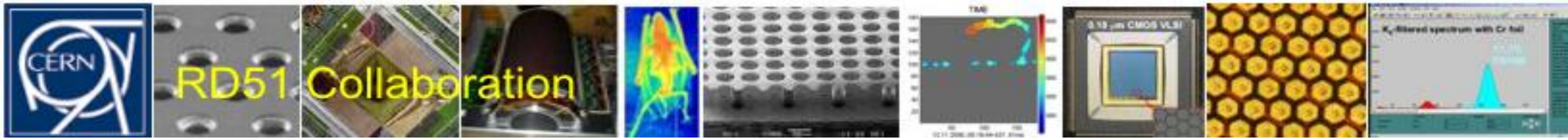
The μ-RWELL detector

G. Morello on behalf of the LNF-DDG group

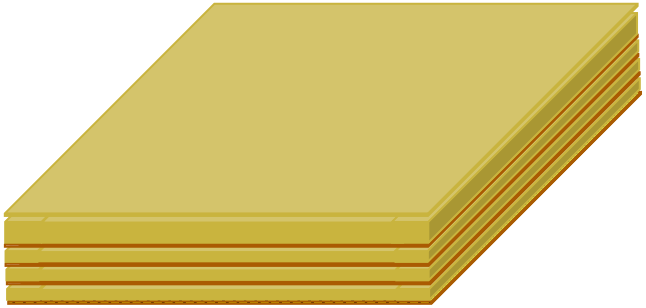
Frascati Detector School

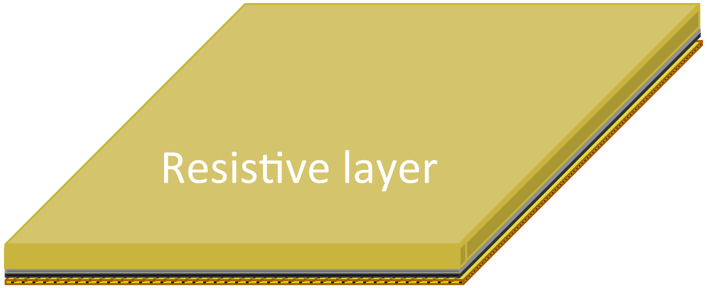
March 23rd, 2018



A brief history of MPGDs towards μ-RWELL

- **G. Charpak et al.**, *The use of multiwire proportional counters to select and localize charged particles*, Nucl. Instr. Meth. **62** (1968) 262-268.
- **A. Oed**, *Position-sensitive detector with microstrip anode for electron multiplication with gases*, Nucl. Inst. Meth. **A 263** (1988) 351-359.
- **Y. Giomataris et al.**, *Micromegas: a high-granularity, position sensitive gaseous detector for high particle flux environments*, Nucl. Inst. Meth. **A 376** (1996) 29.
- **F. Bartol et al.**, *The C.A.T. Pixel Proportional Gas Counter Detector,* J. Phys. III France **6** (1996)
- **F. Sauli**, *GEM: A new concept for electron amplification in gas detectors*, Nucl. Inst. Meth. **A 386** (1997) 531.
- **R. Bellazzini et al.**, *The WELL detector*, Nucl. Inst. Meth. **A 423** (1999) 125.
- **G. Bencivenni et al.**, *A novel idea for an ultra light cylindrical GEM based vertex detector*, Nucl. Inst. Meth. **A 572** (2007) 168.
- **P. Fonte et al.**, *Advances in the Development of Micropattern Gaseous Detectors with Resistive Electrodes,* Nucl. Inst. Meth. **A 661** (2012) 153.
- **G. Bencivenni et al.**, *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD,* JINST **10** (2015) P02008.





GEM µ-RWELL MicroMegas

The μ-RWELL: motivations

Because of the micrometric distance between electrodes, every MPGD suffers from spark occurrence that can damage the detector or the FEE.
A resistive readout quenches the discharge:

- The Raether limit is overcome
- The charge is deposited on the resistive layer
- The charge density spreads with ***τ = RC***
(**M.Dixit**, NIM **A 518** (2004) 721)
- The resistive layer is locally charged-up with a potential ***V=Ri***, reducing the ΔV applied to the amplification stage
- The amplification field is reduced
- The discharge is locally suppressed

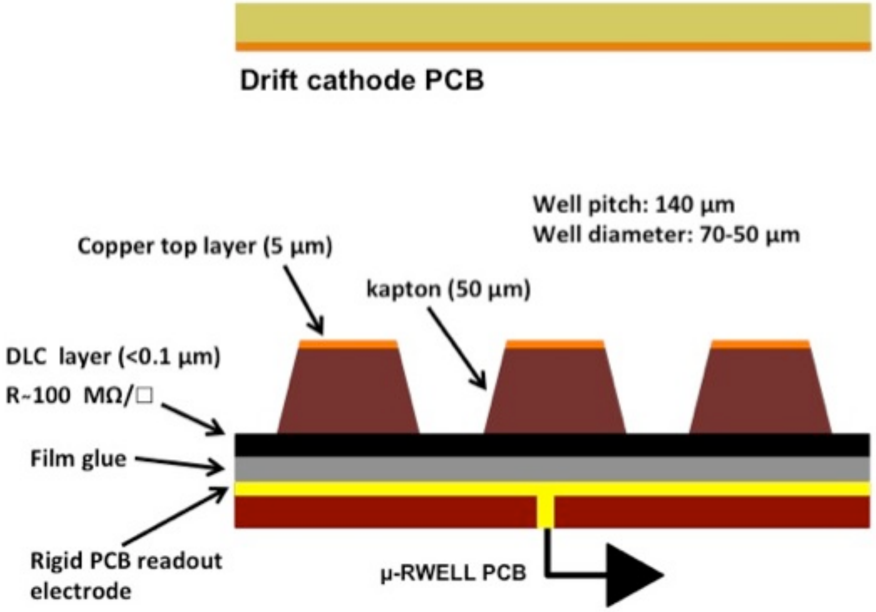
Obviously this has a drawback correlated to high particle fluence, that's why we studied the performance of the detector as a function of the resistivity

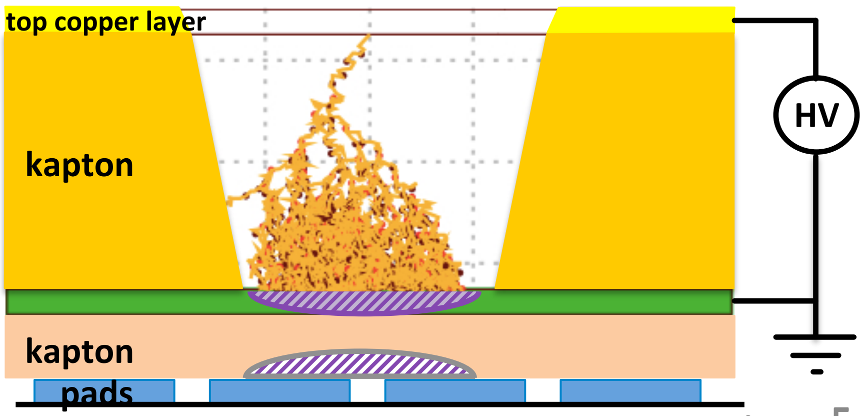
The detector architecture

The **µ-RWELL is composed of** only **two elements**:
the **µ-RWELL_PCB** and the **cathode**

The **µ-RWELL_PCB, the core of the detector,** is realized by **coupling:**

1. a "WELL patterned kapton foil" as **"amplification stage"**
2. a **"resistive sheet"** for the discharge suppression & current evacuation
   - **i. "Single resistive layer" (SL)** < 100 kHz/cm^2**:** single resistive layer → surface resistivity ~100 MΩ/☐ (CMS-phase2 upgrade; SHIP)
   - **ii. "Double resistive layer" (DL)** > 1 MHz/cm^2: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF) suitable for LHCb-Muon upgrade
3. a **standard readout PCB**





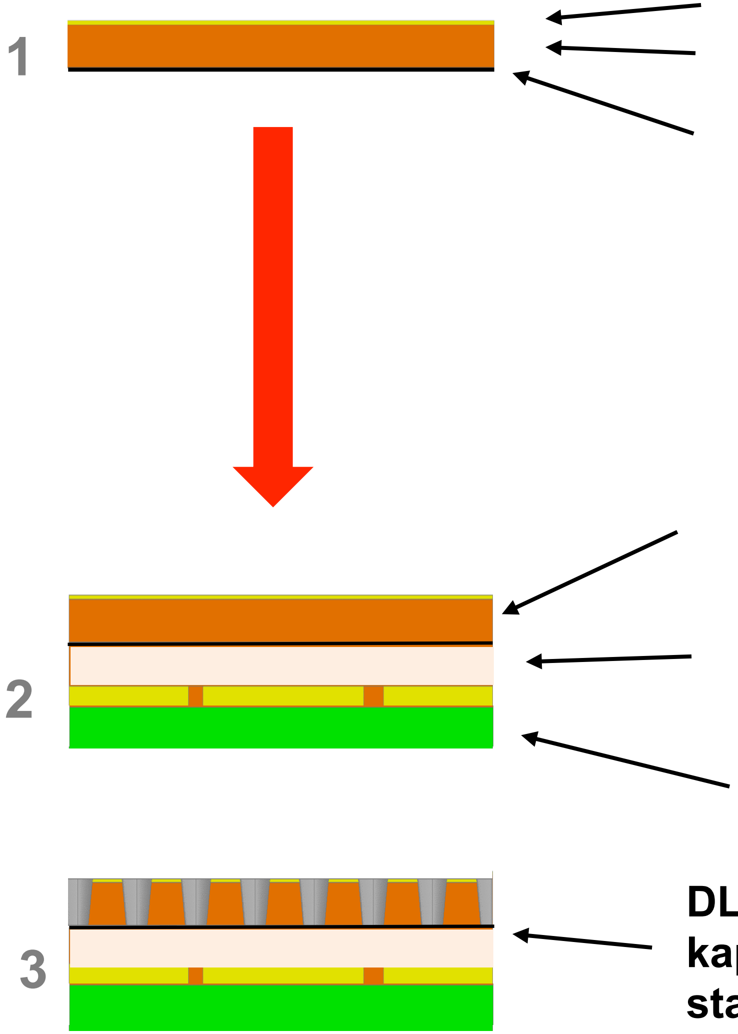
Not in scale

The µ-RWELL

The **µ-RWELL** is a **single-amplification stage**, intrinsically **spark protected** MPGD characterized by:

- ***simple assembly procedure**:*
  - ***only two components → µ-RWELL_PCB + cathode***
  - no critical & time consuming **assembly** steps:
    - ***no gluing***
    - ***no stretching* (→** no stiff & large frames needed)
    - ***easy handling***
  - ***suitable for large area with PCB splicing technique w/small dead zone***
- ***cost effective:***
  - 1 PCB r/o, 1 µ-RWELL foil, 1 DLC, 1 cathode and very low man-power
- ***easy to operate:***
  - very simple HV supply → only ***2 independent HV channels*** or a trivial ***passive divider*** (while 3GEM detector → 7 HV floating/channels)

The single layer scheme (CMS/SHiP)



Copper layer 5 µm

Kapton layer 50 µm

DLC layer: 0.1-0.2 µm (10-200 MΩ/☐)

DLC-coated kapton base material

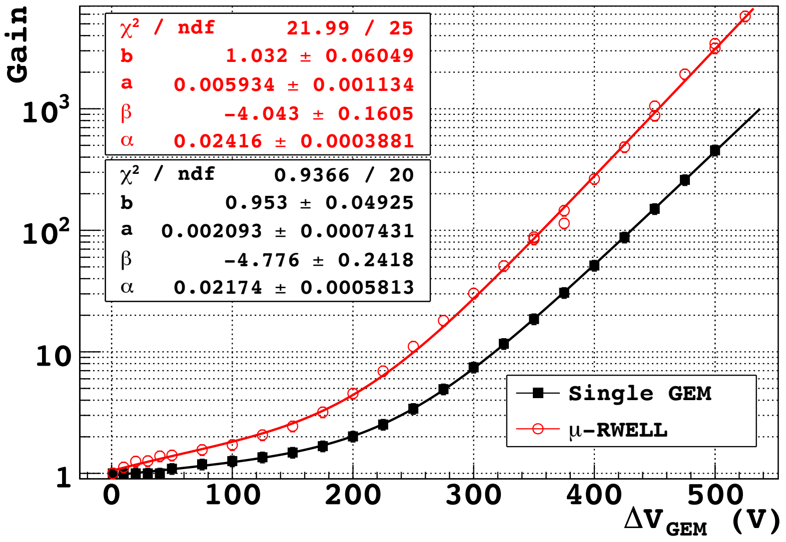
Insulating medium (50 µm)

PCB (1-1.6 mm)

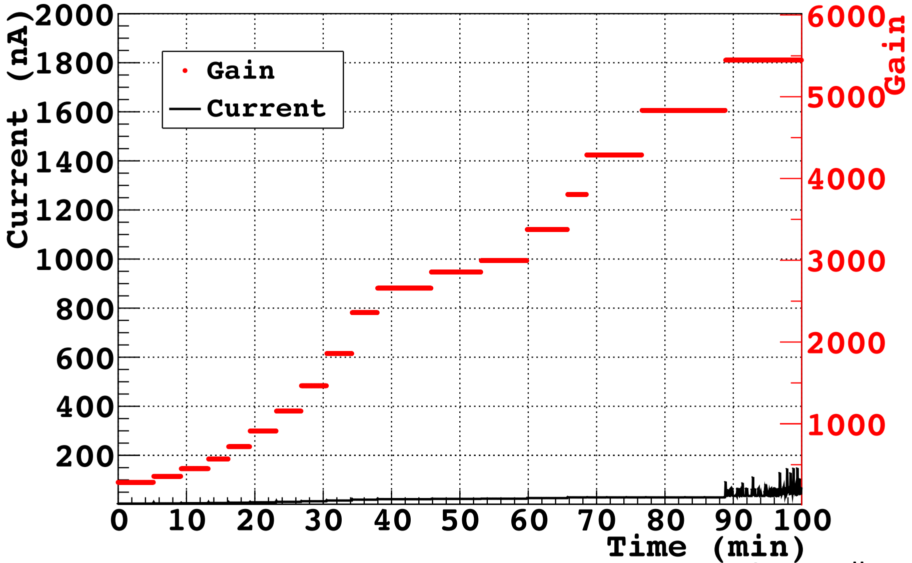
DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)

The µ-RWELL performance

The first prototype (5x5 cm^2 active area) has been tested with Ar:CO$_2$ 70:30 and Ar:iC$_4$H$_{10}$ 90:10 gas mixtures, irradiated with 5.9 keV X-rays generated by a PW2217/20 Philips Tube.



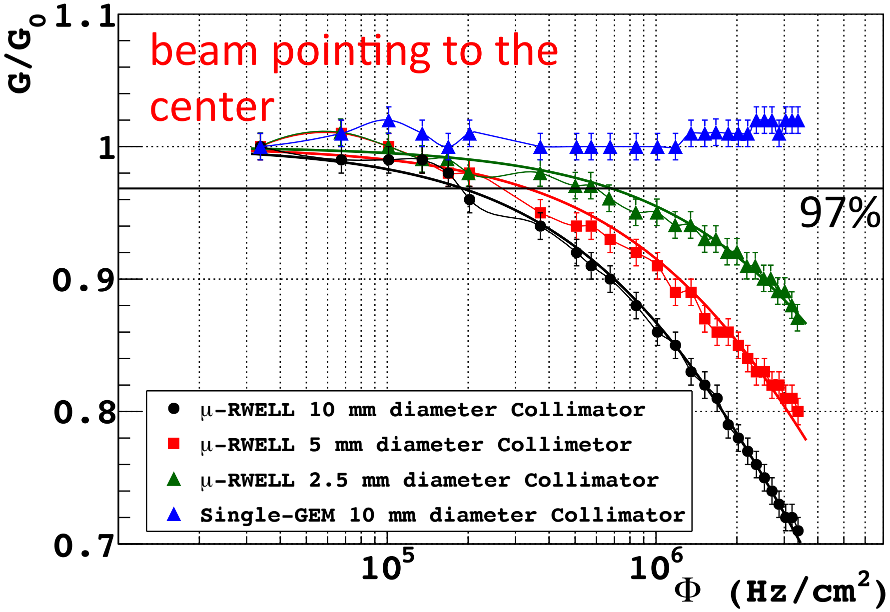
Gas gain (current mode) measured in Ar:CO$_2$ 70:30



Gain parametrized as

$$G=\exp(\alpha\Delta V+\beta)$$

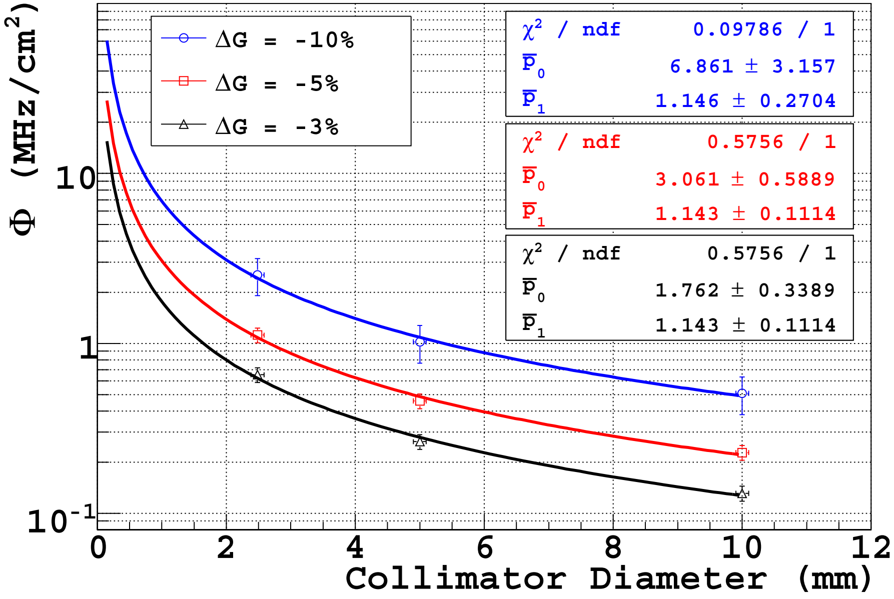
The µ-RWELL performance

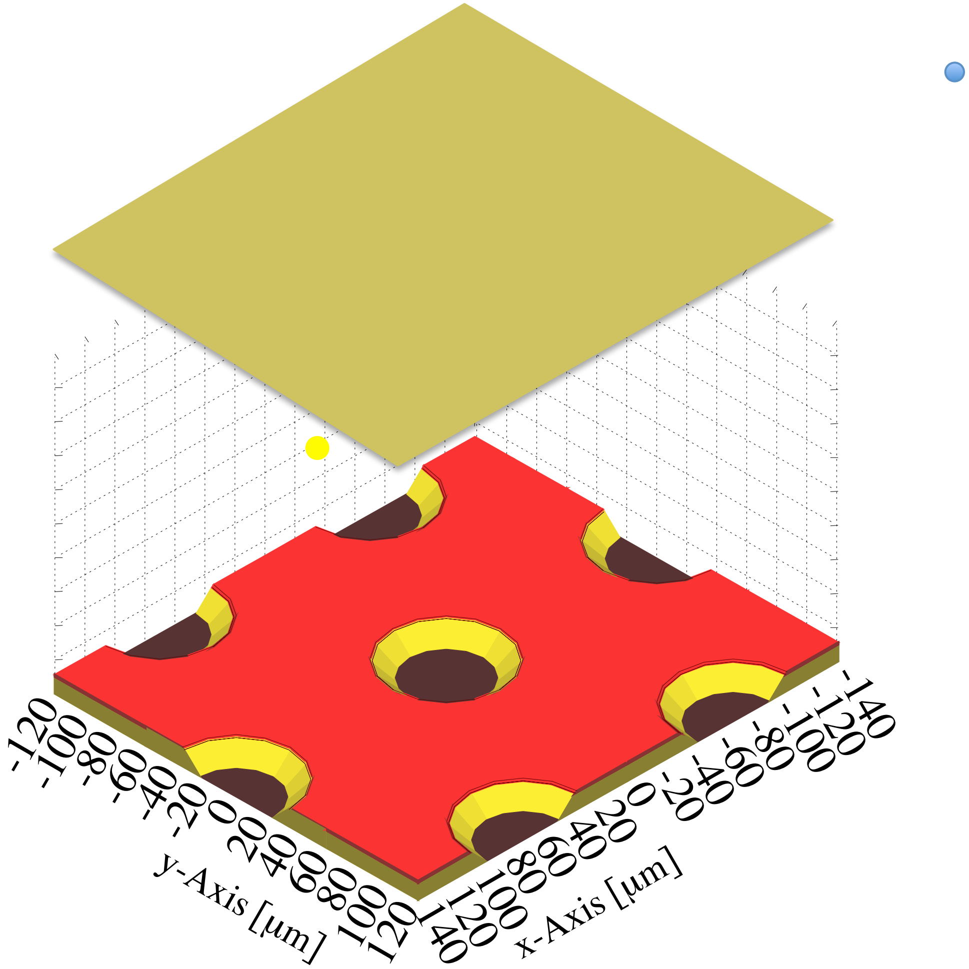

beam pointing to the center

The presence of the resistive layer has a drawback represented by the reduced capability of the detector to stand high particle fluxes

A suitable segmentation of the resistive layer can tune the rate capability of the detector.

