The micro-RWELL detector

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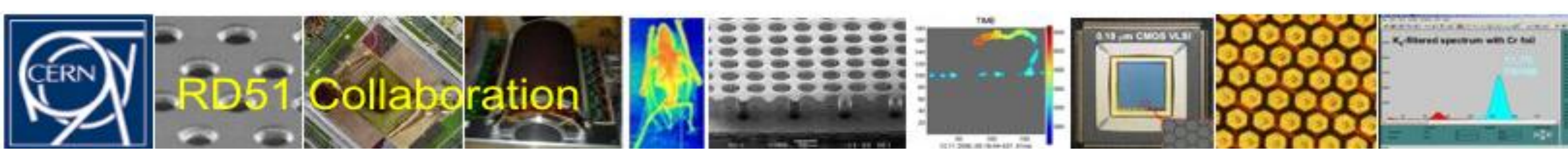
5th International Conference on Micro-Pattern Gas Detectors



Outline

- The architecture & principle of operation
- The Low Rate scheme and its performance
  - Technology Transfer of the Low Rate version
- The High Rate scheme and its performance
- Conclusion

Why a new MPGD

The R&D on μ-RWELL is mainly motivated by the wish of improving the

stability under heavy irradiation

& simplify as much as possible

construction/assembly procedures

Consequently reducing the costs of the device

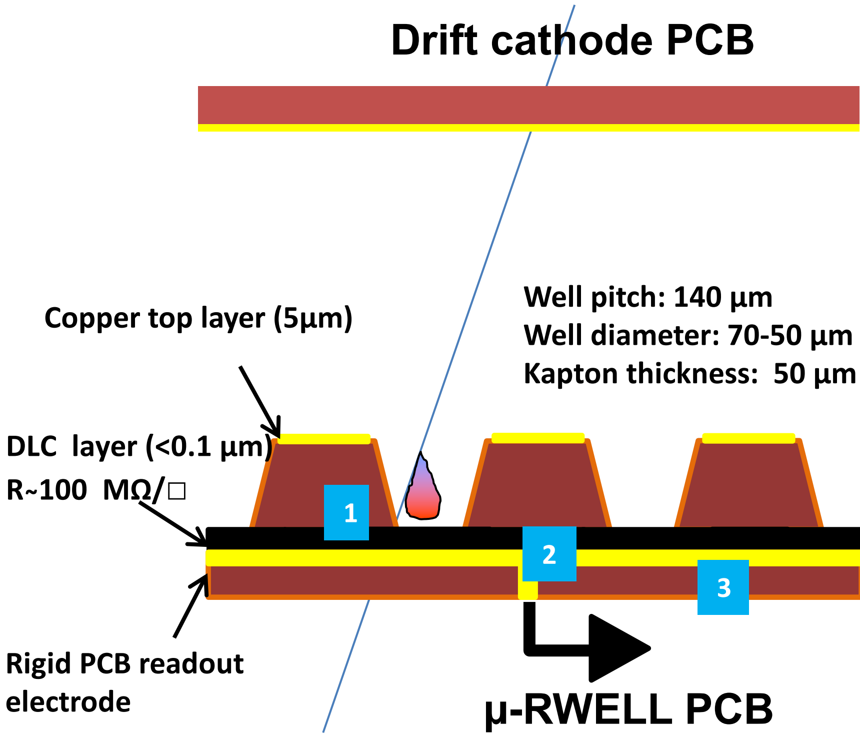
The detector architecture

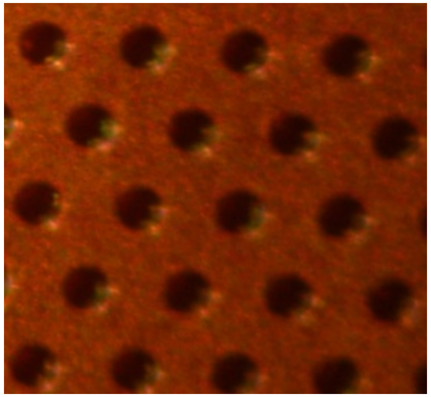
G. Bencivenni et al., 2015_JINST_10_P02008

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 layer"** for discharge suppression & current evacuation:
   i. **"Single resistive layer" (SL) <100 kHz/cm²:** single resistive layer → surface resistivity ~100 MΩ/☐ (CMS-phase2 upgrade; SHIP)
   ii. **"Double resistive layer" (DL) > 1 MHz/cm²**: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF) suitable for LHCb-Muon upgrade
3. a **standard readout PCB**

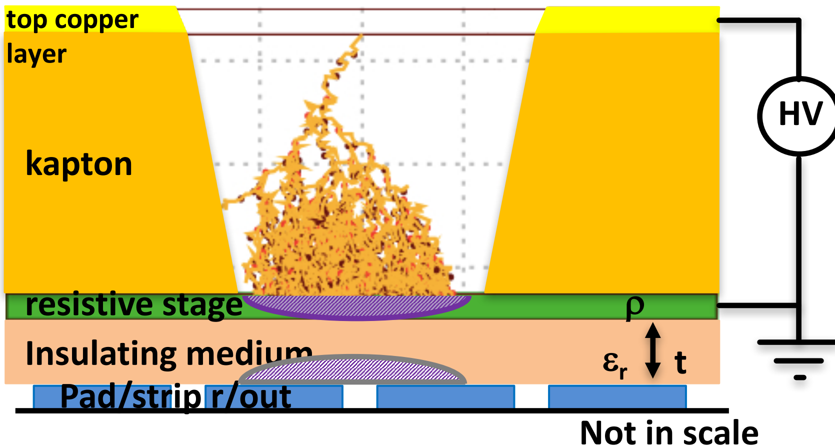




(*) DLC = Diamond Like Carbon
High mechanical & chemical resistant material

Principle of operation

Applying a suitable voltage between top copper layer and DLC the "**WELL" acts as multiplication channel for the ionization.**



The charge induced on the resistive foil is dispersed with a *time constant, τ = ρC ,* determined by

- the ***surface resistivity, ρ***
- the ***capacitance per unit area,*** which depends on the **distance between the resistive foil and the readout plane*, t***
- the ***dielectric constant*** of the insulating medium, ε_r ***[M.S. Dixit et al., NIMA 566 (2006) 281]***

- **The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark**
- As a drawback, the **capability to stand high particle fluxes is reduced**, ***but an appropriate grounding of the resistive layer with a suitable pitch solves this problem (see High Rate scheme)***

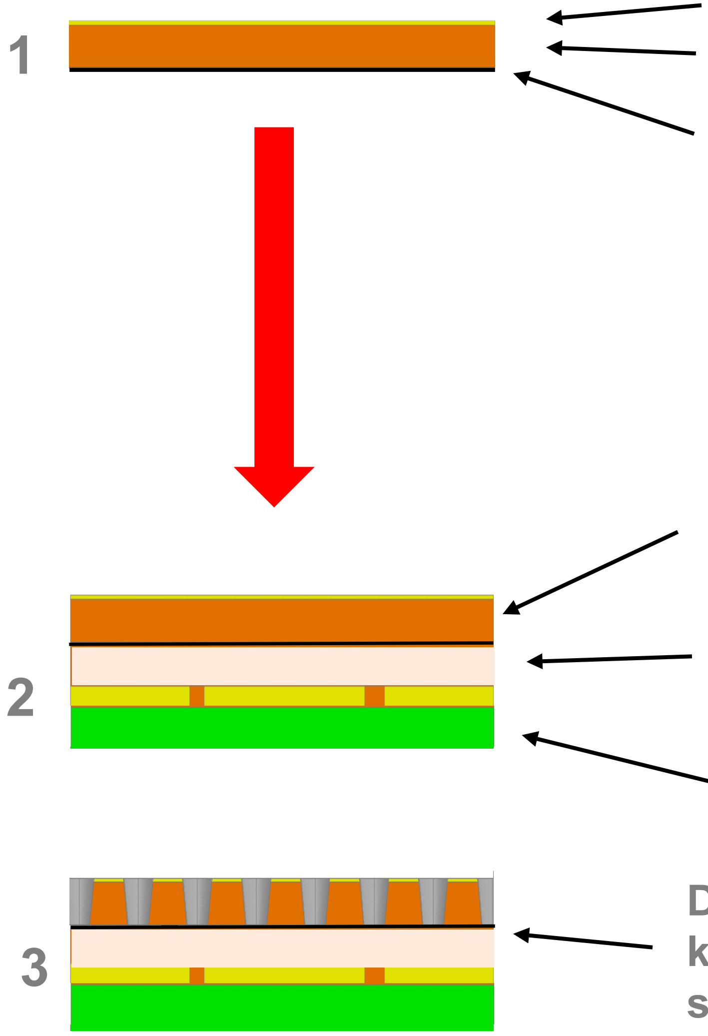
Main detector features

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)

Single resistive layer scheme

The Low Rate scheme (CMS/SHiP)

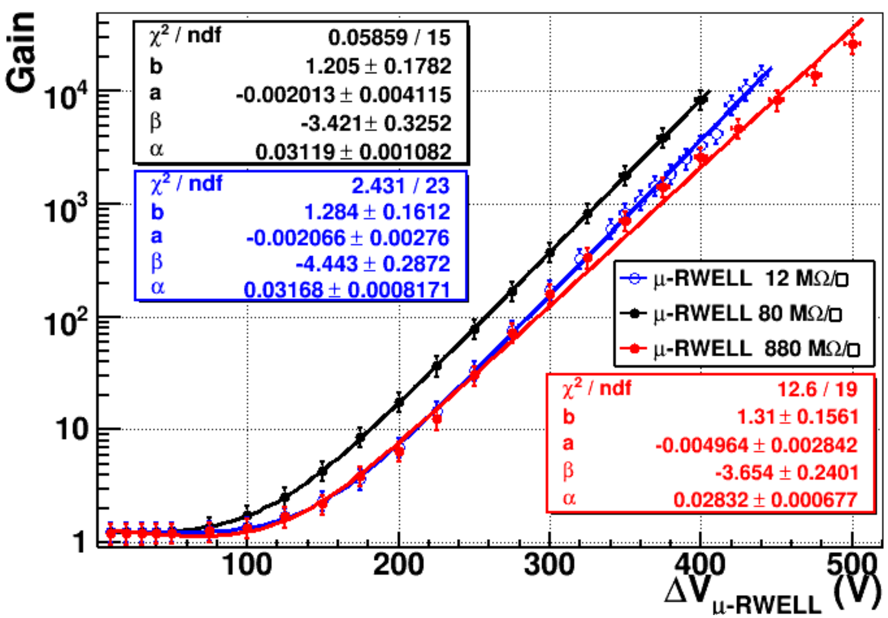


The μ-RWELL performance: X-rays test

The prototypes, with different surface resistivities, have been tested with X-rays for first measurements in current mode (gain and rate capability **under local irradiation**).

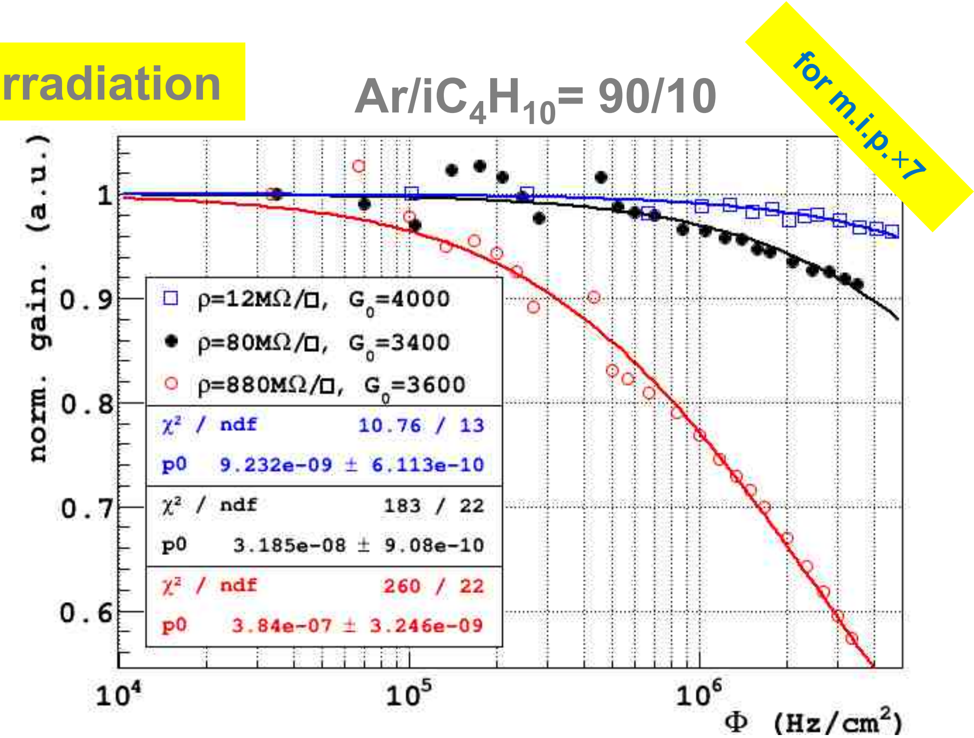
local irradiation

Ar/iC_4H_{10}= 90/10



Detectors safely reach a gain ≥ 10000

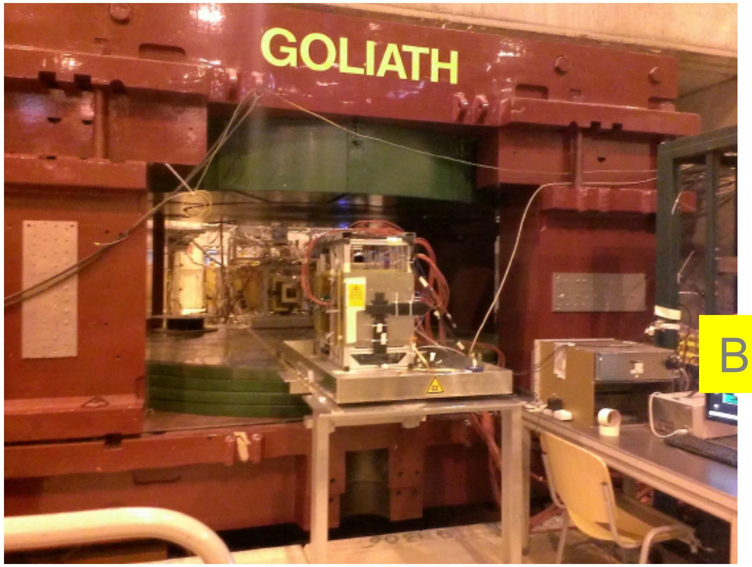
Ar/iC_4H_{10}= 90/10



$\Phi_{0.97}$ = 850 kHz/cm²; $\Phi_{0.97}$ = 77 kHz/cm²; $\Phi_{0.97}$ = 3.4 MHz/cm²;

