Preliminary results from the cosmic data taking of the BESIII cylindrical GEM detectors

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on behalf of
the CGEM-IT working group

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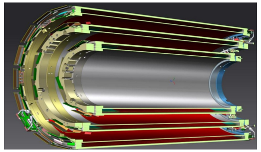
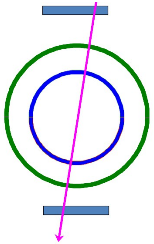
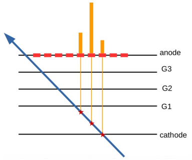
Outline



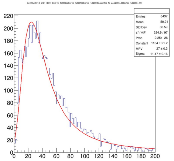
Cylindrical **GEM**: detector and electronics



Cosmic ray **setup**



Reconstruction and **analysis**

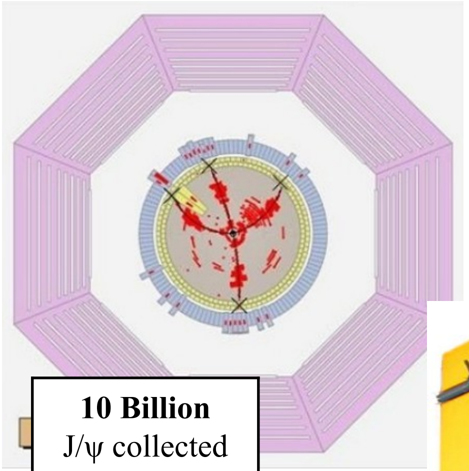


Preliminary **results** of the CGEM-IT

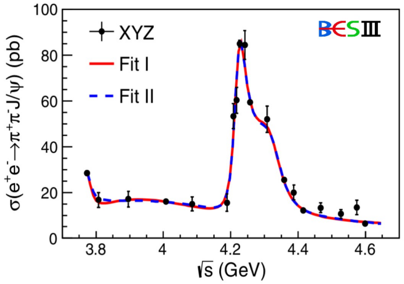
BESIII experiment

Nucl. Instr. Meth. A614, 345 (2010)

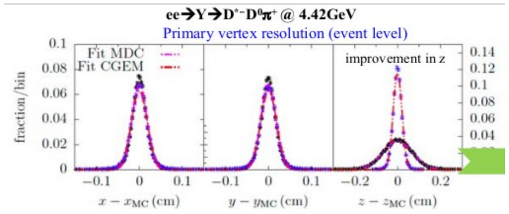
- Beijing Electron-Positron Collider **BEPCII** and BEijing Spectrometer **BESIII** operate in the τ-charm region
- Luminosity = 10^{33} cm^{-2} s^{-1}
- **Energy$_{cm}$: 2 - 4.6 (4.9) GeV**
- The physic program includes:
  1. Test of precision EW
  2. Studies of hadron spectroscopy with high statistic
  3. Exotic charmed states (i.e. XYZ states)
  4. Studies of physics in the τ-charm region
  5. ...



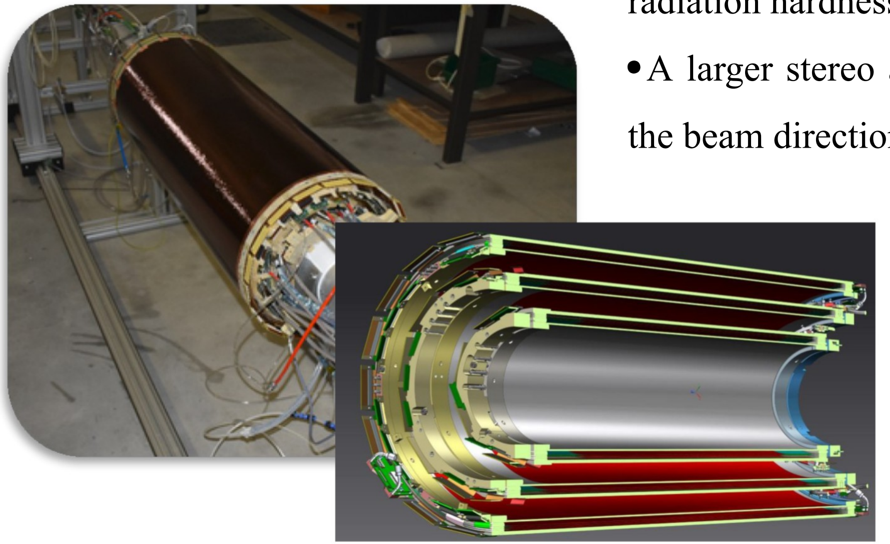
10 Billion
J/ψ collected
on 11 Feb.

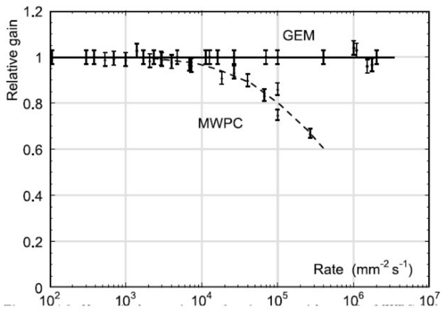


Cylindrical GEM Inner Tracker



- A cylindrical GEM inner tracker will replace the BESIII inner MDC since aging is affecting its performance
- A double view readout measures time and charge to reconstruct a 3D position
- GEM technology improves the rate capability and the radiation hardness
- A larger stereo angle of the strips improves the resolution in the beam direction



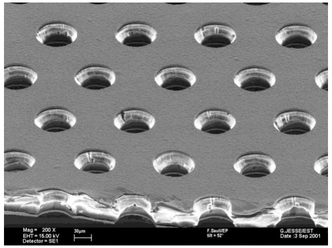


BESIII requirements

- Rate capability: ~10^4 Hz/cm^2
- Spatial resolution: $\sigma_{r\text{-}\phi}$=~130μm : σ_z=~1mm
- Momentum resolution: σ_{pt}/P_t =~0.5% @1GeV
- Efficiency = ~98%
- Material budget ≤ 1.5% X_0 in all layers
- Coverage: 93% 4π
- 1 Tesla magnetic field

