The new Cylindrical GEM Inner Tracker of BESIII

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On behalf of the CGEM-IT group

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Summary

- What is a GEM
- Description of the CGEM-IT project for BESIII
- CGEM-IT peculiarities
- Results from test beams

The project BESIIICGEM was funded by European Commission call H2020-MSCA-RISE-2014
INFN (Torino, Ferrara, Frascati), Mainz, Uppsala, IHEP

WHAT IS A "GEM"?

The Gas Electron Multiplier

Flow of a standard gas tracker:

IONIZATION

↓

ELECTRON DRIFT

↓

MULTIPLICATION

↓

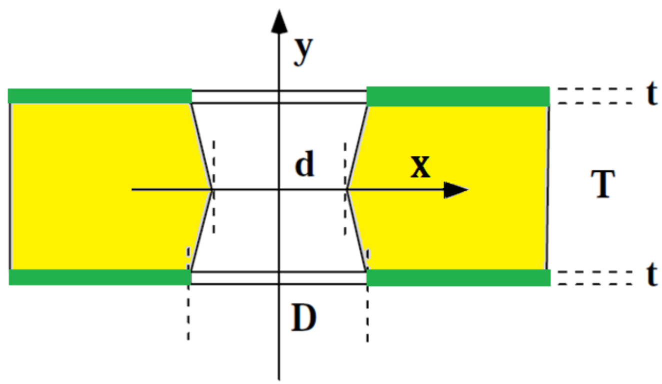
SIGNAL

THE GAS ELECTRON MULTIPLIER

IONIZATION
↓
ELECTRON DRIFT
↓
MULTIPLICATION
↓
SIGNAL

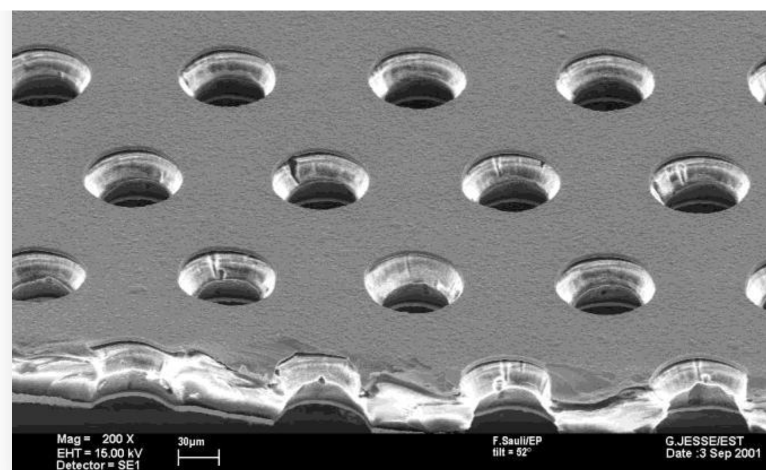
FLOW OF A STANDARD GAS TRACKER:

AVALANCHE GENERATION → MULTIPLICATION

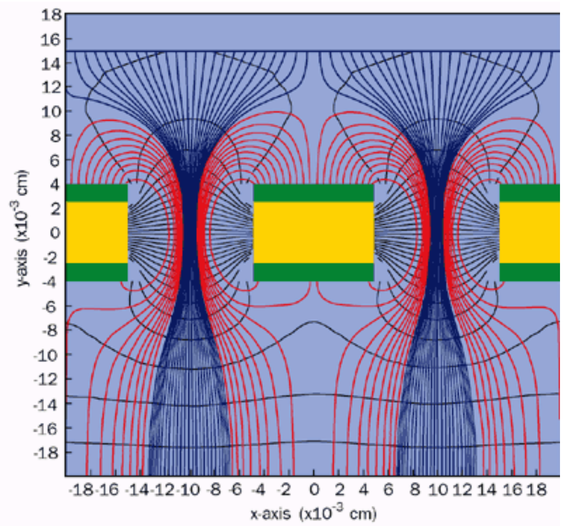


- Kapton, T = 50 µm,
- copper coated (t =3 µm),
- pierced with thousands of holes D = 70 µm, d = 50 µm

INVENTED BY F. SAULI IN 1997

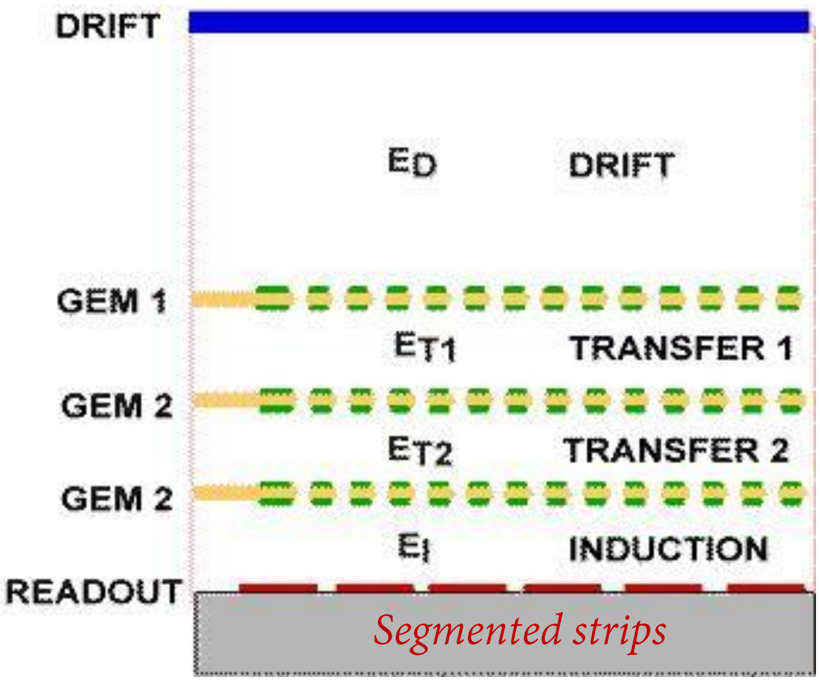


The avalanche multiplication



By applying a potential of some hundreds V, an electric field of some tens kV/cm is created in the holes → avalanche multiplication

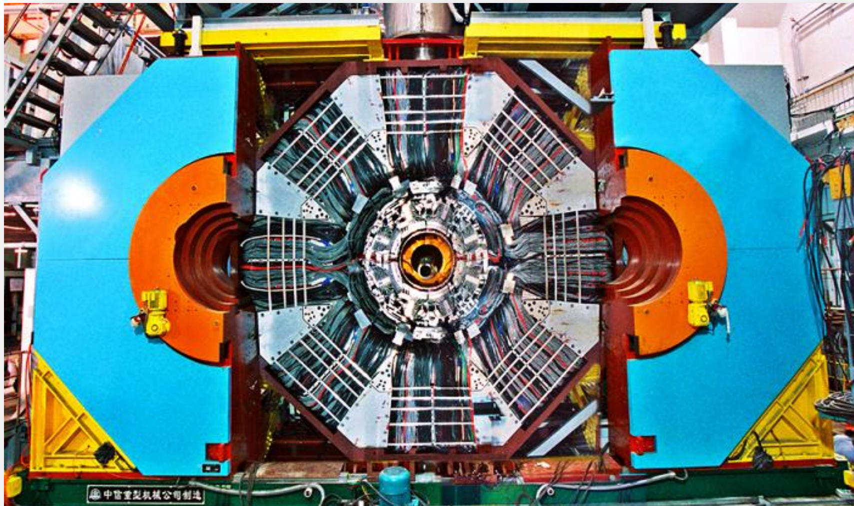
By applying a lower voltage on each GEM and with a series of three GEM foils higher gain values (~10^3 - 10^4) with lower discharge rates can be obtained



1. Ionization & drift
2. Multiplication
3. Multiplication
4. Multiplication
5. Signal induction

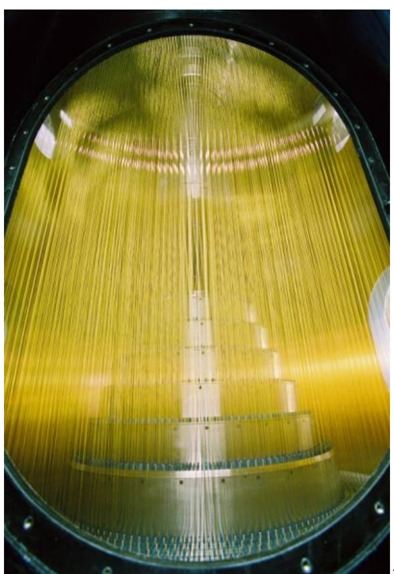
THE CGEM-IT PROJECT

CGEM-IT: Where and why?



- BESIII is a τ-charm factory
- Installed @ BEPCII, Beijing, PRC
- e^+e^- collisions
- Beam energy 1-2.3 GeV
- Data taking since 2009 up to 2022

…maybe 2027 !

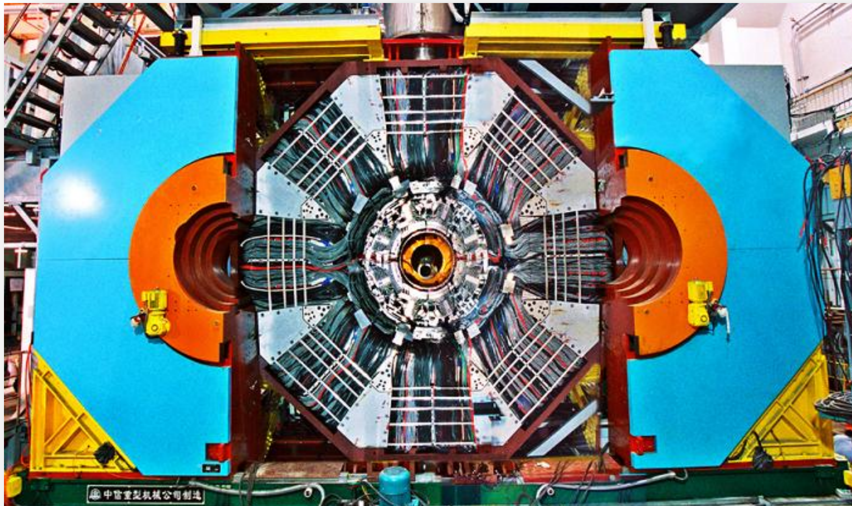


CURRENT IT: 8 (in) + 35 (out) layers in a Main Drift Chamber

- momentum resolution 0.5% @1 GeV/c
- r-ϕ spatial resolution 130 μm
- azimuthal coord. res. 2 mm

…BUT…

CGEM-IT: Where and why?



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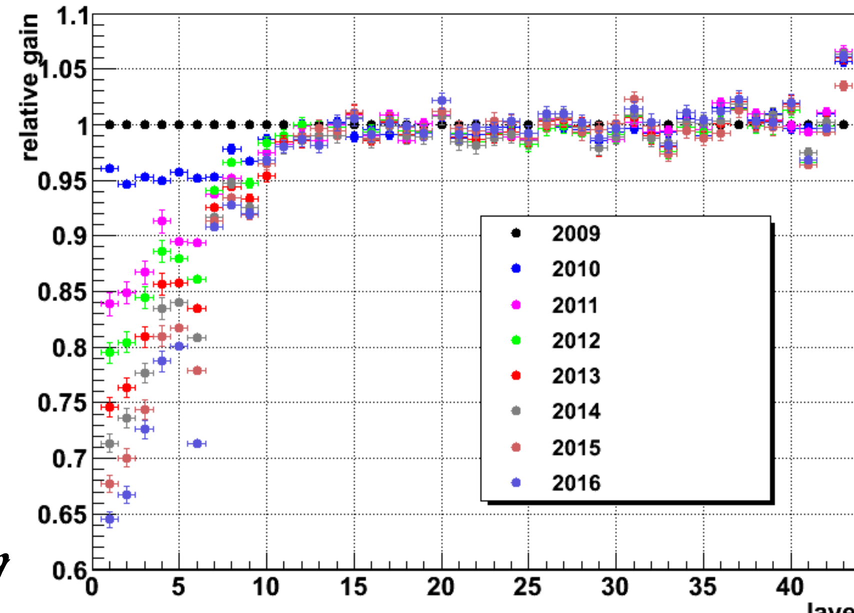
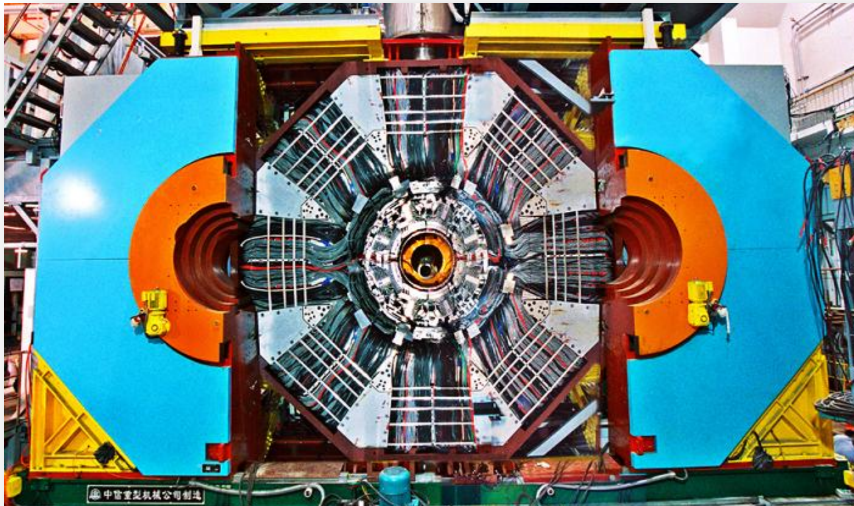
…maybe 2027 !

