GEM/µRWELL TB results

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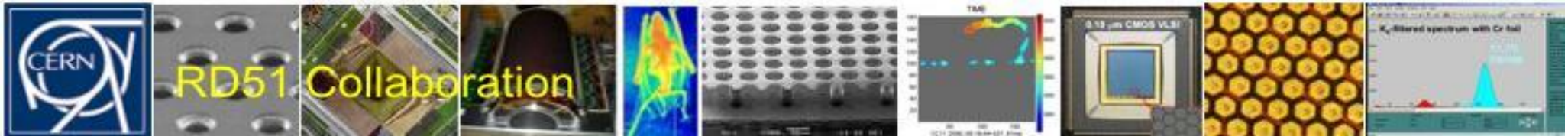
on behalf of
LNF-GEM/µ-RWELL group



OUTLINE

- Goal of the Beam Test
- Beam Test set-up
- Effect of the magnetic field on MPGDs
- Charge Centroid results for GEM
- Toward a μ-TPC approach
- The μ-RWELL option (old TB results)
- Summary

The analysis of these BT data is based on the Analysis-Code developed by the BESIII INFN-Ferrara group (lead by G. Cibinetto)

Goal of the Beam Test

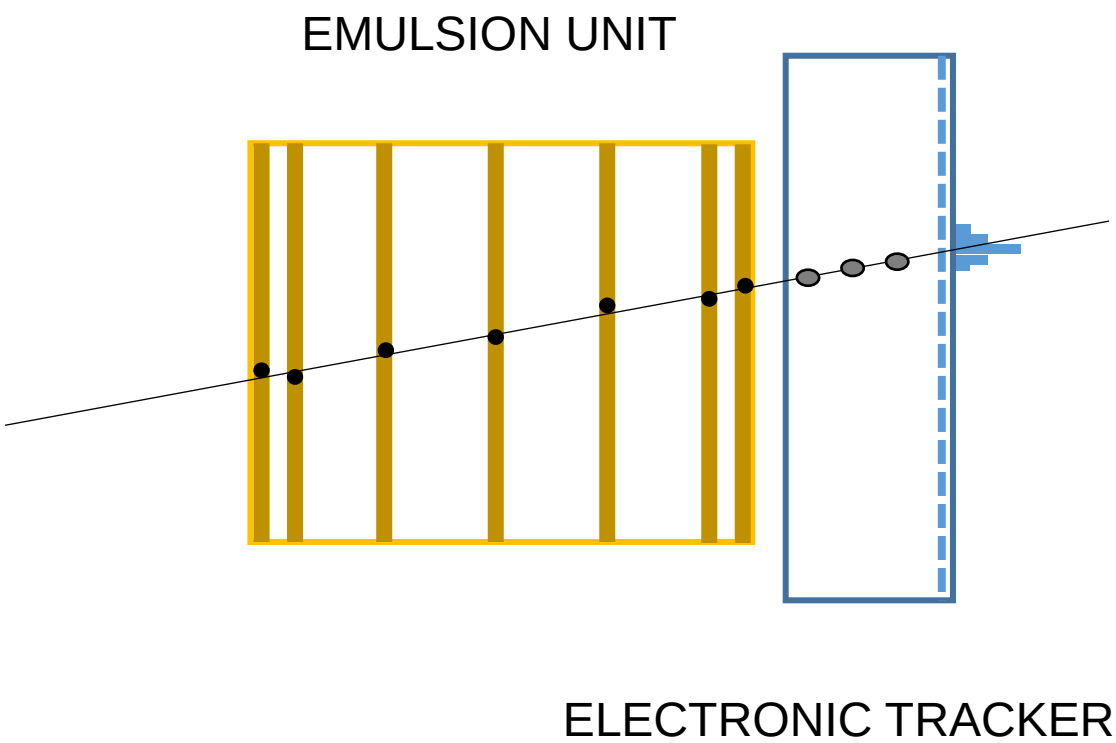
The purposes of the Beam Test:

- study of the **space resolution of the GEM and μ-RWELL** detectors vs **B – magnetic field** and **θ –incidence angle** of the particle

- study of the **matching between the information of the electronic trackers and the emulsions** (in collaboration with INFN-Napoli-group – see Valeri presentation)

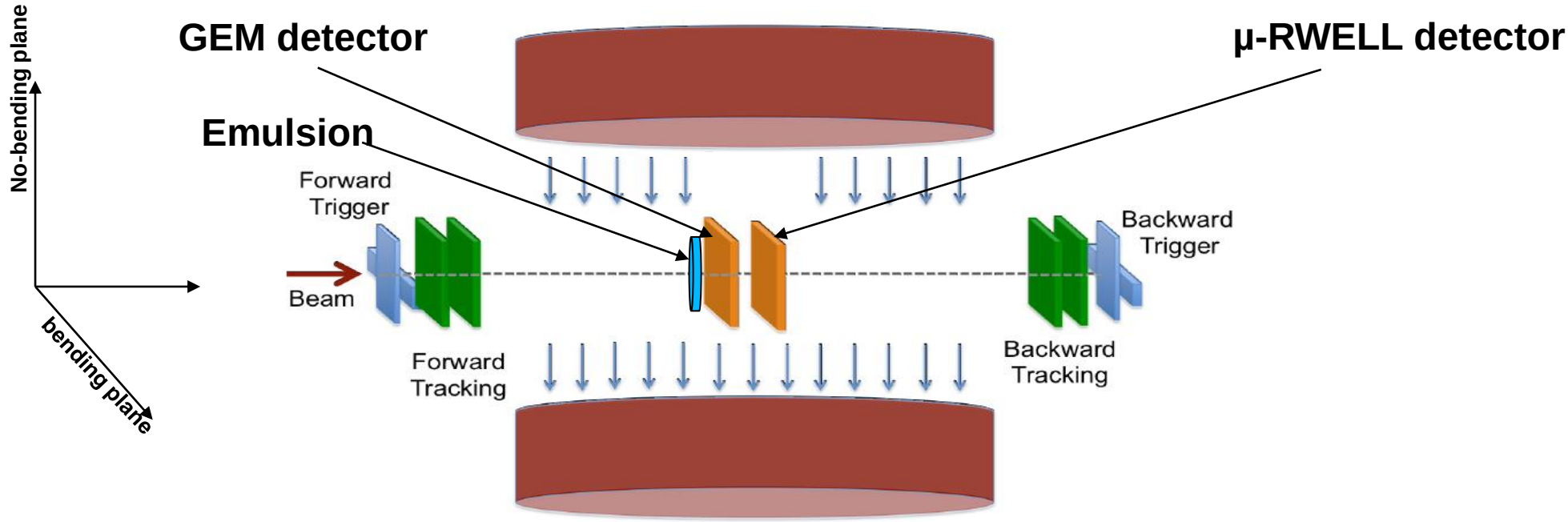
Electronic tracker & Emulsion matching

The **electronic tracker should provide the time stamp** of the event finely (~1μm level) reconstructed by the emulsion unit



The matching requires for a **"good space resolution"** of the electronic detector →
$\sigma_{XY} \leq 200\mu m$
for $0° < \theta < 45°$ and B=1T.

Beam Test Setup



GOAL: study of the matching between emulsion and electronic tracker

- trigger scintillators and GEM trackers outside Goliath
- setup was foreseen two kind of electronic detectors, both independently coupled with emulsion set-up:
  - a large drift gap XY GEM
  - ~~two 1-D μ-RWELL coupled at 90° to supply XY info~~ not delivered
  - beam set-up displaced wrt the beam axis of ~10 cm in order to reduce the irradiation of the emulsion units

- tracking with linear fit
- track residual w/COG
- analysis code by INFN - Ferrara

Electronic Detectors layout

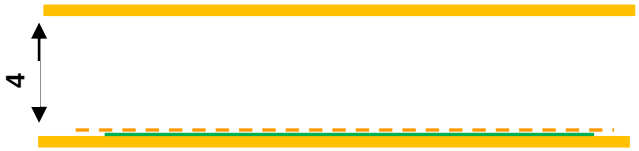
Triple-GEM detector:
6/2/2/2 gap geometry

2D (X-Y) r/o (650 µm strip pitch)

Standard triple-GEM detector with large DRIFT gap (6 mm instead of 3 mm).

In principle **the only limitation** of such an option for the TT of neutrino apparatus is **the maximum achievable size (0.5x1.5-2 m^2)** and the **assembly complexity** of such a large detector (and **costs**)

µ-RWELL detector:
4 mm drift gap & resistivity ~100MΩ/□



1 D r/o (400 µm strip pitch)

The **µ-RWELL is the <u>new frontier of MPGD</u>: compact, single amplifcation stage & intrinsically spark protected.**

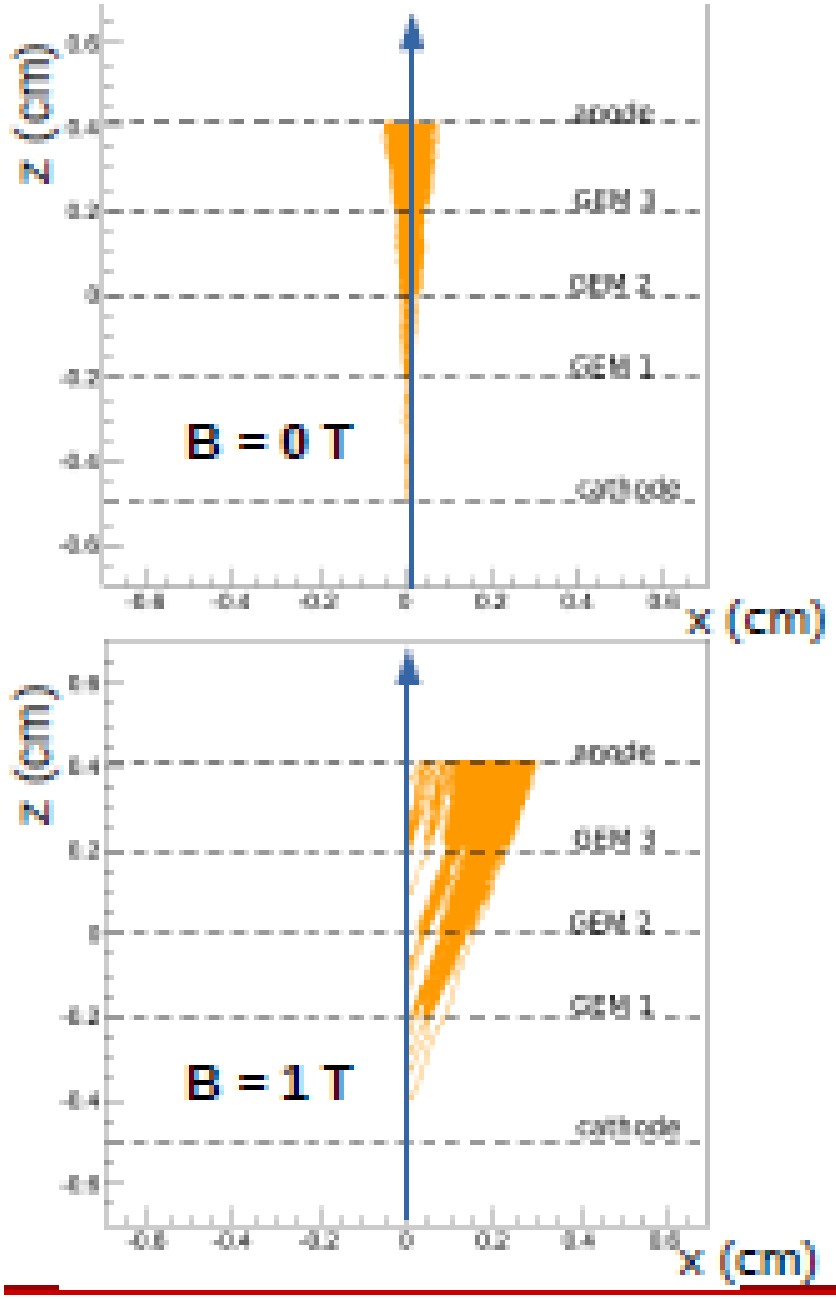
The most simple to built and cost effective MPGD, without any a priori limitation for large size (for the **phase2-upgrade of CMS-muon we are developing a trapezoidal prototype of the order of ~1.8x1.2m^2).**

Effect of the magnetic field in a MPGD

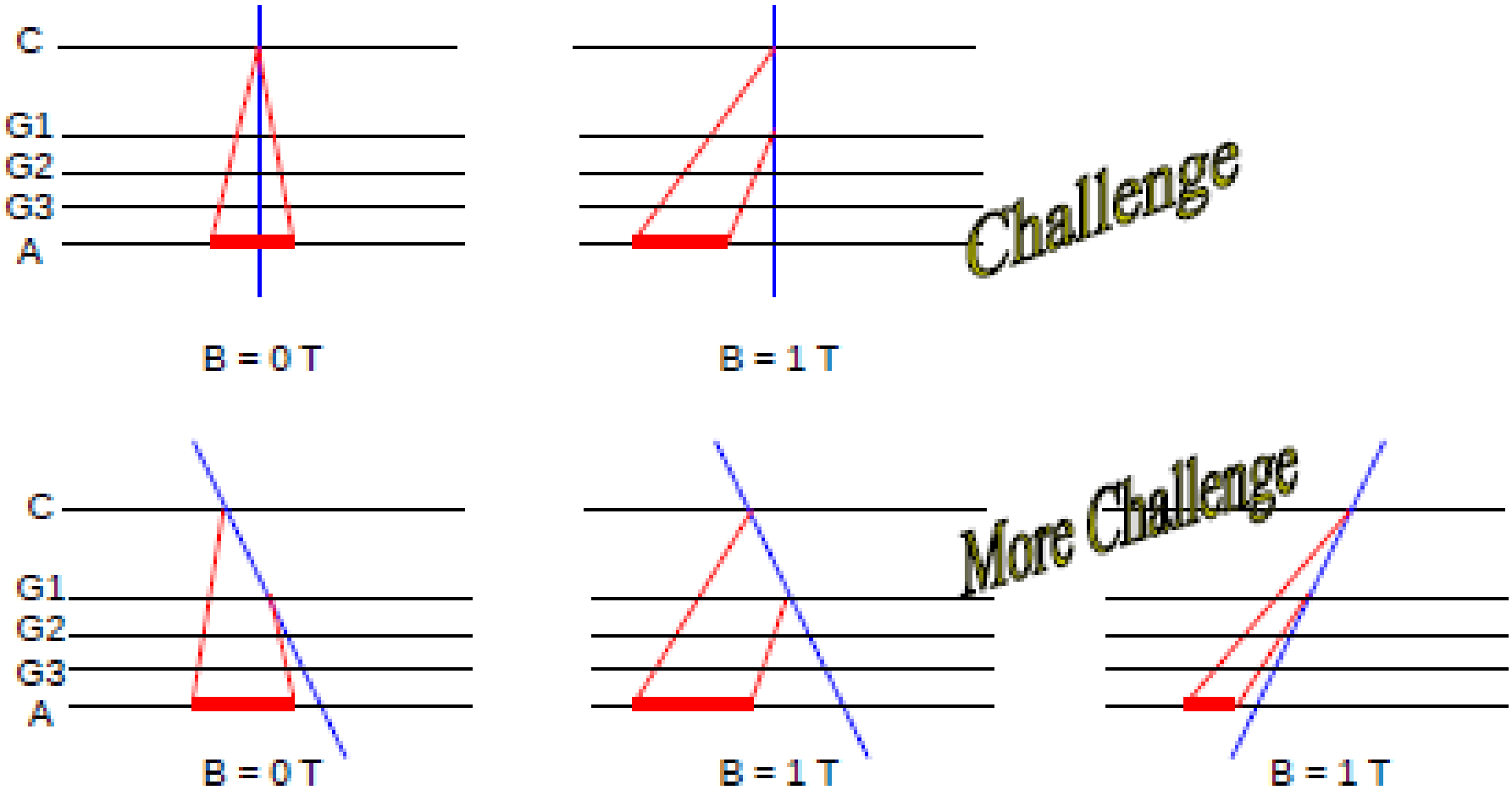
The **effect of the magnetic field** on the electron avalanche has been **simulated with Garfield:**

