The μ-RWELL (13.2.4) and Tools for its large scale implementation (13.4.5)

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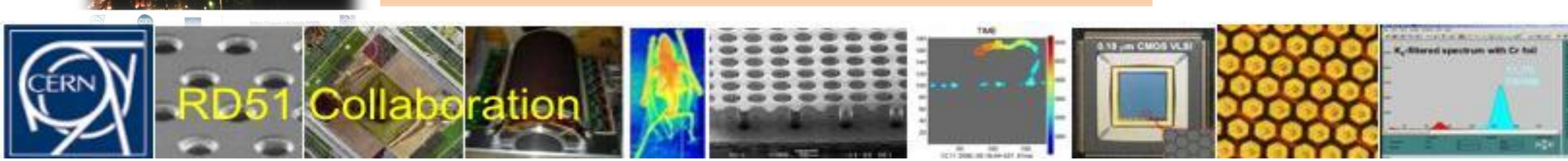


WP 13.2.4: the μ-RWELL detector

Motivation

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

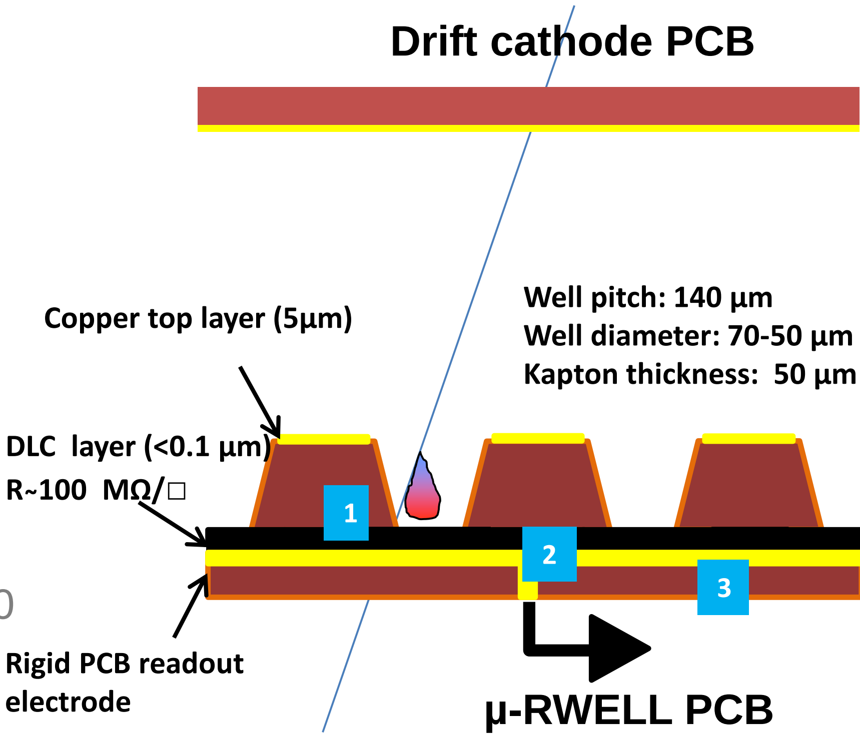
The detector architecture

G. Bencivenni et al., 2015_JINST_10_P02008

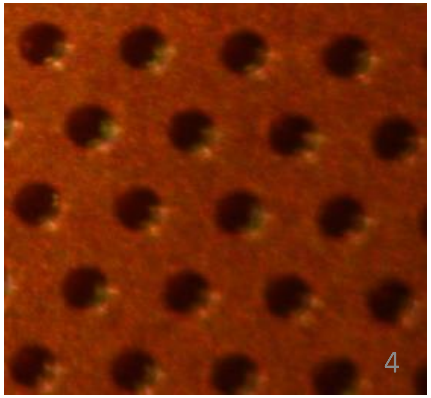
The **μ-RWELL is composed of** only **two elements**:
the **μ-RWELL_PCB** and the **cathode**

