI

TIGER (Torino Integrated GEM Electronics for Readout)

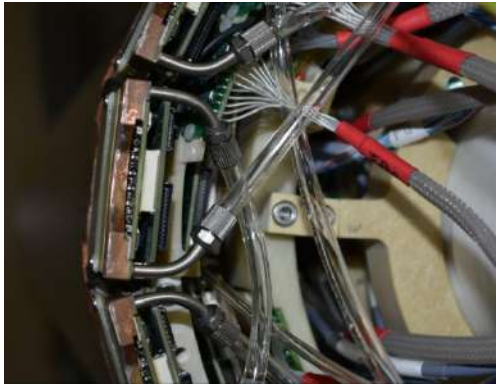
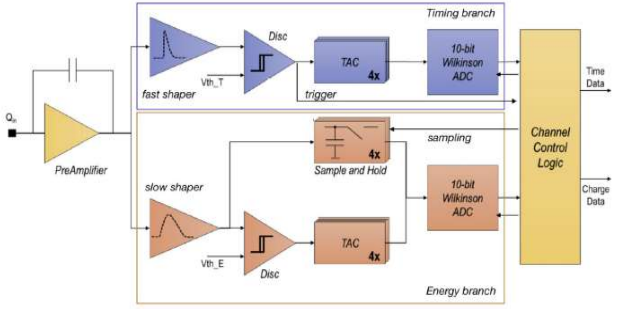
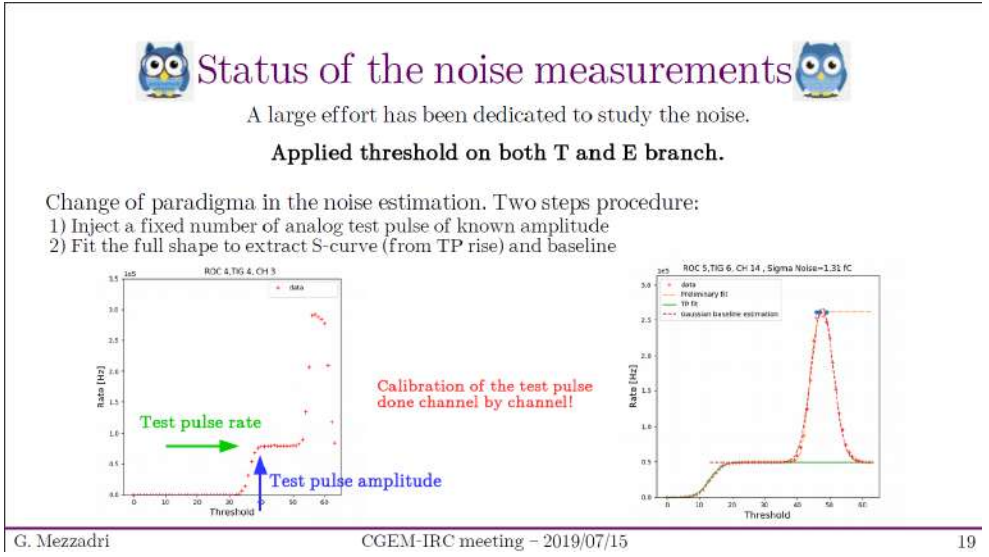


Photo Courtesy of M. Mignone (INFN TO)



64 channel mixed signal triggerless ASIC

A dedicated GUI (GUFI) has been prepared for standalone commissioning
It controls the GEMROCs and the DAQ, plus other status function (e.g., noise extraction, threshold scan, ...)



Commissioning with cosmic rays

November 2023 - March 2024

Results from 4M cosmics rays

The setup

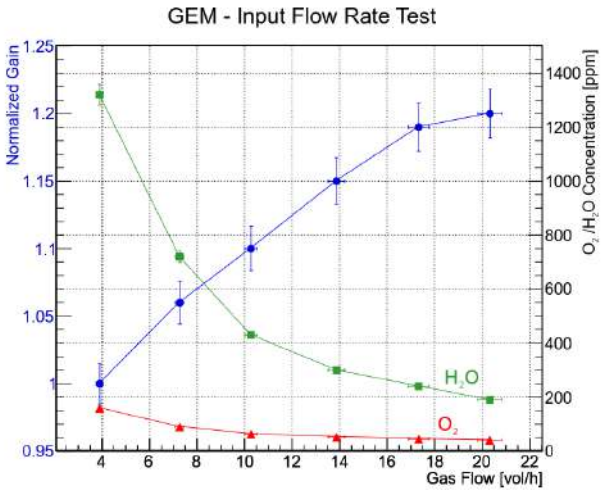
https://inspirehep.net/files/6a82983db656b53db44e5293f8118f2d
Journal of Physics: Conference Series 1498 (2020) 012036
MPGD 2019 proceedings

Gas

We are operating with Ar:Iso (91:9) gas mixture.

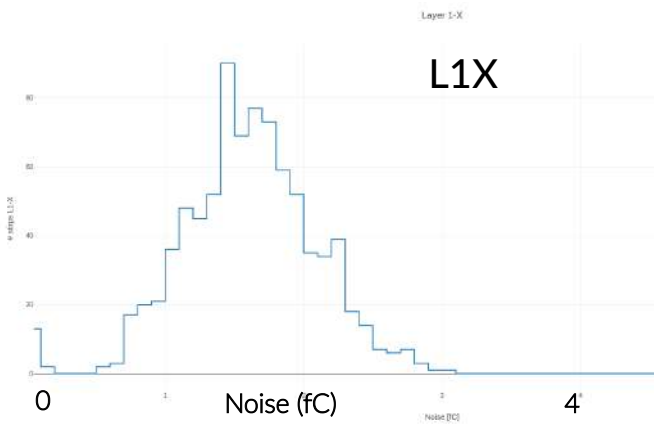
During the commissioning, the three detectors were connected in series

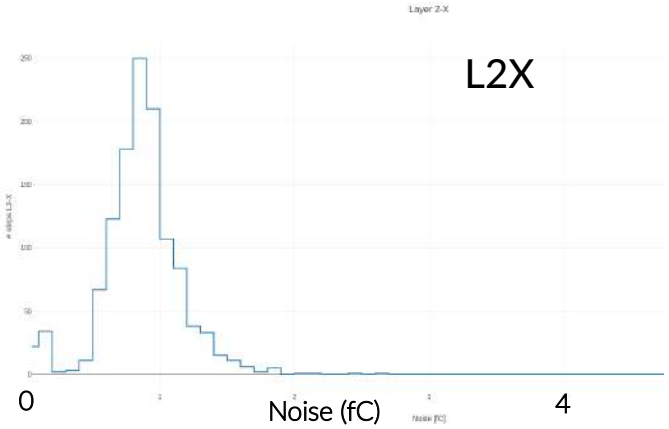
We have tested parallel gas flow for each layer and we saw improvements in the general.

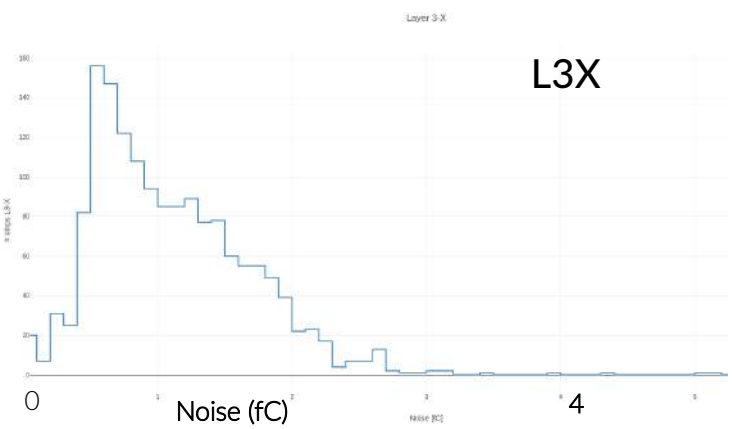


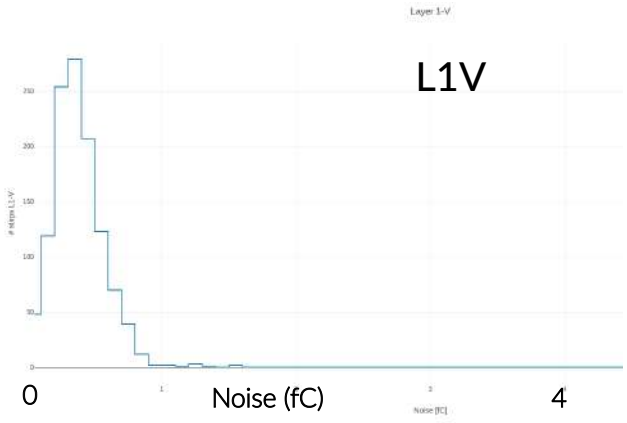
We plan to have at least 4 vol/h gas flow in each layer

