The Cylindrical GEM Inner Tracker of the BESIII experiment: prototype test beam results

LIA LAVEZZI

INFN – IHEP

ON BEHALF OF THE CGEM-IT GROUP

INSTRUMENTATION FOR COLLIDING BEAM PHYSICS INSTR-17

BINP, Novosibirsk, Russia - 27 February - 3 March, 2017

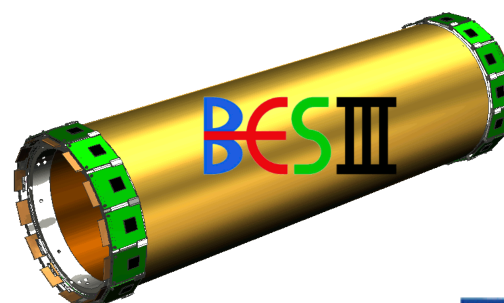
Outline

- BESIII experiment
- CGEM-IT project description
- Test beam of prototype I – PLANAR
- Test beam of prototype II – CYLINDRICAL

BESIIICGEM project has been **funded by the European Commission** within the call H2020-MSCA-RISE-2014

Members of the consortium:

- INFN (Ferrara, LNF, Torino)
- Mainz
- Uppsala
- IHEP

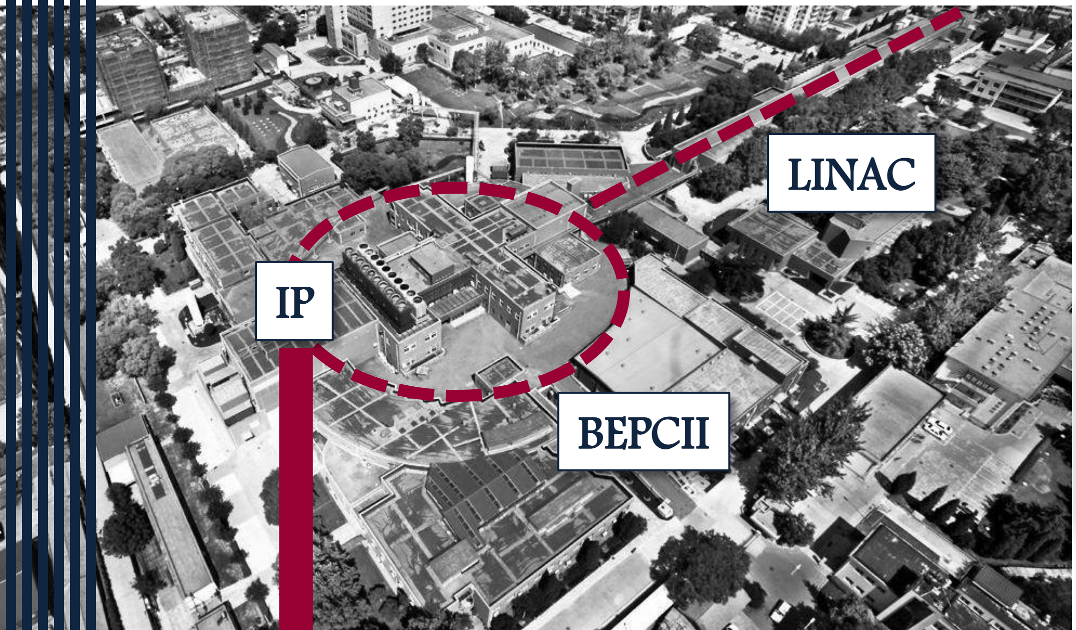


HORIZON 2020

European Commission

BESIII @ BEPCII

Beijing Electron Positron Collider II

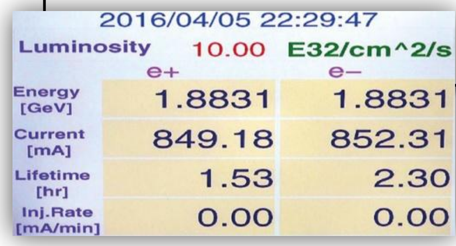


Data taking 2009 ~ today

Beam energy 1~2.1 GeV

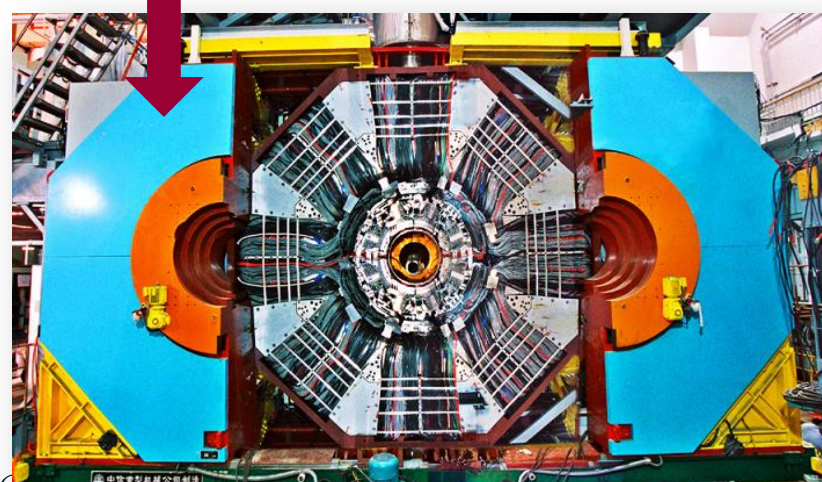
Design luminosity $1 \cdot 10^{33}$ cm^{-2}s^{-1}

@1.89 GeV


2016/04/05 22:29:47

Luminosity	10.00	E32/cm^2/s
	e+	e−
Energy [GeV]	1.8831	1.8831
Current [mA]	849.18	852.31
Lifetime [hr]	1.53	2.30
Inj.Rate [mA/min]	0.00	0.00

ACHIEVED



BEijing Spectrometer III

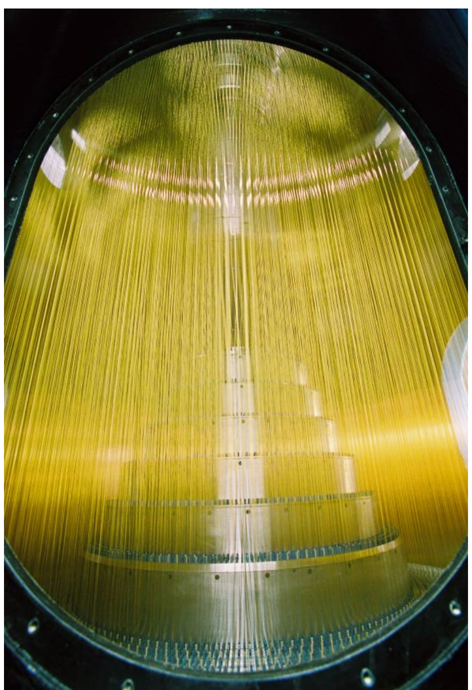
charm & τ factory @
Ecms = 2 – 4.6 GeV

- ~400 members
- 14 countries

Inner Tracker: the present - MDC

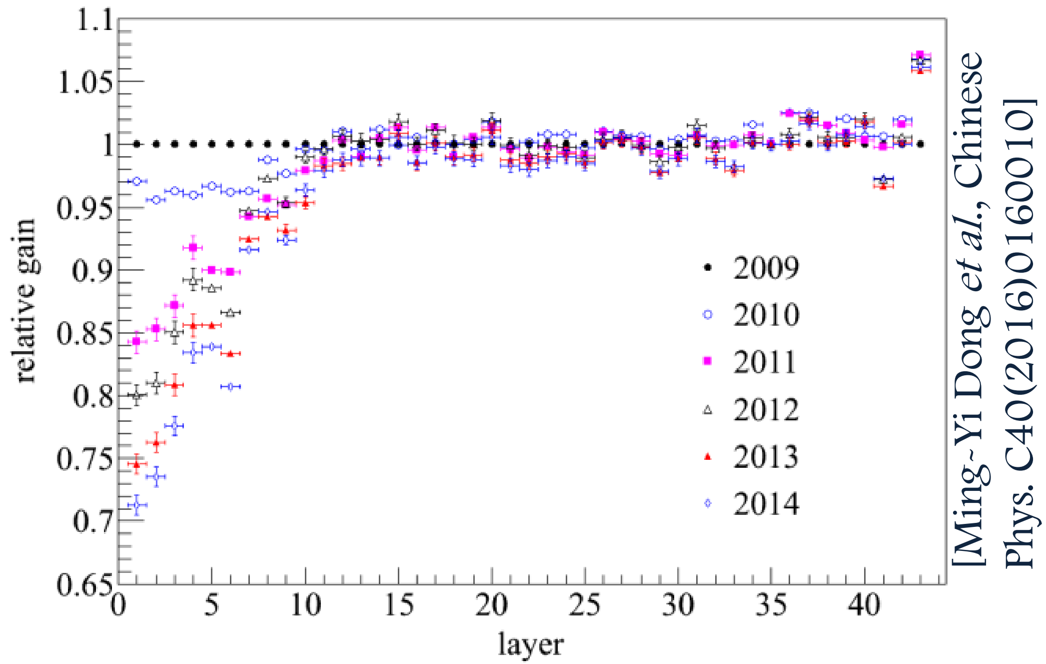
Multilayer Drift Chamber

- Inner Tracker:
  - 8 stereo layers
- Outer Tracker:
  - 12 axial layers
  - 16 stereo layers
  - 7 axial layers



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

AGING PROBLEM



Gain loss/year ~ 4%
on the innermost layers

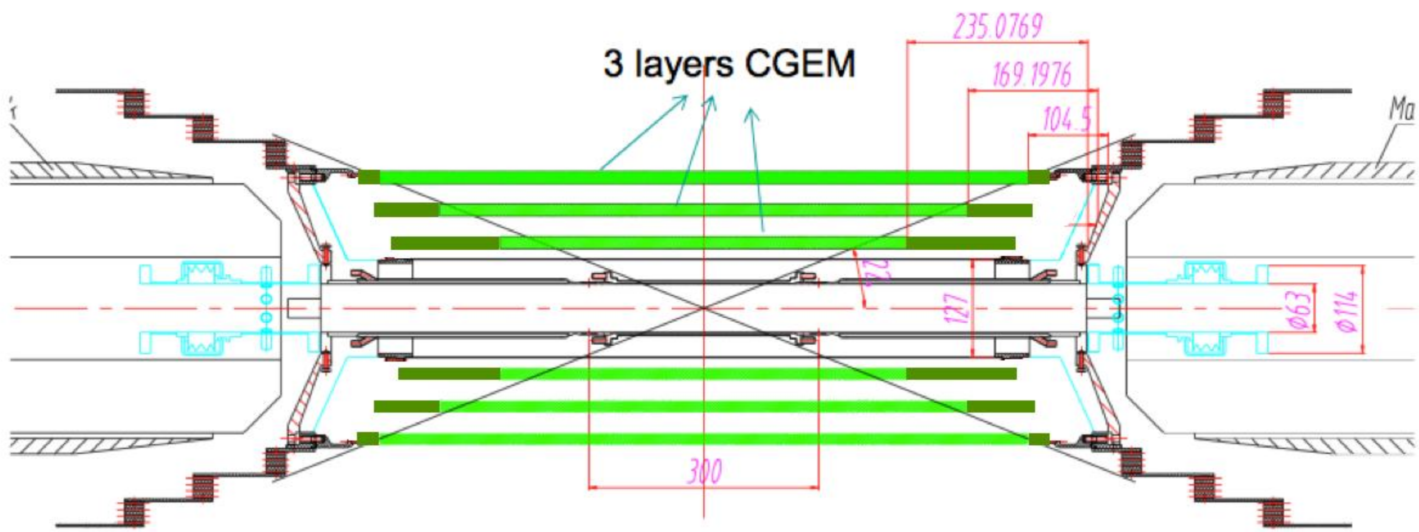
Inner Tracker: the future - CGEM

Cylindrical Gas Electron Multiplier

substitute the 8 inner layers of the MDC with 3 layers of cylindrical triple-GEM

REQUIREMENTS

- momentum resolution 0.5% @1 GeV/c
- r-ϕ spatial resolution 130 μm
- azimuthal coord. res. **1 mm**
- able to run until **2022**