IMPORTANT: for a m.i.p. the primary ionization is 7 times smaller than 5.9 keV X-rays, so with the proper segmentation a flux of ~1 MHz/cm^2 for m.i.p should be achievable




-120
-100
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120
y-Axis [μm]
-140
-120
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-80
-60
-40
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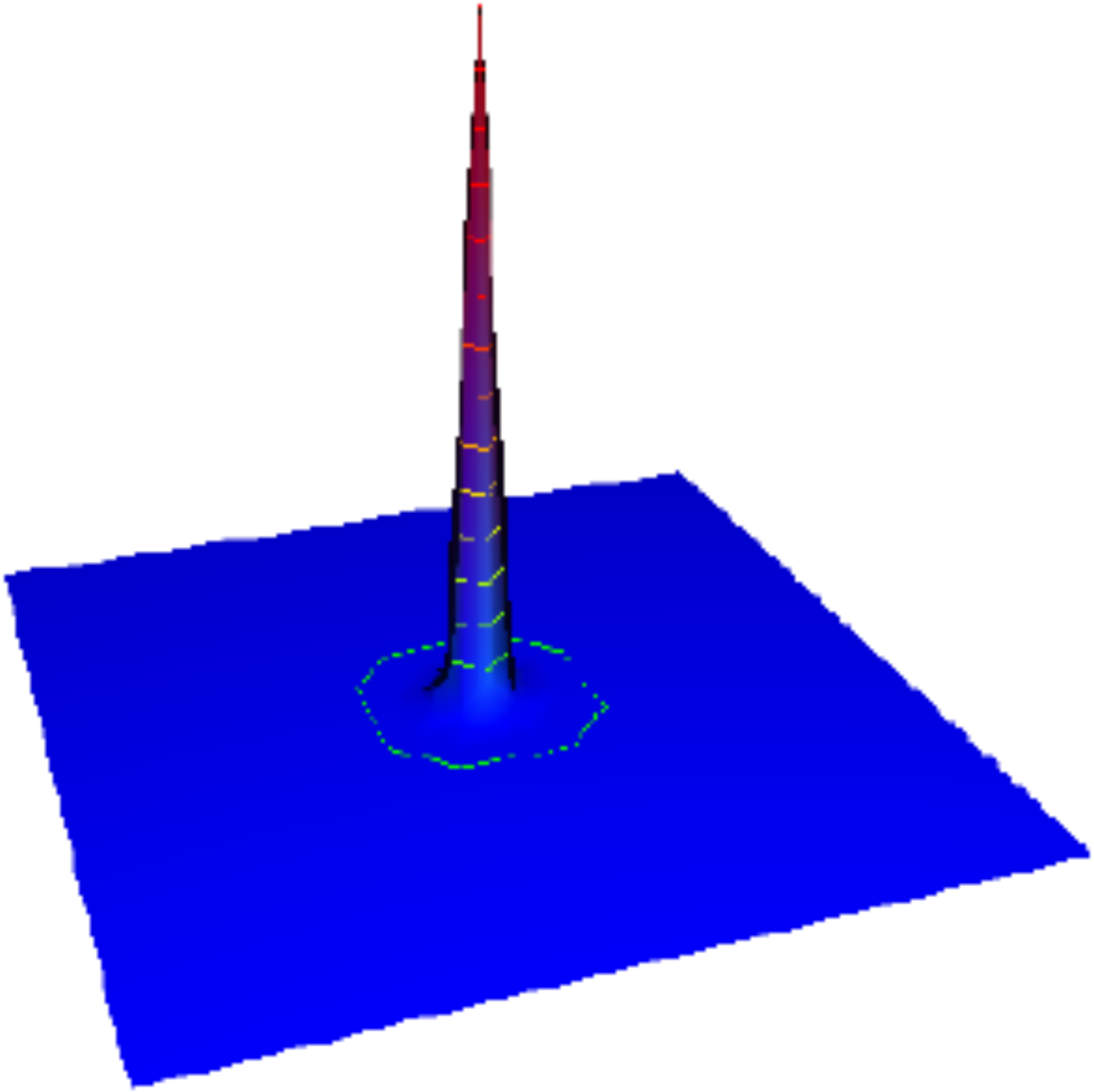
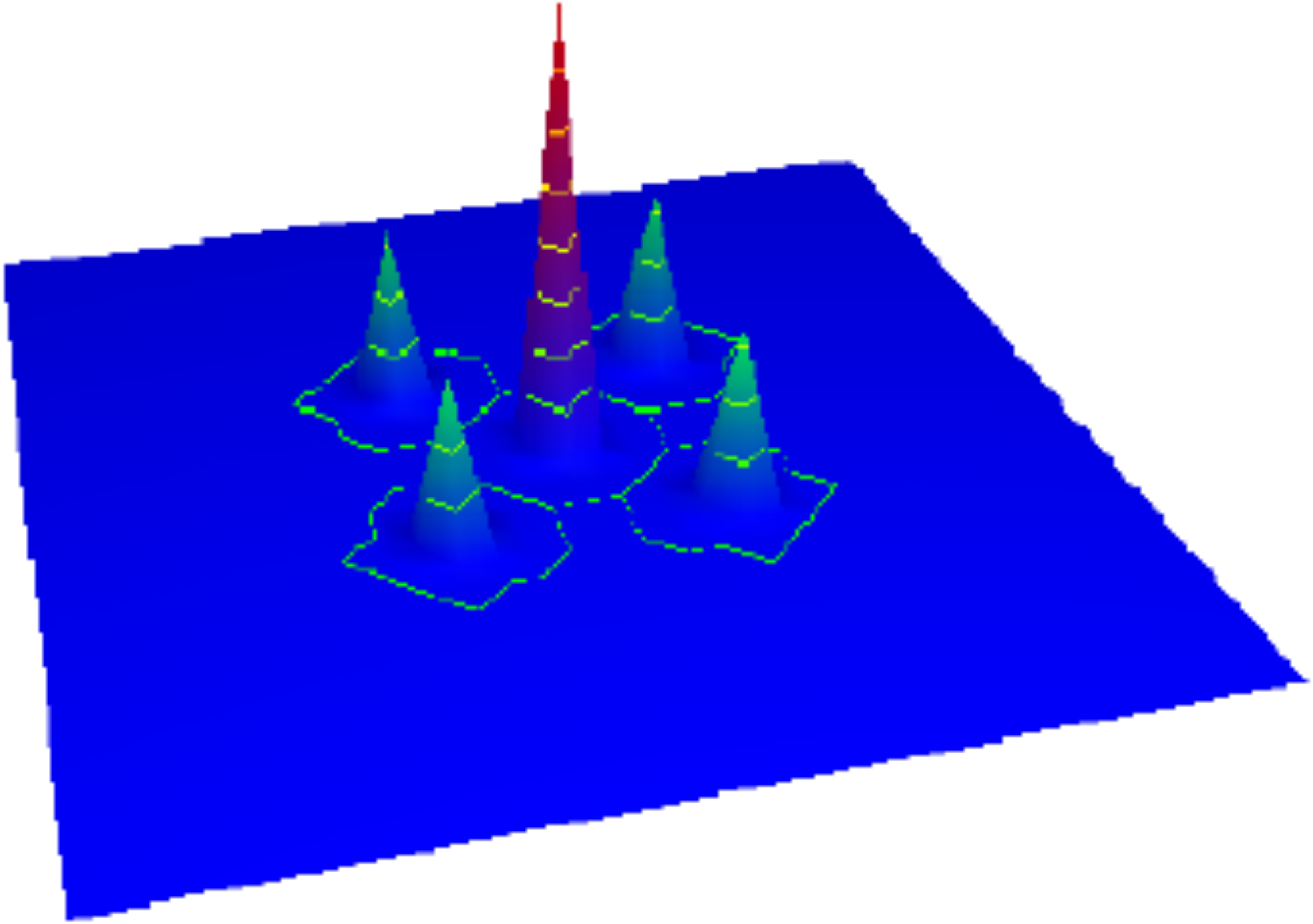
20
40
60
80
100
120
140
x-Axis [μm]





G. Morello, LNF-INFN

The gain drop

It’s easy to understand that the larger is the resistance of the layer, the longer will take the charge to reach the ground. This creates temporary charging-up of the resistive layer with consequent drop of gain.
The gain of a µ-RWELL can be written as follows

$$G_0 = e^{\beta + \alpha V_0}$$

that allows to write a gain drop as

$$G = e^{\beta + \alpha (V_0 - \delta V)} = G_0 e^{-\alpha \delta V}$$

Assuming that the gain drop is only due to the resistive layer, by Ohm’s first law we have

$$\delta V = i \Omega$$

being i the current measured on the resistive layer, depending obviously by the primary ionization N_0, by the gain of the detector and by the radiation rate R

$$i = e N_0 G R$$

so that we can write

$$G = G_0 e^{-\alpha i \Omega} = G_0 e^{-\alpha e N_0 G \Phi \pi r^2 \Omega}$$

The gain drop

That is

$$\frac{G}{G_0}e^{\alpha e N_0 G \Phi \pi r^2 \Omega} = 1$$

Expanding with the Maclaurin series and reordering the terms we have

$$\alpha e N_0 G_0 \Phi \pi r^2 \Omega \left(\frac{G}{G_0}\right)^2 + \frac{G}{G_0} - 1 = 0$$

and eventually

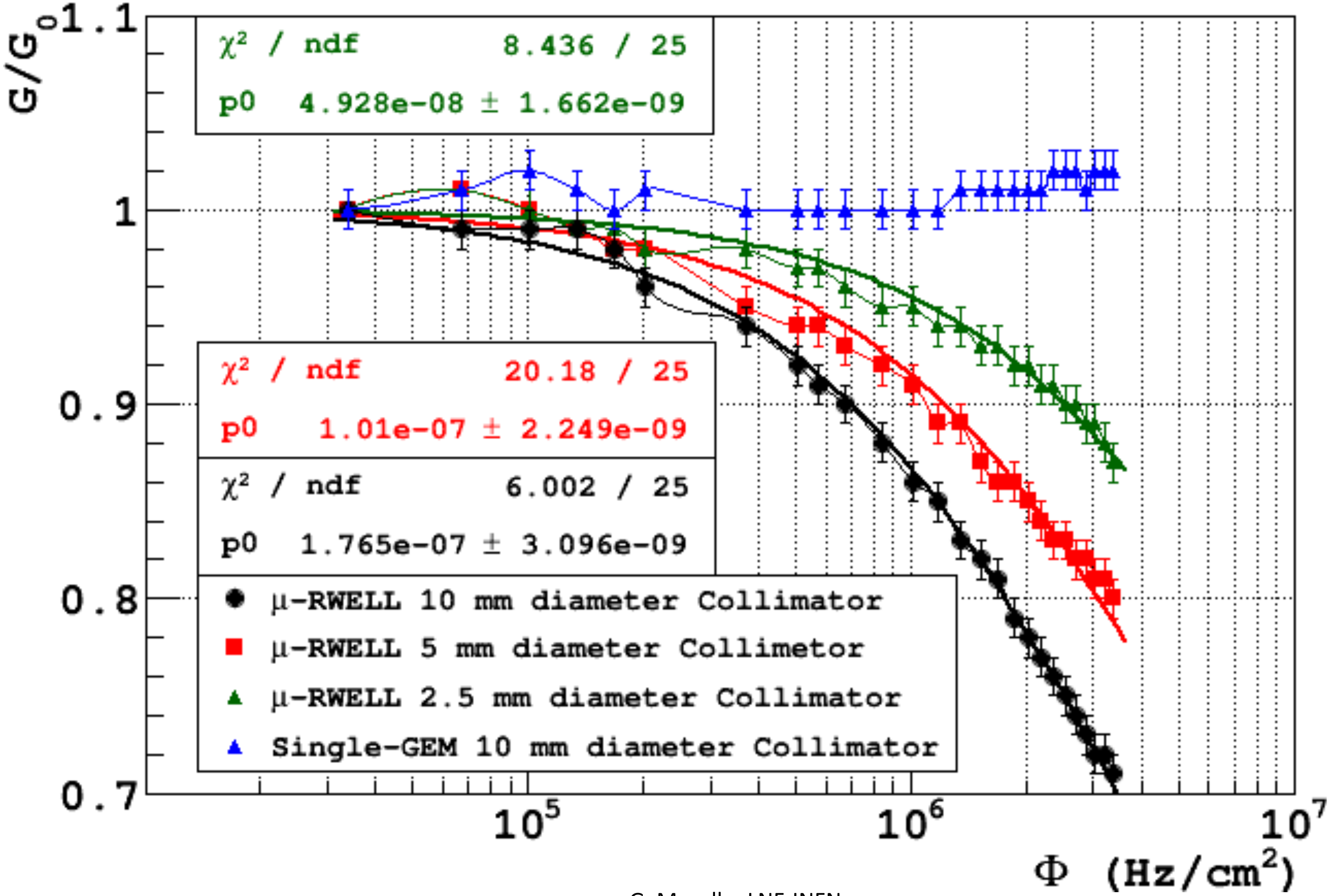
$$\frac{G}{G_0} = \frac{-1 + \sqrt{1 + 4 p_0 \Phi}}{2 p_0 \Phi}$$

where

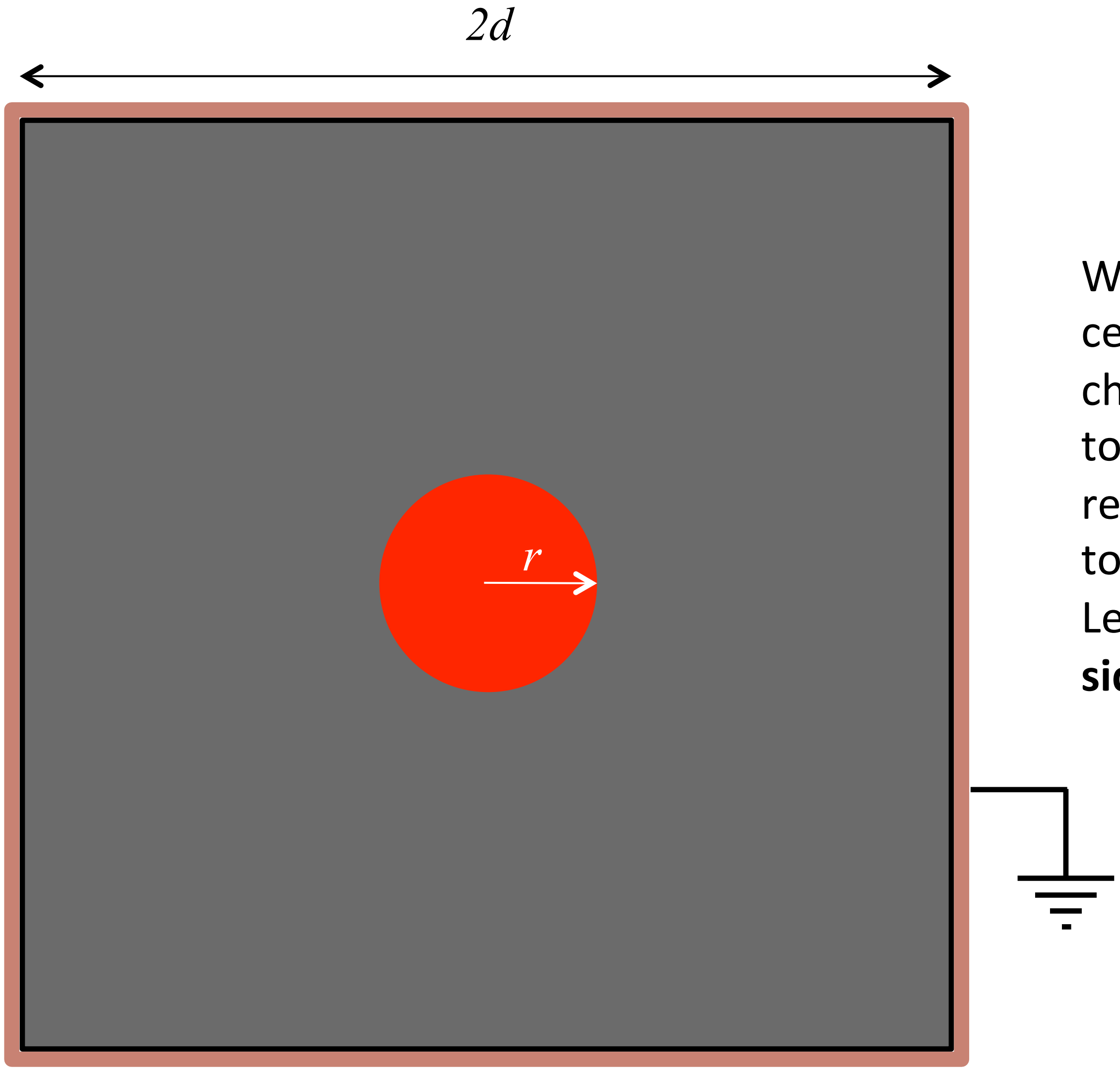
$$p_0 = \alpha e N_0 G_0 \Omega \pi r^2$$

This function includes the dependence on the expected gain and on the rate, here exploited as the product of the tube activity times the collimator surface

The gain drop



The resistance Ω: a simple model



We pointed the X-ray gun in the center of the active area. The charges drift on the resistive layer towards the ground, facing a resistance Ω along their path towards the ground.

Let d be **the half of the active area side** and r **the collimator radius**.

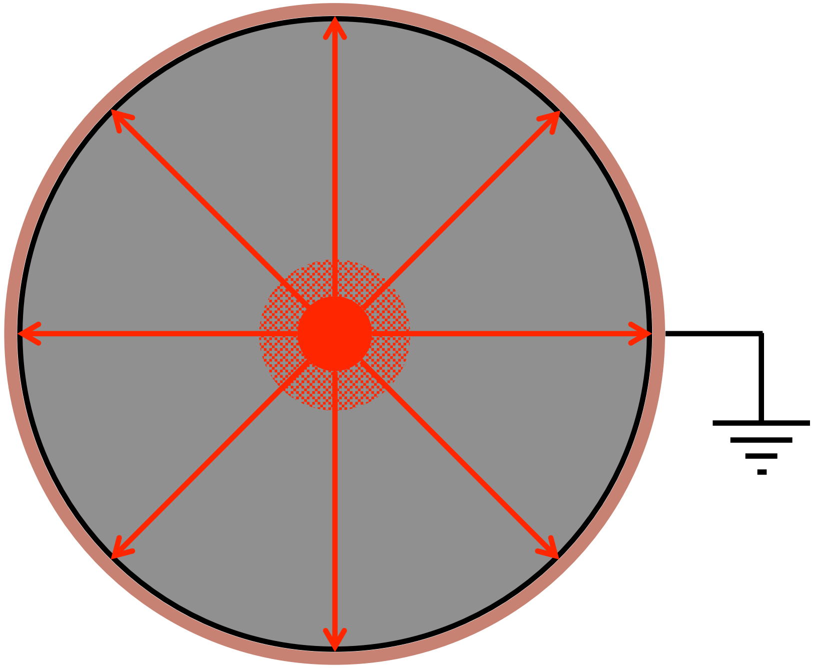
The resistance Ω: a simple model

We consider the case $r<<d$ so that we can approximate the active area with a circle. The charge produced at a distance ξ in the interval $]0,r]$ covers an averge path

$$< d - \xi >= \frac{\int_0^r \int_0^{2\pi} (d-\xi)\,\mathrm{d}\xi\mathrm{d}\theta}{\int_0^r \int_0^{2\pi} \mathrm{d}\xi\mathrm{d}\theta} = d - \frac{r}{2}$$

This looks like the charge is all concentrated in a circle with radius *r/2*. From here the charges drift towards the ground crossing a surface

$$S = \delta \int_0^{2\pi} \frac{r}{2}\mathrm{d}\theta = \delta\pi\mathrm{r}$$

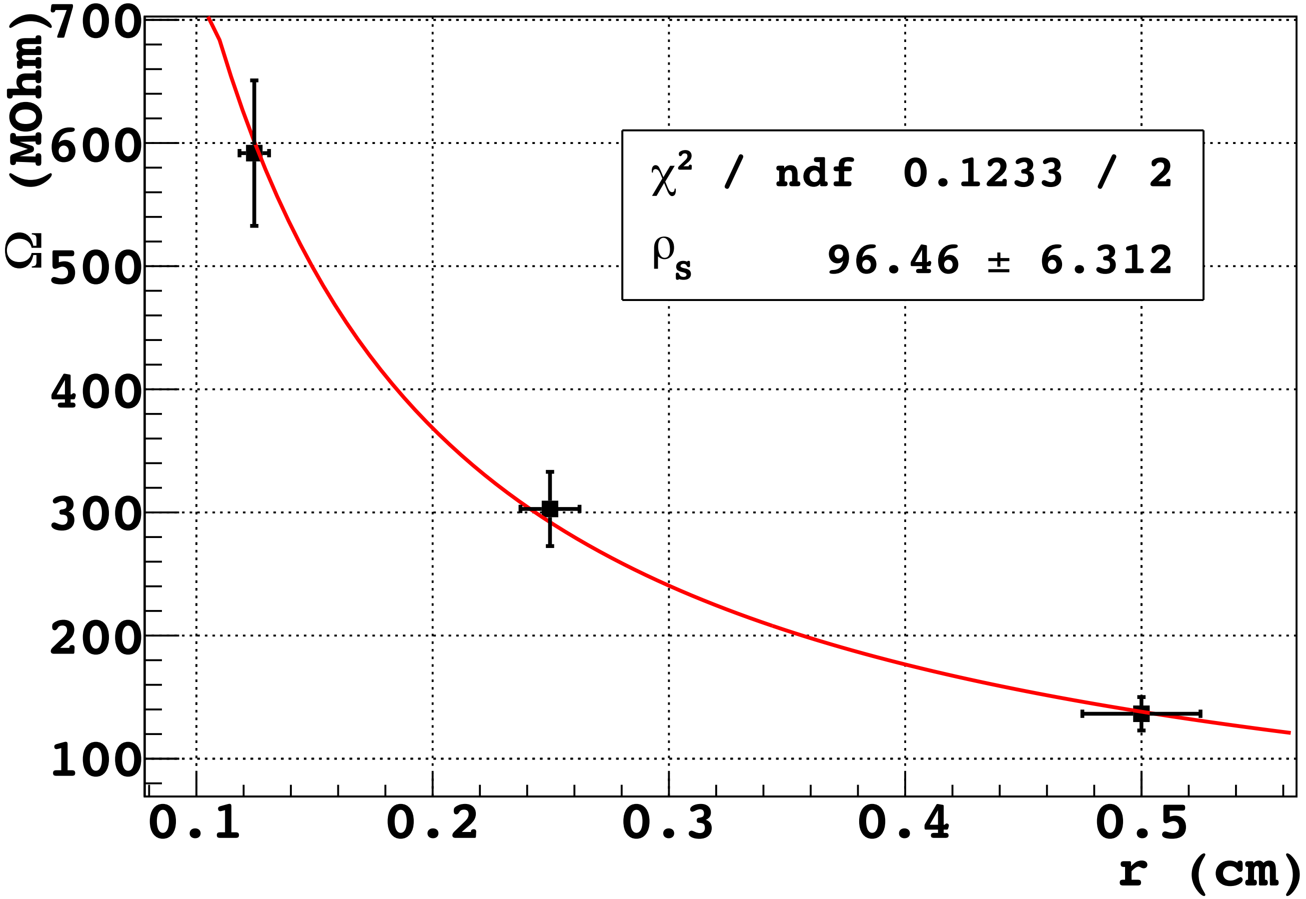


And by second Ohm’s law

$$\Omega = \rho_v \frac{d-\frac{r}{2}}{\delta\pi r} = \rho_S \frac{d-\frac{r}{2}}{\pi r}$$