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**

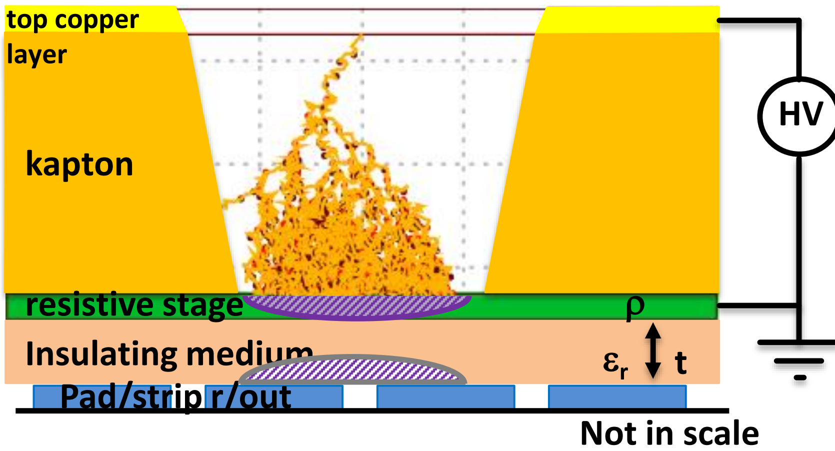


(*) DLC = Diamond Like Carbon
High mechanical & chemical resistant material



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 pad 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)

μ-RWELL: the AIDA program (2016/17)

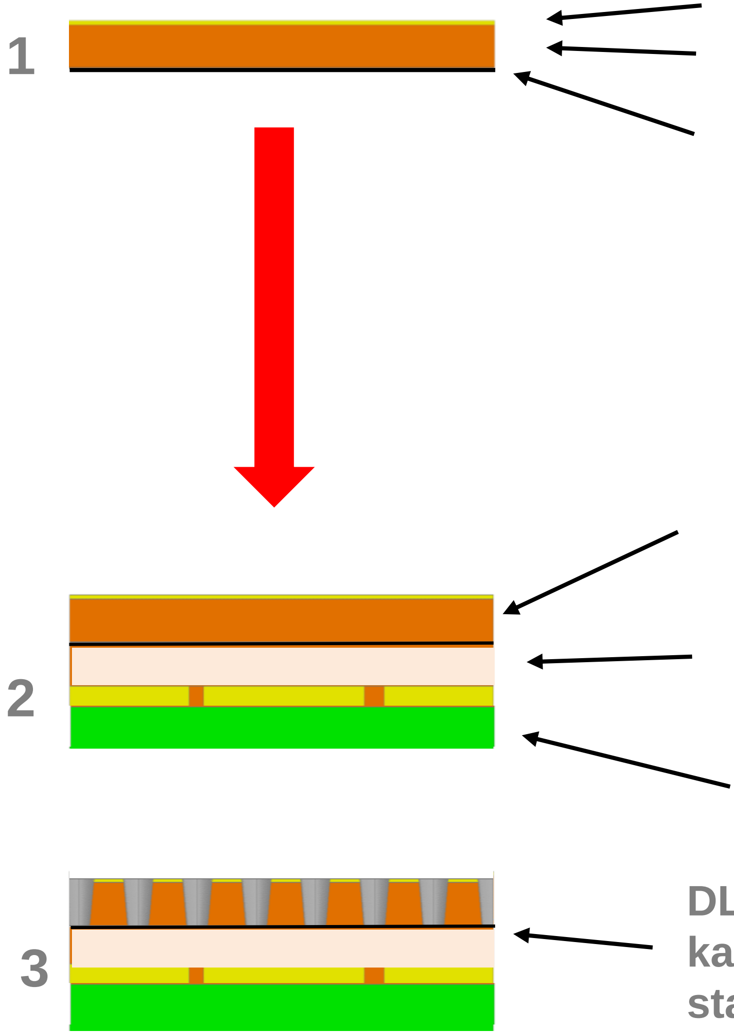
1. Optimization of the detector parameters:

    i. surface resistivity *vs* gain, rate capability, charge spread, space resolution (completed – paper to be submitted)

    ii. study & implementation of the resistive layer segmentation *vs* rate capability (completed - paper to be written)

Work to be done in the first 24 months (M24) of the project

The Low Rate 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)

