The Cylindrical GEM Inner Tracker of the BESIII Experiment

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on behalf of
BESIII collaboration

BESIII

Università degli Studi di Ferrara
- EX LABORE FRUCTUS -

INFN
Istituto Nazionale di Fisica Nucleare

Outline

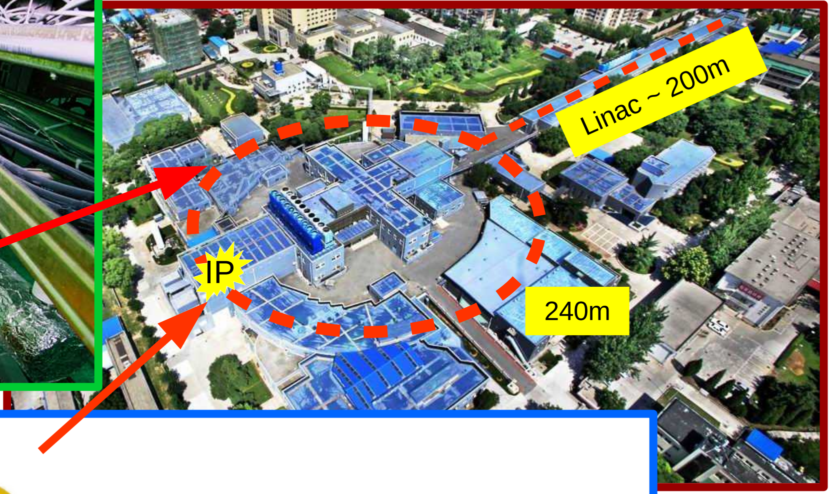
- The BESIII detector
- The CGEM-IT design
- A new ASIC named TIGER
- Reconstruction in a triple-GEM
- R&D and results

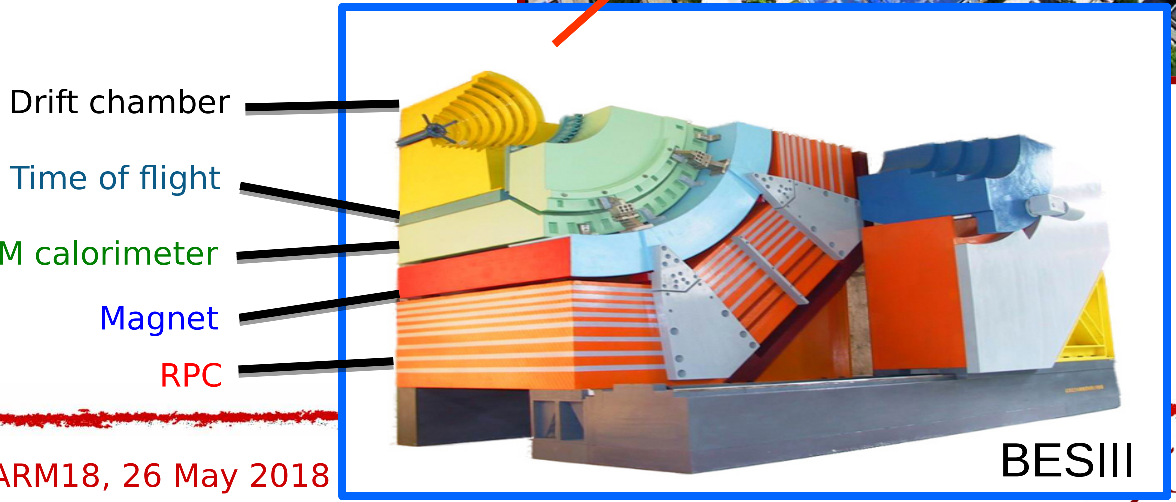
The BESIII experiment

BEijing Spectrometer and the electron positron collider

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

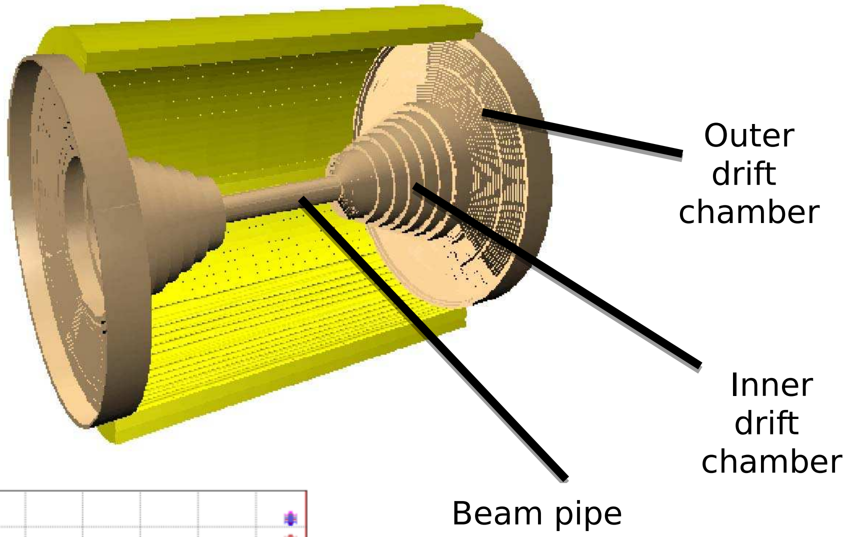
- Beijing Electron-Positron Collider **BEPCII** and BEijing Spectrometer **BESIII** operate in the τ-charm energy region
- Luminosity = 10^{33} cm^{-2} s^{-1}
- **Energy** $_{\mathbf{cm}}$ **: 2 – 4.6 GeV**
- The physics program includes:
  - Test of precision EW
  - Studies on hadron spectroscopy with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