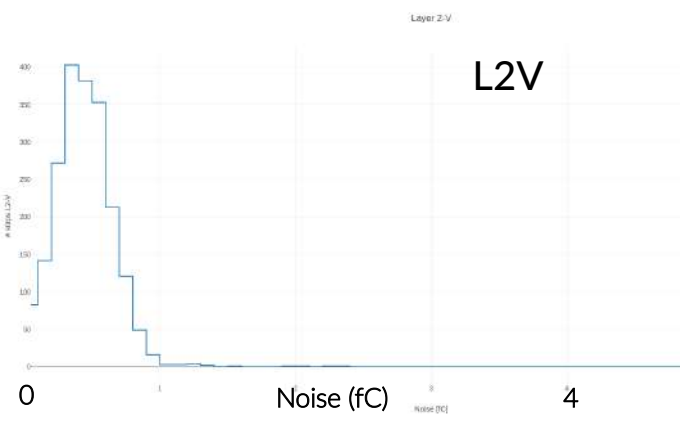
Measured noise on layers

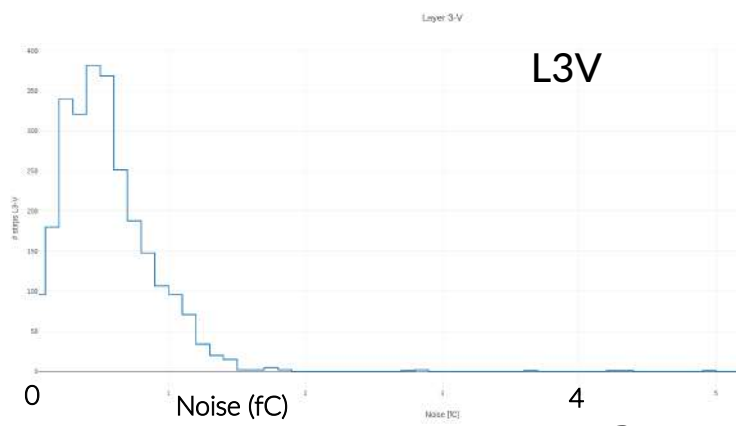




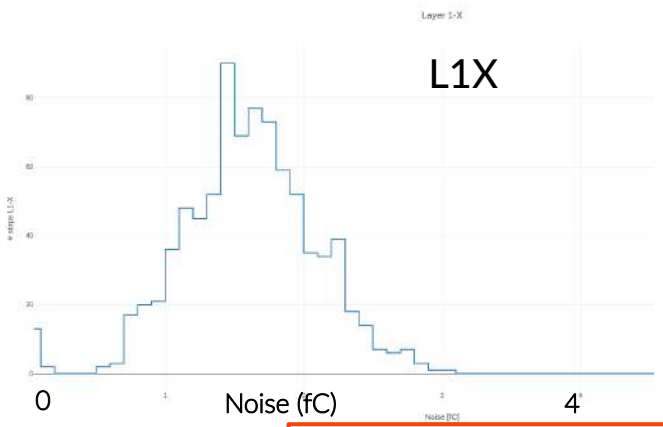


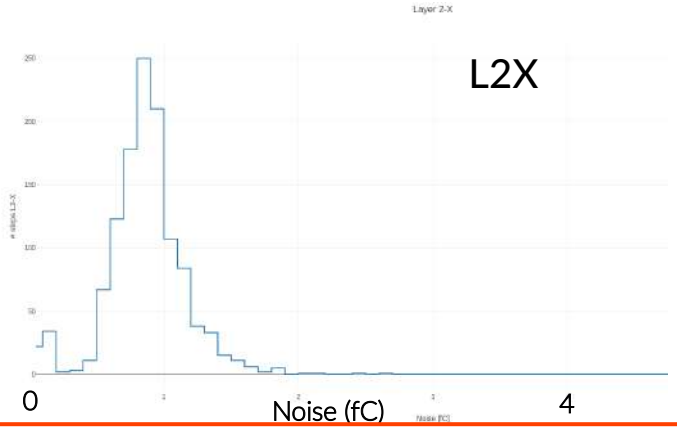




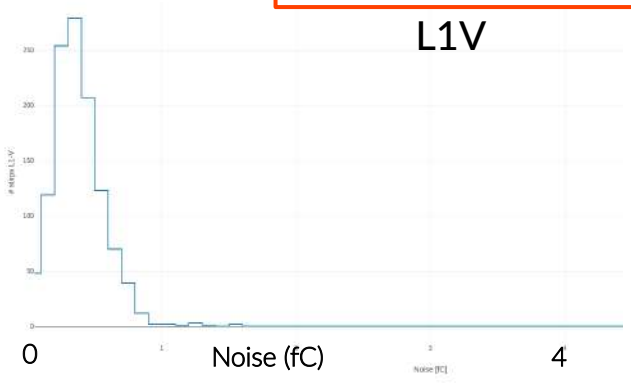


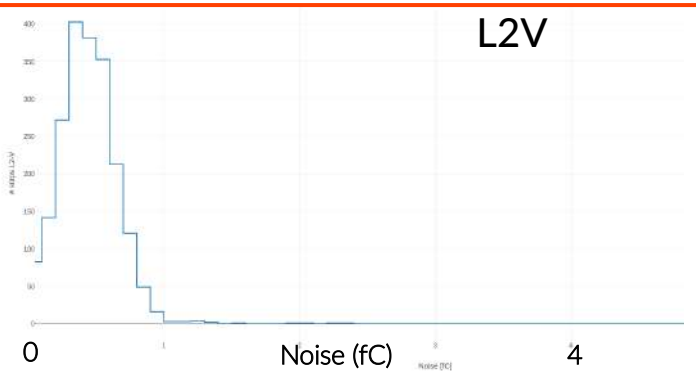
Measured noise on layers

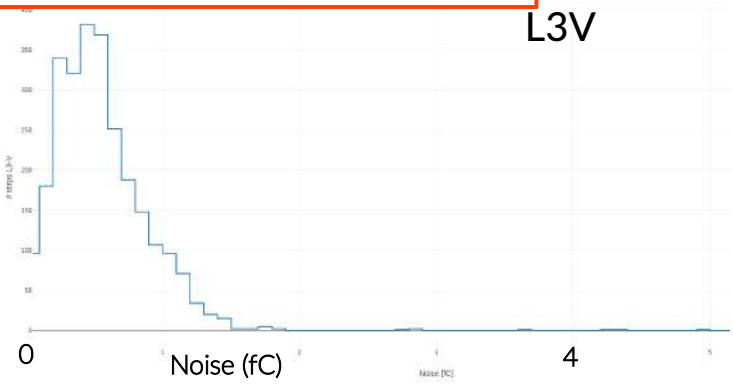




Noise on each layer under control with threshold around few fC on longer strips

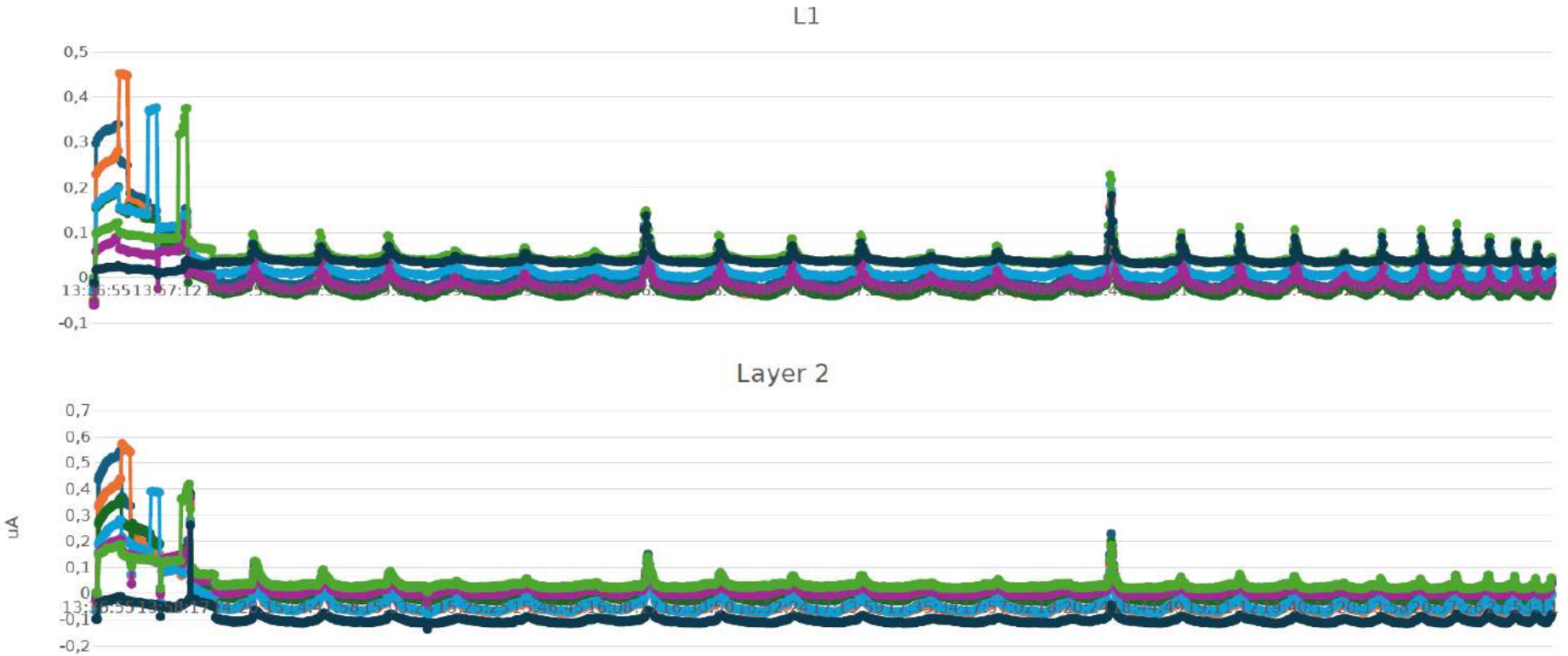




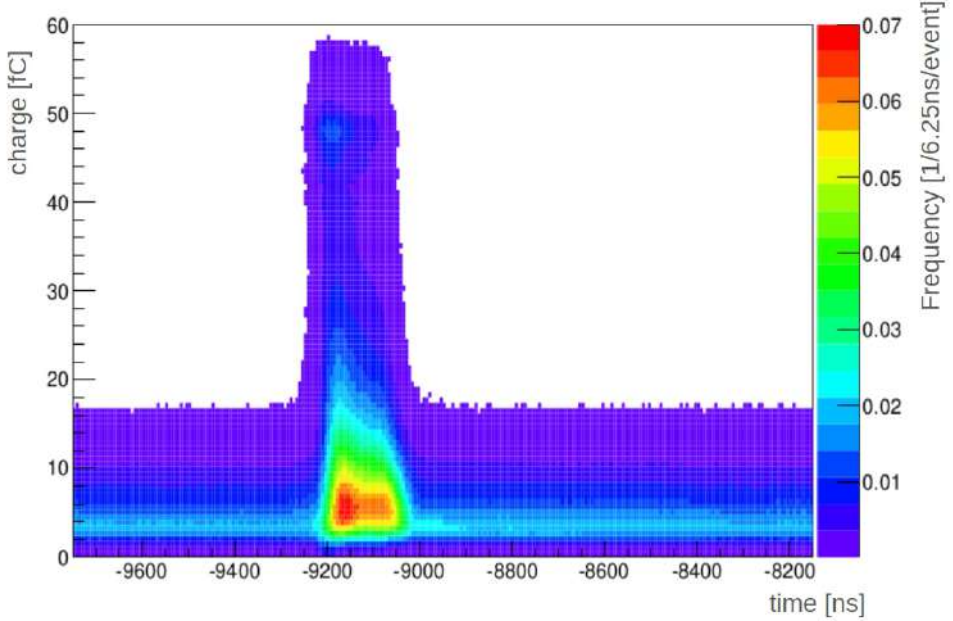


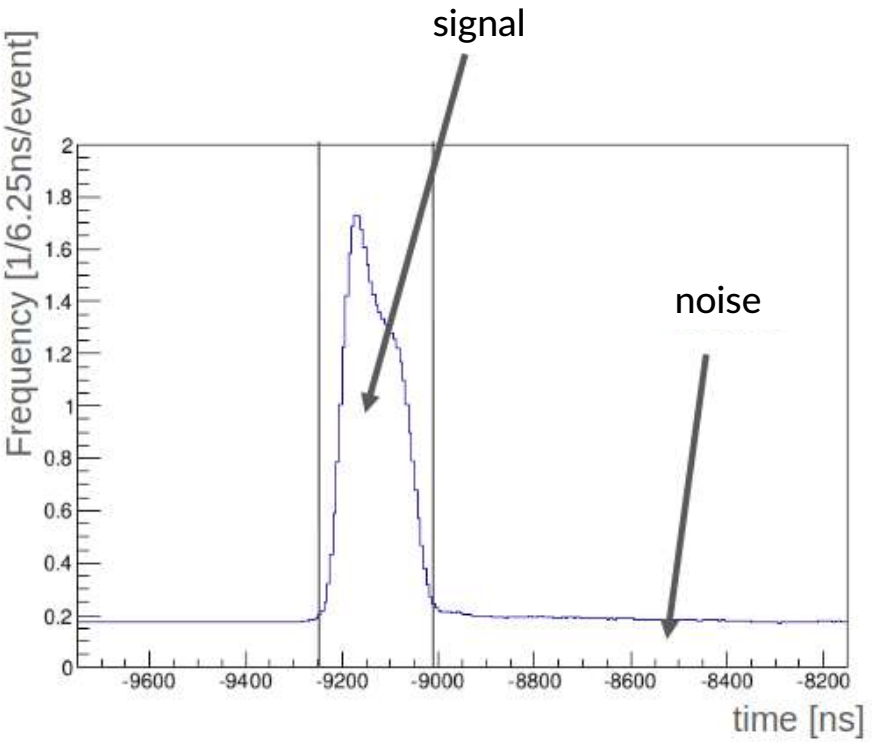
HV monitor

During the operations, modulation of current with humidity observed.



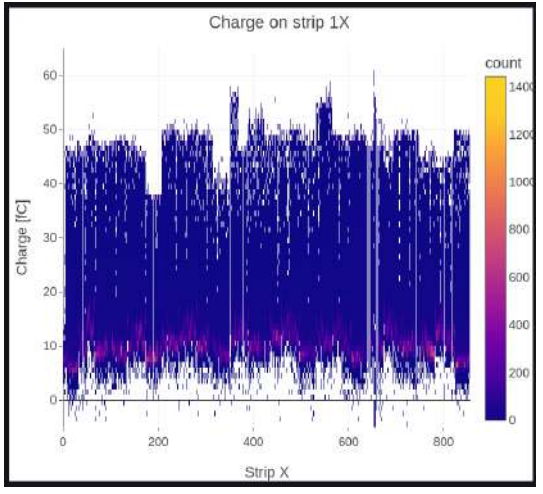
Time and charge

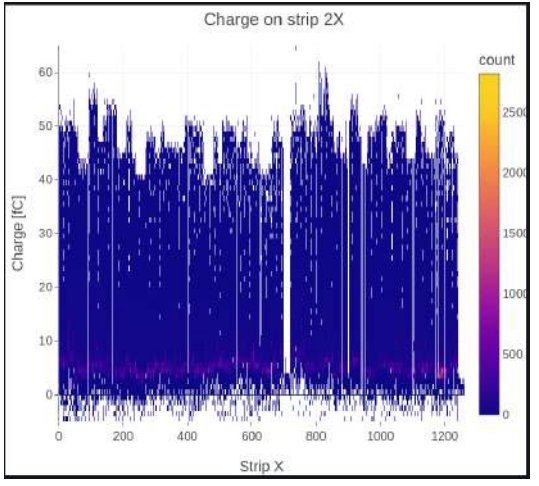


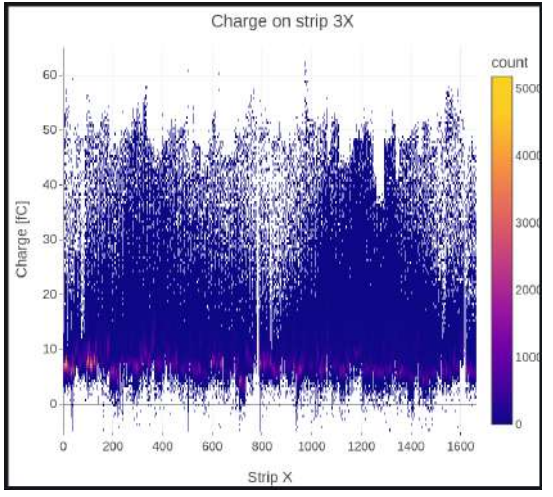


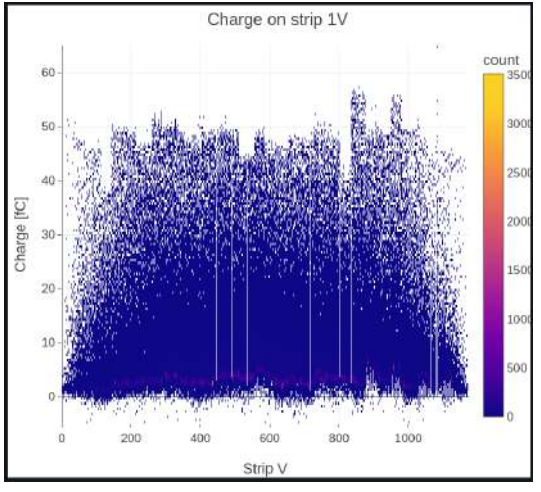
GEMROCs sends out data collected from TIGER in a time window of 1.6 us around the trigger. Expected signal length of about 140 ns