Under global irradiation we expect a lower rate capability for single layer scheme

Beam tests results

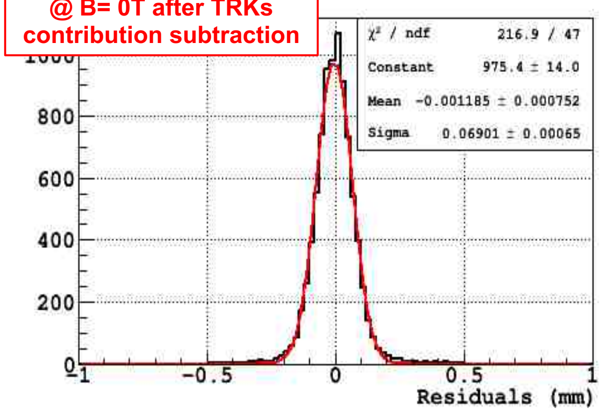


H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

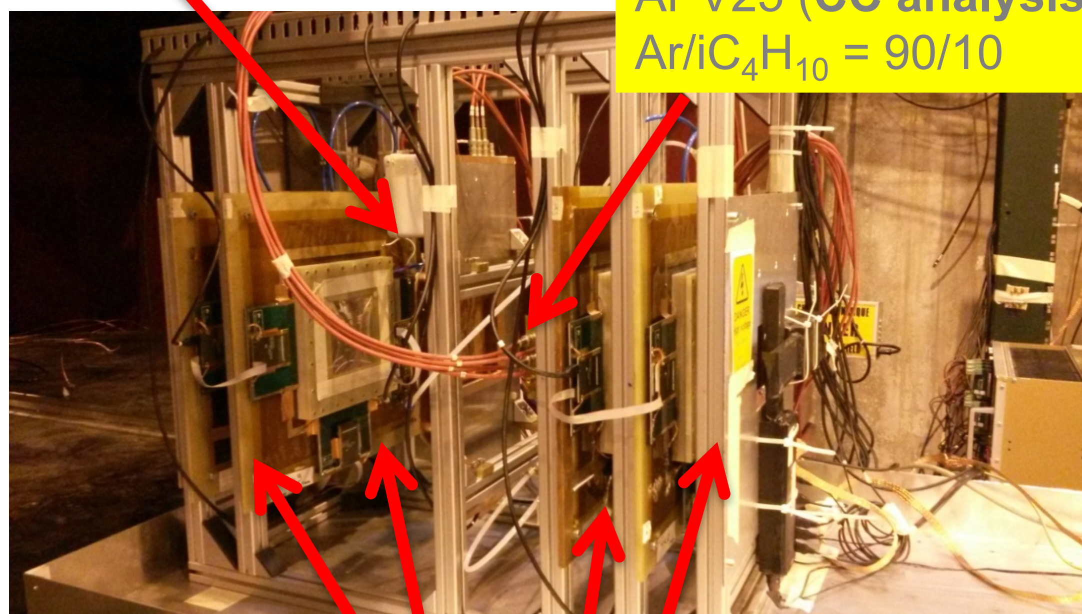
μ-RWELL prototype
5x5 cm^2 active area
12-80-880 MΩ /□
400 μm pitch strips
APV25 (**CC analysis**)
Ar/iC_4H_{10} = 90/10

BES III-GEM chambers

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



M. Poli Lener et al., NIM A 824 (2016) 565

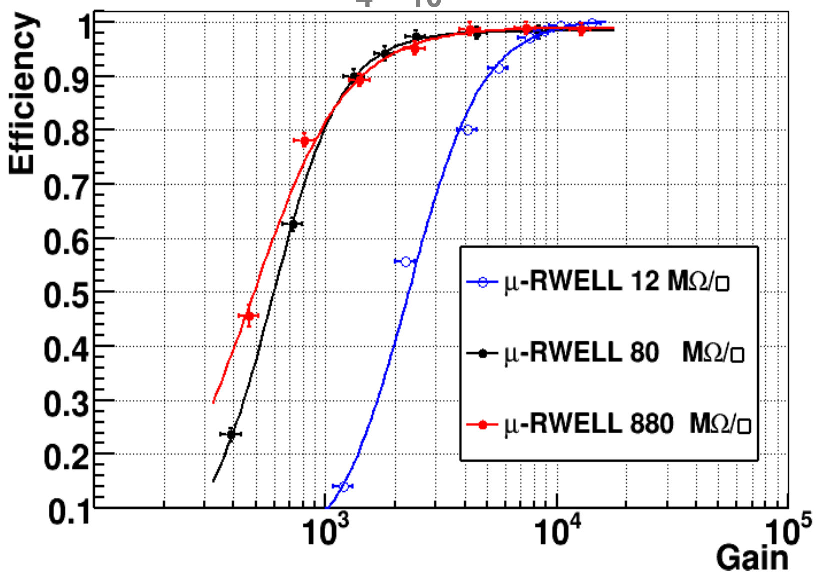


GEMs Trackers

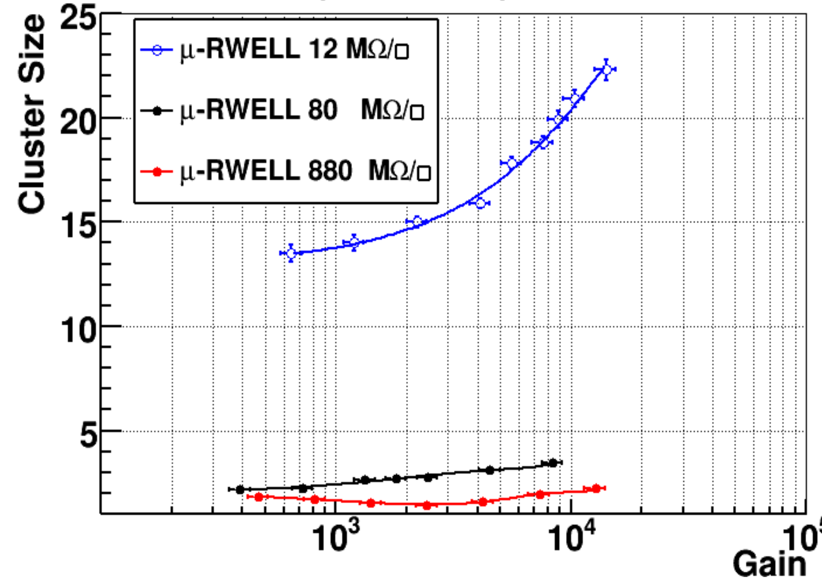
The µ-RWELL performance: Beam Tests

Analysis performed with the CC method, 400 µm strips pitch

Ar/iC_4H_{10}= 90/10



Ar/ISO=90/10

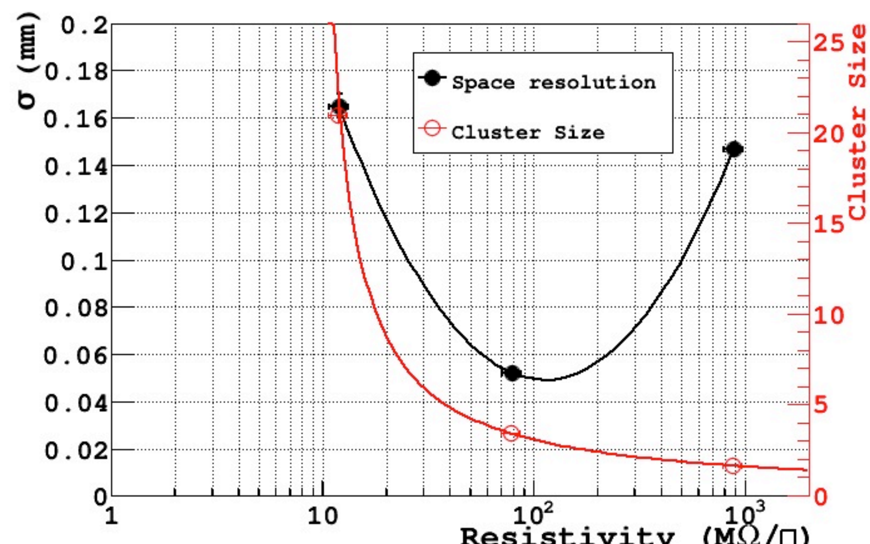


At low resistivity the spread of the charge (cluster size) on the readout strips increases, thus requiring a higher gain to reach the full detector efficiency.

The space resolution exhibit a minimum width around 100 MΩ/□.

At low resistivity the charge spread increases → worse spatial resolution

At higher resistivity → ~ 1 fired strip

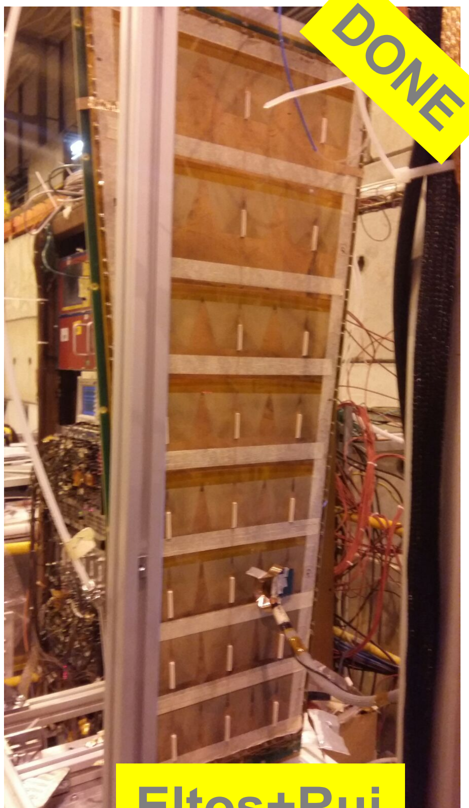


Technology Transfer to Industry

In the framework of the **CMS-phase2 muon upgrade** we have developed **large size μ-RWELLs** , in strict collaboration with **Italian industrial partners** (**ELTOS & MDT**).
The work is performed in **two years** with following schedule:

1. **Construction & test of the first 1.2x0.5m^2 (GE1/1) μ-RWELL — 2016 - DONE**
2. **Mechanical study and mock-up of 1.8x1.2 m^2 (GE2/1) μ-RWELL — 2016-2017 ONGOING**
3. Construction of the first **1.8x1.2m^2 (GE2/1) μ-RWELL (only M4 active) — 01-09/2017 near future**

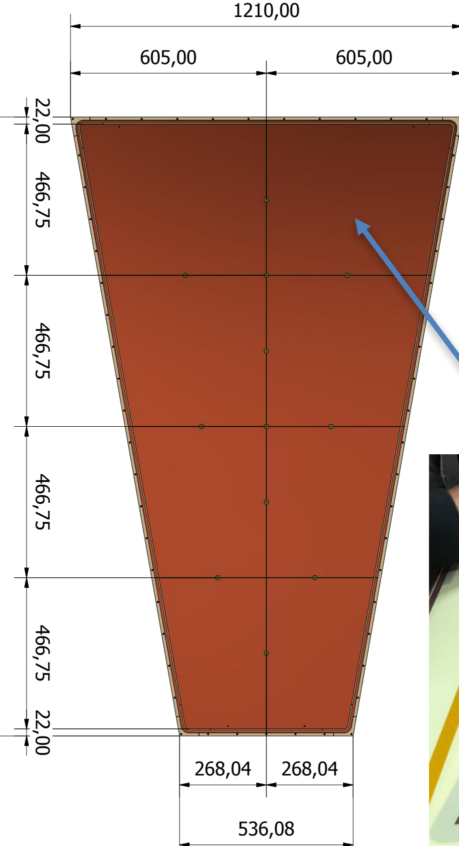
~40 times larger than small protos !!!