Gas Electron Multiplier in a nutshell

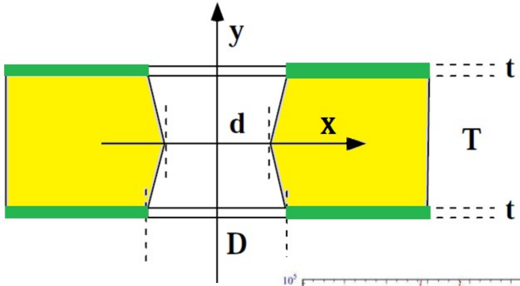
Nucl. Instr. and Meth. A805 2-24 (2016)



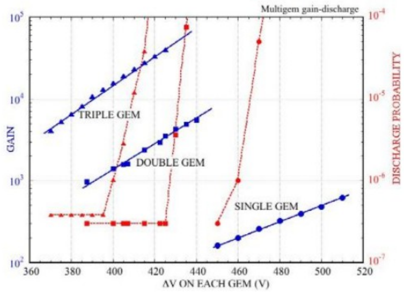
Polymeric kapton foil (T = 50 μm)

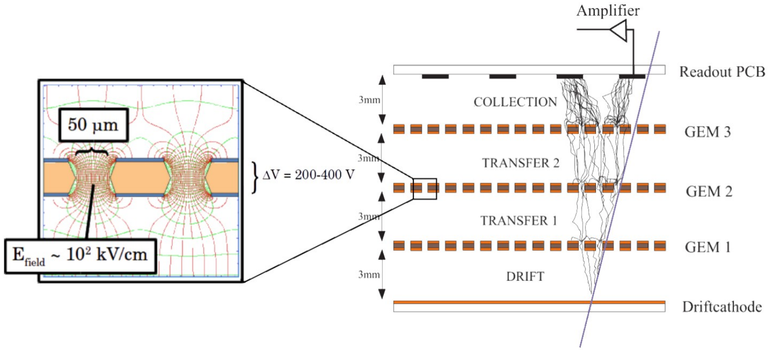
Copper coated (t = 3/5 μm)

Pierced by etching technique (d = 50 μm)



- GEM technology was invented by **F. Sauli** in 1997
- Hundreds of Volts applied on the **two copper faces** generate an electric field
- An electron entering the hole creates an **electron avalanche**

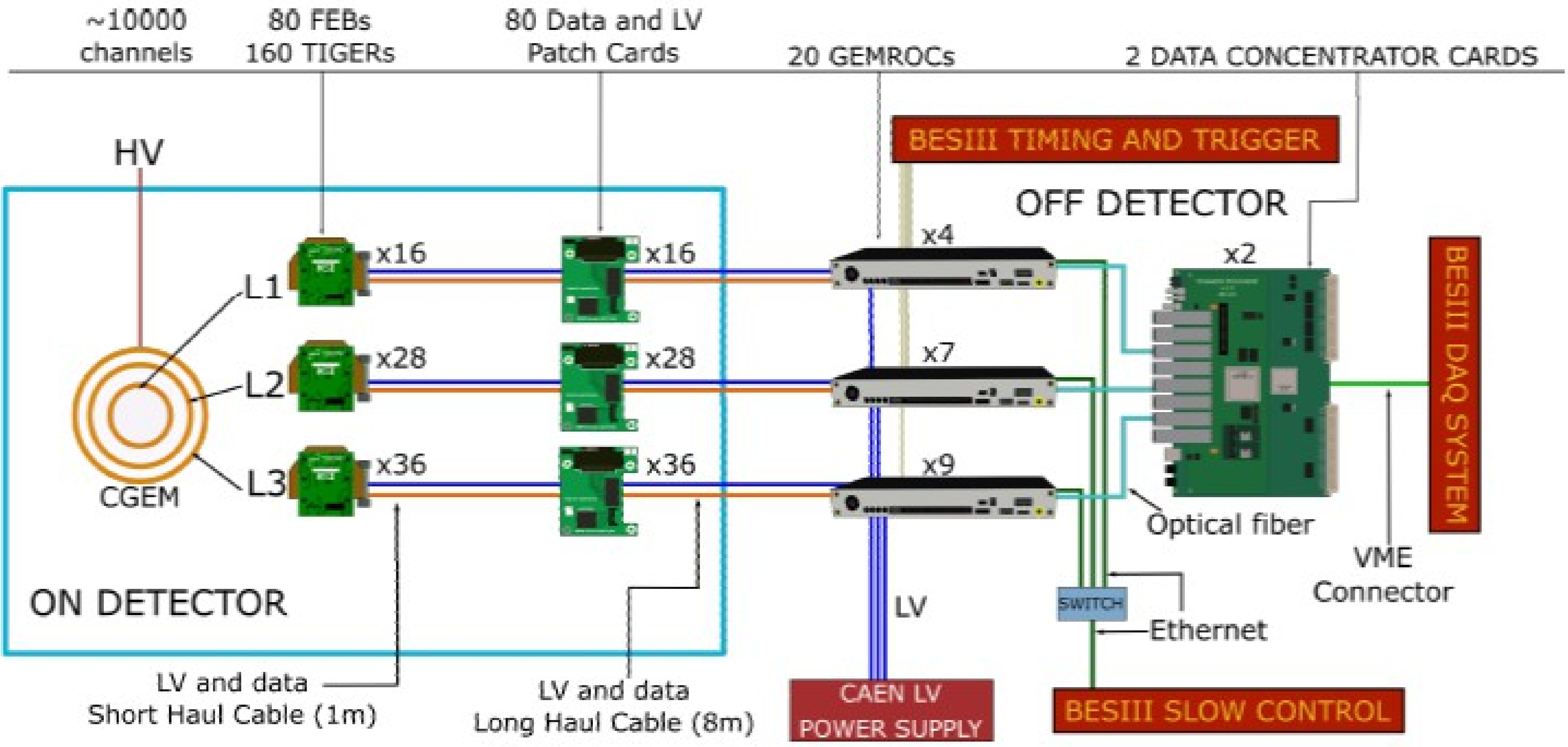




- A proper **gas mixture** fills the volume
- Three amplification stages allow the triple-GEM to reach a **gain** of 10^3 - 10^4 while the **discharge probability** is below 10^{-5}
- Primary electrons from ionizing particles generate signals that are collected on the anode

