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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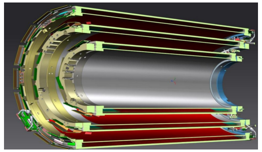
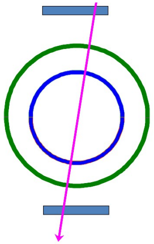
Istituto Nazionale di Fisica Nucleare

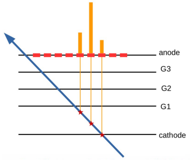
Outline



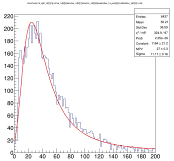
Cylindrical **GEM**: detector and electronics



Cosmic ray **setup**



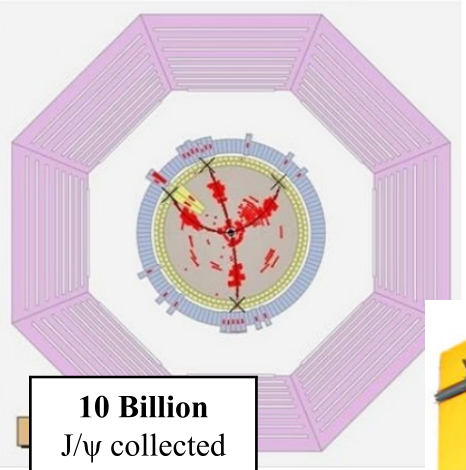
Reconstruction and **analysis**



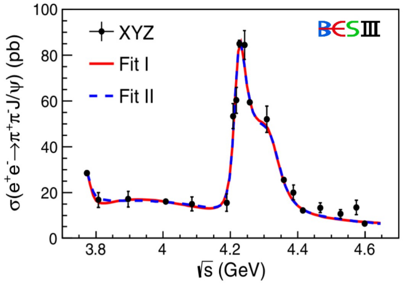
Preliminary **results** of the CGEM-IT

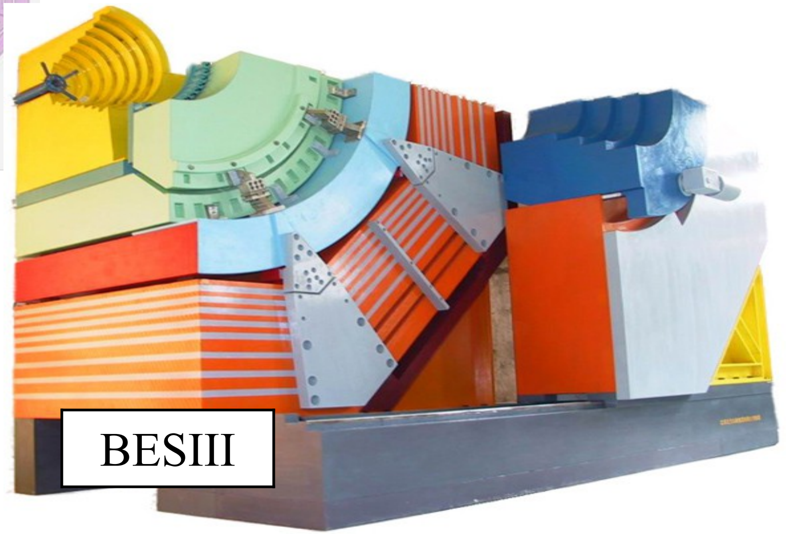
BESIII experiment

- 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 main physic programs include:
  1. Light hadron physics with meson and baryon spectroscopy
  2. QDC exotics and XYZ charmed states
  3. Studies in τ-charm region and R values
  4. Charm physics, CPV, D mixing, charmed baryon