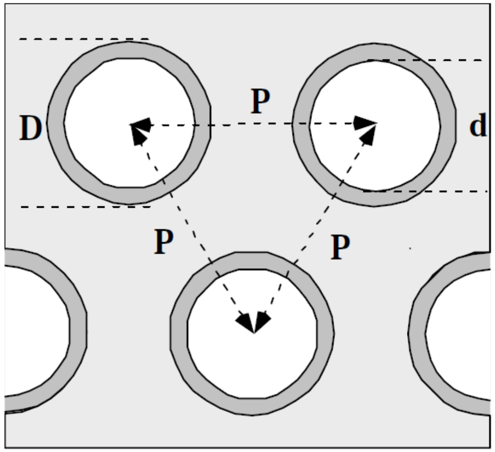
GEOMETRICAL REQUIREMENTS

- inner radius 78 mm
- outer radius 179 mm

- angular coverage 93%
- $X_0 < 1.5$ %
- particle rate ~ 10^4 Hz/cm^2

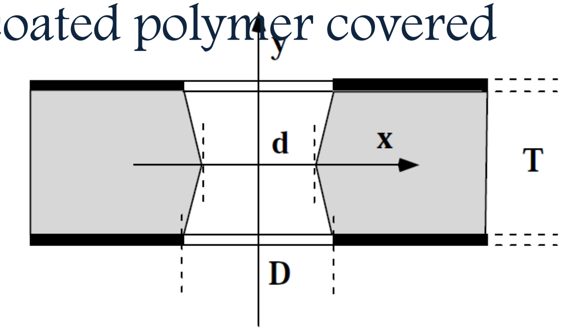
What is a GEM?

It is a gas detector invented by F. Sauli in 1997



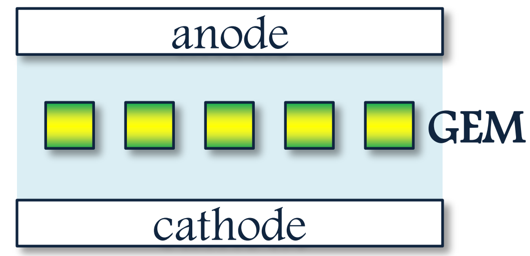
The GEM foil is a metal-coated polymer covered with holes Ø ~ 50 μm

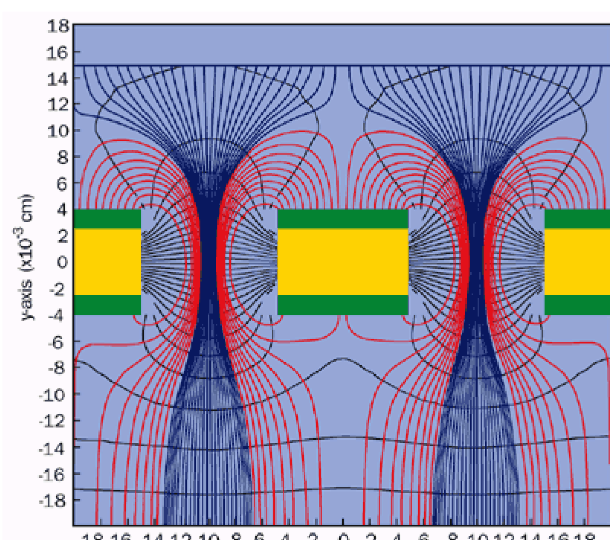
- 3-5 μm copper
- 50 μm kapton
- 3 μm copper



[S.Bachmann et al., CERN-EP/99-48]

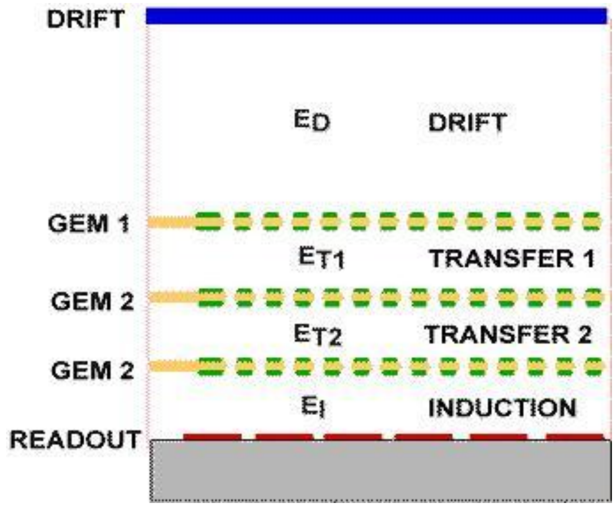
The GEM foil is placed between anode and cathode and a potential is applied to its faces (200/400 V)



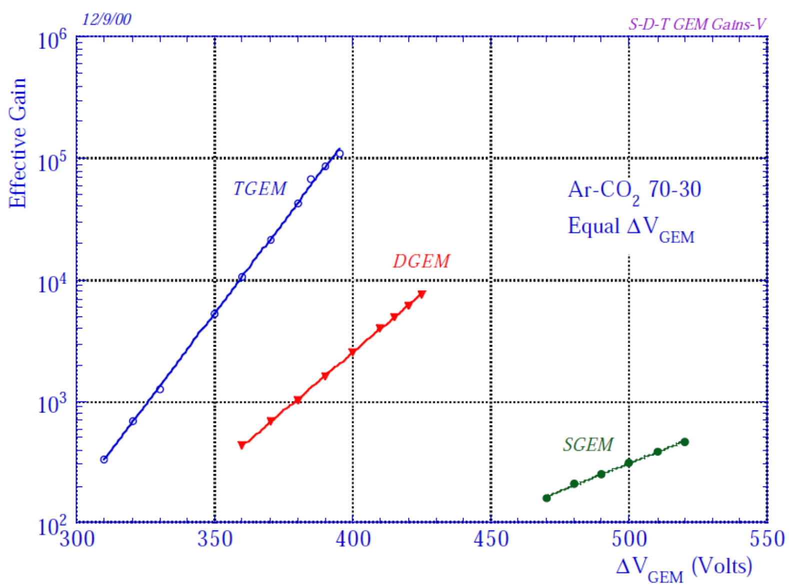


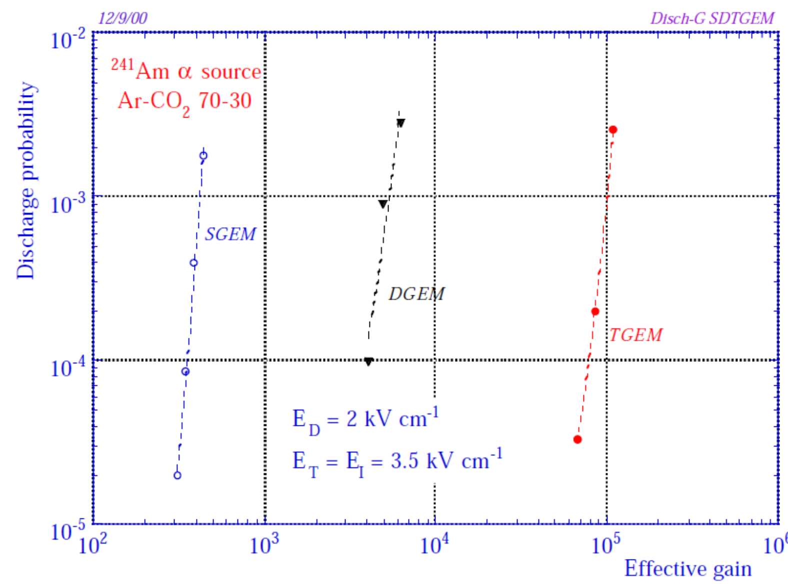
An electric field is then present and the drifting electrons along the field lines enter the holes where the field is sufficiently intense (some tenth kV/cm) to create avalanche multiplication → GAIN

What is a 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

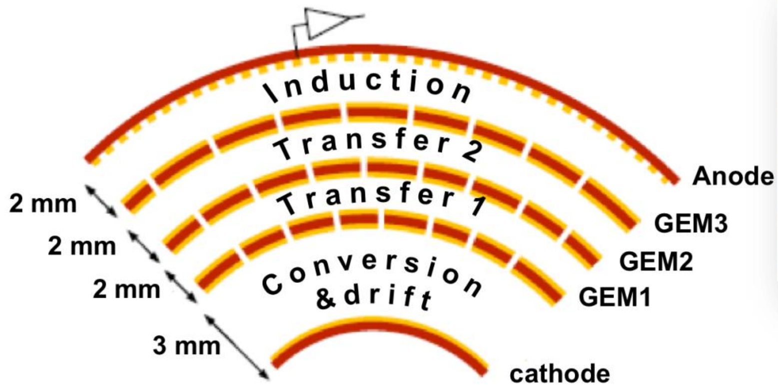




[S. Bachmann et al, Nucl. Instr. and Meth A479 (2002) 294]

What is a cylindrical triple GEM?