Nucl. Instr. and Meth. A438 376-408 (1999)

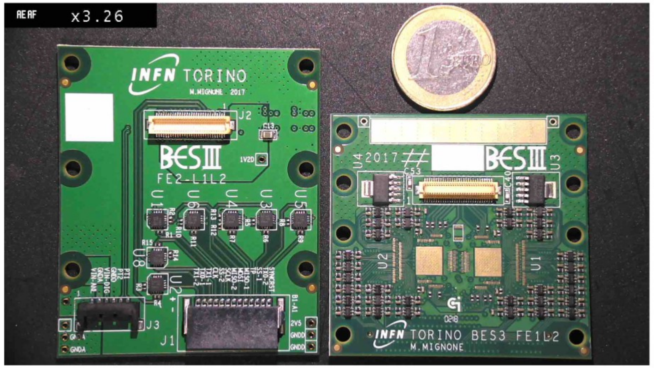
Readout chain

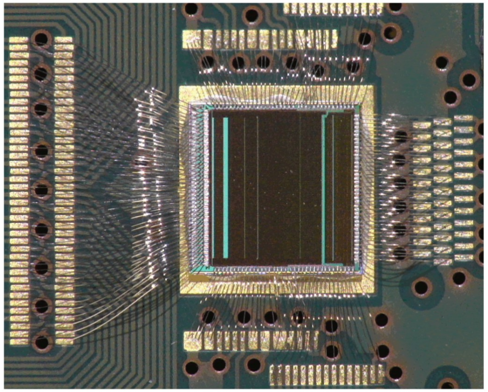


TIGER chip

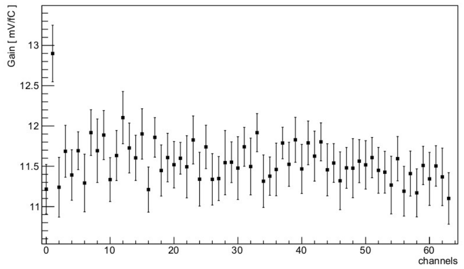
- TIGER: **T**orino **I**ntegrated **G**em **E**lectronics for **R**eadout is a chip that provides **time** and **charge** measurement and features a fully digital output
- Each chip has **64 channels**
- Two readout methods are implemented: “sample and hold” or “time over threshold”

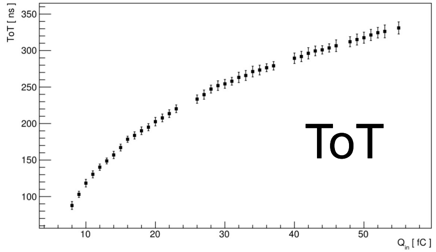
Parameters	Value
Input Charge	2-50 fC
Input Capacitance	Up to 100 pF
Data Rate	60 kHz/ch
Readout Mode	Trigger-less
Non-linearity	<1%
Charge Collection Time	60 ns
Time resolution	<5 ns
Power Consumption	<12 mW/ch
Technology	110 nm process

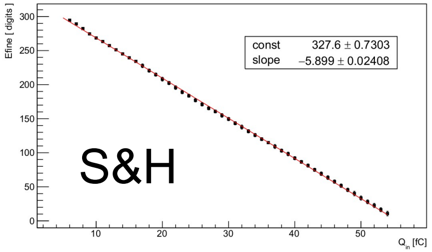




TIGER characterization





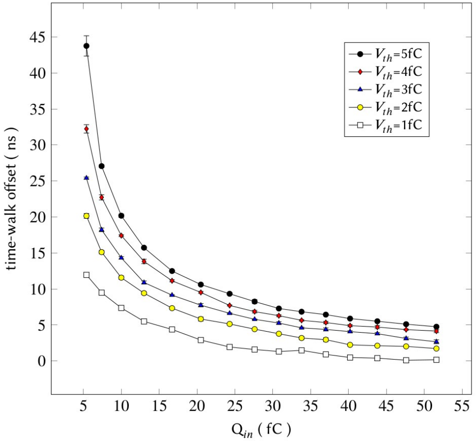


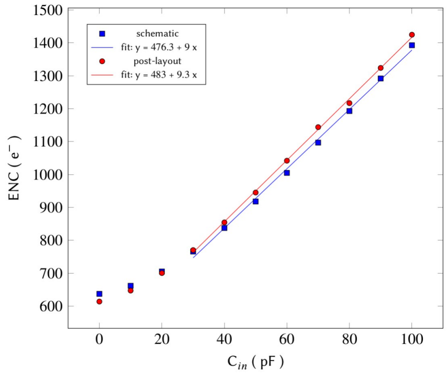
Calibration of the **dynamic range** with an external test pulse generator for **S/H** and **ToT**

Baseline equalization leads to an average gain of 12 mV/fC

Calibration of the **time-walk** contribution for different input charge and threshold