Continuous luminosity increasing

MDC inner layers suffer from aging

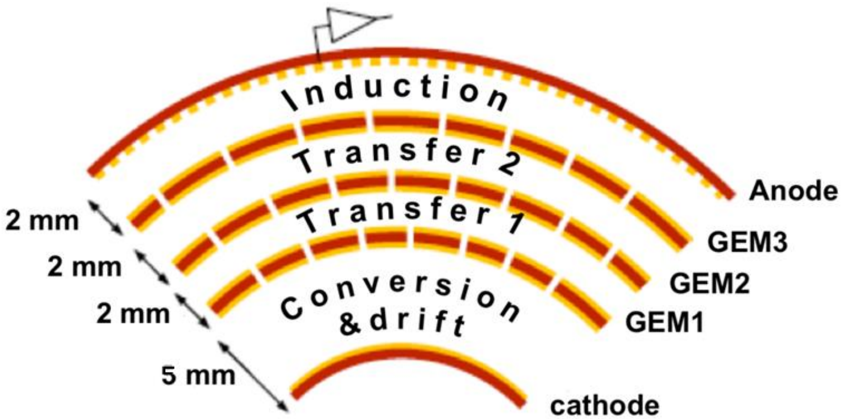


CGEM-IT: ...AND WHAT IS IT?



CYLINDRICAL
GAS
ELECTRON
MULTIPLIER
INNER
TRACKER

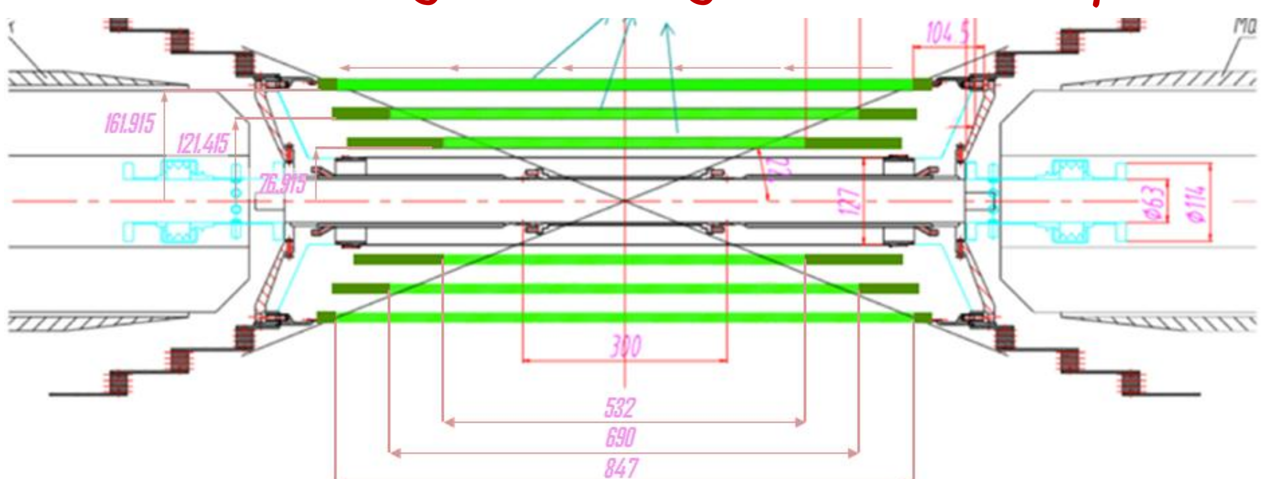
CGEM-IT: ...and what is it?



Geometrical requirements

- inner radius 78 mm
- outer radius 179 mm
- angular coverage 93%
- $X_0 < 1.5$ %
- particle rate ~ 10^4 Hz/cm^2
- anode with axial & tilted strips

FUTURE IT: 3 layers of cylindrical triple-GEMs



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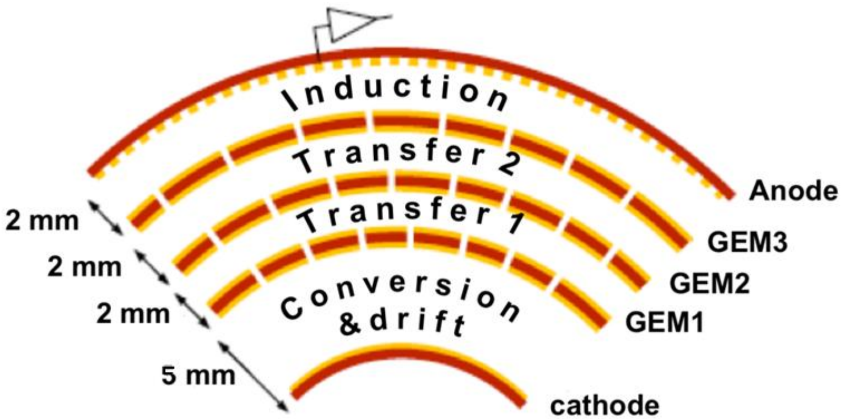


Why the choice of the GEM

- low spatial charge
- high rate capability
- fast response
- light support frame (self-sustaining GEM foils)

FUTURE IT: 3 layers of cylindrical triple-GEMs

Advantages

- restore efficiency
- improve the resolutions
  - on z coordinate [< 1 mm]
  - on secondary vertices

Guarantees

- keep the resolution
  - on trasverse plane [130 μm]
  - on momentum [0.5% @1 GeV/c]
- Low material budget [X0 < 1.5%]

THE CGEM-IT PROJECT
The goal

Objectives

Operate the cylindrical triple GEM:

1. WITH THE SIMULTANEOUS MEASUREMENT OF CHARGE & TIME
2. INSIDE A MAGNETIC FIELD OF 1 T
3. WITH A JAGGED ANODE

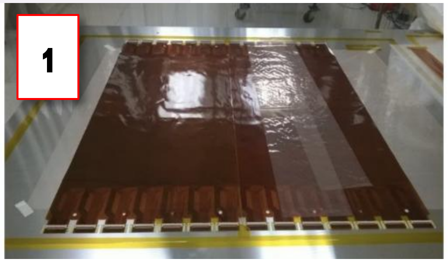
The first cylindrical triple GEM was built and installed for **KLOE-2** (Frascati) with digital readout in 0.5T. The achieved resolution is 350 μm [arXiv:1002:2572]

BESIII inherits the construction procedure and adds improvements

We will exploit LEGACY & INNOVATIONS

LEGACY & INNOVATIONS

The first cylindrical triple GEM was built and installed for **KLOE-2** (Frascati):
BESIII inherits the construction procedure and adds improvements



The GEM foil is produced @ CERN in plane

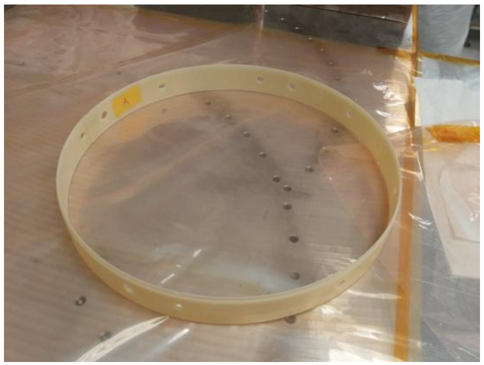
It is shaped around an Al mandrel

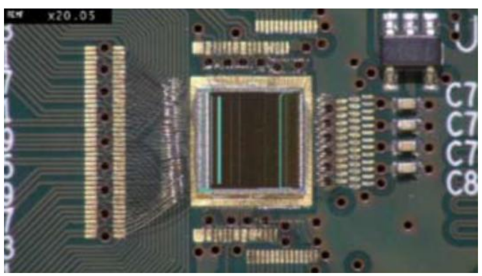
Is is glued by means of a vacuum bag

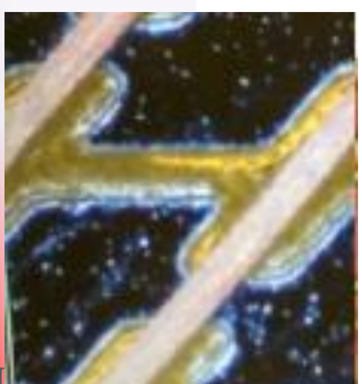
One layer is inserted into the other in the Vertical Inserting Machine

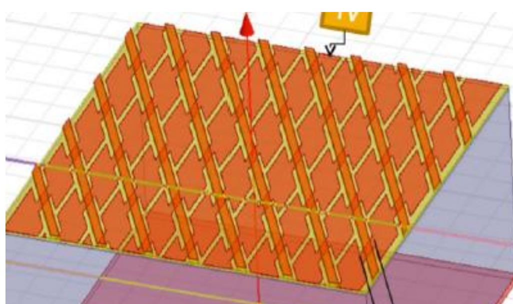
LEGACY & INNOVATIONS

The first cylindrical triple GEM was built and installed for **KLOE-2** (Frascati): BESIII inherits the construction procedure and adds improvements









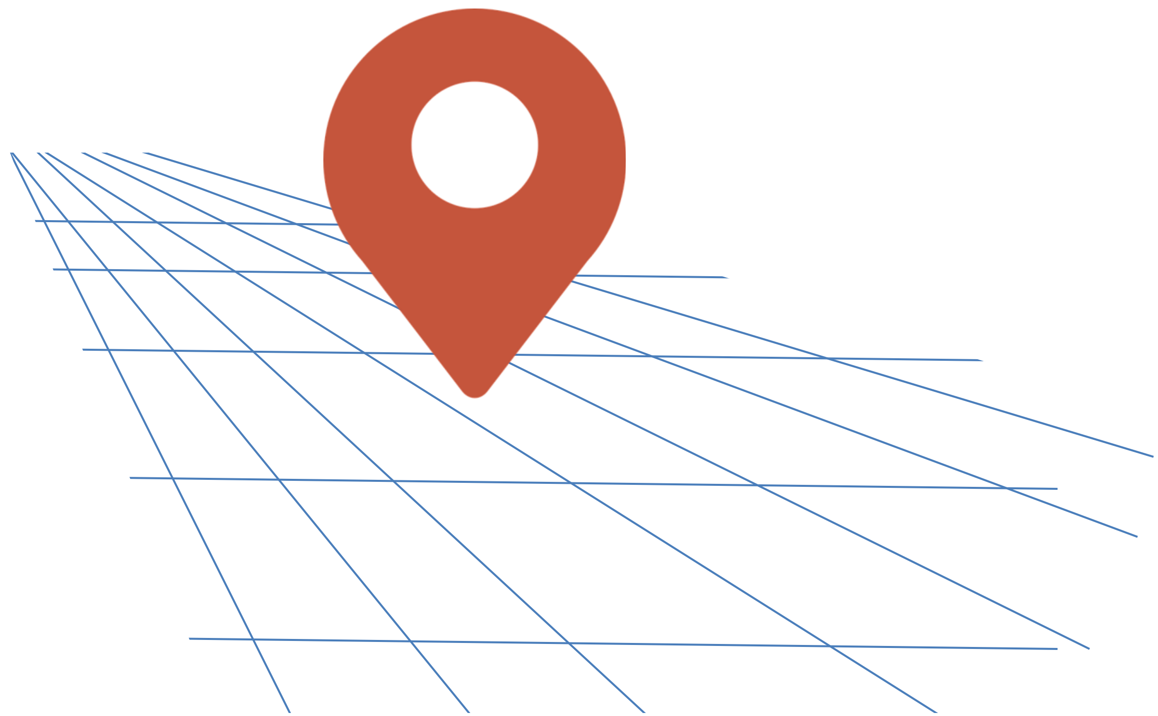
MECHANICS:

- ROHACELL31 to sustain anode & cathode
- Permaglass rings only out the active area

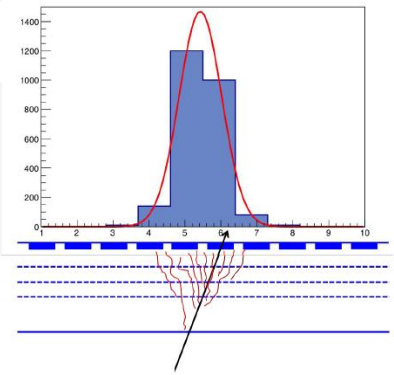
ELECTRONICS:

- Dedicated ASIC – Torino Integrated GEM Electronics for Readout (TIGER)
- Anode with Jagged strips, to decrease of ~30% the inter-strip capacitance

THE CGEM-IT PROJECT
The position reconstruction



Processes of interest



Charge distribution @anode

Depending on the shape of the charge distribution at the anode two reconstruction methods can be used

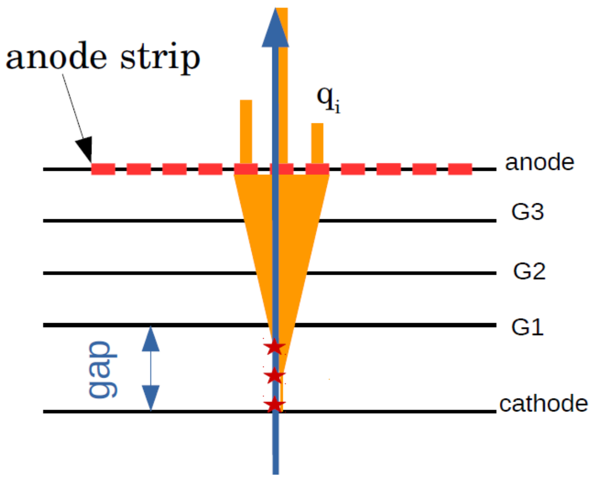
Diffusion

The effect of the **gas mixture** on the drifting electrons is to deviate their path (multiple scattering) due to the diffusion: this creates an charge distribution on the anode lighting more than one strip

Lorentz force

The presence of the **magnetic field** on the drifting electrons is to curve their trajectory due to the Lorentz force. This moves the charge distribution at anode from the Gaussian shape