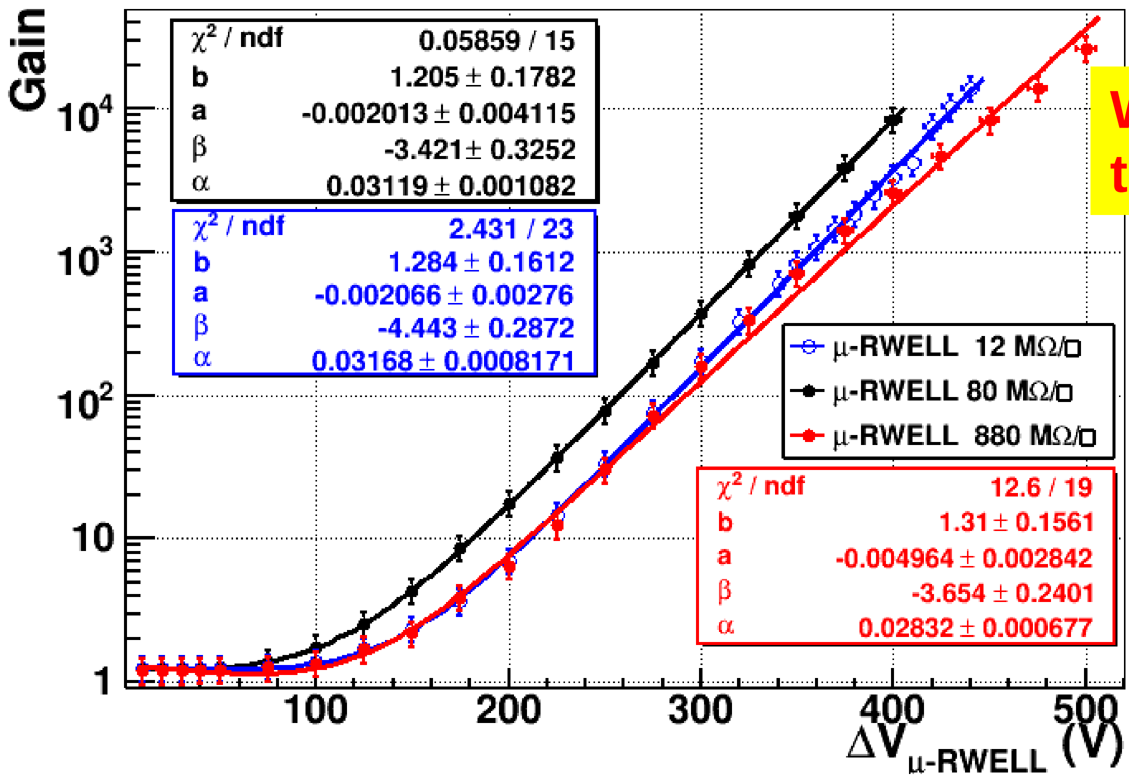
DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)

Detector performance: Lab Tests

Detector Gain

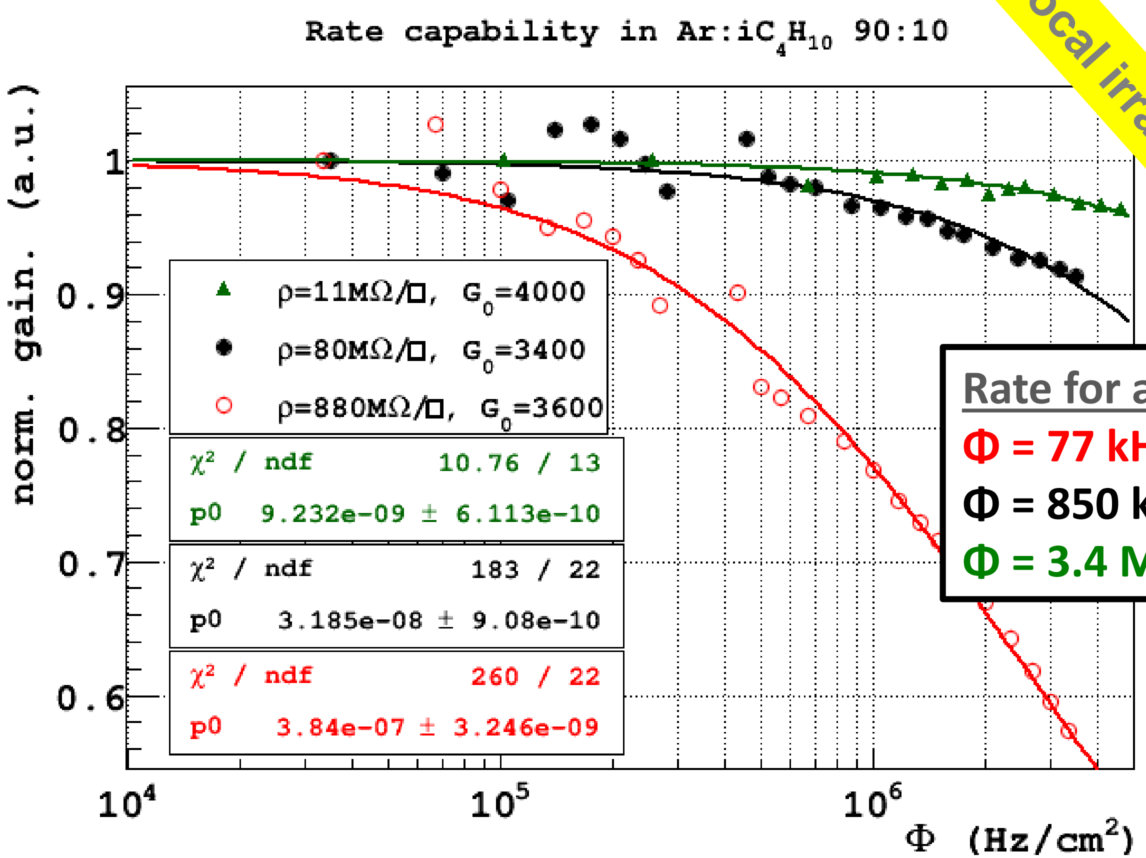
Prototypes with different resistivity (12-80-880 MΩ/☐) have been tested with **X-Rays** (5.9 keV), with different gas mixtures, and characterized by measuring the **gas gain** in **current mode**.