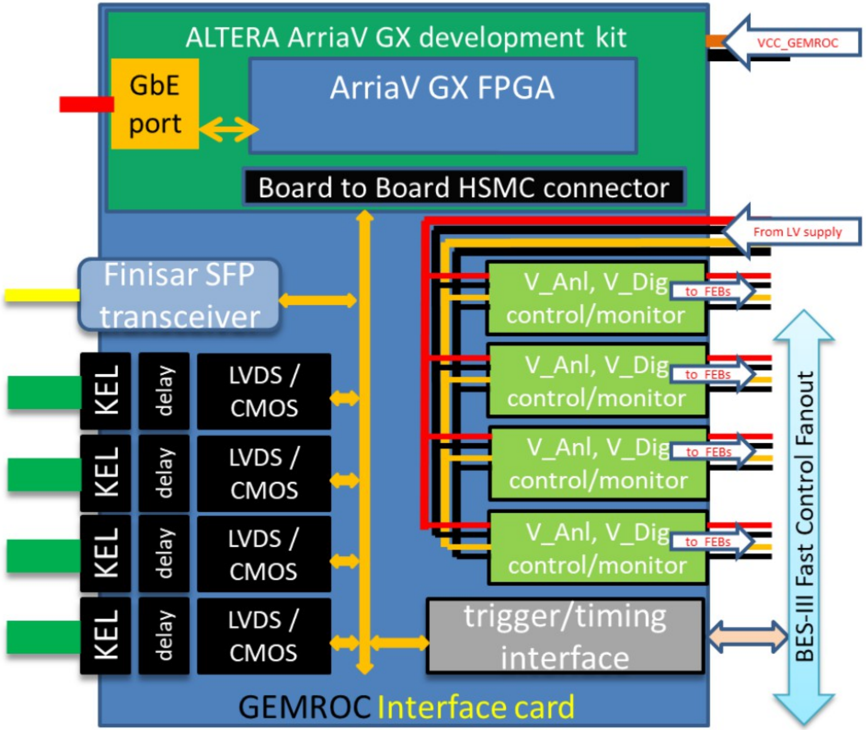
Noise evaluated for each input capacitance





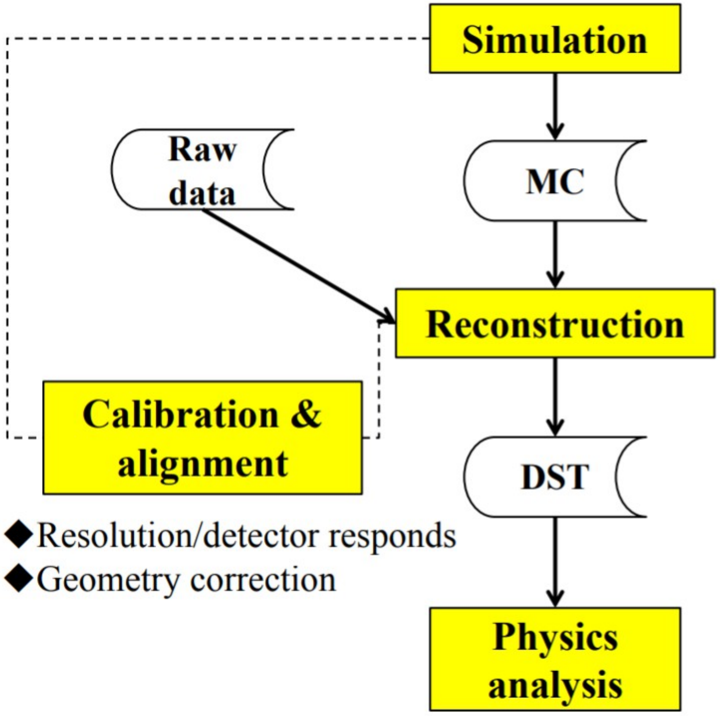
GEM - Read Out Card module

- The off-detector readout electronics GEM-ROC manages the LV, the configuration of the TIGER and the data collection from the detector to the DAQ computer
- For each signal above the threshold, the TIGER chip sends its output to the GEMROC
- When a trigger signal from the scintillating bar reaches the GEMROC then the proper memory slot is readout from the memory to the computer
- The entire readout electronics is designed to take care to up to 10k channels and a rate of 50 kHz per channel



CGEM - **B**es **O**ffline **S**oftware **S**ystem

- CGEMBOSS is the BESIII collaboration framework used for the data reconstruction, for simulation and physics analysis

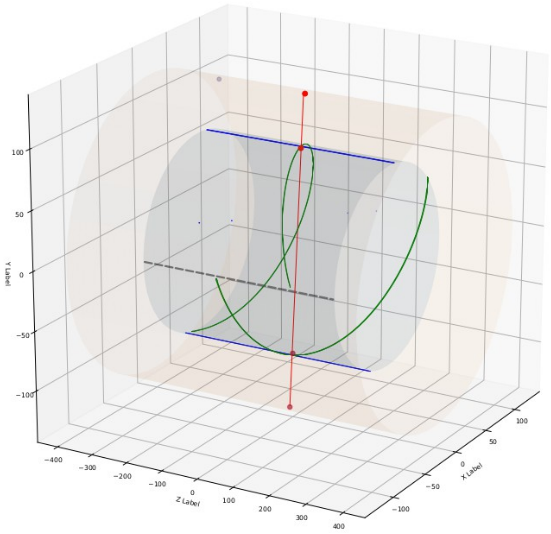


- ◆Resolution/detector responds
- ◆Geometry correction

- ◆Detector description (Geometry/material)
- ◆Digitization

- ◆Cluster reconstruction
- ◆Track segment finding with CGEM
- ◆Track matching
- ◆Global track finding with Hough transform
- ◆Track fitting

- ◆ performance check (efficiency, resolution ...)