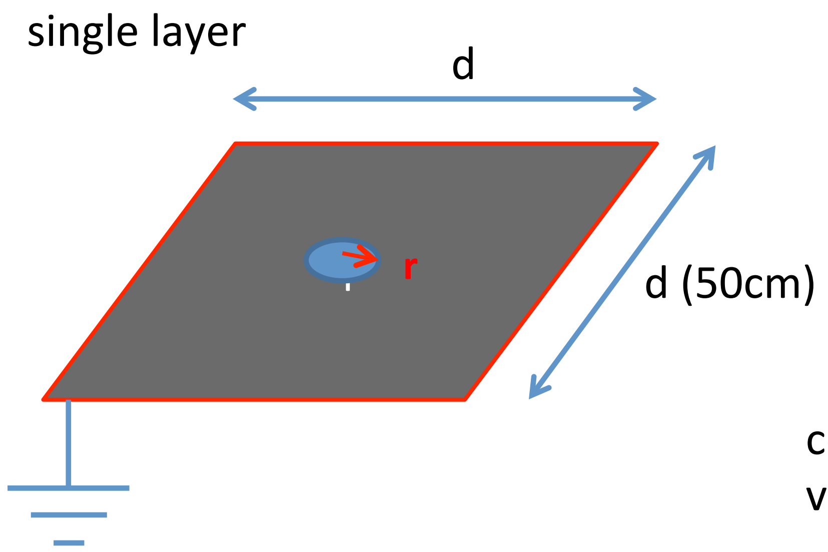
We computed Ω from the fit and we plot it vs r

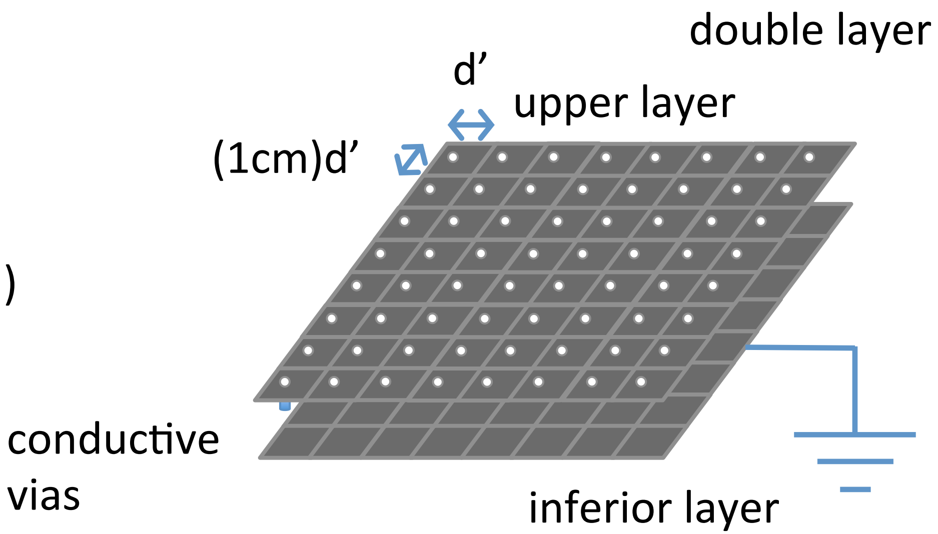
The resistance Ω: a simple model



Compatible with the value of **100 MΩ/☐** declared by the deliverer

The two different schemes





(*) point-like irradiation, r<<d
Ω is the resistance seen by the current generated by a radiation incident in the center of the detector cell

$$\Omega \sim \rho_s \times d/2\pi r \qquad \Omega' \sim \rho_s' \times 3d'/2\pi r$$

$$\Omega/\Omega' \sim (\rho_s/\rho_s') \times d/3d'$$

$$\text{If } \rho_s = \rho_s' \rightarrow \Omega/\Omega' \sim \rho_s/\rho'_s * d/3d' = 50/3 = 16.7$$

(*) Morello’s model: appendix A-B (G. Bencivenni et al., 2015_JINST_10_P02008)

The two different schemes

Single layer scheme

Low rate applications

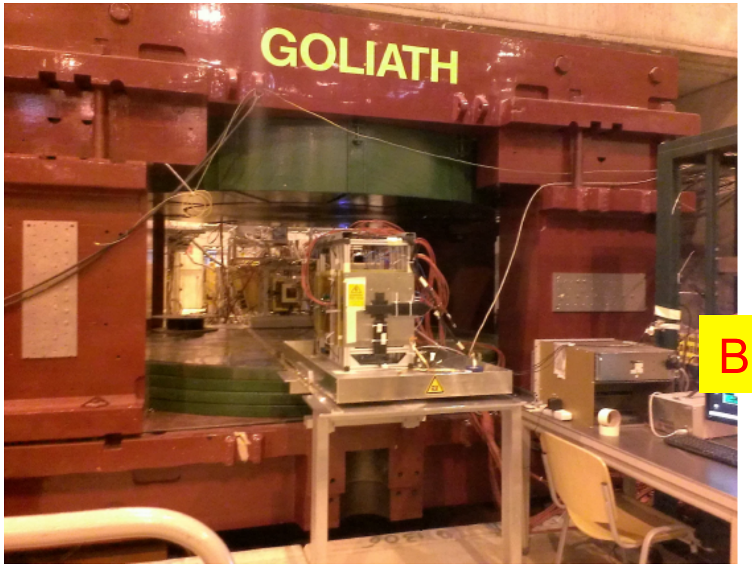
CMS, SHiP

Double layer scheme

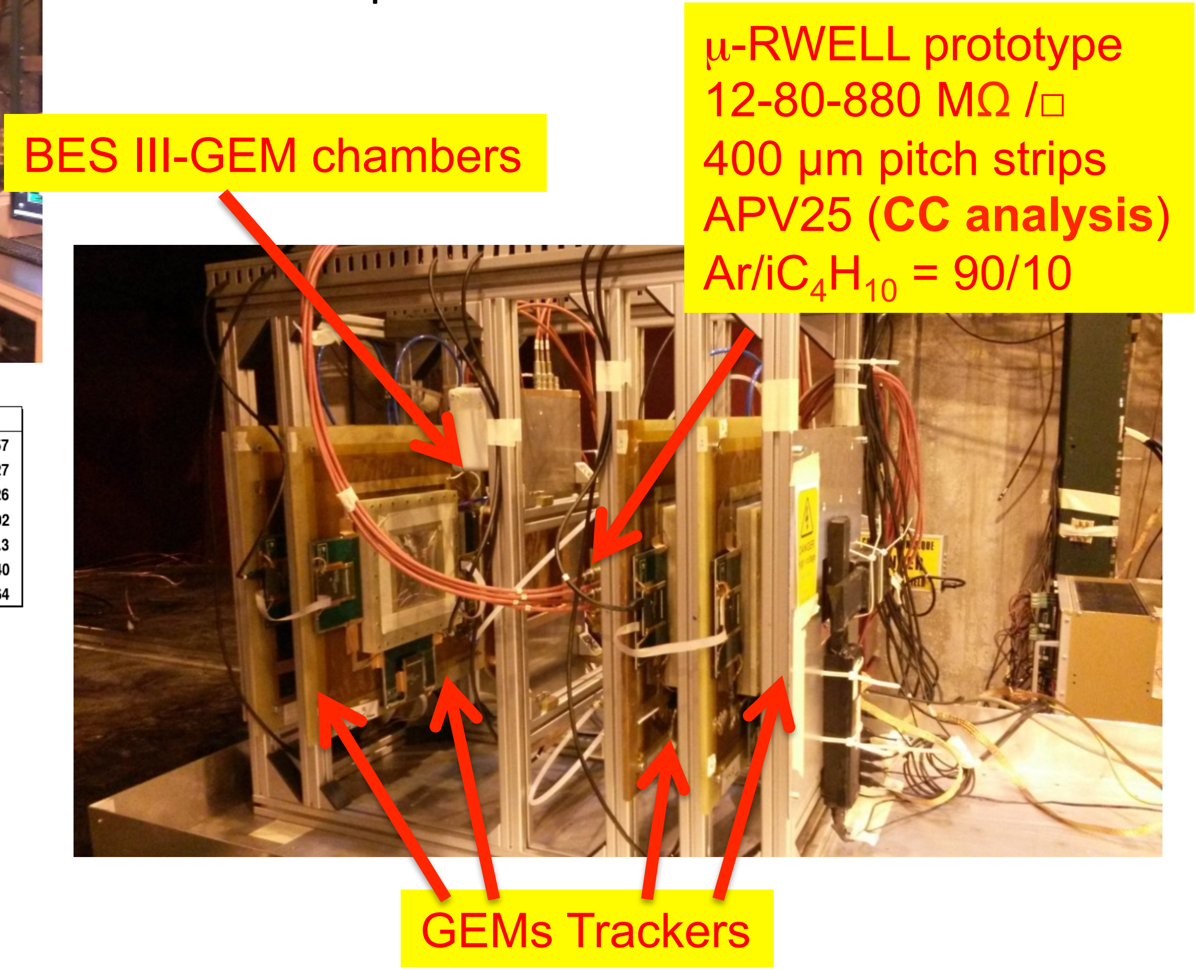
High rate applications

LHCb

Status of the single resistive layer



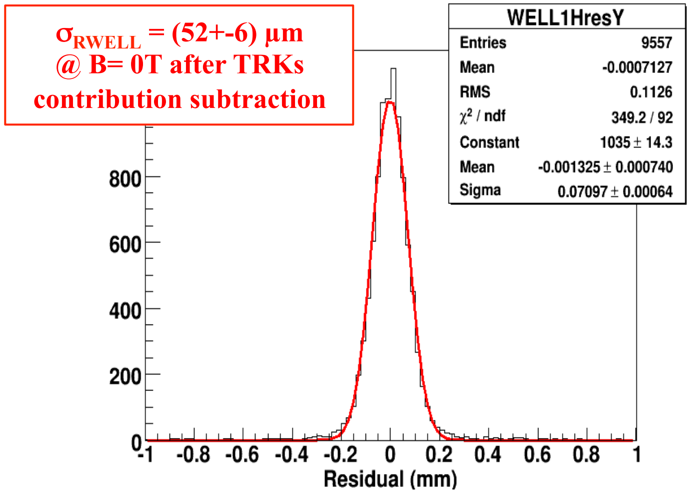
H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T



µ-RWELL prototype
12-80-880 MΩ /□
400 µm pitch strips
APV25 (**CC analysis**)
Ar/iC_4H_{10} = 90/10

BES III-GEM chambers

GEMs Trackers



σ_{RWELL} = (52+-6) µm
@ B= 0T after TRKs
contribution subtraction

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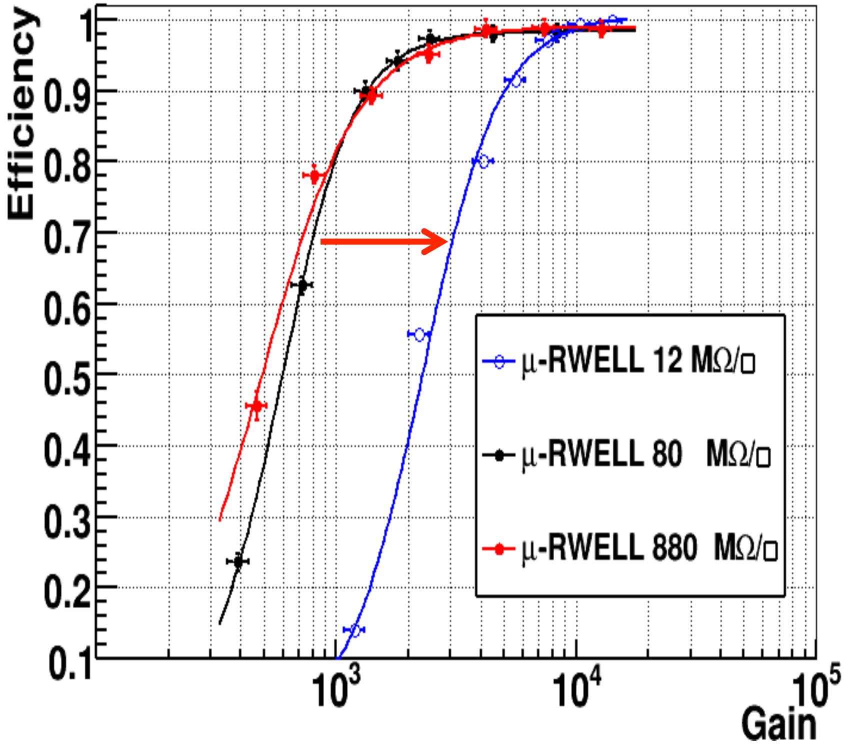
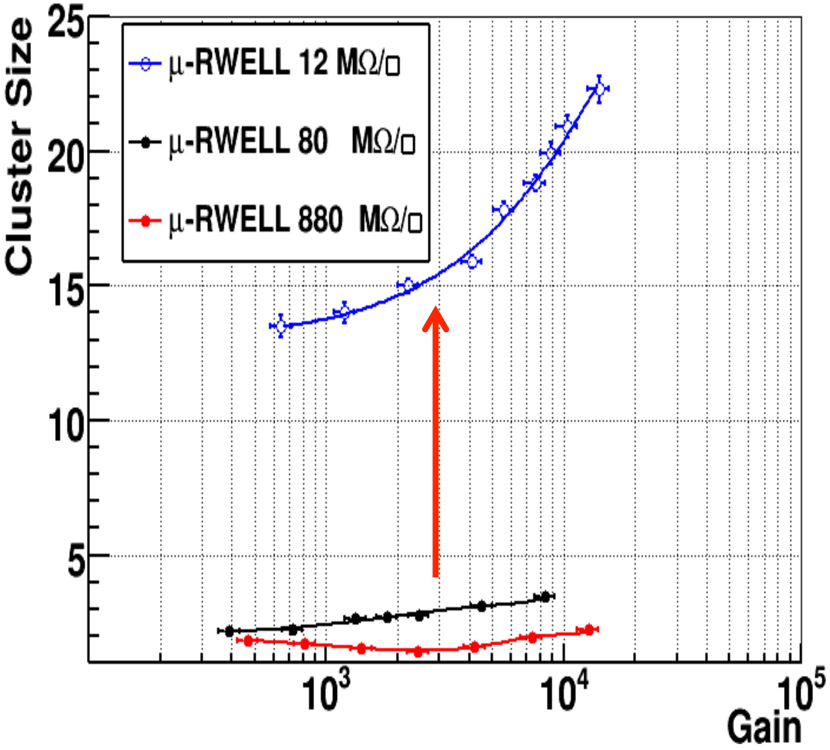
μ-RWELL: tracking efficiency

CC analisys

Ar/ISO=90/10



Ar/ISO=90/10

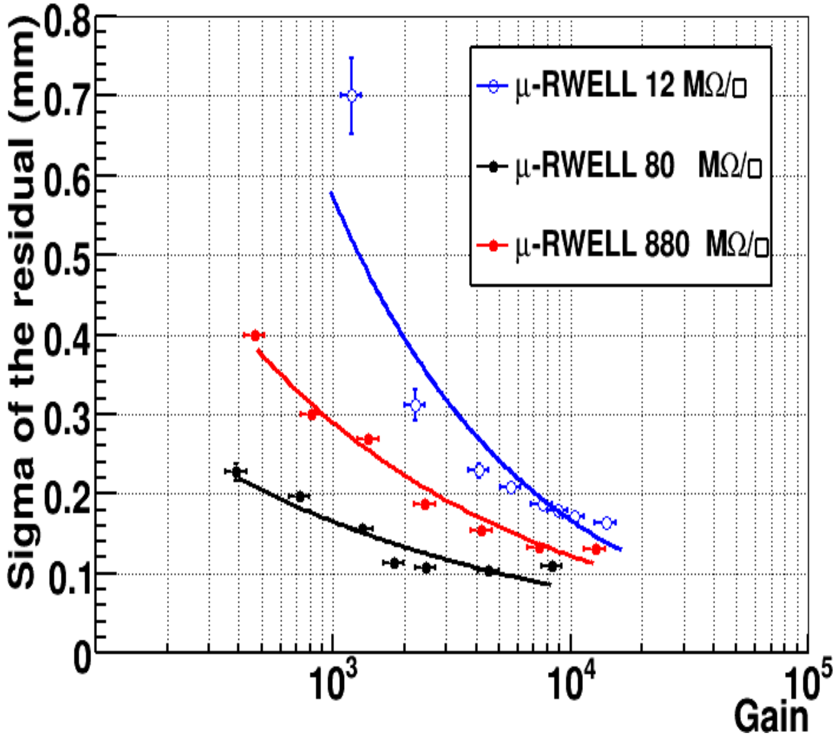


At **low resistivity the spread of the charge** (cluster size) on the readout strips **increases**, thus requiring a **higher gain** to reach the **full detector efficiency.**

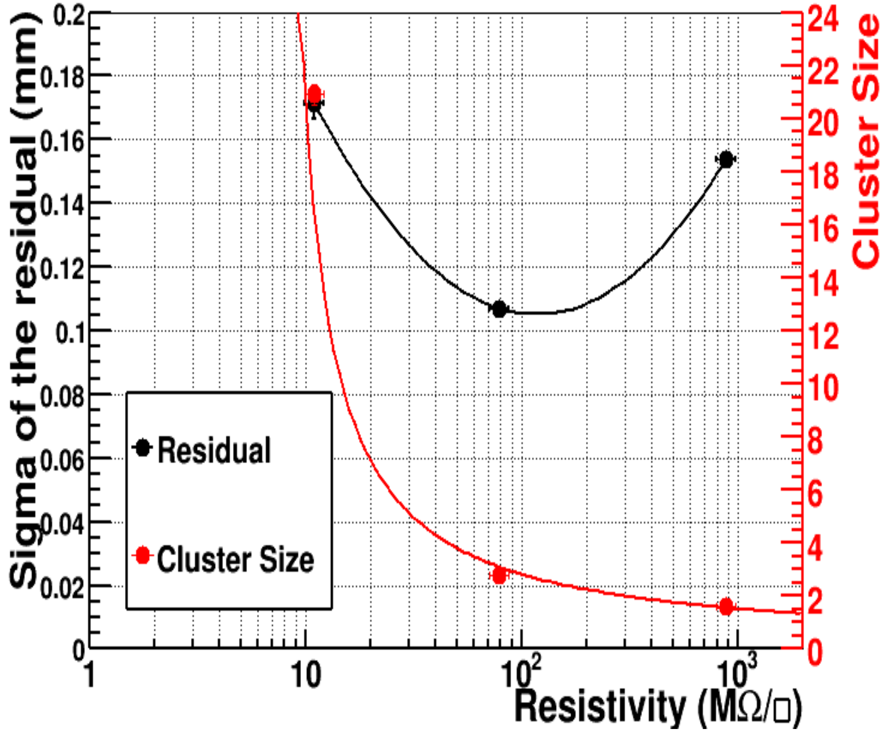
Space resolution: orthogonal tracks

CC analisys

Ar/ISO=90/10



Ar/ISO=90/10

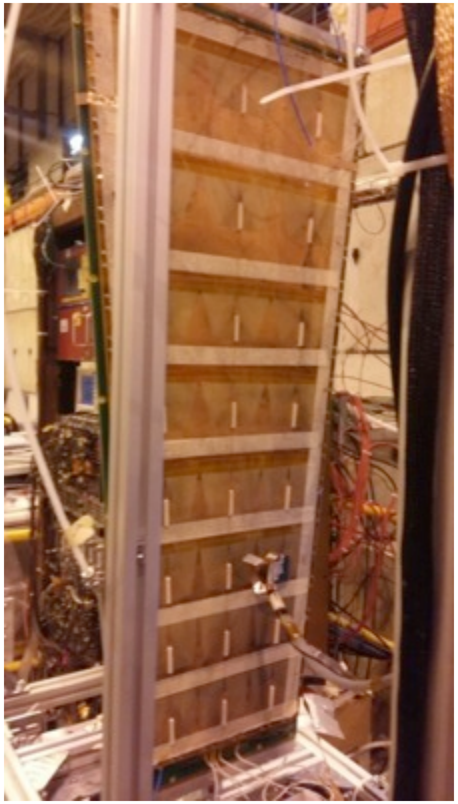


The **space resolution** exhibits a **minimum around 100MΩ/□.**

At **low resistivity** the **charge spread increases** and then **σ is worsening.**

At **high resistivity** the **charge spread is too small (Cl_size → 1)** then the Charge Centroid method becomes no more effective **(σ → pitch/√12).**

Status of the single resistive layer



The R&D on the single resistive layer has been completed with the realization of two large area detectors of about 1.2 x 0.5 m^2 in the framework of the CMS-phase2 muon upgrade

These detectors have been realized in collaboration with Italian companies (ELTOS & MDT) within the TT project.