Methods for reconstruction

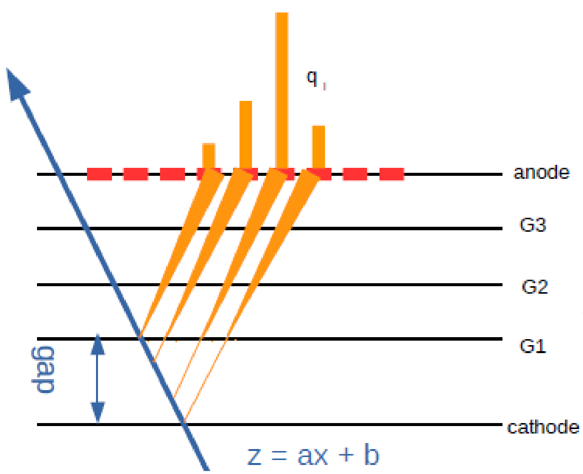


Charge Centroid

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

$$< x > = \frac{\sum_i x_i q_i}{\sum_i q_i}$$

GAUSSIAN



micro-TPC

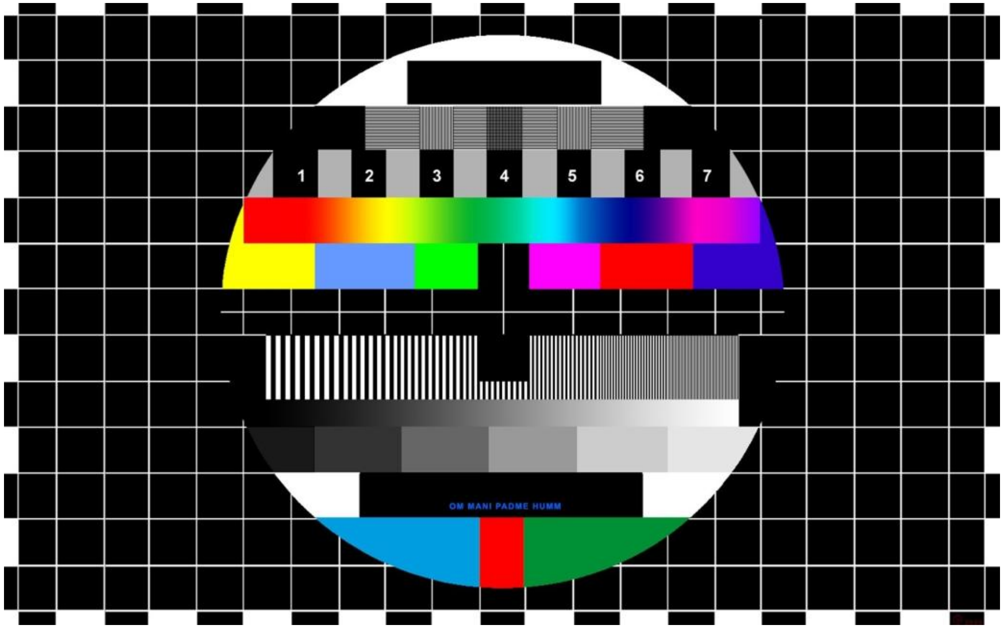
[M. Iodice, JINST, 9 C01017, 2014]

Use the Drift Gap as a “micro time projection chamber” and reconstruct the position of each primary ionization by knowing the drift velocity

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

NON GAUSSIAN

THE CGEM-IT PROJECT
THE TESTBEAMS



Test beam environment

WHERE

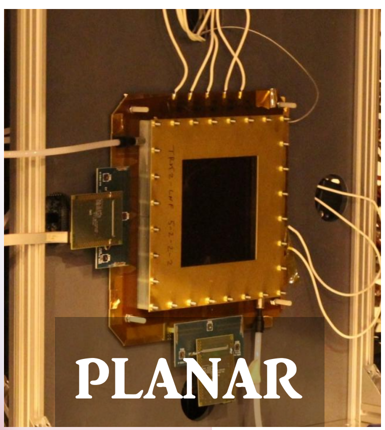
- H4 beam line @ SPS, North Area, CERN

MAGNETIC FIELD

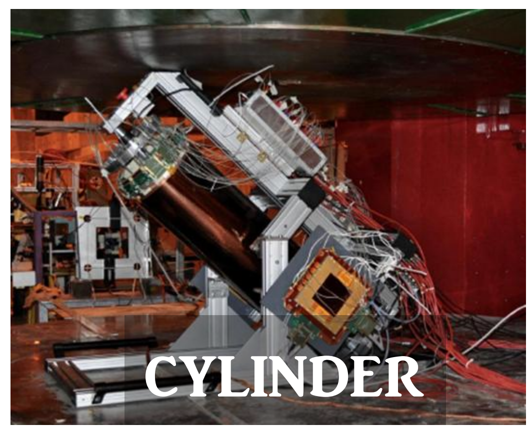
- GOLIATH dipole in [-1.5, +1.5] T

BEAM

- muons/pions @150 GeV/c



- 10×10 cm^2 triple GEM
- x/y views
- strip pitch 650 μm
- gas mixtures:
  - Ar/CO2 (70/30%)
  - Ar/Iso (90/10%)
- ASIC APV-25



October 2016
1st CGEM test beam

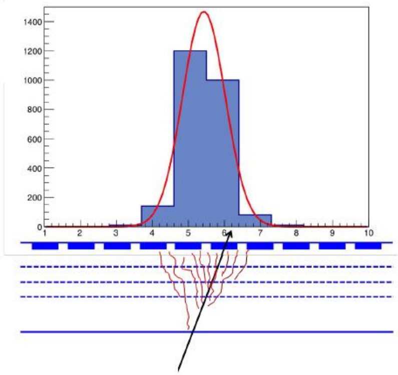
- Ar/CO2 (70/30%)
- x & v views
- 3 mm drift gap

And additional tests:

on high intensity electron beam @MAMI – cosmic rays @ Frascati & Ferrara

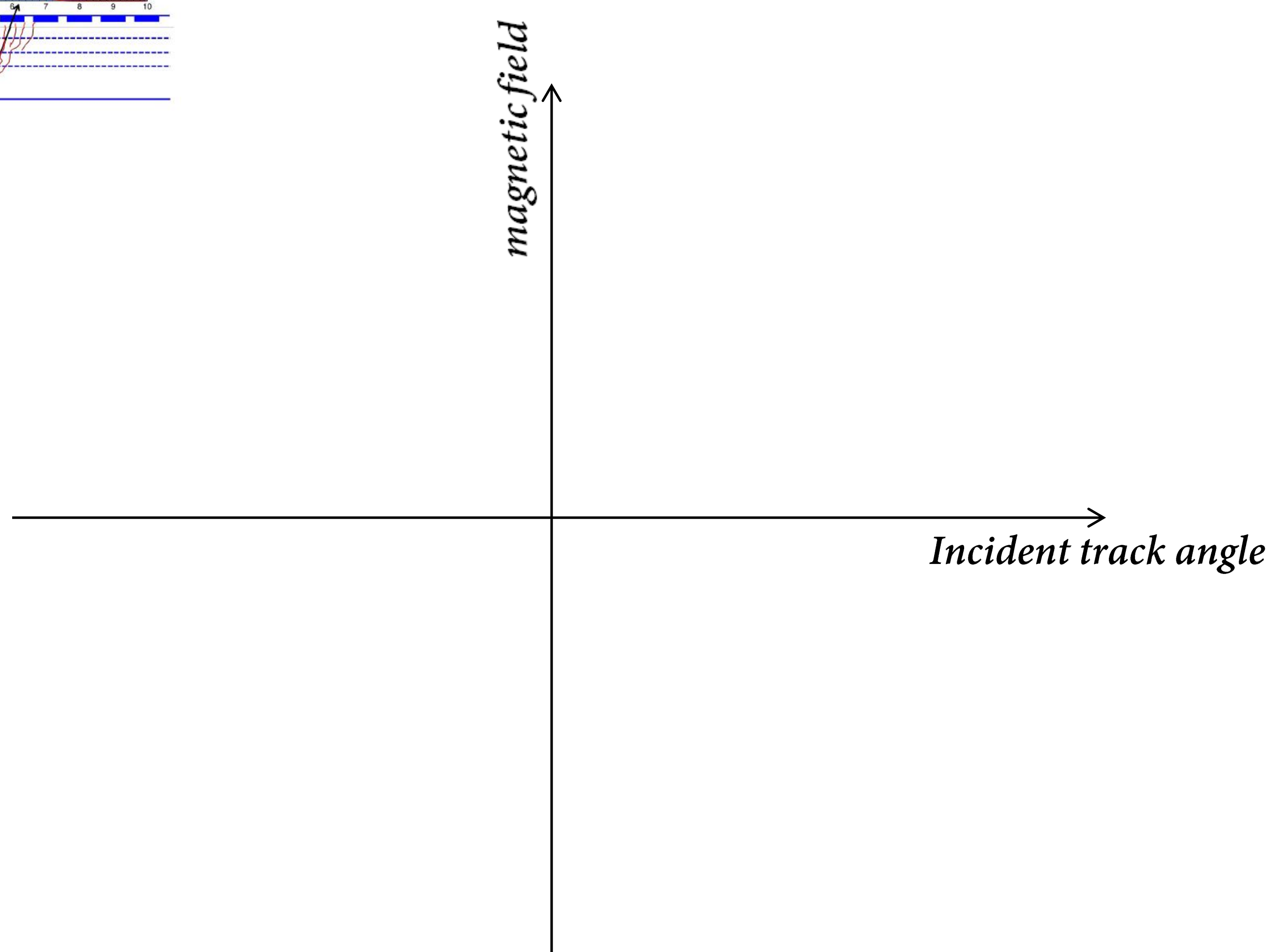
July 2017 – Layer 1 test beam

Track patterns



Charge distribution @anode

Depending on the shape of the charge distribution at the anode two reconstruction methods can be used



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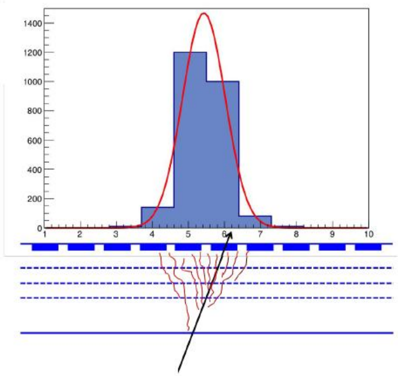

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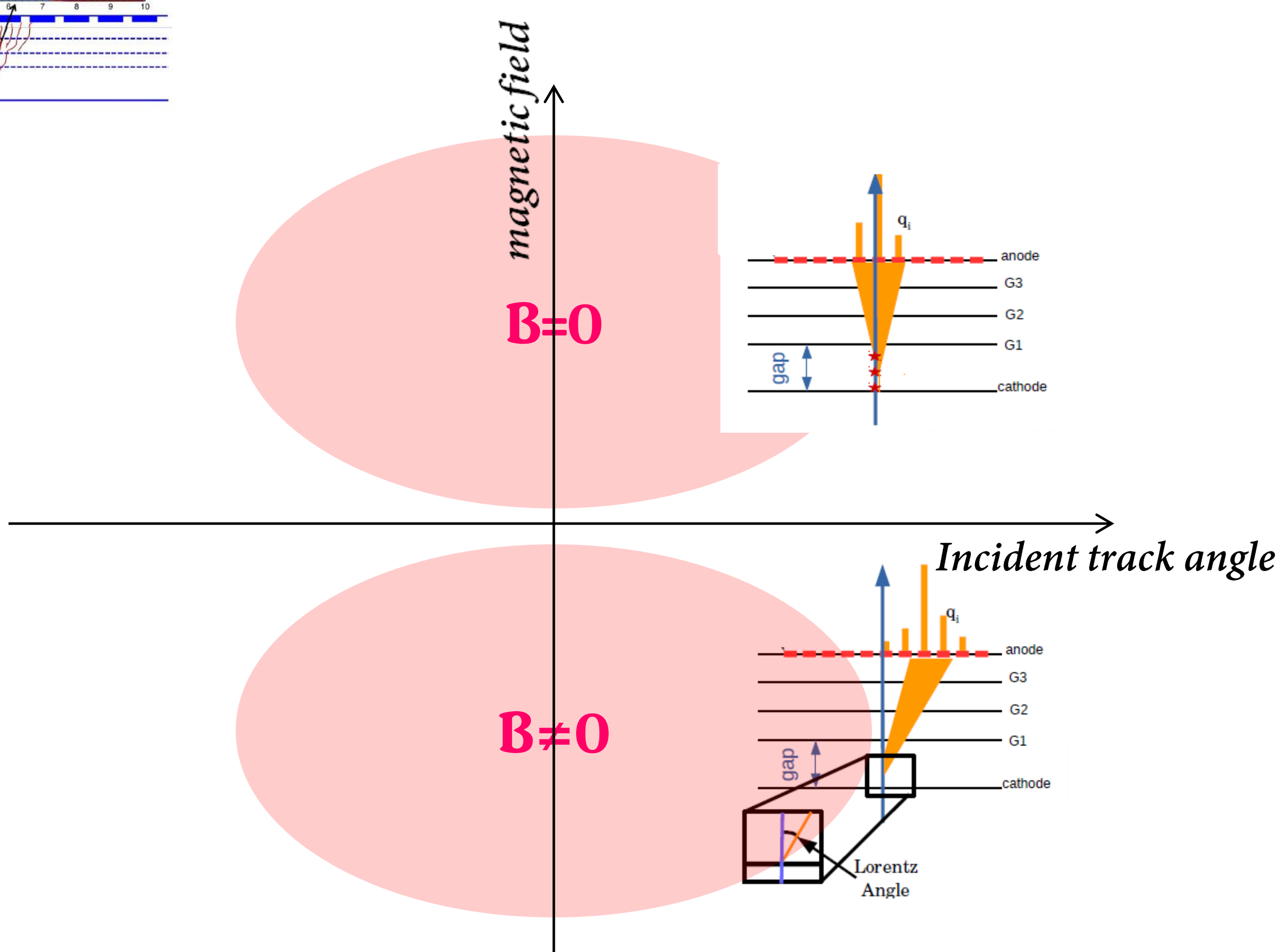
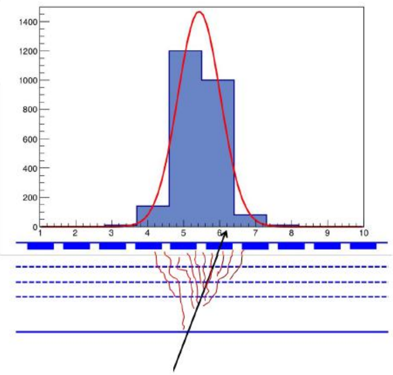
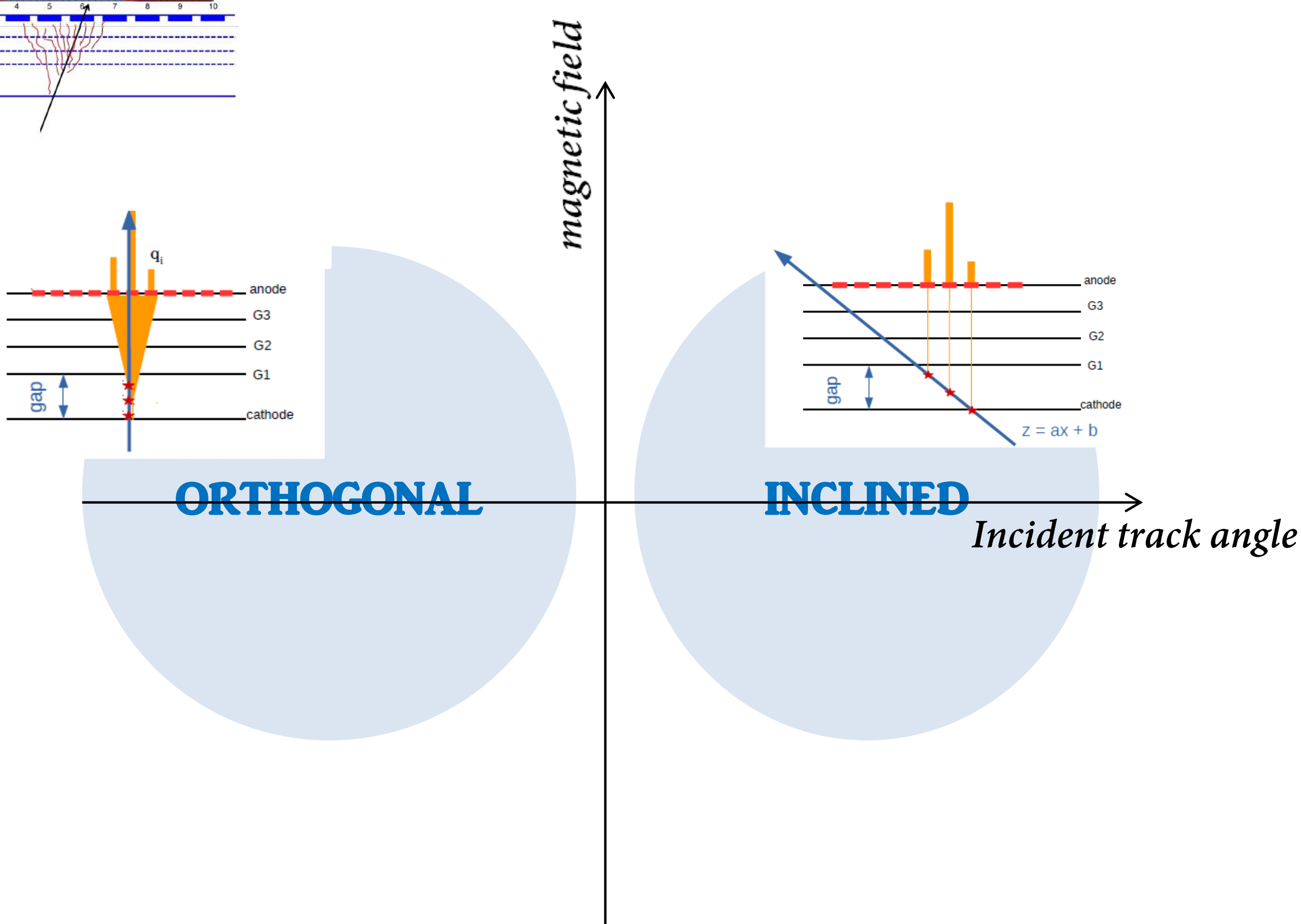