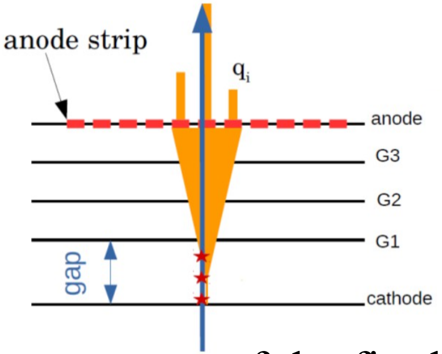


Cluster digitization

•Contiguous strips with charge higher than the threshold

particle position reconstruction → two algorithms are used:

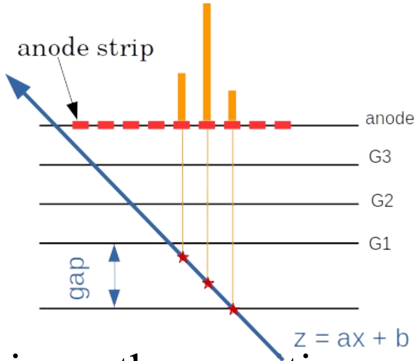
Charge Centroid



position reconstructed as average of the fired strips weighted by the charge on each strip

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

micro-TPC*



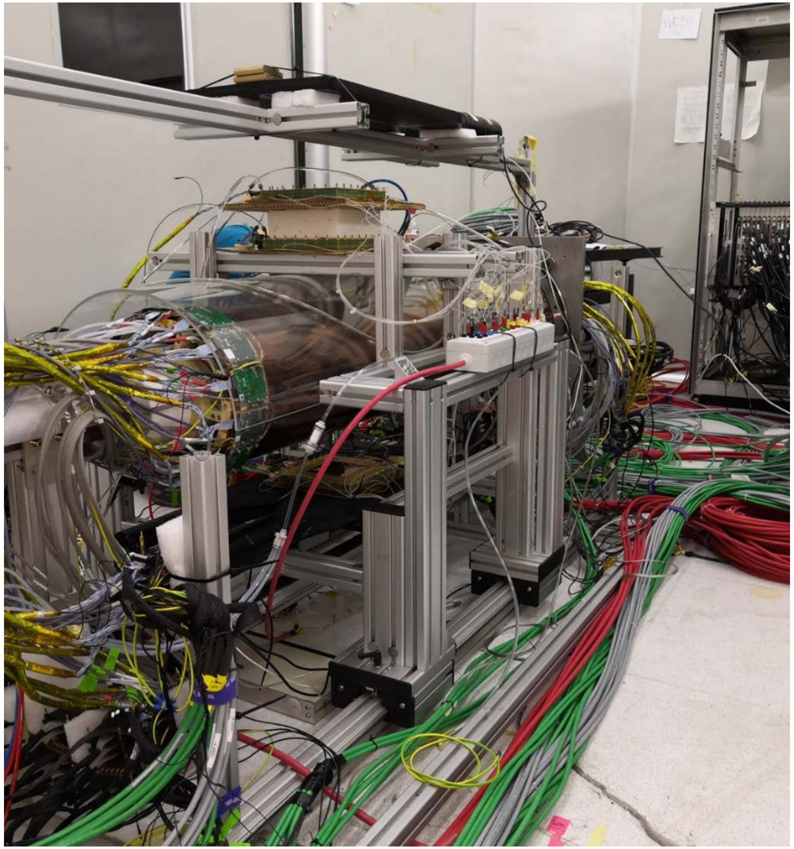
drift gap as a TPC gives the position of each ionization by the drift time and velocity → linear fit

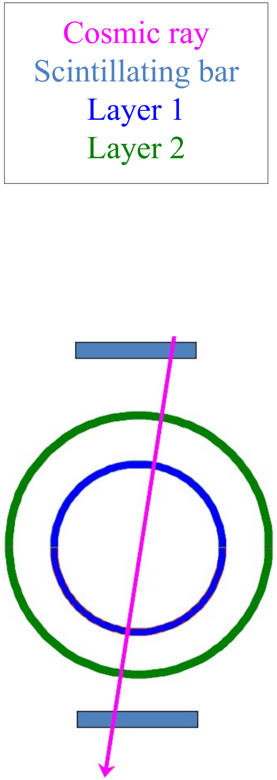
$$x_{\mu\mathrm{TPC}} = \frac{gap/2 - b}{a}$$

* T. Alexopoulos *et al*., Nucl. Instr. And Meth. A617 (2010) 161; M. Alexeev *et al* 2019 *JINST* **14** P08018

Cosmic setup status

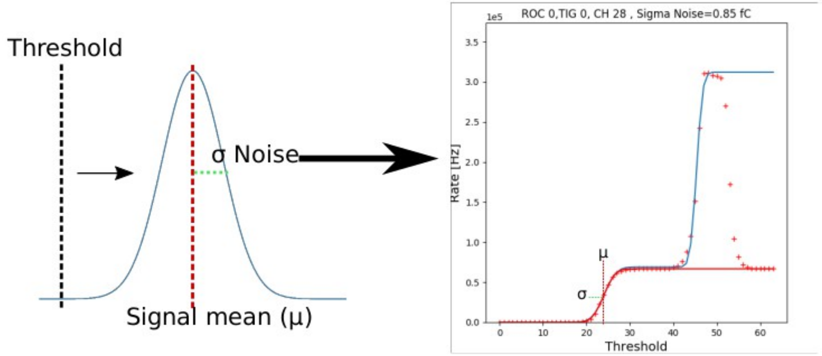
- Two CGEM layers have been installed in a clean room in Beijing with a trigger system and a lot of cables!
- About 5000 channels are instrumented and readout by the on-detector and off-detector electronics
- Debug of the DAQ chain and the noise optimization are ongoing
- Fine alignment and time calibration are not yet implemented
- The third layer will be integrated with the other two after the summer
- An aluminum cylinder sustains the detectors