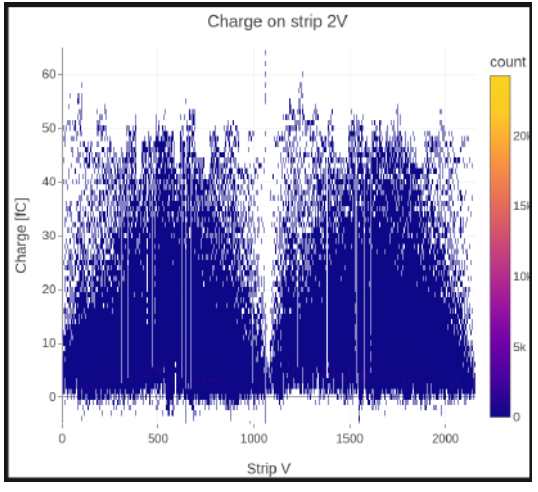
Strip and charge

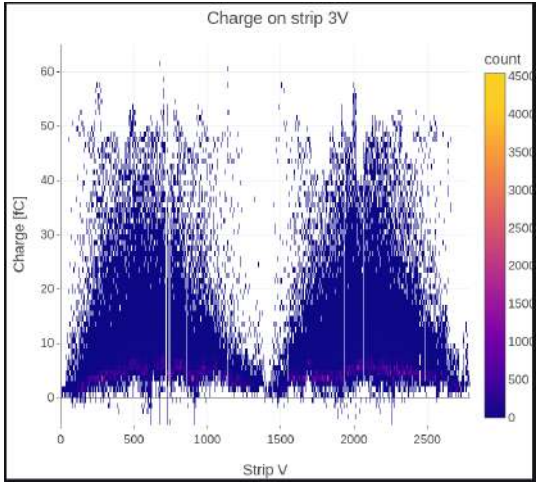




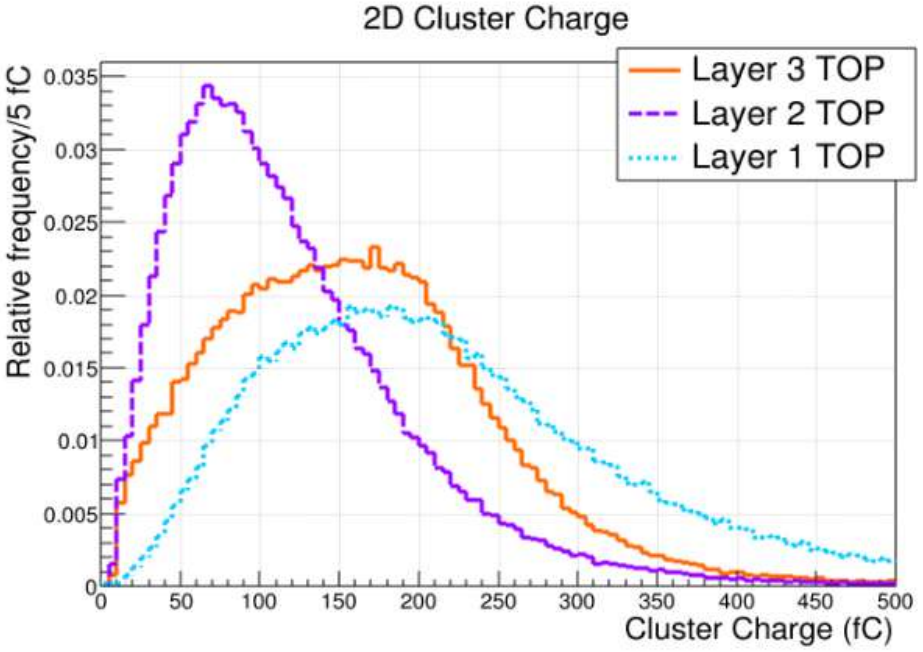


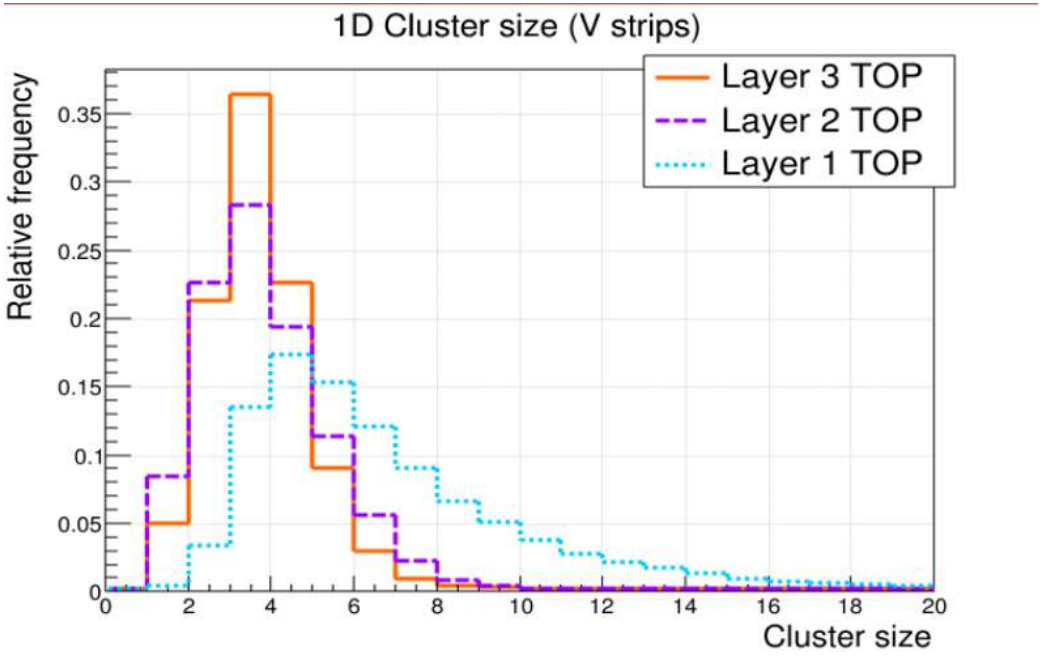






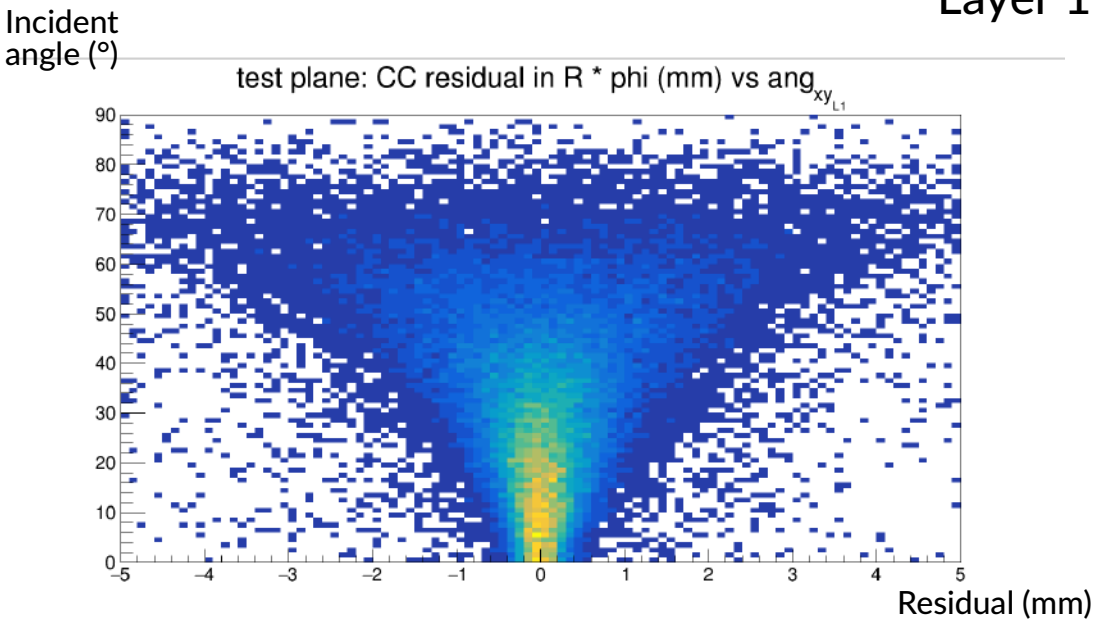
Cluster Charge and size

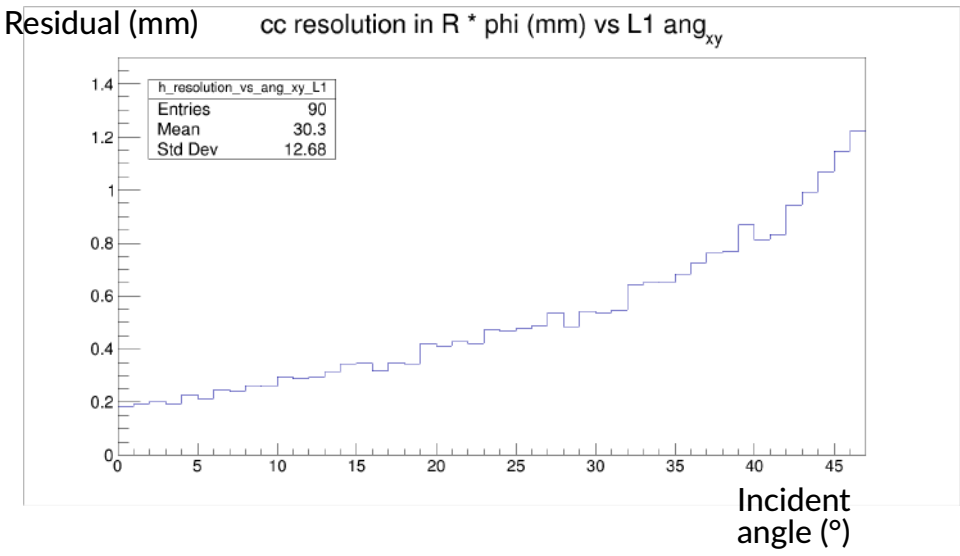




Residual distribution

Layer 1





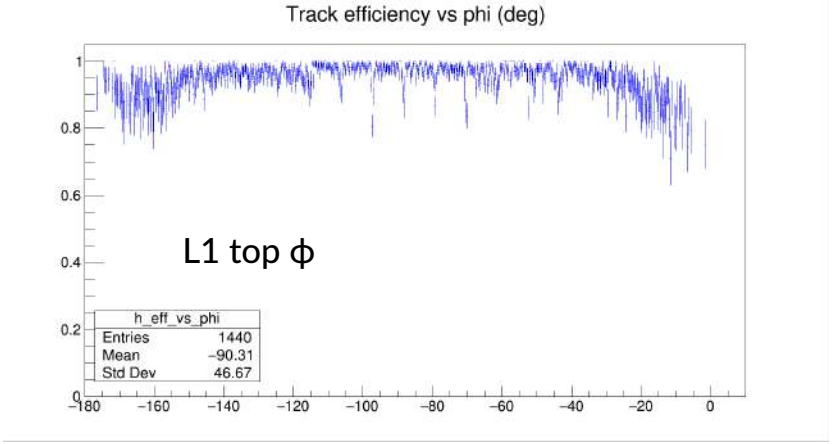
Clear dependence of the charge centroid (CC) residual with the incident angle

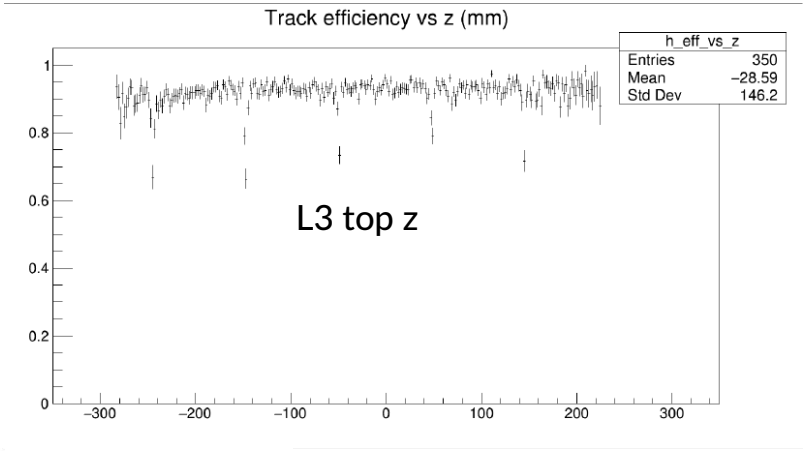
For results below 5°, for each layer residual ~ 200 um