Ar/iC_4H_{10}= 90/10



WELL kapton thickness = 50µm

Rate capability with X-rays (single layer)



Rate for a drop ΔG = -3%

Φ = 77 kHz/cm² - 880 MΩ/□

Φ = 850 kHz/cm² - 80 MΩ/□

Φ = 3.4 MHz/cm² - 11 MΩ/□

for m.i.p. × 7

The **gain decrease** is correlated with the **voltage drop** due to the **resistive layer: larger the resistivity lower the rate capability.**

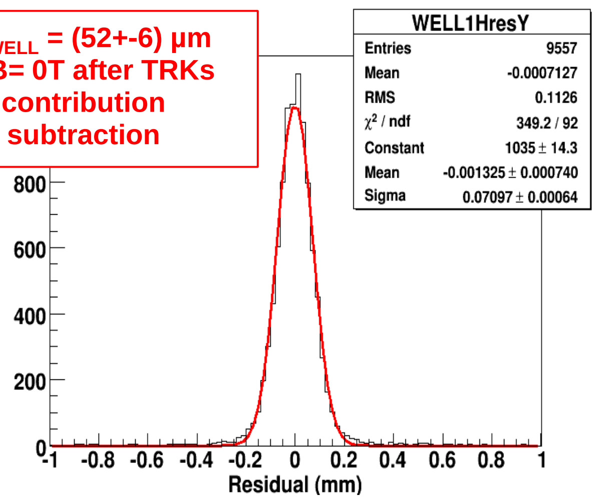
local irradiation ≠ global irradiation

Detector performance: Beam Tests

Beam tests results

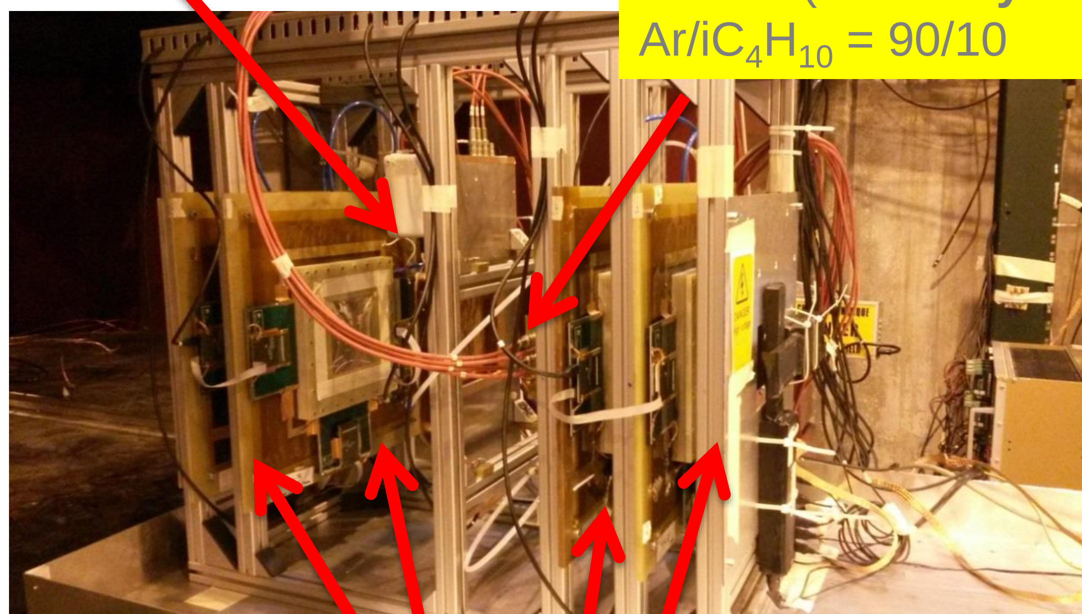
H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