- the Lorentz force **displaces the electron avalanche**
- the B field produces a **broadening of the charge distribution** on the readout strips

- the shape of **the charge distribution is no more Gaussian and the centroid method (COG) is no more effective**



Electron avalanche behaviour (I)

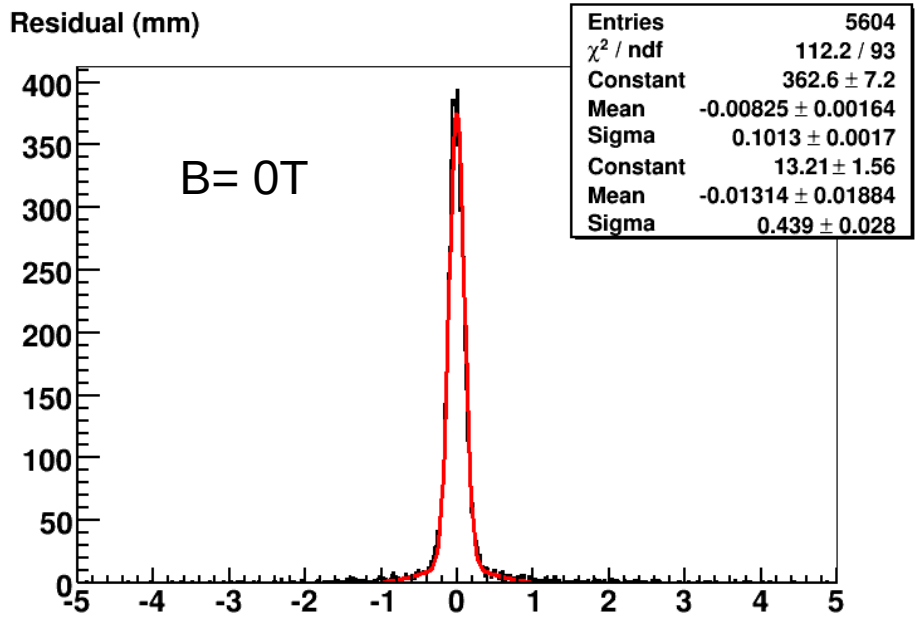


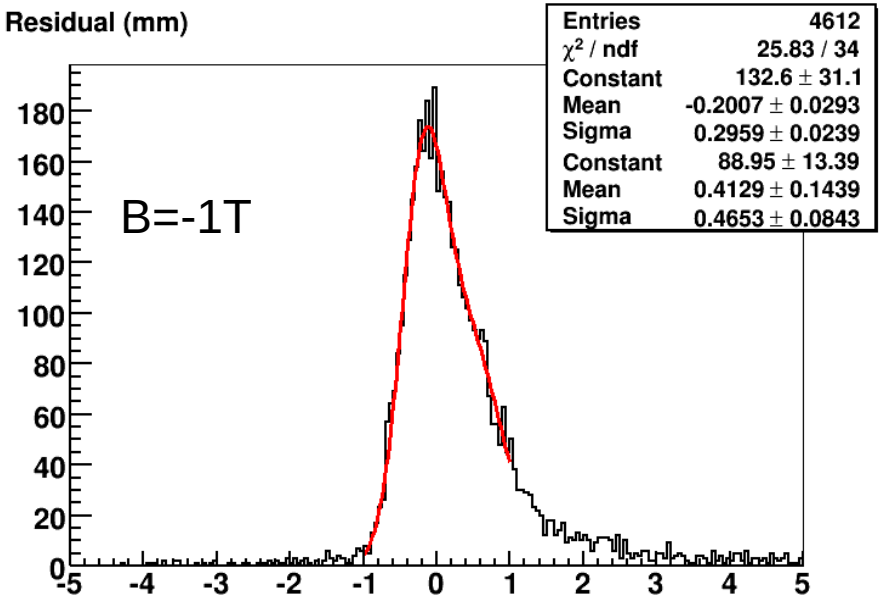
The situation becomes **more challenge for non-orthogonal** tracks

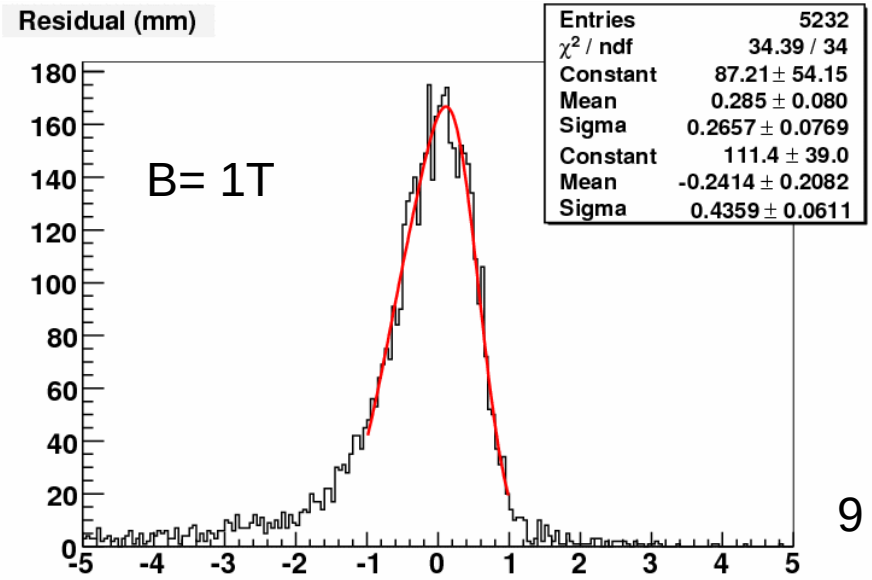
Electron avalanche behaviour (II)

Charge distribution with Ar/CO_2 (70/30) on the readout strips vs B & θ

$\theta = 0°$



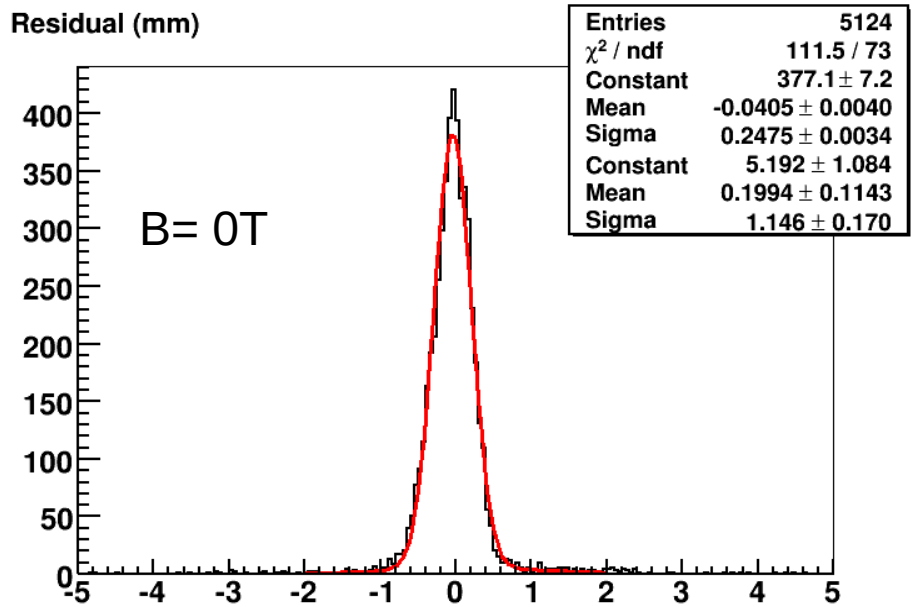


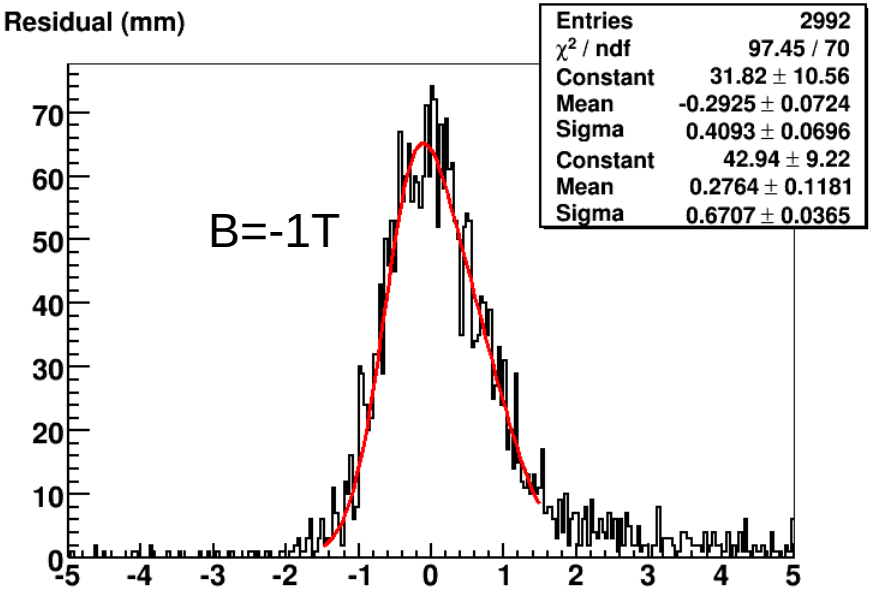


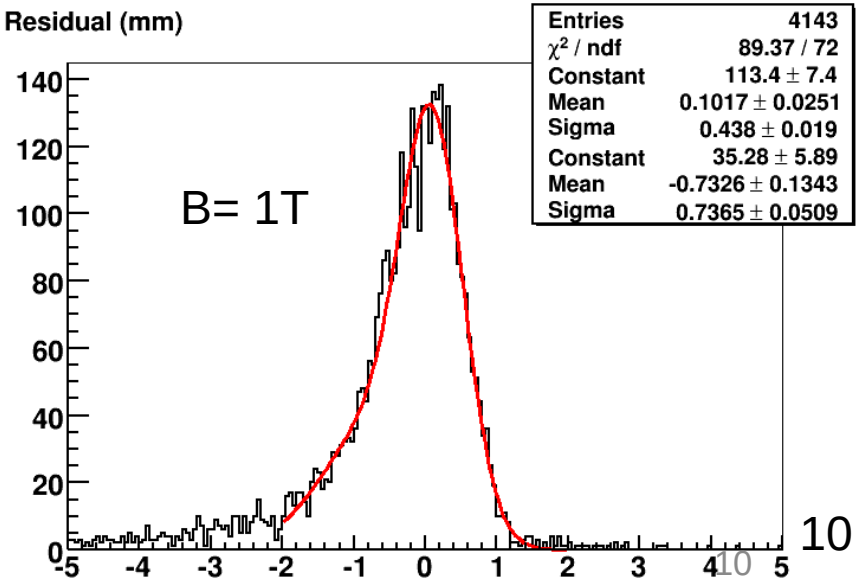
Electron avalanche behaviour (III)

Charge distribution with Ar/CO_2 (70/30) on the readout strips vs B & θ

$\theta = 7{,}5°$



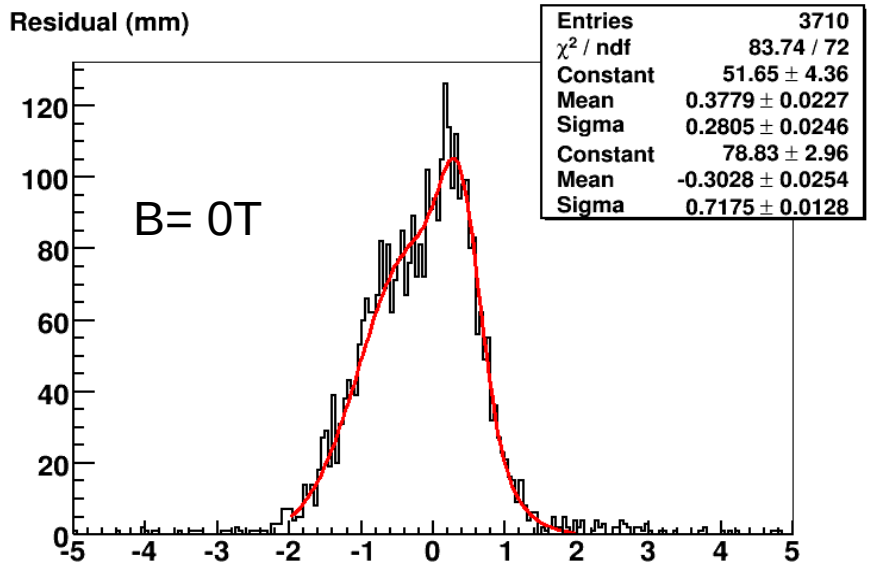


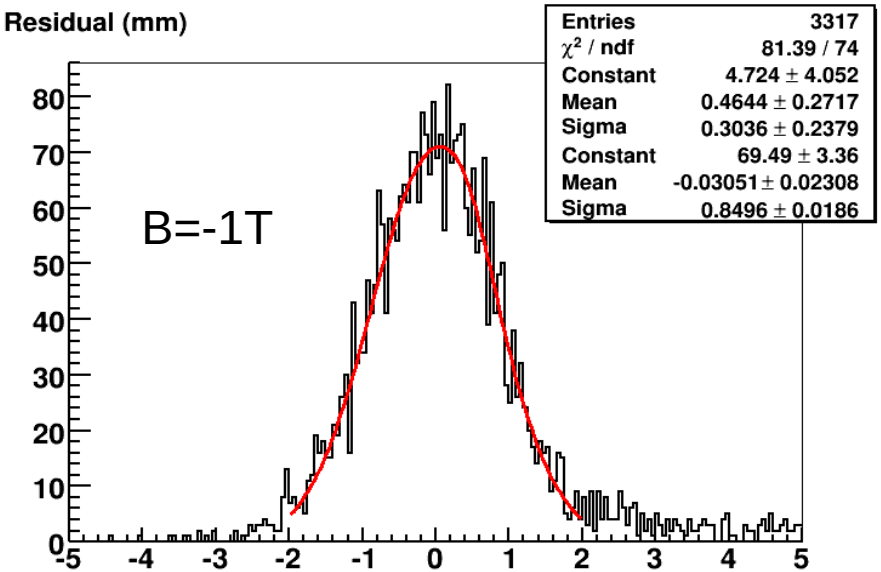


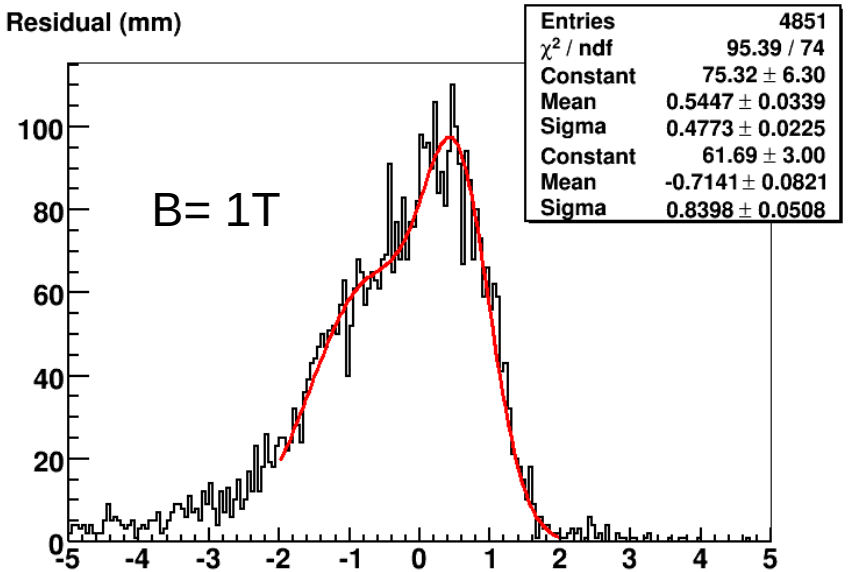
Electron avalanche behaviour (IV)