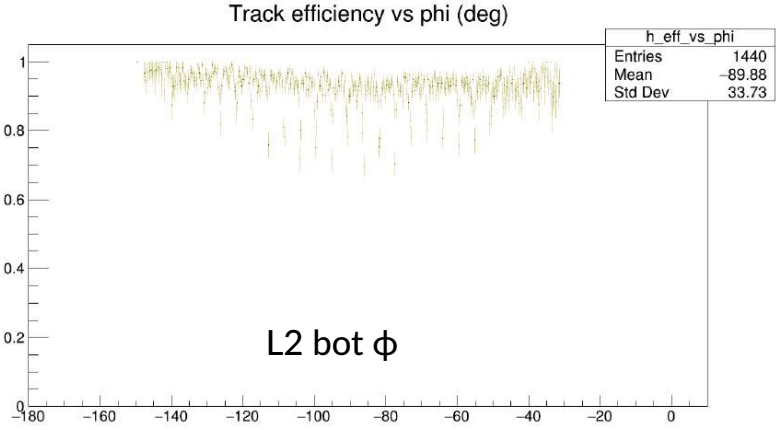
µTPC algorithm under development using these results

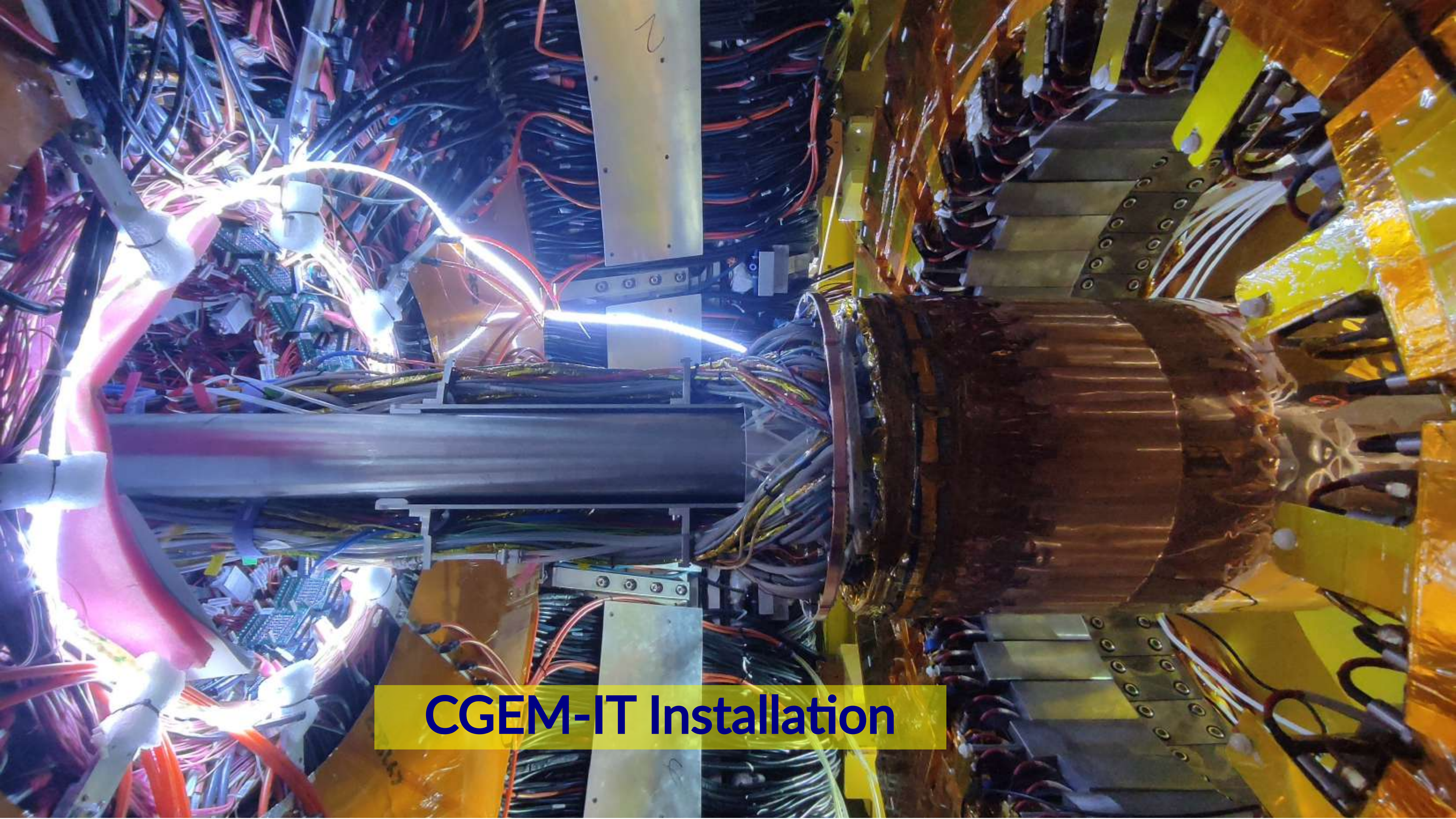
Efficiency

Extracted from signals with 20σ of residual distribution (few mm)

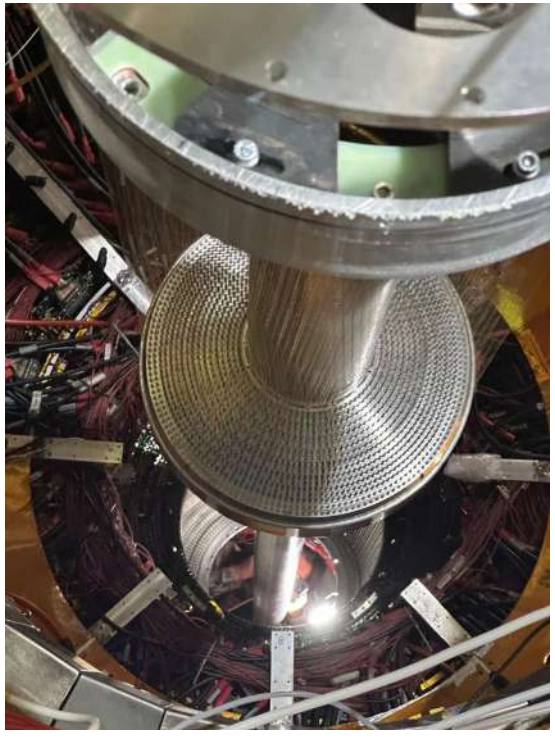




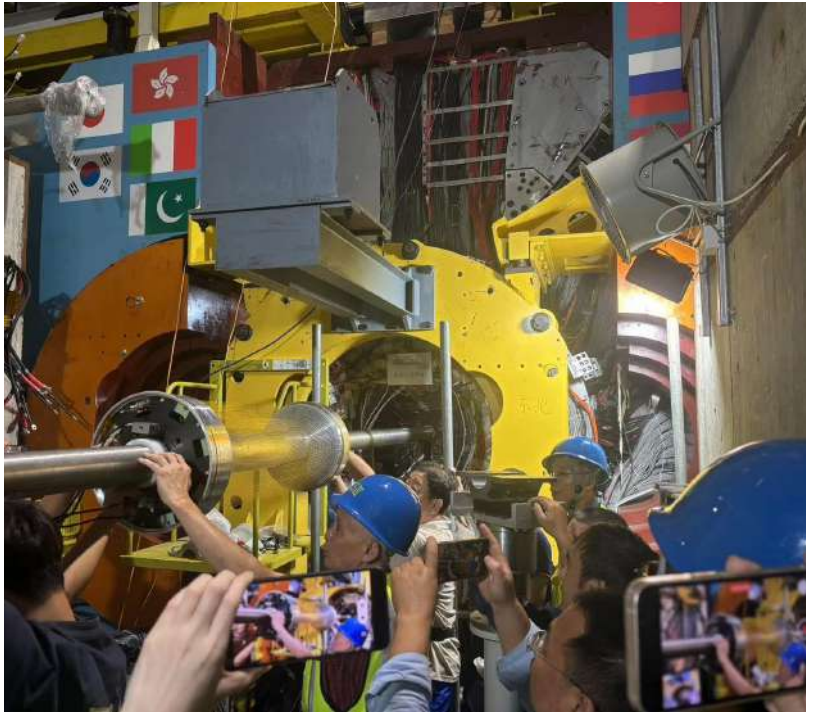


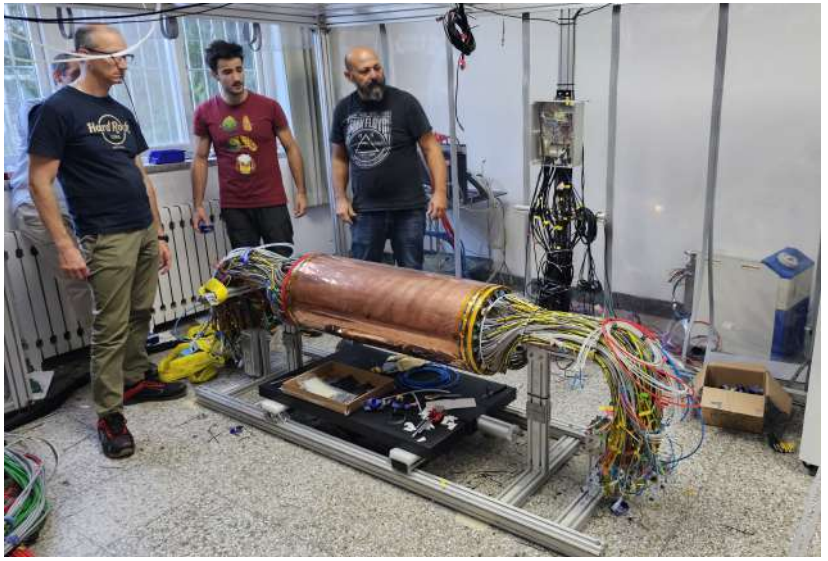


CGEM-IT Installation

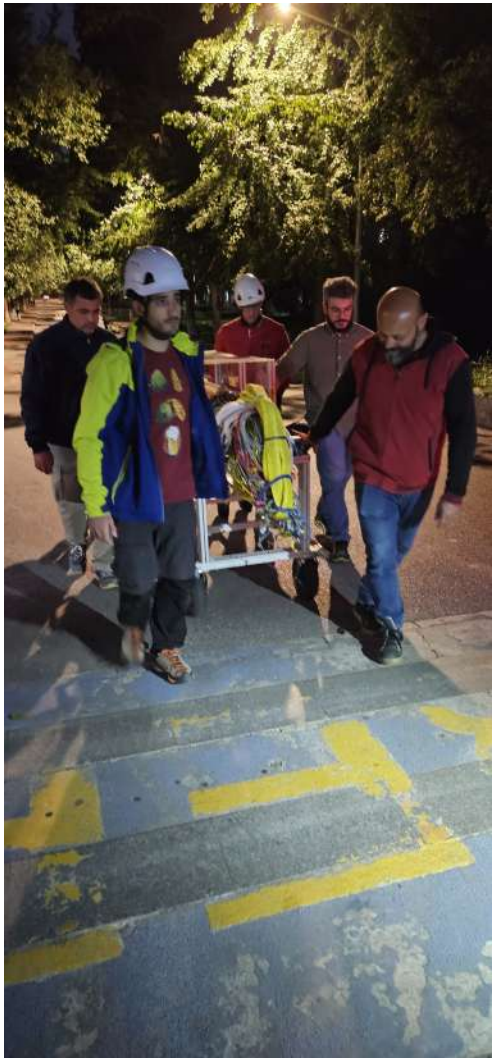


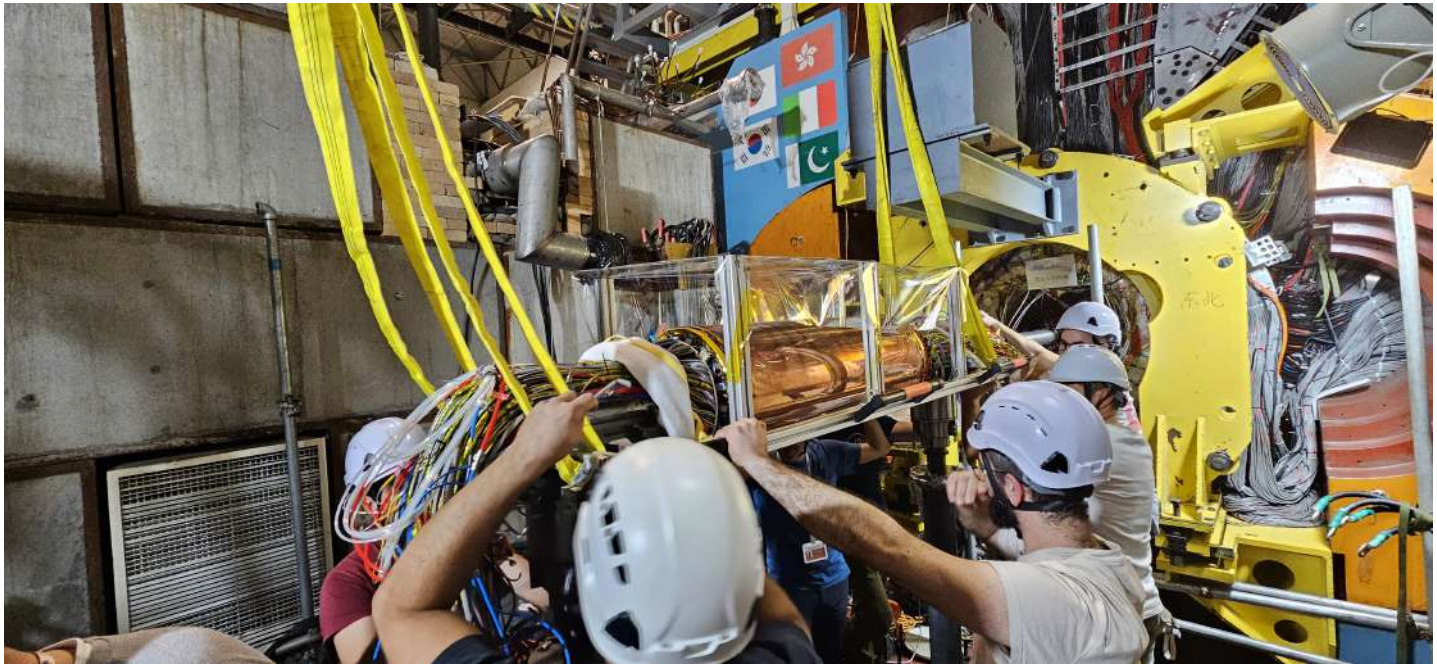
MDC was successfully removed in September by IHEP colleagues