TRACK PATTERNS

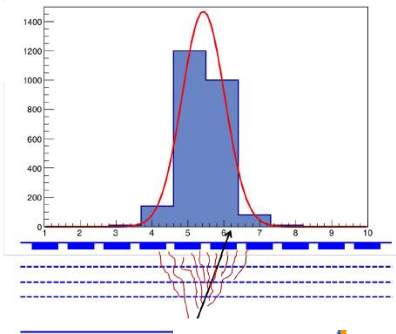


CHARGE DISTRIBUTION @ANODE

Depending on the shape of the charge distribution at the anode two reconstruction methods can be used



Track patterns



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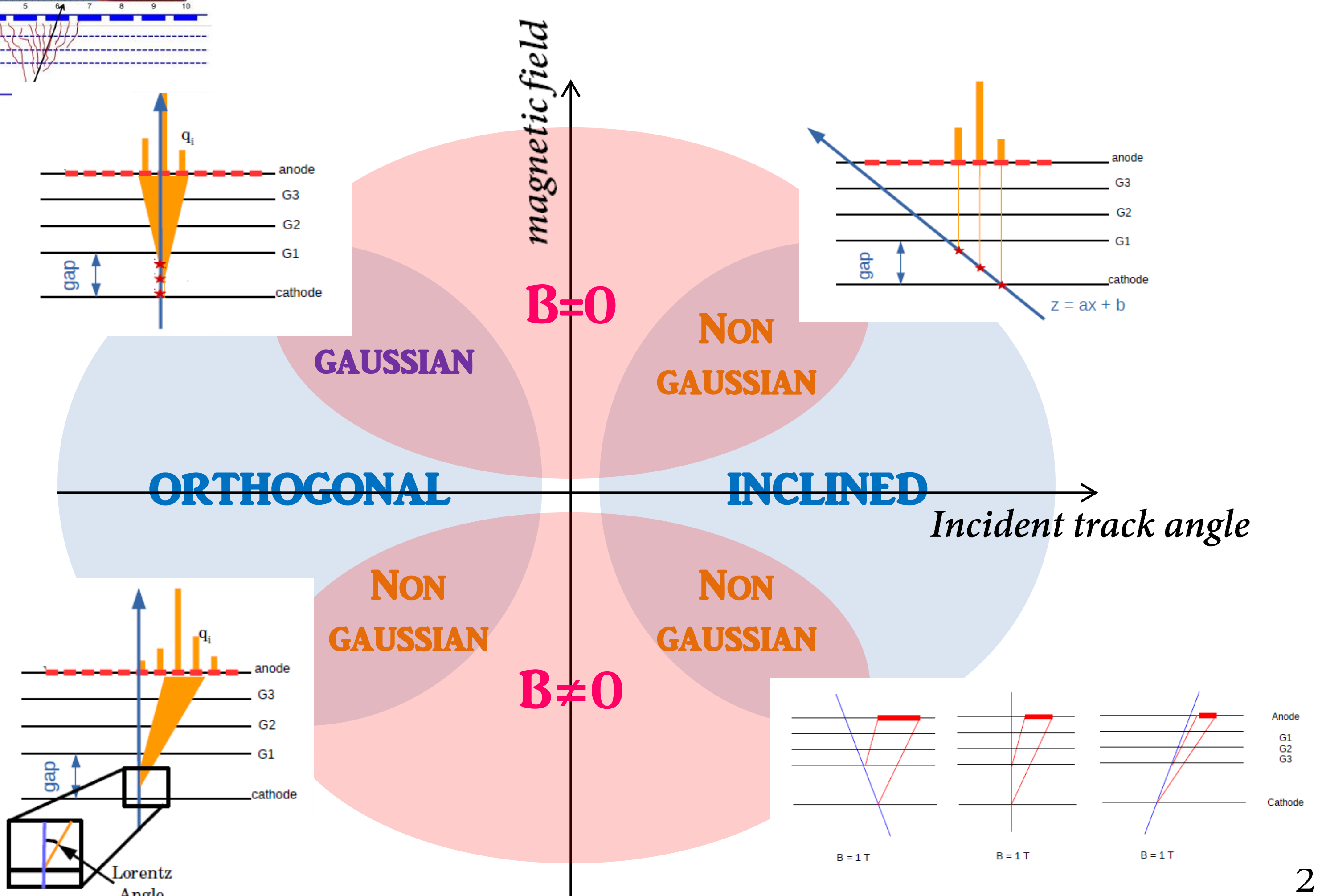
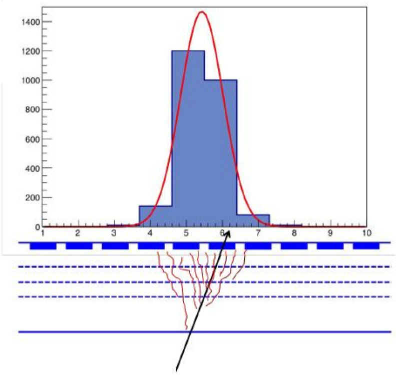


Methods for reconstruction



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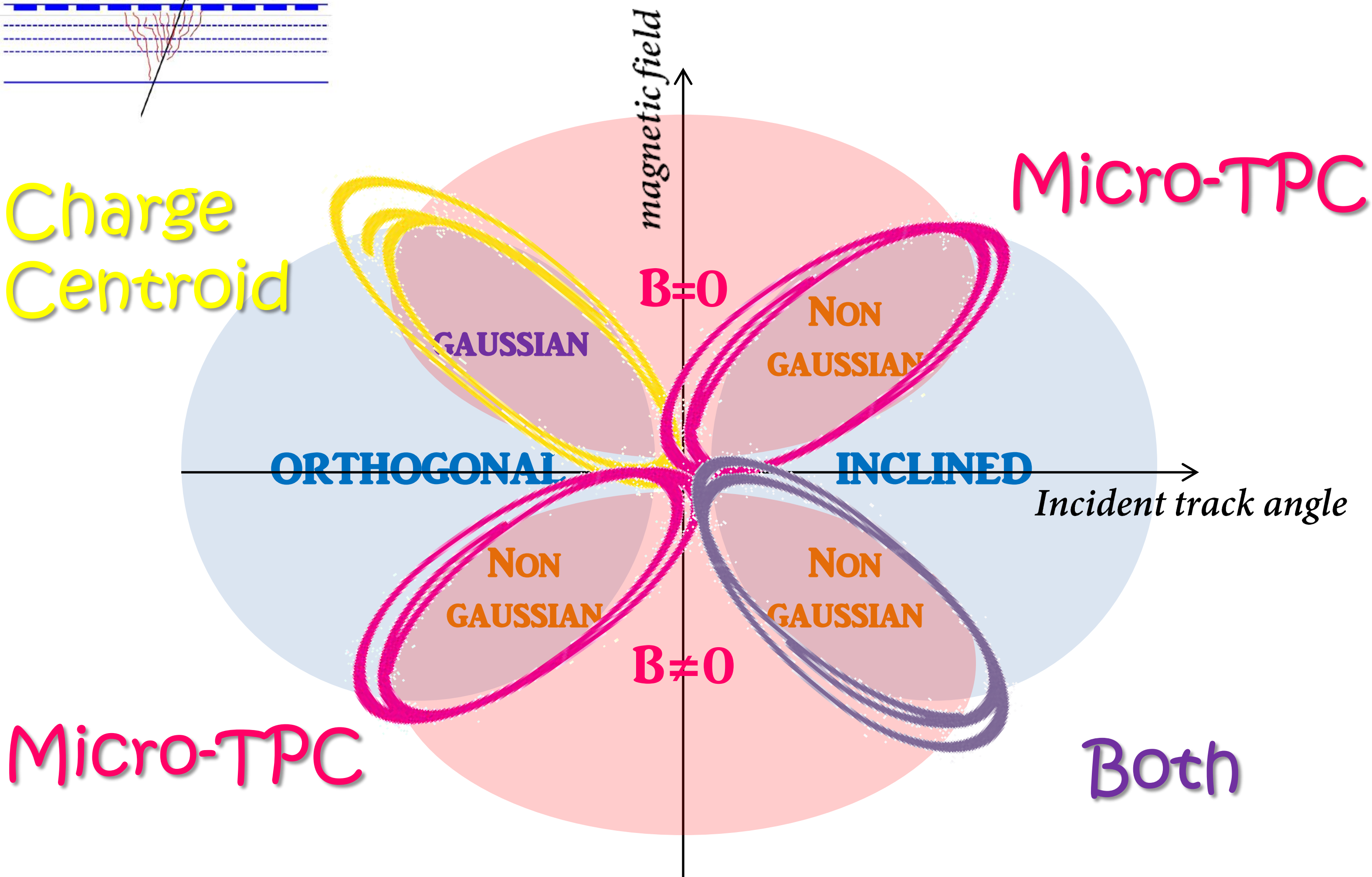
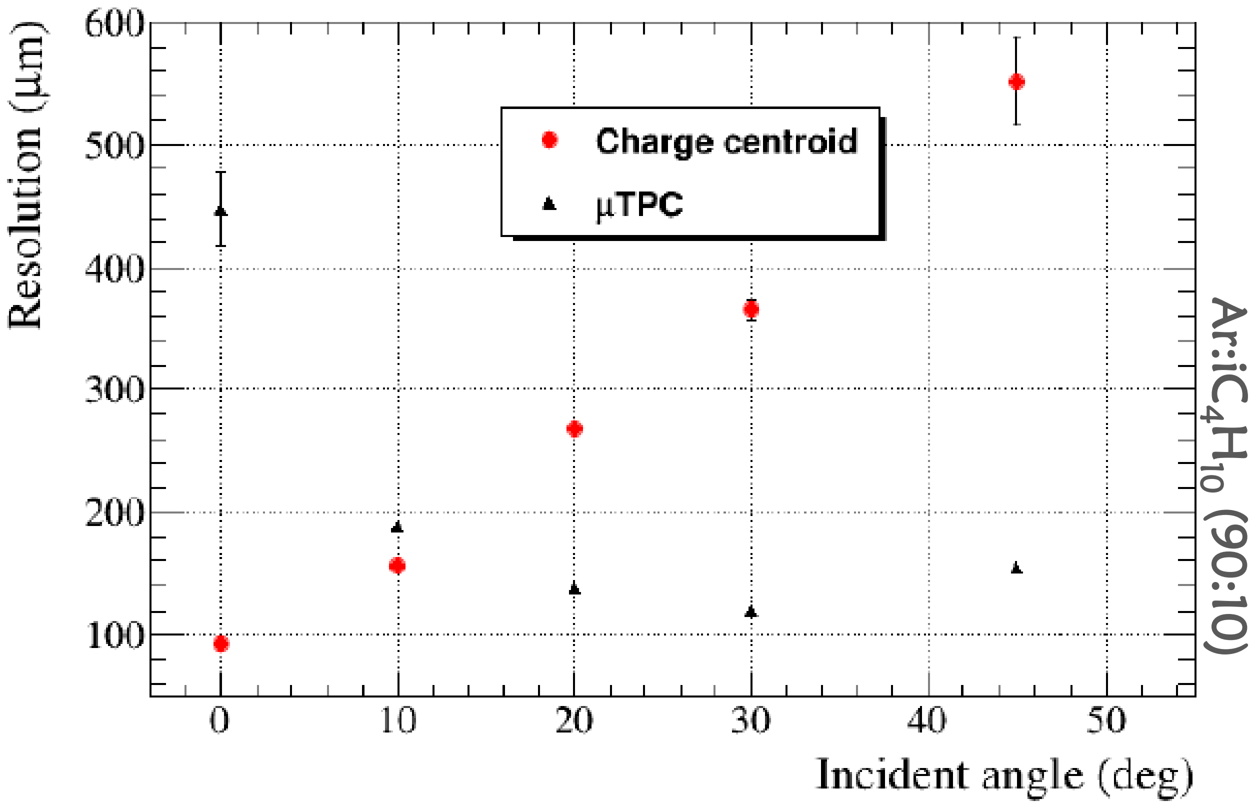