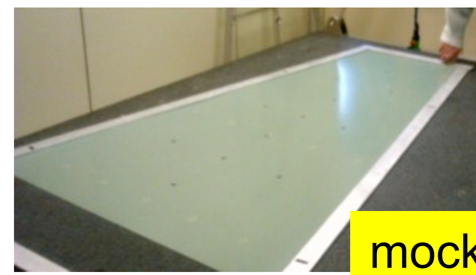
DONE

Eltos+Rui

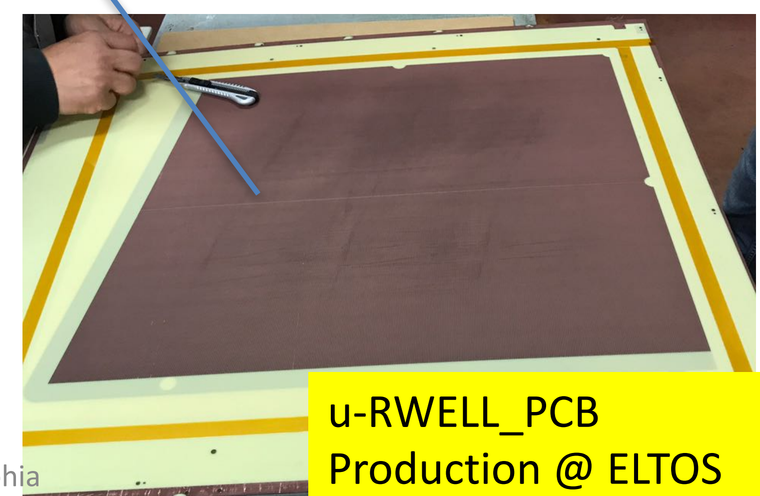
~200 times larger than small protos !!!



1.8x1.2m^2 (GE2/1) μ-RWELL



mock-up

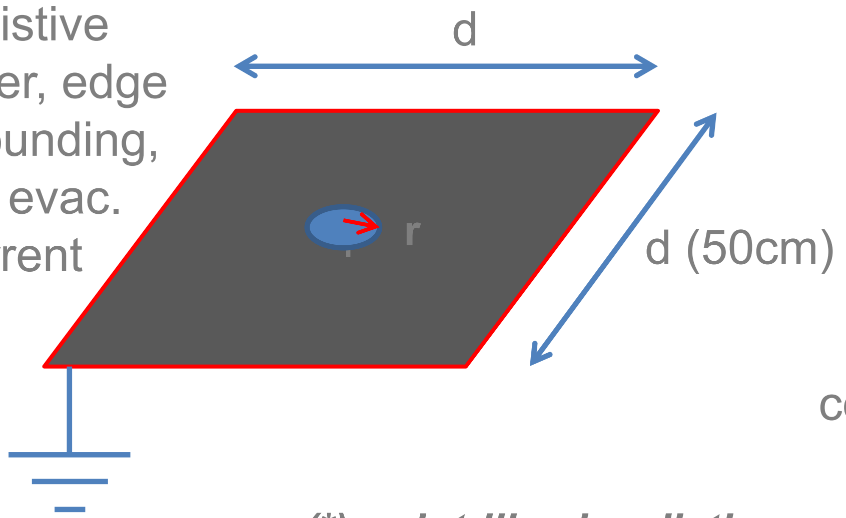


u-RWELL_PCB
Production @ ELTOS

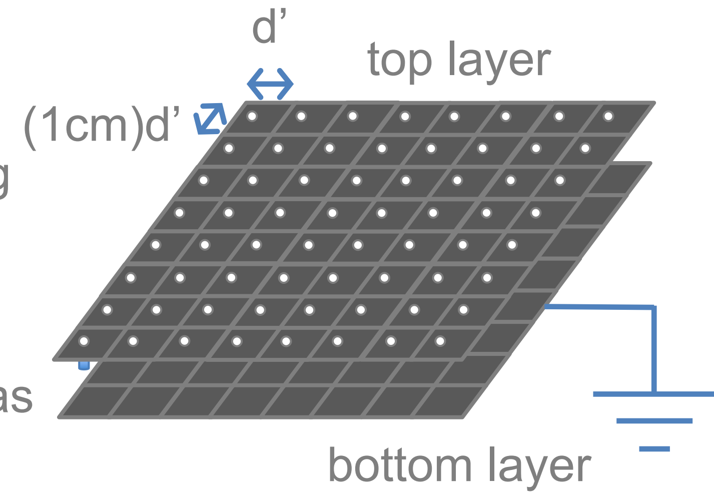
Double resistive layers scheme

Towards the High Rate scheme

single resistive layer, edge grounding, 2D evac. current



double resistive layer, 3D grounding



(*) 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

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

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

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

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

The High Rate scheme (LHCb)

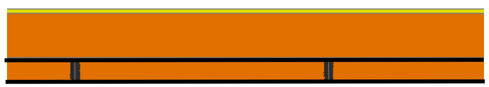
1

Copper layer 5 µm

Kapton layer 50 µm

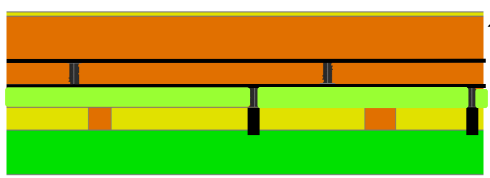
DLC layer: 0.1 – 0.2 µm
(10-200 MΩ/☐)

2



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

3



DLC-coated kapton base material

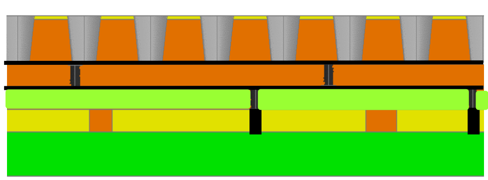
2nd resistive kapton layer

insulating layer

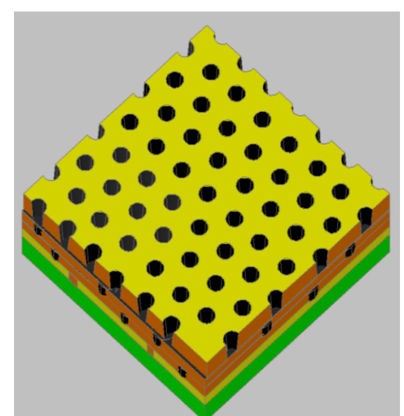
pad/strips readout on standard PCB

"through vias" for grounding

4

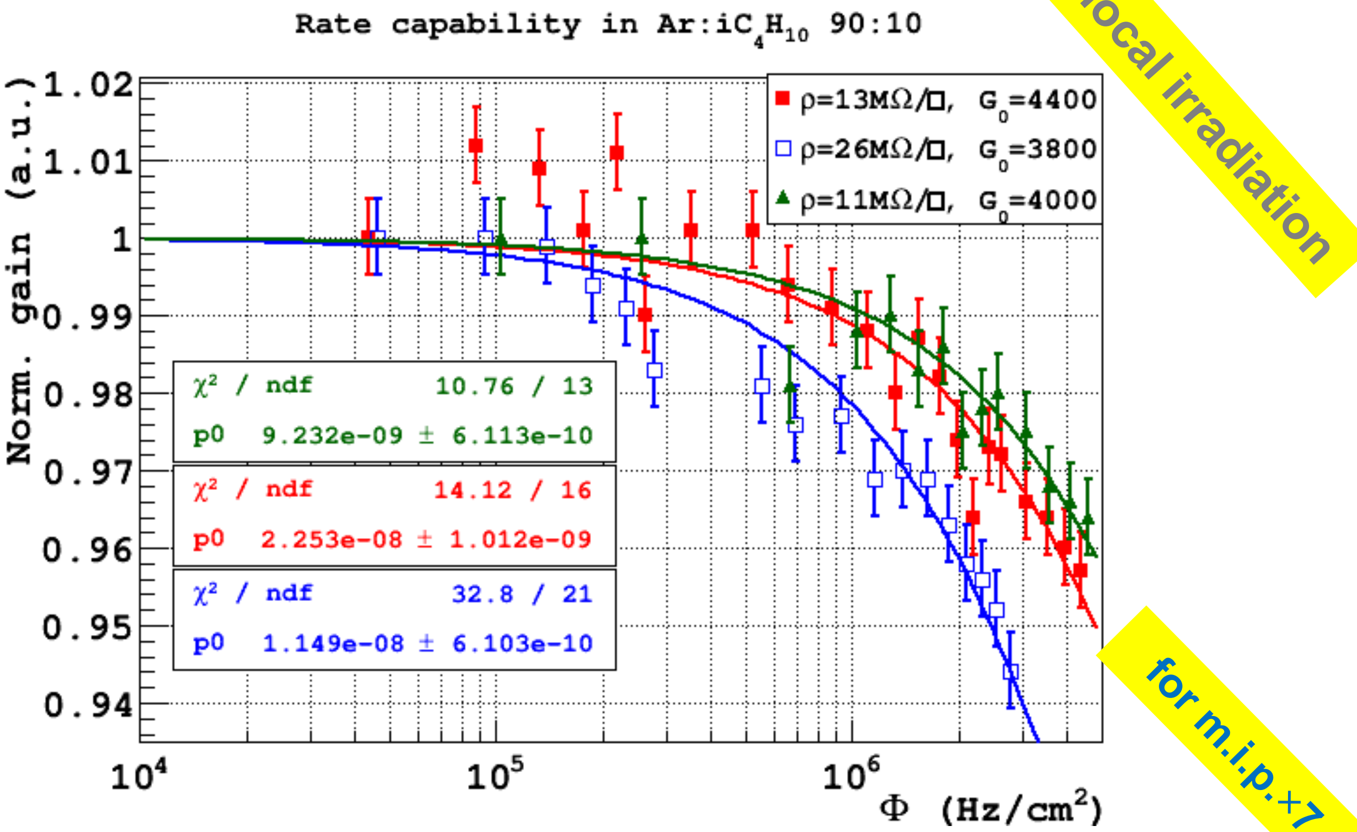


DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)



Rate capability with X-rays (double layer)

Double resistive layer w/ 1x1 cm^2 *through-vias* grounding pitch



Φ = 3.4 MHz/cm^2; Φ = 2.8 MHz/cm^2; Φ = 1.6 MHz/cm^2

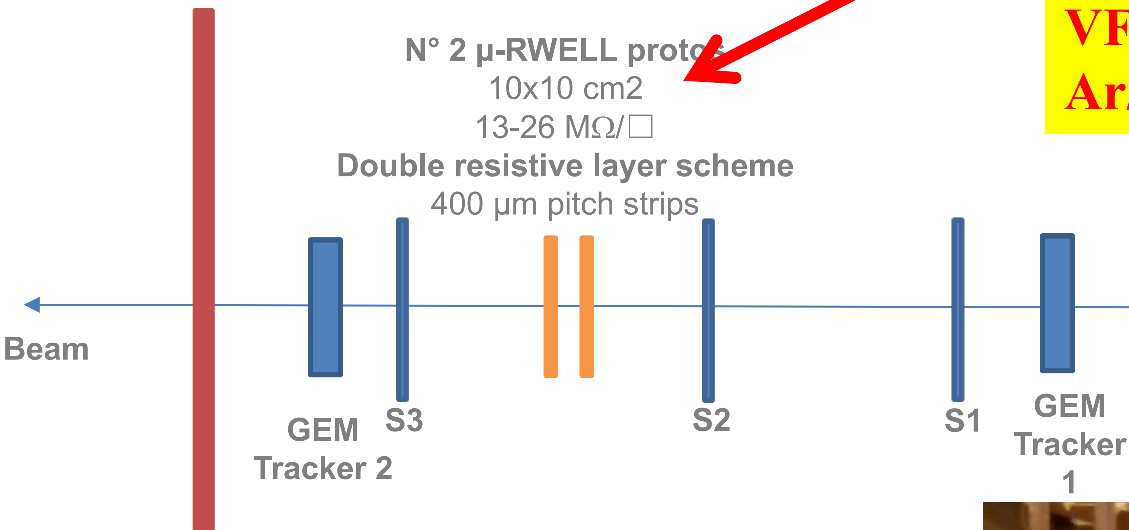
Local irradiation is practically equivalent to global irradiation

Beam Test (CMS/LHCb collaboration)

H8 Beam Area (18th Oct. – 9th Nov 2016)
Muon/Pion beam: 150 GeV/c

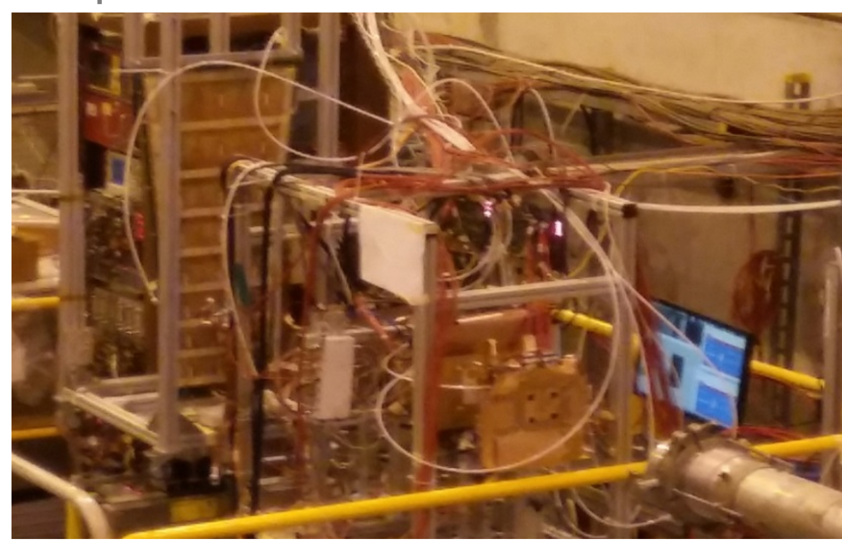
3 μ-RWELL prototypes
13-26-70 MΩ /□
VFAT (digital FEE)
$Ar/CO_2/CF_4$ = 45/15/40