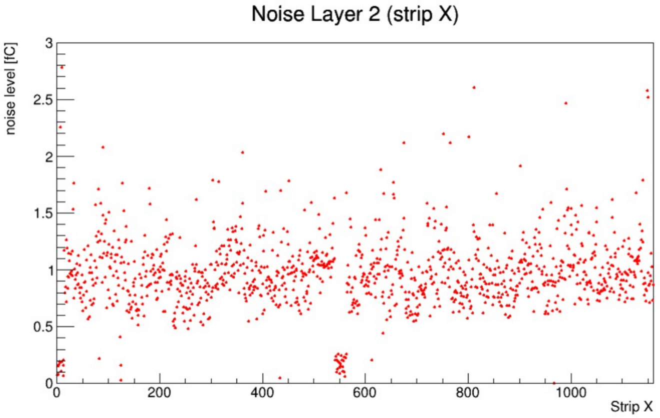


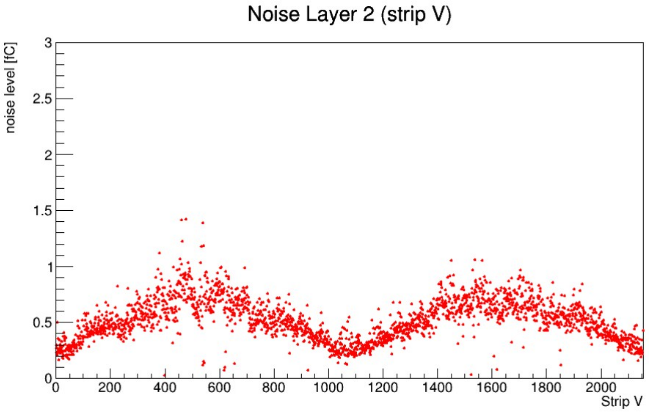


Setup configuration: **threshold**

- Calibration of the threshold performed channel by channel
- On chip test pulse is used to measure the width of the noise distribution
- Different behavior for strip X and V due to different strip lengh

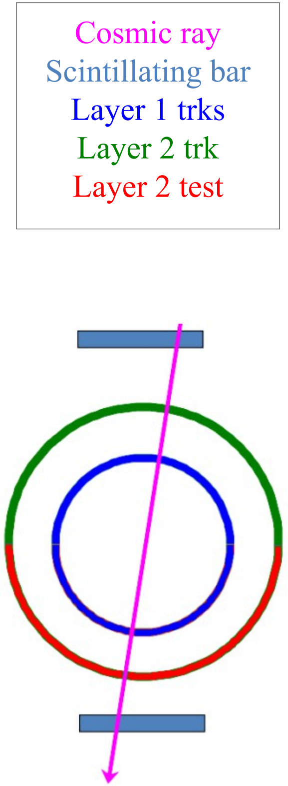


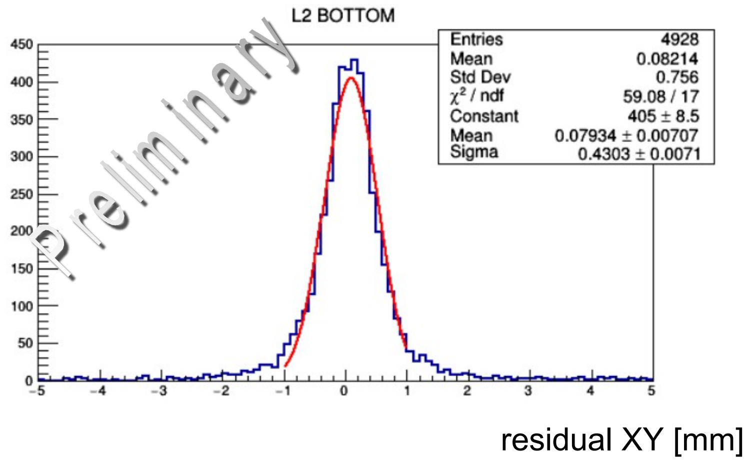


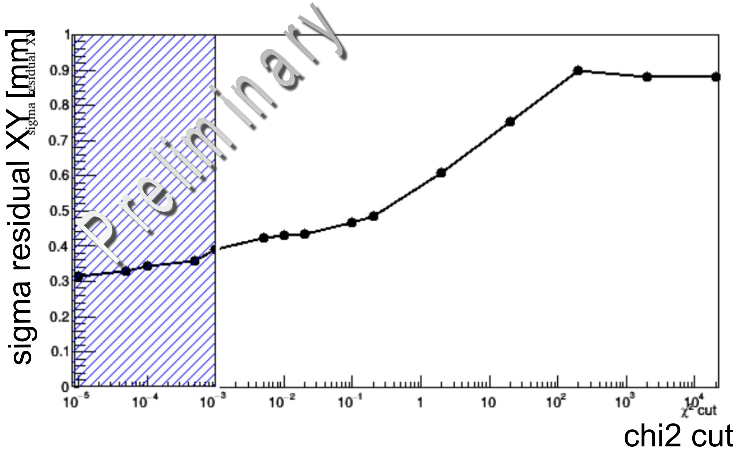


Tracking system and signal evaluation

- A cosmic ray creates at least two clusters for each CGEM layer: three reconstructed points are used to track the cosmic ray while the fourth is used to characterize the CGEM signal
- The residual distribution of the fourth point position is fitted with a Gaussian distribution
- A selection of the good tracks is performed with a chi2 cut on the tracking system
- The position of the clusters up to now is measured with charge centroid only

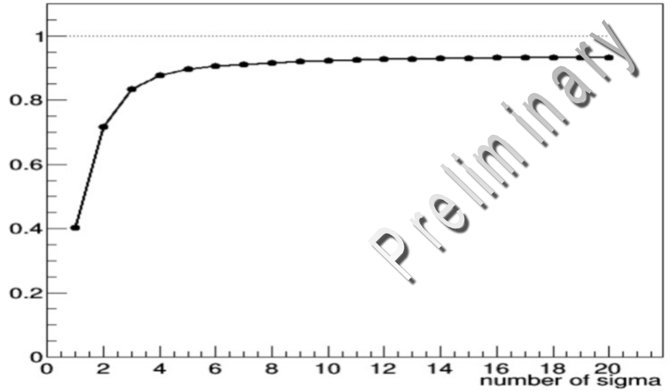






CGEM efficiency vs sigma of signal

- Once the good tracked events are selected, the definition of the cut for the good cluster selection on the detector under test is needed
- A Gaussian fit on the residual distribution is used to evaluate its sigma, then the range of good signal clusters
- A first preliminary measurement of the CGEM efficiency has been performed
- The efficiency reaches a plateau of 90 - 92% on the double view if five sigma is considered
- Good events are still in the tails of the residual distribution due to problems in the recostruction (missing strips, mechanical support interference, etc ...)
- The present status of the GEMROC firmware together with few remaining bugs has a communication efficiency of 92-94%
- Some clusters of signal are still missing but this is compatible with the present communication efficiency of the DAQ chain