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



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

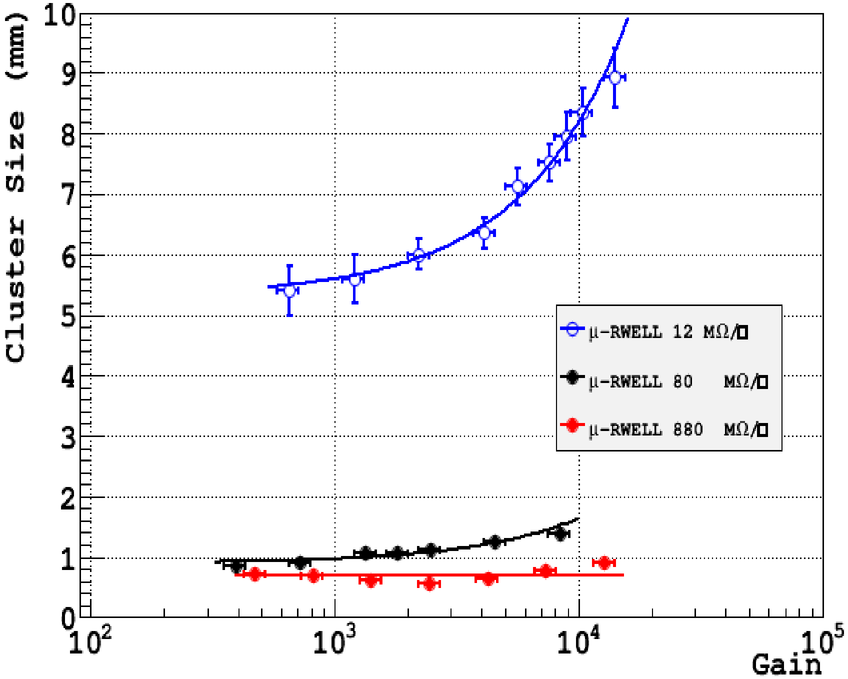
BES III-GEM chambers

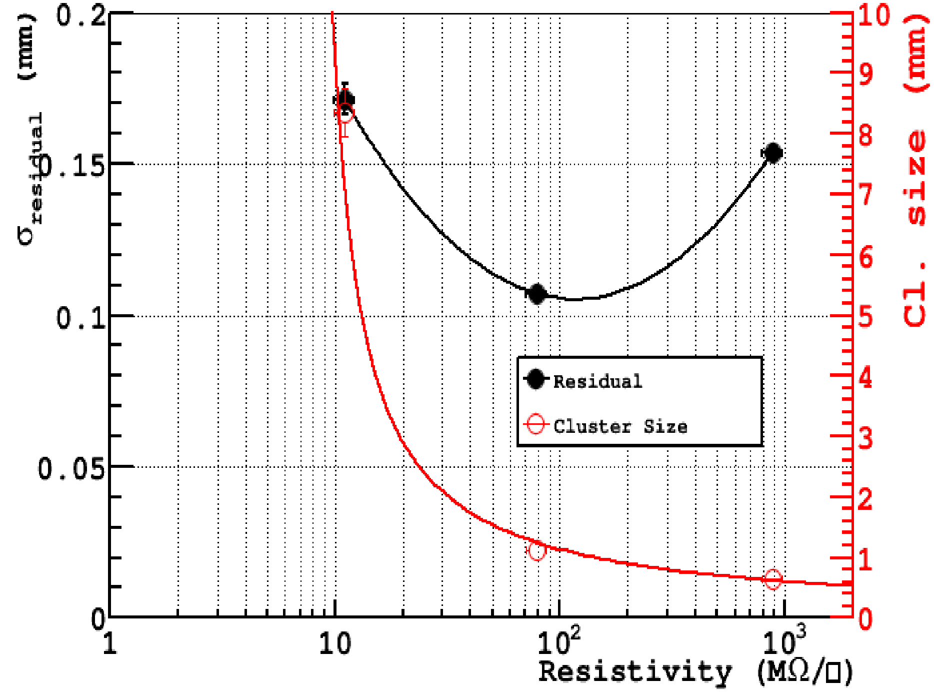


GEMs Trackers

Space resolution *vs* resistivity

CC analysis





The "**space resolution**" *(<u>σ of the residual</u> – no subtraction of the external trackers contribution*) exhibits a **minimum around 100MΩ/□.**

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

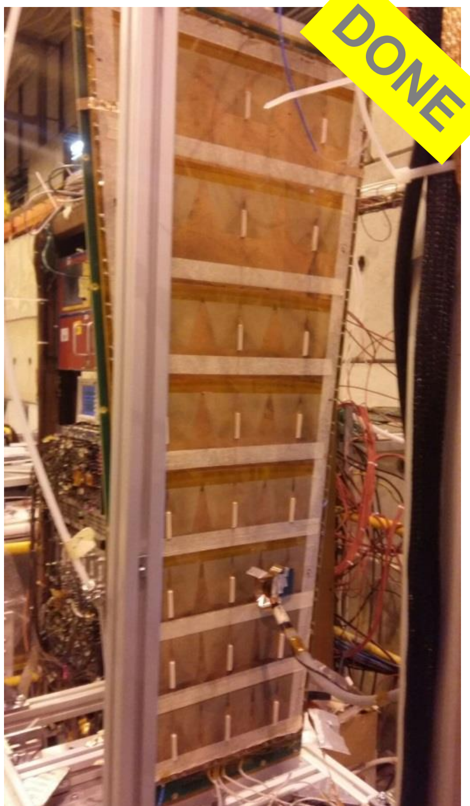