N° 2 μ-RWELL proto
10x10 cm2
13-26 MΩ/□
Double resistive layer scheme
400 μm pitch strips



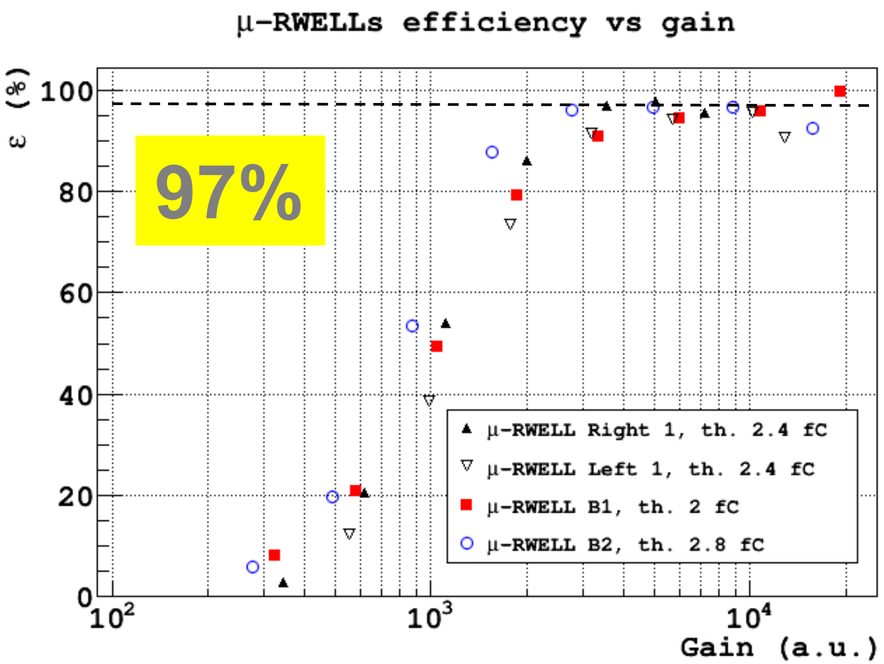
N° 1 μ-RWELL proto
100x50 cm2
70 MΩ/□
Single resistive layer scheme
800 μm pitch strips

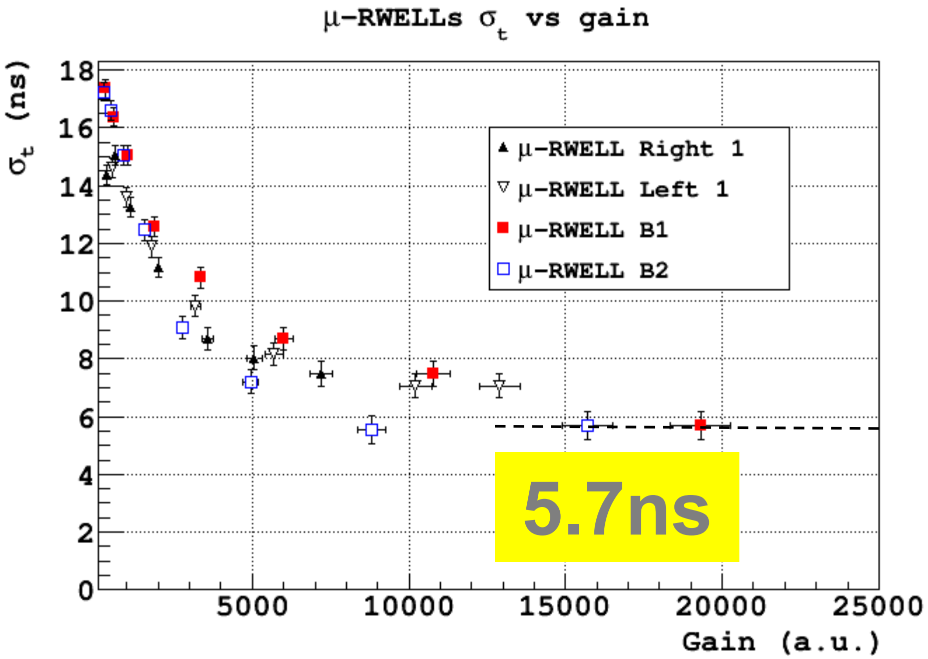
Trigger=S1+S2+S3



GOAL: <u>time resolution measurement (never done before)</u>

Time Performance





Different chambers with **different dimensions and resistive schemes** exhibit a **very similar behavior** although realized in **different sites** (large detector realized @ ELTOS)

The **saturation at 5.7 ns** is dominated by the fee (measurement done with VFAT2).

*Past measurements done with **GEM by LHCb group gave σ_t = 4.5 ns** with VTX chip **[1].***
We wish to perform the same measurement with μ-RWELL in order to have a direct comparison with GEM.

[1] G. Bencivenni et al, NIM A 494 (2002) 156

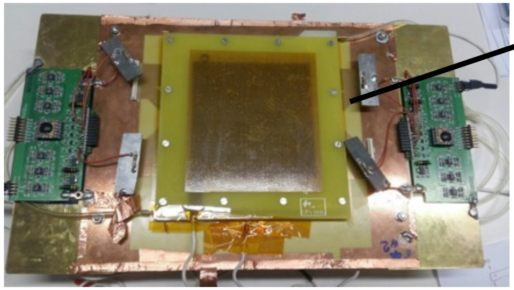
Ageing test: GIF++ (LNF, INFN-BO)

To validate the DLC-based detector in the GE2/1 region @CMS, it is necessary (mandatory) to study the behaviour of the chamber under global irradiation.

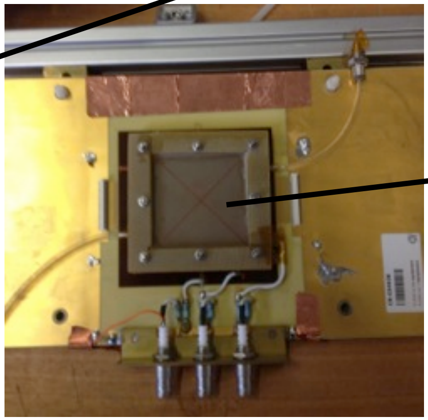
The detector, working at a gain 4000 (efficiency plateau) in Ar/CO2/CF4 45/15/40, will integrate about 2.5 mC/cm^2

We plan to integrate 25 mC/cm^2 in about 60 days (10 years with s.f. 10)

The setup has been completed with two more µ-RWELL:

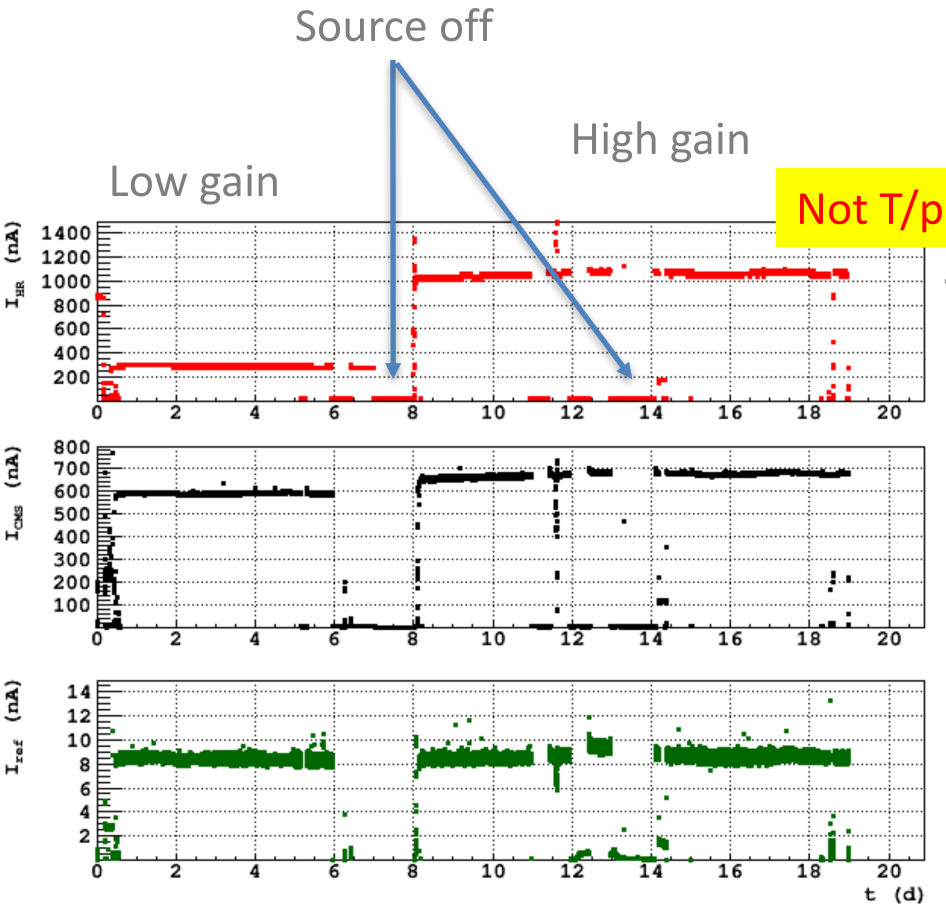


Double resistive layers scheme (high rate)

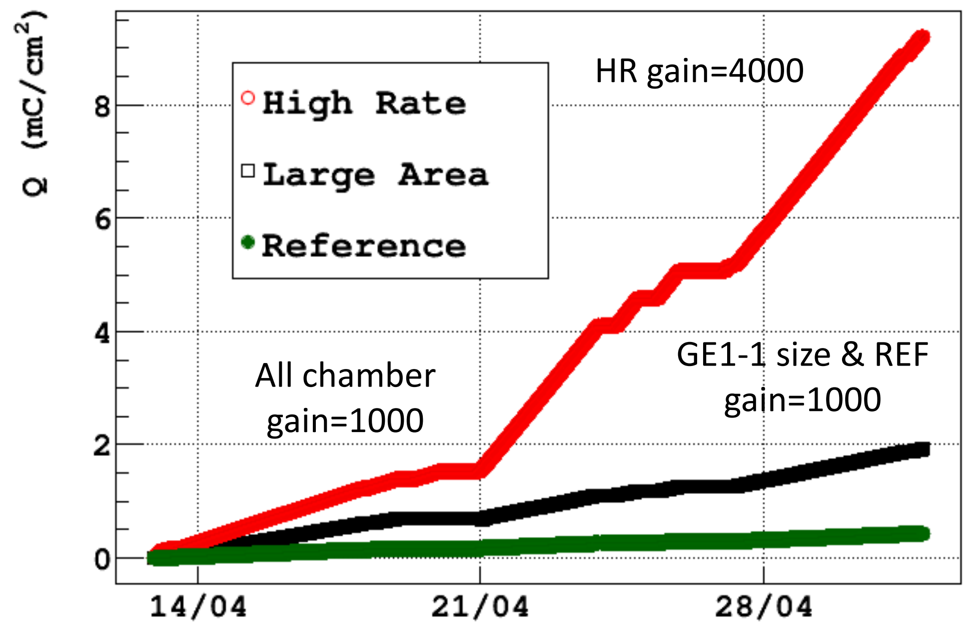


Single layer scheme (reference chamber)

Ageing test: GIF++ (LNF, INFN-BO)



Not T/p correction



Currents quite constant during the operating time gates & no dark current observed when source is off

High Rate= 9.2 mC/cm²
Large Area= 1.95 mC/cm²
Reference= 0.43 mC/cm²

Conclusion

The **μ-RWELL is a compact, single-amplification stage, simple to assemble & suitable for large area, MPGD:**

- ✓ **gas gain > 10^4**
- ✓ **intrinsically spark protected**
- ✓ **rate capability > 1 MHz/cm^2 (HR version)**
- ✓ **space resolution < 60μm**
- ✓ **time resolution ~ 5.7 ns**
- ✓ **cost effective detector**

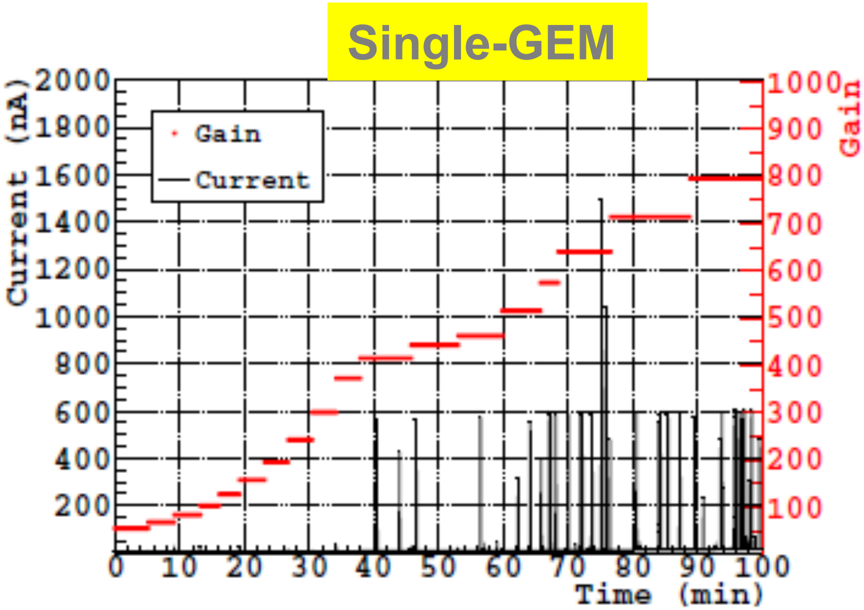
R&D/engineering in progress:

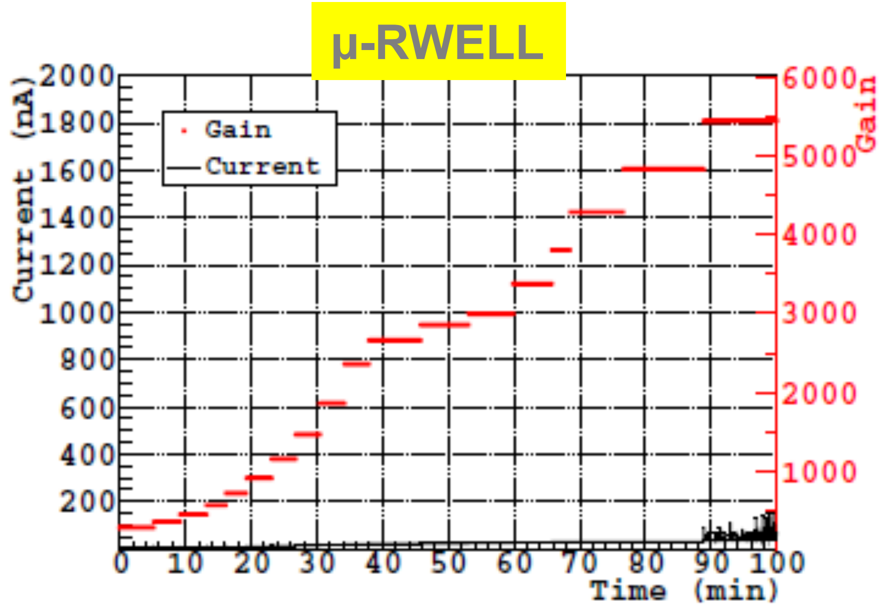
- **Low rate** (<100kHz/cm^2) :
  - small and large area prototypes built and extensively tested
  - a <u>well defined roadmap towards Technological Transfer to industry</u>
- **High rate** (>1 MHz/cm^2):
  - first prototypes show very promising performance
  - the engineering is going to be started

Spare slides

The μ-RWELL performance

Discharge study: μ-RWELL vs GEM





- discharges for μ-RWELL of the order of few tens of nA (<100 nA @ max gain)
- for GEM discharges the order of 1μA are observed at high gas gain

The µ-RWELL vs GEM

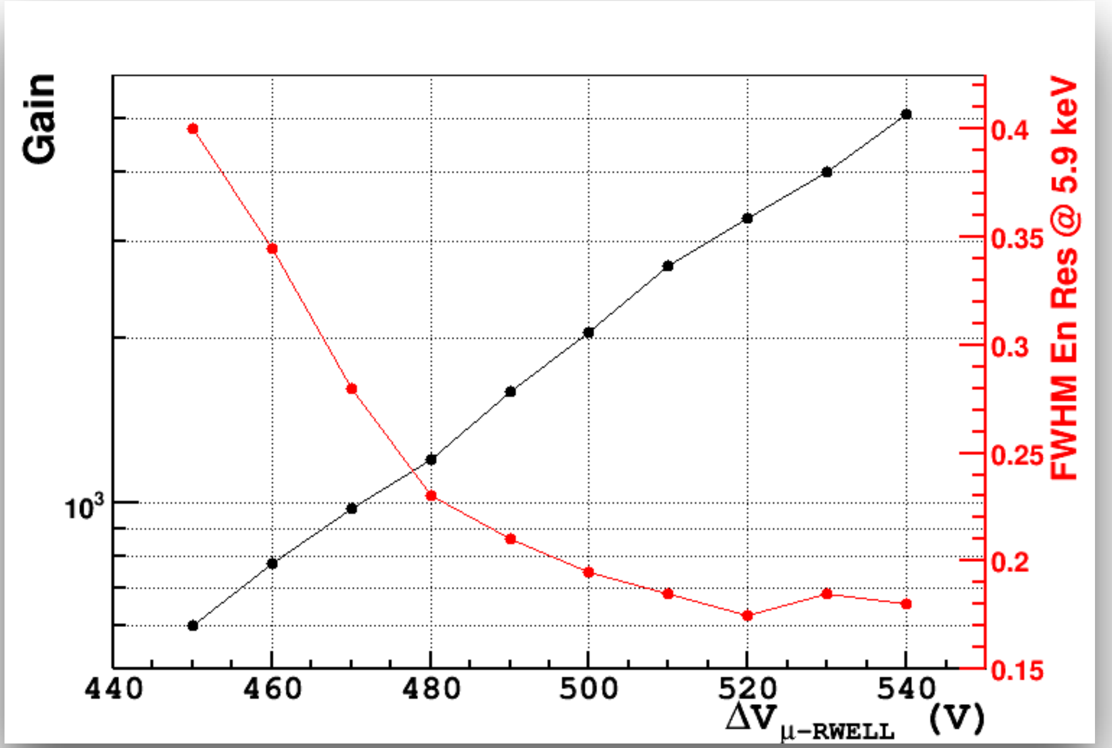
The µ-RWELL is expected to exhibit a gas gain larger than a single-GEM.

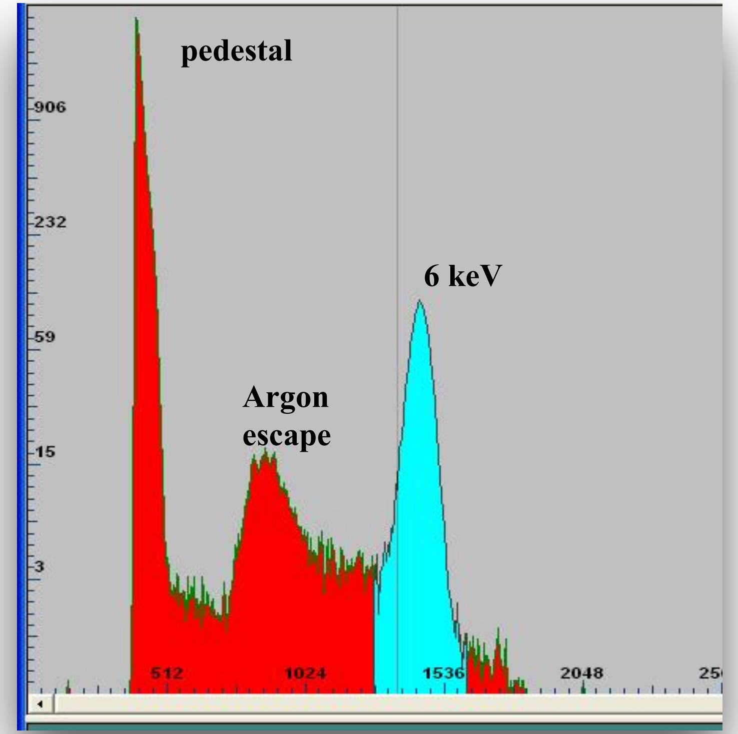
- Single-GEM:
  - only 50% of the electron charge produced into the hole contributes to the signal, the rest of the electron charge is collected by the bottom side of the GEM foil
  - the signal is mainly due to the electron motion, the ion component is largely shielded by the GEM foil itself

- µ-RWELL:
  - 100% electron charge produced into the amplification channel is promptly collected on the resistive layer
  - the ionic component, apart ballistic effects, contributes to the formation of the signal
  - further increase of the gain achieved thanks to the resistive electrode which, quenching the discharges, allows to reach higher amplification field inside the channel

μ-RWELL: Energy Resolution

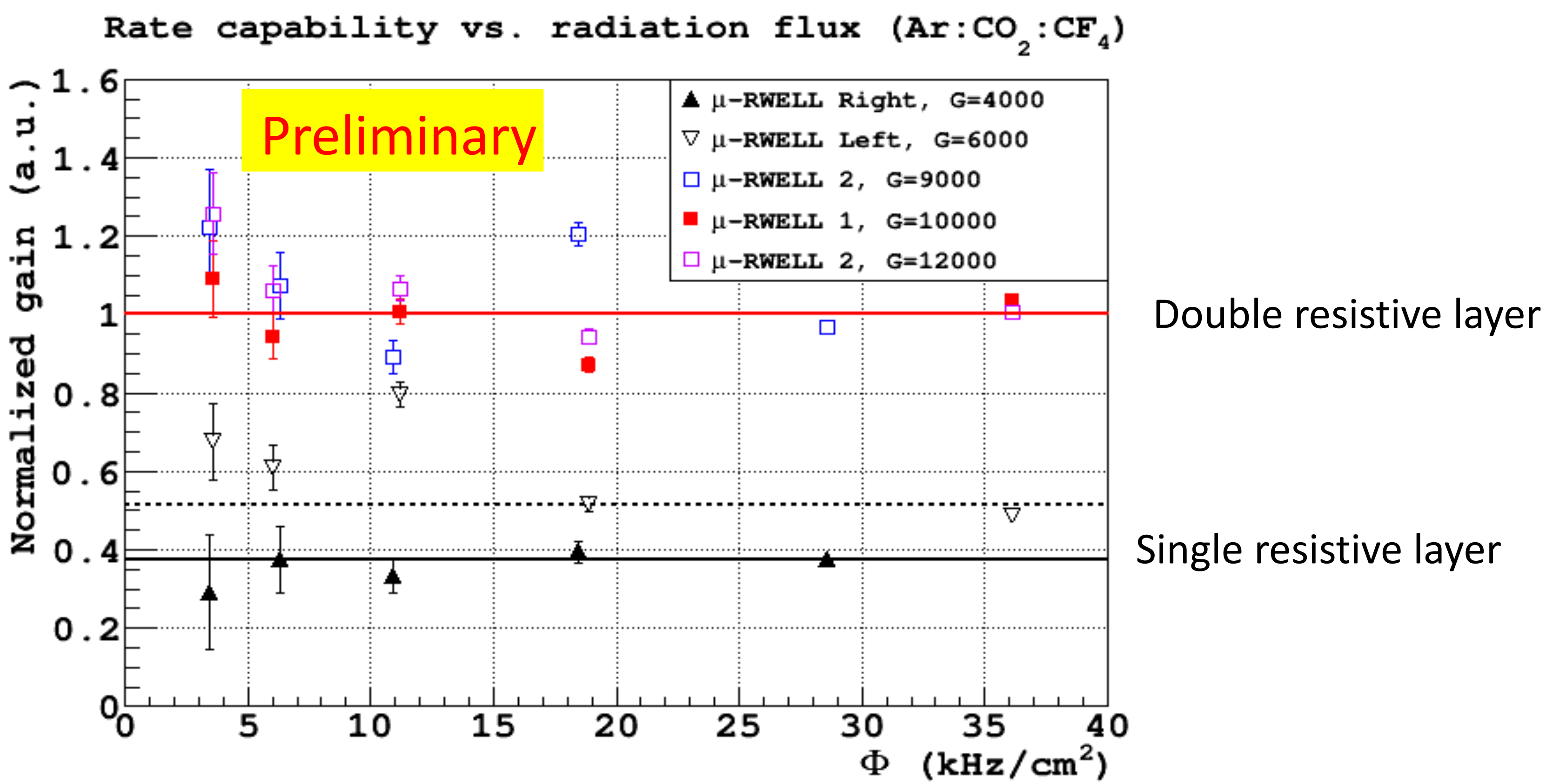
The prototype of μ-RWELL (100 MΩ/□) has been tested with X-rays tube (6keV) (Ar/CO2=70/30) & the signal has been readout vith an ORTEC amplifier





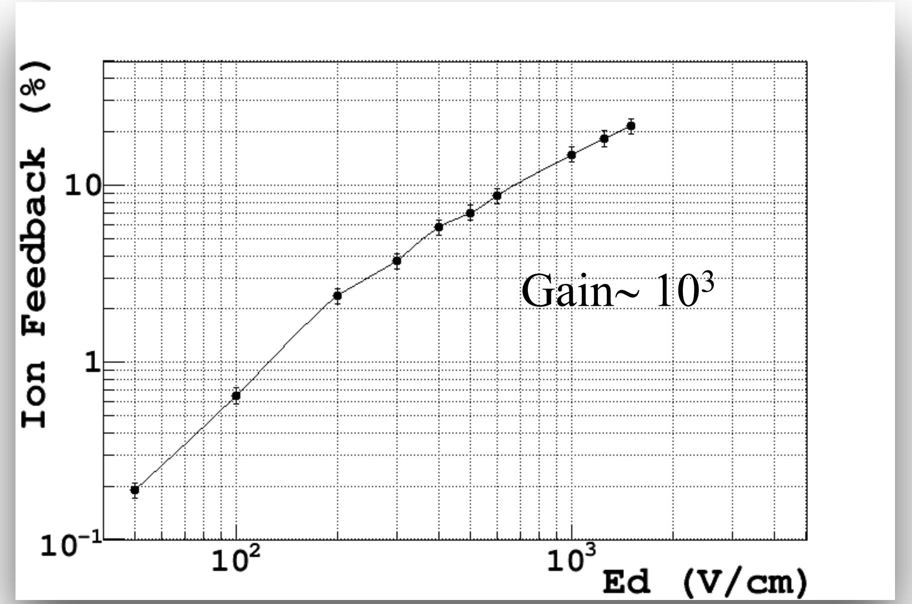
Performance vs Rate

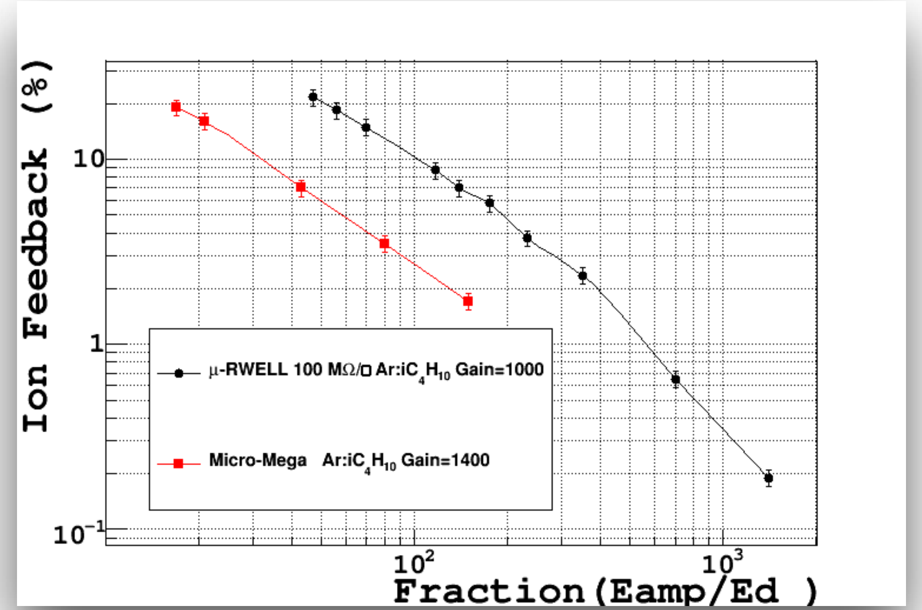
The detector rate capability (with Ed=3,5 kV/cm) has been measured in current mode with a pion beam and irradiating an area of ~ 3 x 3 cm^2 (FWHM)