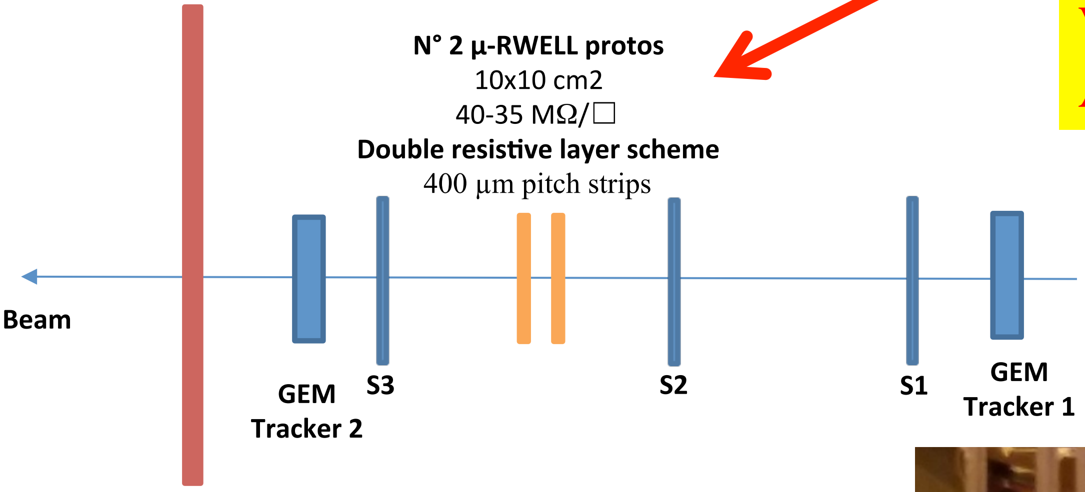
Thanks to: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

Beam Test Setup

H8 Beam Area (18th Oct. 9th Nov 2016)

Muon/Pion beam: 150 GeV/c

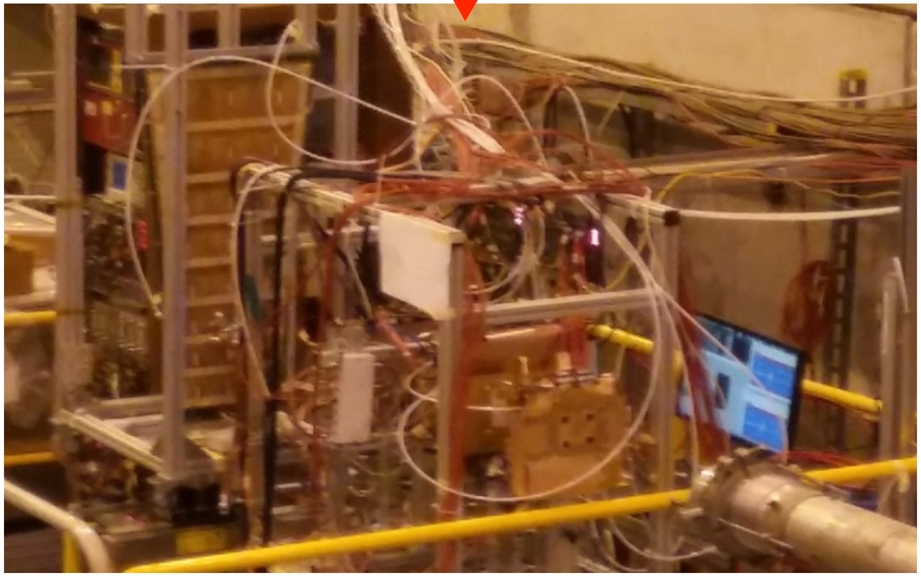
3 μ-RWELL prototypes
40-35-70 MΩ /□
VFAT (digital FEE)
$Ar/CO_2/CF_4 = 45/15/40$



N° 2 μ-RWELL protos
10x10 cm2
40-35 MΩ/□
Double resistive layer scheme
400 μm pitch strips

N° 1 μ-RWELL proto
100x50 cm2
70 MΩ/□
Single resistive layer scheme
800 μm pitch strips

Trigger=S1+S2+S3



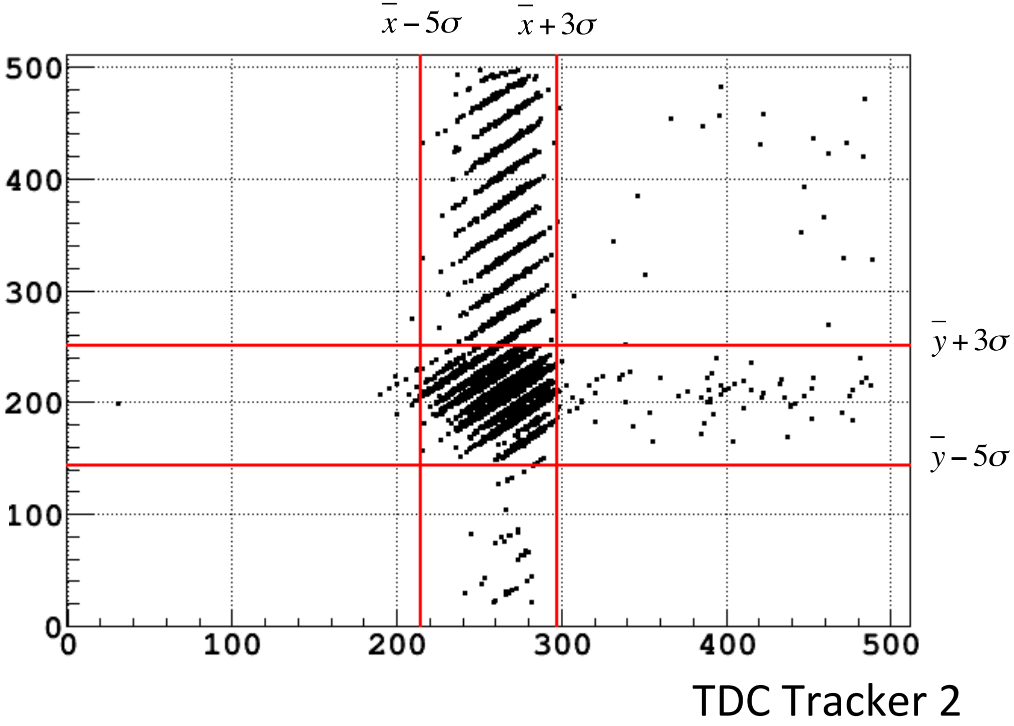
The goal was the <u>time resolution measurement (never done before)</u>

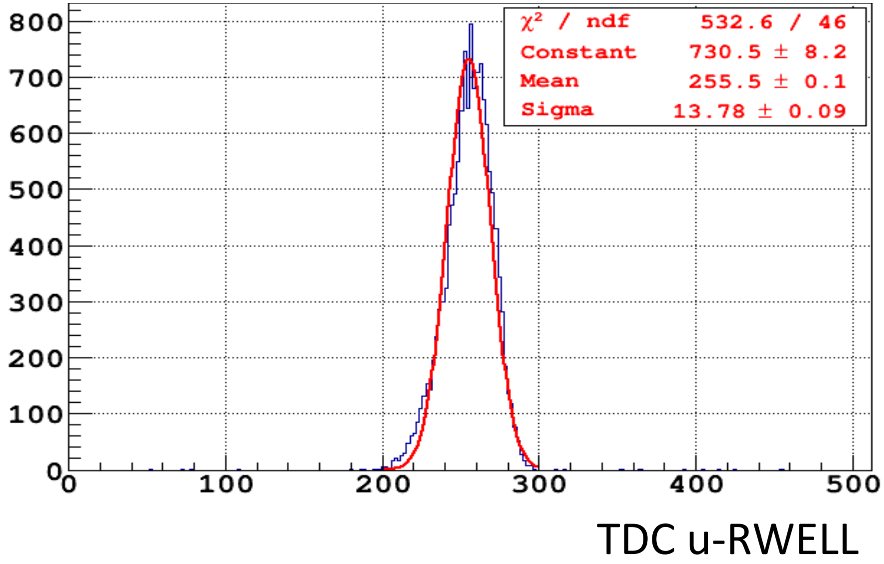
Thanks to: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

Efficiency & time resolution measurement

The efficiency (as extracted by TDC measurement) has been evaluated asking for **TDC coincidence** selected in a proper range.
Then the ratio of the triplets on the doublets gives the value.

$$\varepsilon = \frac{TDC_{\mu-RWELL} \wedge TDC_{trk1} \wedge TDC_{trk2}}{TDC_{trk1} \wedge TDC_{trk2}}$$





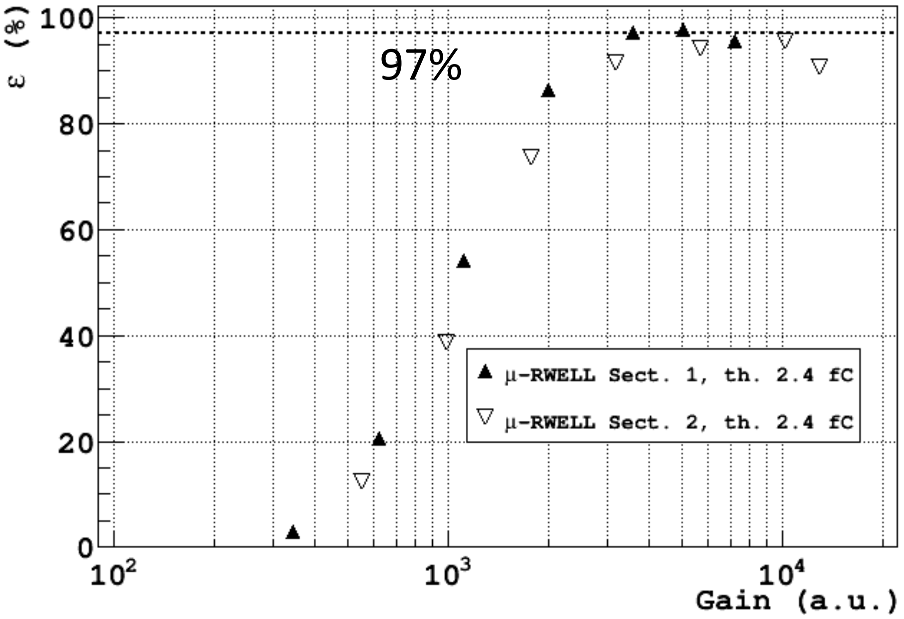
The TDC distribution is then fitted with a simple gaussian and the sigma is then **deconvoluted** by the contribution of the VFAT.

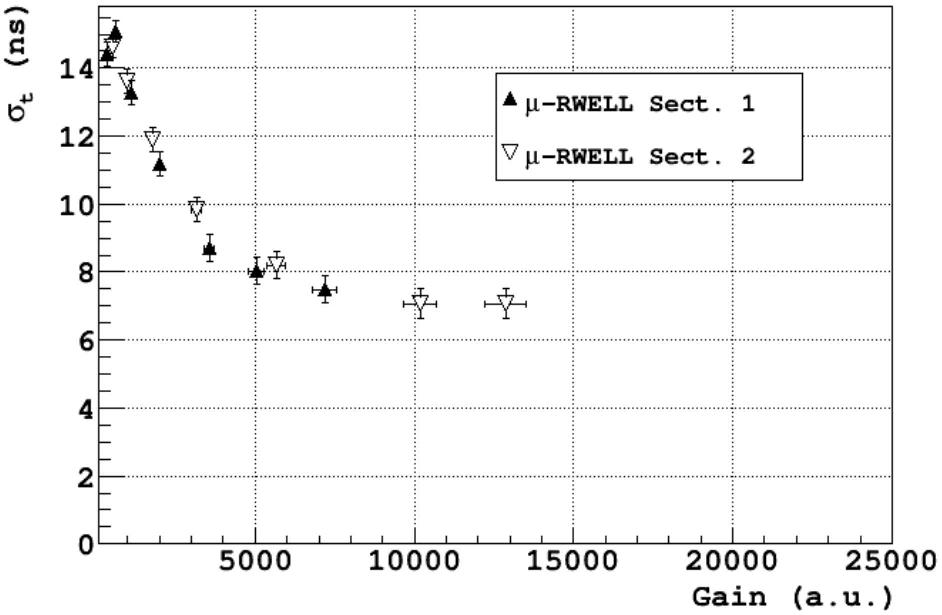
$$\sigma_t^2 = \sigma_{TDC}^2 - \left(\frac{25}{\sqrt{12}}\right)^2$$

J. A. Merlin, Etude de fonctionnement à long terme de détecteur gazeux l'environment à haut flux de CMS, PhD thesis, 2016

Thanks to: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

Performance vs Gain with Ed=3.5 kV/cm





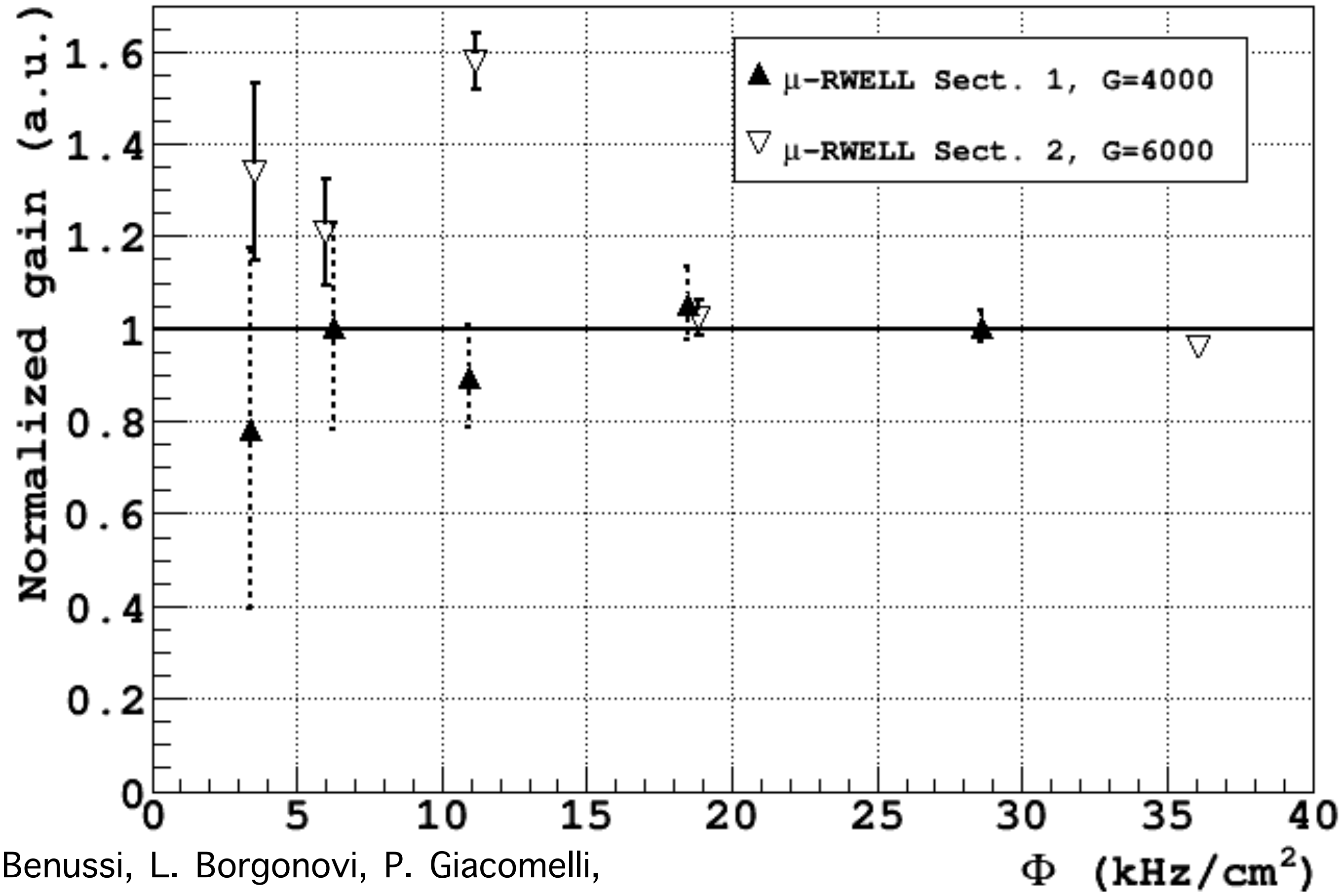
Measurements done with GEM by LHCb group gave σ_t = 4.5 ns with VTX chip, constant fraction discriminator [1]. We wish to perform the same measurement with μ-RWELL at BTF (LNF).

*[1] G. Bencivenni et al, "Performance of a triple-GEM detector for high rate charged particle triggering", NIM **A** 494 (2002) 156*

Thanks to: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

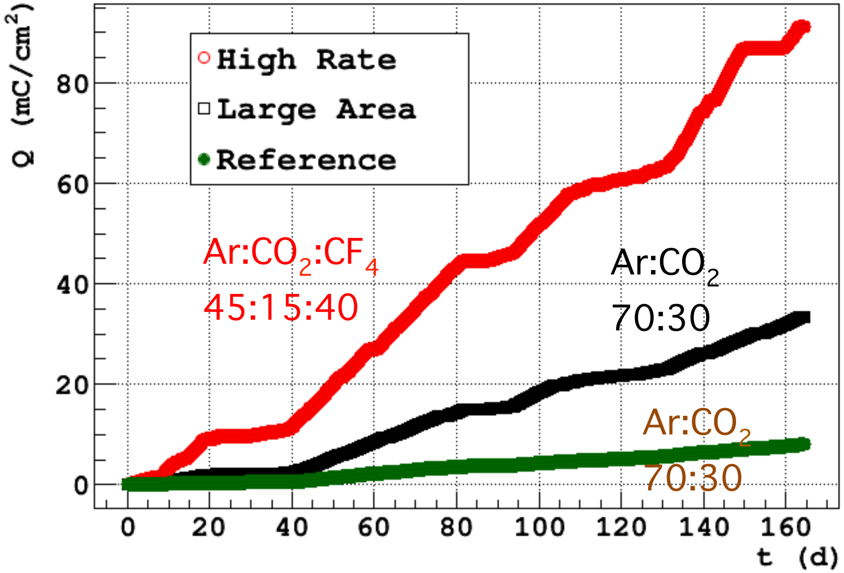
Performance vs Rate

The detector rate capability (with Ed=3.5 kV/cm) has been measured in current mode with a pion beam and irradiating an area of ~3 x 3 cm^2 (FWHM) ("local" irradiation, ~10 cm^2 spot)

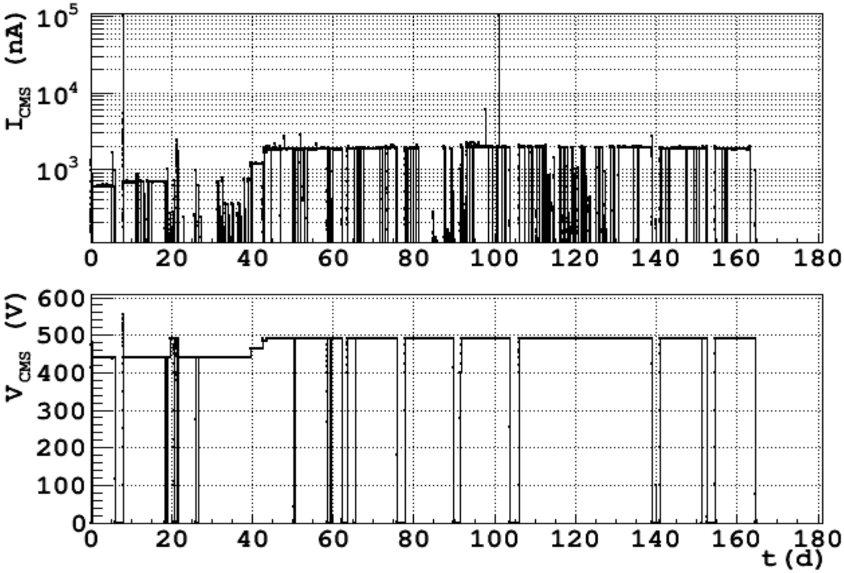


Thanks to: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

The single resistive layer: GIF++ exposure (2017)



m.i.p. equivalent rate ~10 kHz/cm^2

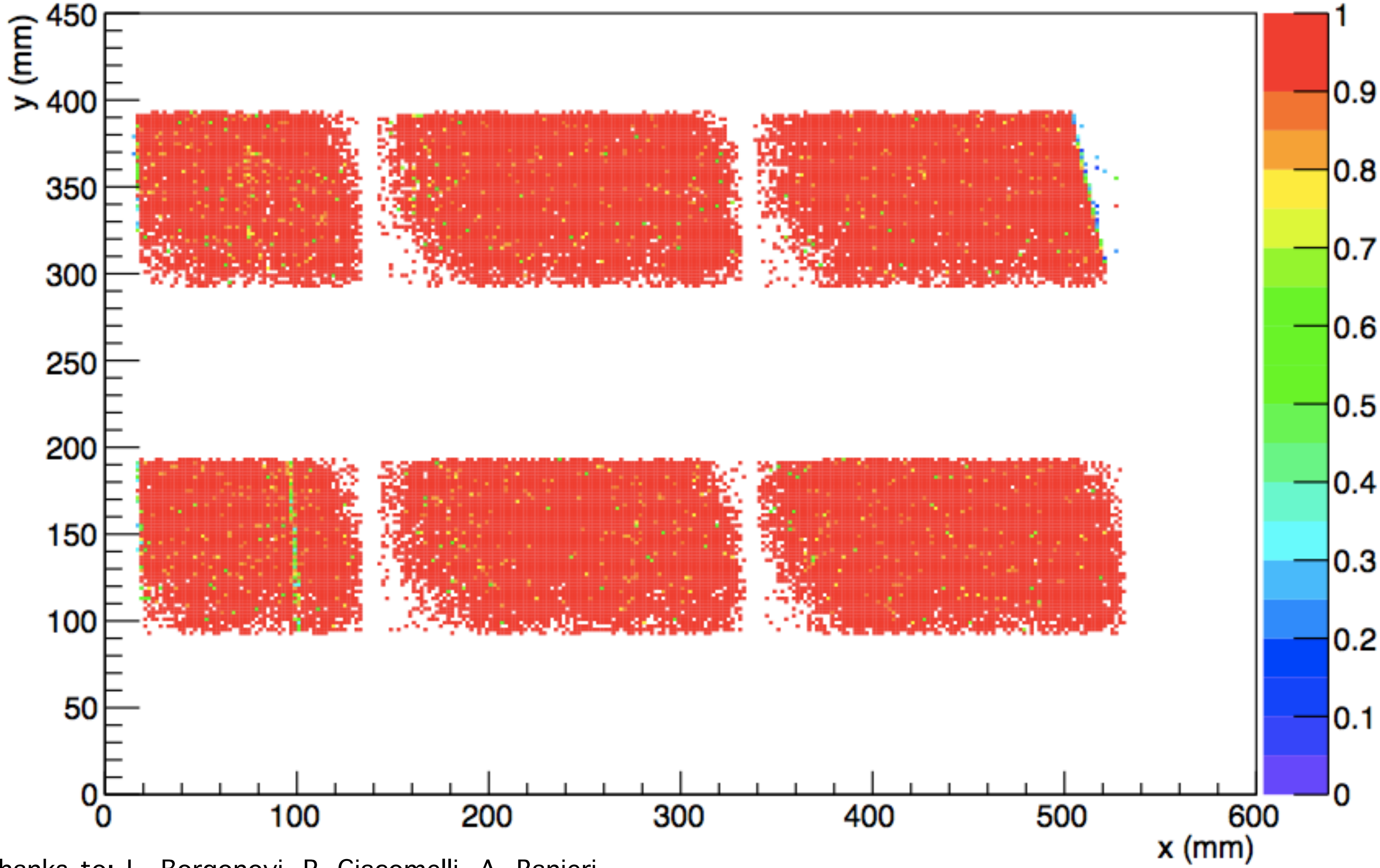


The study of ageing effects on DLC has been done by integrating the charge expected in 10 years of operation in the CMS GE2/1 region (1 kHz/cm^2).