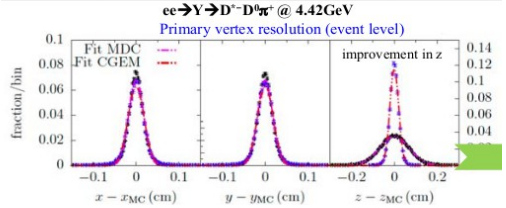
10 Billion
J/ψ collected
on 2019



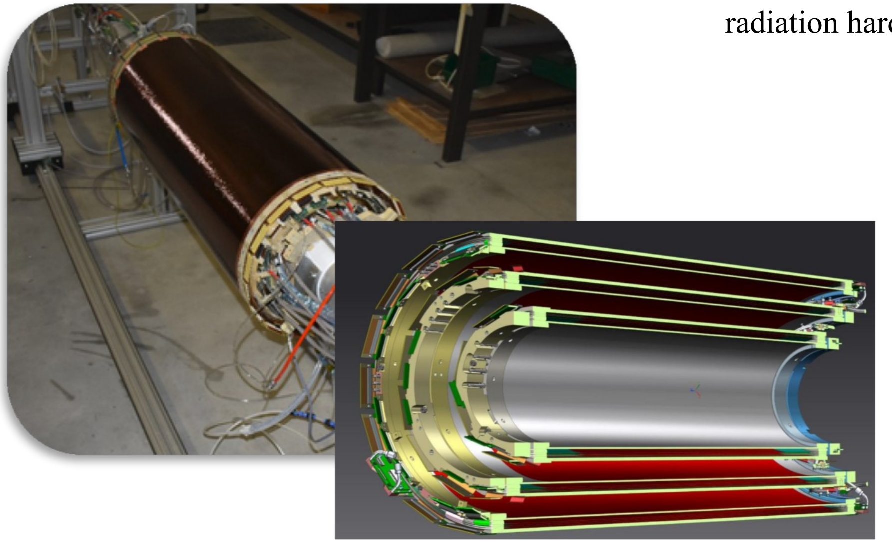


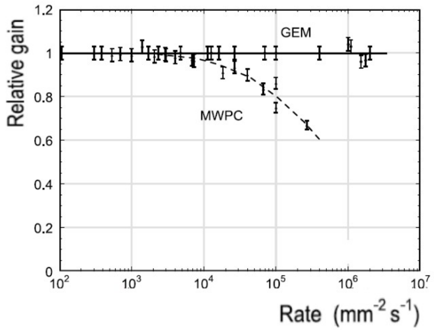
Cylindrical GEM Inner Tracker

Benchmark channel



- A cylindrical GEM IT will replace the BESIII inner **MDC** since **aging** is affecting its performance
- A double view readout for **3D** reconstruction with time and charge measureemnts
- GEM technology improves the rate capability and the radiation hardness

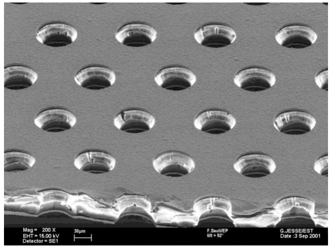




BESIII requirements

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

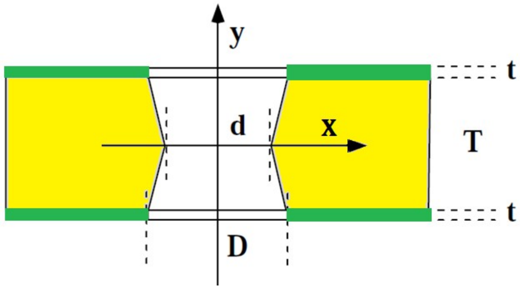
Gas Electron Multiplier in a nutshell

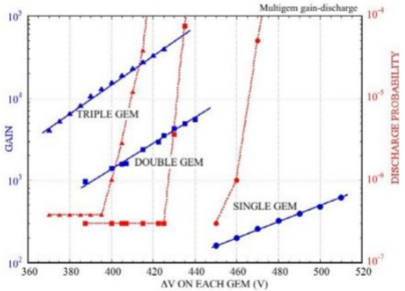


Polymeric kapton foil (T = 50 μm)

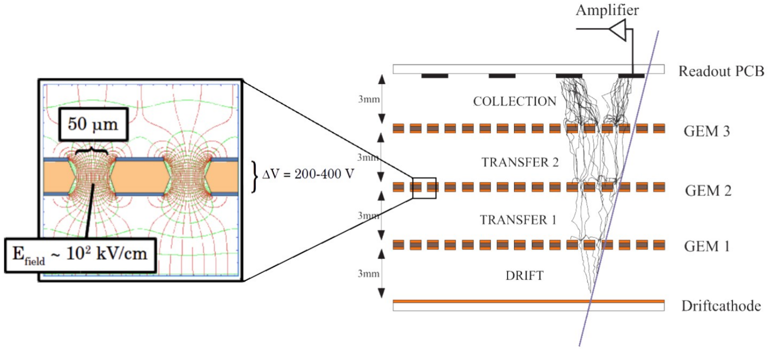
Copper coated (t = 3/5 μm)

Pierced by etching technique (d = 50 μm)