Charge distribution with Ar/CO_2 (70/30) on the readout strips vs B & θ

$\theta = 15°$



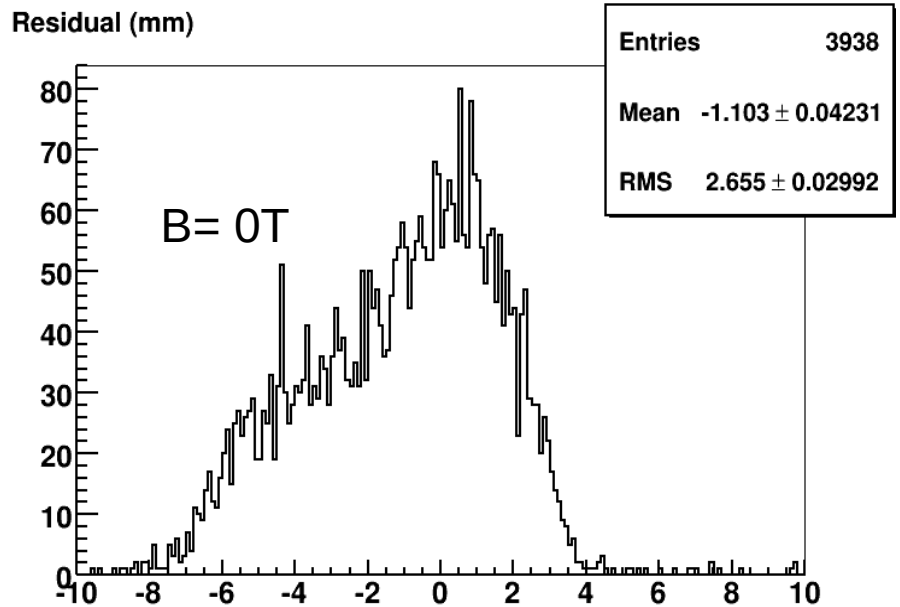


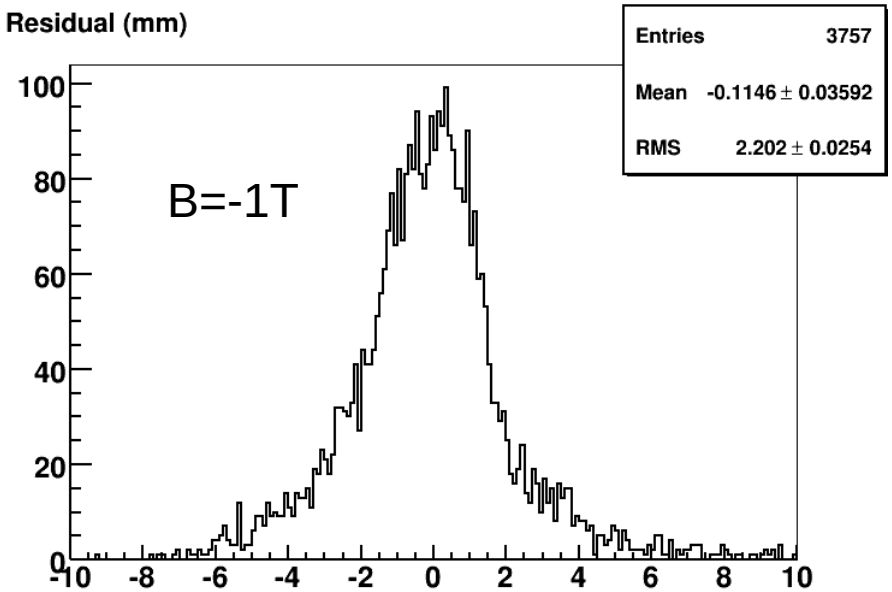


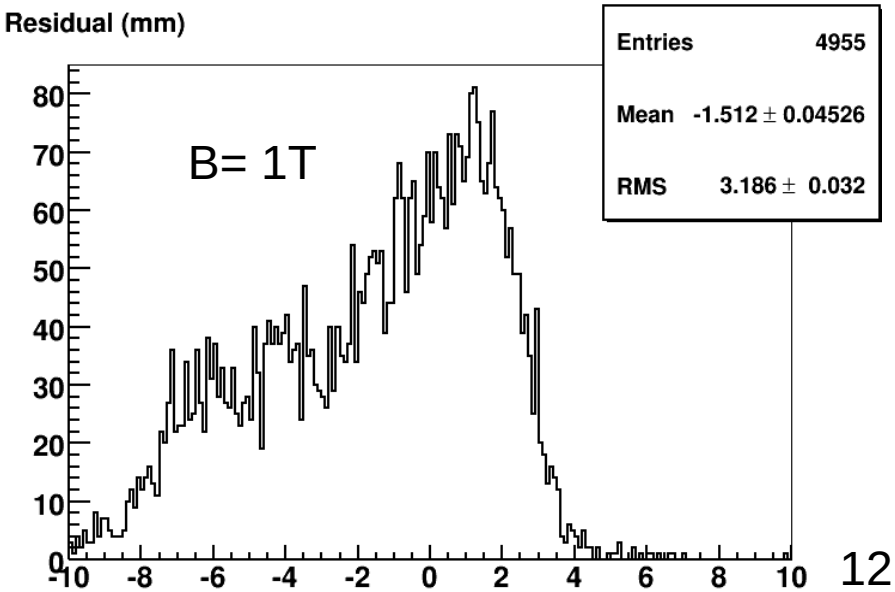
Electron avalanche behaviour (V)

Charge distribution with Ar/CO_2 (70/30) on the readout strips vs B & θ

$\theta = 30°$



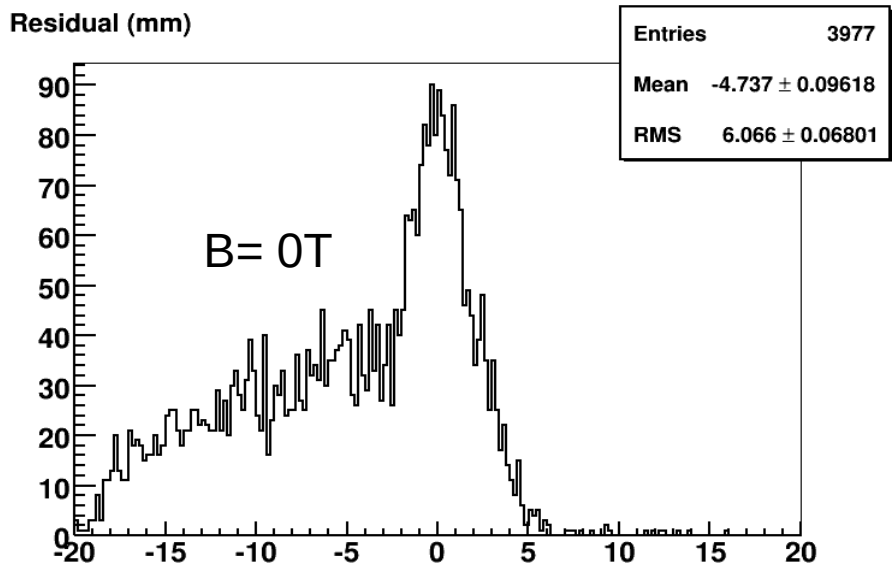


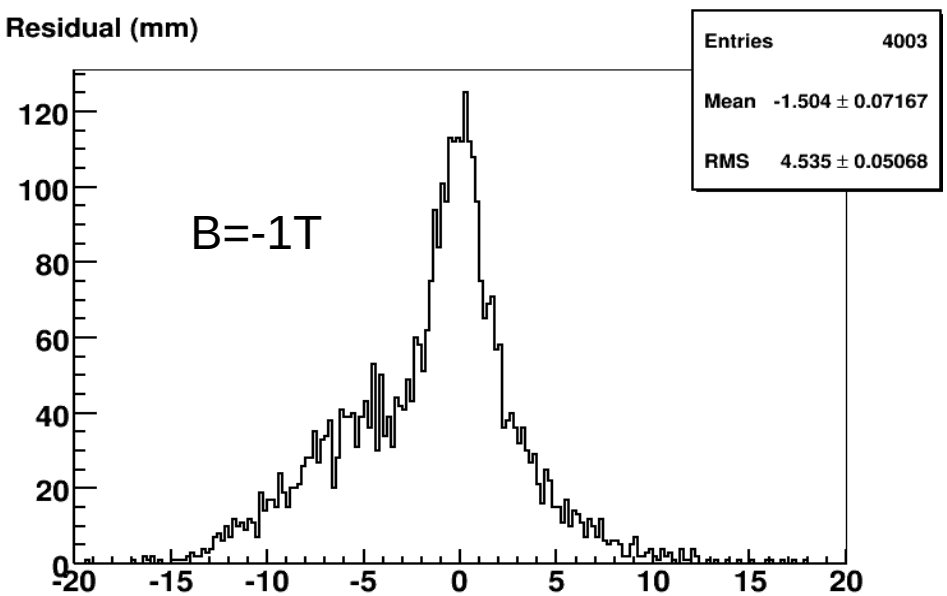


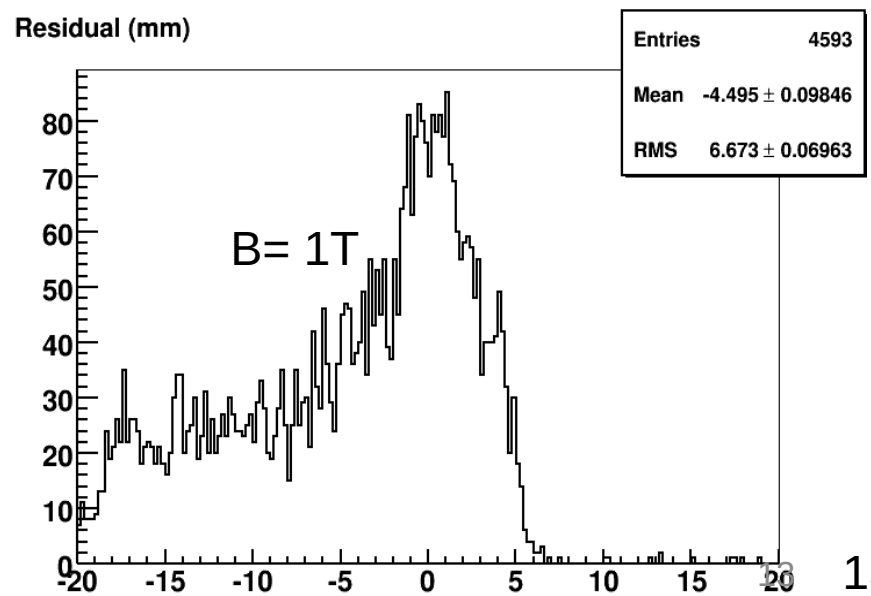
Electron avalanche behaviour (VI)

Charge distribution with Ar/CO_2 (70/30) on the readout strips vs B & θ

$\theta = 45°$



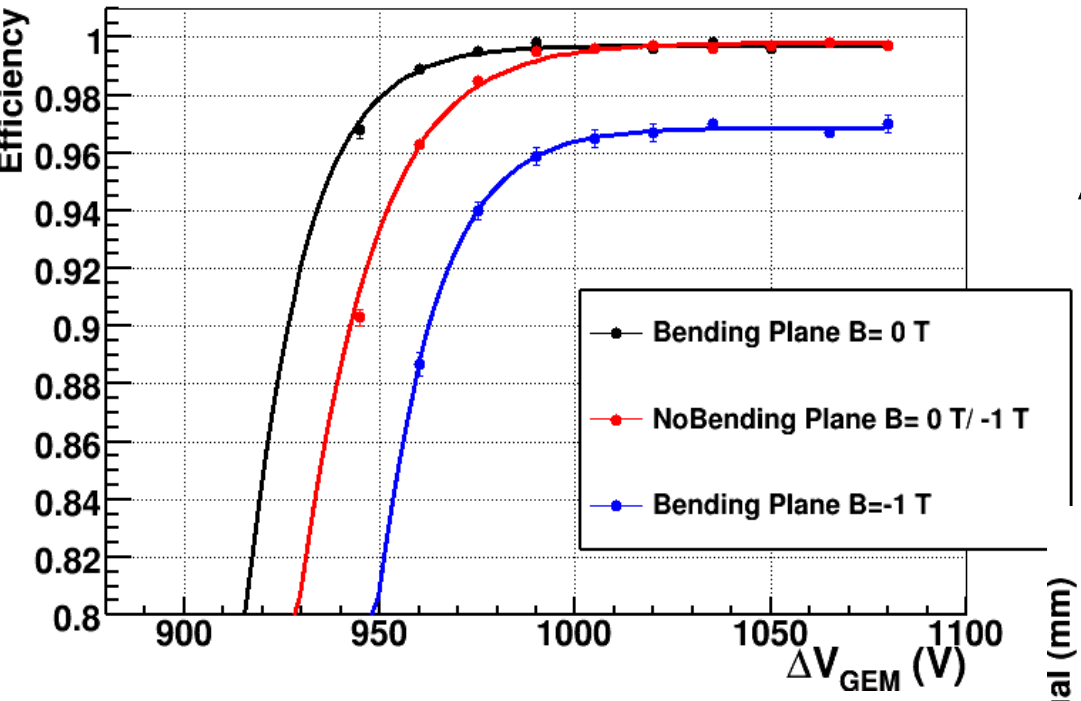




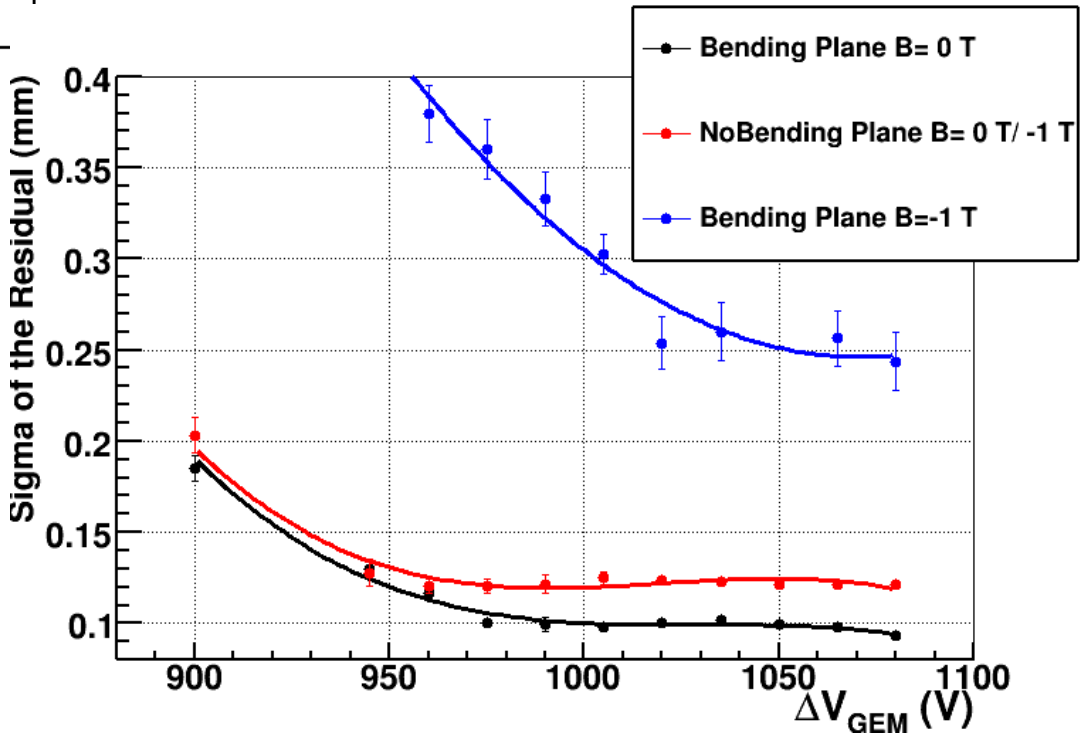
Results
with
Charge Centroid method(GEM)
$0 \leq \theta \leq 15$ & $B=0, \pm 1T$