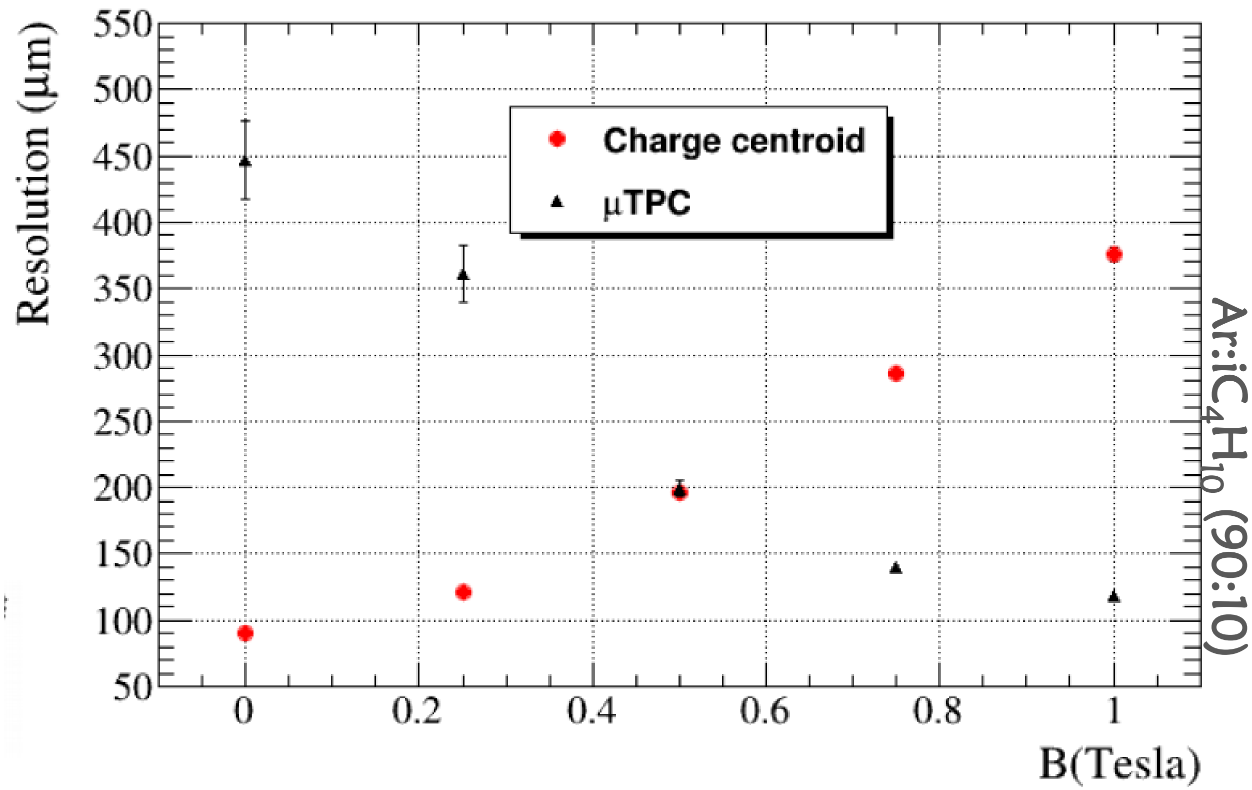
Inclined tracks in B = 0



The cluster size increases for more inclined tracks: the three GEMs amplify the number of electrons and the gas diffusion enlarges the avalanche size with a shape that is not Gaussian.

→ The CC degrades its performance, while the μ-TPC improves

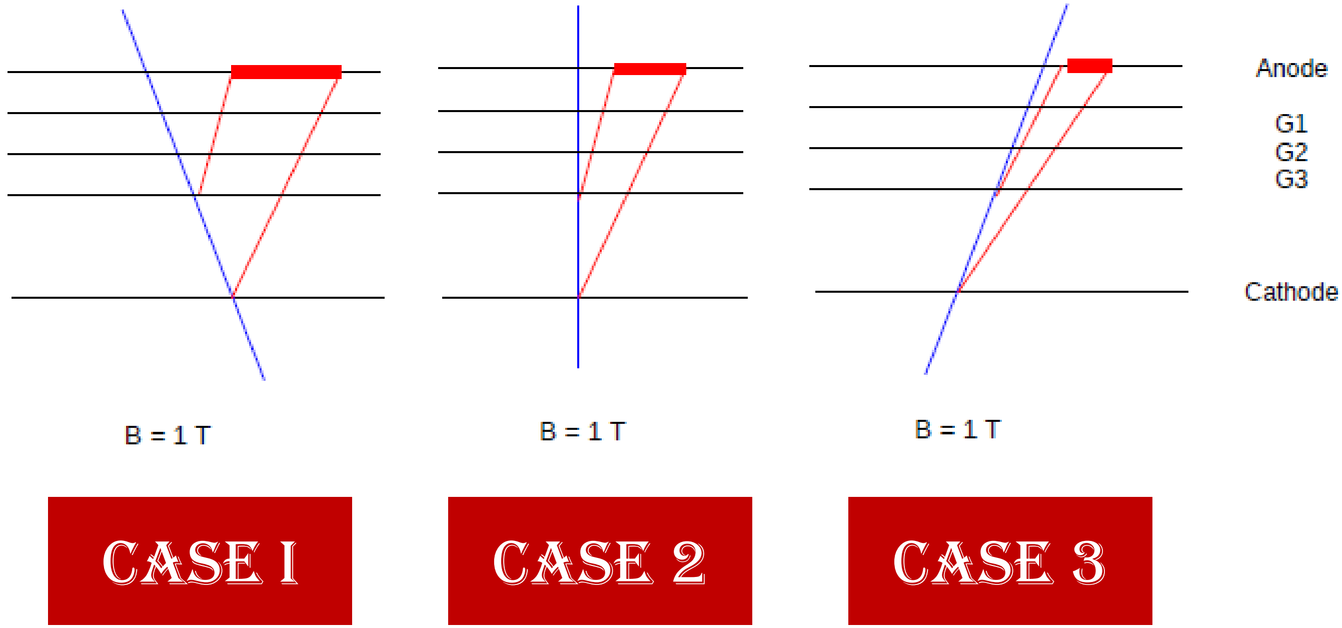
Orthogonal tracks in B ≠ 0



The cluster size increases and the distribution is no longer Gaussian
→ The CC degrades its performance, while the μ-TPC improves under increasing magnetic field