➔ at **high resistivity** the **charge spread is too small (Cl_size ➔ 1 fired strip)** then the Charge Centroid method becomes no more effective **(σ ➔ pitch/√12)**

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:

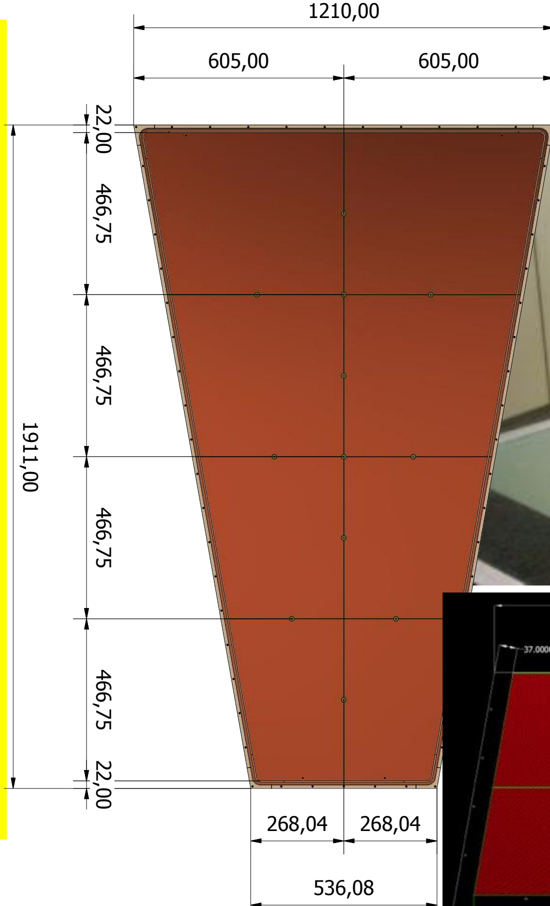
1. **Construction & test of the first 1.2x0.5m^2 (GE1/1) μ-RWELL 2016 - DONE**
2. **Mechanical study and mock-up of 1.8x1.2 m^2 (GE2/1) μ-RWELL 2017 - DONE**
3. Construction of the first **1.8x1.2m^2 (GE2/1) μ-RWELL (only M4 active) > 2018**

~40 times larger than small protos !!!