GEM: HV scan with B=0/-1 T, θ=0

preliminary



GEM operated in Ar/CO_2=70/30 & Ed=0.8 kV/cm



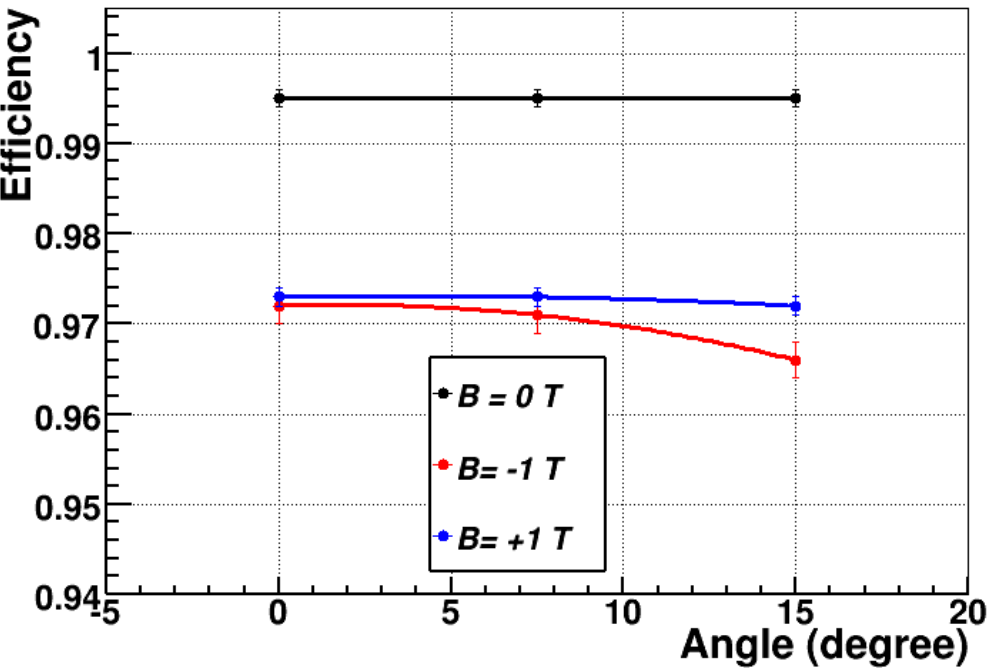
For θ=0° (orthogonal tracks) in CC mode:

@ B= 0 T, ε > 99% ,σ < 100μm

@ B=-1 T, ε ~ 97%, σ ~ 250μm.

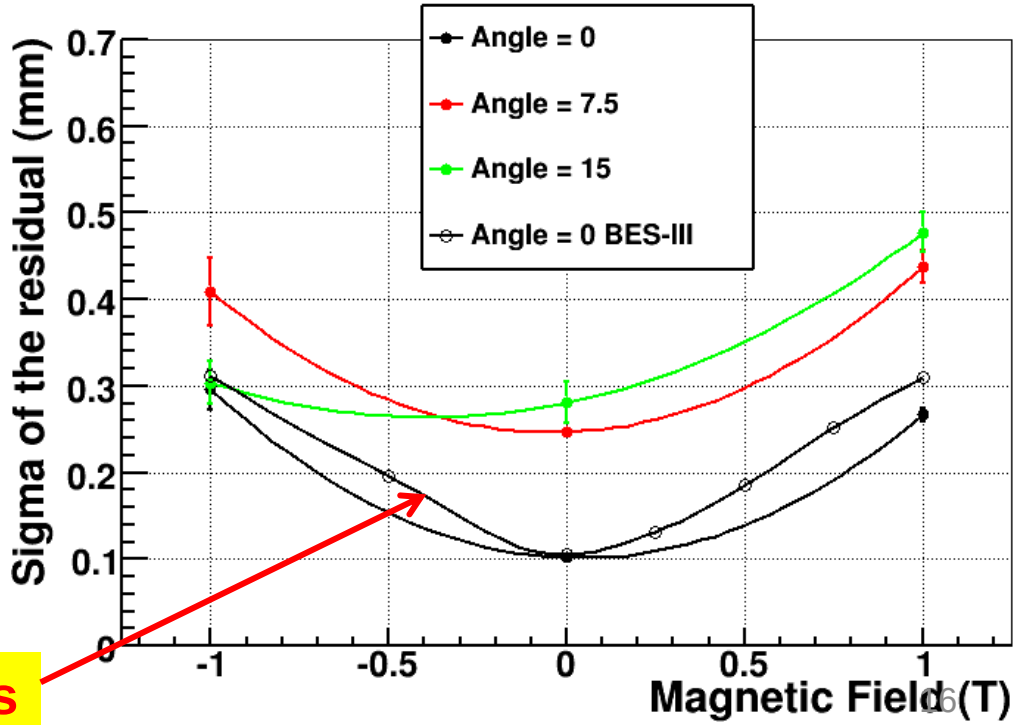
GEM: θ-scan with B=0, ±1T

preliminary



GEM operated in
Ar/CO_2=70/30
& Ed=0.8 kV/cm & HV=1035 V

At **larger incident angle (θ)** and **B≠0** the space resolution in CC mode worsens down to **σ ~ 300÷400 μm** while **efficiency** remains at level of **97%.**



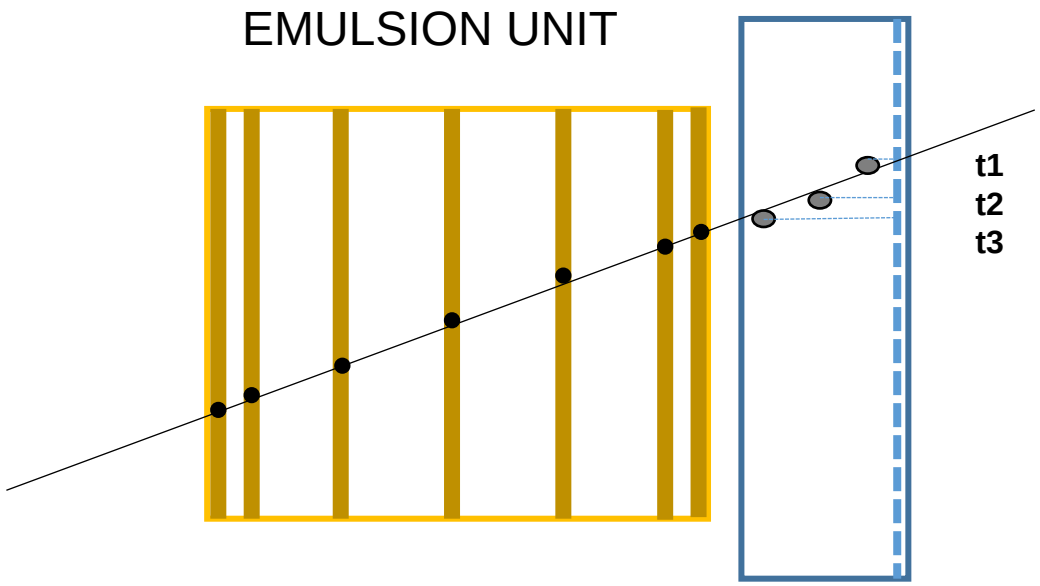
BESIII results

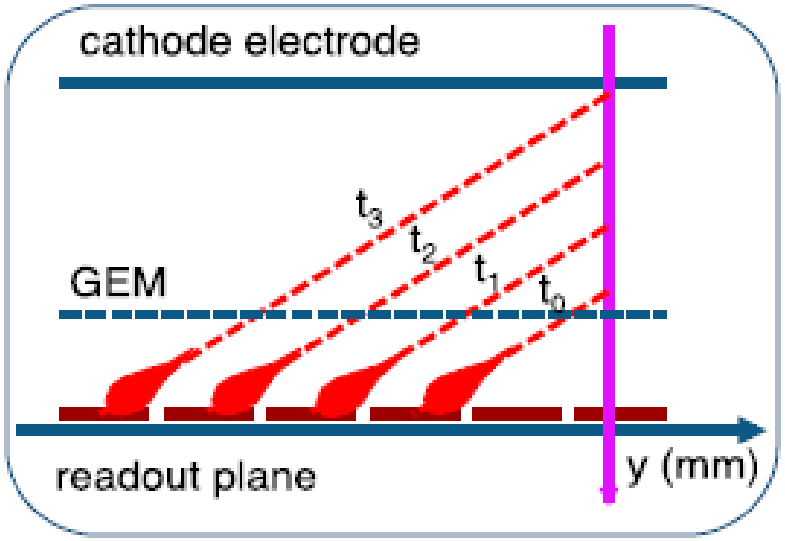
Improving space resolution: the μ-TCP mode

- The information of the **arrival time of the ionization cluster** can be used to improve the spatial resolution **at high B field and not perpendicular tracks.**

- The time information can be extracted from the **time sampling of the APV signal (just for TB !)**

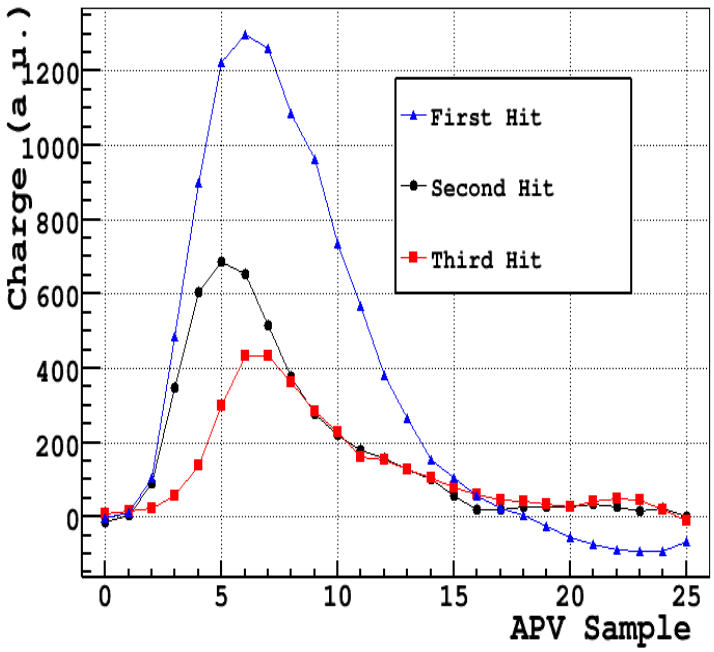
- A **time resolution of ~10ns** is enough to allows this approach

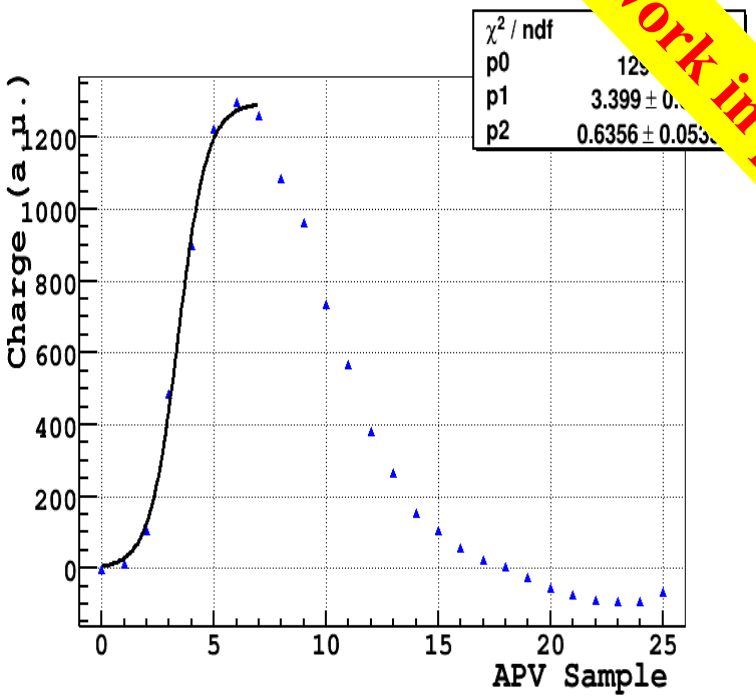




μ-TCP mode (I) w/orthogonal tracks & B = 1T

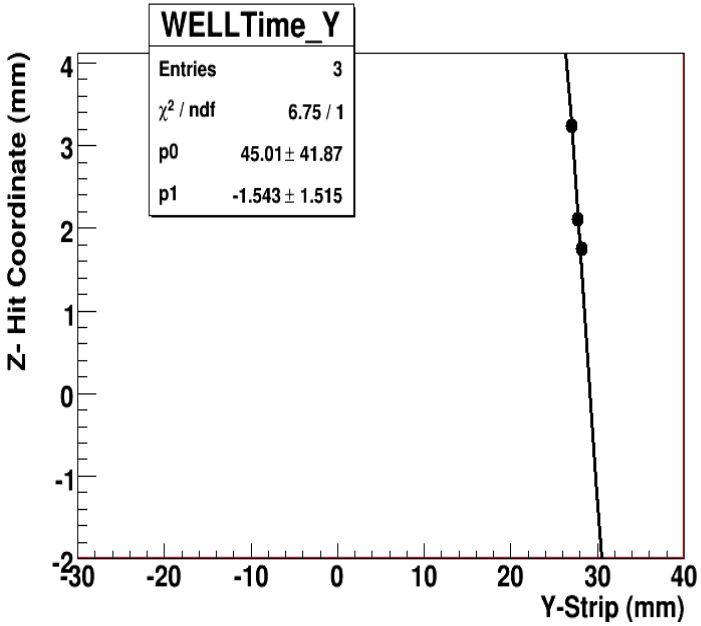
Event with 3 neighbour hits





work in progress

1. The **rise time of the signal** is fitted with a Fermi-Dirac to estimate the arrival time of the hit (APV-time sample=25 ns)
2. The time information **is translated in space** (through the V_{drift})
3. **spatial fit of the reconstructed position of the ionization clusters** inside the drift gap (better than 1°)



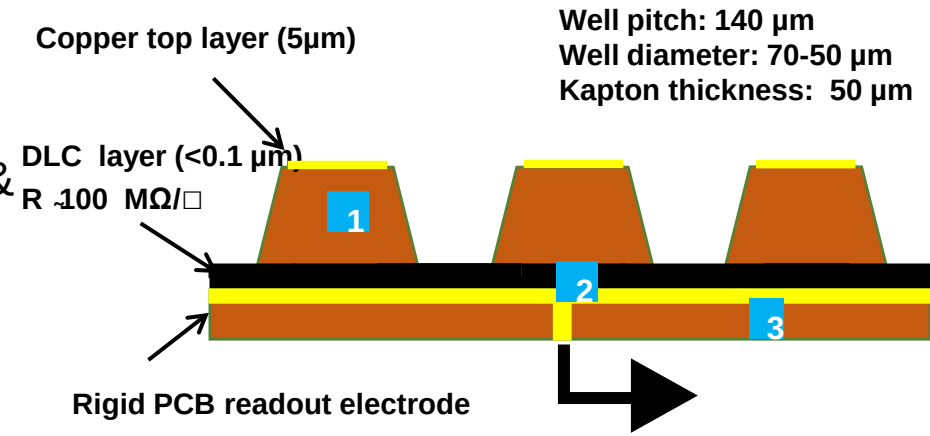
The μ-RWELL option

The **μ-RWELL_PCB** is realized by coupling:

1. a "**suitable patterned GEM foil**" for the "amplification stage"

2. a **"resistive stage"** for the discharge suppression & current evacuation
   - **i. "Low particle rate" (LR)** << 100 kHz/cm^2**:** single resistive layer → surface resistivity (≈100 MΩ/□) **This architecture is considered for the CMS Phase 2 Upgrade (and SHIP too !!!)**
   - **ii. "High particle rate"** (HR) >> 100 kHz/cm^2 : more sophisticated resistive scheme must be implemented (performed by MPDG_NEXT- LNF financed by GR5-INFN)

3. a **simple readout PCB** board



Please look there !!!