The **first cylindrical triple GEM** was built and installed for **KLOE-2** (Frascati)



[A. Balla *et al.*, NIM A732(2013)221]

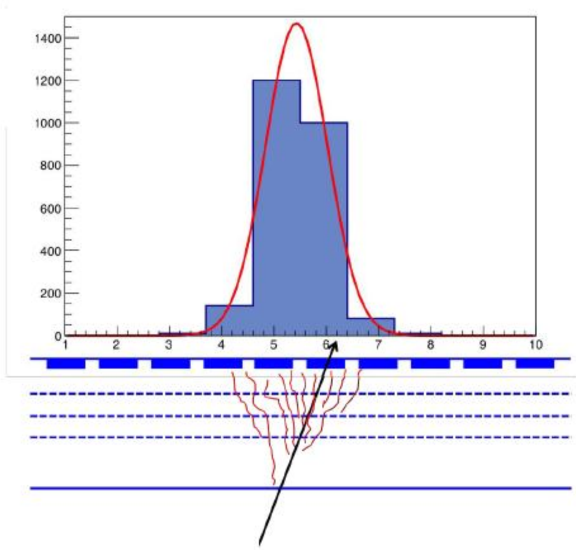
BESIII borrows the construction procedure from KLOE-2:

1. Production of the GEM and electrodes foils. Gluing of two foils to get a bigger surface
2. Shaping and gluing on molds: the electrode is put around the mold and surrounded by a vacuum bag to obtain the perfect cylindrical shape
3. Layer assembly by means of the **Vertical Inserting Machine**

[A. Balla *et al.*, 2014 JINST 9 C01014]

BESIII CGEM originality

Measurements with triple GEM in magnetic field & with analog readout



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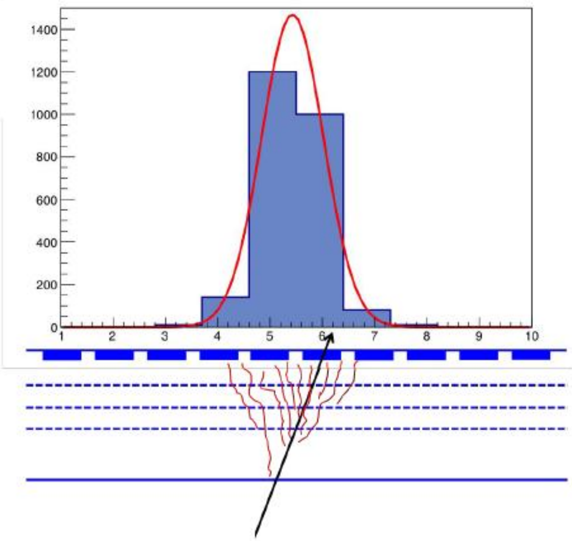
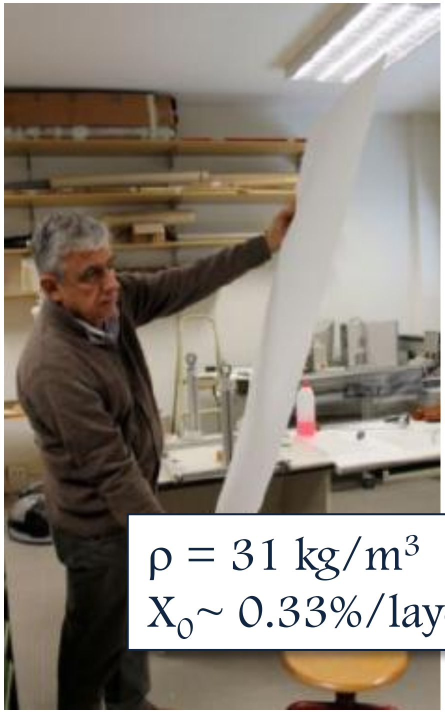


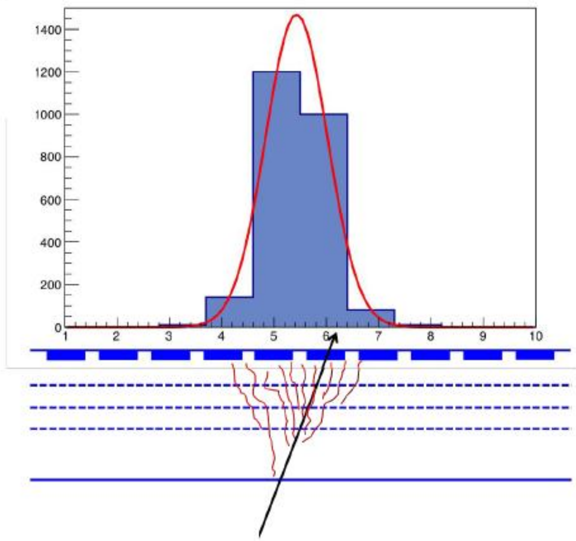


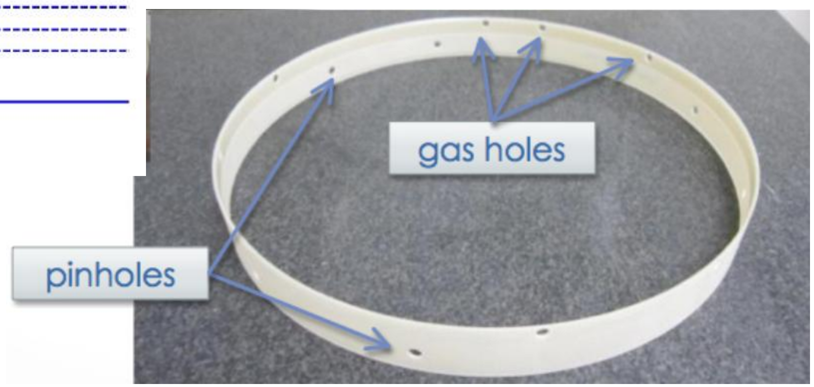
ρ = 31 kg/m^3
X_0~ 0.33%/layer

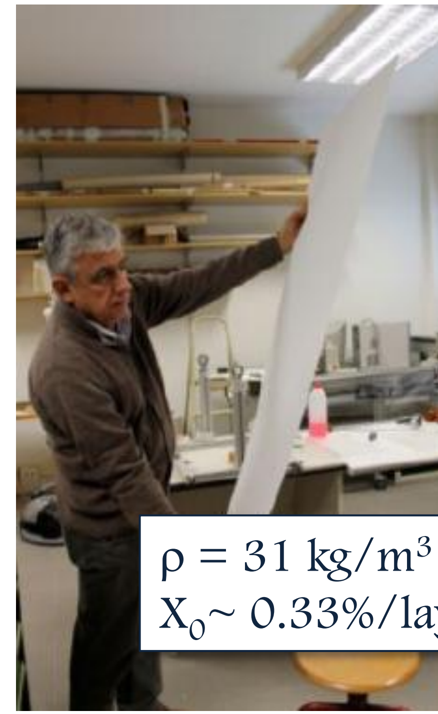
- Mechanics
  - Rohacell 31

BESIII CGEM originality

Measurements with triple GEM in magnetic field & with analog readout







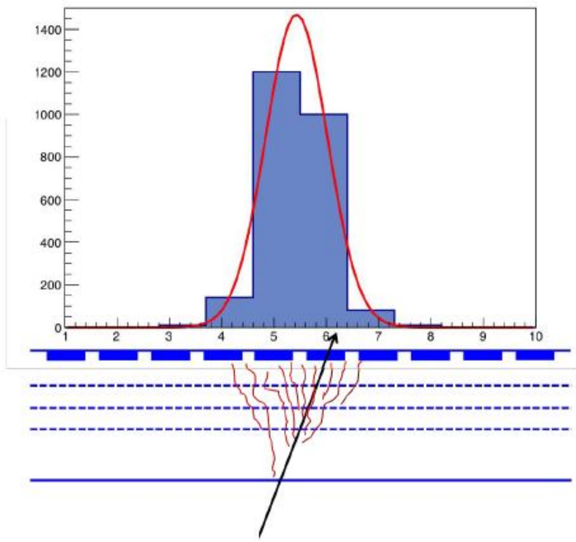
$\rho = 31\ kg/m^3$

$X_0 \sim 0.33\%/\text{layer}$

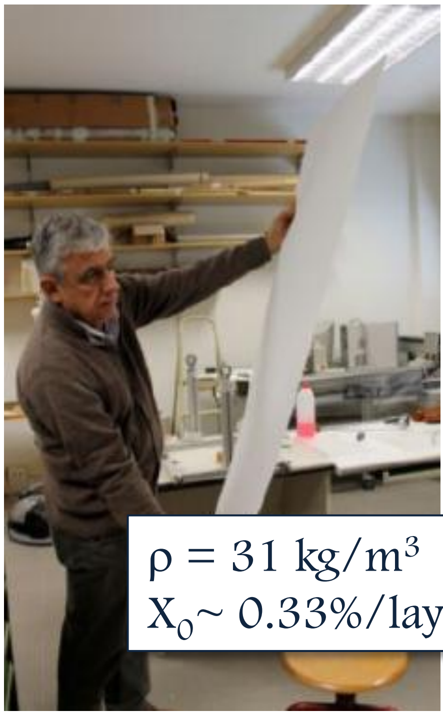
- **Mechanics**
  - Rohacell 31
  - permaglass rings only outside the active area

BESIII CGEM originality

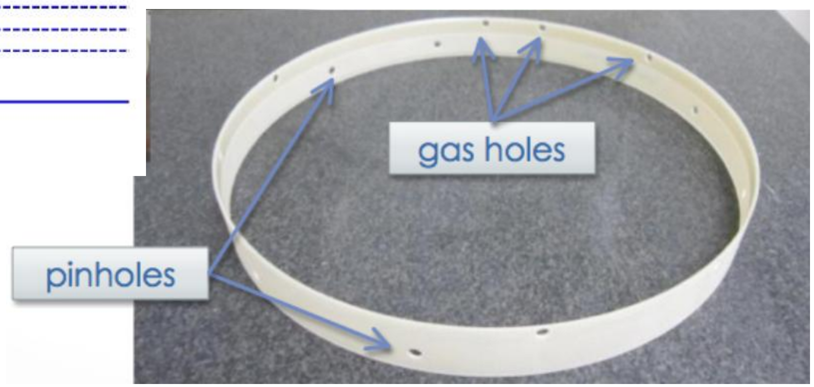
Measurements with triple GEM in magnetic field & with analog readout



Torino **I**ntegrated
Gem **E**lectronics for
Readout
[M. Rolo "A custom readout electronics for the BESIII CGEM detector"]



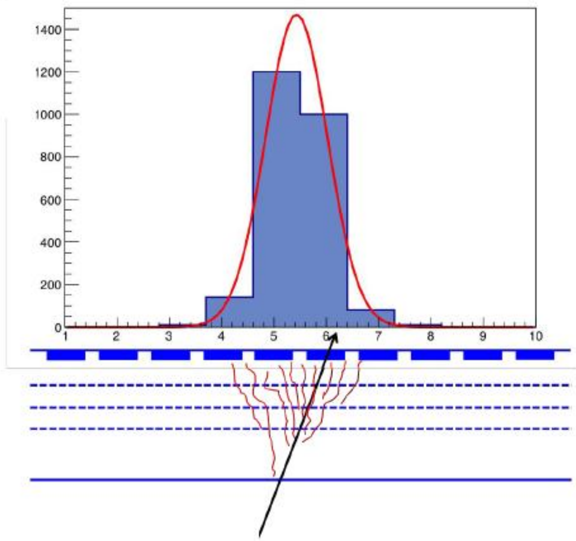
ρ = 31 kg/m^3
X_0~ 0.33%/layer



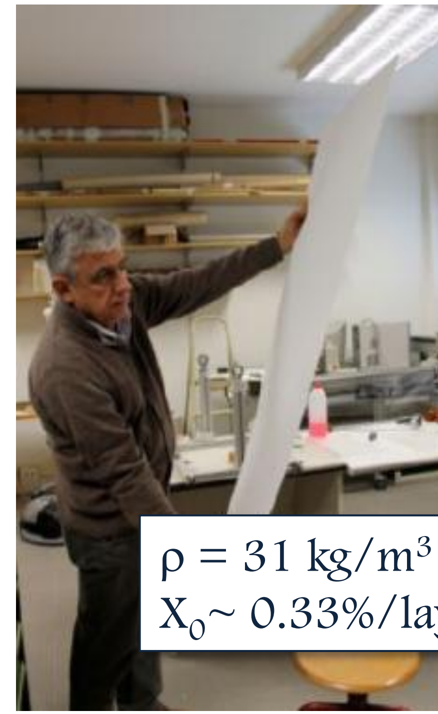
- **Mechanics**
  - Rohacell 31
  - permaglass rings only outside the active area
- **Readout**
  - Dedicated ASIC