At a gain of 4000 the total charge expected is **2.6 mC/cm^2**

Thanks to: L. Benussi, L. Borgonovi,
P. Giacomelli

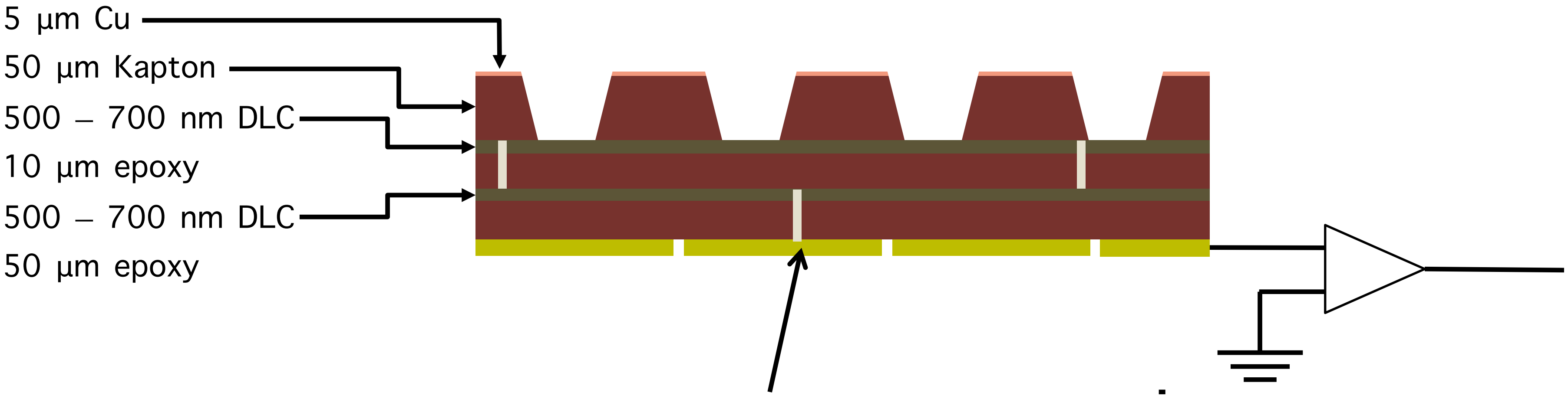
The single resistive layer: M4 efficiency



Thanks to: L. Borgonovi, P. Giacomelli, A. Ranieri

High rate version: the double resistive layer

- The charges collected on the resistive layer move towards the ground with a characteristic time τ(R,C) [Dixit et al, NIMA 518 (2004) 721, NIMA 566 (2006) 281].
- The idea is to reduce the path covered by the electrons on the DLC



A matrix of conductive vias connects the two resistive layers. Another matrix of vias chains the second resistive layer to ground through the readout

The double layer scheme (LHCb)

1

Copper layer 5 µm

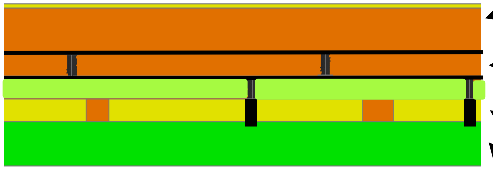
Kapton layer 50 µm

DLC layer: 0.1 – 0.2 µm
(10-200 MΩ/☐)

2

2nd resistive kapton layer with ~ $1/cm^2$ "*through vias*" density

3



DLC-coated kapton base material

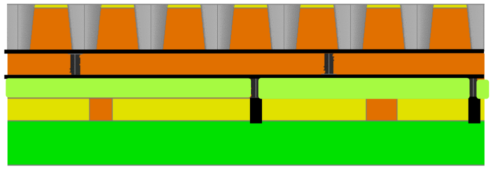
2nd resistive kapton layer

insulating layer

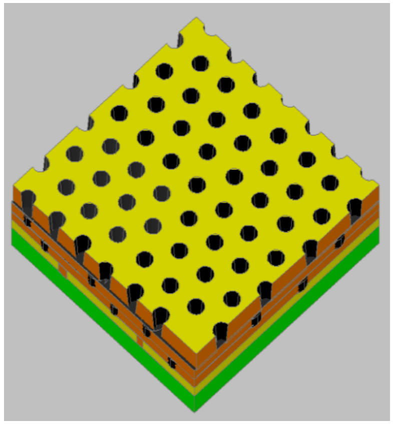
pad/strips readout on standard PCB

***"through vias"* for grounding**

4



DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)



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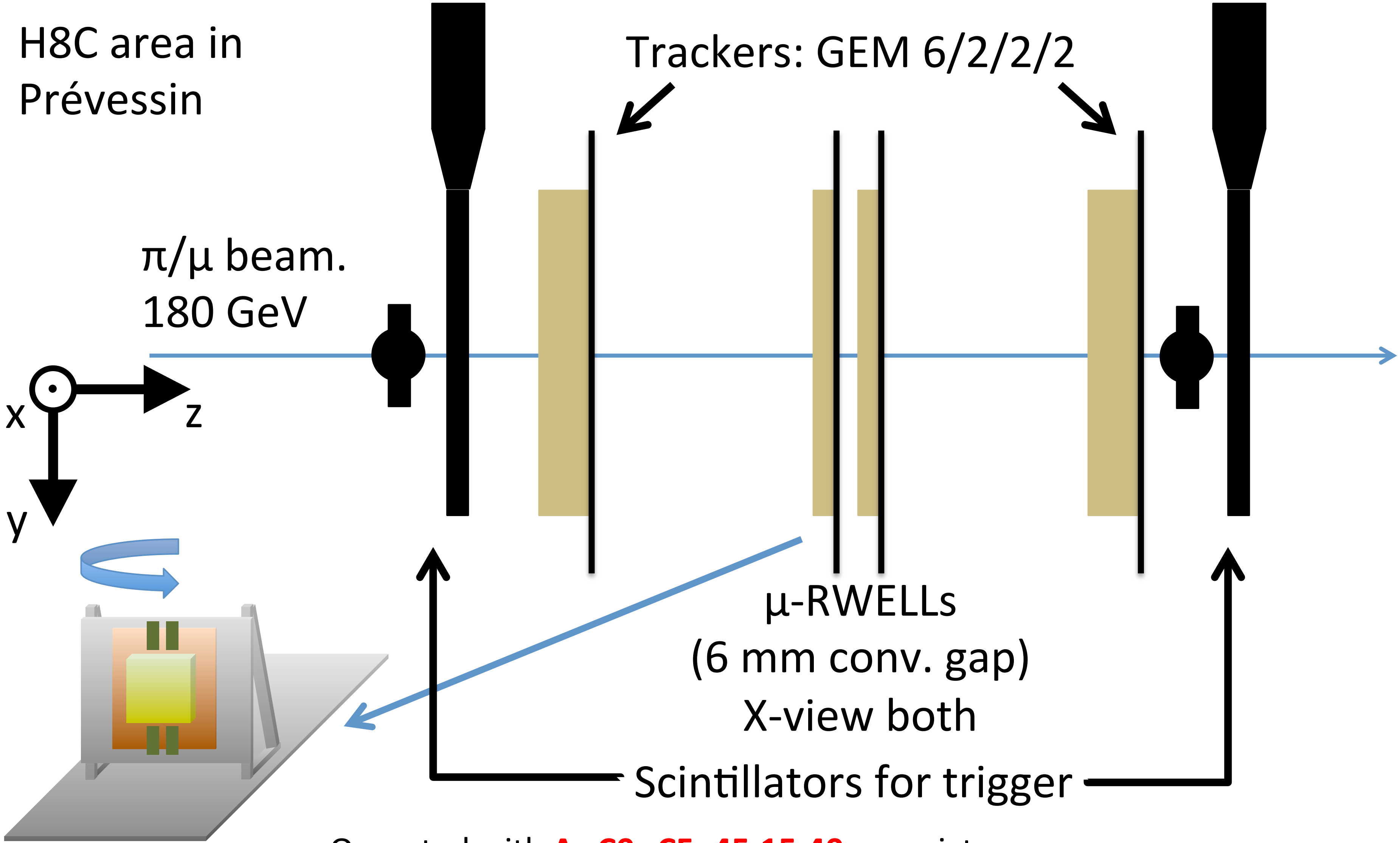
The test beam setup, conf. 1



H8C area in Prévessin

Trackers: GEM 6/2/2/2

π/μ beam.
180 GeV

μ-RWELLs
(6 mm conv. gap)
X-view both

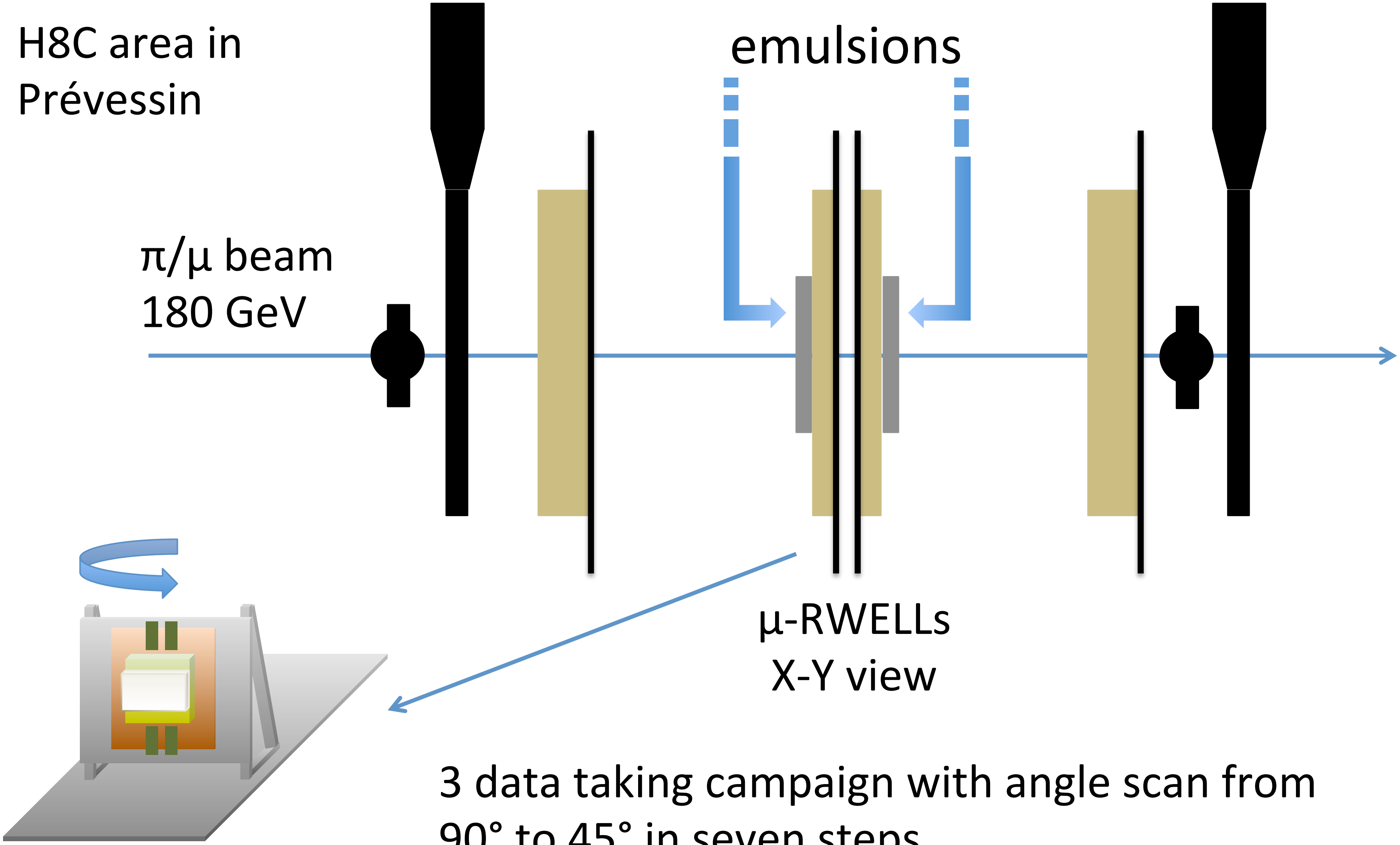
Scintillators for trigger

Rotatable plate

Operated with **Ar:C0$_2$:CF$_4$ 45:15:40** gas mixture
All the detectors equipped with **APV25 boards** handled by an **SRS system**

The test beam setup, conf. 2

H8C area in
Prévessin



emulsions

π/μ beam
180 GeV

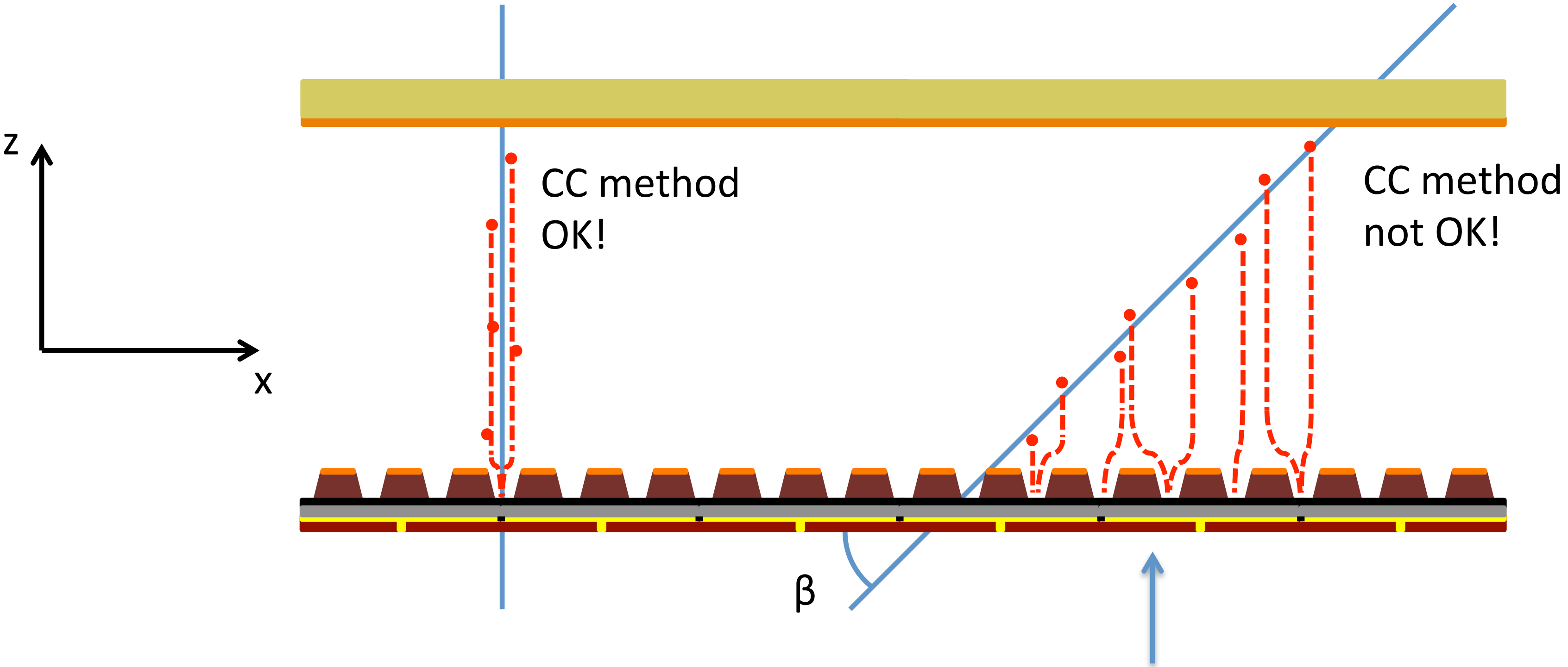
μ-RWELLs
X-Y view

Rotatable plate

3 data taking campaign with angle scan from 90° to 45° in seven steps

Improving space resolution: the µ-TCP mode

The use of an analog front-end allows to associate a hit to a track using the charge centroid (CC) method. The uncertainty associated to the hit with this algorithm is dependent on the track angle: minimum for orthogonal tracks and larger as the angle increases



To improve the space resolution we implemented the u-TPC algorithm to be combined with the CC method

Improving space resolution: the µ-TCP mode

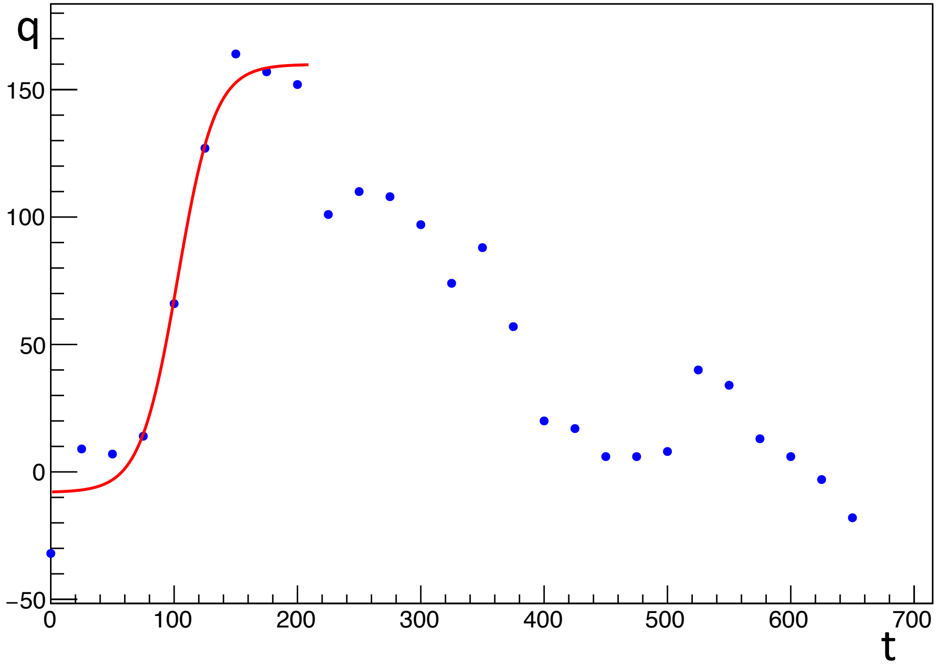
Introduced for MicroMegas by T. Alexopoulos et al., NIM **A 617** (2010) 161, it suggests a way to overcome big errors associated to sloped tracks.

Each hit is projected inside the conversion gap, where the *x* position is given by each strip and the $z = v_d t$

The drift velocity is provided by the Magboltz libraries.

The drift time is obtained with a fit of the charge sampled every 25 ns (APV25) from each FEE channel associated to the strip.

For each event we then obtain a set of projected hits that once fitted provide a track segment



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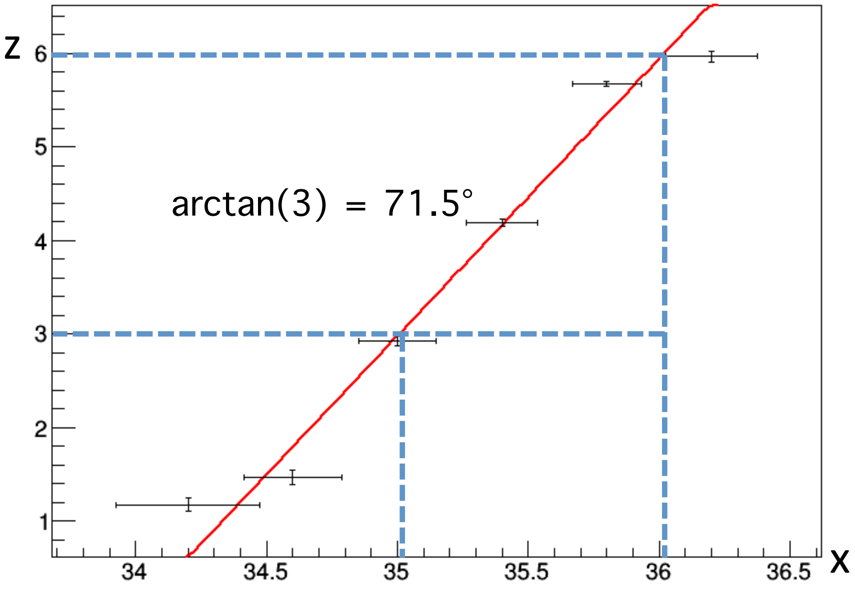
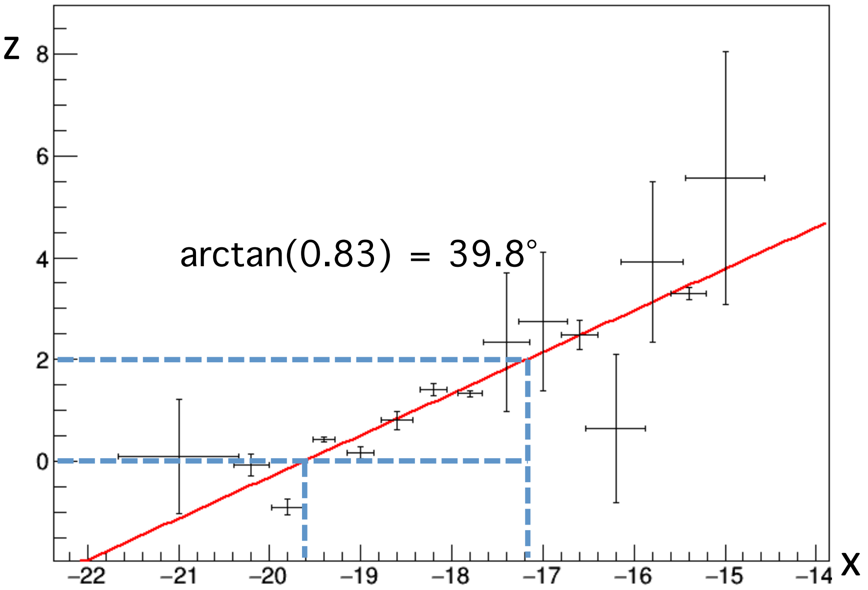
Example of μ-TPC reconstruction

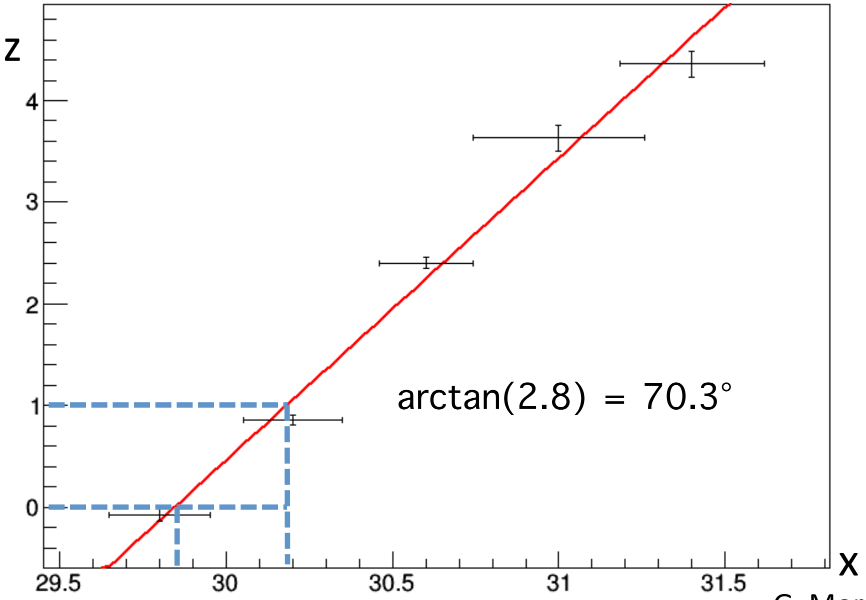
Here we have some examples where the tracks have an angle w.r.t. the readout plane of:

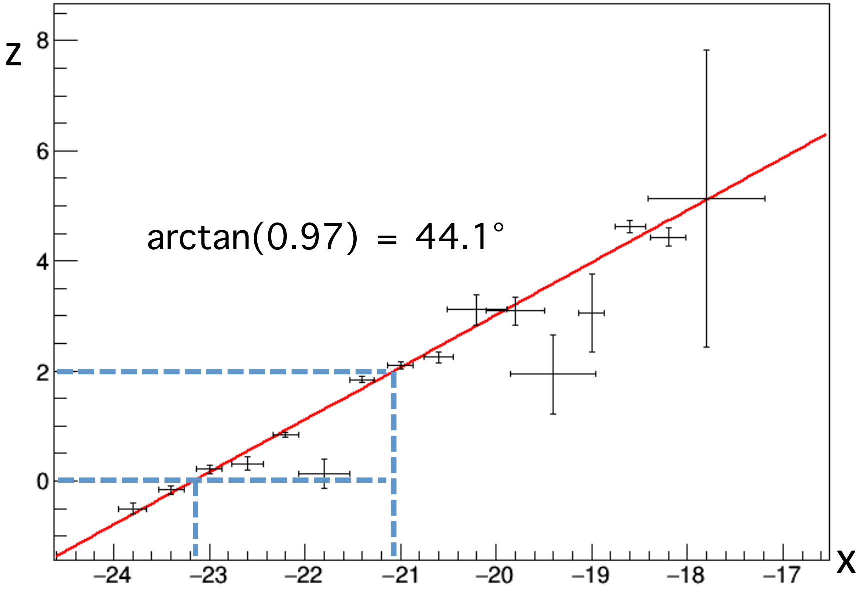
75° tracks

45° tracks

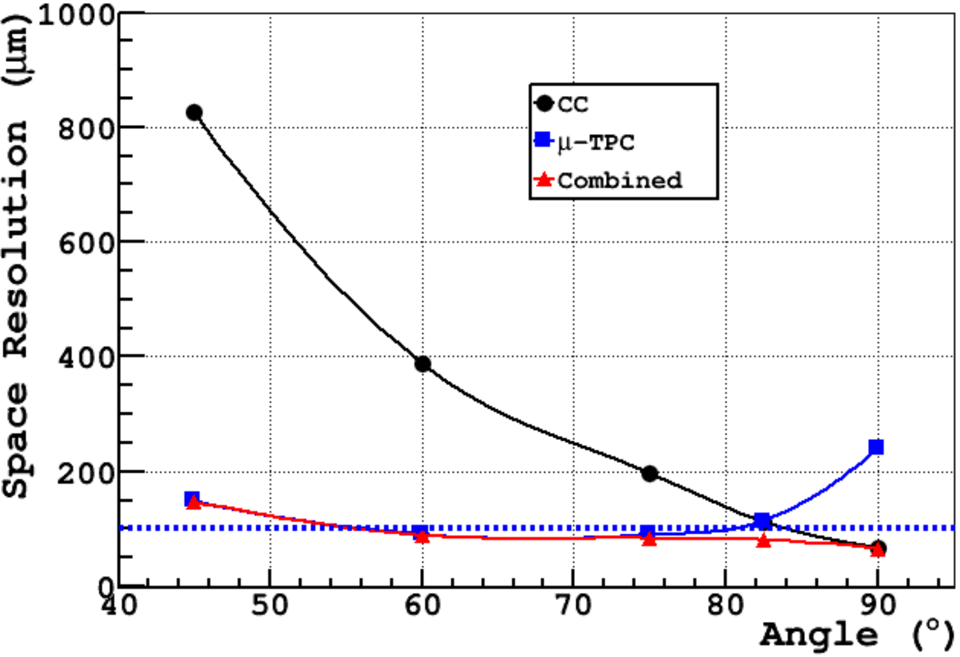








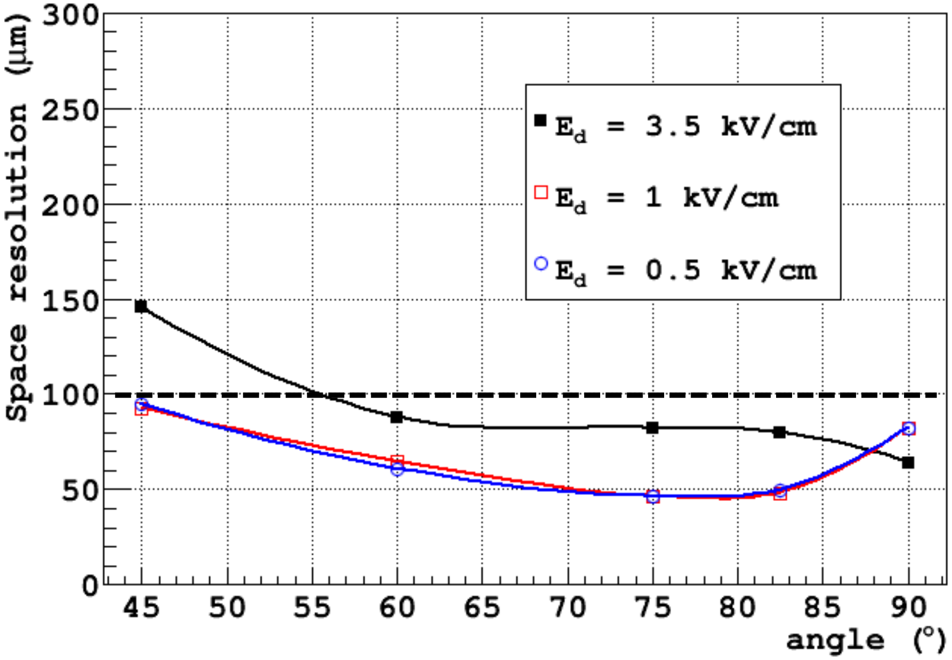
Improving space resolution: the µ-TCP mode



The combination of the CC and the µ-TPC mode with E_d= 3.5 kV/cm
The resolution is flattened for a wide range of angles.

$$x_{merge} = \frac{x_{cc} \cdot w_{cc} + x_{tpc} \cdot w_{tpc}}{w_{cc} + w_{tpc}}$$

$$w_{cc} \propto (clsize)^{-2} \quad w_{\mu-TPC} \propto (clsize)^{2}$$

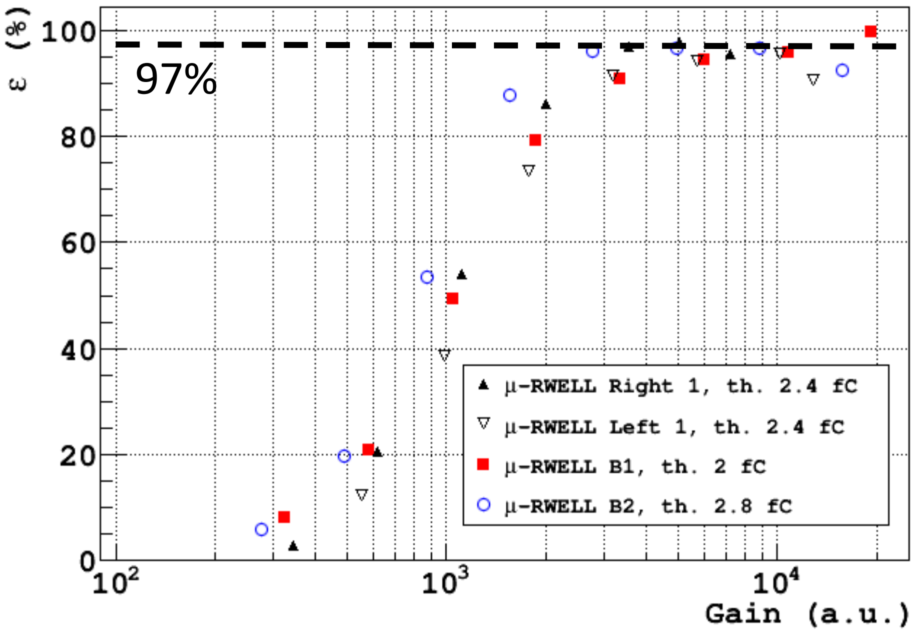


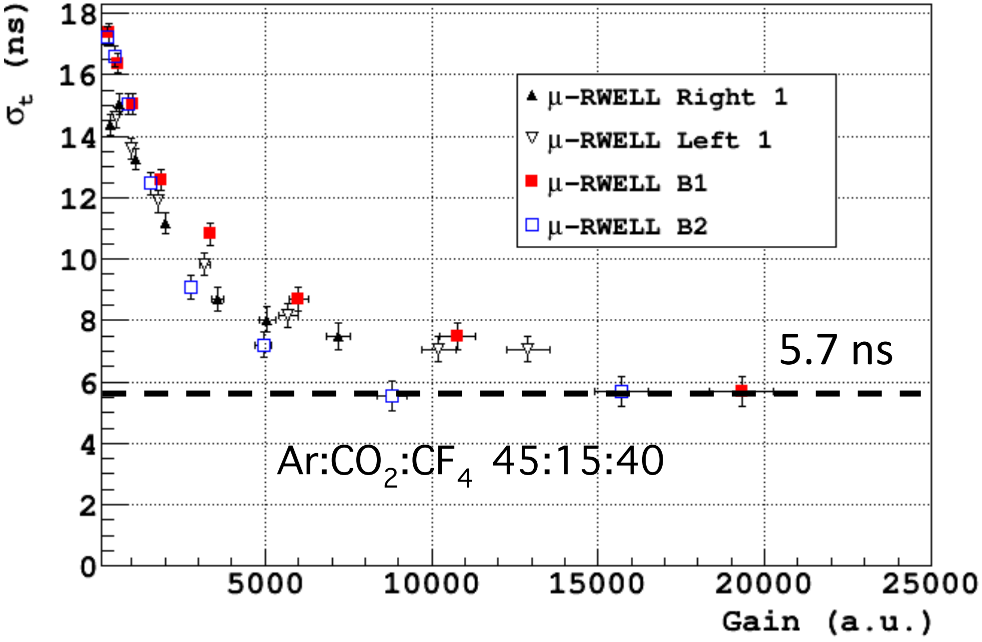
A study on the optimization of the drift field: low fields correspond to low drift velocities, allowing a better resolution of the primary ionization clusters.

Thanks to: R. Farinelli, M. Giovannetti, L. Lavezzi

The double resistive layer: H8C test beam (2016)

Two double resistive layer prototypes have been tested with muon beam and equipped with VFAT2



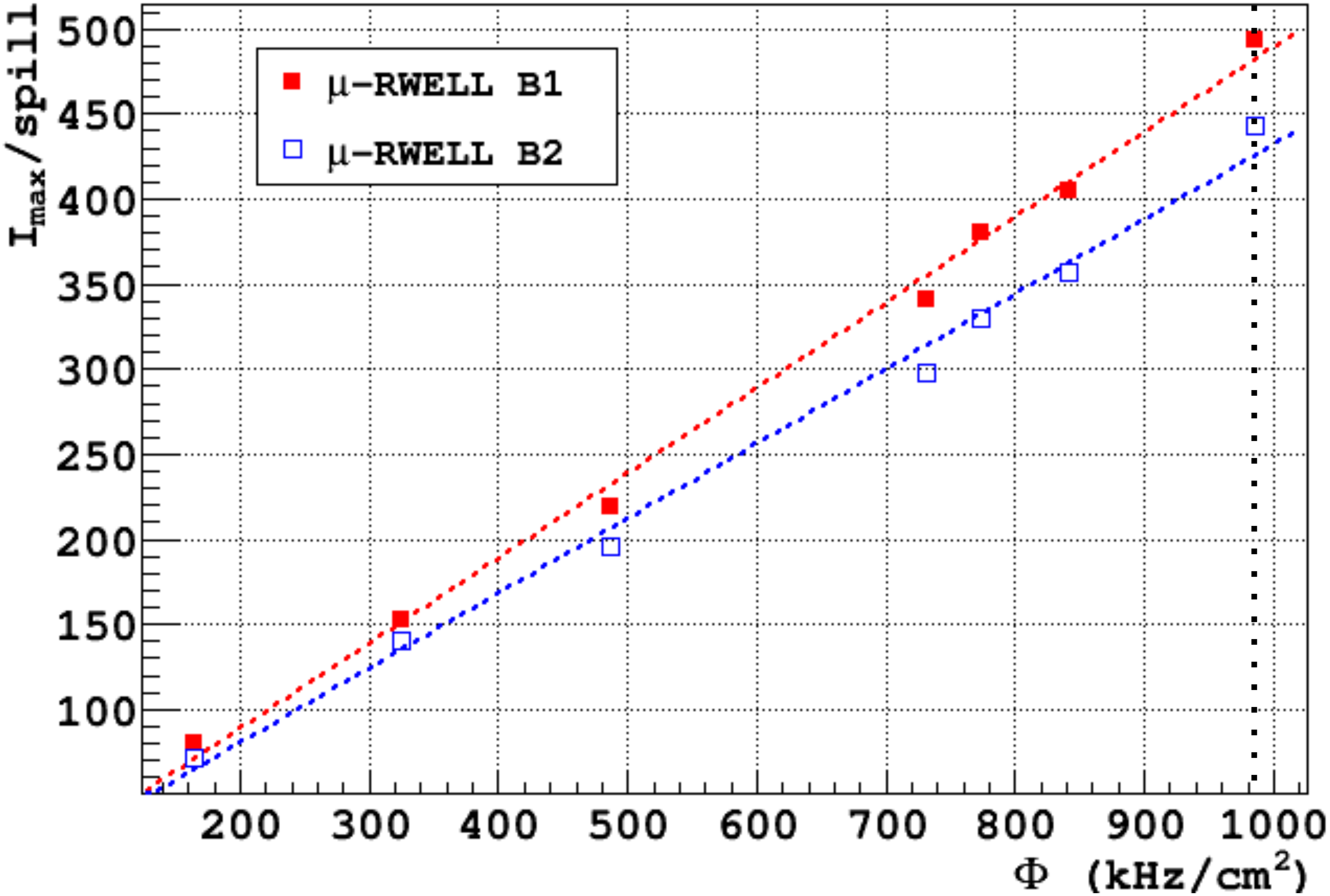


Different chambers with **different dimensions and resistive schemes** exhibit a **very similar behavior** although realized in **different sites** (large detector partially realized outside CERN).

Thanks to: P. De Simone

The double resistive layer:

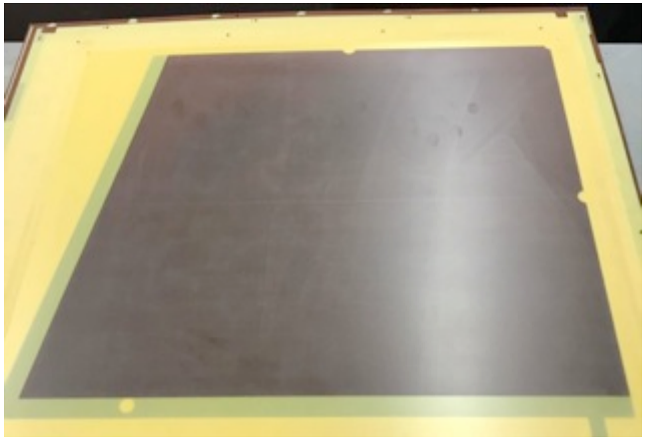
Rate capability as a function of the pion beam intensity



Detectors operated at a gain of 10^4. Beam spot ~2 cm^2 (RMS^2)

Status of the technological transfer

- As already mentioned, the strict collaboration with **ELTOS** made possible the construction of large area detectors with single resistive layer (GE1/1-, GE2/1-like)



- This allowed us to well define the coupling procedure of the amplification stage with the readout
- ELTOS is now producing other µ-RWELL_PCB to be etched at CERN
- The industrialization of the double resistive layer construction is much more difficult due to the manufacturing of the conductive vias
- Other (simpler) layouts must be developed in order to be included in an industrial process

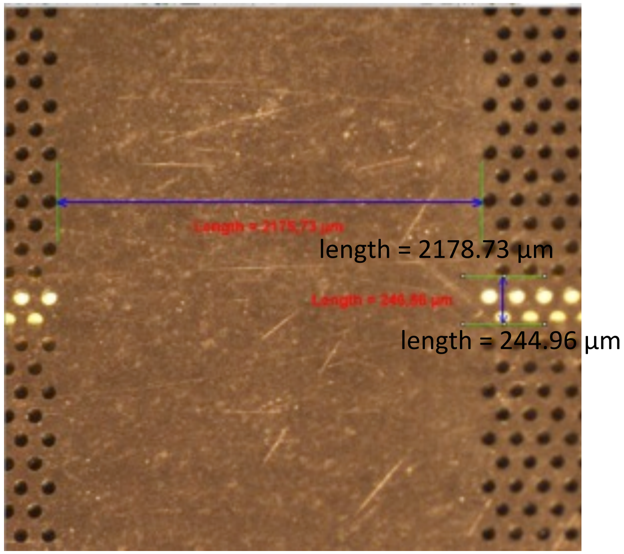
New layouts, new ideas, new challenges

The aim is to maintain a very short path for charges drifting on the resistive layer, while simplifying the construction process.

Two ideas are now under development: silver grid and resistive grid

- Silver Grid (SG)
- Small conductive strips are screen-printed on the bottom part of the DLC

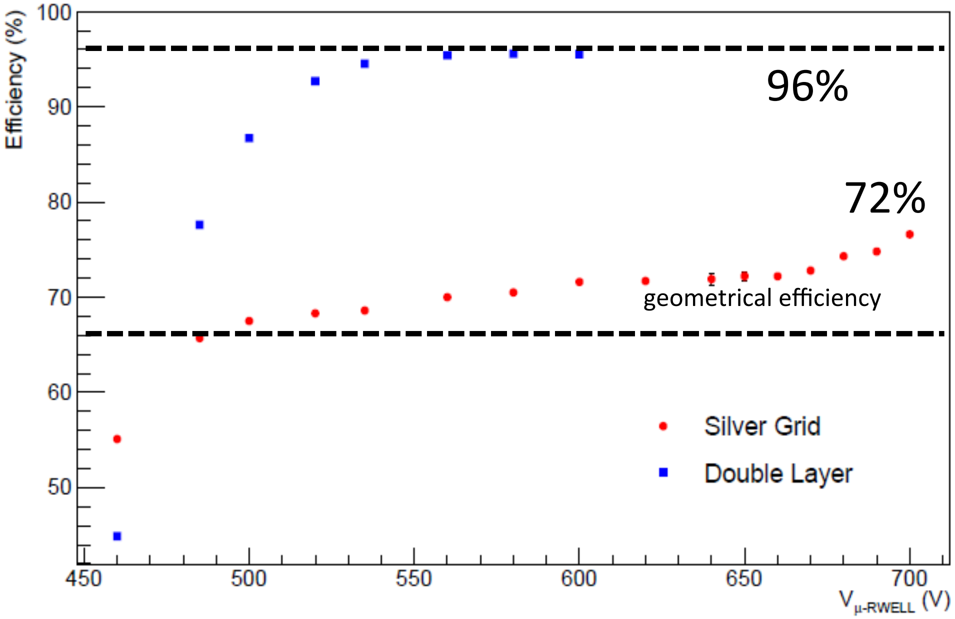
Clearly the introduction of a conductive strip on the bottom layer of the amplification stage can induce strong instabilities due to discharges over the DLC surface.

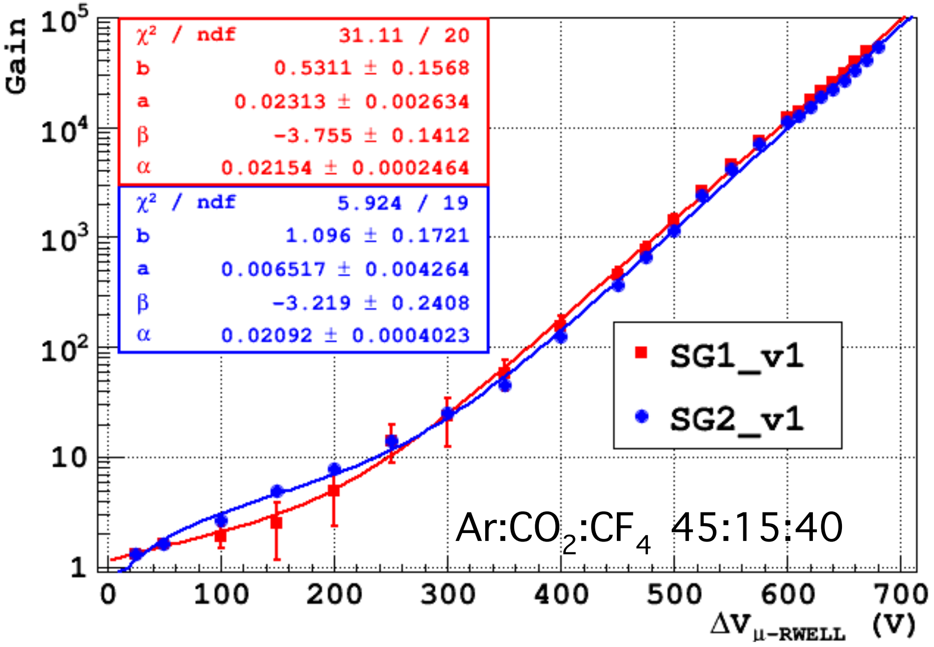


First prototypes of SG designed with safe geometrical parameters: grid pitch 6 mm, dead area around 1/3 of the total area

Silver Grid v1: X-rays and H4 test beam (July 2017)

- A SG µ-RWELL has been installed inside the RD51 tracking system and characterized together with a Double Layer chamber





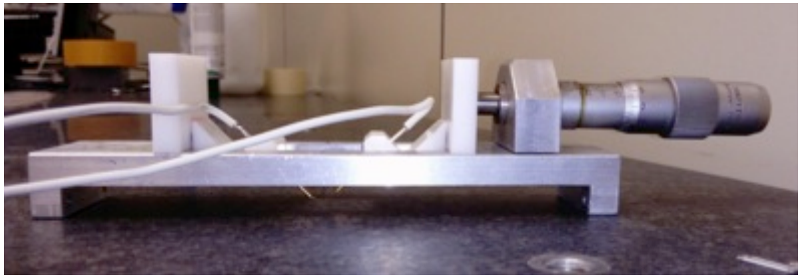
At the H4 test beam we could supply **up to 700 V**, much more than for the other µ-RWELL without instabilities. The reason of a so high instability voltage is **under investigation**.