μ-RWELL: Ion Feed-Back measurement

The prototype of μ-RWELL (100 MΩ/□) has been tested in current mode with X-rays tube (6keV) (Ar/ISO=90/10)



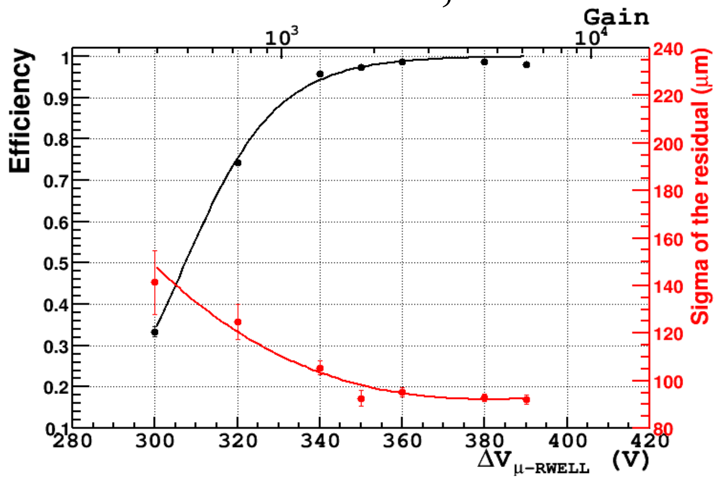


MM IBF measurement: NIMA 535 (2004) 226

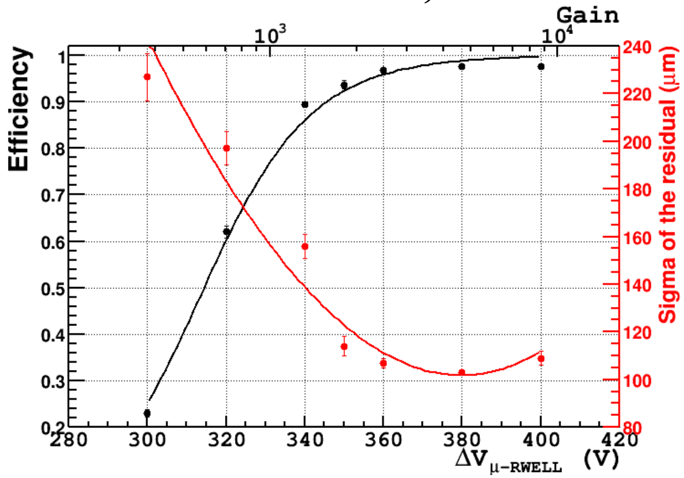
μ-RWELL: B≠0 with Ar/ISO=90/10

CC analisys

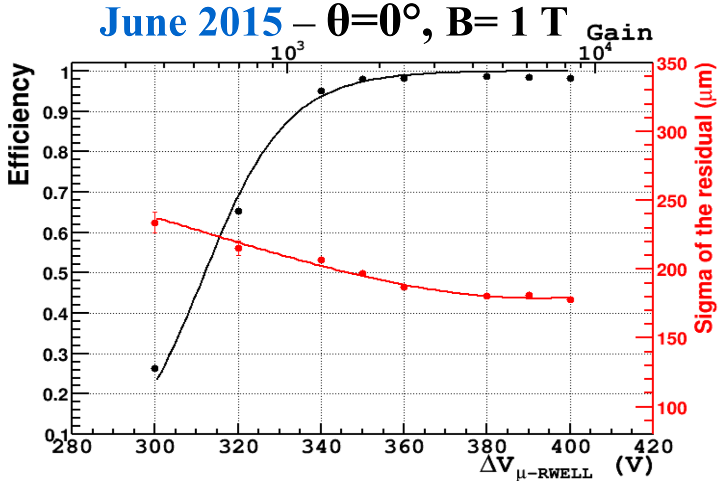
June 2015 – θ=0°, B= 0 T



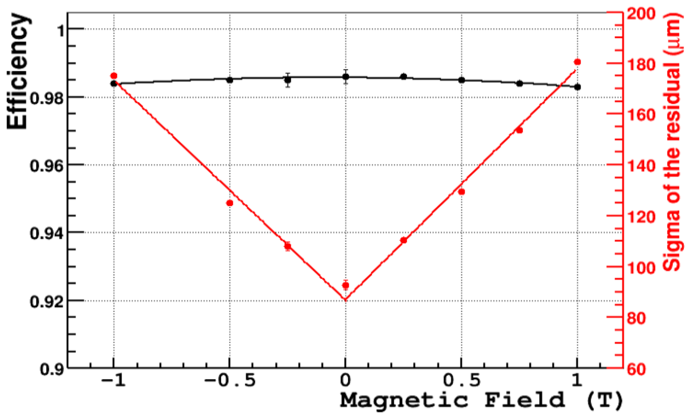
Dec 2014 – θ=0°, B= 0.5 T



June 2015 – θ=0°, B= 1 T



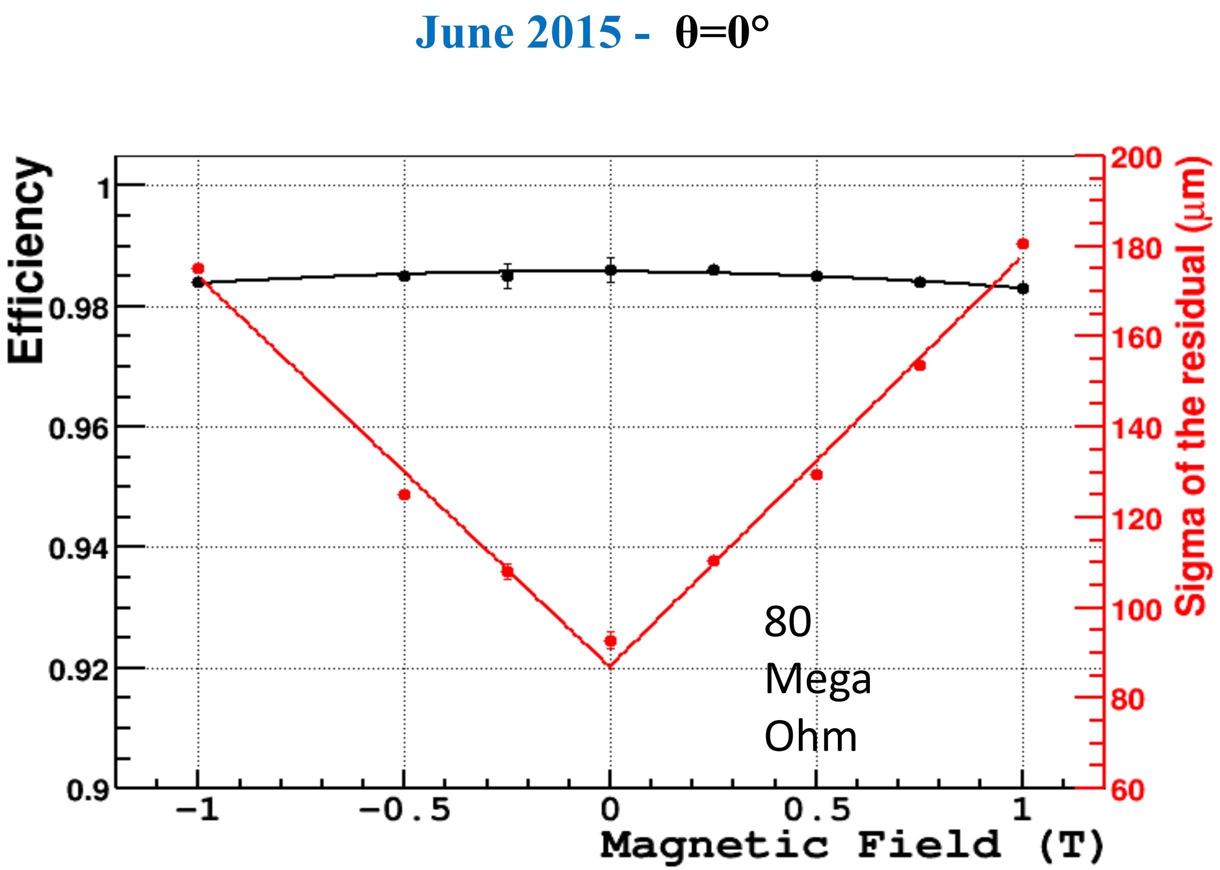
June 2015 - θ=0°



For **θ=0° and 0 < B < 1 T** → **σ < 180 μm** and **ε > 98%**

µ-RWELL: B≠0 with Ar/ISO=90/10

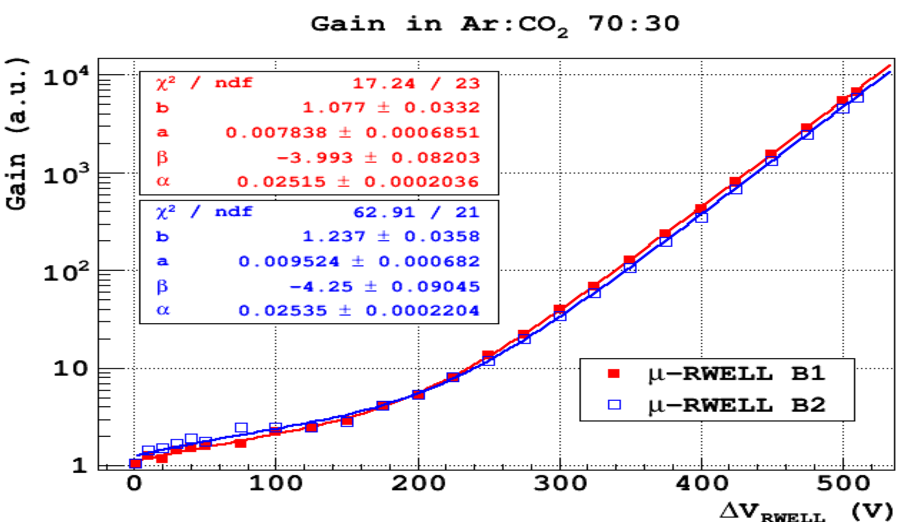
CC analisys

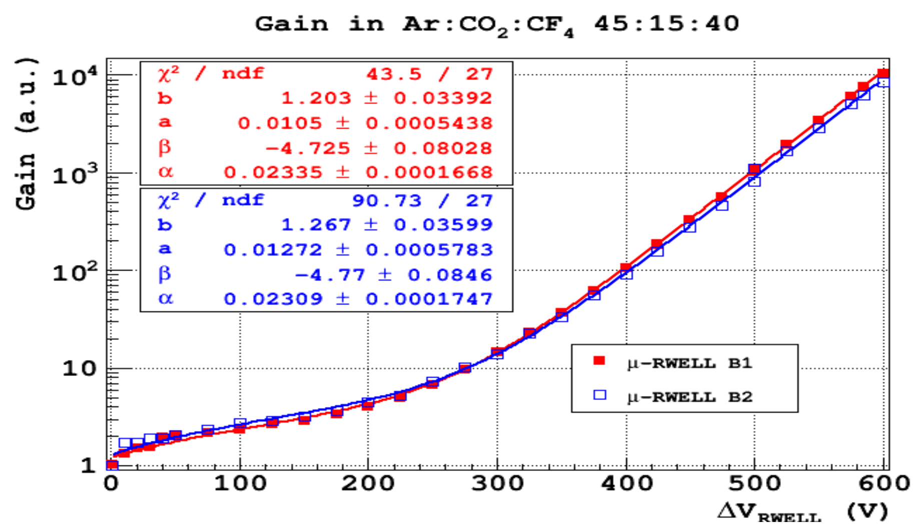


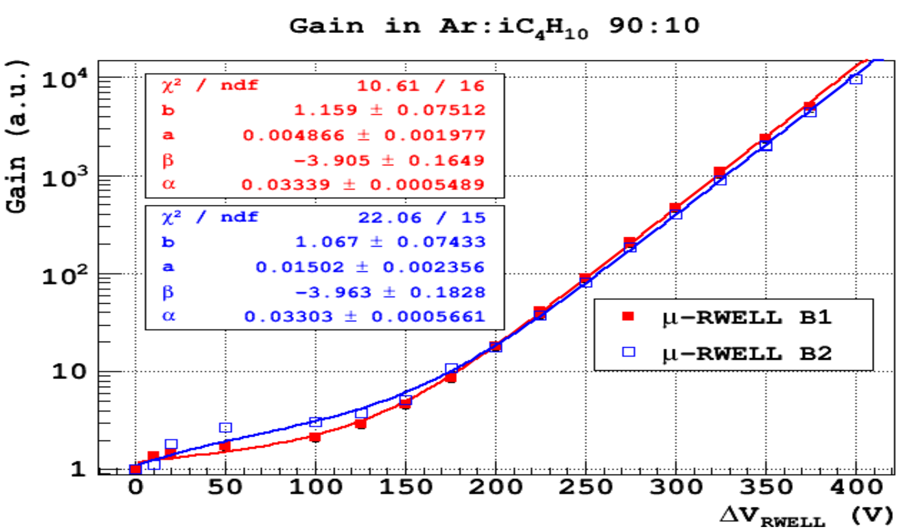
For **$\theta=0°$ and $0 < B < 1$ T** → **$\sigma < 180$ µm** and **$\varepsilon > 98\%$**

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 5.9 keV X-rays **(local irradiation)**.