BESIII CGEM originality

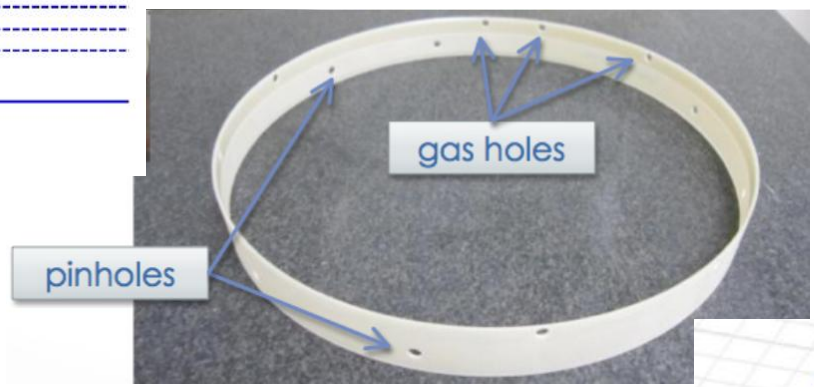
Measurements with triple GEM in magnetic field & with analog readout



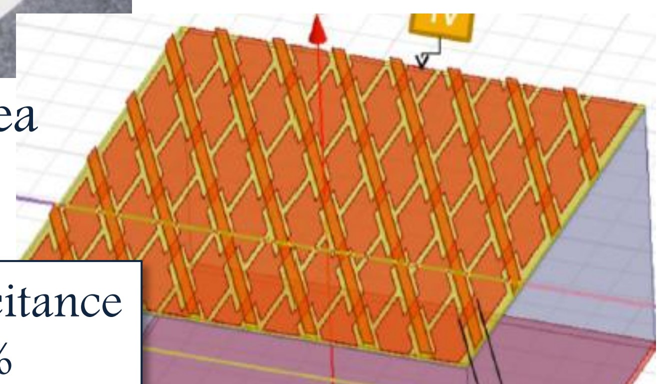
Torino Integrated Gem Electronics for Readout [M. Rolo "A custom readout electronics for the BESIII CGEM detector"]



$\rho = 31\ kg/m^3$
$X_0 \sim 0.33\%/layer$



- Mechanics
  - Rohacell 31
  - permaglass rings only outside the active area
- Readout
  - Dedicated ASIC
  - Jagged strips



Inter-strip capacitance reduced of ~30%

The TB environment

Location

- H4 beam line @ in the SPS line North Area, CERN

Magnetic field:

- GOLIATH dipole
- B from -1.5 T to +1.5 T

Beam

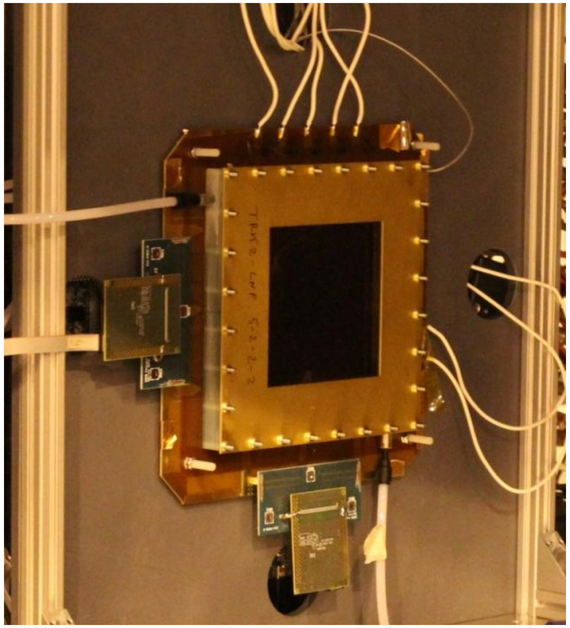
- muons/pions
- momentum: 150 GeV/c
- intensity = 2k evts/spill

RD51

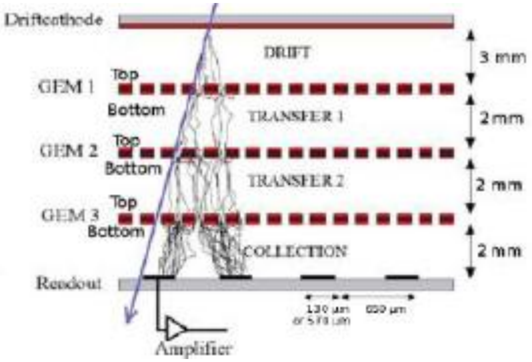
Test Beams

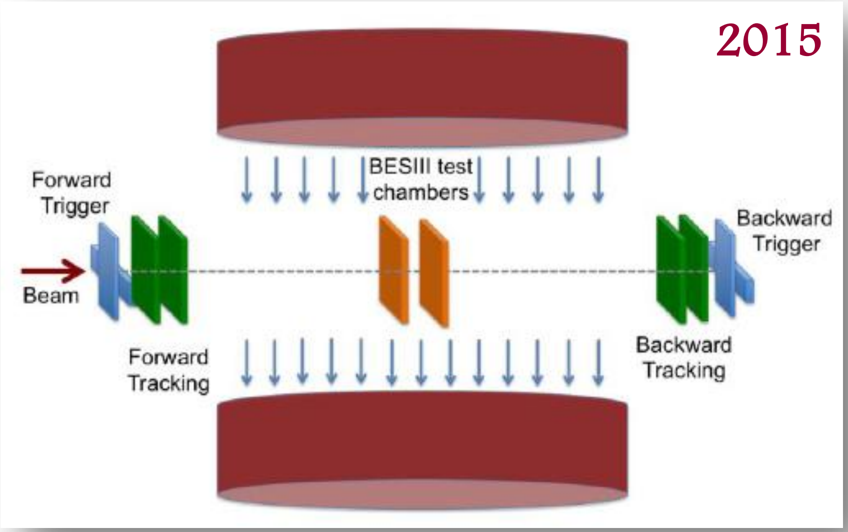
- with planar chambers - June 2015
- with planar chambers - May/June 2016
- with cylindrical chamber - October 2016

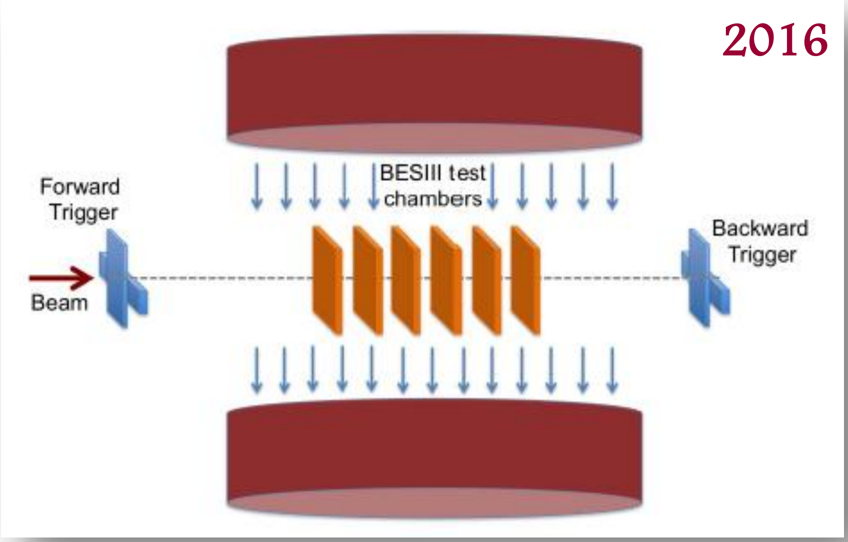
PLANAR chambers



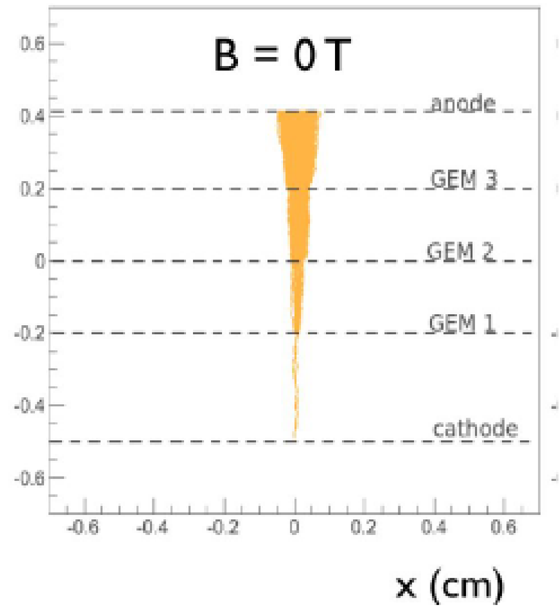
- 10×10 cm^2 triple GEM
- x view + y view
- strip pitch 650 μm
- gas mixtures:
  - Ar/CO_2 (70/30%)
  - Ar/Iso (90/10%)
- ASIC APV-25