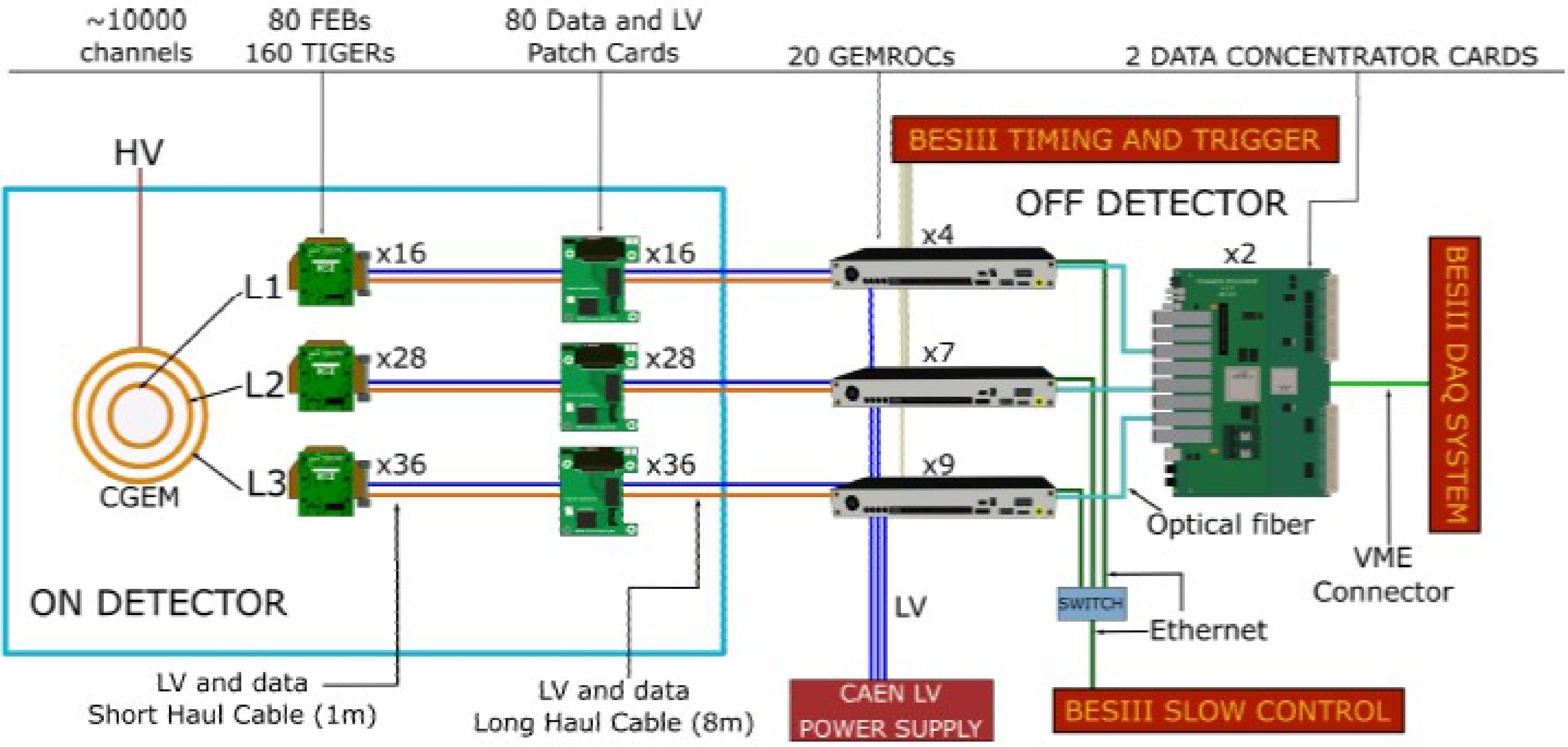


- GEM technology was invented by **F. Sauli** in 1997
- Hundreds of Volts applied on the **two copper faces** generate an electric field
- An electron entering the hole creates an **electron avalanche**



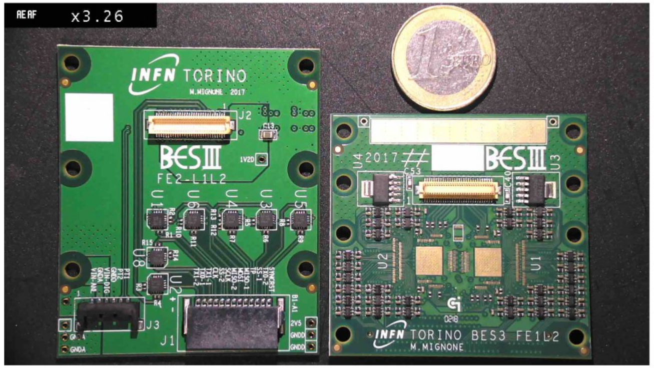
- Three amplification stages allow the triple-GEM to reach a **gain** of 10^3 - 10^4 while the **discharge probability** is below 10^{-5}

Final readout chain

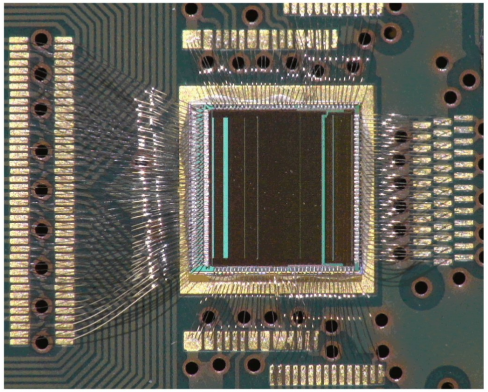


TIGER chip

- 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”

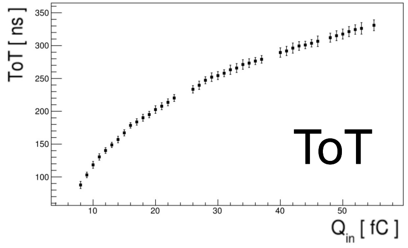


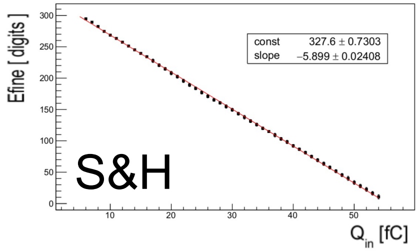
Parameters	Value
Input Charge	2-50 fC
Input Capacitance	Up to 100 pF
Data Rate	60 kHz/ch
Readout Mode	Trigger-less
Non-linearity	<1%
Charge Collection Time	60 ns
Time resolution	<5 ns
Power Consumption	<12 mW/ch
Technology	110 nm process