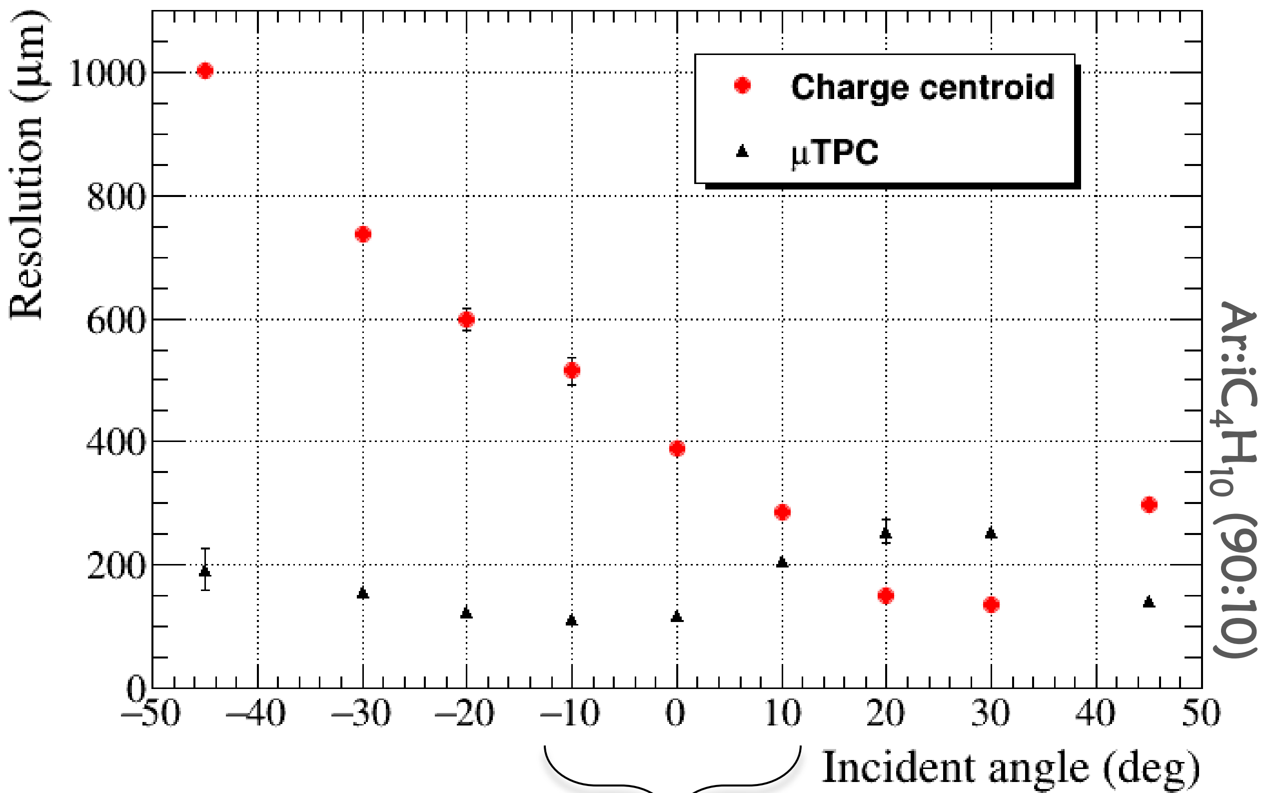
Inclined tracks in $B \neq 0$

It depends on the incident and Lorentz angle respective sign

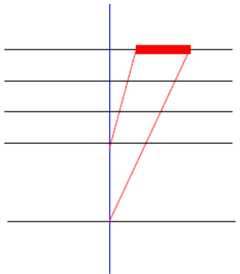


INCLINED TRACKS IN B ≠ 0

CASE I



normal

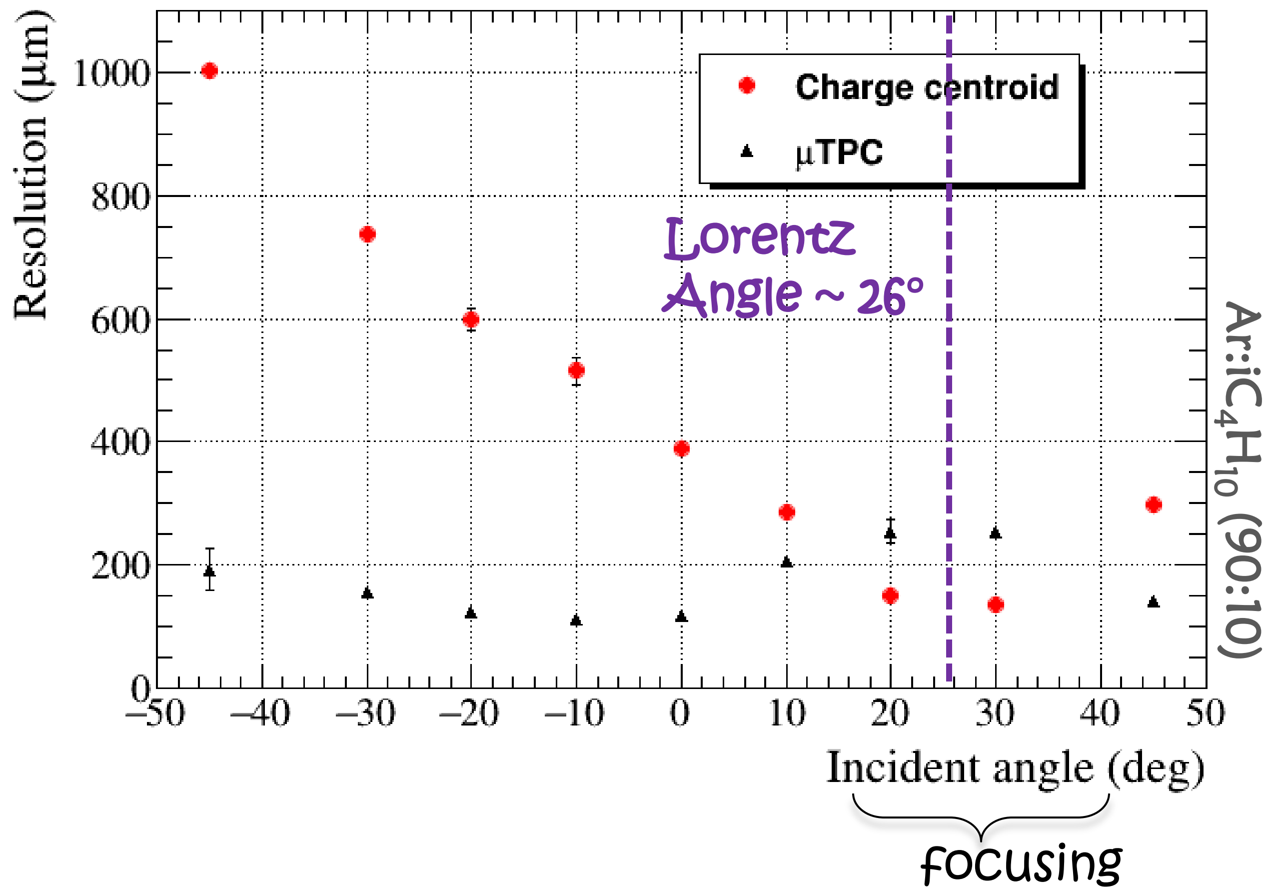


incident angle ~ 0°

only the magnetic field effect applies

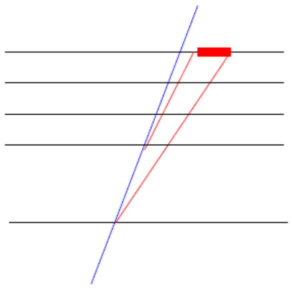
INCLINED TRACKS IN B ≠ 0

CASE 2



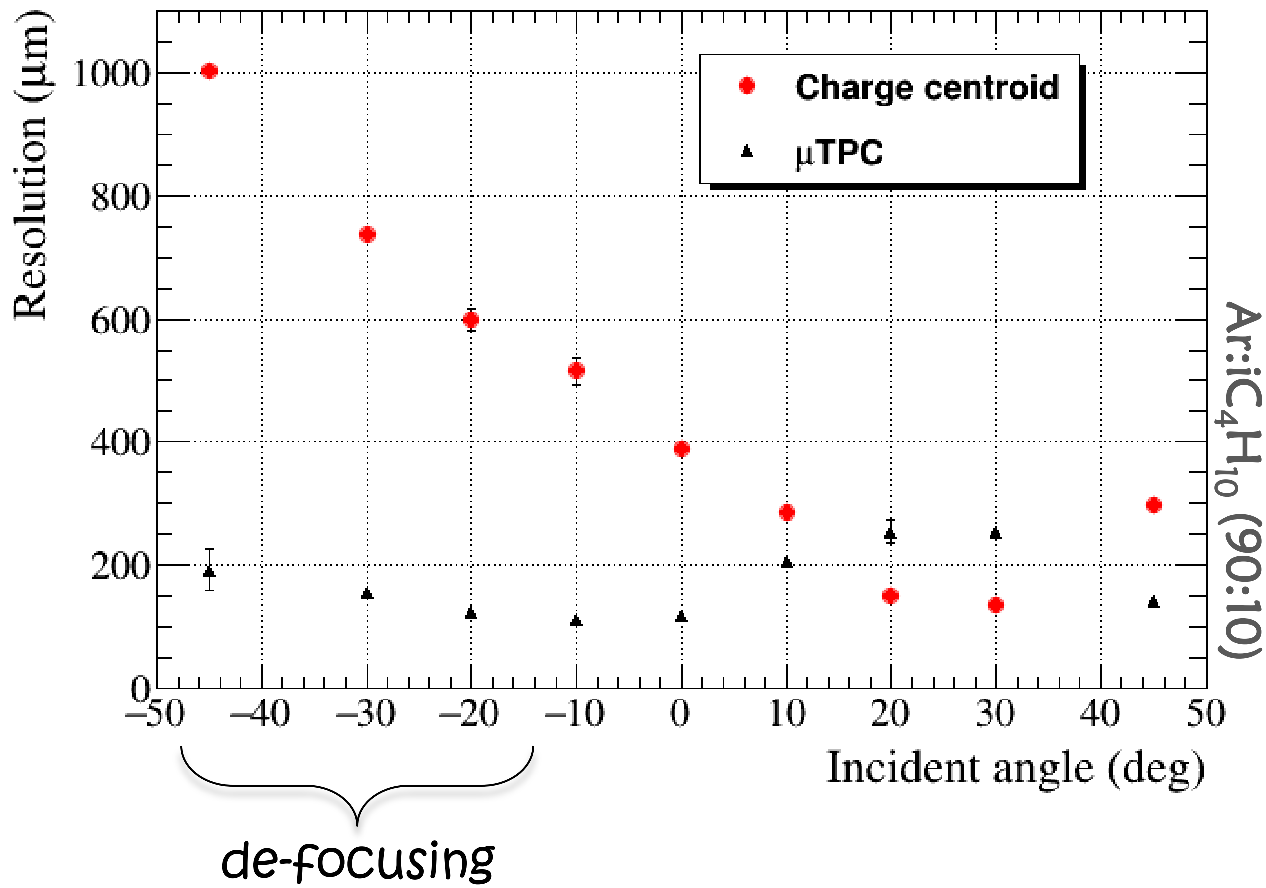
incident angle ~ Lorentz angle

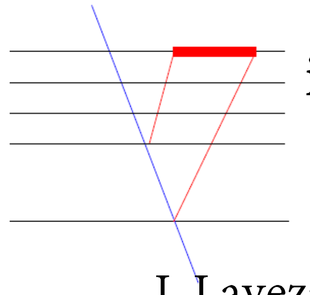
Shrunk cluster size



INCLINED TRACKS IN B ≠ 0

CASE 3

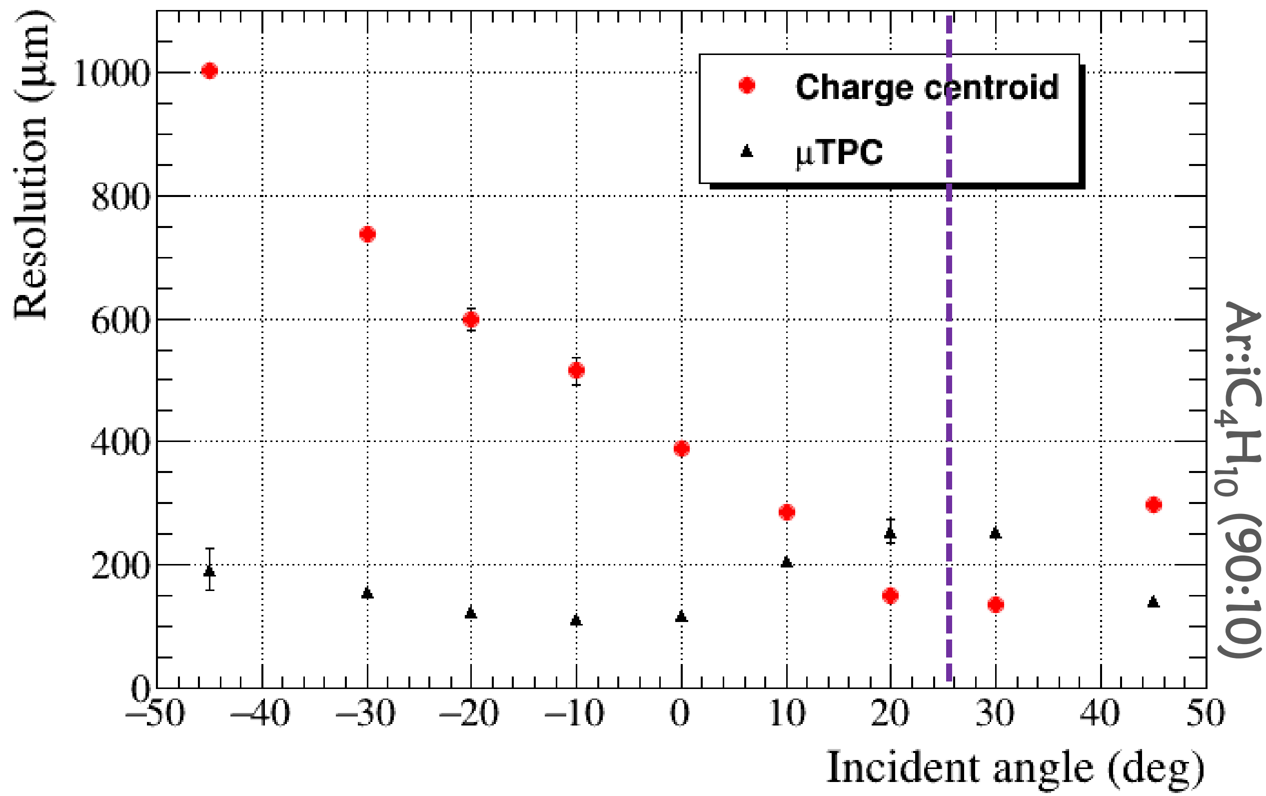


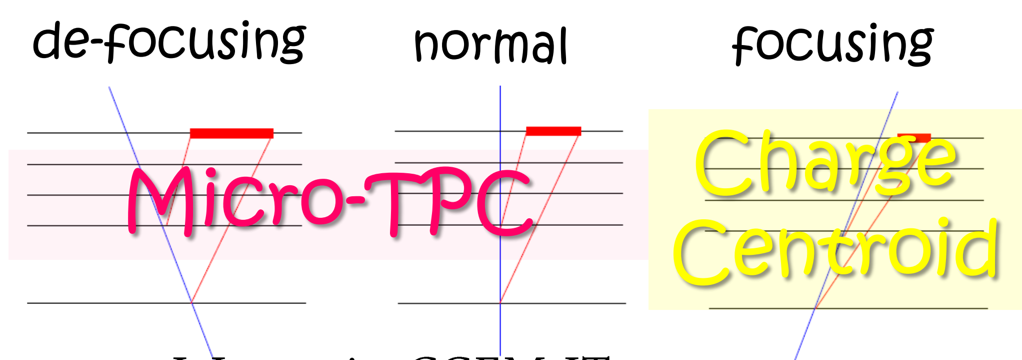


incident angle opposite to Lorentz angle

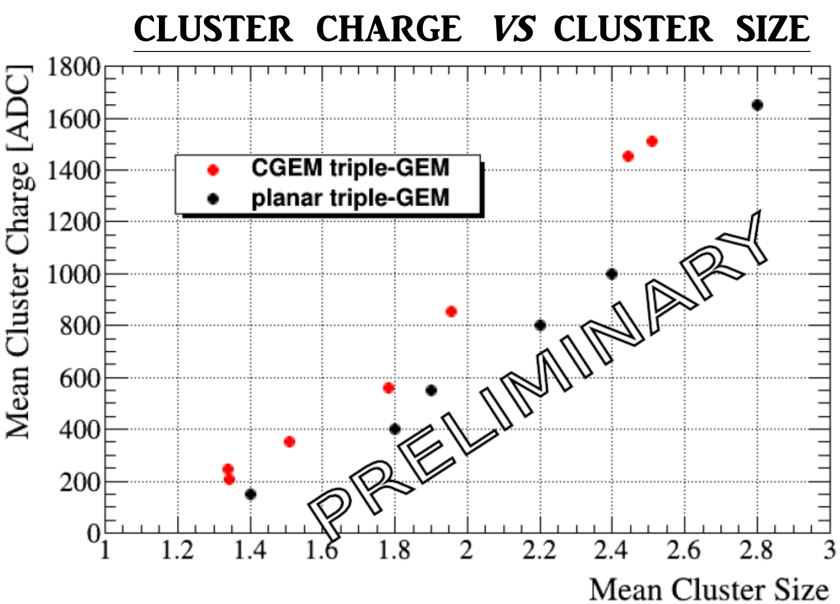
Enlarged cluster size

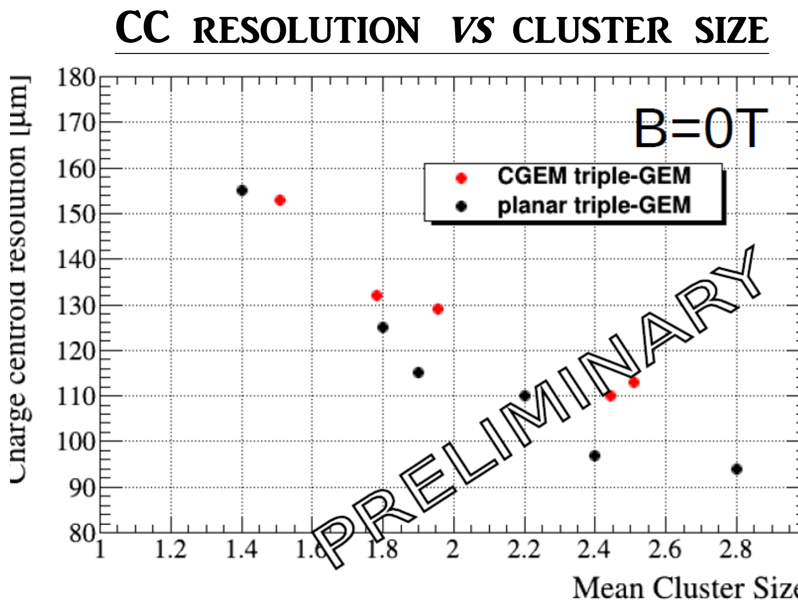
Inclined tracks in B ≠ 0





Comparison planar/cylinder





- Orthogonal π tracks and B = 0
- The cluster size shows the number of the fired strips. This is related to the signal dimension then to the gain and the drift properties of the electrons
- CC resolution shows that the CGEM and planar GEM performances are compatible within tens of µm

CONCLUSIONS

PLANAR CHAMBERS

Tested with and without magnetic field, with different gain (HV) and field values, with different gas mixtures. A combination of CC and μ-TPC reconstruction methods will provide the expected resolution in xy = 130 μm

CYLINDRICAL CHAMBER

Showed high stability with different HV and fields, under high intensity π beam.
Showed results comparable to the planar chambers without magnetic field