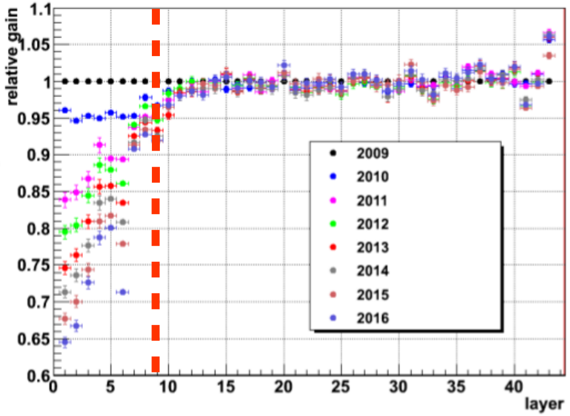




Drift chamber aging

- Multilayer Drift Chamber (MDC)
  - ➢ 43 layers
    - 8 Inner DC
    - 35 Outer DC
- Significant **aging** around the beam pipe in the first 8 layers
- HV lowered to keep the current under control
  - ➢ **Worsen** the reconstruction efficiency





CGEM-IT proposal

- BESIII is an experiment that will take data until 2022 or more and needs a new IT. The Italian group proposed to replace the inner part of the DC with 3 independent layers of triple-GEM

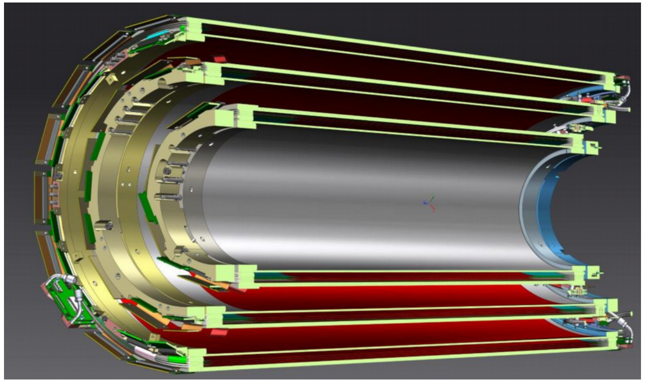
- The new IT has to **match the MDC tracking performance** with 3 layers instead of 8:

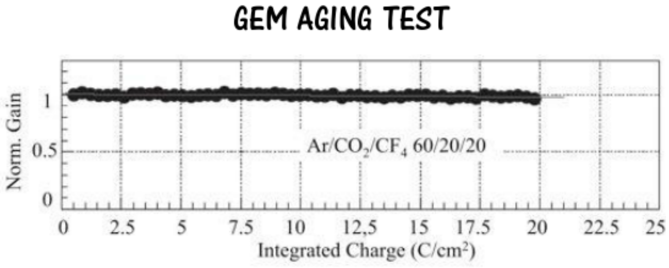
  - It improves the radiation hardness

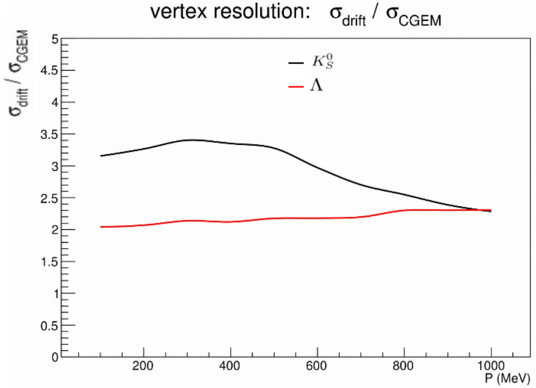
    - Aging test on this technology shows a **long-term stability**

  - **Improves the spatial resolution** in the beam direction

    - Benefit for decays with secondary vertex



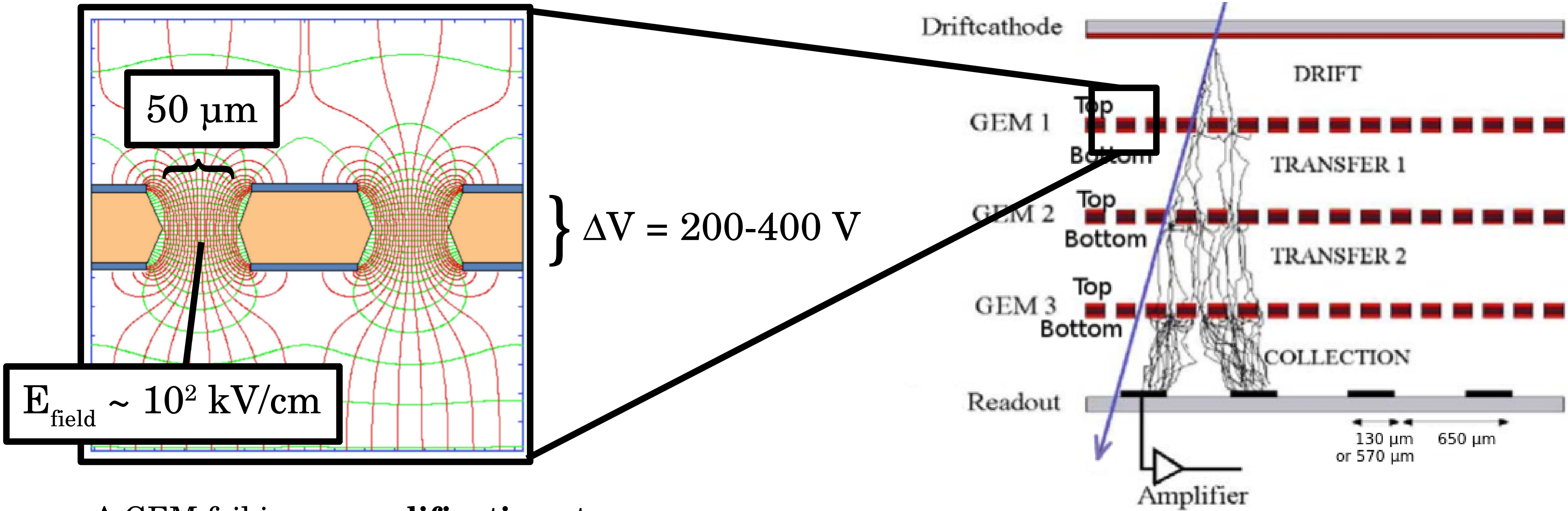




- GEM technology in a nutshell
- Construction technique
- The mechanical structure
- A new anode design