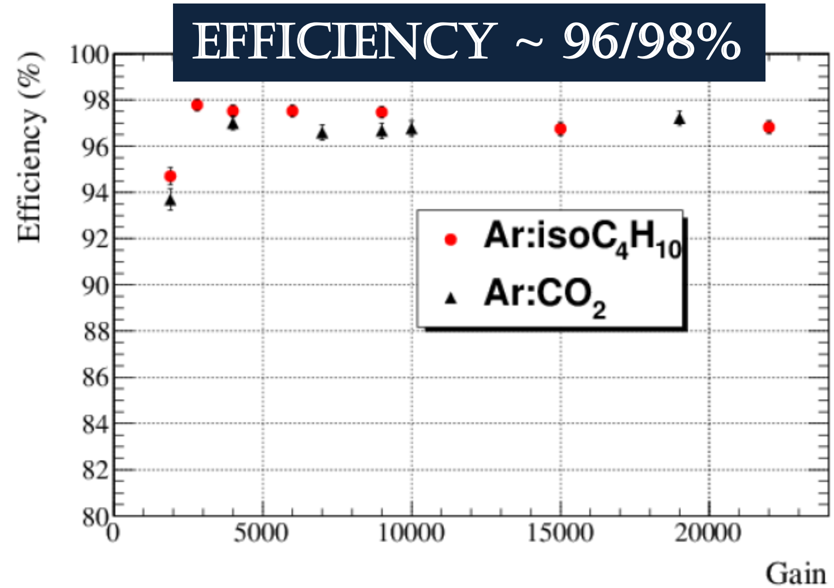


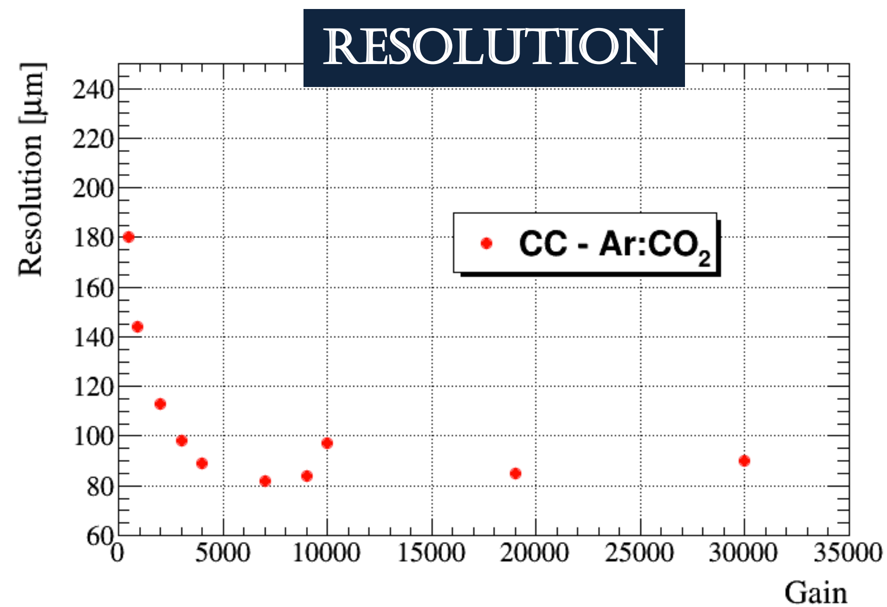




Results for orthogonal tracks and B = 0





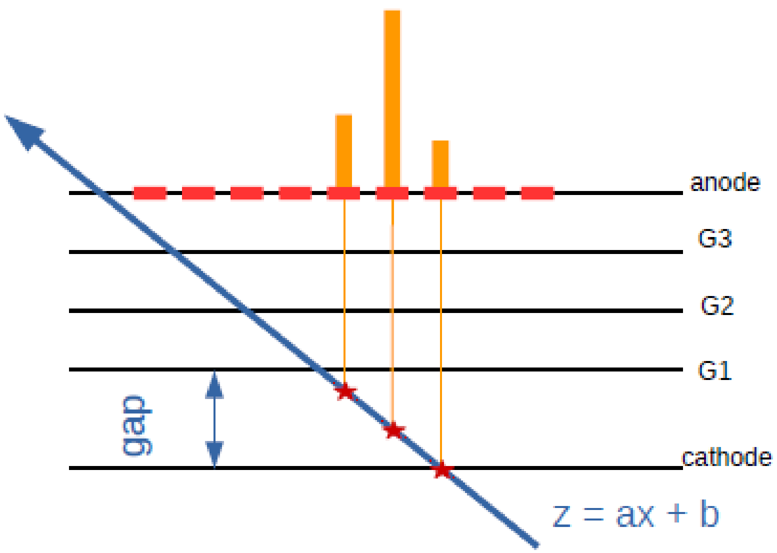


- The charge distribution on anode is gaussian
→ **charge centroid**

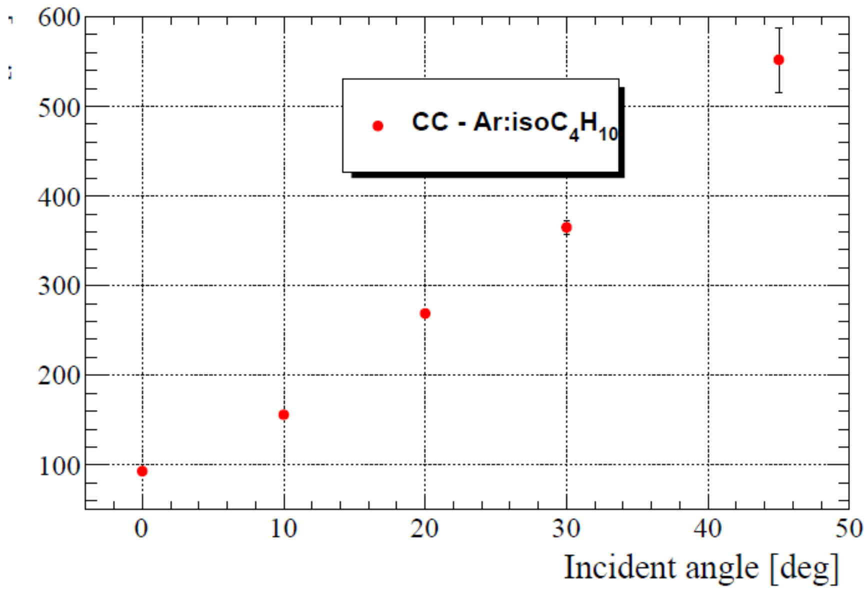
$$< x > = \frac{\sum_i x_i q_i}{\sum_i q_i}$$

[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016]

Issue 1: inclined tracks



RESOLUTION

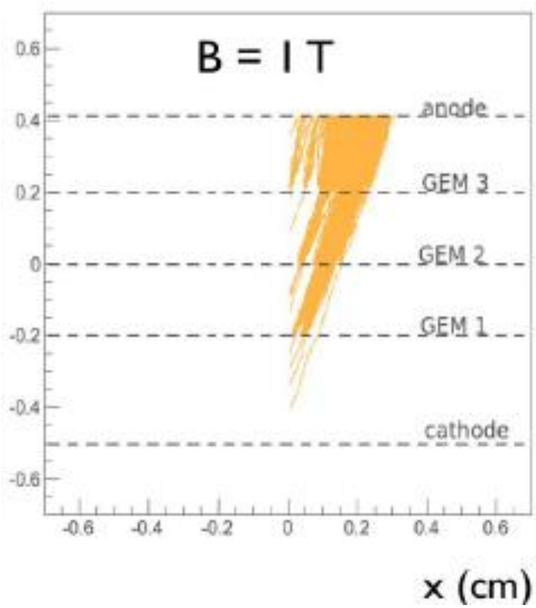


[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016]

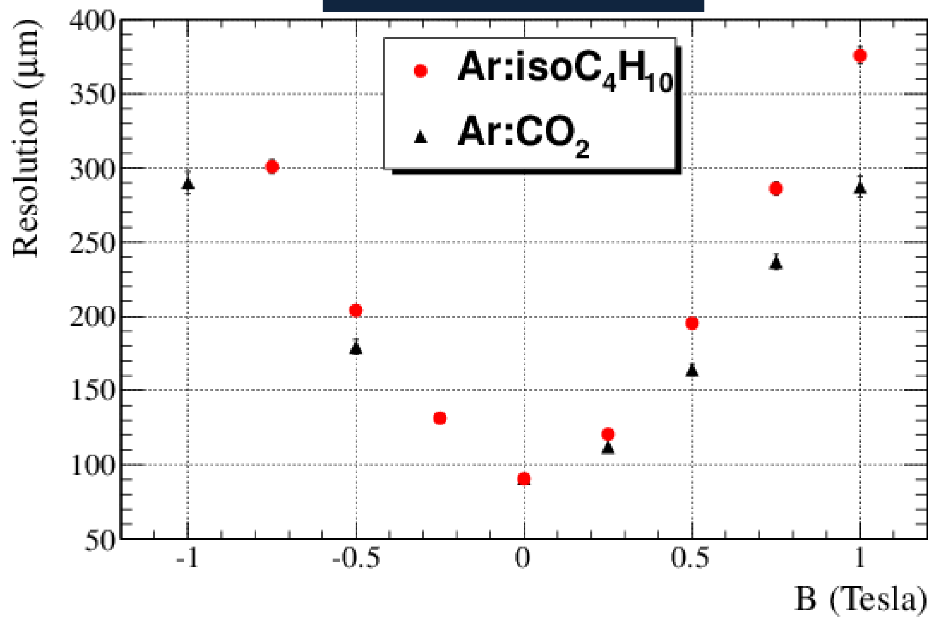
- the cluster size increases and the charge distribution at anode is no longer gaussian
→ the charge centroid starts failing

Issue 2: magnetic field ≠ 0

- The simultaneous presence of **E and B** creates a **Lorentz force ∝ qE + B** which bends the drift electron trajectories → charge distribution nomore gaussian
→ again, charge centroid failing

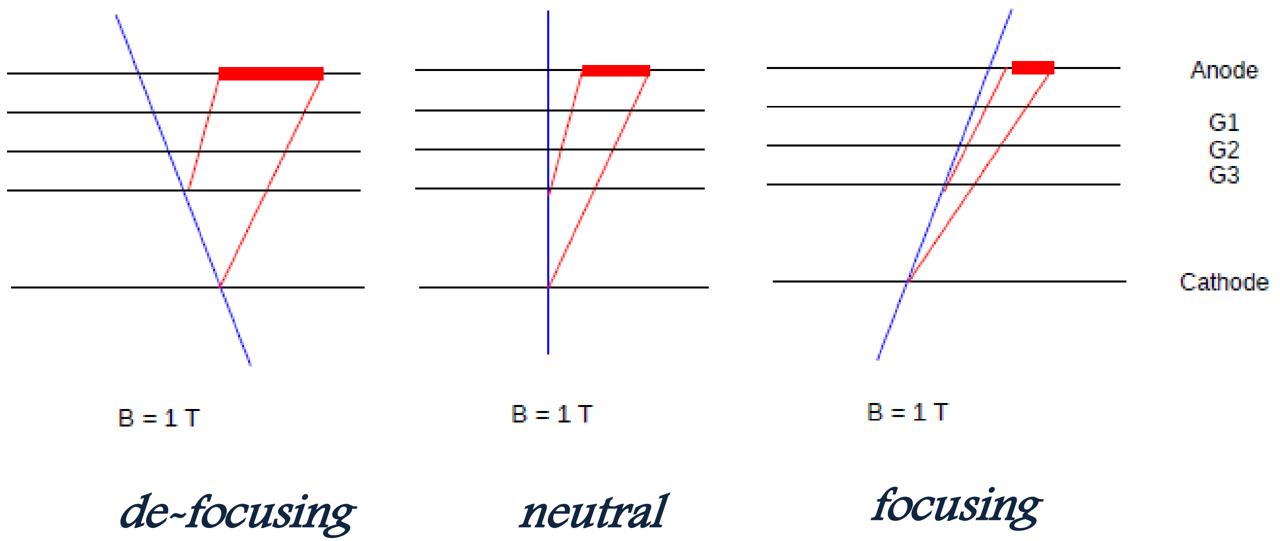


RESOLUTION



[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016]

Issue 3: issue 1 + issue 2



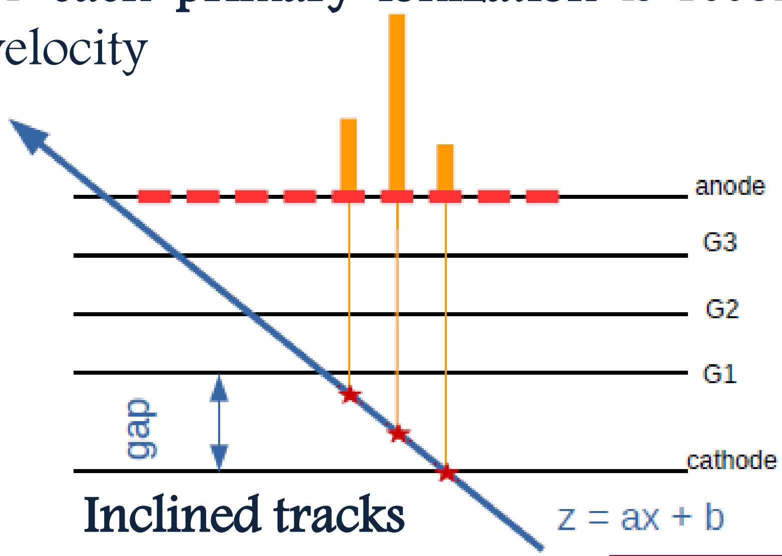
- When inclined tracks are inside magnetic field there are two possibilities:
  - *focusing* effect: Lorentz & inclination angles concordant
  → smaller cluster size
  - *de-focusing* effect: Lorentz & inclinaton angles discordant
  → bigger cluster size