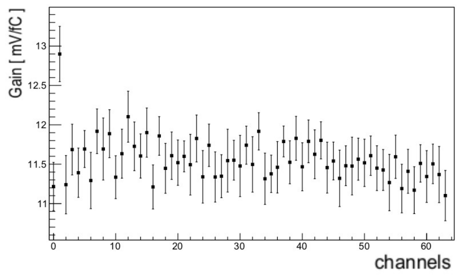
TIGER characterization

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

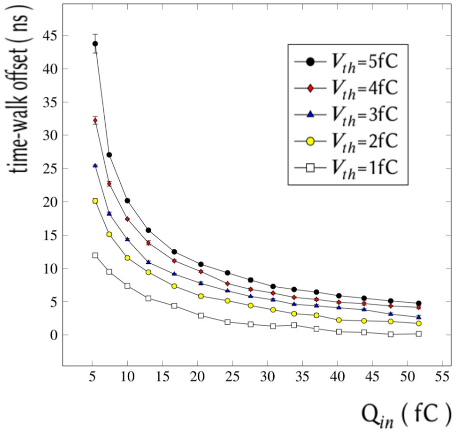




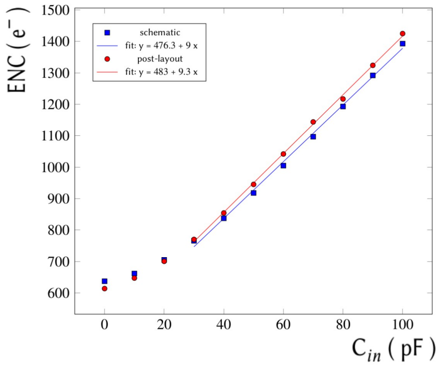
Baseline equalization leads to an average gain of 12 mV/fC



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

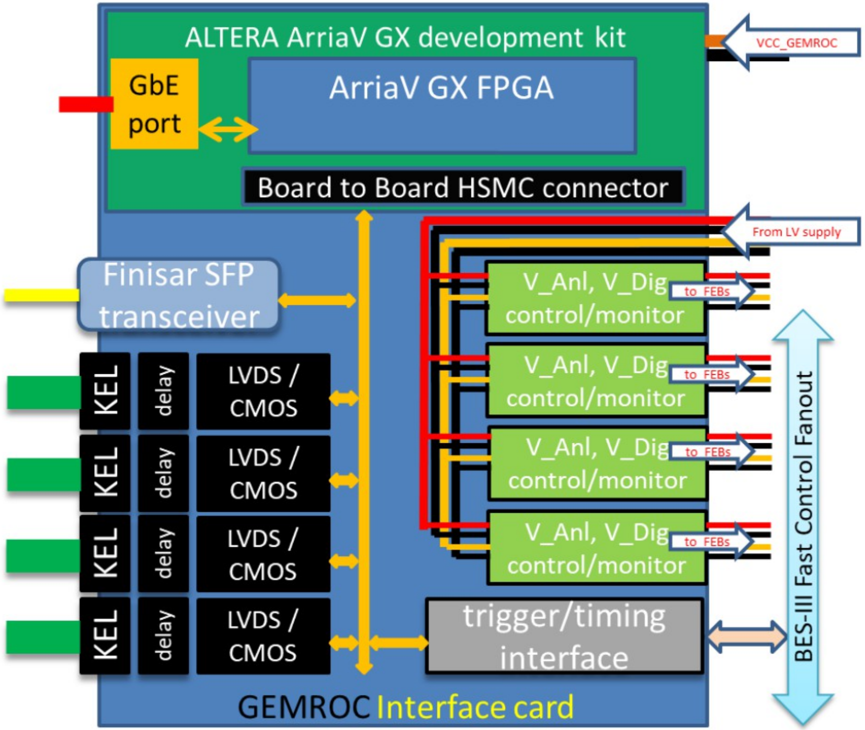


Noise evaluated for each input capacitance



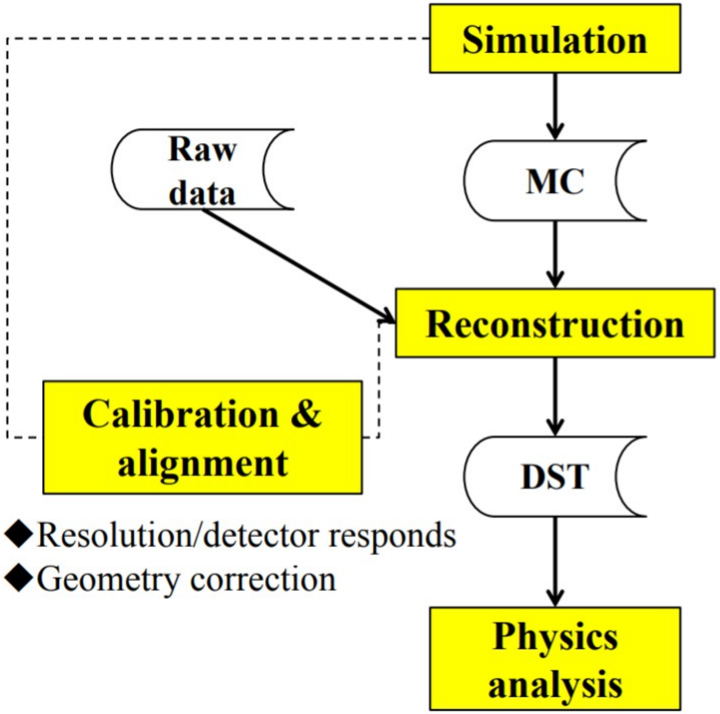
GEM - Read Out Card module

- 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
- The GEMROC recoveries the data from the proper memory slot for each trigger
- The entire readout electronics is designed to take care to up to 10k channels and a rate of 50 kHz per channel



CGEM - Bes Offline Software System

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

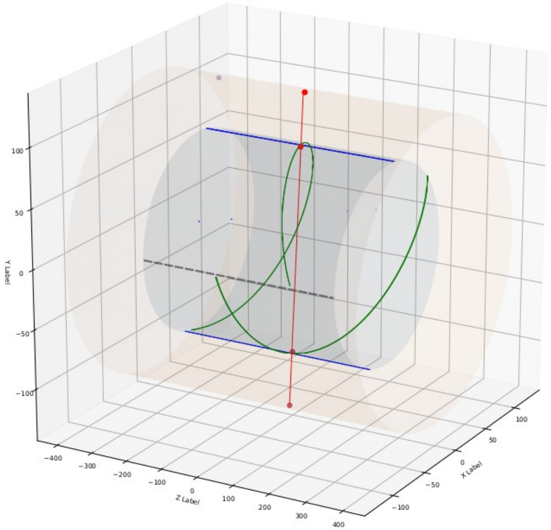


- Detector description (Geometry/material)
- Digitization

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

- Resolution/detector responds
- Geometry correction

- performance check (efficiency, resolution ...)