The **μ-RWELL is a compact & simple to build:**

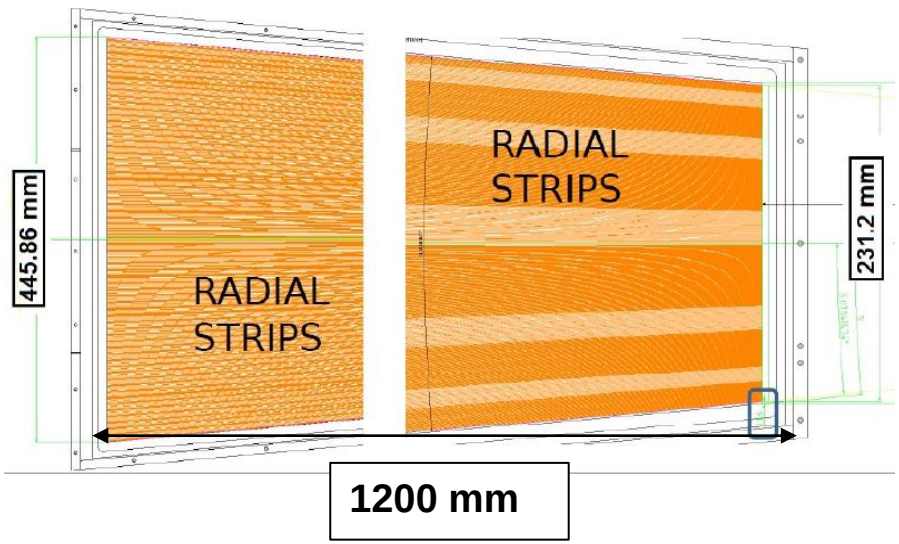
- only two mechanical components: μ-RWELL_PCB + cathode
- no critical & time consuming assembly steps:
  - no gluing, no stretching, easy handling
- no stiff & large frames
- **large area with PCB splicing technique (more simple than GEM and MM)**

The R&D on large size μ-RWELL

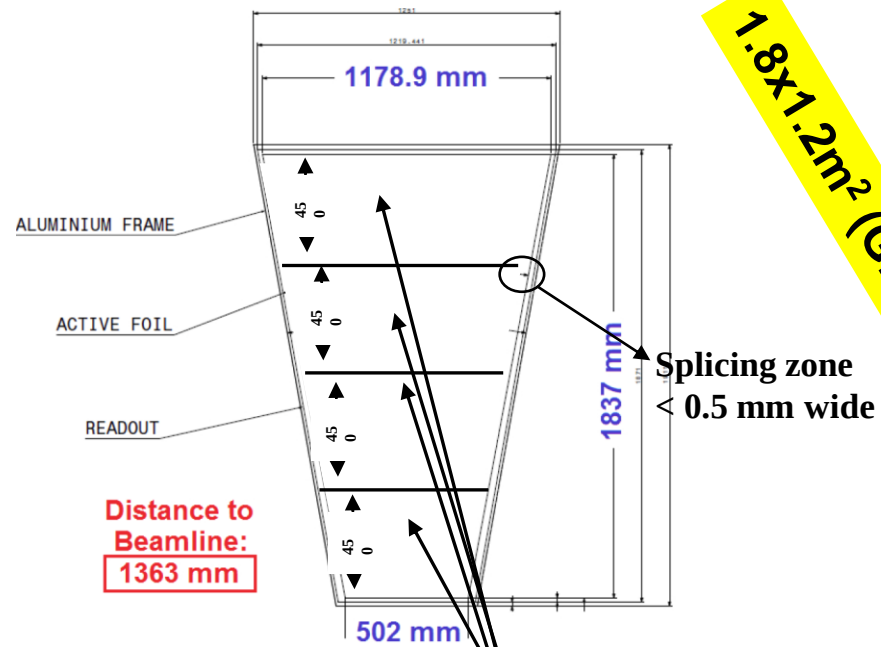
In the framework of the **CMS-phase2 muon upgrade** we are developing large size μ-RWELL. The R&D is performed in strict collaboration with an Italian industrial partner (ELTOS SpA). The work will be performed in two years with following (very tight schedule):

1. Construction of the first **1.2x0.5m^2 (GE1/1) μ-RWELL** **(07/2016)**
2. Full characterization of the **1.2x0.5m^2(GE1/1) μ-RWELL** **(12/2016)**
3. Mechanical study and mock-up of 1.8x1.2 m^2 (GE2/1) μ-RWELL **(05/2017)**
4. Construction of the first **1.8x1.2m^2 (GE2/1) μ-RWELL** **(12/2017)**
5. Full characterization of the **1.8x1.2m^2 (GE2/1) μ-RWELL** **(06/2018)**

1.2x0.5m^2 (GE1/1) μ-RWELL



1.8x1.2m^2 (GE2/1) μ-RWELL

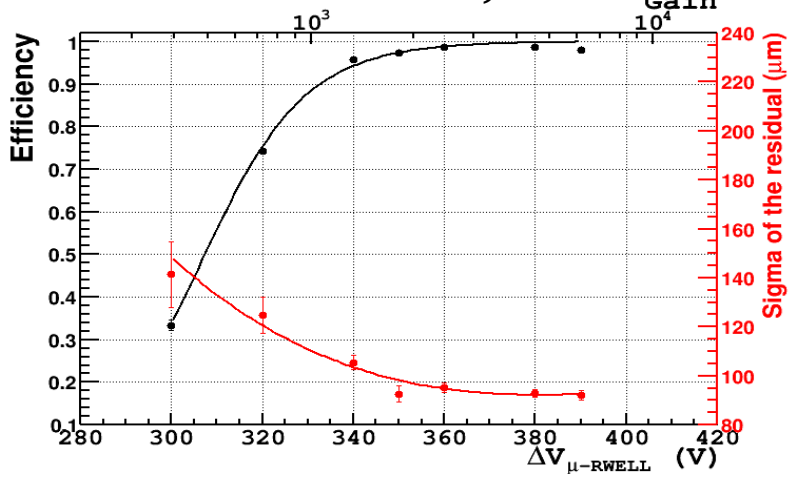


Four PCB μ-RWELL spliced with the same technique used for large ATLAS MM + only one cathode closing the detector

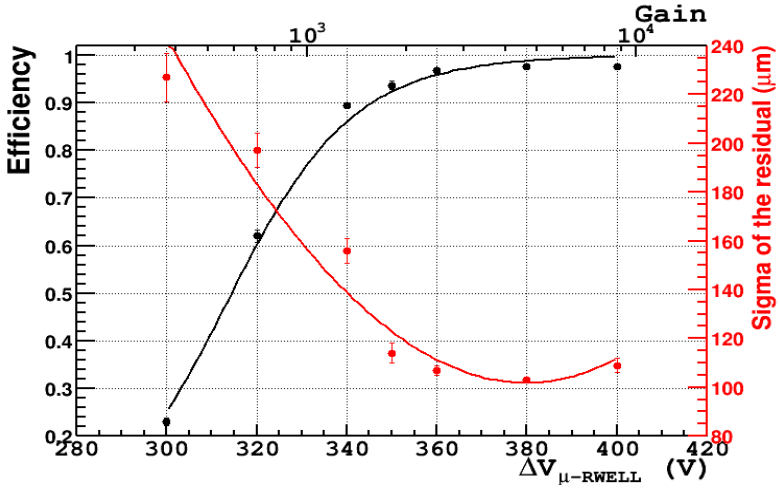
Test Beam results for μ-RWELL(*)

(*) **TB campaign of Dec.2014/June 2015** (μ-RWELL weren't installed in Nov. 2015)

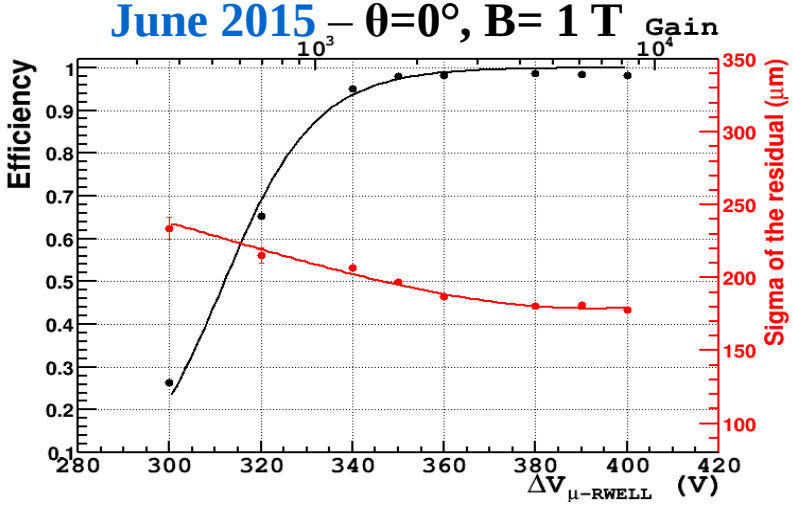
June 2015 – θ=0°, B= 0 T



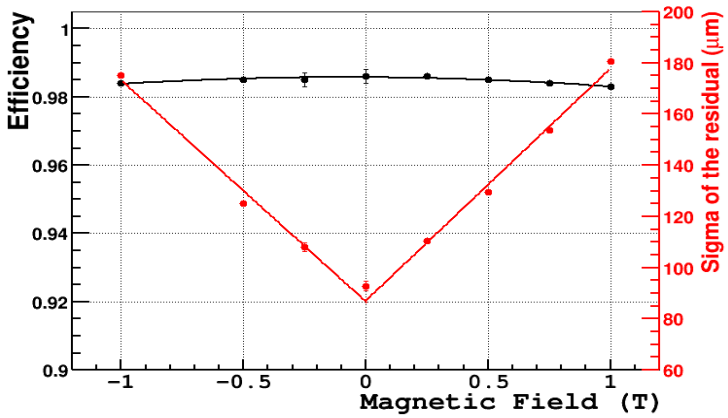
Dec 2014 – θ=0°, B= 0.5 T



June 2015 – θ=0°, B= 1 T



June 2015 - θ=0°,



For **θ=0° and 0 < B < 1 T ,** μ-RWELL exhibits a **σ < 180 μm** and **ε> 98%**

Towards the Comprehensive Design Report

1. **Detector R&D** and large size prototyping: the **work done for CMS phase-2 upgrade (GE2/1)** can be "cut and paste" for SHIP (apart the FEE)
   a. Milestone1 (GE1/1 RWELL built & characterized): **12/2016**
   b. Milestone2 (GE2/1 RWELL built & characterized): **6/2018**

   Manpower (2016/18): 2FTE mech. engineer, 2FTE elect. engineer, 6 FTE physicists
   Costs: R&D performed in the framework of CMS-muon phase2 upgrade

b. **Electronics** (in data drive mode→triggerless):
   a. **VMM ASIC:** R&D by G. De Geronimo - BNL Instr. Div - MM - ATLAS **6/2019**
   b. **BES3-IT ASIC**: R&D by A. Rivetti - INFN To **6/2018**
   c. **OFF detector Electronics:** to be developed (other groups are welcome !!!)

   Manpower (2018/19): 0.5 FTE electr. engineer
   Costs: 10 k€

3. **Beam Test** μ-RWELL/emulsion: **10/2017- 6/2018**
   Costs: 10k€ (detector) + 10k€ (missions)

4. **General Layout optimization** and drawings (for CDR): **0.5 FTE (2018**)

Summary

- The **GEM** option, for **θ <15° & B= 0,±1T,** shows:

$100 < \sigma(\mu m) < 400$ & $97 < \varepsilon(\%) < 99$

while large size (assembly complexity and costs) seems to be an issue

- **Improvement of space resolution (**large angle and high B) can be achieved with **μ-TCP approach** (work in progress – sinergy w/INFN-Ferrara - BESIII)

- The **μ-RWELL** detector, **for θ=0° and 0 < B < 1 T,** shows:

$\sigma < 180$ μm & $98\% < \varepsilon < 98.5\%$

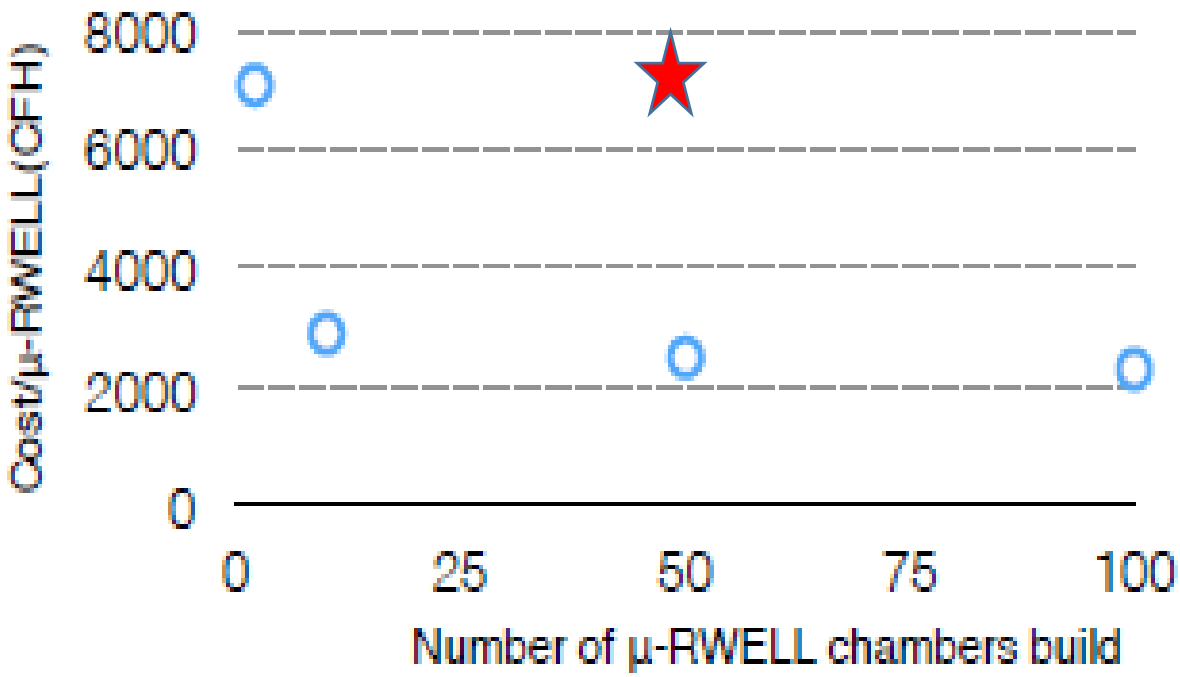
is a very promising technology & **allows the most simple & cost effective large area MPGD solution**