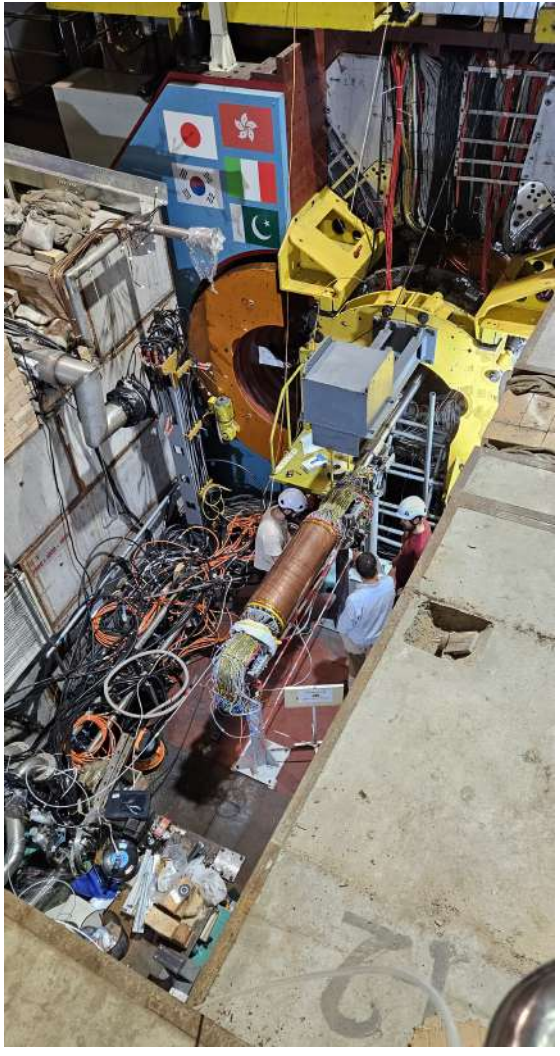


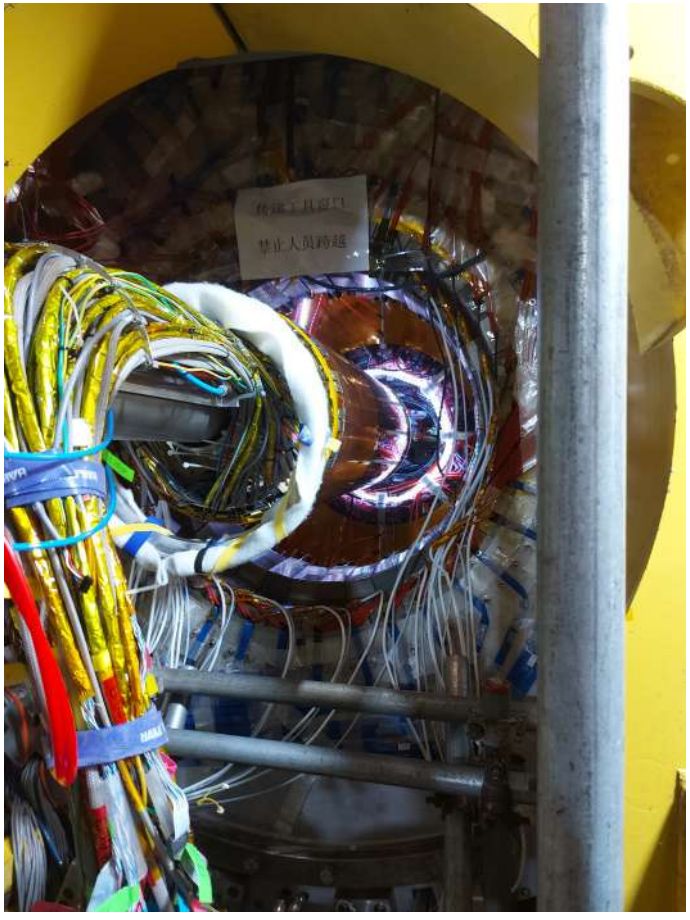
CGEM-IT was uncabled and moved to the experimental hall on October 2...



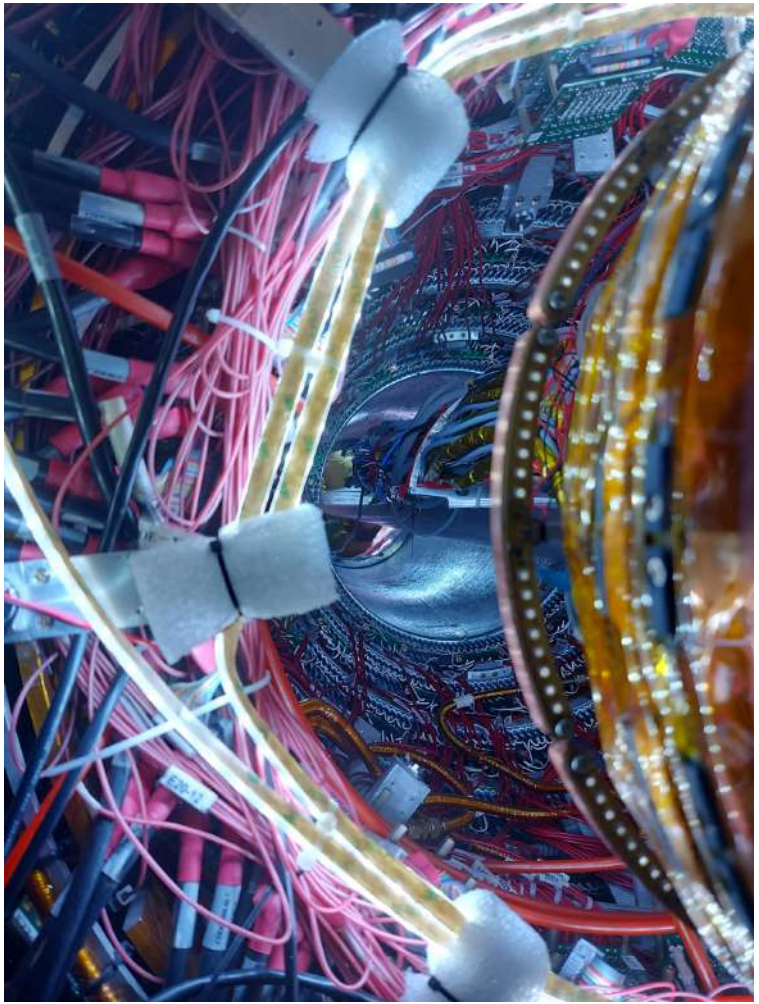


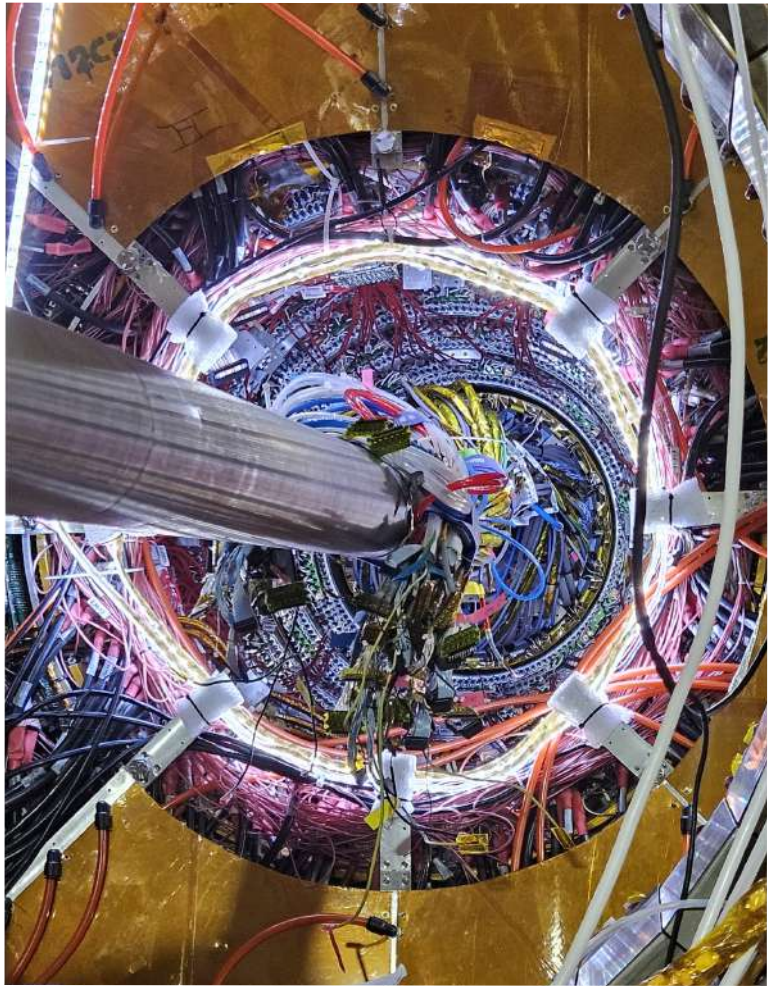
...Lifted and adjusted on the insertion pole





Slowly pushed inside



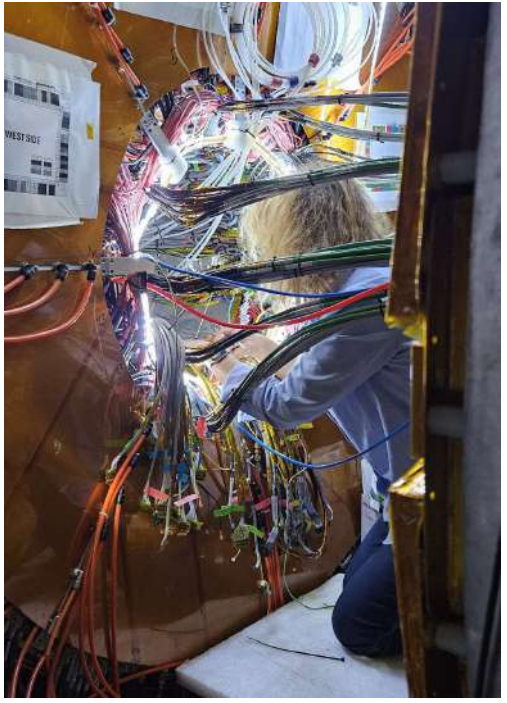


It reached the nominal position on October 5!!

And now we are cabling!

We are working to power it on for the first time in BESIII

Next:
- Commissioning with cosmic ray until end of the year
- Commissioning with beam starting from January



Summary and outlook

- The **CGEM-IT** deploys 3 layers of cylindrical triple-GEMs to replace the inner tracker of BESIII
  - Italy-China Hybrid construction of L3 with peek grids
  - A dedicated readout chain was developed and tested

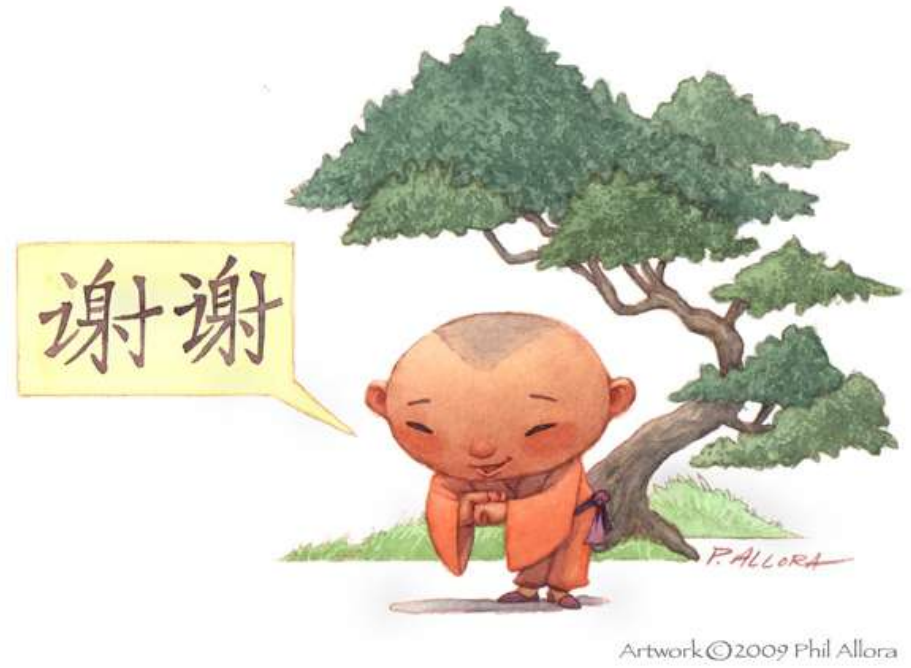
- The standalone commissioning of the CGEM-IT started in November
  - Collected more than 4M cosmic rays
  - Tested different grounding scheme

- Efficiency flat about 95% for all the layers on both views
  - Cluster charge and size matches the expectations, L2 slightly lower

- Resolution with charge centroid about 200 μm
  - μTPC under development

- Passed internal reviews, received the green light for the installation, now we are on floor!