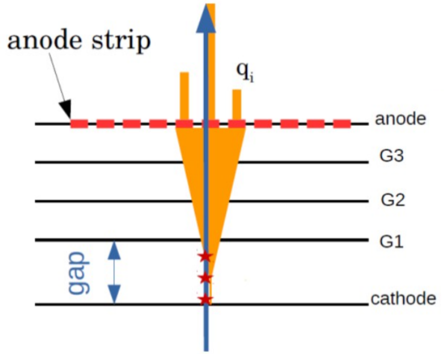


Cluster digitization

Contiguous strips with charge higher than the threshold

particle position reconstruction → two algorithms are used:

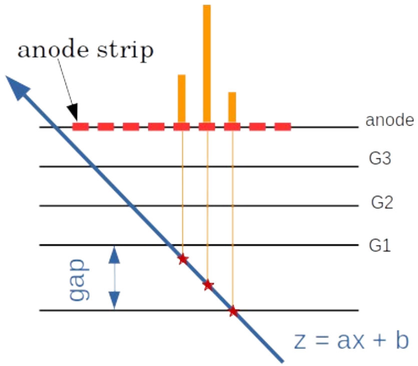
Charge Centroid



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

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

micro-TPC

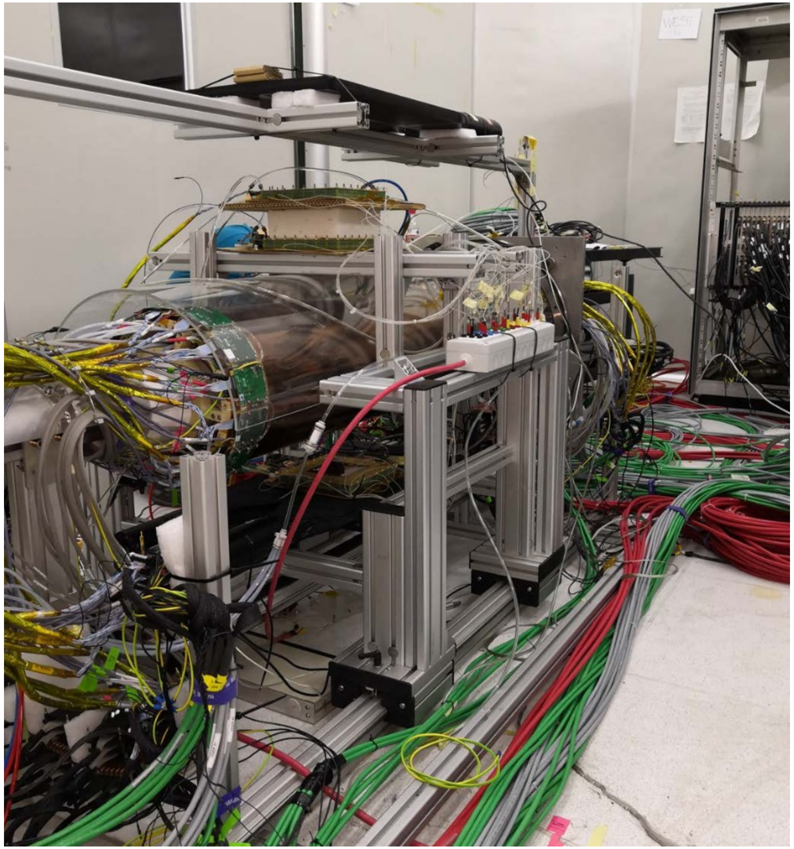


drift gap as a TPC gives the position of each ionization by the drift time and velocity → linear fit

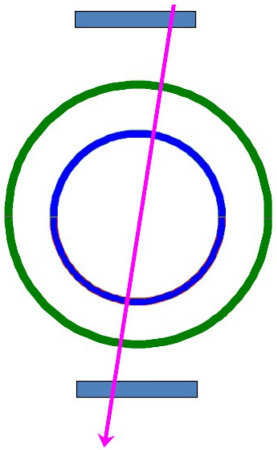
$$x_{\mu TPC} = \frac{gap/2 - b}{a}$$

Cosmic setup status

- Two CGEM layers have been installed in a clean room in **Beijing** with a trigger system
- About **5k 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



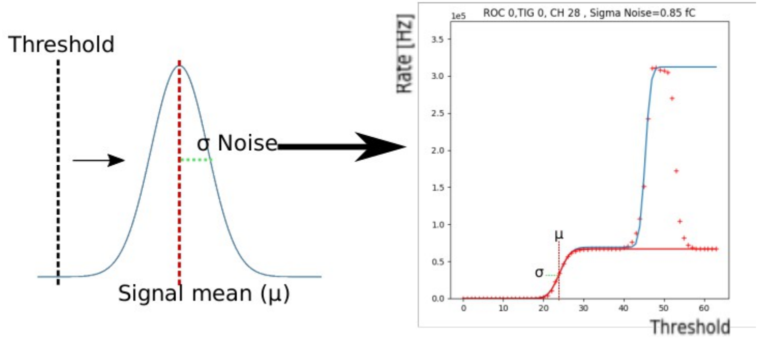
Cosmic ray
Scintillating bar
Layer 1
Layer 2