CGEM-IT design

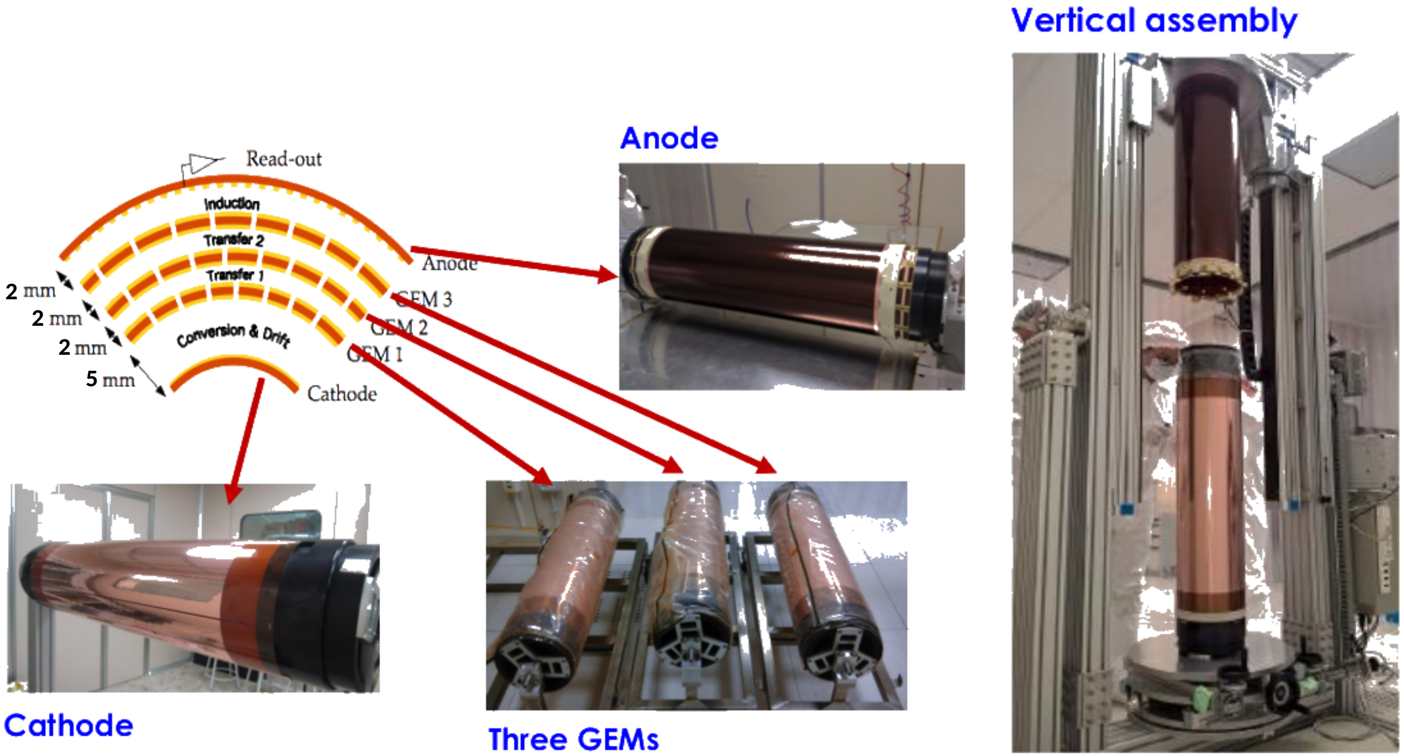
GEM technology in a nutshell



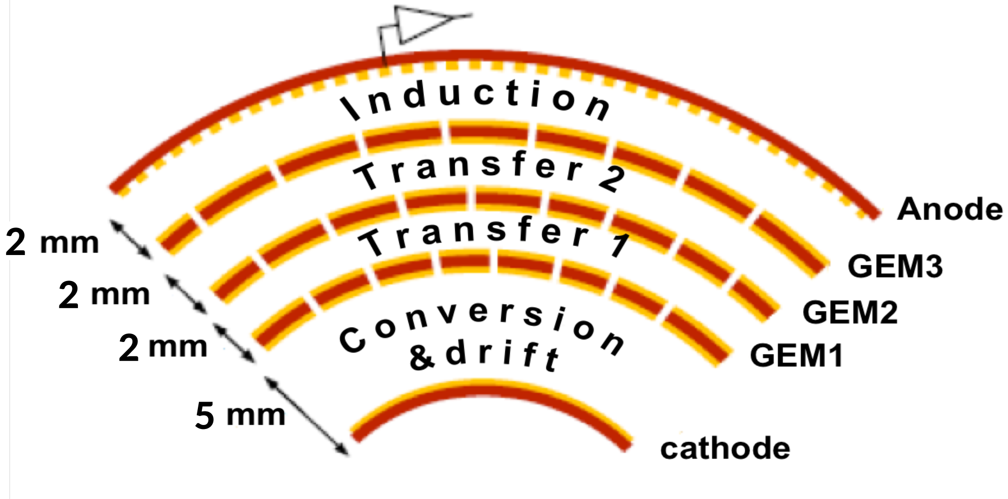
- A GEM foil is **an amplification stage**
- Multiple structure of GEM allows to reaches a **gain of ~ 10^3-10^4**
- Primary electrons are generated if a charged particle crosses the gas
- An electric field of few kV/cm drift the electrons to the anode where a **segmented anode** readout the amplified signal

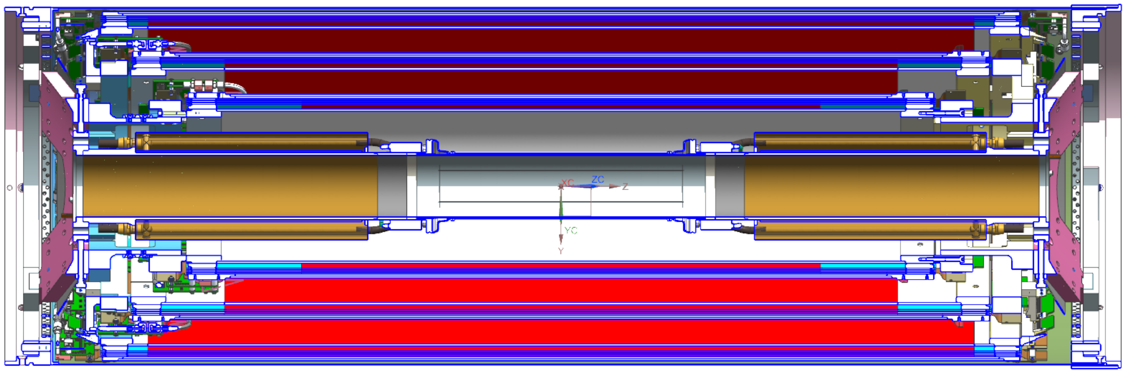
Construction technique

- The new IT of BESIII follows the same construction technique of KLOE-2 CGEM:
  - ➢ Each electrode has been cylindrically shaped
  - ➢ A vertical insertion system is used to assembly CGEM with its 5 cylinders (3 GEMs, anode and cathode)
- Several improvements have been applied w.r.t. KLOE-2 CGEM-IT