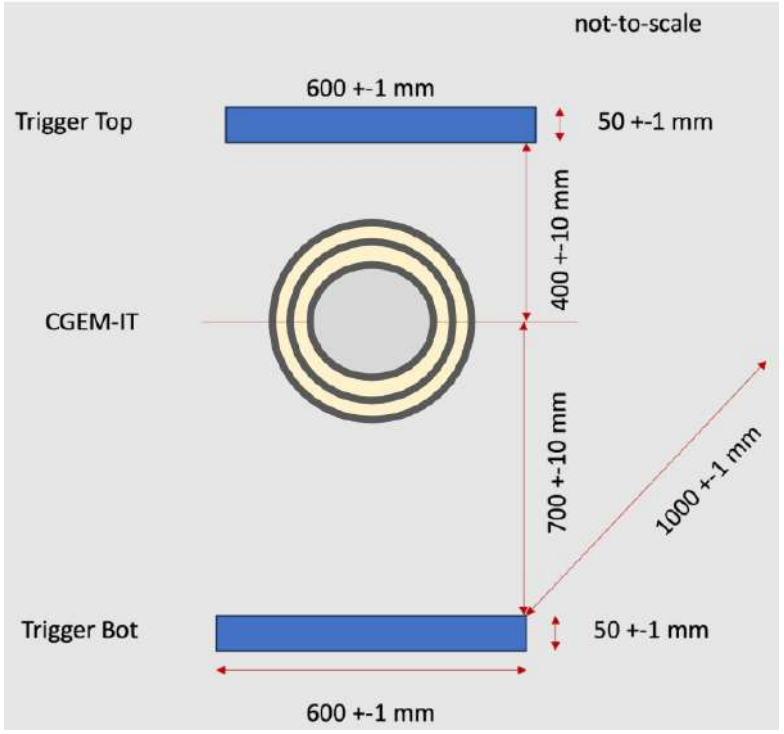
Thanks for your attention

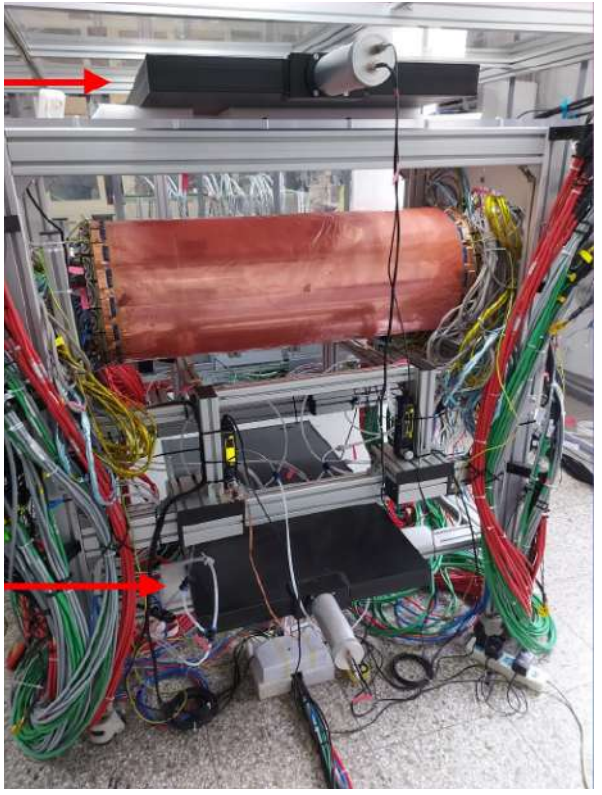


This work is supported by the European Commission:
FEST project (872901) H2020-MSCA-RISE-2019
BESIIICGEM Project (645664) H2020-MSCA-RISE-2014

Backup slides

Cosmics stand





December to February

March to May

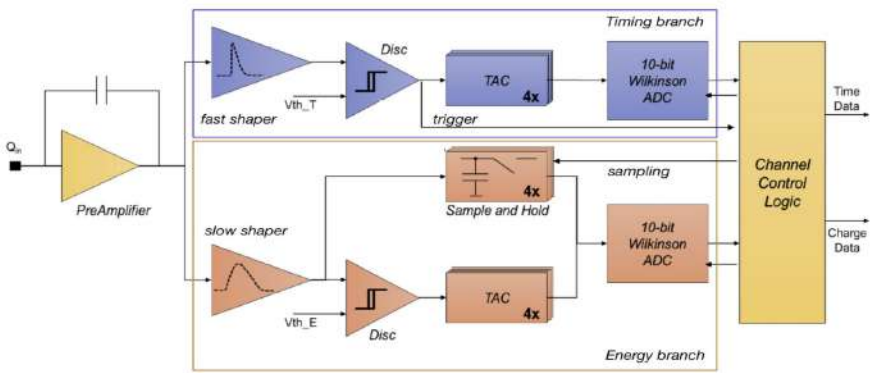
(a) Nucl. Instrum. Meth. Phys.Res. Sec. A 924 (2019) 181;
(b) JINST 14 (2019) 08, P08013

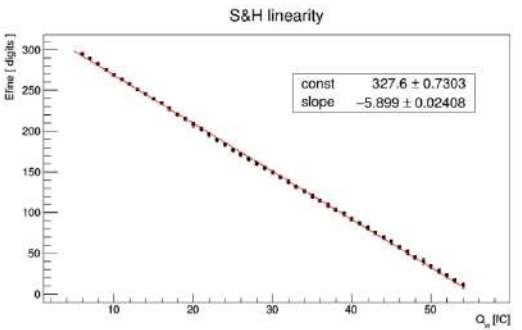
TIGER

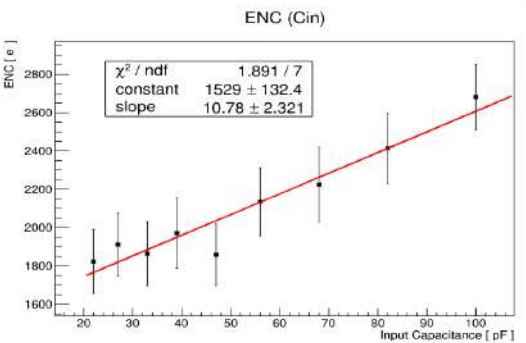
64 channels mixed-mode signal ASIC
Digital back-end from TOFPET-2
110 nm CMOS technology and operated at 1.2 V power supply
~60 kHz per channel
Jitter < 2 ns

Table 2
Measured performance of the TIGER ASIC.

Parameters	Values
Input charge	5-55 fC
TDC resolution	30 ps RMS
Time-walk (5-55 fC range)	12 ns
Average gain	10.75 mV/fC
Nonlinearity (5-55 fC range)	0.5%
RMS gain dispersion	3.5%
Noise floor (ENC)	1500 e^-
Noise slope	10 e^-/pF
Maximum power consumption	12 mW/ch



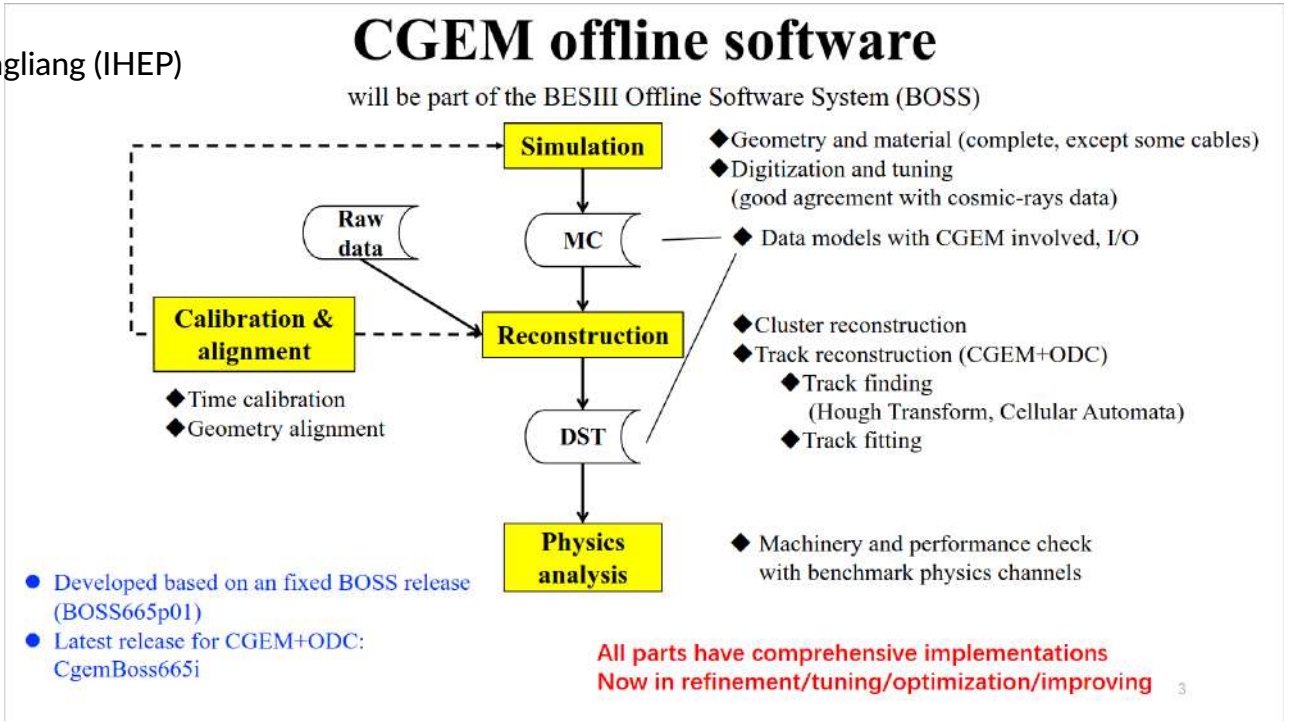




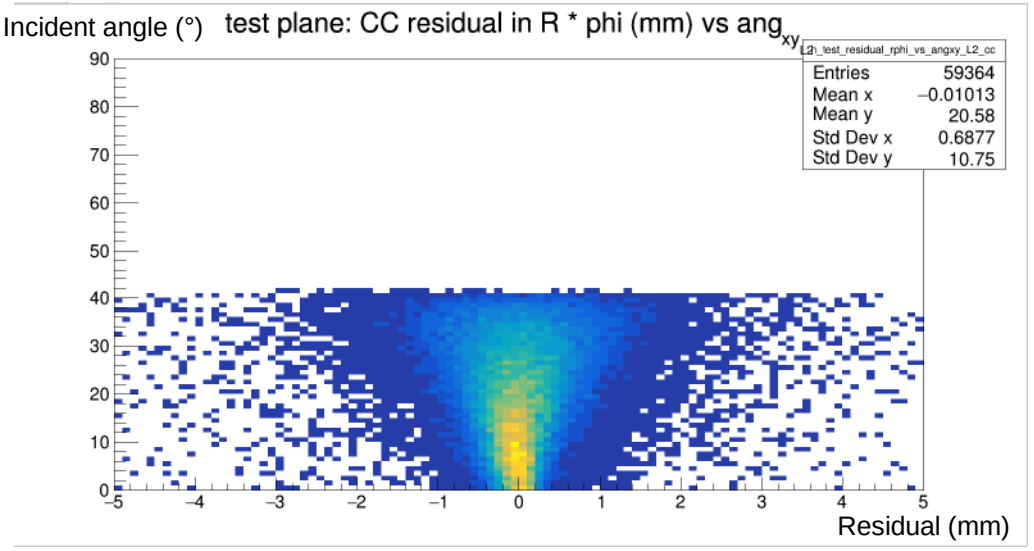
CGEMBOSS

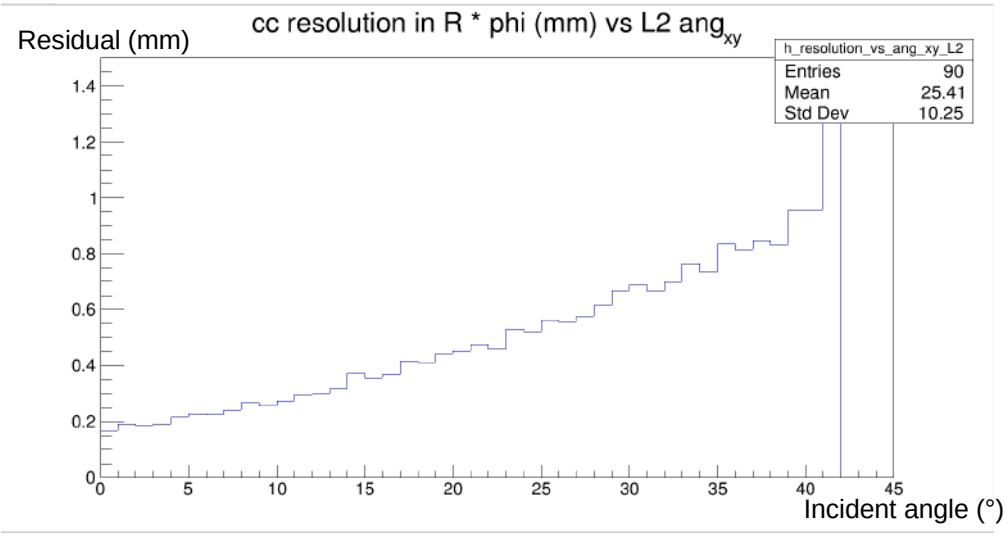
Version of the BESIII offline code that is developed expecially for CGEM-IT to provide a smooth transition at the start of operation.