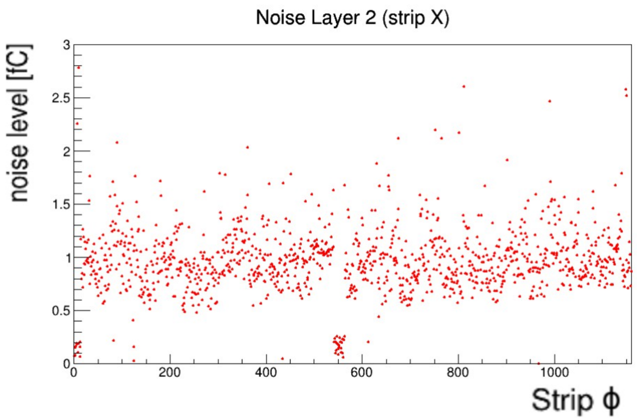


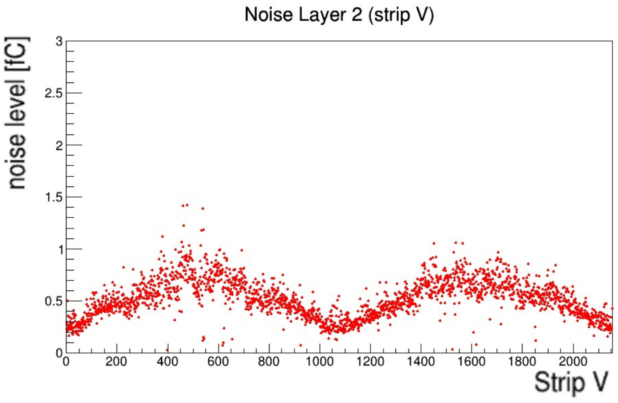
CGEM numbers
pitch: 650 µm
gas mixture. :
$Ar+10\%C_4H_{10}$
radius: 76.9 mm / 121.4 mm
lenght: 532 mm / 690 mm

Setup configuration: **thresholds**

- 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
- Equalization of the noise rate around 5kHz/channel

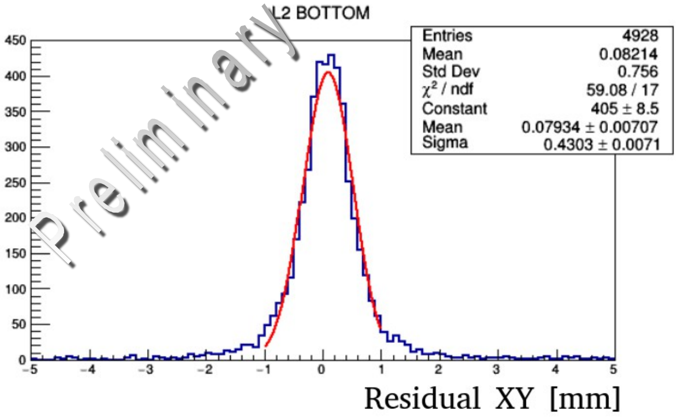


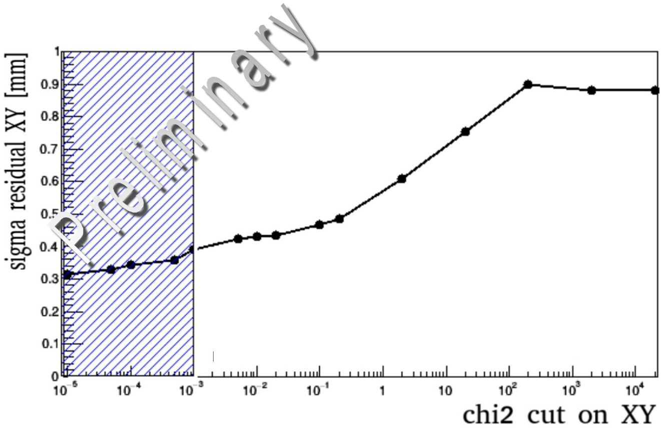


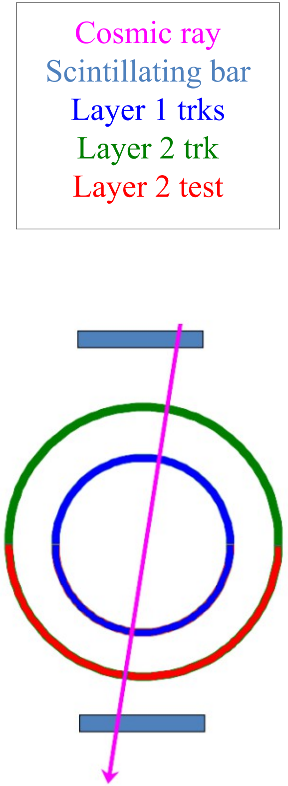


Tracking system and signal evaluation

- Each cosmic ray creates two clusters for each CGEM layer: three points tracks the cosmic ray while the fourth characterizes the CGEM signal/detector
- 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**