SPARE SLIDES

Cost of μ-RWELL and GEM for large volume production

Open dots: cost estimate (by ELTOS SpA) of a1.2x0.5m^2 μ-RWELL

Star: cost (by CERN) of a 1.2x0.5 m^2 GEM



Front End Electronics R&D for MPGDs

Two ASIC development with charge/time readout and data-driven architecture (trigger less) are going on:

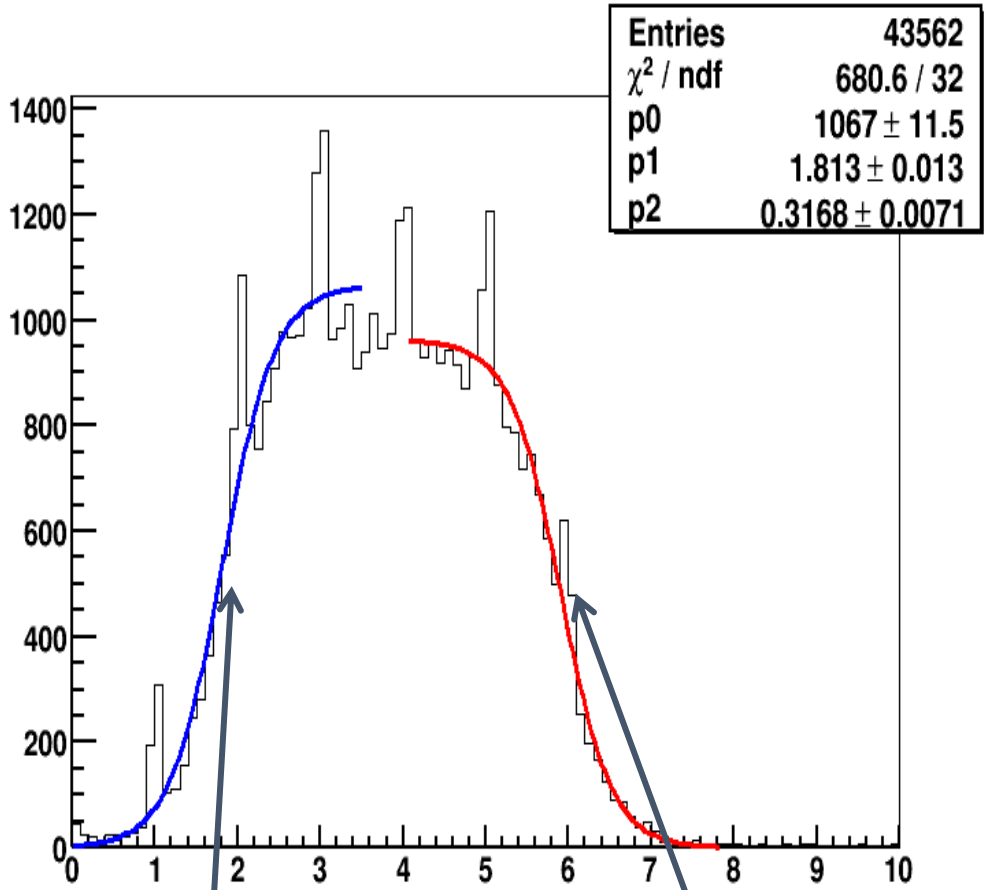
1. **VMM ASIC:** developed by G. De Geronimo - BNL Instr. Div (can operate in data drive mode)
2. **BES3-IT ASIC:** developed by A. Rivetti - INFN To (operate only in data driven mode)

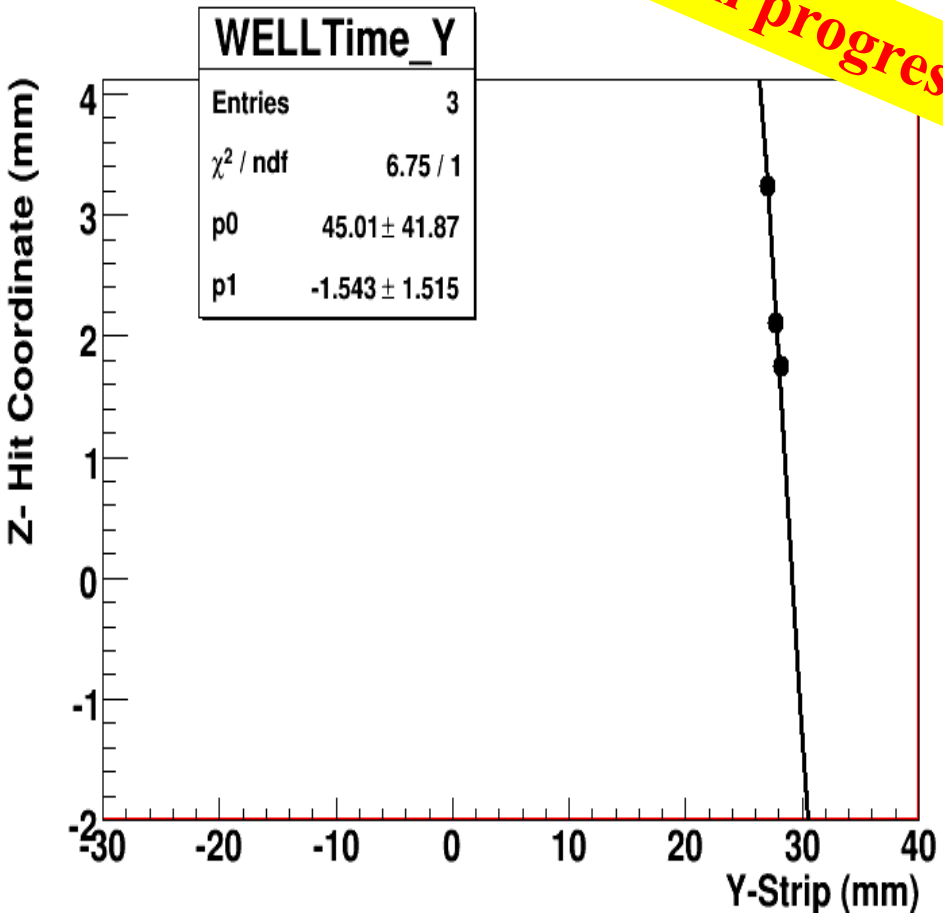
VMM will be used with resistive Micromegas & s-TGC detectors in the NSW upgrade of the ATLAS Muon spectrometer.
Installation foreseen in 2019.

The BES3-IT readout ASIC is a development of the TOFPET chip and will be used to instrument the new CGEM Inner Tracker designed to replace the BES3 Inner Chamber.
Installation foreseen for 2018

μ-TCP mode (II) w/orthogonal tracks & B = 1T

The Fermi-Dirac's parameter p1 for all events





work in progress

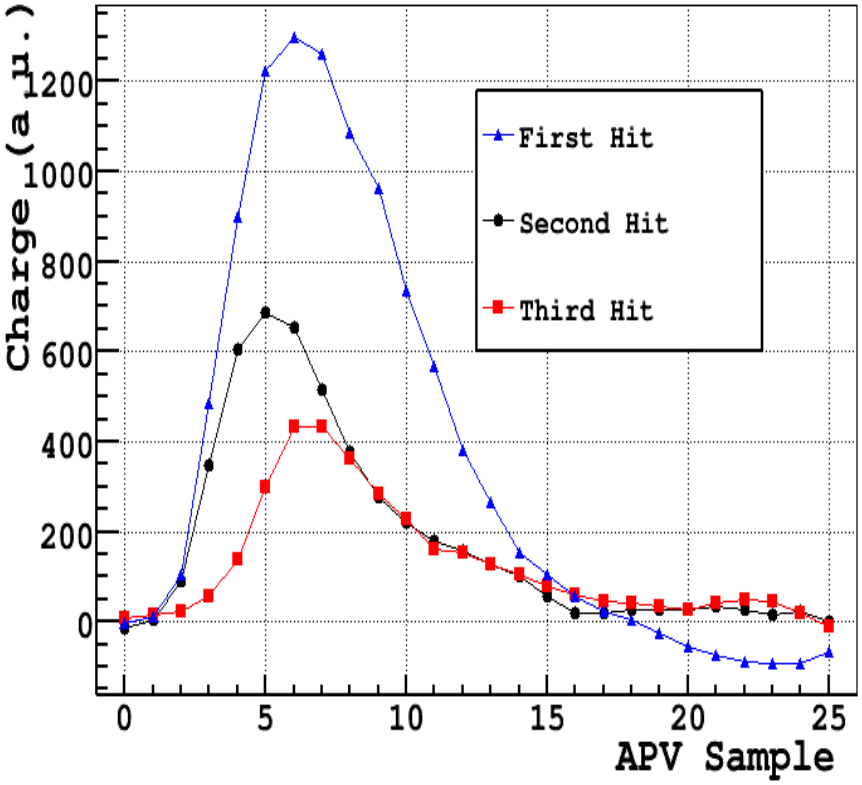
T0 = 1.81 APV Sample → (45.323 +- 0.003) ns	**Tmax = 5.91 APV Sample → (147.657 +- 0.004) ns**

Double Fermi-Dirac Fit

ΔT = 102.3 +- 0.1 ns
Drift Gap = 4 mm
Drift Velocity = (3.9 +- 0.1) cm/μs
Drift Velocity (Garfield) = (3.5+-0.1) cm/ μs

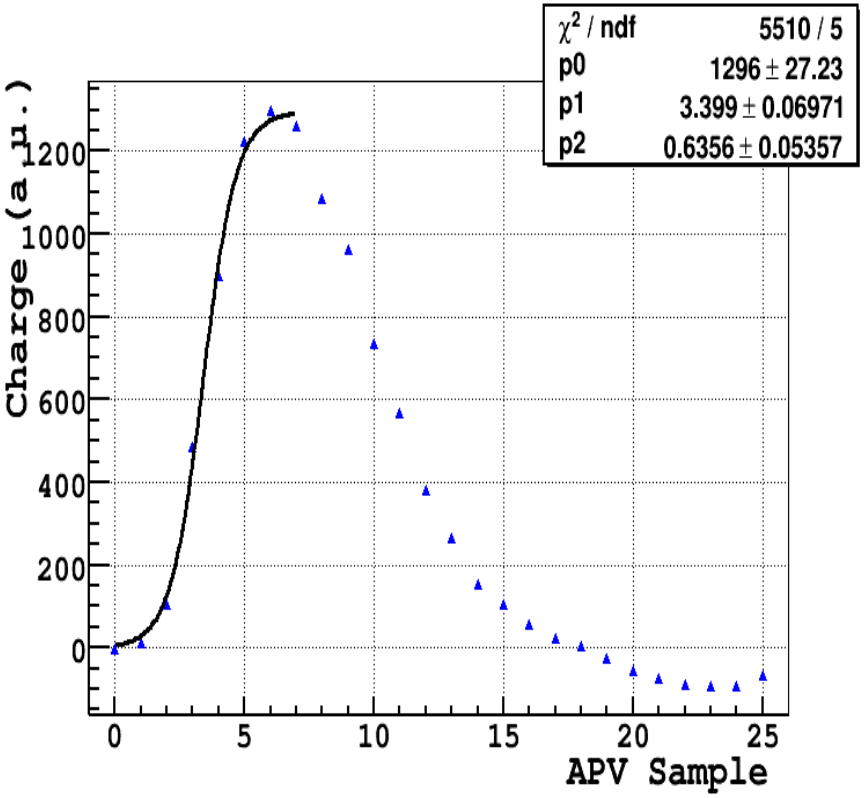
μ-TCP mode (I) w/orthogonal tracks & B = 1T

Event with 3 hits



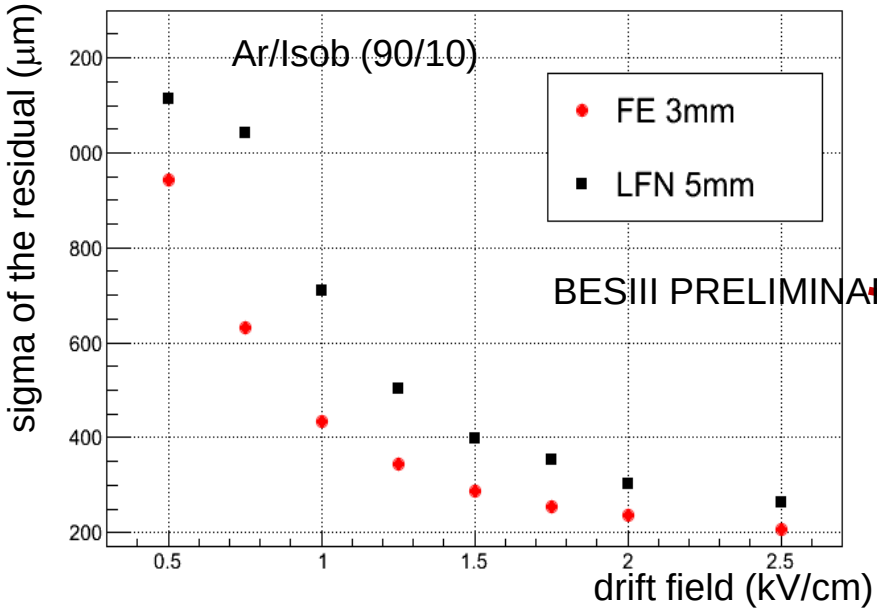
work in progress

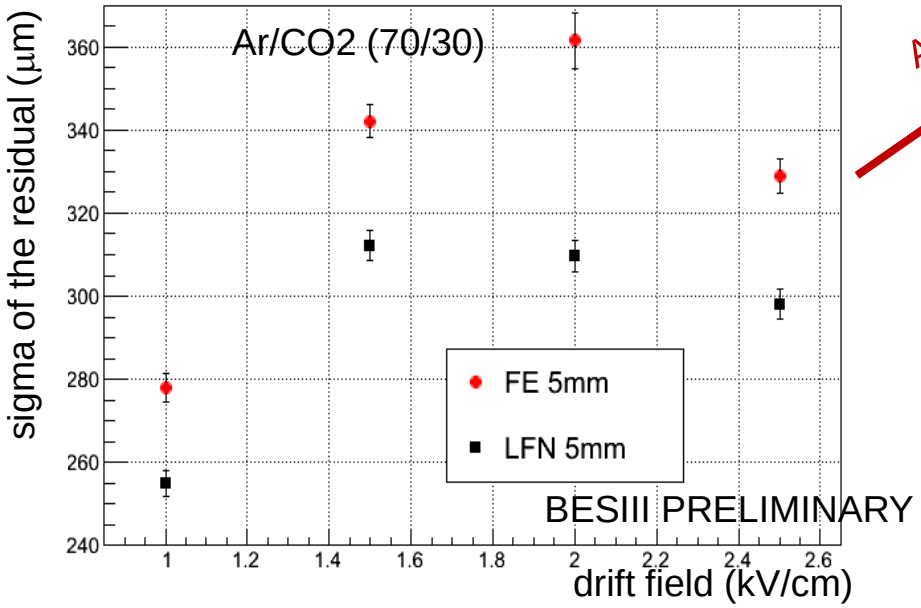
$$FD(t) = \frac{p0}{1 + exp^{\frac{-(t-p1)}{p2}}}$$



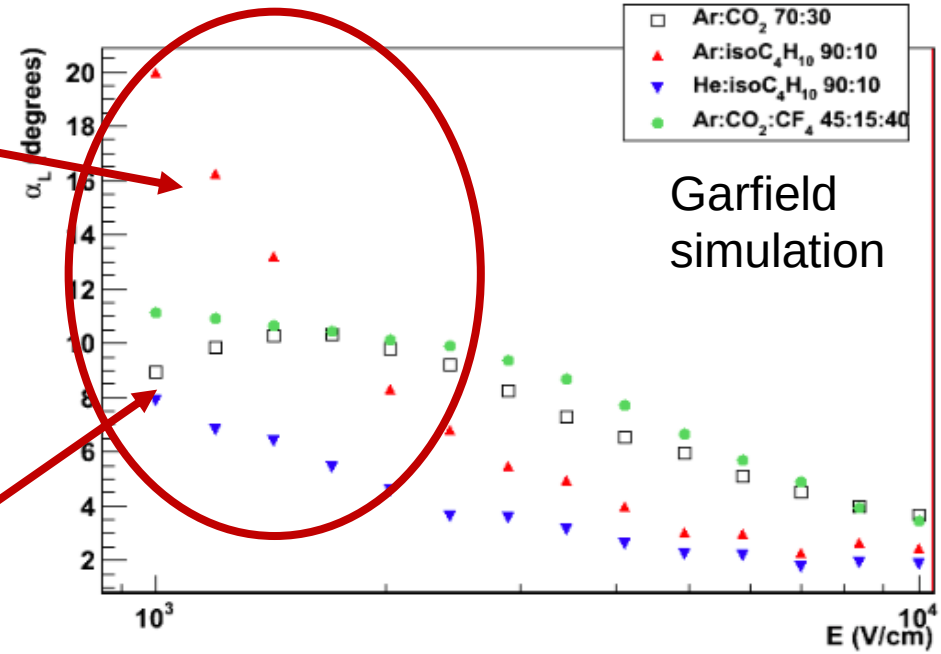
The **rise time of the signal time development** is fitted with a Fermi-Dirac:
p1 is the time at half-maximum of the charge signal distribution.
APV-time sample=25 ns

GEM: drift field scan – θ=0, B=1T





Performed a drift field scan to improve the space resolution. The behavior of the resolution copy the Lorentz angle for each gas mixture.