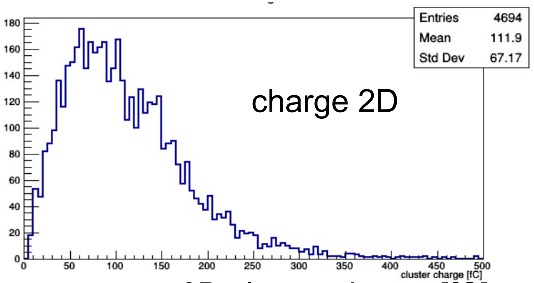


number of sigma

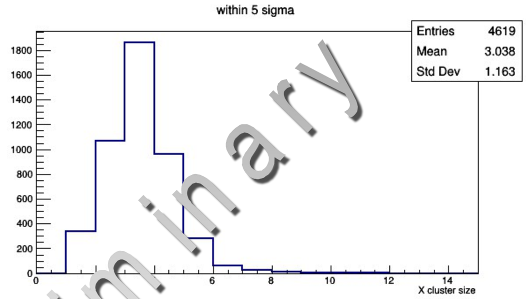
$$\epsilon = \frac{n^\circ\, of\, events\, in\, N_{sigma}}{n^\circ\, of\, goodtracks}$$

Signal characterization

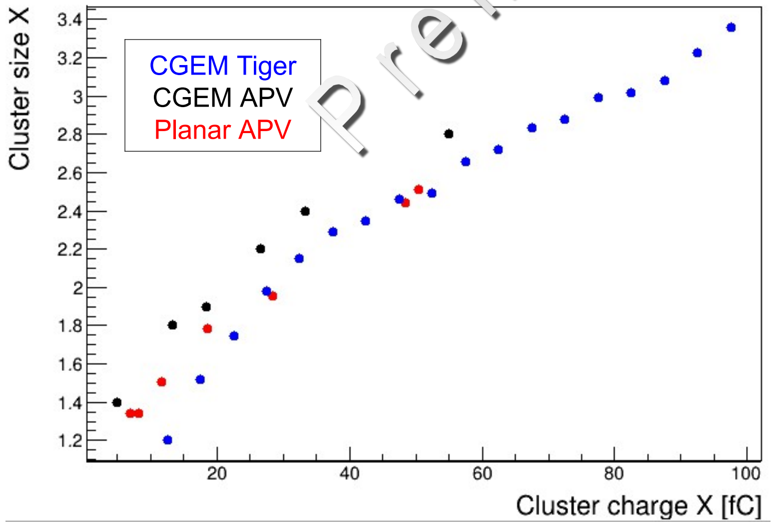
- Studies of the detector behavior are performed with the clusters within five sigma of the residual distribution
- A mean cluster charge above 100 fC on the 2D and a cluster size greater that 2.5-3 for each view have been measured, as expected in this setup configuration
- Data from the cosmic ray setup (blue dots) and previous results from testbeam (black and red dots) are in agreement



2D cluster charge [fC]

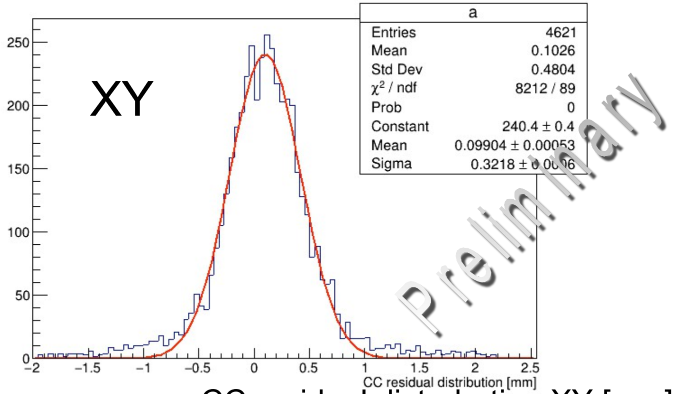


1D cluster size X

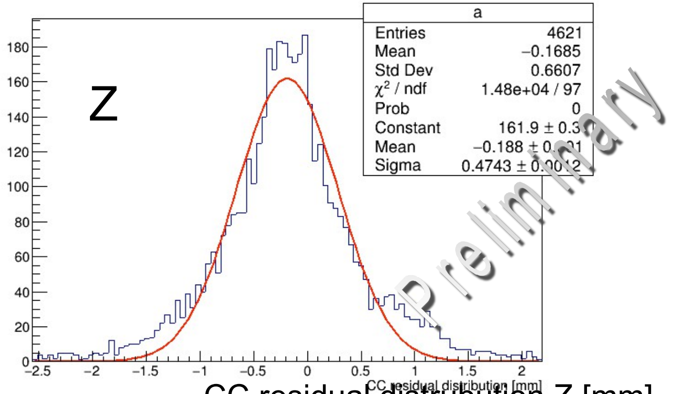


Charge Centroid performance

- Despite the setup is **not optimal** due to the interference of the mechanical support, calibration and alignment not fully applied, good results have been achieved
- A Gaussian fit of the residual distribution of the CC position is used to extract a raw measurement of the resolution of the detector: the **sigma** of the fit contains the contribution of the **test chamber** resolution and the one of the **tracking system**
- Good tracks are selected with the **chi2 cut** and an incident **angle orthogonal** to the CGEM
- A **Monte-Carlo** simulation is used to evaluate the tracking system **contribution**. A resolution of about 250 μm in XY plane and 350 μm in Z direction have been extracted, if the resolution of each part of the detector is supposed to be the same.