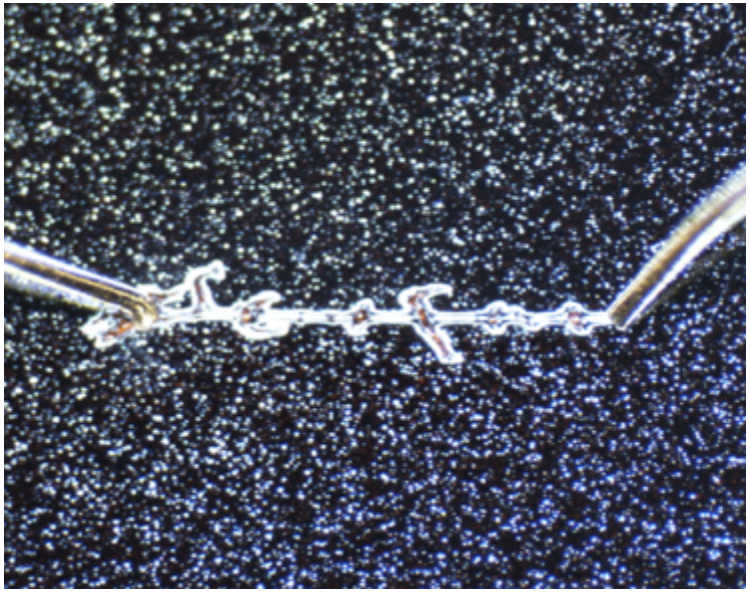
The lower efficiency is due to the geometrical effects. The increasing gain improves the collection efficiency partially compensating this leak.

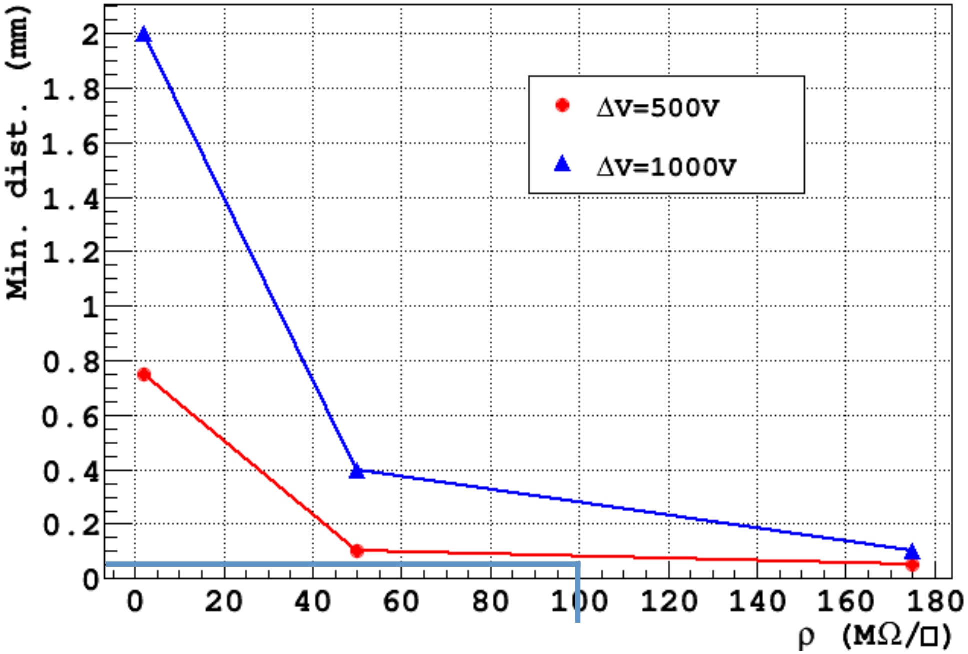
A dedicated study on the minimum distance between the strip and the holes has been done to increase the efficiency

Silver Grid: optimization

In order to reduce the dead area, we measured the Distance Of Closest Approach (without discharges) between two tips connected to a PS. We recorded the minimum distance as a function of the ΔV supplied for different foils before a discharge on the DLC occurs







Two more prototypes delivered in November, with grid pitch 12 mm, dead area 1/10 of the active area

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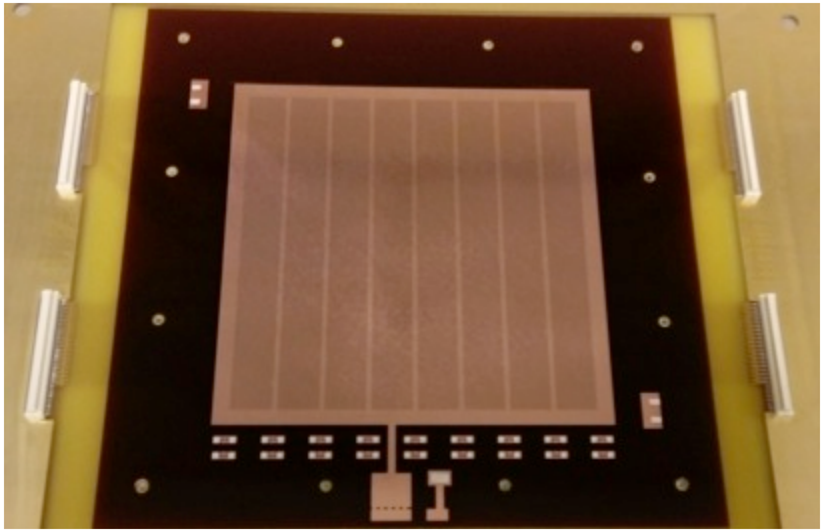
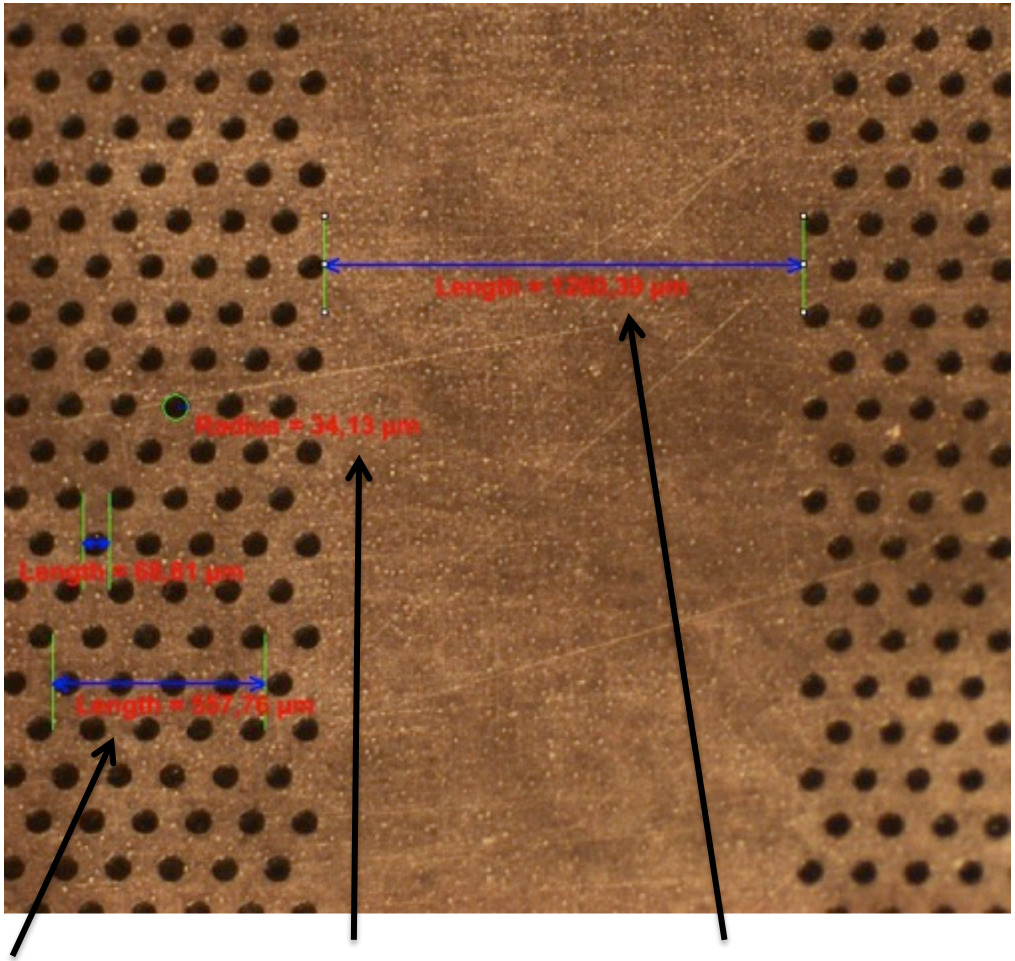
Silver Grid: 2^{nd} generation

The two detectors have been equipped with 6 x 8 mm^2 pad-segmented readout

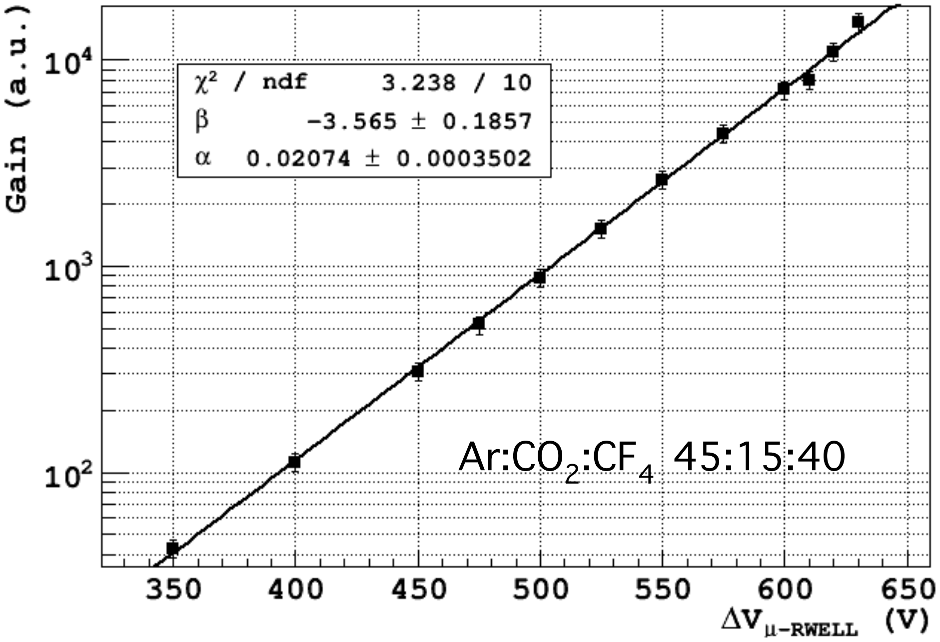


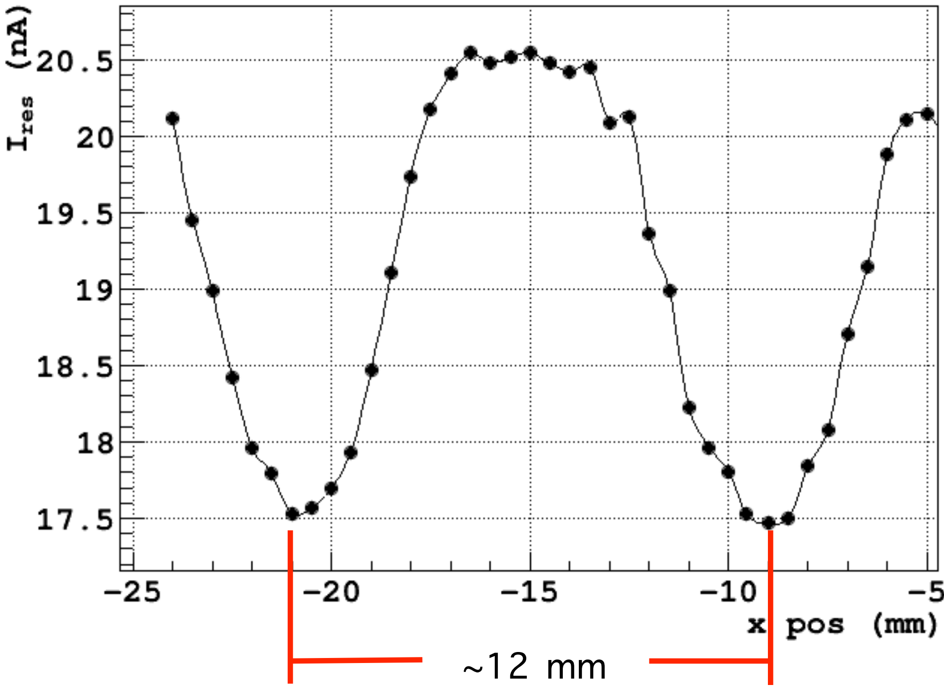
The grid lines are connected to the ground through the resistance provided by the DLC itself (9-10 MΩ)



557.76 µm 34.13 µm 1260.39 µm

Silver Grid: 2^{nd} generation



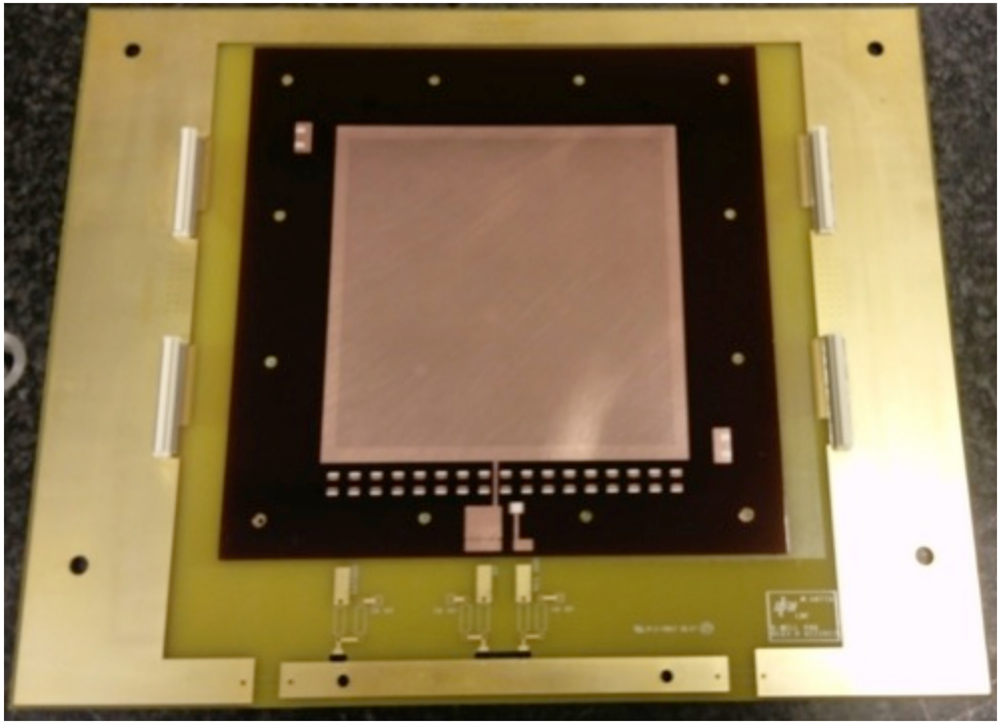


The detector is mounted on a support moved by a stepper motor. The position is given within few tenths of millimeter.

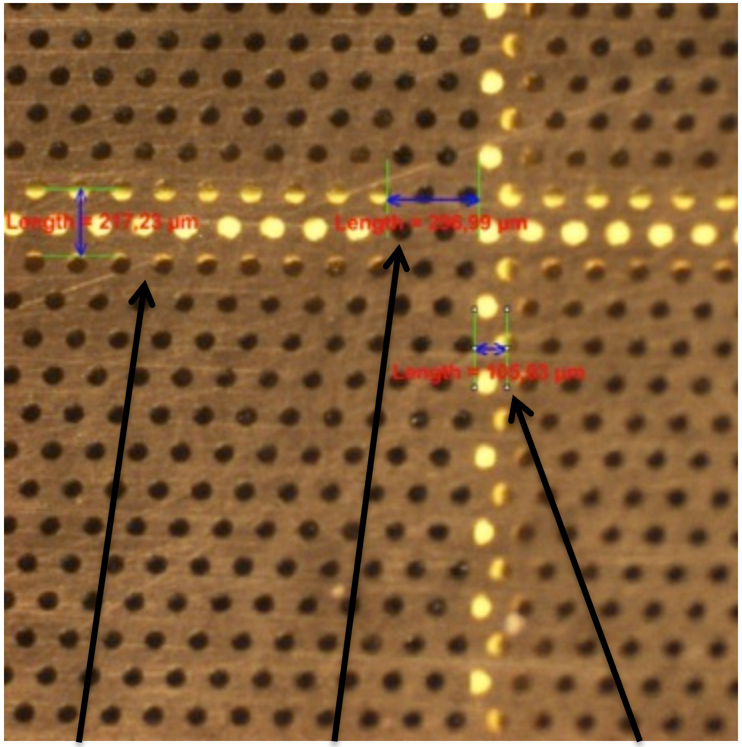
Scan along the coordinate orthogonal to the grid lines direction

Resistive grid

Small resistive strips are screen-printed on the bottom side of DLC



No dead areas

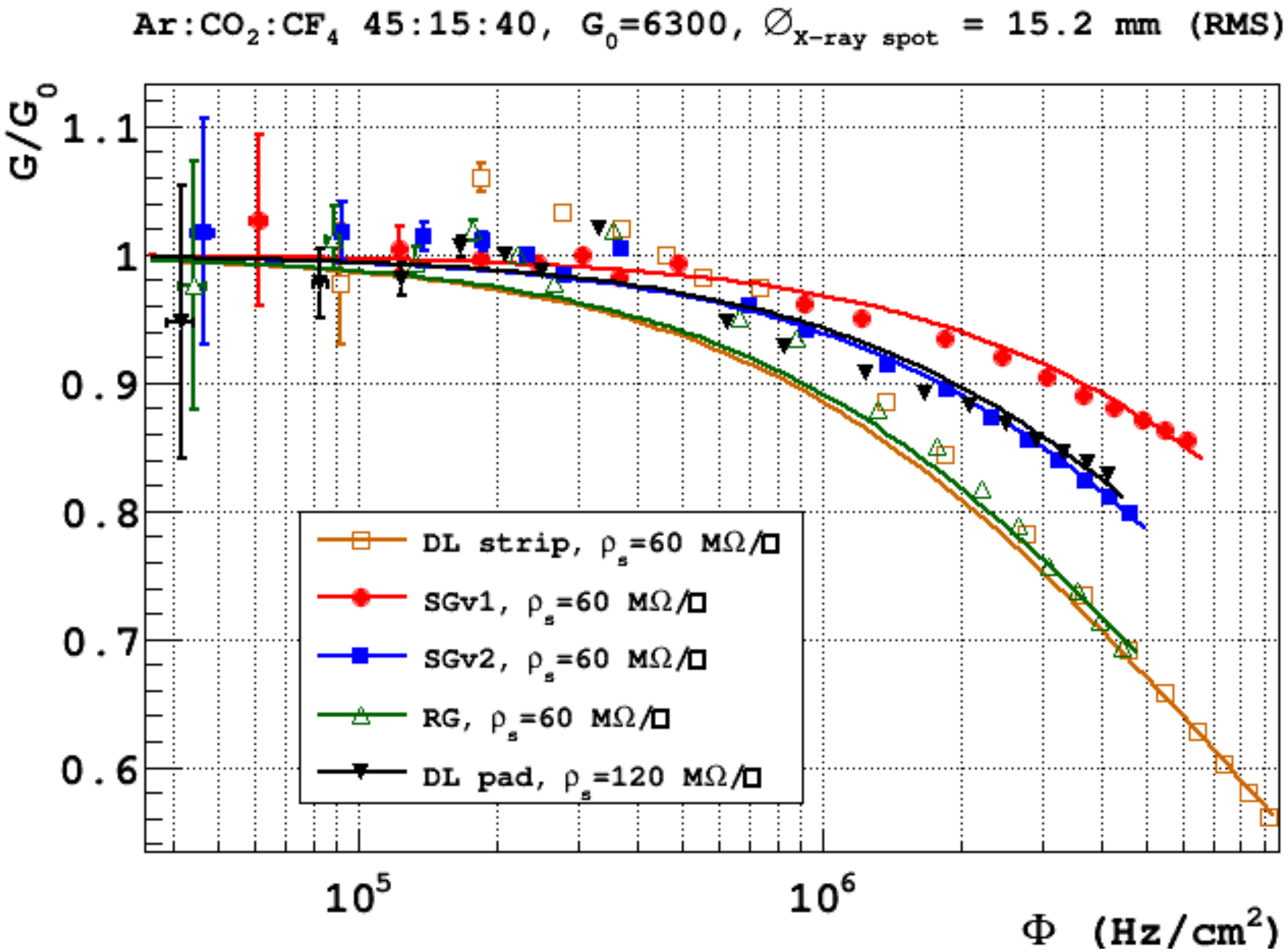


Y distance of pads: 217.23 µm

Resistive strip width: 296.99 µm

X distance of pads: 105.03 µm

Gain drop measurement with 5.9 keV X-ray

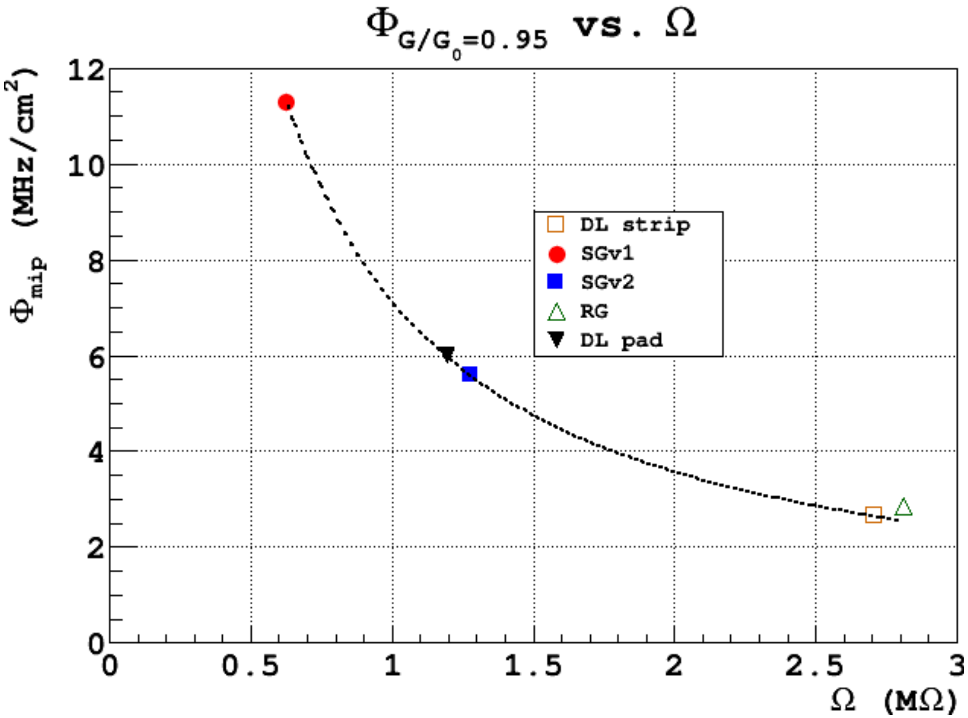


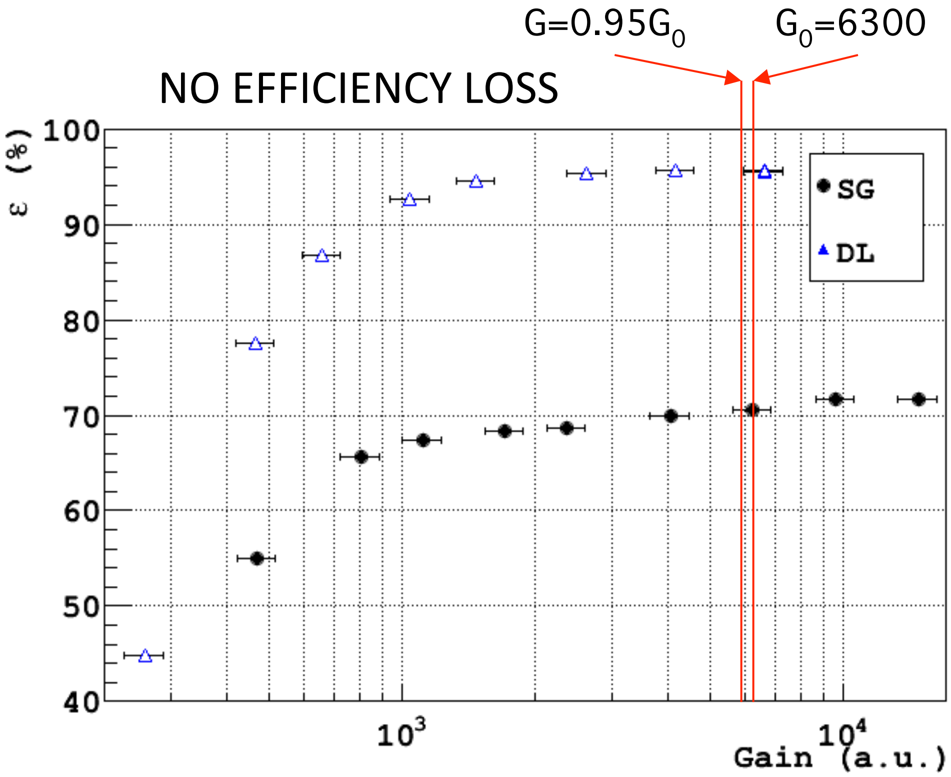
$Ar:CO_2:CF_4$ 45:15:40, $G_0=6300$, $\varnothing_{\text{X-ray spot}}$ = 15.2 mm (RMS)

The gain drop is only due to Ohmic effect on the resistive layer: the charges collected on the DLC drift towards the ground facing an effective resistance Ω, depending on the evacuation scheme and computed by the parameter p_0

$$\frac{G}{G_0} = \frac{-1+\sqrt{1+4p_0\Phi}}{2p_0\Phi}$$

Gain drop and efficiency





The primary ionization of 5.9 keV is ~7 times larger than the one created by a m.i.p. In order to face a **3 MHz/cm^2 m.i.p. fluence, with a 5% gain drop,** the effective resistance Ω must be at maximum 2 MΩ.