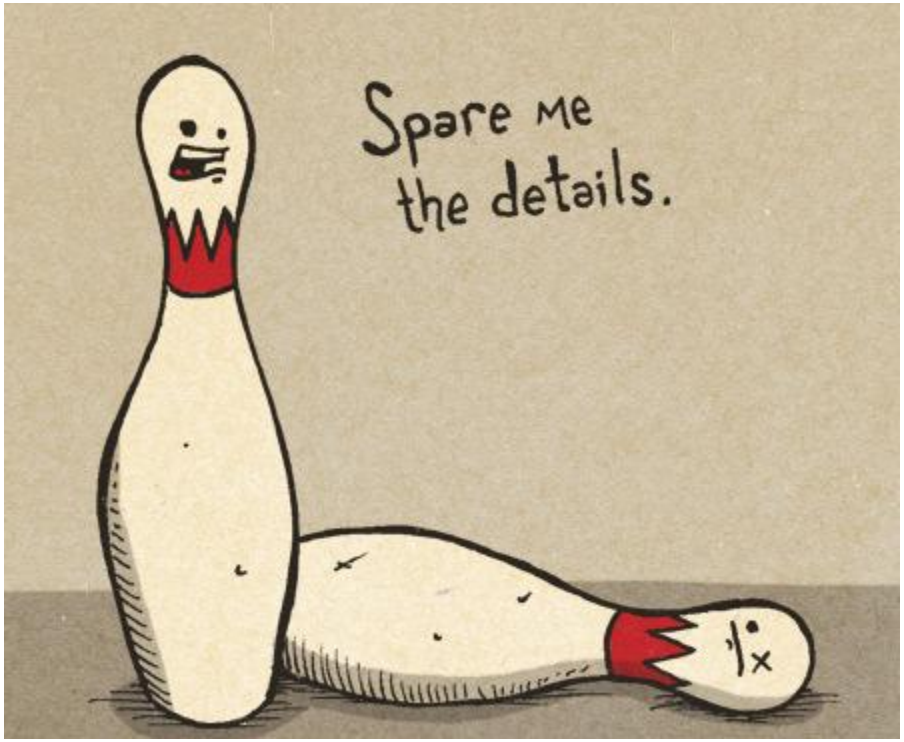
In July the *final layer 1* has been tested on the H4 line @ SPS, CERN

Further studies on efficiency and resolution ongoing on the cylinder

THE FULL CGEM-IT IS UNDER CONSTRUCTION
IT WILL BE COMPLETED AND COMMISSIONED IN 2018

在北京明年见！　　谢谢！

SPARE



BESIII detector & physics

Beam Pipe
berillium

Multilayer Drift Chamber
dp/p ~ 0.5% @ 1 GeV/c

Time Of Flight
Time res = 90 ps

Electromagnetic Calorimeter
CsI, dE/E ~ 2.5% @ 1 GeV

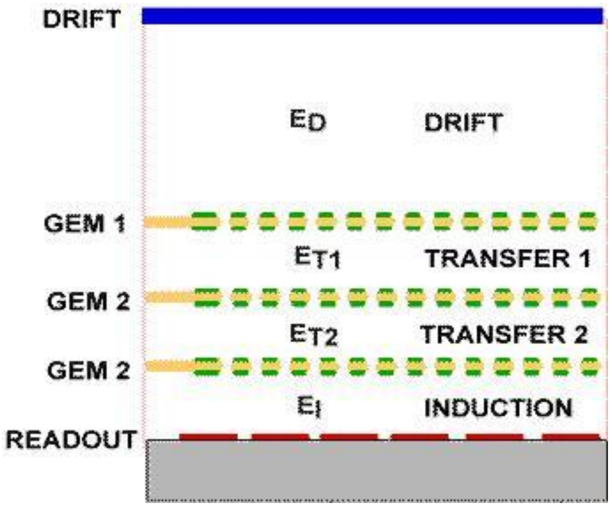
Solenoid Magnet
Superconducting, 1 Tesla

Muon system
RPC

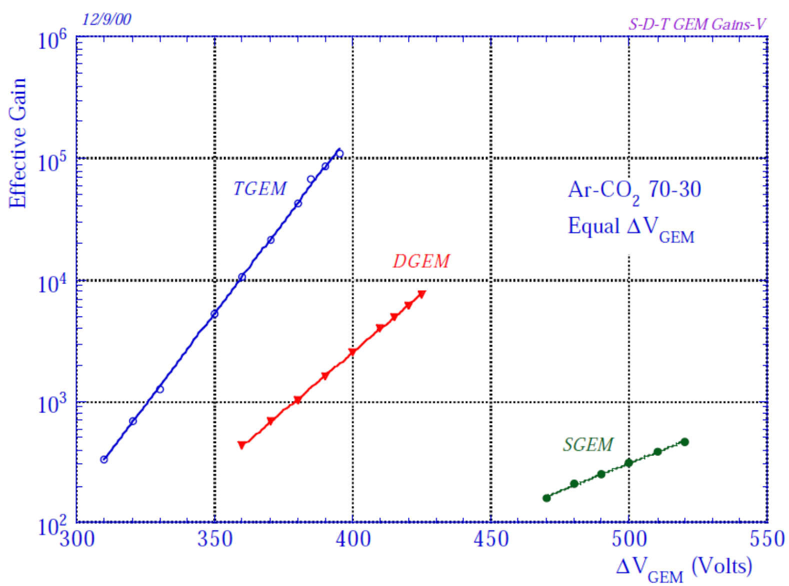
Physics program
- spectroscopy:
  - charmonium
  - charm
  - exotics0
  - light hadrons
- Form Factors
- τ physics

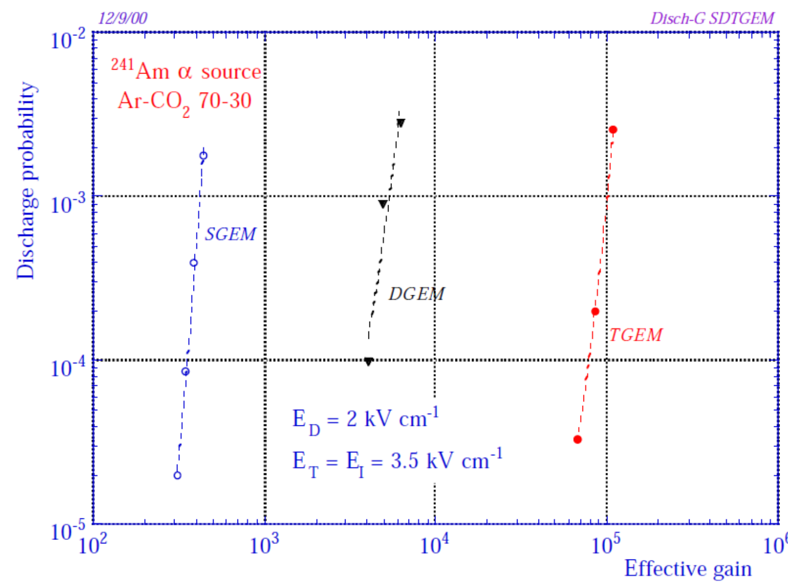
- CMS energy [2, 4.6] GeV
- Optimum @ 1.89 GeV
- Data rate = 5 kHz, 50 Mb/s

Triple GEM



Triple GEM are detectors where three GEM foils are arranged between anode and cathode, granting a final gain ~$10^3/10^4$ with lower voltages applied → lower discharge rates





[S. Bachmann et al, Nucl. Instr. and Meth A479 (2002) 294]

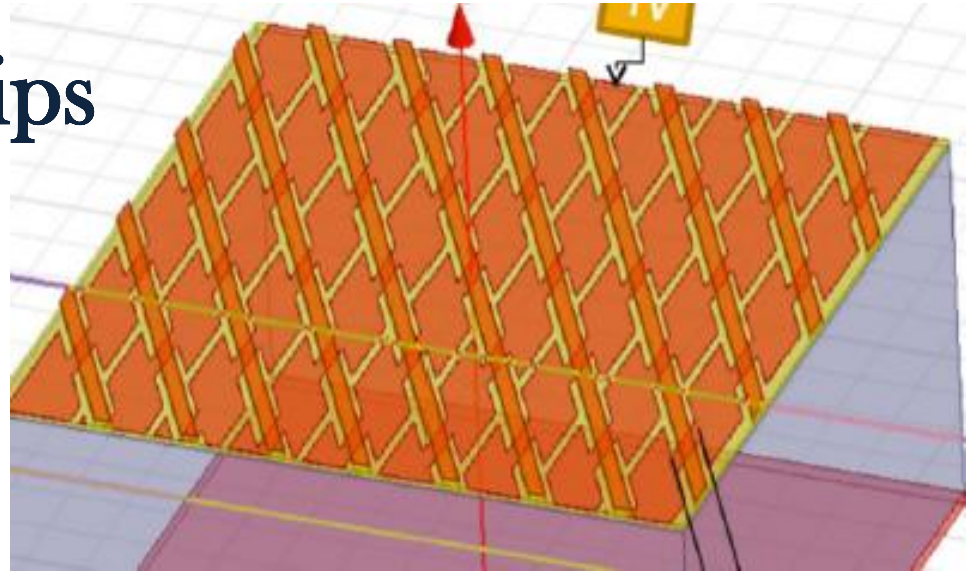
Example of HV and drift field settings

Ar/CO2 70/30

3655/3905 V

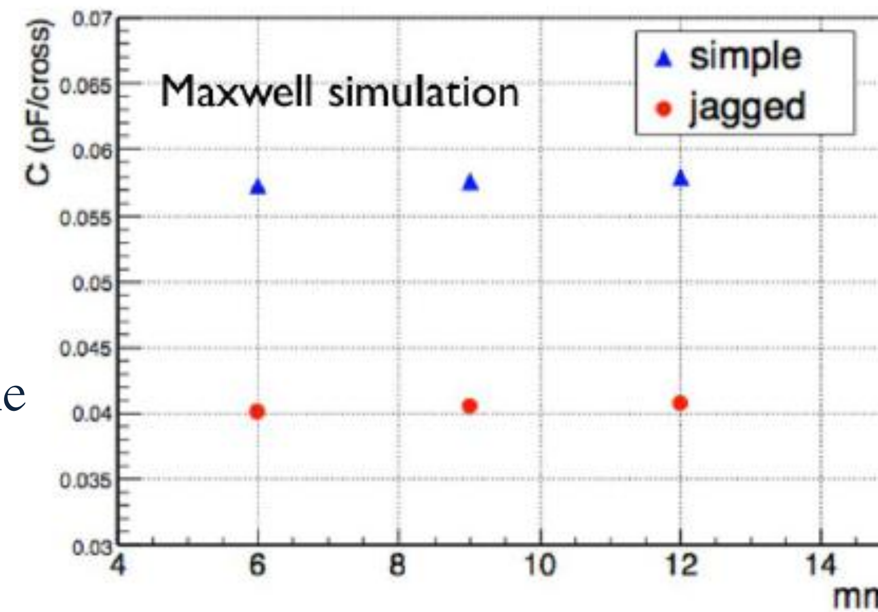
	Thickness (mm)	Voltage (V)	Field (kV/cm)
Cathode			
Gap	3 or 5	375/625	1.25
G1_TOP			
Gap	0.050	360	72
G1_BOTTOM			
Gap	2	600	3
G2_TOP			
Gap	0.050	360	72
G2_BOTTOM			
Gap	2	600	3
G3_TOP			
Gap	0.050	360	72
G3_BOTTOM			
Gap	2	1000	5
Anode		ground	

Jagged strips



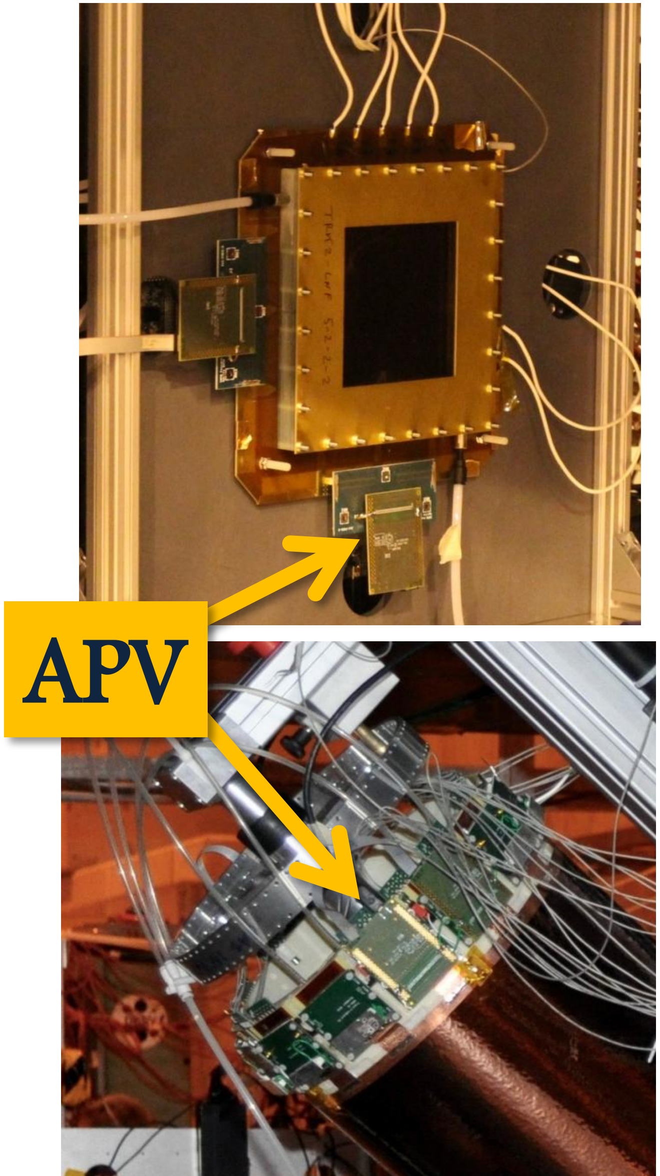
The x strips pitch is shrinked in coincidence of v strip crossings in order to decrease the inter-strip capacitance.