The BESIII requirements





BESIII requirements

- Rate capability:~10^4 Hz/cm^2
- Spatial resolution:

  σ_{xy}=~130µm : σ_z=~1mm
- Momentum resolution:

  σ_{Pt}/P_t =~0.5% @1 GeV/c
- Efficiency = ~98%
- Material budget

  ≤ 1.5% X_0 in all layers
- Coverage: 93% 4π
- Inner (Outer) radius:

  78 mm (178 mm)

BESIII CGEM-IT inherits from KLOE-2 with relevant pecularieties

	KLOE-2	BESIII	action
Number of detector layers	4	3	→ 5 mm drift gap
Drift gap	3 mm	5 mm	also for μTPC
Material budget per layer	0.5% X_0	0.4% X_0	rohacell and anode
Momentum resolution @1 GeV	not used	σ_{pt}/P_t =~0.5%	
Rate capability – radiation hardness	< 10 kHz/cm^2	few 10 kHz/cm^2	
Spatial resolution φ	250-350 μm (B=0.5T)	100-150 μm (B=1T)	with μTPC
Spatial resolution Z	~1 mm	<500 μm	with μTPC
Magnetic field	B = 0.52 T	B = 1 T	→ μTPC
Internal/external diameter	244/440 mm	156/356 mm	higher rate
Readout	digital	charge + time	new ASIC chip

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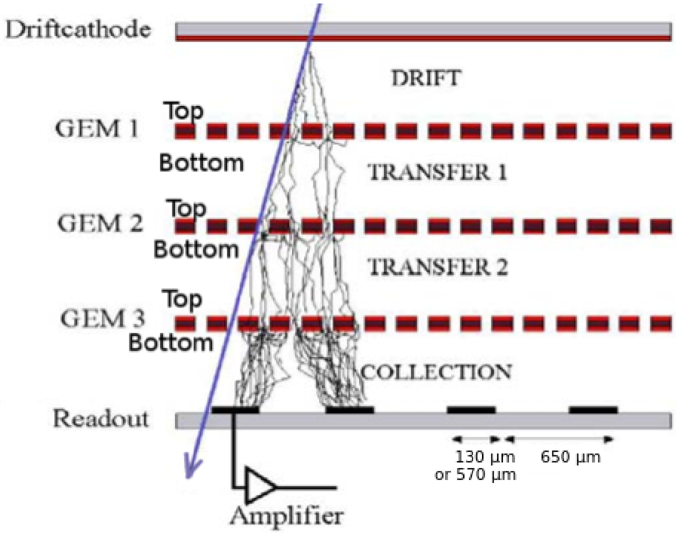
Larger drift gap



- The primary electrons that are generated in the drift gap **are amplified 3 times**, then only those electrons contribute significantly to the signal
- Increasing the drift gap means:
  - Increase the # primary electron → increase the **collected charge**
  - Increase the “sensitive” gas volume → increase the **efficiency**
    → improve the **µTPC reconstruction**

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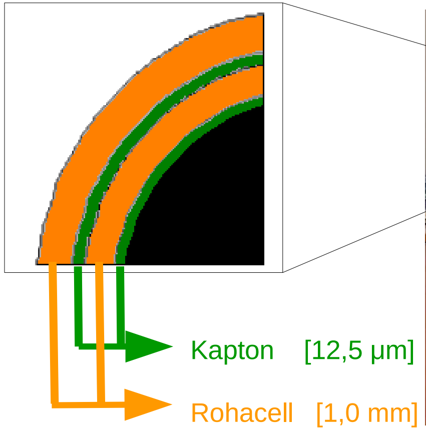
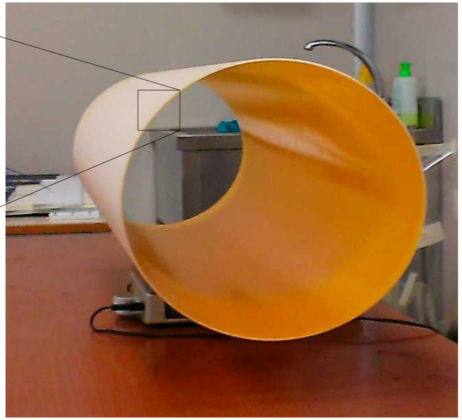
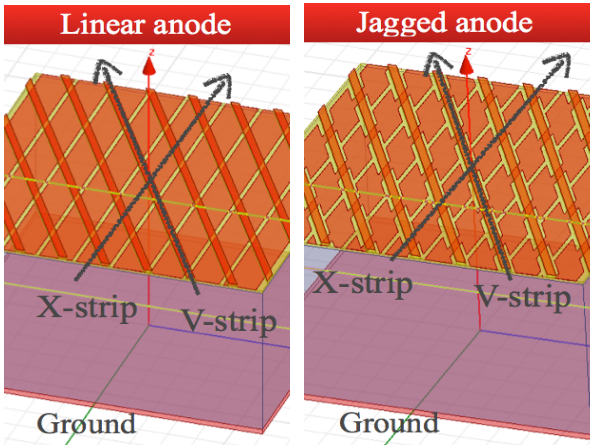
Mechanical structure with Rohacell and a new anode design







- A **double sandwich** of Kapton and Rohacell providea a structure with a **reduced radiation length**
- The structure is used to sustain the **cathode** and the **anode**
- Together with the **permaglass rings**, glued at the edges, provides the entire mechanical support of the detector
- The anode is segmented with a XV **bi-dimensional** readout
- A jagged design **reduces** the inter-strip **capacitance** thanks to a smaller overlap area between the strips of about **30%** from simulations