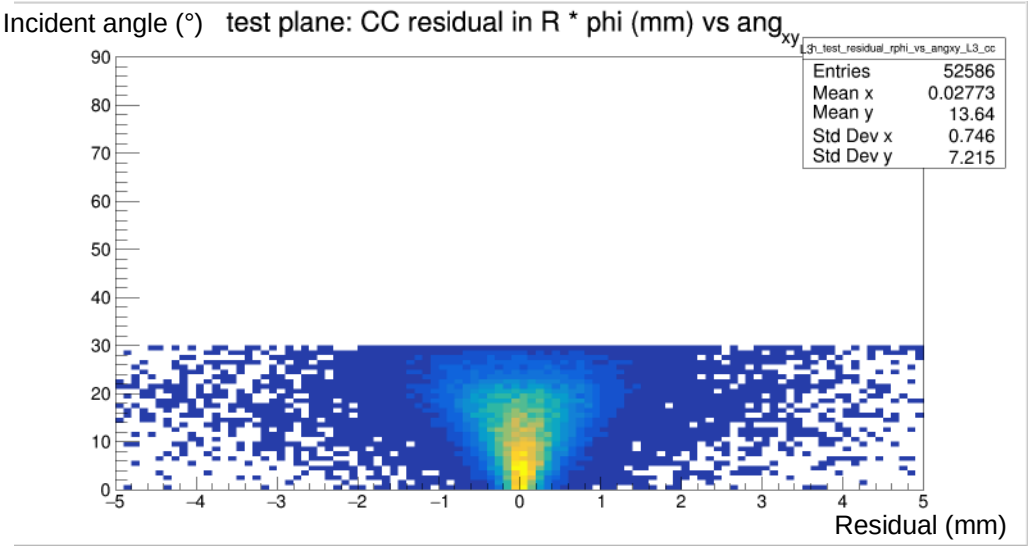
Slide courtesy of Wang Liangliang (IHEP)

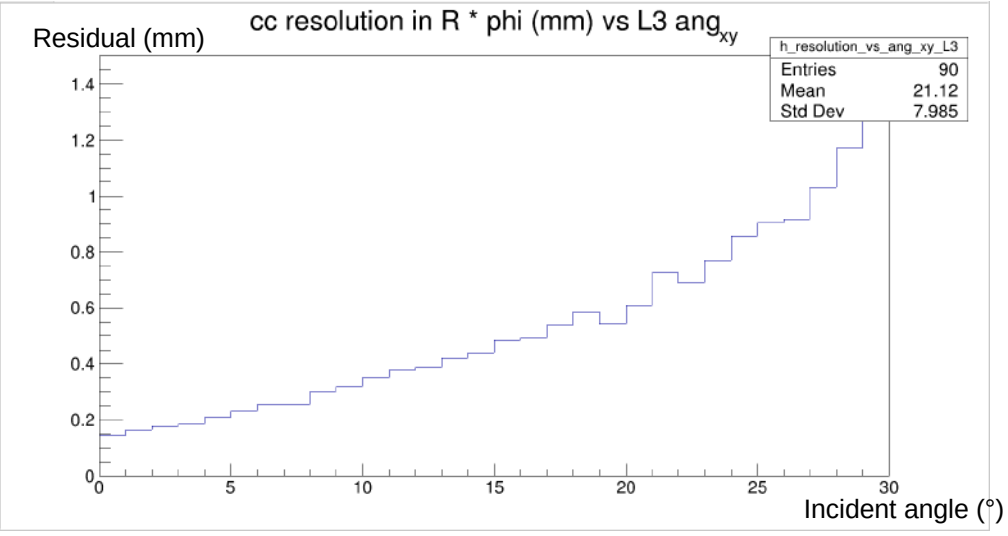


All the results of the commissioning obtained with this software

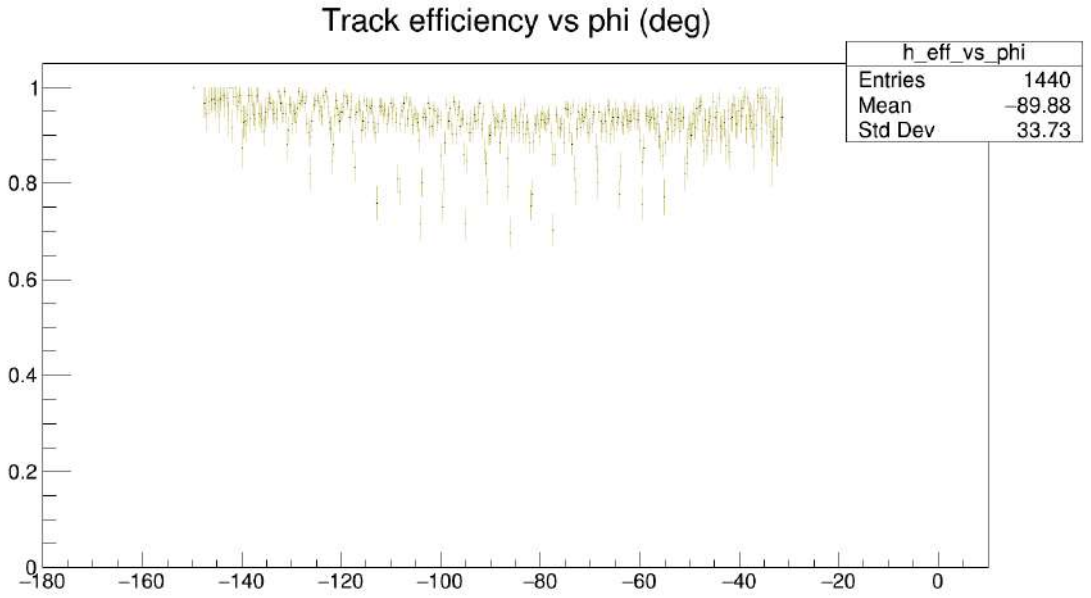

Incident angle (°)
test plane: CC residual in R * phi (mm) vs ang$_{xy}$
h_test_residual_rphi_vs_angxy_L2_cc
Entries 59364
Mean x −0.01013
Mean y 20.58
Std Dev x 0.6877
Std Dev y 10.75
Residual (mm)


Residual (mm)
cc resolution in R * phi (mm) vs L2 ang$_{xy}$
h_resolution_vs_ang_xy_L2
Entries 90
Mean 25.41
Std Dev 10.25
Incident angle (°)


Incident angle (°)
test plane: CC residual in R * phi (mm) vs ang$_{xy}$
h_test_residual_rphi_vs_angxy_L3_cc
Entries 52586
Mean x 0.02773
Mean y 13.64
Std Dev x 0.746
Std Dev y 7.215
Residual (mm)


Residual (mm)
cc resolution in R * phi (mm) vs L3 ang$_{xy}$
h_resolution_vs_ang_xy_L3
Entries 90
Mean 21.12
Std Dev 7.985
Incident angle (°)

Efficiency – some details

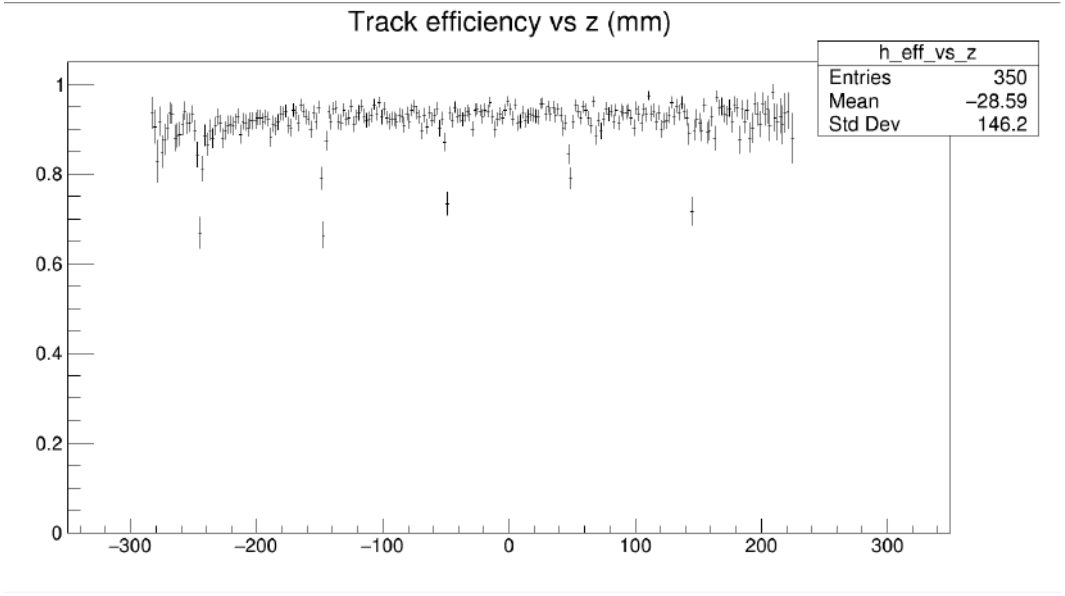


Micro sector effect:

GEM HV is segmented. This creates a small gap where there is less amplification.

For straight tracks the effect is larger

Efficiency – some details



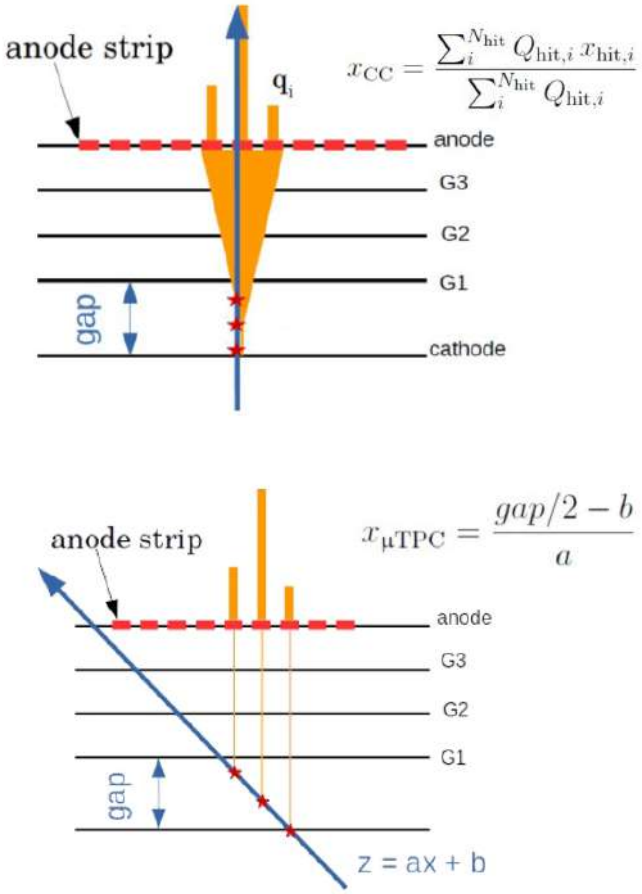
Supporting grids effect:

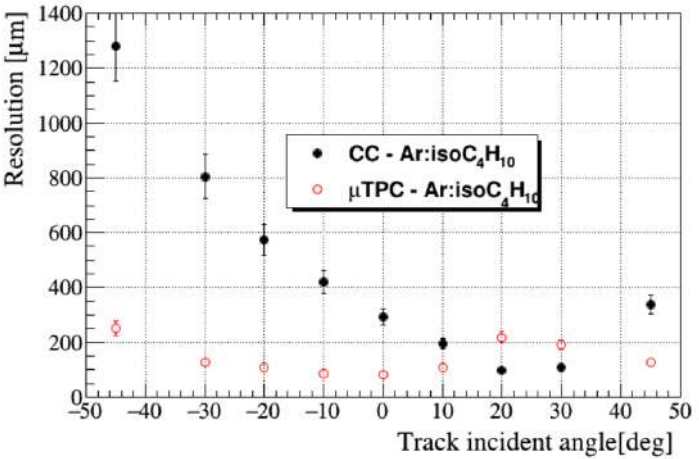
Supporting grids are aligned in z direction (every 10 cm), but not in ϕ direction. This creates a small gap where there is less amplification.