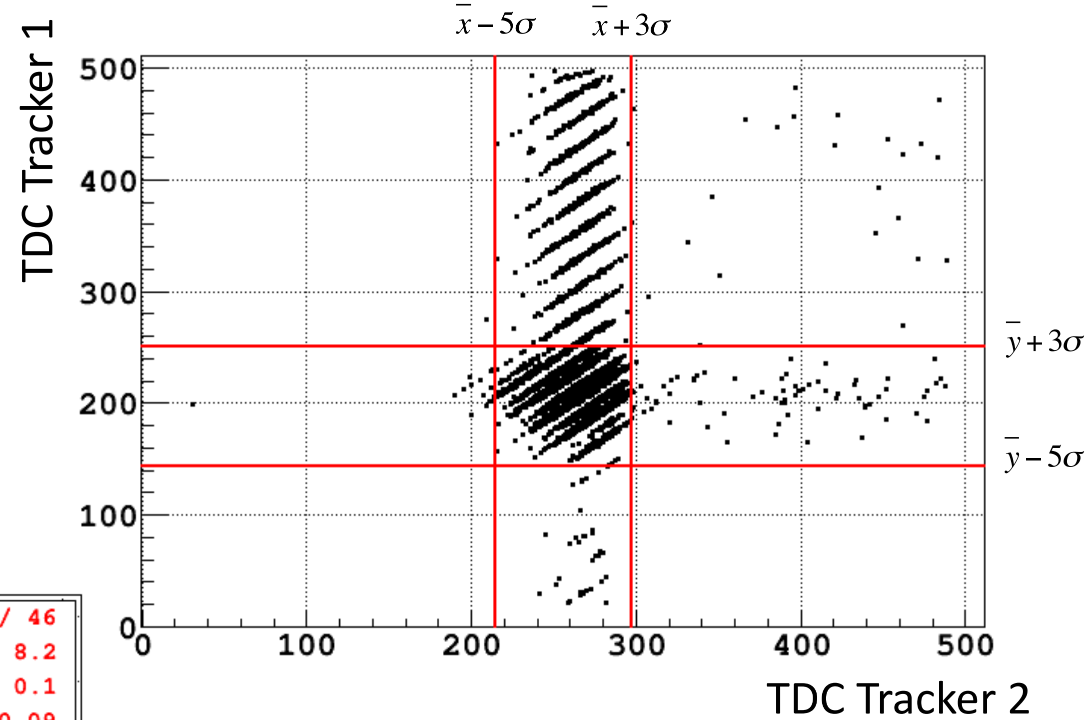


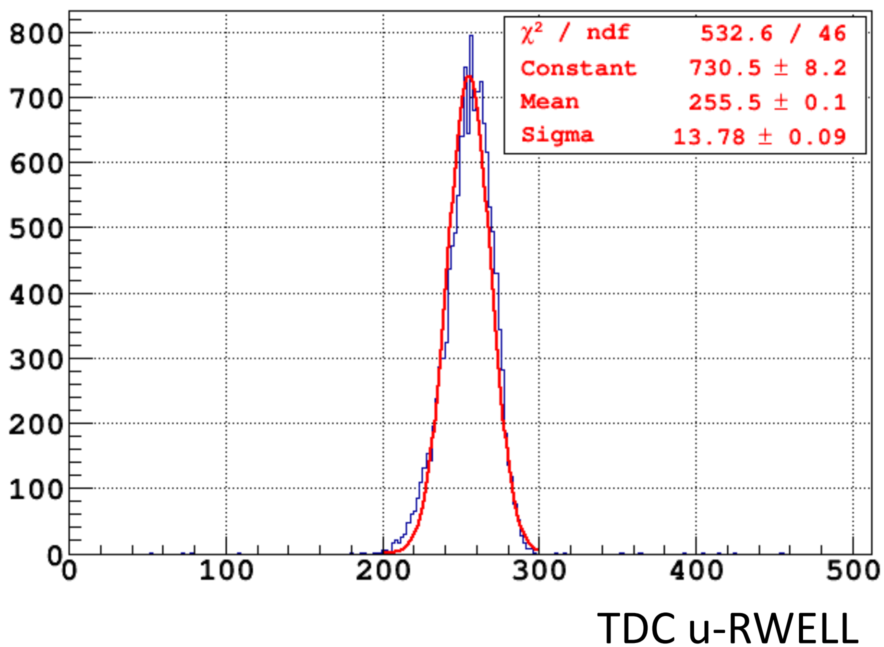


Measurement performed in current mode.
Gain measured up to 10000.
Similar behavior for the two chambers.

Efficiency & time resolution measurement

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



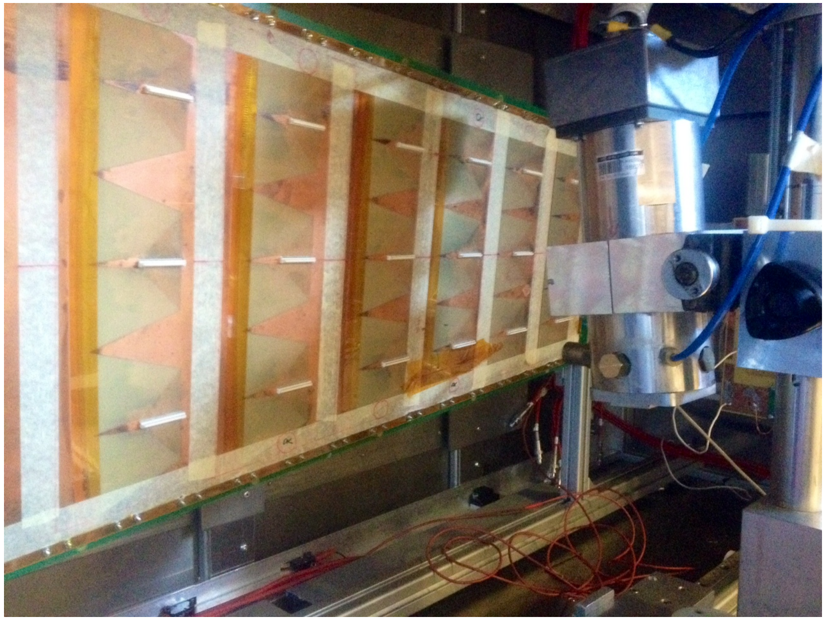


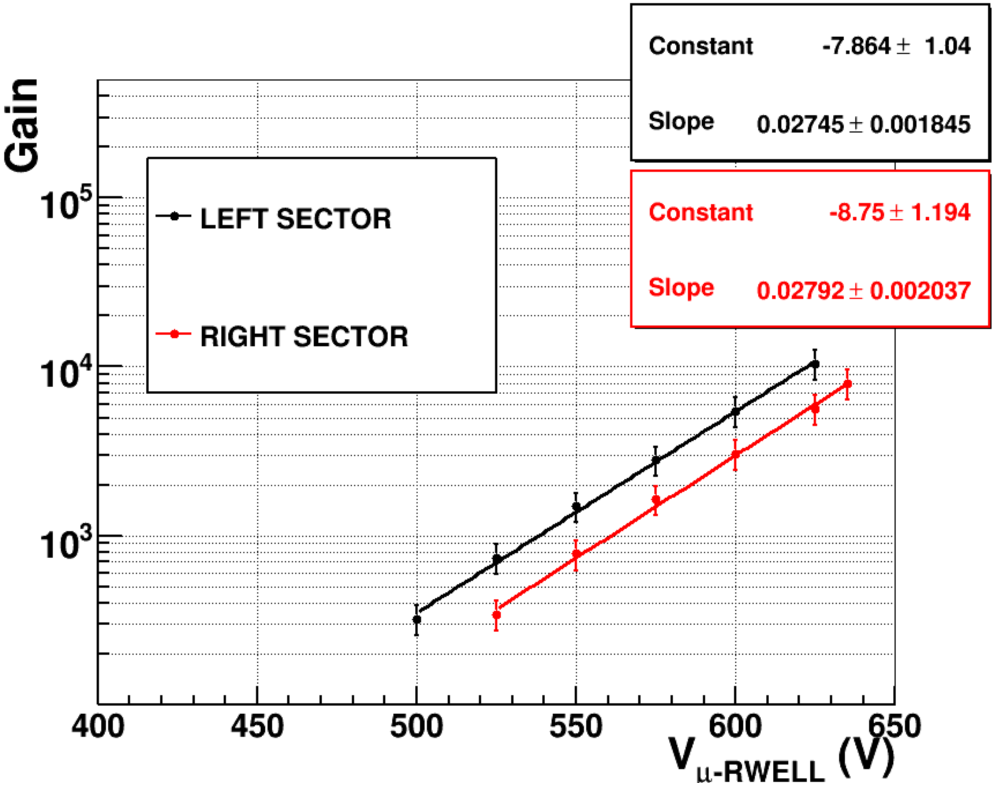
The TDC distribution is then fitted with a simple gaussian and the sigma is then **deconvoluted** by the contribution of the VFAT.

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

Detector Gain (large area)

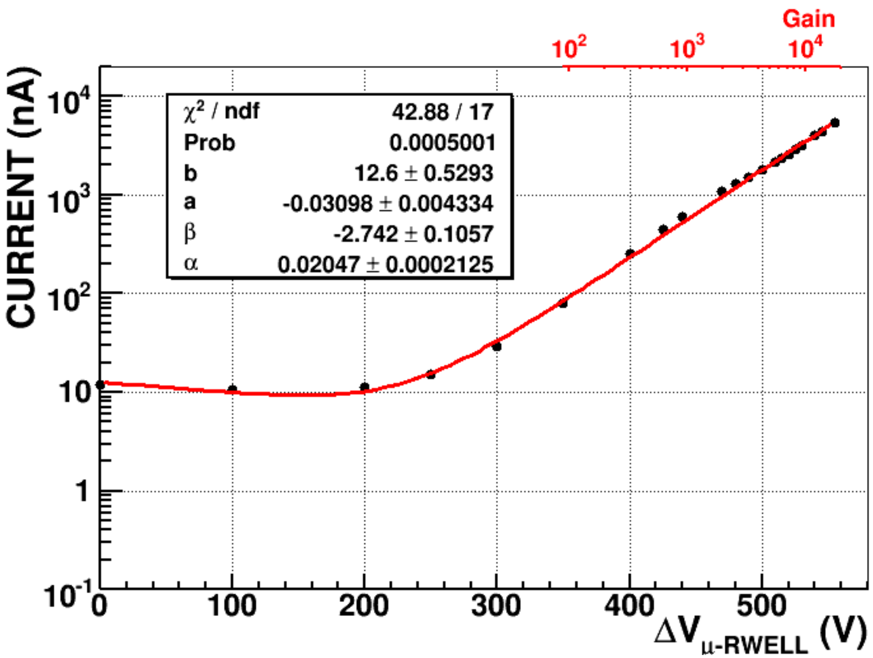
The prototype has been characterized by measuring the **gas gain, rate capability** in **current mode** with an **5.9 keV X-rays (local irradiation, ~1cm^2 spot)**.