BESIII CGEM-IT inherits from KLOE-2 with relevant pecularities

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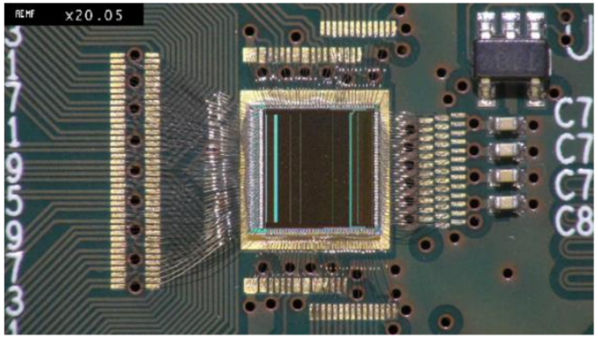
Readout	digital	charge + time	new ASIC chip

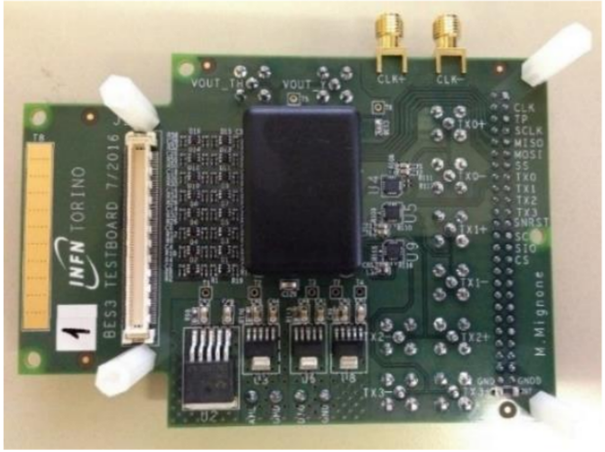
- Design
- Chip characterization
- Integration test

TIGER ASIC

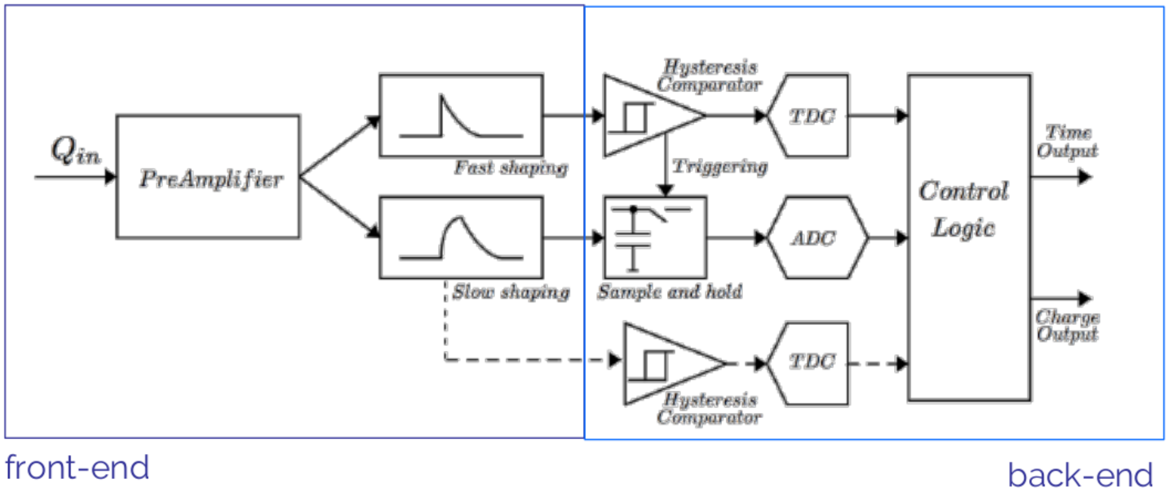
A new ASIC named TIGER

- TIGER: Torino Integrated Gem Electronics for Readout is a chip that provides **time** and **charge** measurement and features a fully-digital output
- Each chip has **64 channels**
- The expected signal from CGEM-IT:
  - Duration: 30-50 ns
  - Sensor capacitance: up to 100 pF
  - Time resolution: ~ 5ns
  - Rate per channel: 60 kHz
  - Power consumption: ~ 10 mW/channel



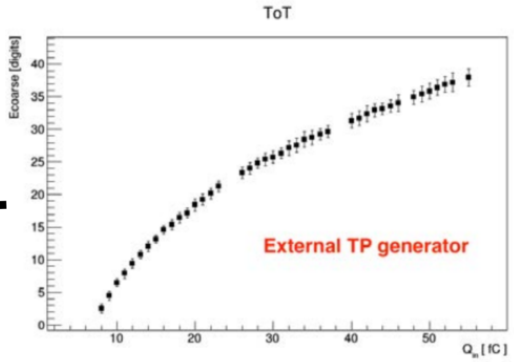


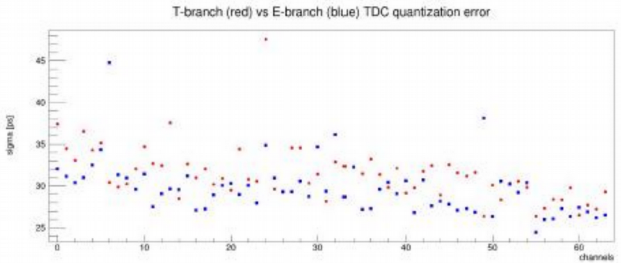
Channel circuit



- The chip can work in two different modes: T-Branch and E-Branch
- T-Branch: timestamp on rising/falling edge (sub-50 ps binning quad-buffered TDC) charge measurement with **Time-over-Threshold**
- E-Branch: timestamp on rising edge (sub-50 ps binning quad-buffered TDC). **Sample-and-Hold** circuit for peak amplitude sampling. A slow shaper output voltage is sampled and digitized with a 10-bit Wilkinson ADC