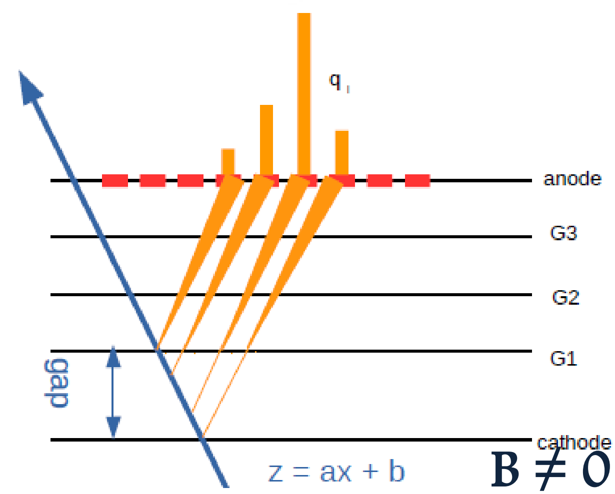
A new position reconstruction method is needed

The μ–TPC mode

- inclined tracks and/or magnetic field → increased cluster size → μ-TPC mode available [M. Iodice, JINST, 9 C01017, 2014]

- 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



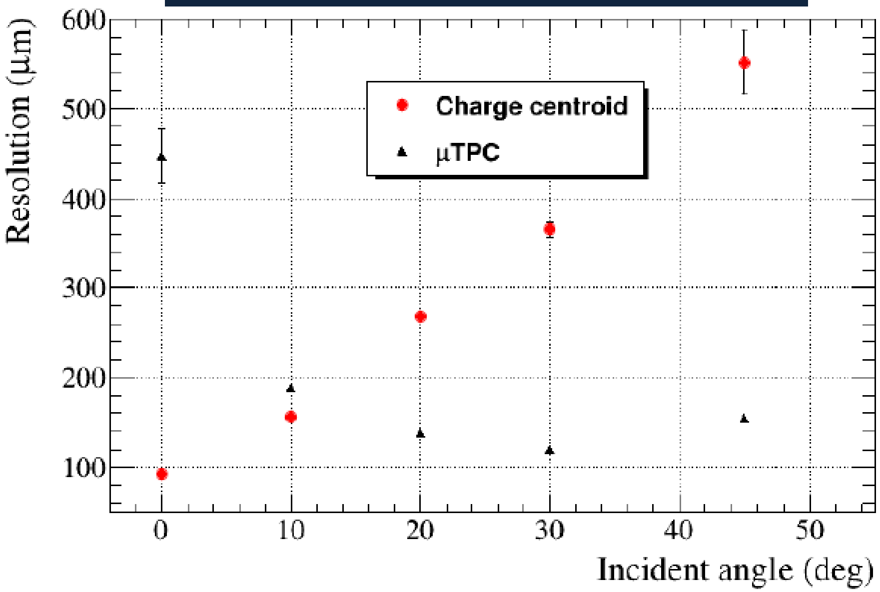


$$x = \frac{\frac{gap}{2} - b}{a}$$

The μ–TPC mode - resolution

- CC and μ–TPC are complementary → a combination of the two will give the best resolution

B=0/INCLINED TRACKS



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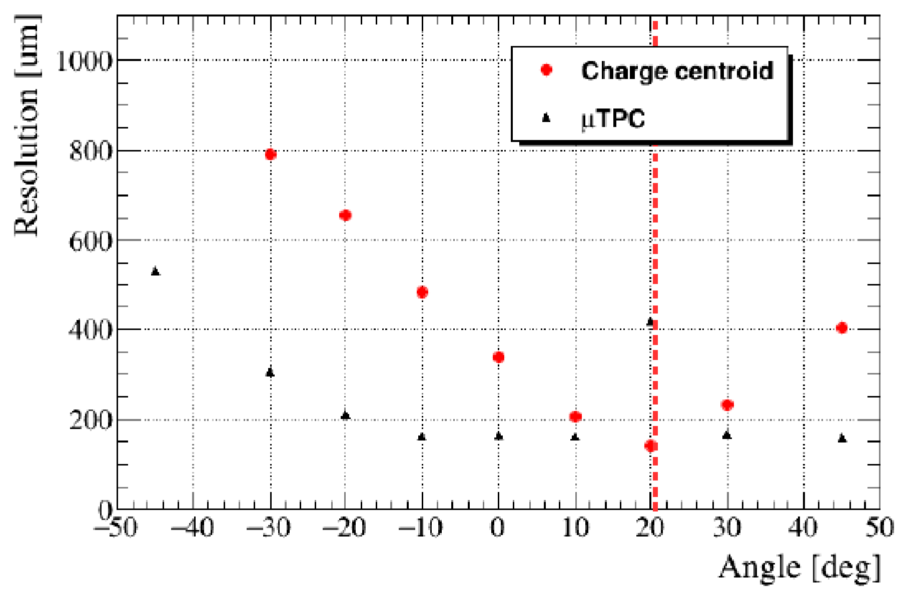
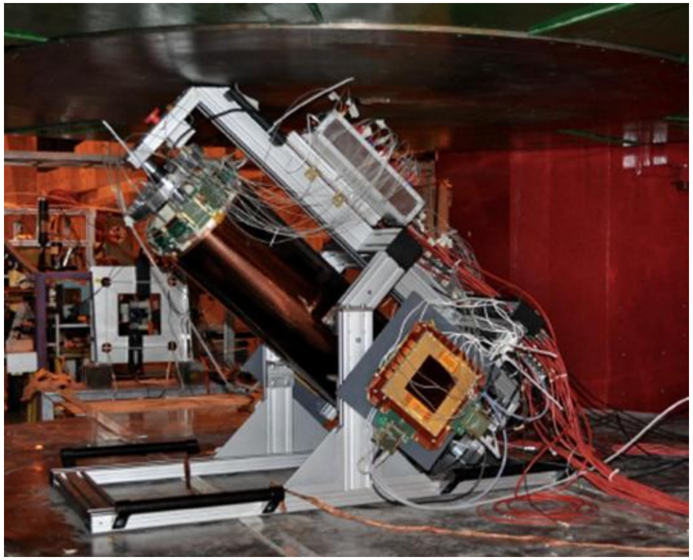


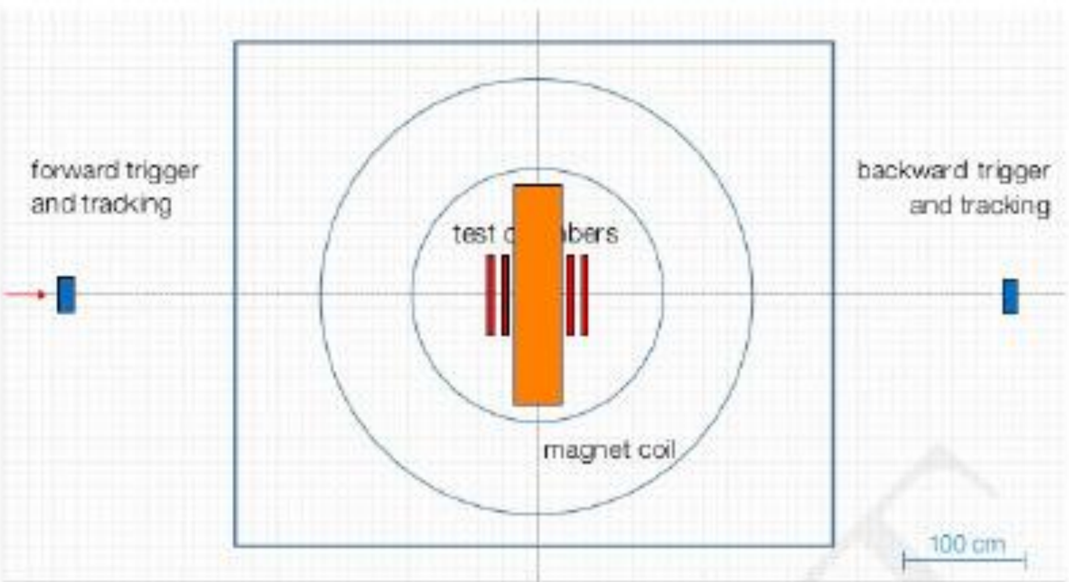
Summary for PLANAR chambers

- the planar chamber tests with and without magnetic field and in different configurations of HV and field showed that the **combination of charge centroid and μ-TPC** reconstruction modes are going to provide the required position resolution of ~130 μm in xy plane

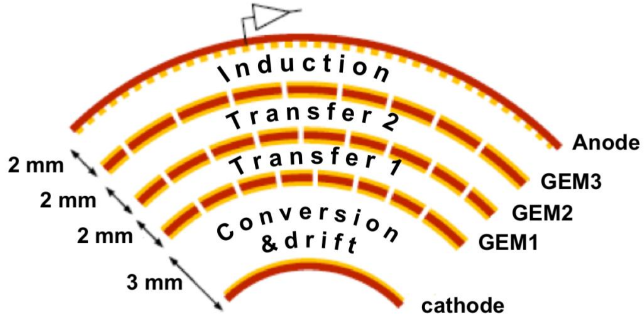
- in May, a testbeam on high intensity electron beam @ **MAMI, Mainz** is foreseen to evaluate the μ-TPC capabilities in such an environment

CYLINDRICAL chamber





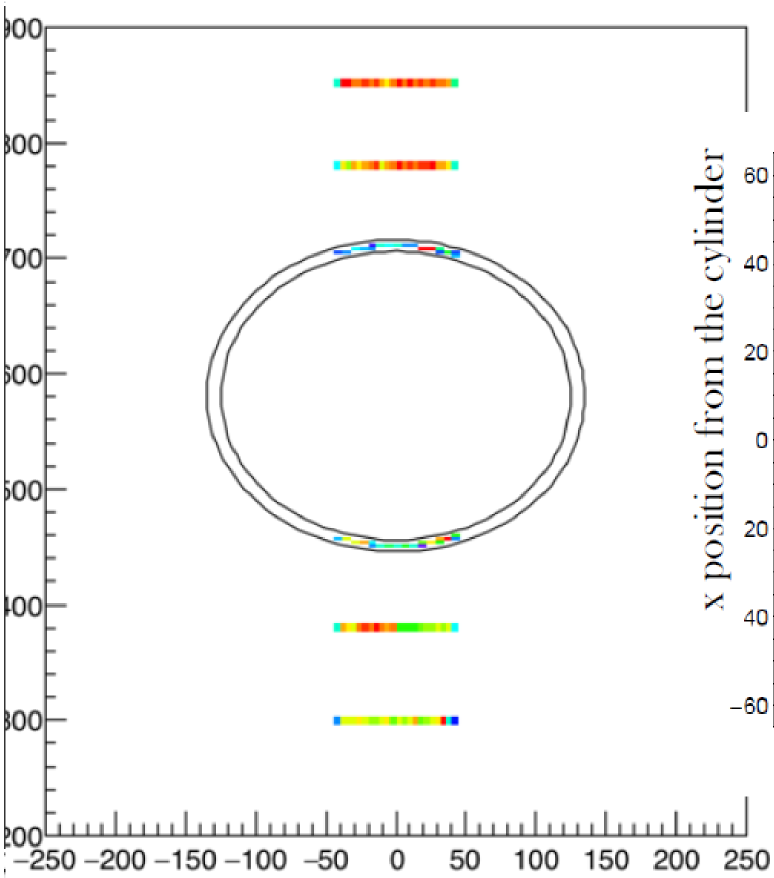
- **first testbeam with layer 2 prototype**
- gas mixture Ar/CO_2 (70/30%)
- x & v views, only x instrumented
- 3 mm drift gap