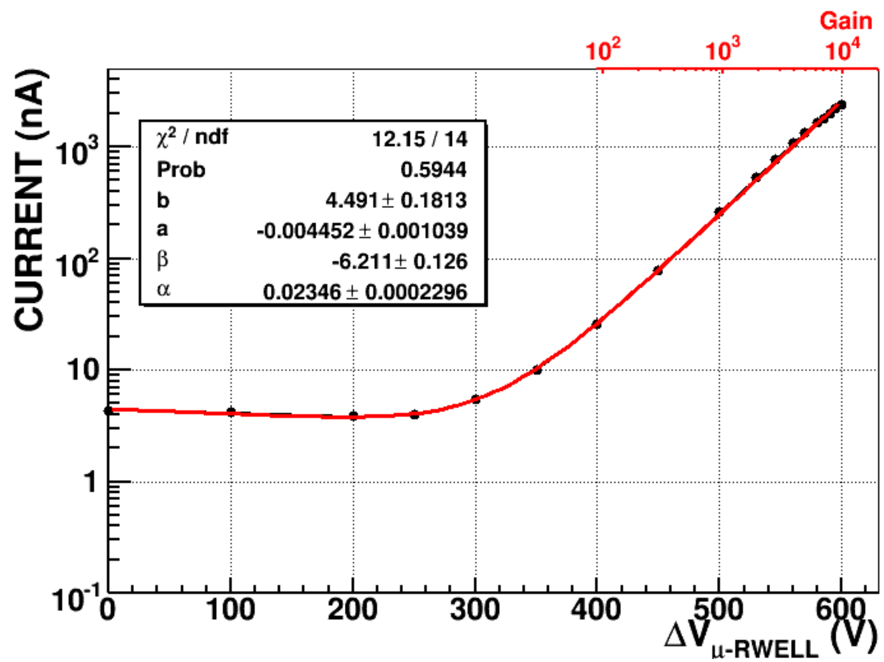




A shift of ~ 25 V has been measured between the two sectors probably due to the different geometry of the amplification stage (to be confirmed with microscope check – left/right asymmetry)

Ageing test: GIF++





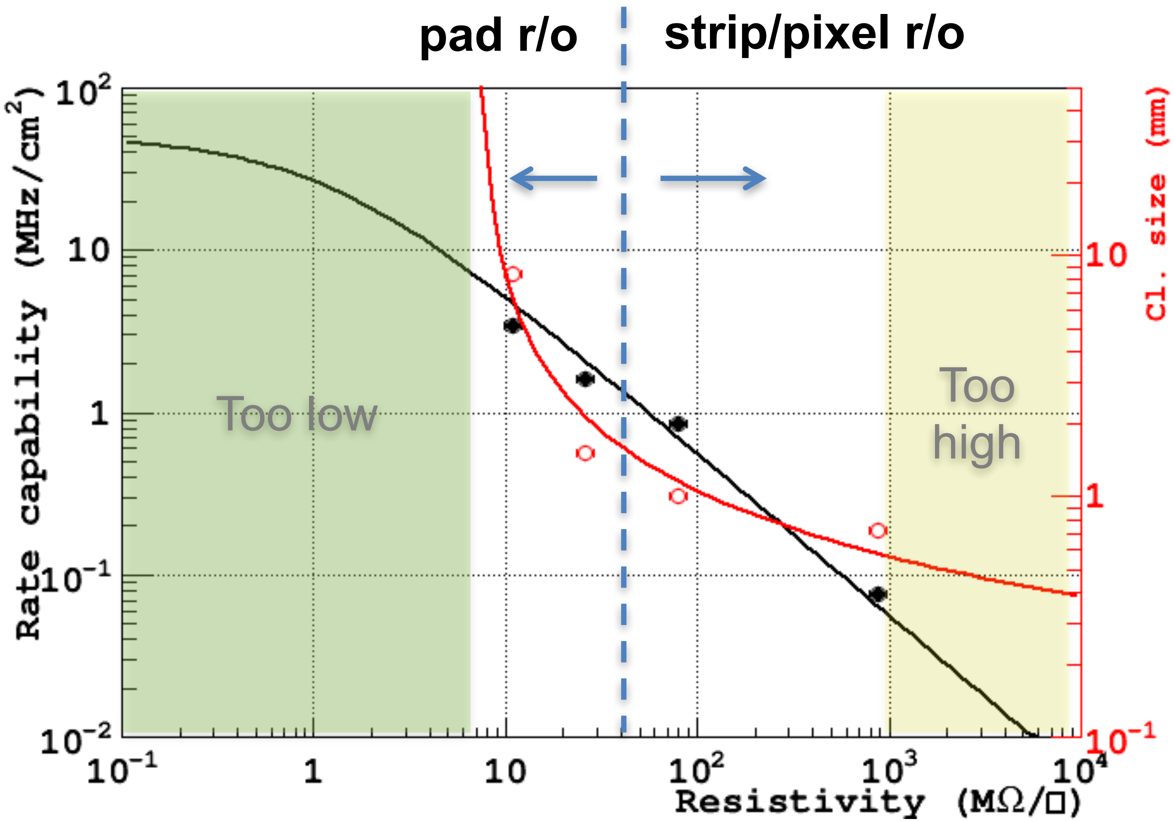
GE1/1 CMS chamber operation stability up to gain = 20 000 ↔ ΔV = 550 V

I(g=4000) ~ 5 nA/cm2 corresponding to an **equivalent mip rate of ~ 60-90 kHz/cm2** evaluated on sectors #3

High Rate chamber operation stability up to gain = 10 000 ↔ ΔV = 600 V

I(g=4000)~ 10 nA/cm2 corresponding to an **equivalent mip rate of ~ 250 kHz/cm2**

Detector scheme vs particle flux

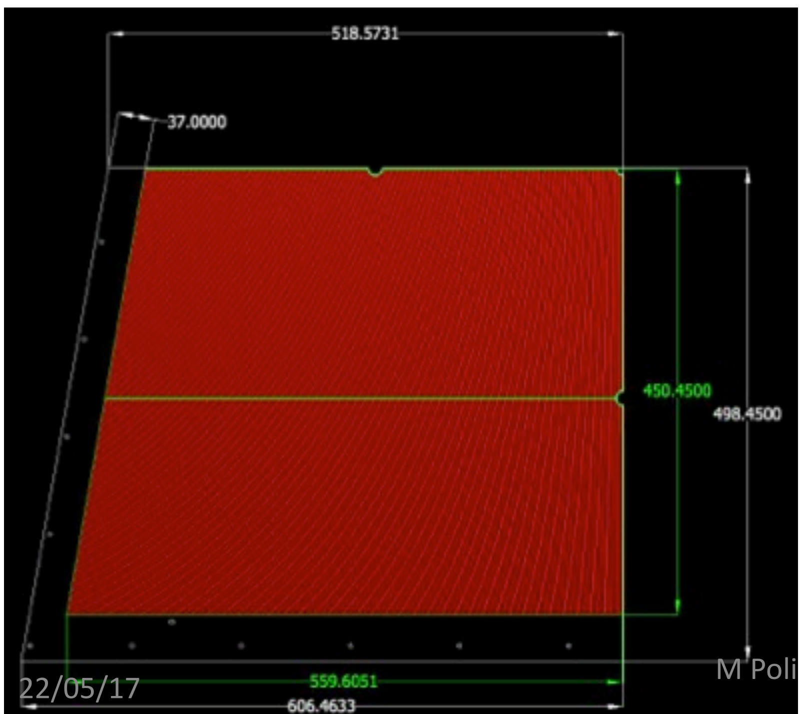


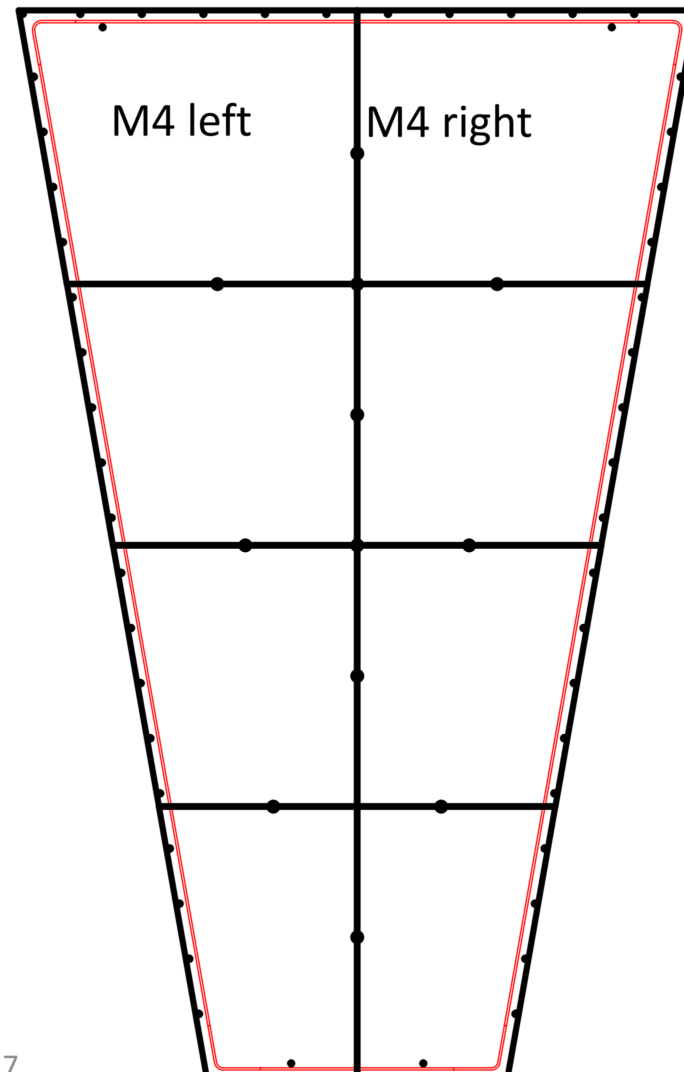
<u>Qualitatively</u>: low resistivity → pad r/out & higher rate
high resistivity → strip/pixel r/out & lower rate

GE2/1 u-RWELL preparation

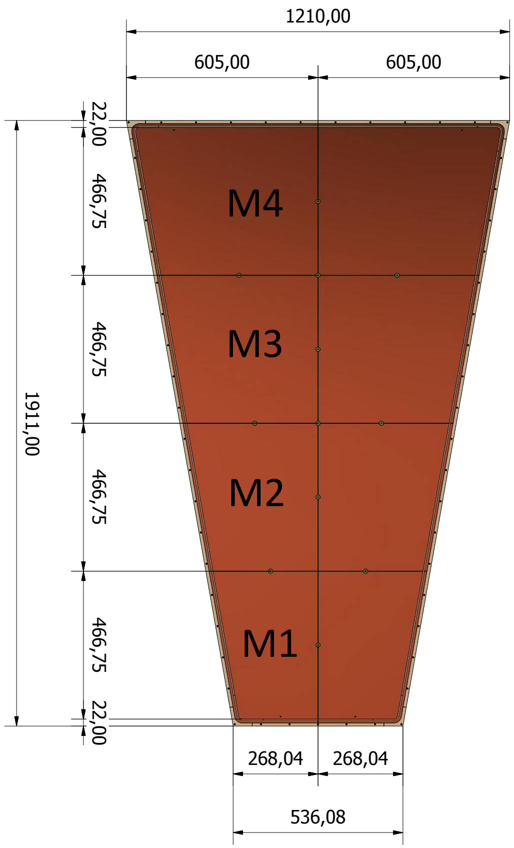
Once validated the mechanics, the plan is to build a full scale GE2/1 μ-RWELL with M4 operating sectors.

1) M4 left and right are mirrored.
2) Size: 606.5 x 498.5 x 1 mm
3) Strip layout inspired to the GE2/1 GEM option
4) Final drawing ongoing (Gatta-LNF)
5) DLCed foils almost ready (Ochi-Kobe)
6) Preliminary tests at ELTOS done

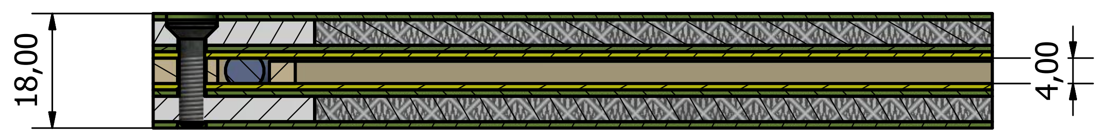




GE2/1 μ-RWELL: mechanical studies

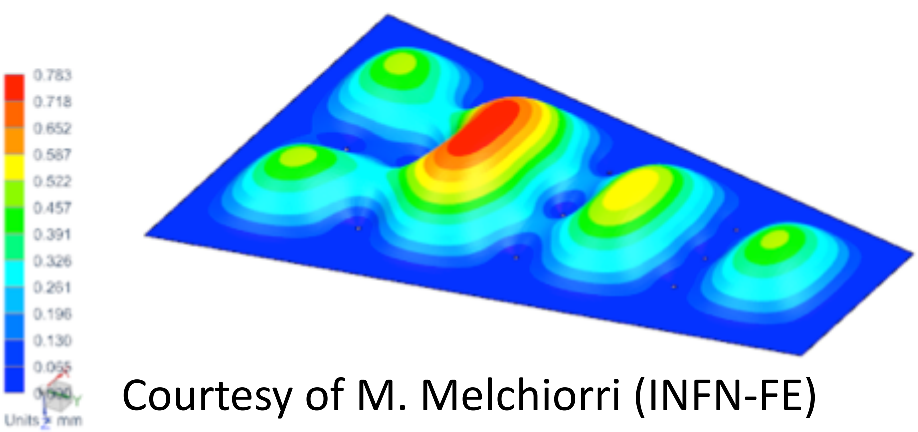


A very large μ-RWELL with the dimensions close to the GE2/1 chamber is going to be realized at LNF, in collaboration with INFN-BA and INFN-BO with M4 operating detectors.
The dimensions of the chamber suggest preliminary studies on the mechanical aspect of the project.



The active volume is limited by two honeycombed panels, which composition has been validated by ANSYS simulations.

The largest deformation (0.78 mm) at 8 mbar has been obtained with 3 mm thick honeycomb glued between two 1 mm thick fiberglass skins with the presence of 10 pillars.



Courtesy of M. Melchiorri (INFN-FE)

After these results:

- the thickness of the honeycomb increased up to 4 mm
- the number of pillars in the active volume increased to 12
- **Expected maximum deformation: < 0.2 mm per panel (5 mbar) → < 10% on conversion drift gap**