For straight tracks the effect is larger

Cluster reconstruction

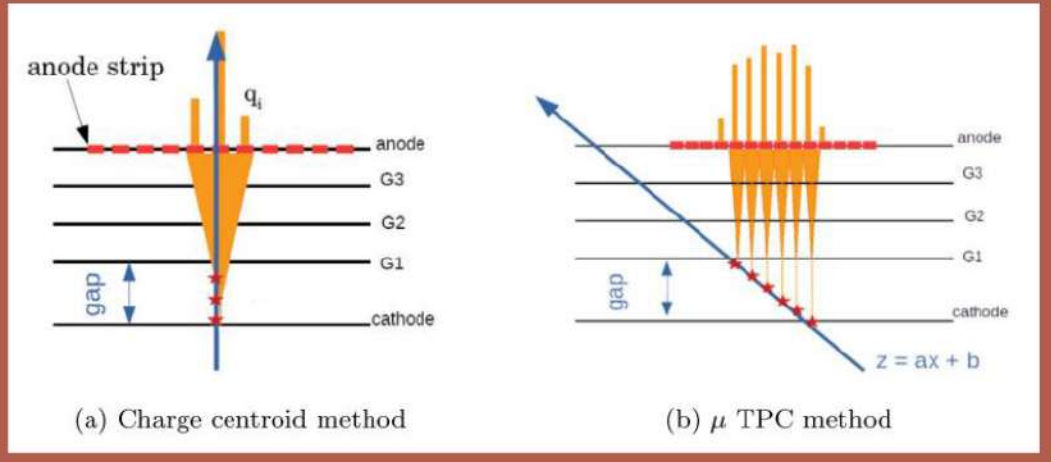
Contiguous fired strips on the anode form a **cluster**





M. Alexeev et al 2019 JINST 14 P08018
R. Farinelli PhD Thesis, arXiv: 1904.06548

Charge centroid & μTPC concepts



(a) Charge centroid method (b) μ TPC method

$$x_{\mathrm{CC}} = \frac{\sum_i^{N_{\mathrm{hit}}} Q_{\mathrm{hit},i}\ x_{\mathrm{hit},i}}{\sum_i^{N_{\mathrm{hit}}} Q_{\mathrm{hit},i}}$$

$$x_{\mu\mathrm{TPC}} = \frac{gap/2 - b}{a}$$

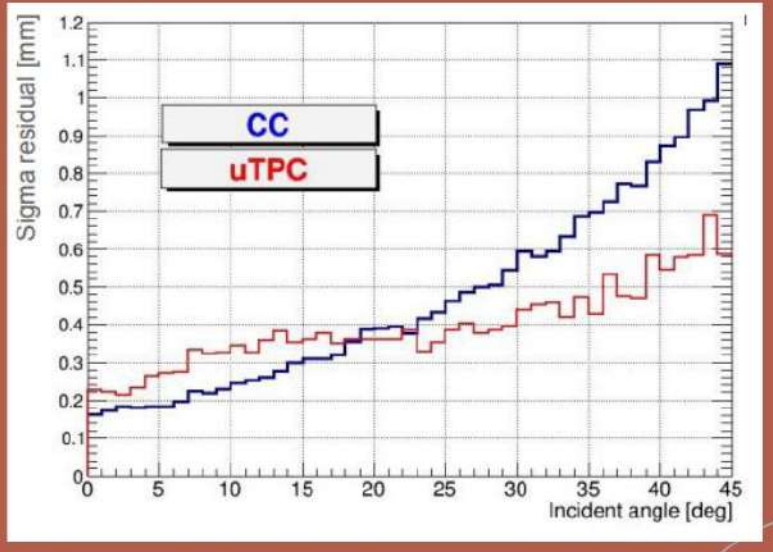
- The CC averages the charge of all the strips of the cluster by weighting it by its charge
- The μTPC instead considers the drift gap as a tiny TPC and with position and time information, it associates each strip with a bi-dimensional point and uses a linear fit to extrapolate the particle position

Charge centroid & µTPC CGEM-IT state

Preliminary result, also need to take into account:

- time calibrations to be optimized (contribution of 200-250µm)
- the contribution of tracking must be subtracted (contribution of 100-200 µm)

PRELIMINARY PLOT



HV stability from our experience

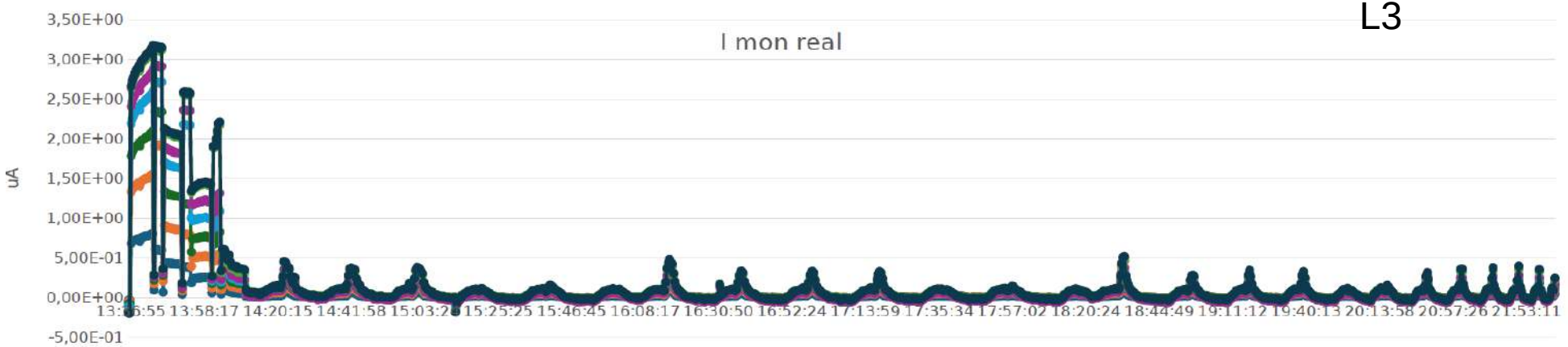
- L1-L2 on a stand (not suitable for cosmic performance studies) in 2020
  - Continuous run for more than 700 hours
  - Continuous data taking with restart scheme (run 17 of digitization studies)

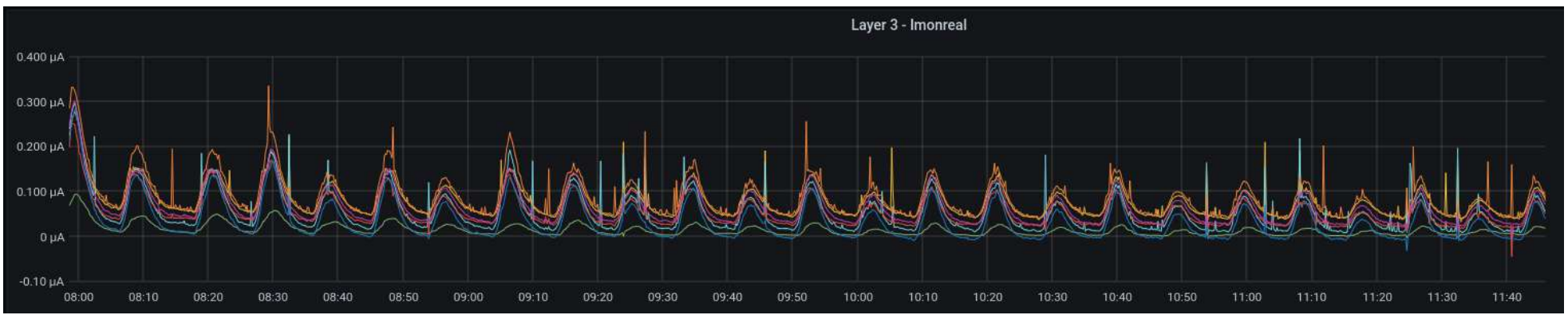
- Full CGEM-IT
  - Daily power on (~10 hours per day) – about total 500 hours
  - Data taking

Order few (3-4) trips in detector life so far, current dependence with humidity

HV monitor

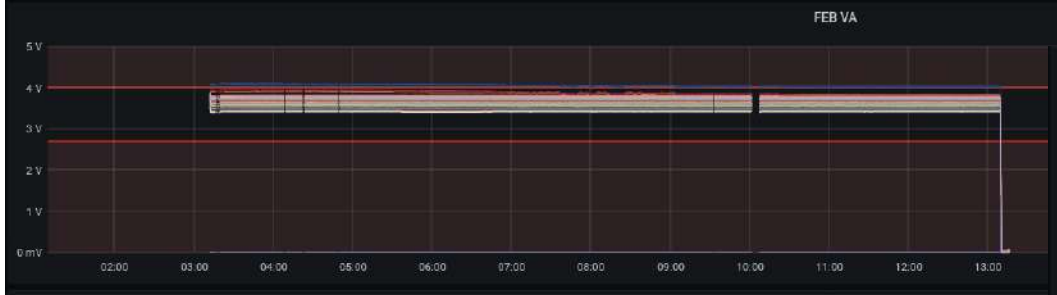
L3

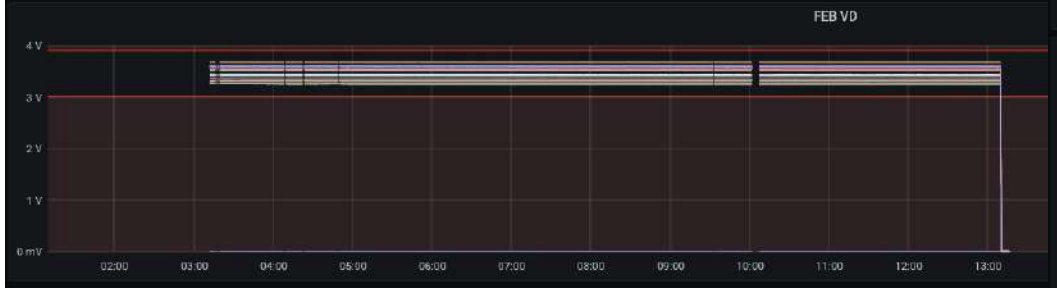


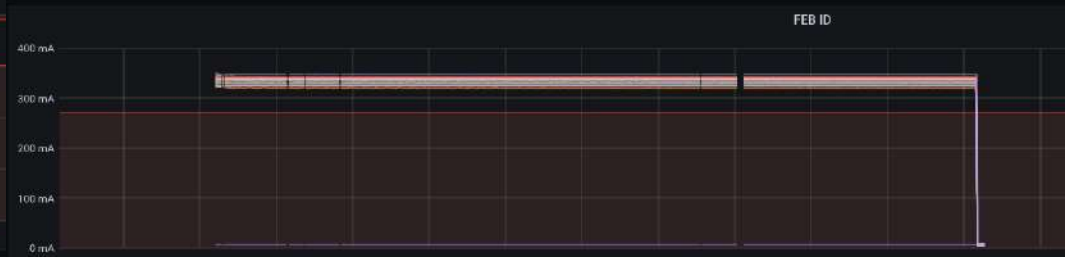


On L3, Discharges of hudrends of nA that do not prevent the operations or the data taking

LV and DAQ monitor - I





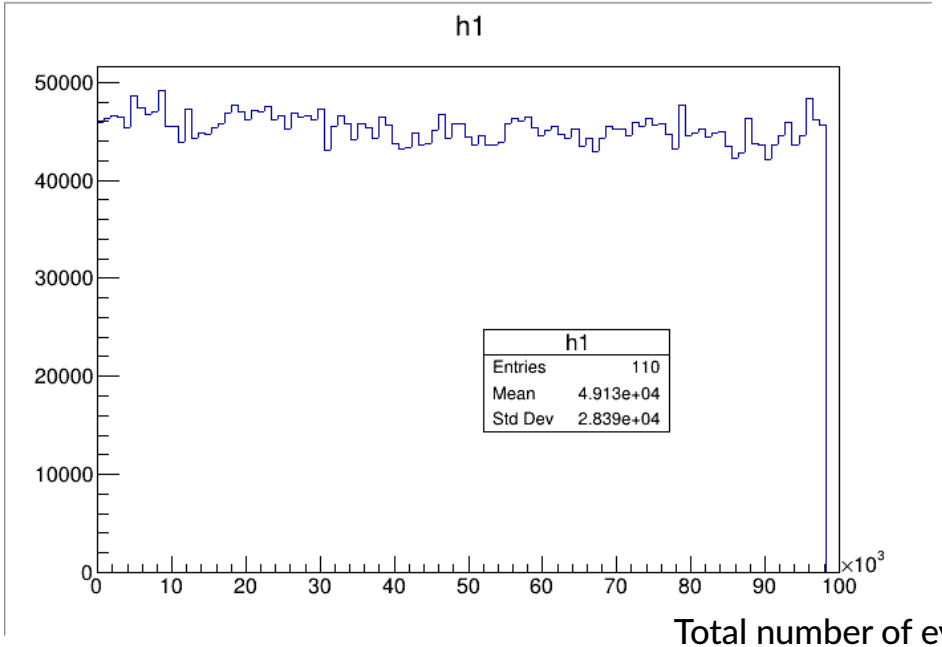


Stable FEB temperature, voltages, currents during all the operations

LV and DAQ monitor – II

- During cosmic data taking, typical run integrates few hours of triggers, but we do reconfigure FEBs after 30 minutes (or 30k events)
- We have taken two runs of 60 (run 1044) and 75 (run 1045) minutes with no reconfiguration (closer to BESIII standard “decay mode” data taking) with no issue

Each bin represents the number of hits in time window (-9300,-8800) for 900 events



Total number of events in the run