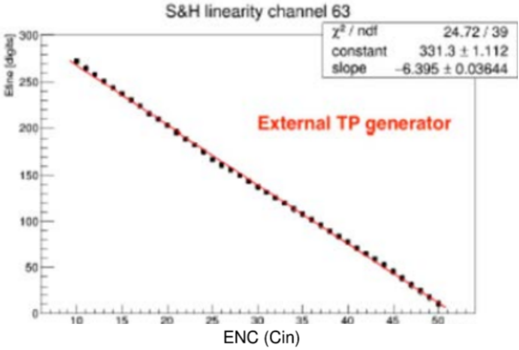
Chip characterization

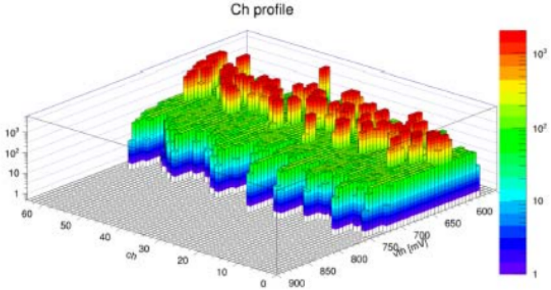




Calibrated the **dynamic range** with external test-pulse

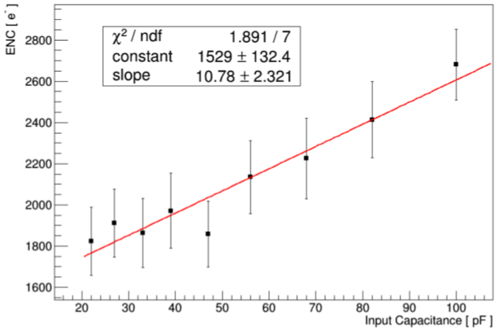
Average TDC quantisation error after calibration ~ **30 ps** r.m.s.





Baseline equalization leads average gain above 10mV/fC

Noise evaluated for each input **capacitance**



Integration test

Detector

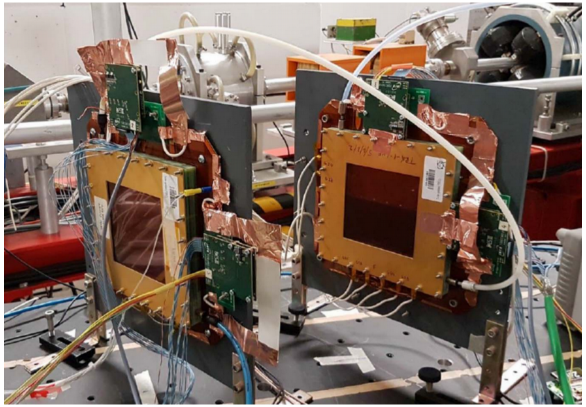
Two planar triple-GEM
XY readout
$ArCO_2$ (70:30) gas mixture

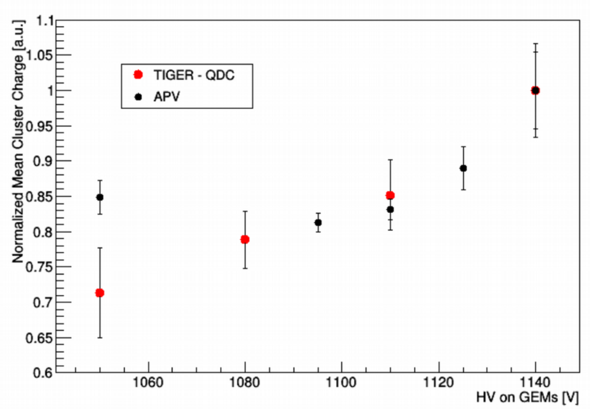
Electronics

8 TIGER v0
4 FEBs
2 view per chamber readout

Beam

Beam type: electron
Energy beam: 855 MeV
Beam collimation: 1 mm^2





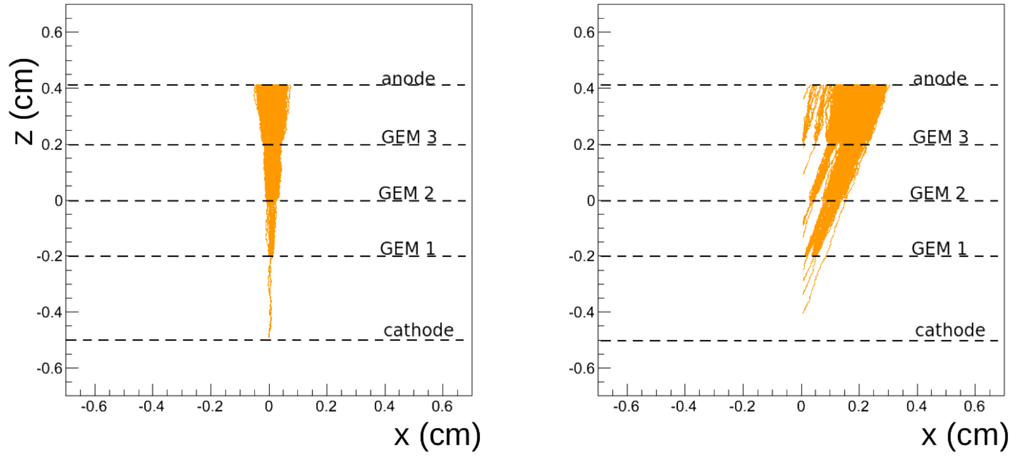
→ The test was **successfully** completed and the results are in **agreement** with the ones collected with **APV-25**

- Electron diffusion in gas
- Magnetic field effect
- Charge centroid algorithm
- micro-Time projection chamber algorithm

Signal reconstruction

Electron diffusion and the magnetic field

Signal formation simulations



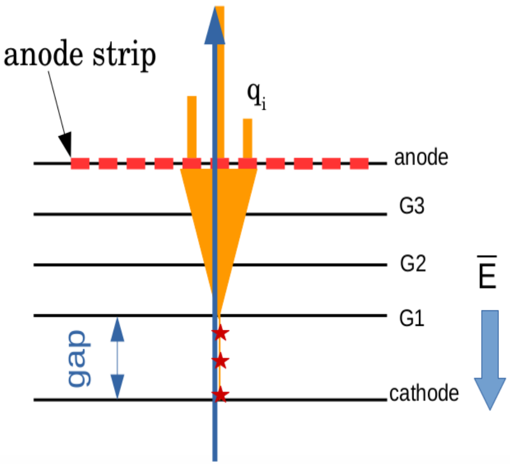
B = 0 T   B = 1 T

- Diffusion effect of the gas mixture on the drifting electrons is to deviate their path and this creates a Gaussian distribution at the anode
- The Lorentz force bends the drifting electron trajectories. This moves the charge distribution to a non-Gaussian shape