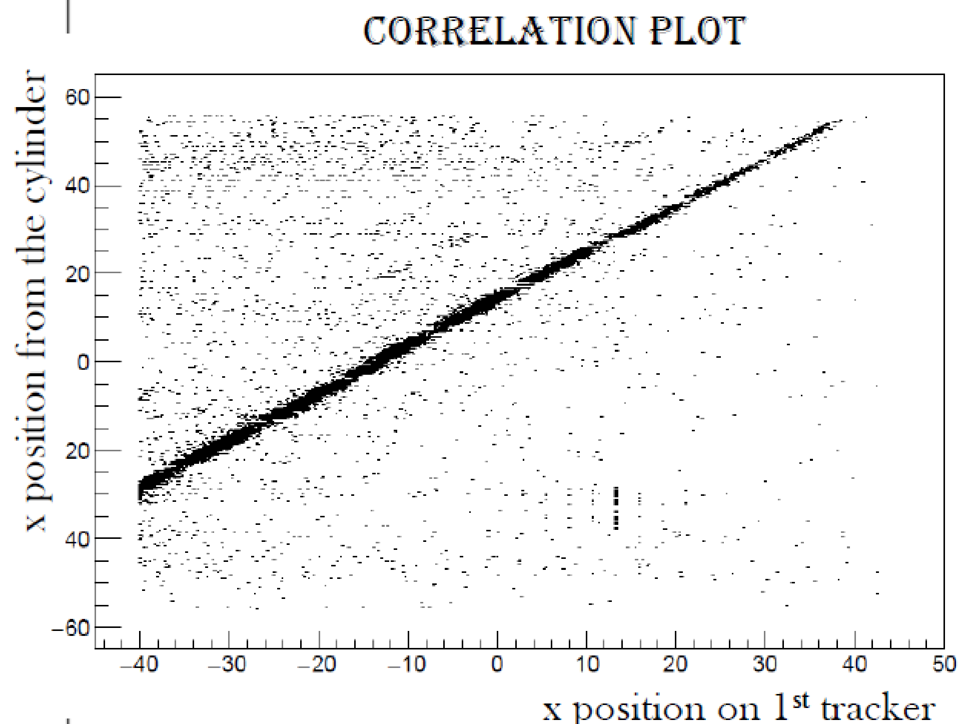


OBJECTIVES

- test the **stability** of the detector under beam conditions
- **comparison** between cylindrical and planar chamber results
- test under **high intensity** pion beam

Reaction to beam conditions





- tested also under *extreme* conditions:
  - HV = 400 V for each GEM foil → 10^5 gain: stable
  - high intensity pion beam, up to some tenth of kHz/cm^2: no current peaking problem

Summary for CYLINDRICAL chamber

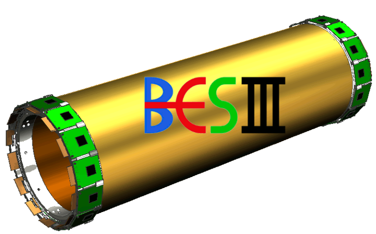
- the first test of the cylindrical prototype was successful:
  it showed great stability under different HV and drift field settings
- the evaluation of efficiency and resolution is ongoing
- further tests with cosmic and radioactive source are ongoing
- The layer I construction is ongoing and the next step is the testing on it

Conclusions

- The **planar** chambers already allowed studies on resolution and efficiency

- The same studies on the **cylindrical** GEM are ongoing

- The **full CGEM-IT** under construction: expected to be completed by the end of 2018



HORIZON 2020

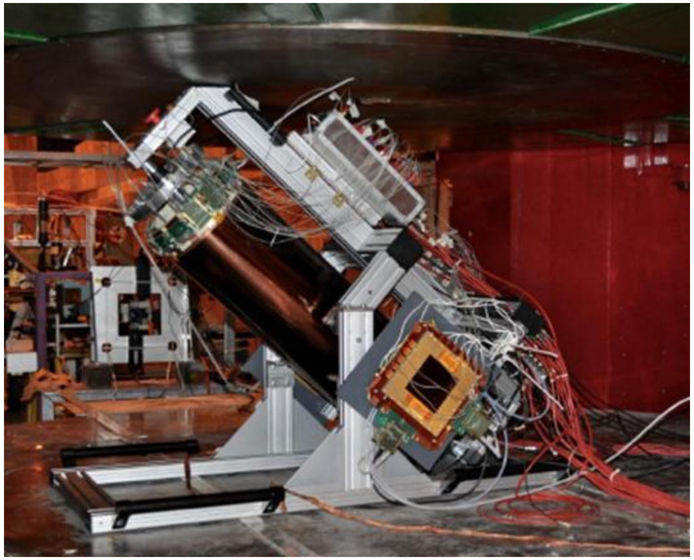
European Commission

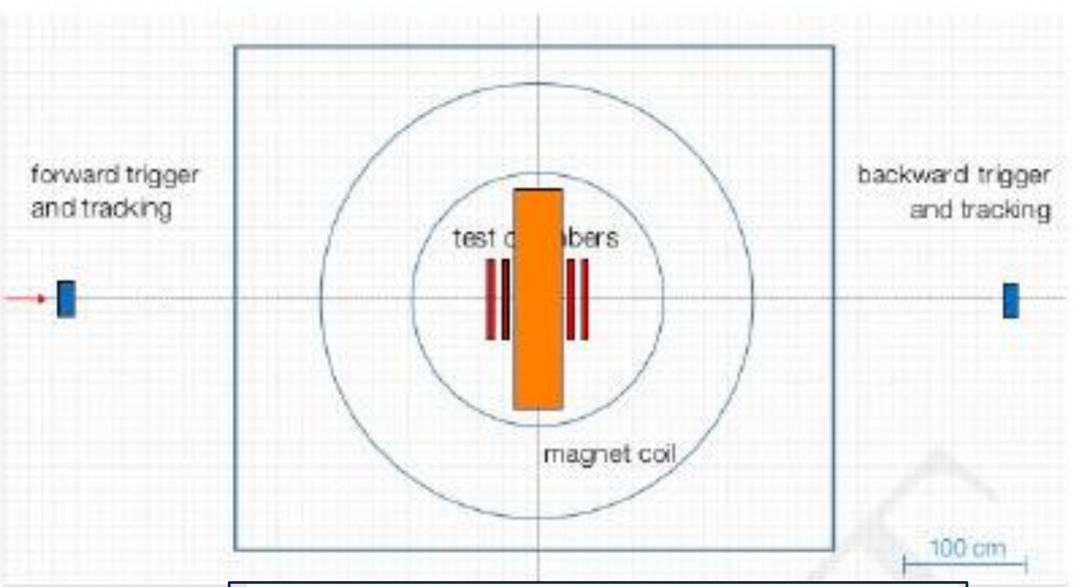
Thank you

for your attention

Spare

Cylindrical chamber





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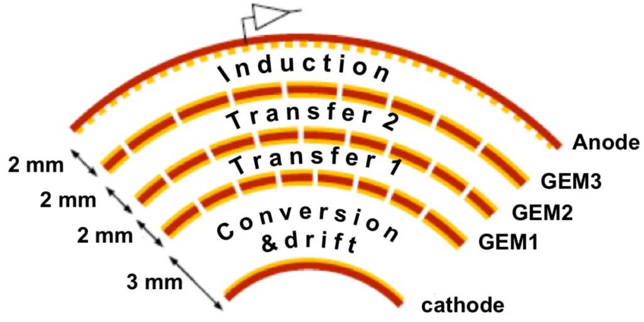
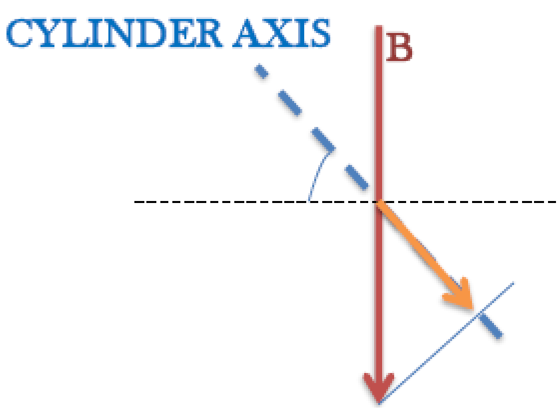
- 3 mm drift gap