In figure:
- y axis: value of the capacitance at crossing between x and v strips (pF) from simulations
- x axis: value of the dimensions of the simulated area in MAXWELL



Study by I. Garzia – presented @ IEEE 2014

Readout @ testbeams

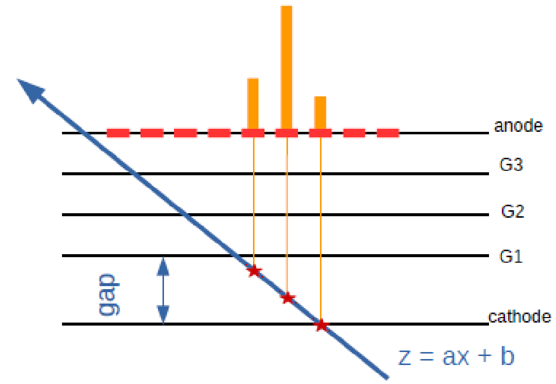


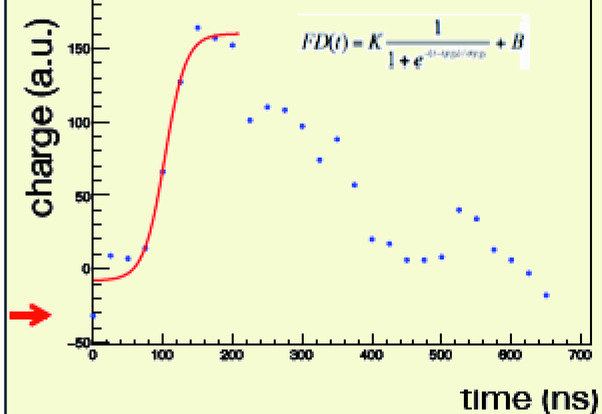
- The ASIC used for the readout is the APV-25
- Each APV has 128 channels, each one reads the charge and time of an anode strip
- Each channel has a flash-ADC which performs 27 **charge** samplings (one every 25 ns). The highest value is the "hit" charge.
- The number of bins in the charge axis is 2500 bins (-560; +1950)
- A typical event lasts **~100ns** (→4/5 time bins)

- ASIC = Application Specific Integrated Circuit
- PCB = Printed Circuit Board
- APV = Analogue Pipeline Voltage mode

The μ–TPC mode

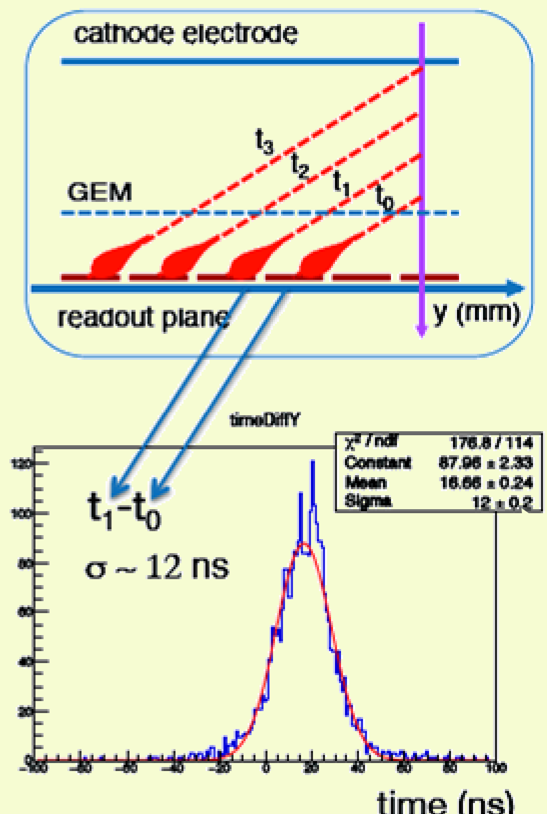
- inclined tracks and/or magnetic field → increased cluster size → μ-TPC mode available
- the drift gap is seen as a "*micro* time projection chamber" and the position of **each primary ionization** is reconstructed by knowing the electron drift velocity





STEP 1

∀ strip fit time samples of the charge with a Fermi-Dirac to **extract the t_i**

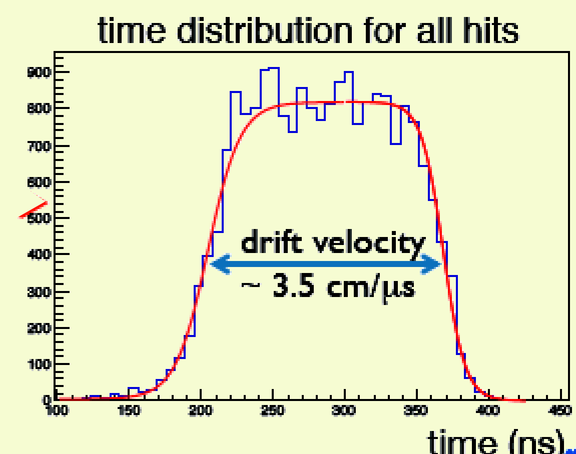


STEP 2

Δt resolution ~ **12 ns**

STEP 3

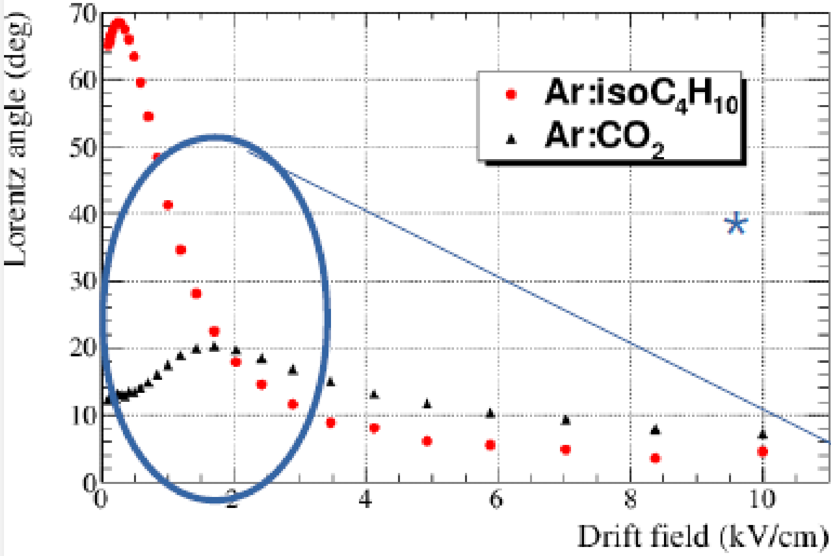
v_{DRIFT} from t_i distribution on 5 mm gap



Lorentz angle vs drift field

Study by R. Farinelli ~ presented @ IEEE NSS/MIC 2016

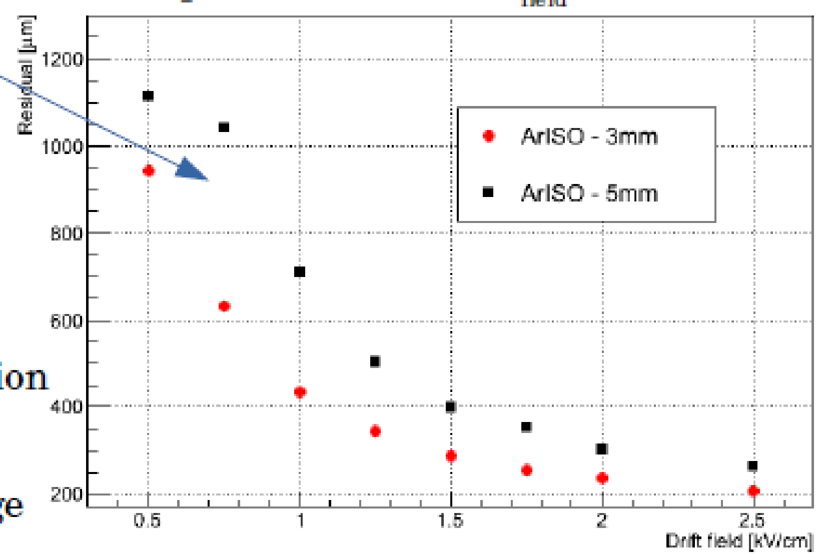
Optimization of the charge centroid @ 1 Tesla



- The behavior of the spatial resolution and the Lorentz angle are similar.

→ The worsening of the resolution of the charge centroid is due to the increasing of the Lorentz angle.

→ The drift field has to be increased to reduce the displacement of the B_{field}



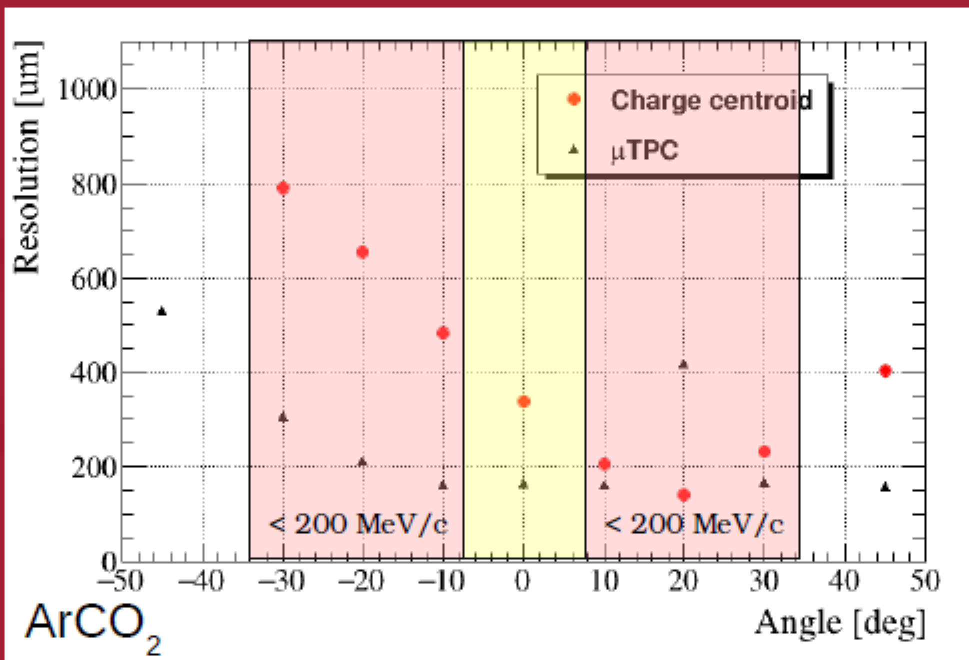
- Argon-Isobutane (90/10) with high field in the drift region reaches a spatial resolution of ~ 190 µm with magnetic field of 1 T
- The efficiency is flat within those field range

* Data from Garfield simulations

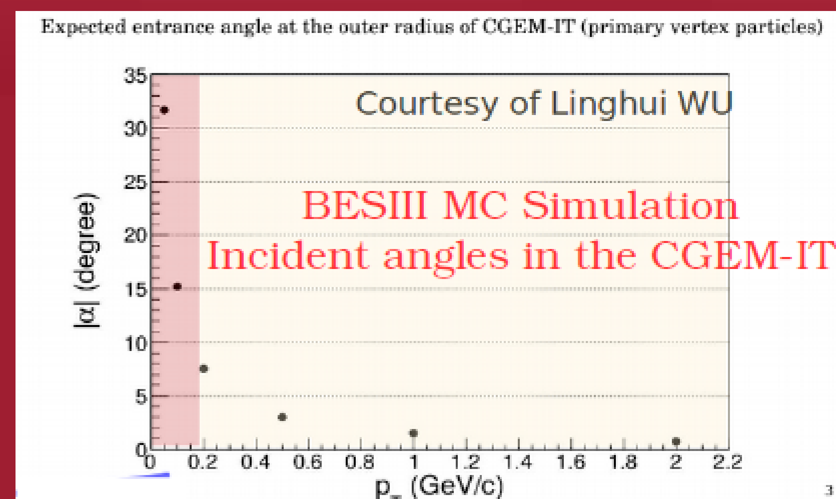
IEEE NSS/MIC Strasbourg, France 29 October – 5 November 2016 R.Farinelli 7

Field & angle

Results with angles and magnetic field



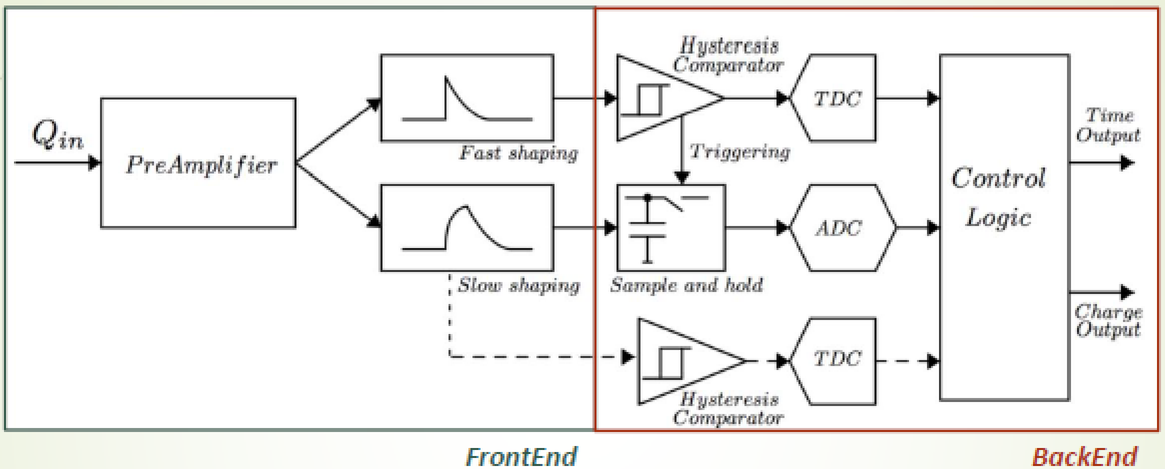
Spatial resolution is below 200 μm for very large angle interval



TIGER

- Provide **charge & time** measurements → analog readout
- Input charge: **1 – 50 fC**
- Sensor Capacitance: up to **100 pF**
- Rate per Channel: **60 kHz** (safety factor of 4 included)
- Time resolution: **4~5 ns**
- Power consumption ~ **10 mW/channel**
- Should be radiation tolerant for Single Event Upset

TIGER Design



Front End
- Charge Sensitive Amplifier + two shapers (Time and Charge)

Time-based readout
- Single or double threshold readout
- Time stamp on rising/falling edge (sub-50 ps binning quad-buffered TDC)
- Charge measurement with Time-Over-Threshold

Time and amplitude sampling
- Time stamp on rising edge (sub-50 ps binning quad-buffered TDC)
- Sample-and-Hold circuit for peak amplitude sampling

→ Slow shaper output voltage is sampled and digitised with a 10-bit Wilkinson AD

S. Marcello ~ presented @ CRETE2017