Space resolution of about 190 microns (subtracting the tracking contribution) with Ar/Isobutane (90:10), and with 650 micron strip pitch.

Efficiency not affected by drift field variation in the studeied range.

Still room for improvement for the charge centroid method.

RUN conditions

Calibration RUN (upstream – downstream trigger):

- Scan in drift field with orthogonal tracks & B=0 T (7 runs)
- Scan in HV with orthogonal tracks & B=0, -1 T (18 runs)
- Scan in angle (0,7.5,15,30,45) & B= 0, ± 1 T & 2 GEM Gain (30 runs)

Run with emulsion setup (trigger w/forward scintillators + SW trigger based on forward trackers + μ-RWELL):

- Scan with CS emulsion: angle (0,7.5,15,30,45) & B= 0, ± 1T (10 runs)
- Scan with CES & ECC emulsion: tilt angle (0,7.5,15,30,45) & B= 0 T (10 runs)

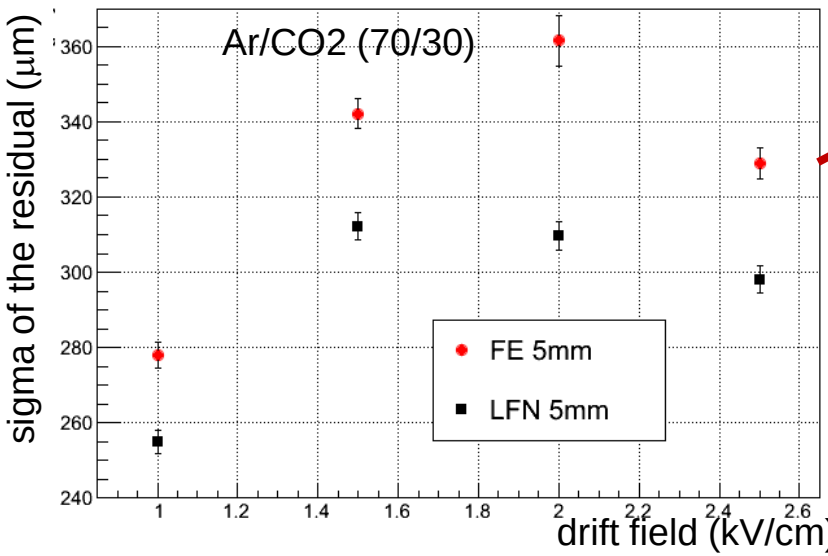
We present preliminary results based on (COG) method for the Calibration runs

NO micro-TPC MODE ANALYSIS (the code is under development by INFN-FE)

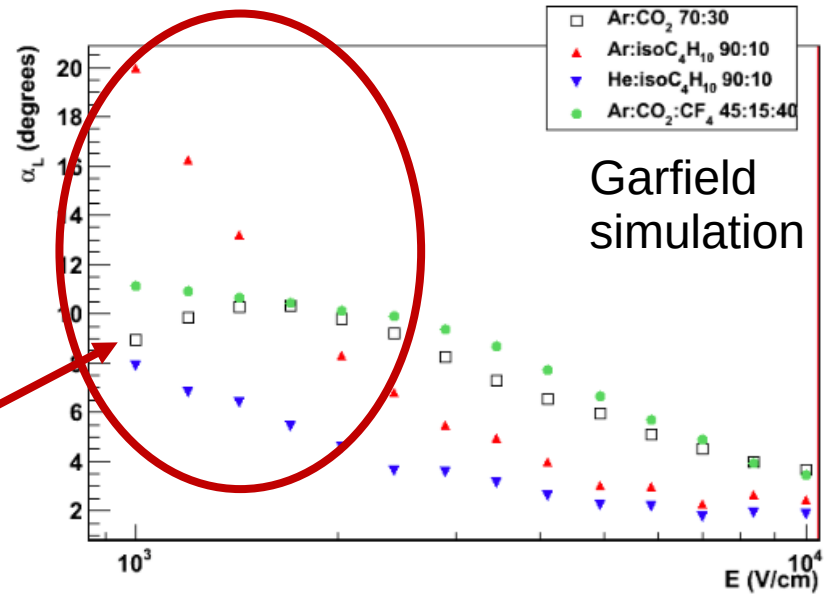
NO COMBINED RESULTS BETWEEN GEM & EMULSIONS SETUP

BES-III Prototype: Residual vs Ed with B=1 T

Performed a drift field scan to improve the space resolution. The behavior of the resolution copy the Lorentz angle for each gas mixture.



Ar/CO2 (70/30)



TB_Giugno_2015

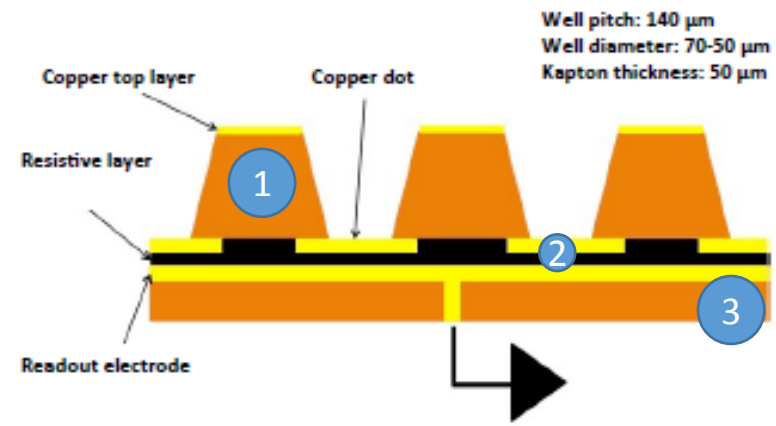
The μ-RWELL architecture

The **μ-RWELL(*) PCB** is realized by coupling:

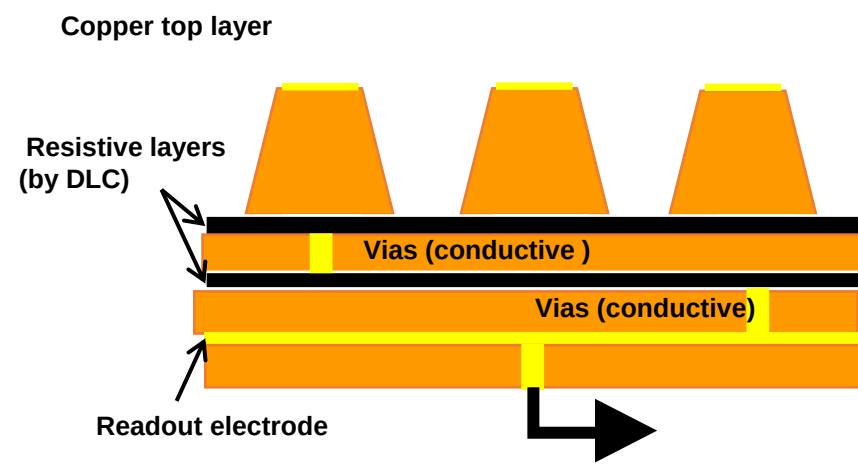
1. a "**suitable patterned GEM foil**" for the "amplification stage"

2. a **"resistive stage"** for the discharge suppression & current evacuation
   - **i. "Low particle rate" (LR)** << 100kHz/cm^2**:** single resistive layer → surface resistivity (~100 MΩ/□)
   - **ii. "High particle rate" (HR**)** >> 100kHz/cm^2: more sophisticated resistive scheme must be implemented (*performed by MPDG_NEXT- LNF financed by GR5-INFN*)

3. a **simple readout PCB** board → OK



The simplest scheme of μ-RWELL detector

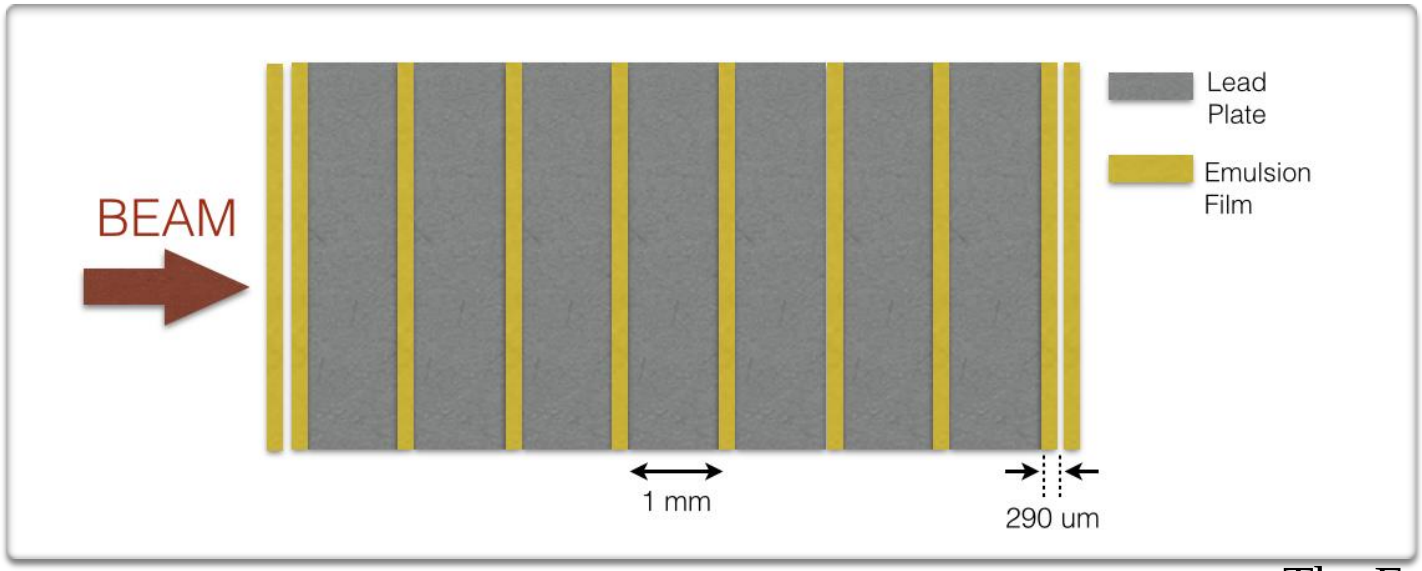


(**) the final goal being O(1 MHz/cm^2)

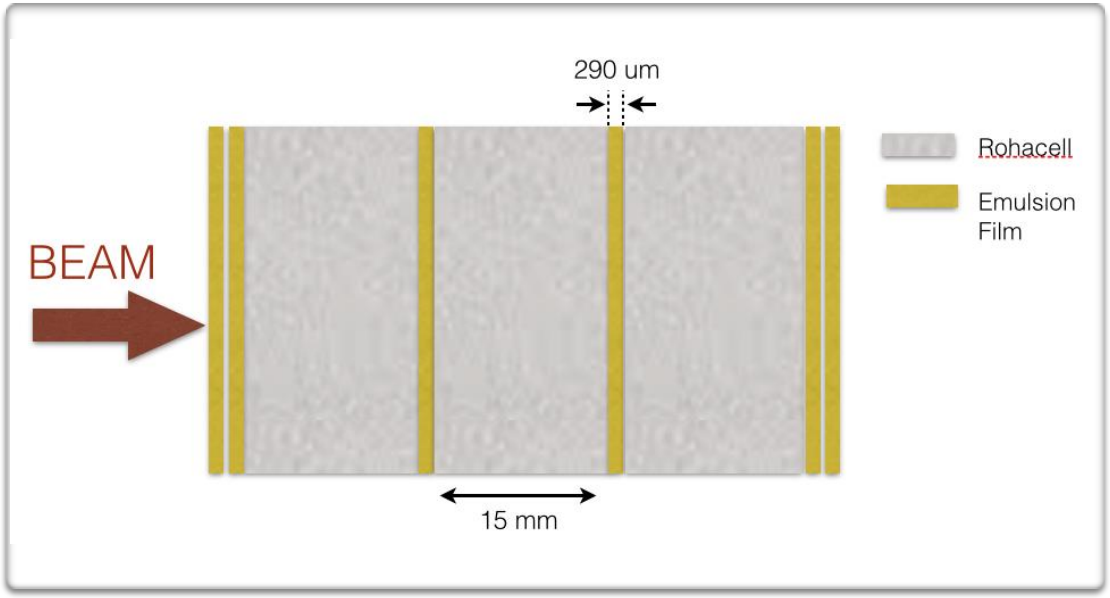
(*) the first prototype of such a type of detector (at that time called *Blind-GEM* detector) has been proposed in the 2009 by the author.