Inclination = 42°

1.5 T × sin(42°) = 1.00 T

magnetic field along the axis

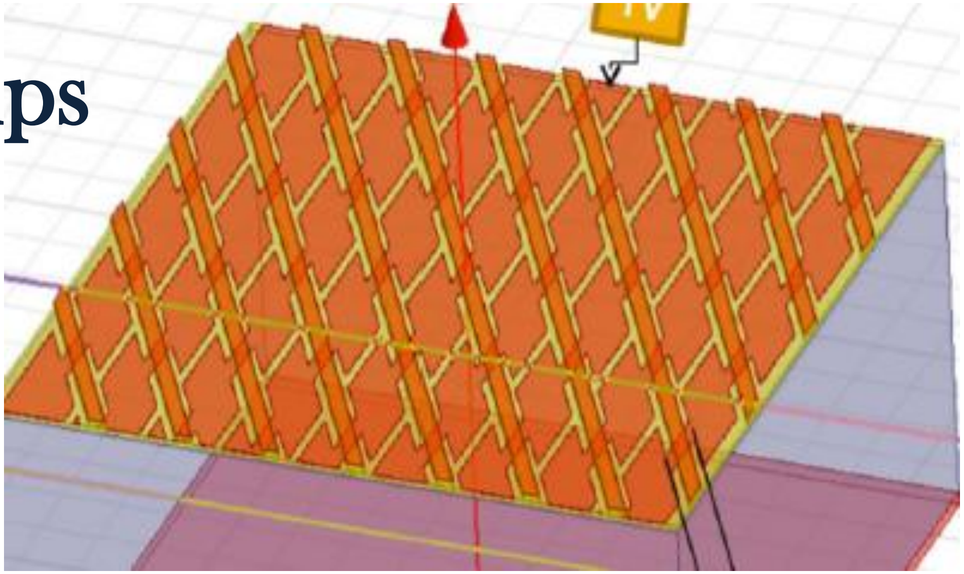
Example of HV and drift field settings

Ar/CO2 70/30

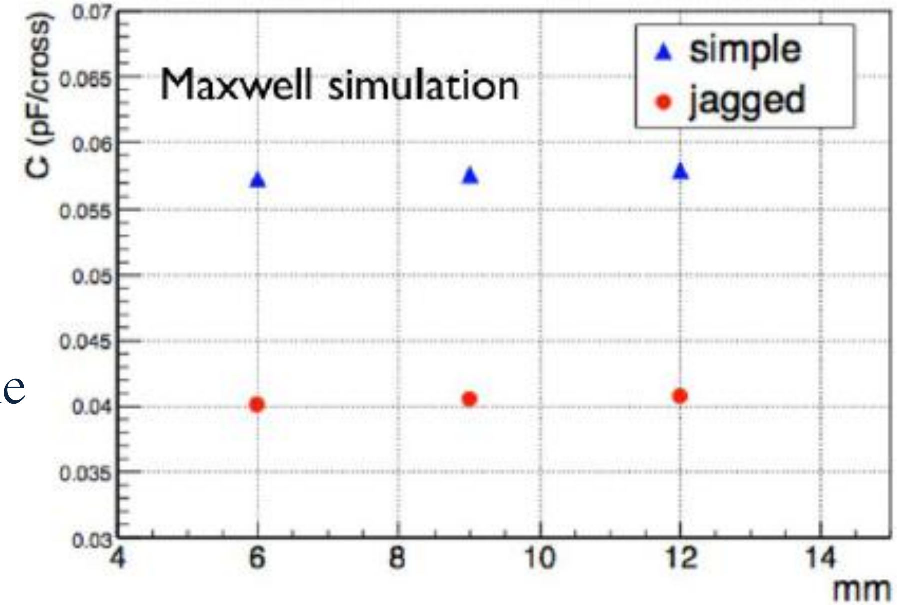
3655/3905 V

	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



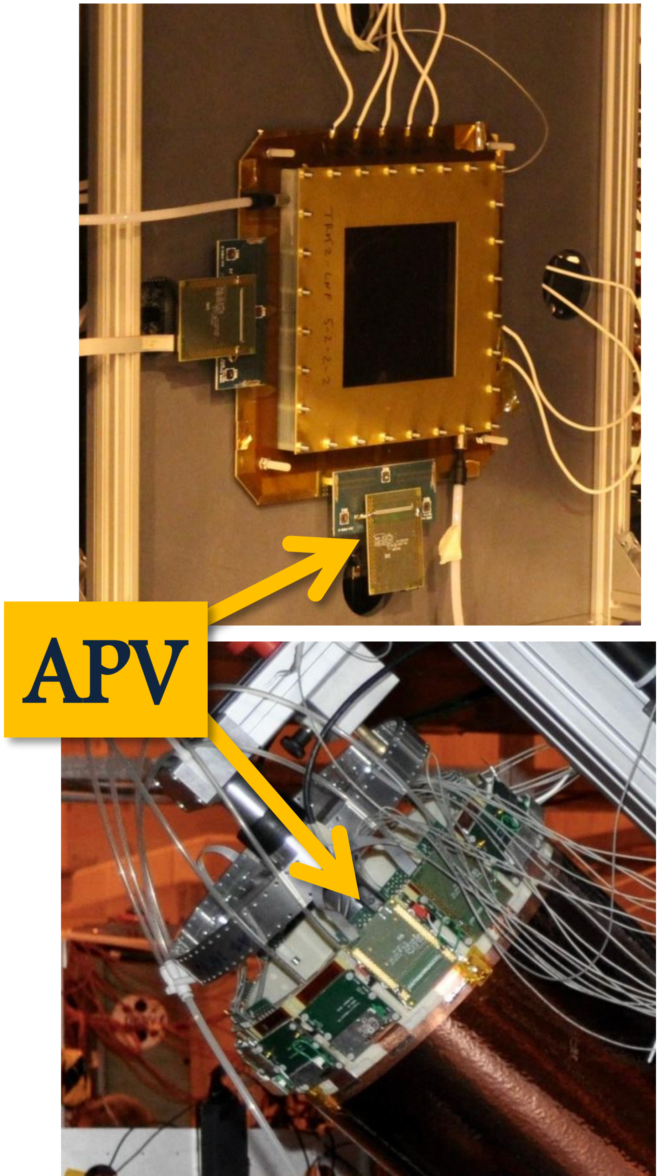
The x strips pitch is shrinked in coincidence of v strip crossings in order to decrease the inter-strip capacitance.



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

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 plan

Final goal

RESOLUTION

EFFICIENCY

130 μm ρϕ - 1mm z

98%

Tune on

GAIN

~10^4

CLUSTER SIZE

contiguous strips firing

What needs to be chosen in advance

GEM HV

DRIFT FIELD

DRIFT GAP

GAS MIXTURE

What to deal with

MAGNETIC FIELD

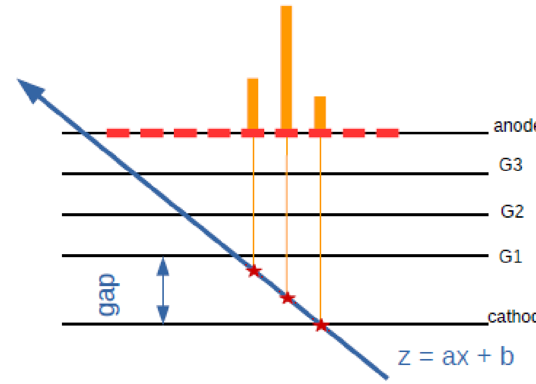
TRACK INCLINATION

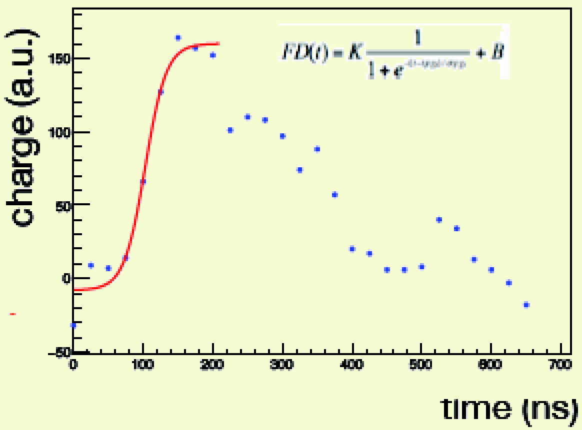
Software

RECO ALGORITHMS

The μ–TPC mode

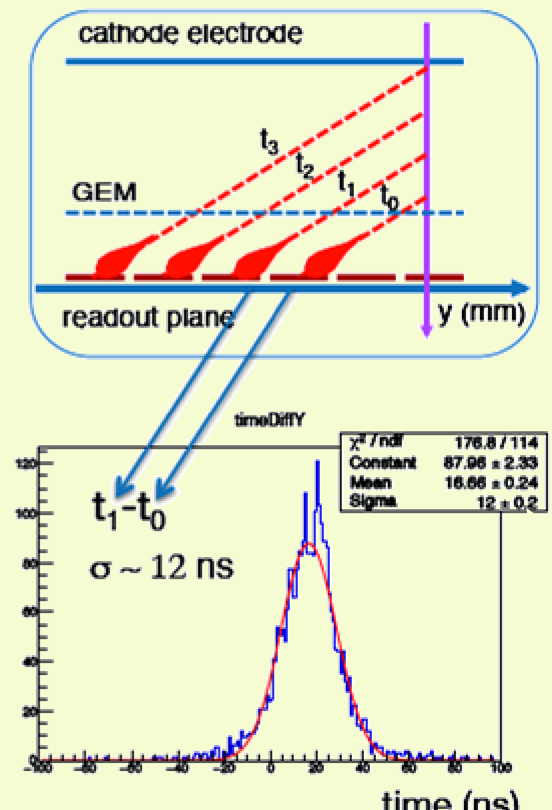
- inclined tracks and/or magnetic field → increased cluster size → μ-TPC mode available
- the drift gap is seen as a "*micro* time projection chamber" and the position of **each primary ionization** is reconstructed by knowing the electron drift velocity





- **STEP 1**

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

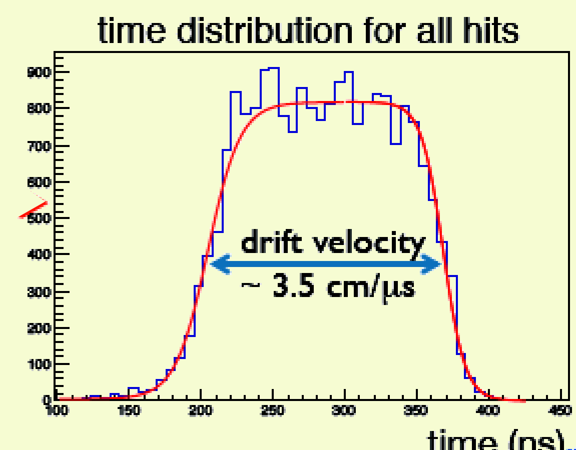


- **STEP 2**

Δt resolution ~ **12 ns**

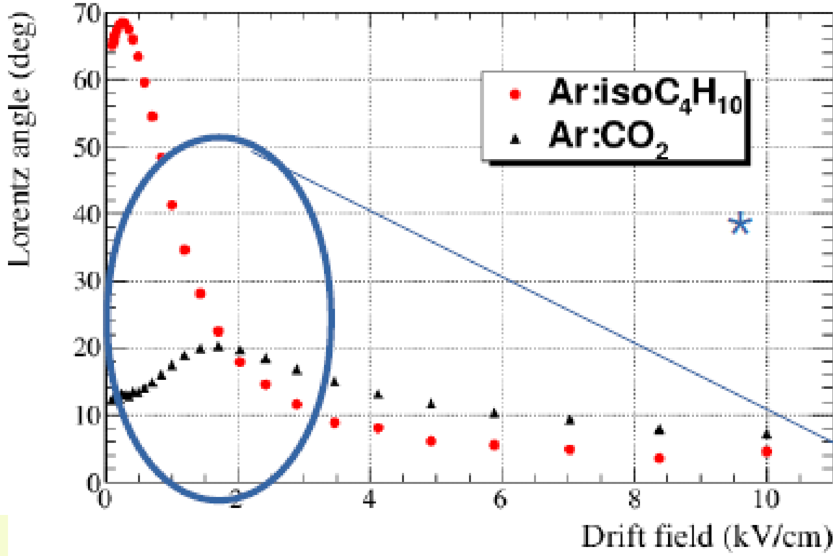
- **STEP 3**

v_{DRIFT} from t_i distribution on 5 mm gap

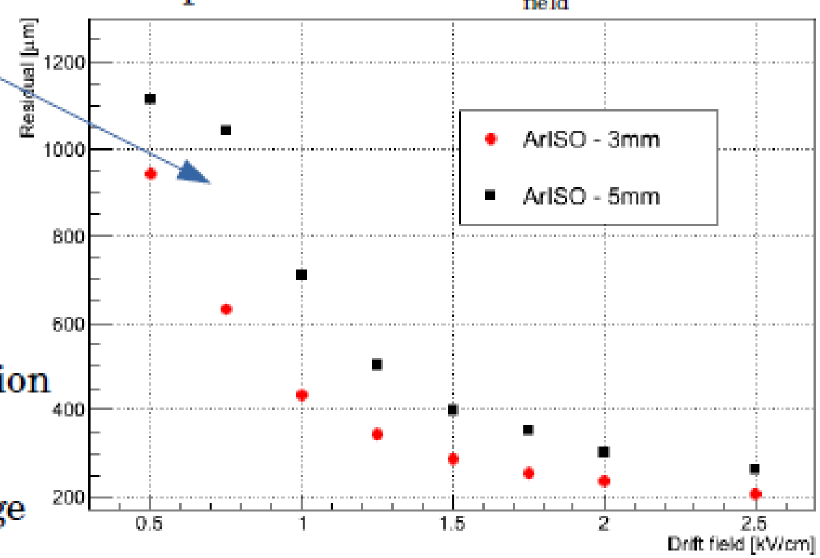


Lorentz angle vs drift field

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