Anyway a 5% drop of G_0=6300 allows still to operate the detector at full efficiency. A measurement of the efficiency with a high rate particles has been planned for the next test beam

Conclusions & outlook

- The single layer layout has been exploited to build large area detectors (~1/2 m^2), but we also demonstrated that even larger detectors can be realized with the splicing technique, with the cooperation with ELTOS SpA, within TT
- Several prototypes have been realized, with different simplified evacuation charge scheme for high rate purposes
- Further optimization of the new high rate schemes must be done, addressed by the measurement of the gain drop done with X-rays

So far the best measured performances are:

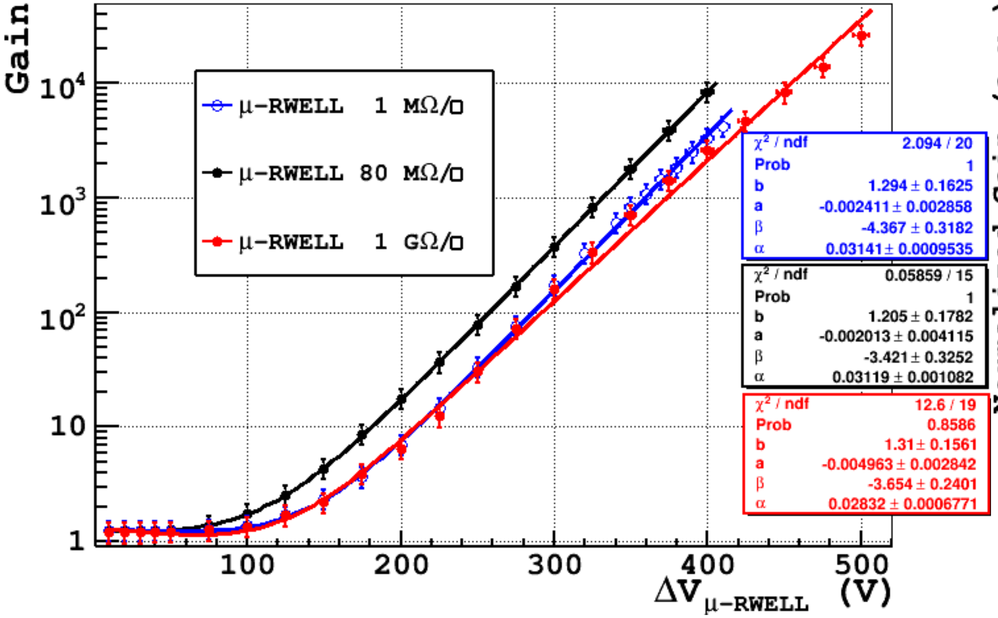
- 1 MHz/cm^2 rate capability with pion beam (Double Layer working at G=10000)
- space resolution 52 ± 6 μm (80 MΩ/☐, orthogonal tracks, no B field)
- well below 100 μm with non-orthogonal tracks, with the μ-TPC/CC combination
- time resolution 5.7 ns (with FEE saturation)
- Both the Silver Grid v1 reached a gain of almost 10^5 (to be understood)
- **An ageing test at GIF++** is ongoing: the detector integrated up to 90 mC/cm^2 without showing gain loss

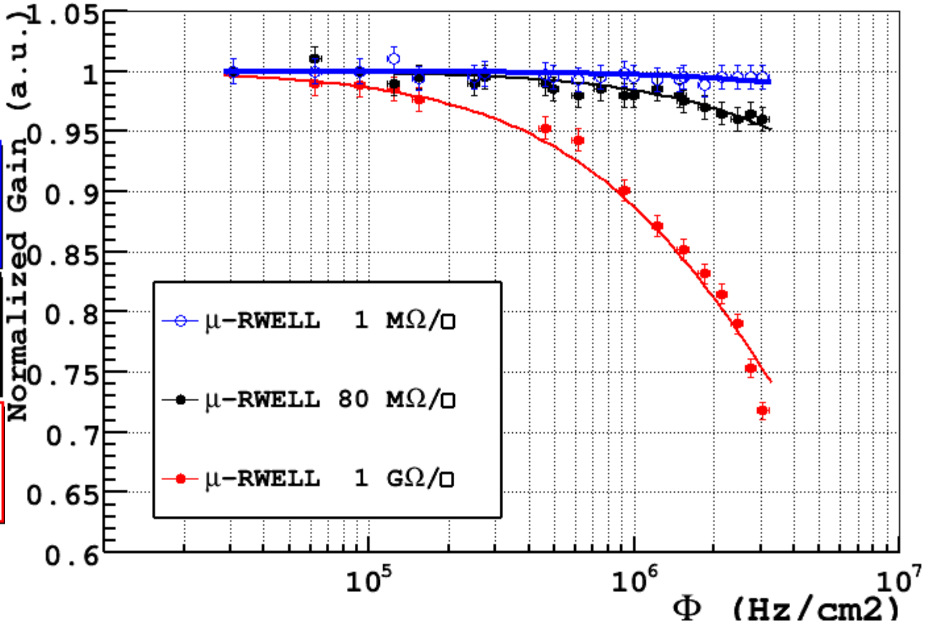
Spare

μ-RWELL: other prototypes

X-ray tube, Ar:iC$_4$H$_{10}$ 90:10

2,5 mm Diameter Collimator



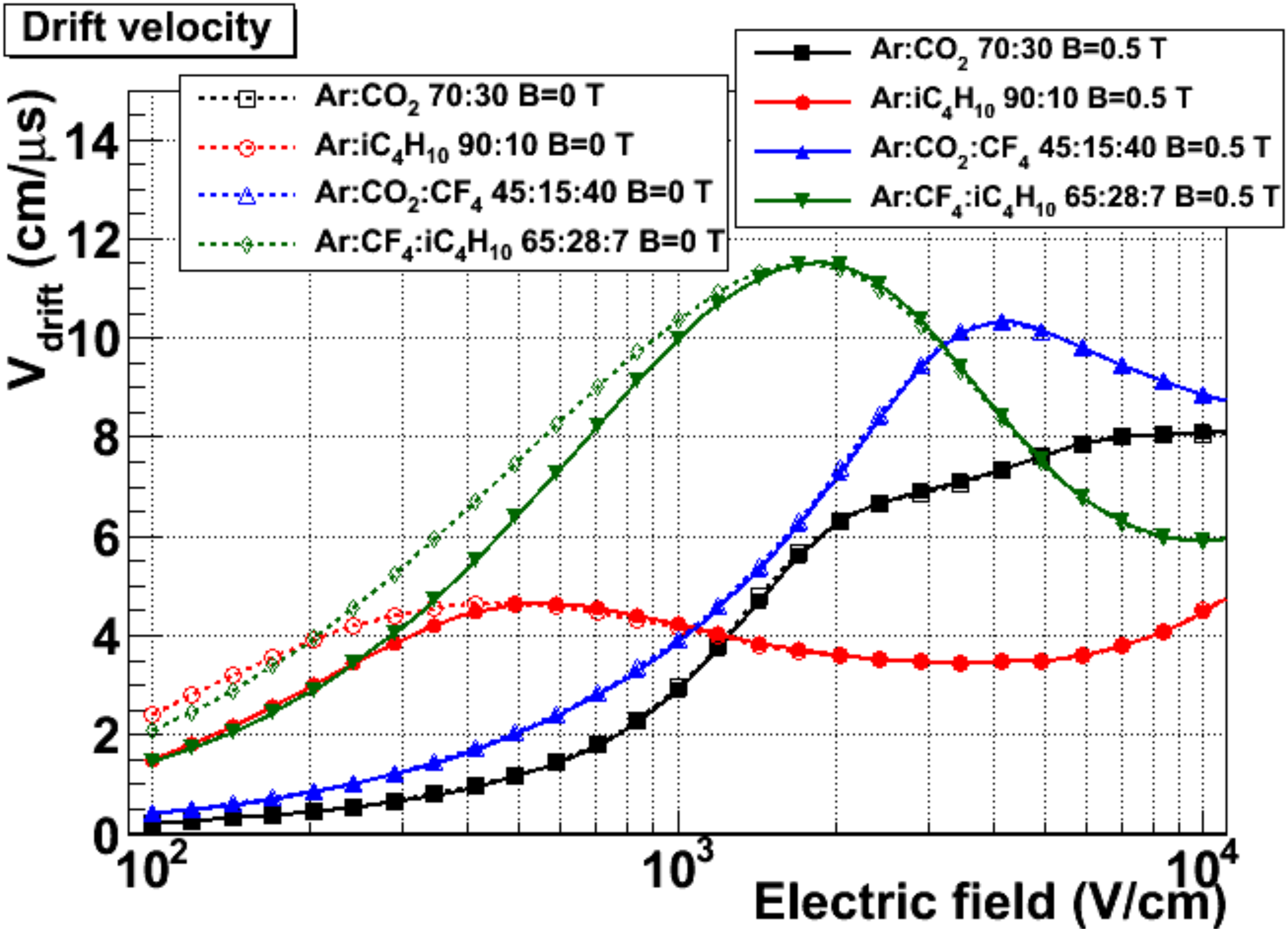


Fit Results:

Resistivity declared by the deliverer: **1 GΩ/☐**; from fit **ρ_S= 883.8 ± 176.7 MΩ/☐**

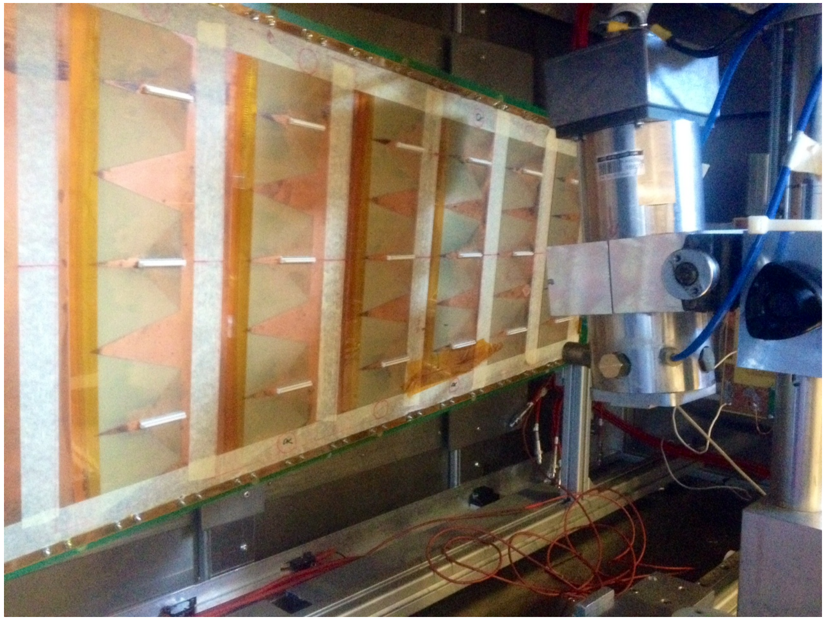
Resistivity declared by the deliverer: **80 MΩ/☐**; from fit **ρ_S= 79.3 ± 15.8 MΩ/☐**

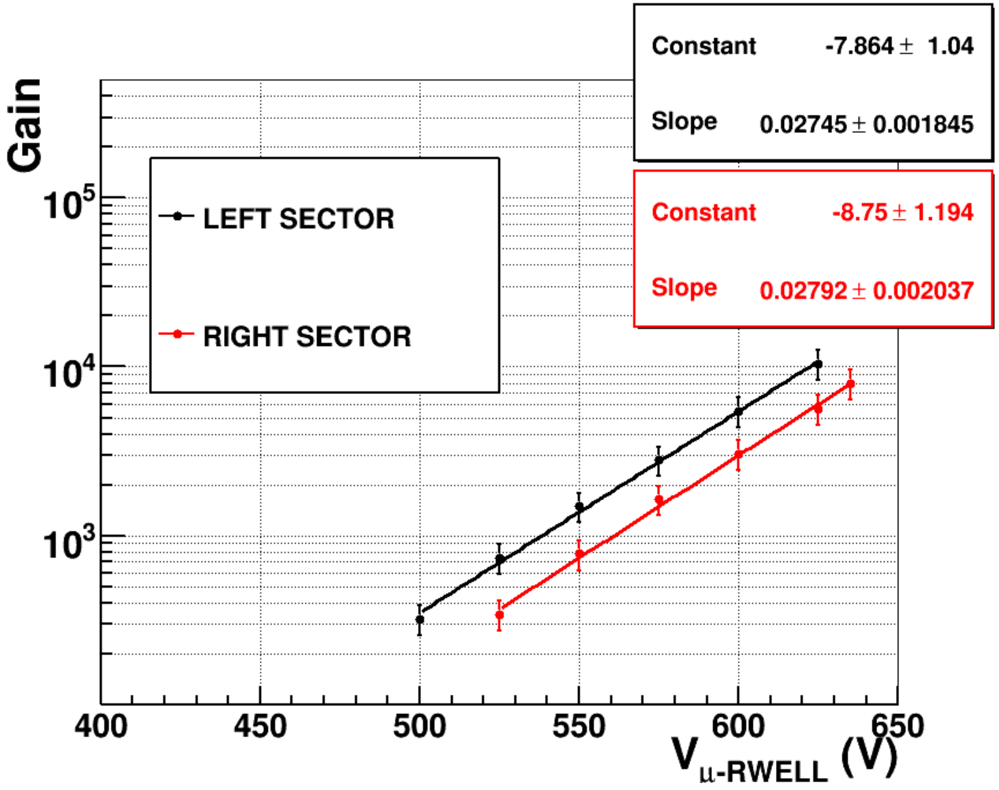
Resistivity declared by the deliverer: **1 MΩ/☐**; from fit **ρ_S= 11.7 ± 2.3 MΩ/☐**


Drift velocity
Ar:CO2 70:30 B=0 T
Ar:iC4H10 90:10 B=0 T
Ar:CO2:CF4 45:15:40 B=0 T
Ar:CF4:iC4H10 65:28:7 B=0 T
Ar:CO2 70:30 B=0.5 T
Ar:iC4H10 90:10 B=0.5 T
Ar:CO2:CF4 45:15:40 B=0.5 T
Ar:CF4:iC4H10 65:28:7 B=0.5 T
Vdrift (cm/μs)
0
2
4
6
8
10
12
14
10^2
10^3
10^4
Electric field (V/cm)

Detector Gain

The prototype has been characterized by measuring the **gas gain, rate capability** in **current mode** with an **5.9 keV X-rays (local irradiation, ~1cm^2 spot)**.

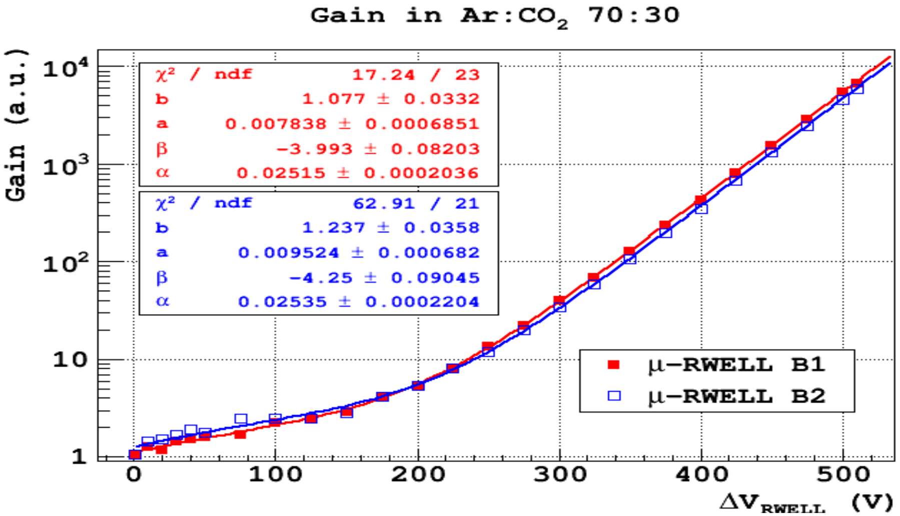


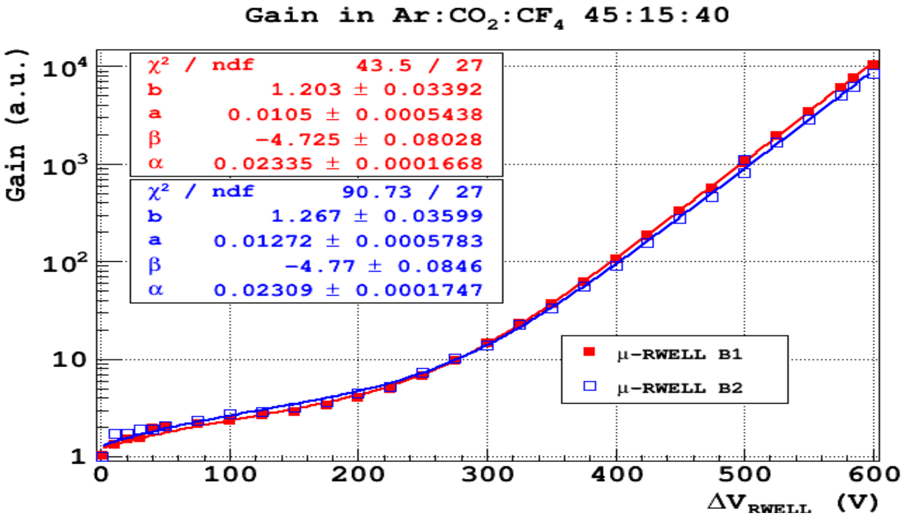


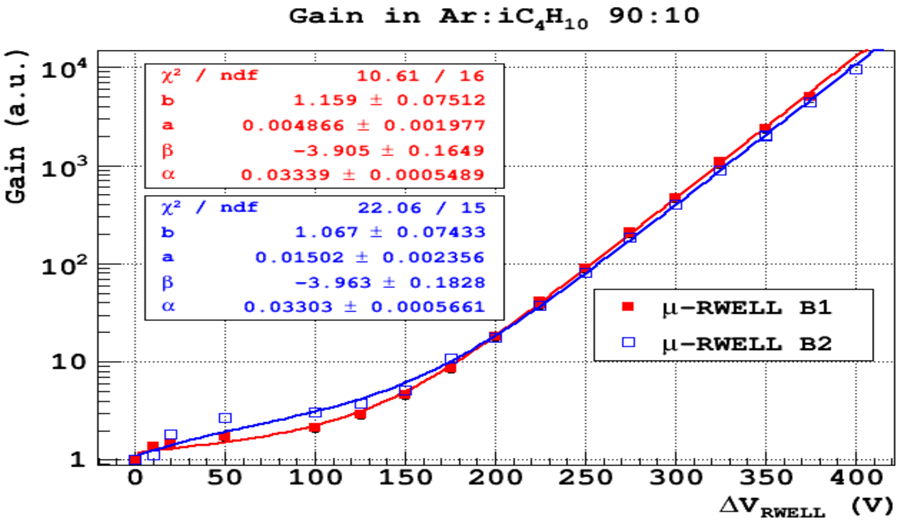
A shift of ~ 25 V has been measured between the two sectors probably due to the different geometry of the amplification stage (to be confirmed with microscope check – left/right asymmetry)

X-ray measurements

Two prototypes with the **double resistive layer scheme** (ρ=40 MΩ/□) have been completed last Summer; the detectors have been tested with a 5.9 keV X-rays flux **(local irradiation)**.


Gain in $Ar:CO_2$ 70:30


Gain in $Ar:CO_2:CF_4$ 45:15:40


Gain in $Ar:iC_4H_{10}$ 90:10

Measurement performed in current mode.
Gain measured up to 10000.
Similar behavior for the two chambers.