Charge-Centroid and micro-Time-Projection-Chamber

$$x = \frac{\sum x_i * q_i}{Q_{TOT}}$$

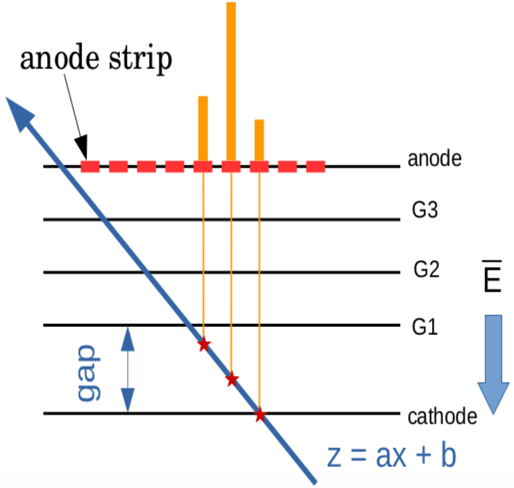
Charge Centroid



- Signal is collected on the anode and time and charge information are measured
- CC: weighted average of the strips position with the measured charge
- µTPC: reconstructs the particle path associating to each strip a bi-dimensional point (x_strip, time * drift velocity)
- CC performs well if the charge distribution is Gaussian
- µTPC performs well if the number of firing strip is above 3

$$x = \frac{\frac{gap}{2} - b}{a}$$

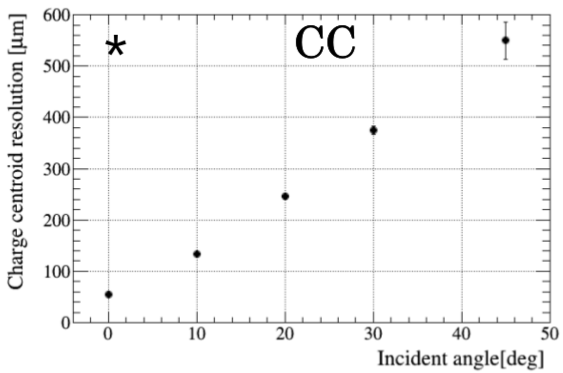
µTPC

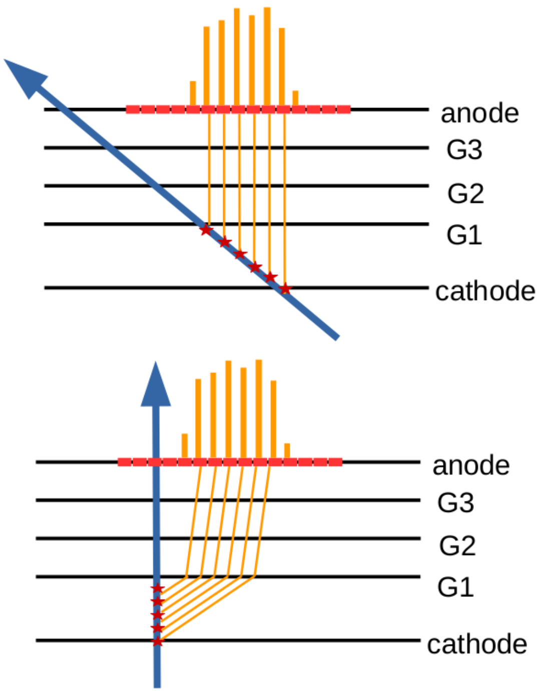


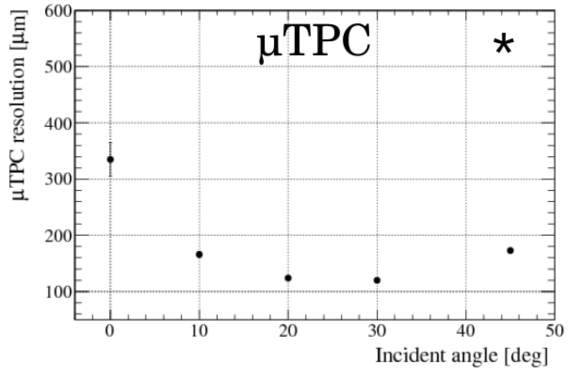
- CC & μTPC angular performances
- CC & μTPC in magnetic field
- High rate measurements

R&D and results

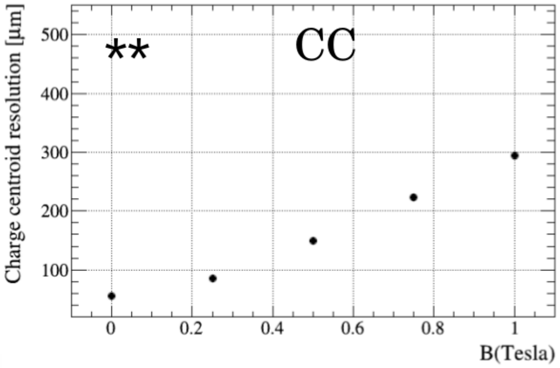
Charge-Centroid and micro-Time-Projection-Chamber