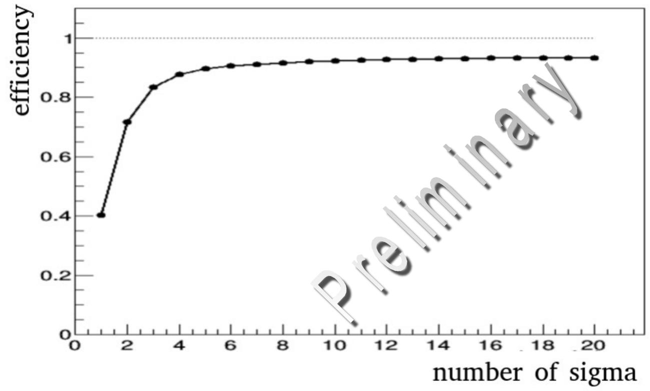






CGEM efficiency vs sigma of signal

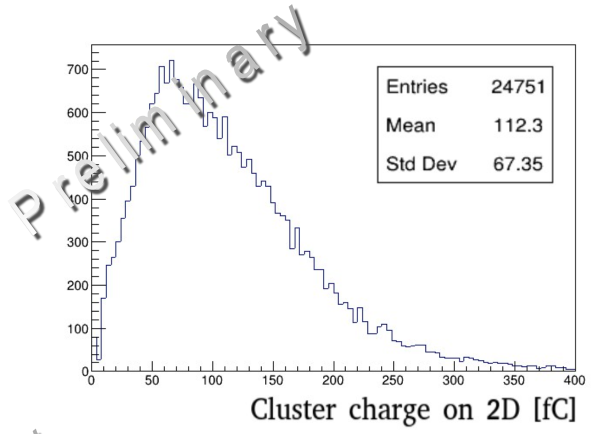
- A Gaussian fit on the **residual distribution** is used to evaluate its sigma, then the range of good signal clusters
- A first preliminary measurement of the CGEM at plateau of **90-92 %** on the double view if **five sigma** is reached
- **Good events are still in the tails** of the residual distribution due to problems in the recostruction (missing strips, mechanical support interference, etc ...)
- Actual DAQ chain bugs recude the data comunication efficiency to 92-94 %



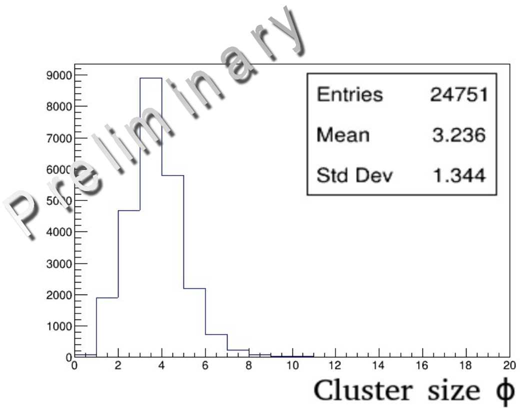
$$\epsilon = \frac{n^\circ\, of\, events\, in\, N_{sigma}}{n^\circ\, of\, goodtracks}$$

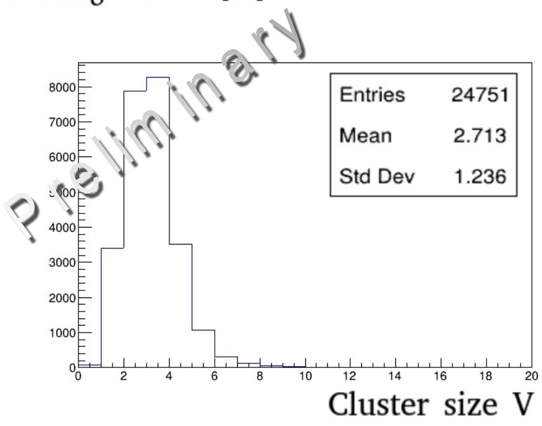
Signal characterization

- Studies of the detector behavior are performed with the clusters within five sigma of the residual distribution



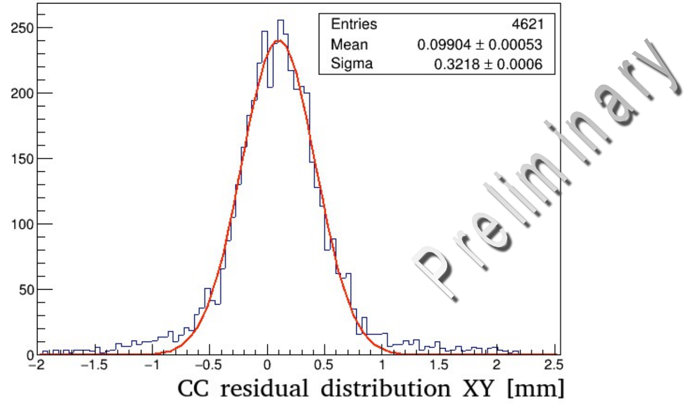
- A mean cluster charge above 100 fC on the 2D and a cluster size of about 3 for each view have been measured, as expected in this setup configuration