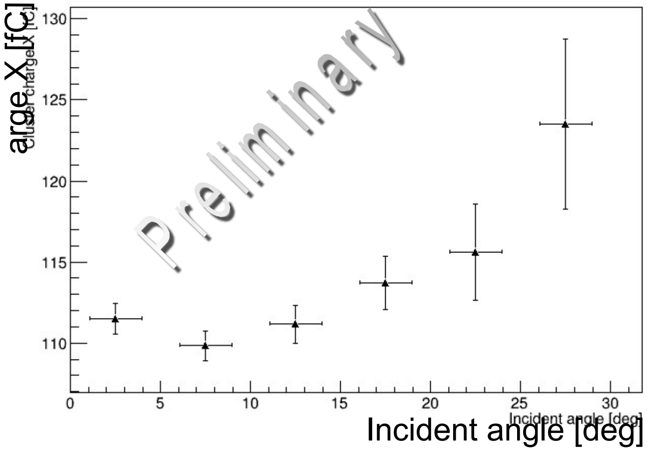
CC residual distrubution XY [mm]

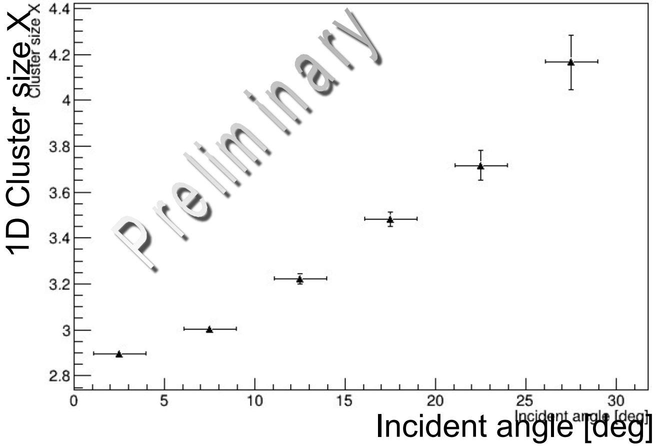


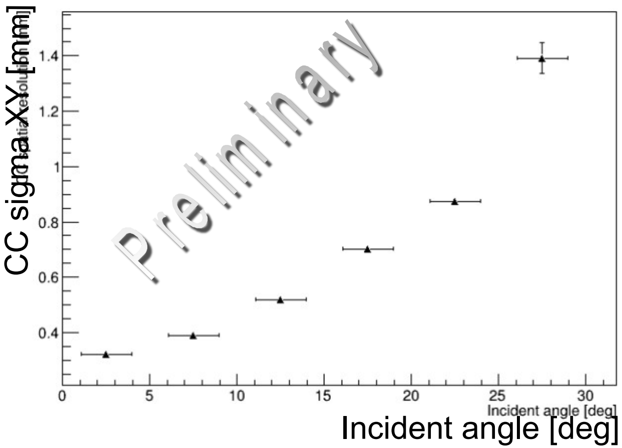
CC residual distrubution Z [mm]

Charge Centroid performance

- Evaluation on the single view (XY) of the cluster charge, size and CC residual shows a dependency of these variables on the incident angle between the cosmic ray and the CGEM surface
- As the angle increases, the cosmic ray ionizes on a longer path then charge and size increase too
- As the angle increases, the charge distribution collected at the anode is no more Gaussian and the CC degrades, as expected from planar triple-GEM studies

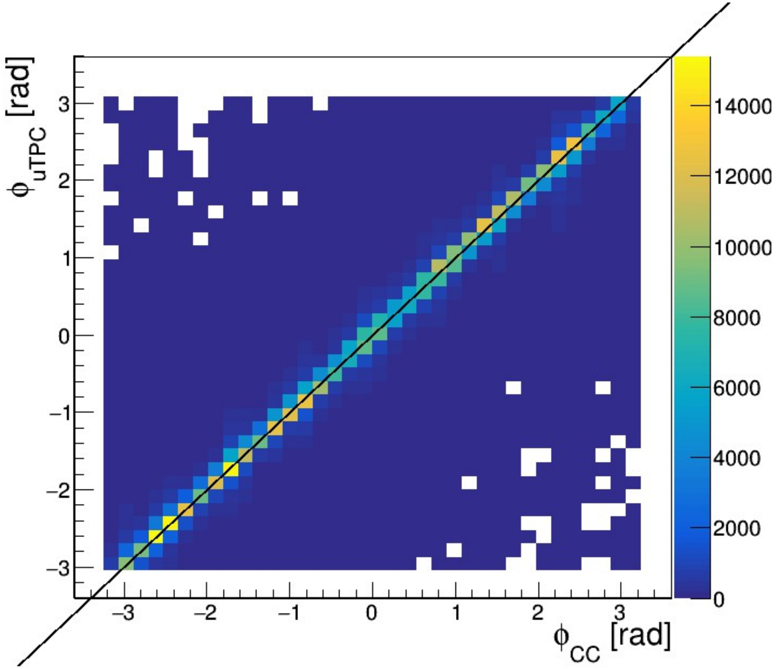






First µTPC event in a CGEM

- Time reconstruction is needed to extend the effectiveness of the reconstruction in the region where the CC degrades
- A first implementation of the µTPC method has been implemented in CGEMBOSS and the preliminary result shows a good correlation with the CC
- The reconstruction efficiency of this algorithm is above 98% if a cluster has at least 2 hits
- This method is more complicated than the CC and more work is needed for a proper reconstruction



Conclusion

- A cosmics ray stand has been instrumented with two CGEM layers
- The detectors have been integrated with the final readout chain: more that 5k channels, 86 TIGER chips and 11 GEMROCs together with proper softwares to control the configuration and acquisition (GUFI) and the data reconstruction (CGEMBOSS)
- The noise level is in a good shape, within the expectations
- Despite the preliminary configuration of the setup and the work needed to improve the present situation, the signal shape (charge and size) is in agreement with the previous data collected in testbeam
- A nice resolution of the CC has been evaluated and the results in the Z direction are three times better than the BESIII requirements
- The first reconstruction with μTPC in a CGEM readout by the TIGER chip has been implemented successfully

Thanks