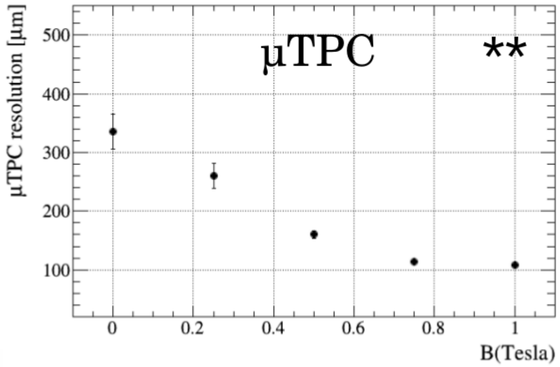






B = 0 T





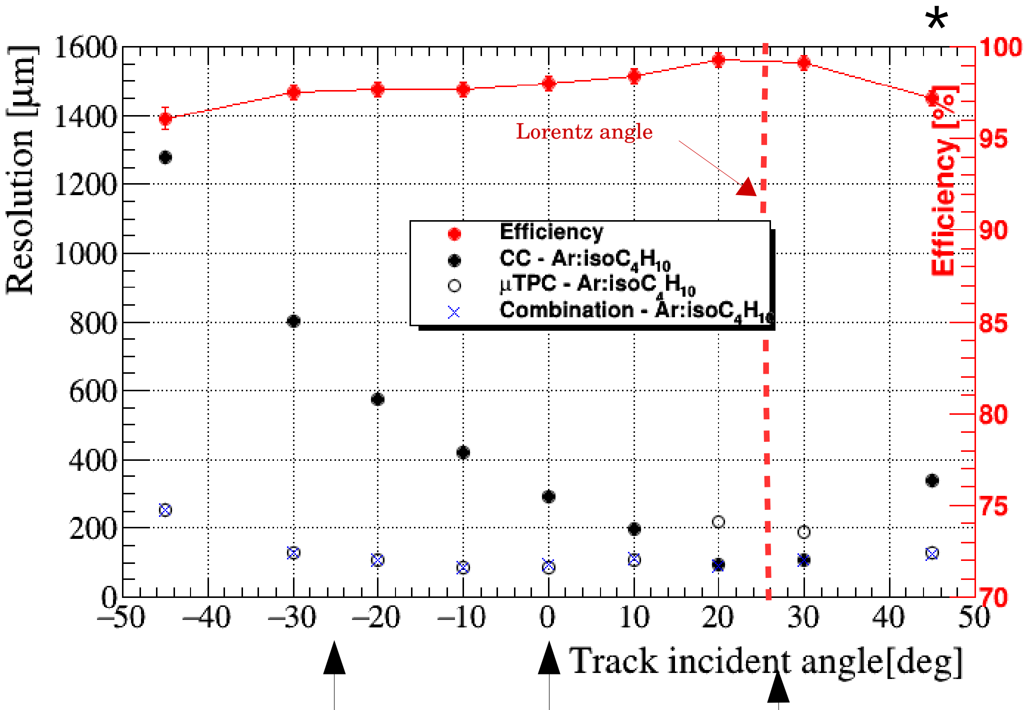
B ≠ 0 T

* **Angle scan**
5 mm drift gap
820V on the GEMs
Ar:iC_4H_{10}
1.5 kV/cm drift field
no magnetic field

** **Magnetic field scan**
5 mm drift gap
820V on the GEMs
Ar:iC_4H_{10}
1.5 kV/cm drift field
orthogonal tracks

Charge-Centroid and micro-Time-Projection-Chamber

- µTPC has to take into account the Lorentz angle to reconstruct the tracks with the magnetic field. That angle is calculated with simulations.
- The Lorentz angle with Ar:iC_4H_{10} @ 1.5 kV/cm drift field is ~ 26°. In this region CC is more efficient. In the other regions µTPC is flat around a resolution of ~100 µm
- A **combination of the two methods keeps the resolution stable** in the full range of incident angles



* **Angle scan**
5 mm conversion gap
820V on the GEMs
Ar:iC_4H_{10}
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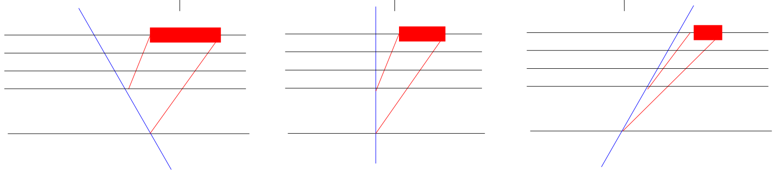
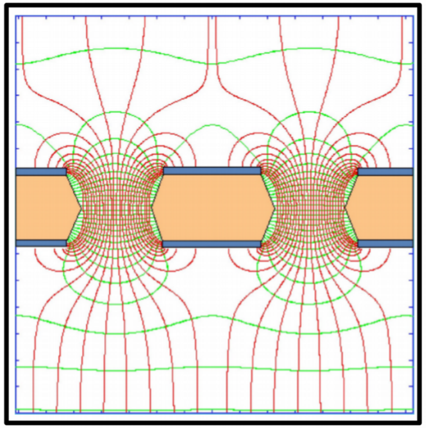
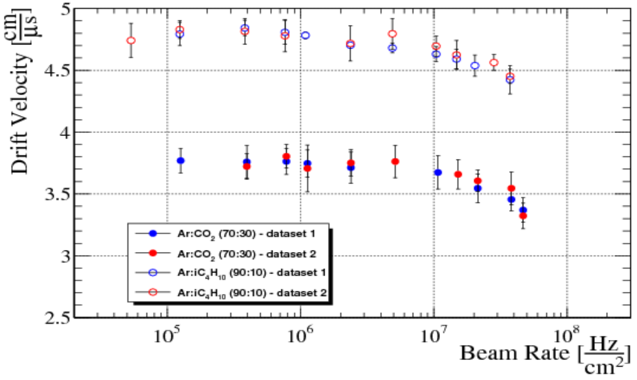
1 T magnetic field



High rate test

- The aim of this test is to measure the performance of the µTPC reconstruction algorithm at **high rate** (10^6 Hz/mm^2)
- A high particle flux can **affect** the triple-GEM performances
- The ion **space charge** changes the electric field around the GEM holes
- This affects the gain of the GEM and the **drift properties** of the electrons
- A **distortion of the drift properties** is observed since the drift velocity slows down at a certain rate





Conclusion

- A Cylindrical-GEM detector has been developed to substitute the BESIII inner tracker
- The detector shares with KLOE-2 the construction technique but it has implemented several features to improve its performances
- The most relevant upgrade is the new ASIC which performs charge and time measurements. This allows to apply the CC and the μTPC algorithms
- The two reconstruction algorithms give a stable resolution around 130 μm in strong magnetic field for several incident angle in magnetic field
- The drift velocity is constant up to 10^6-10^7 Hz/cm^2 then it start decreasing. This is a limit for the μTPC in high rate environment well below the request by the BESIII experiment

Thanks

Backup