Emulsion Target Units

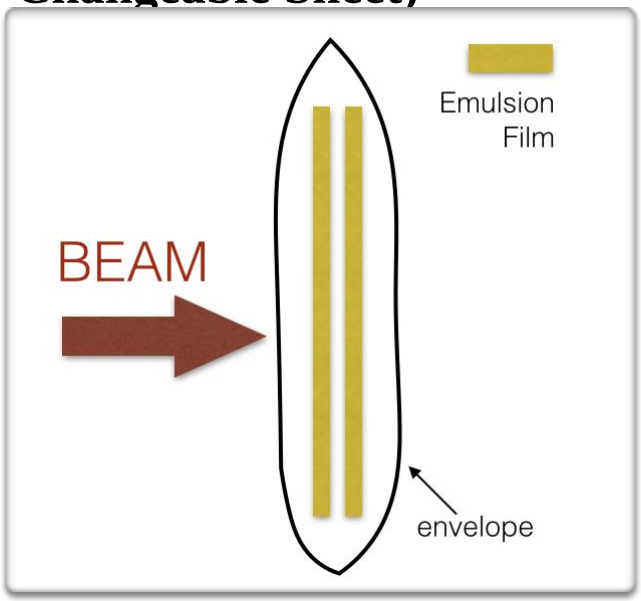
- The Emulsion Cloud Chamber **(ECC)**



- The Compact Emulsion Spectrometer **(CES)**



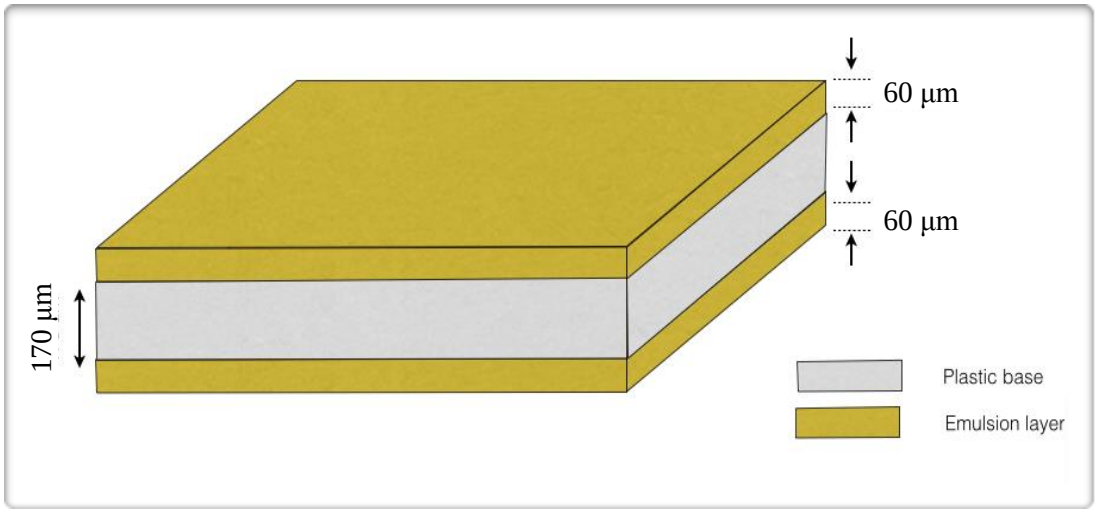
- The Emulsion Doublet **(CS – Changeable Sheet)**



Emulsion Films

- Emulsion films produced in Nagoya University

- Film dimensions
  - Surface: 125 mm x 100 mm
  - Total thickness: 290 μm



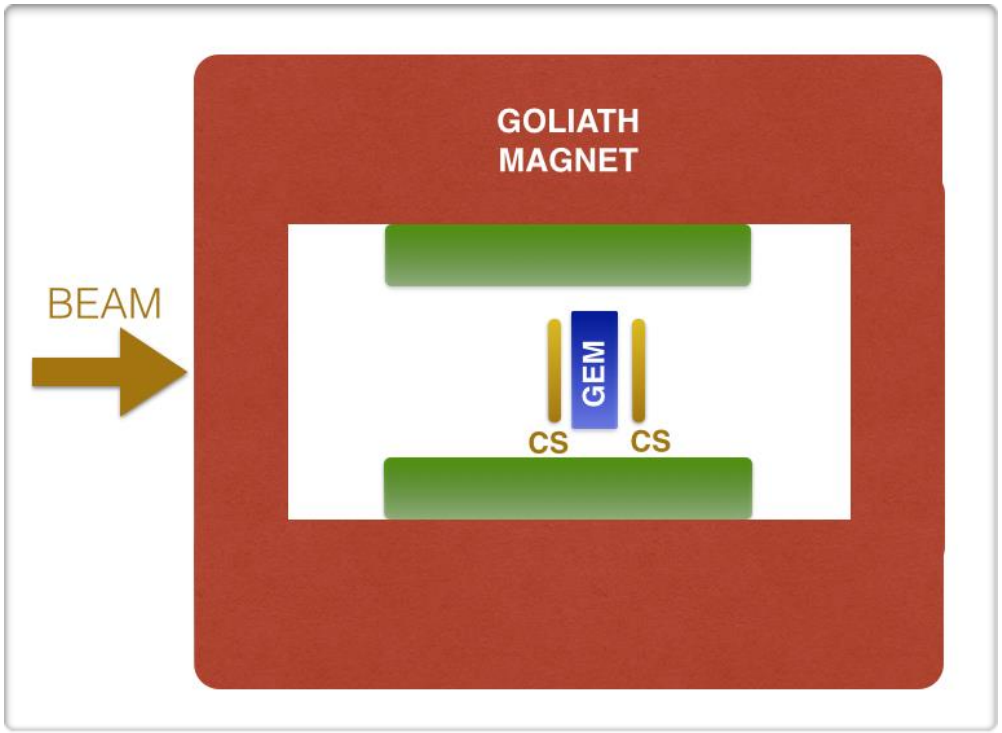
- New emulsion gel developed in Nagoya University
  - Grain density: 50 grains/100 μm (higher than OPERA films)

- Emulsion production
  - Emulsion poured in middle August 2015 and cut by hand
  - Shipped to CERN by plane
  - Total amount of emulsion films produced: 120
  - Emulsion films used in the Emu+GEM test beam: 30

CS exposure

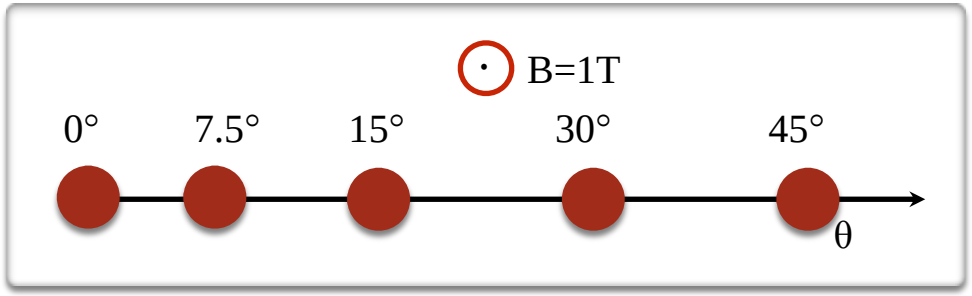
- Aim: study of the GEM space resolution with external track point (coming from the two CS) reconstructed with precision at level of few µm

- Experimental setup: #2 CS attached on GEM upstream and downstream surfaces
- Low density: 50 tracks/cm^2/angle
- 5 exposure angles



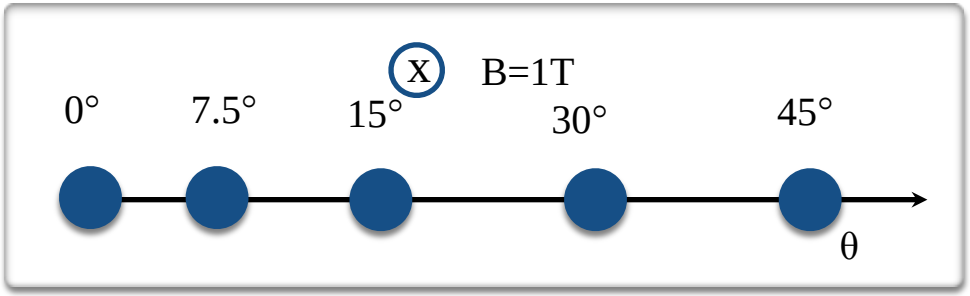
Exposure 1

- Target: 2 x CS
- Magnetic Field: + 1T



Exposure 2

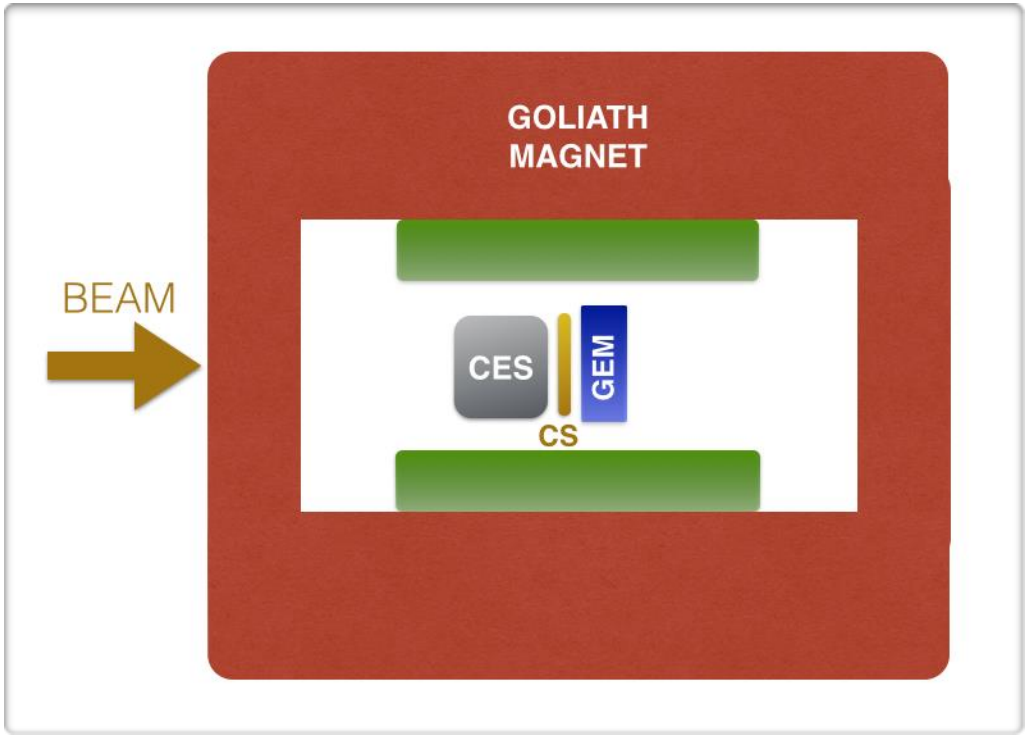
- Target: 2 x CS
- Magnetic Field: - 1T

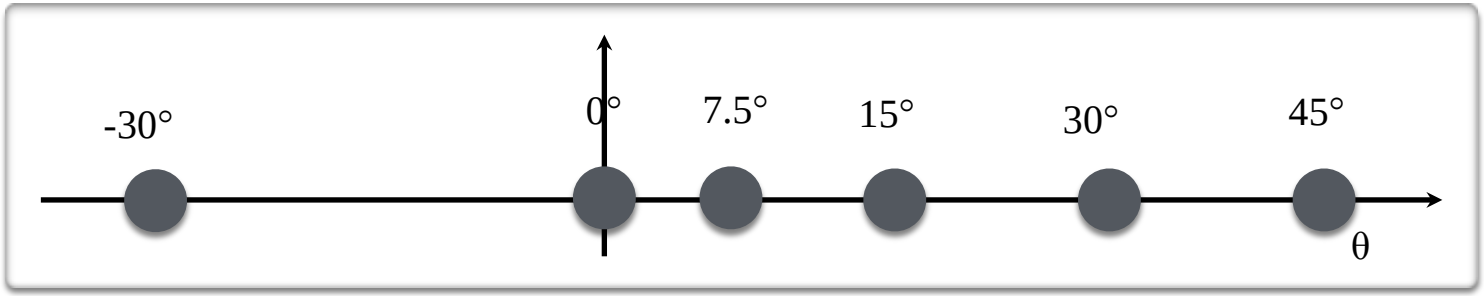


CES exposure

- Aim: track matching between GEM and CES (Emulsions interleaved with Rohacell)

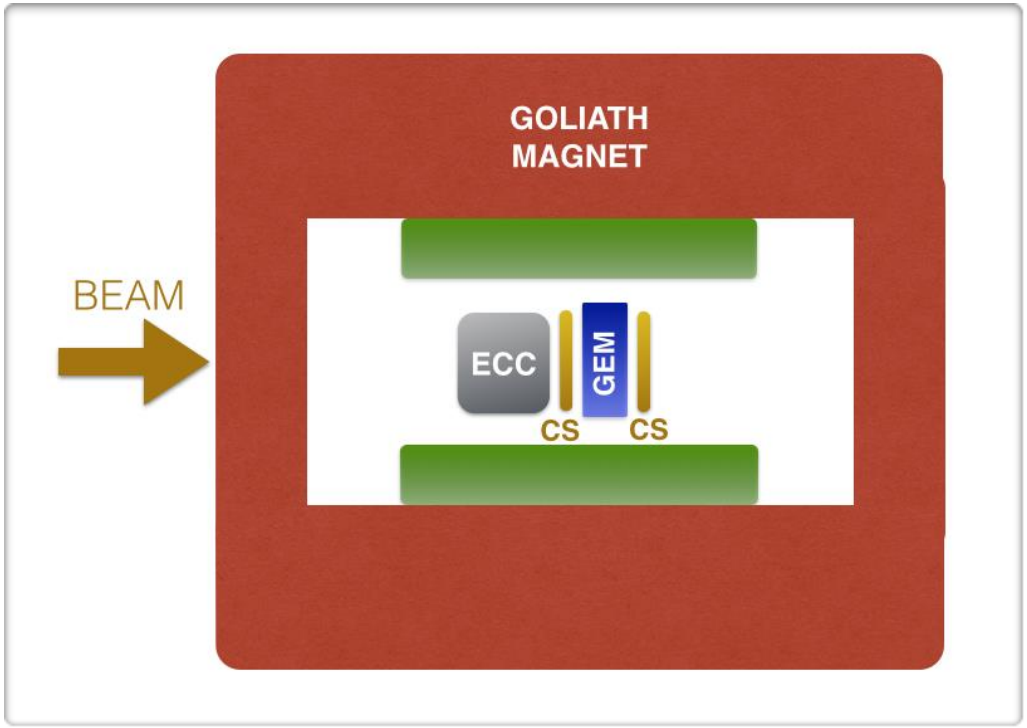
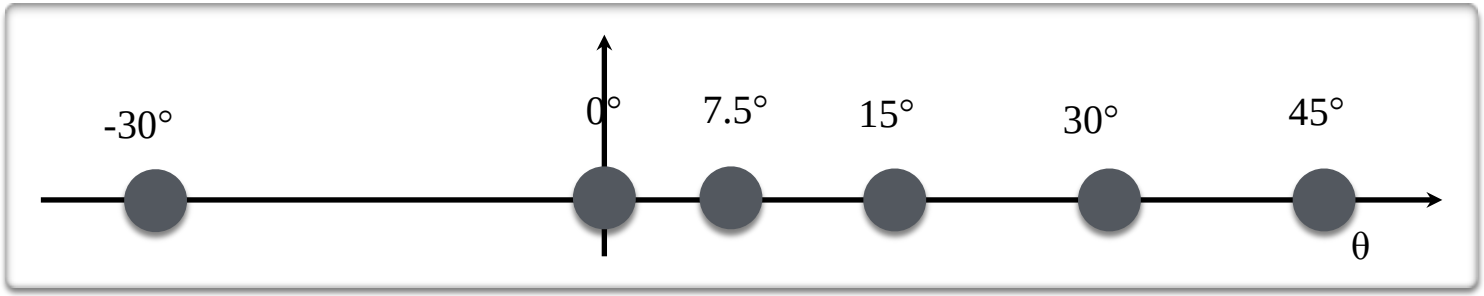
- Target: 1 CES + 1 CS (Emulsion doublet)
- Low density: 100 tracks/cm^2/angle
- 6 exposure angles
- No magnetic field





ECC exposure

- Aim: track matching between GEM and ECC (Emulsions interleaved with Lead)



- Target: 1 ECC + 2 CS (Emulsion doublet)
- Low density: 100 tracks/cm^2/angle
- 6 exposure angles
- No magnetic field