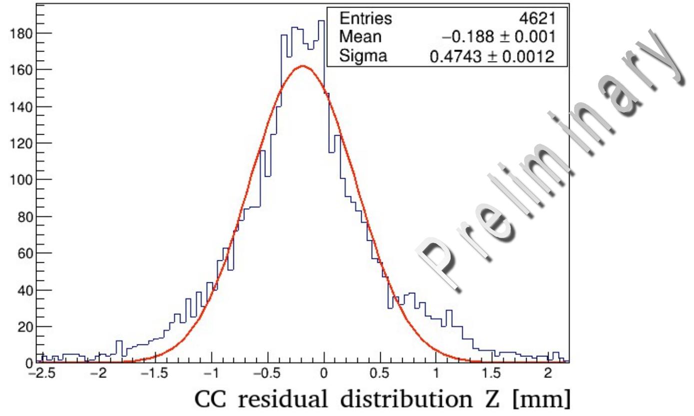




Charge Centroid performance

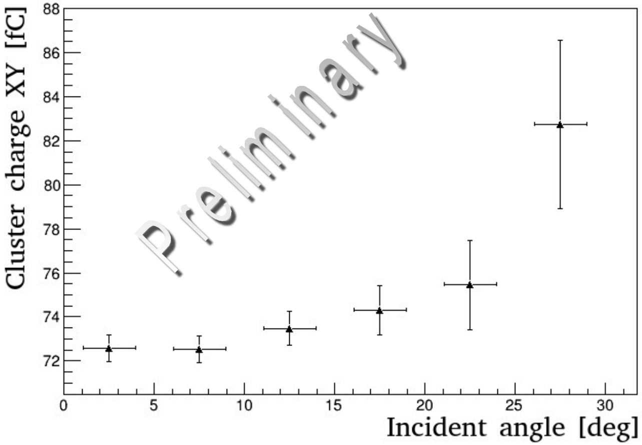
- Despite the setup is **not optimal** due to the interference of the mechanical support, calibration and alignment not fully applied, good results have been achieved
- A Gaussian fit of the residual distribution of the CC position is used to extract a raw measurement of the resolution of the detector: 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.

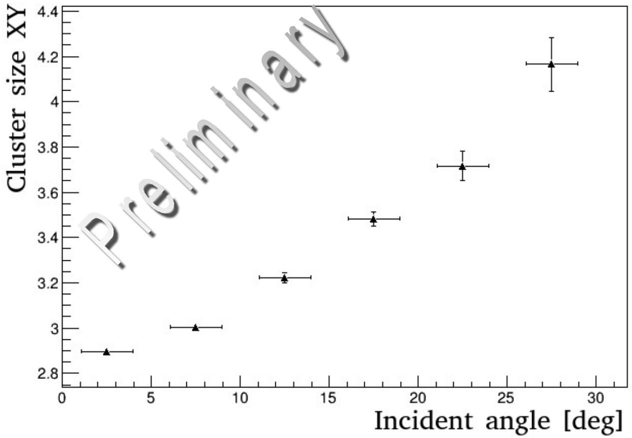


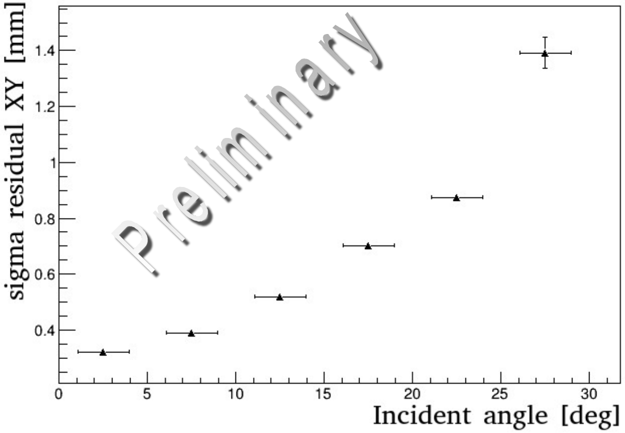


Charge Centroid performance

- 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

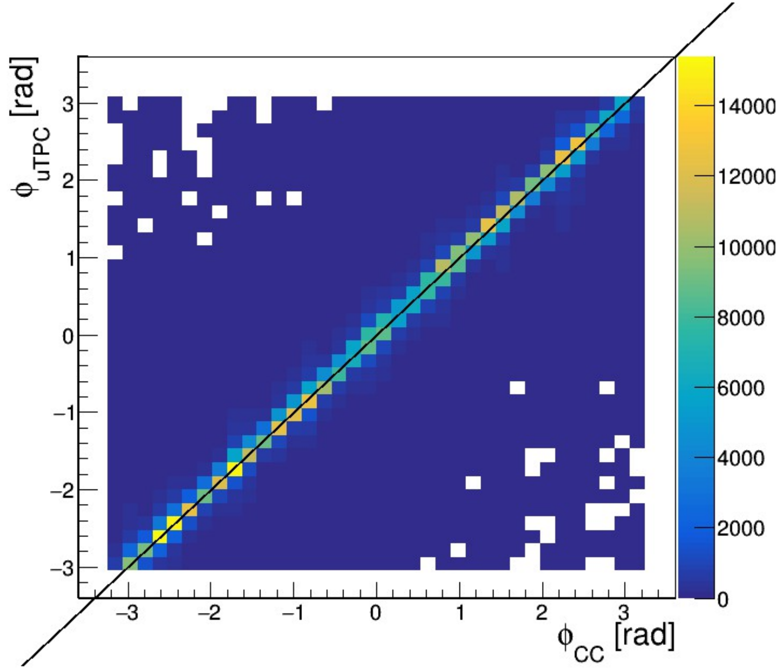






First μTPC event in a CGEM

- 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 strips
- 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 in the last **three months**
- 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 configuration and acquisition (GUFI) and 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) follows the results from testbeams
- A **nice resolution of the CC** has been evaluated and the results in the Z direction are three times better than the current BESIII-MDC resolution
- The first reconstruction with **μTPC** in a **CGEM** read out by the **TIGER chip** has been implemented successfully

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