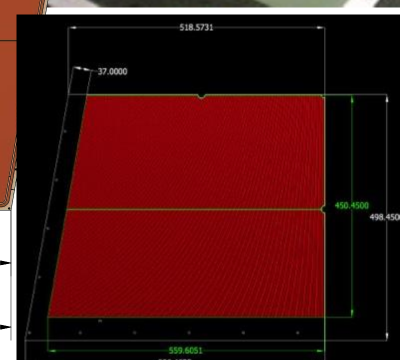
DONE

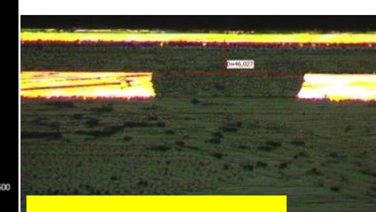
~200 times larger than small protos !!!



1.8x1.2m^2 (GE2/1) μ-RWELL

mock-up

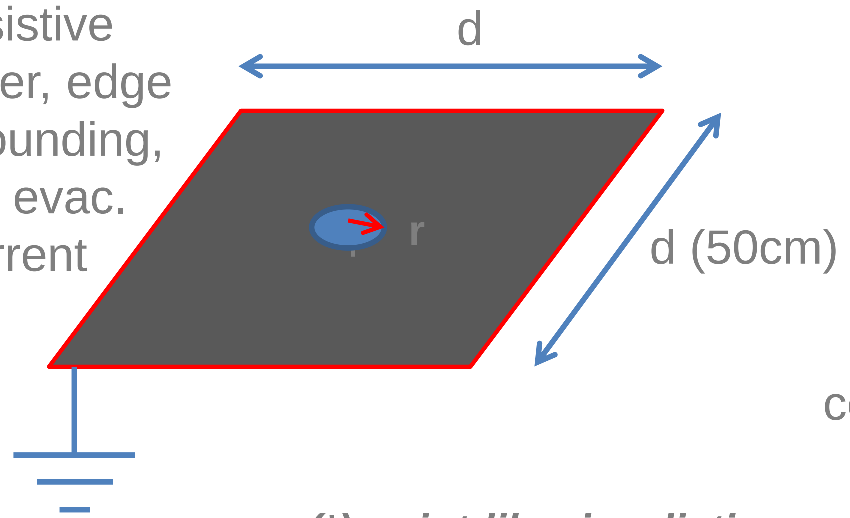




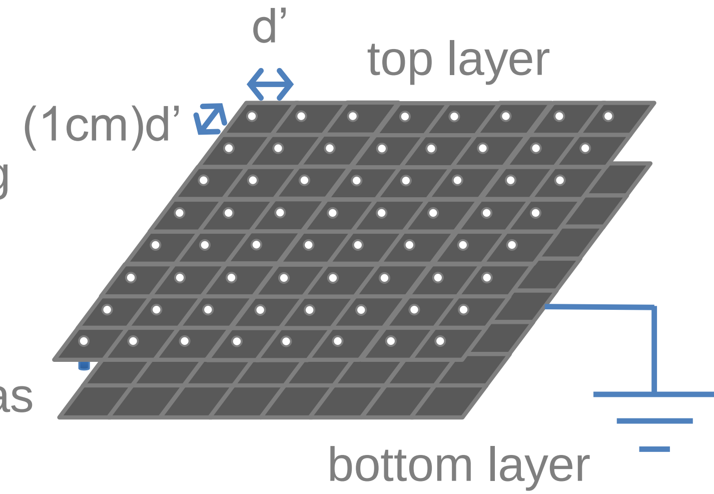
ELTOS tests

Towards a 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

$$\Omega \sim \rho_s \text{ x } d/2\pi r \qquad\qquad \Omega' \sim \rho_s' \text{ x } 3d'/2\pi r$$

$$\Omega / \Omega' \sim (\rho_s / \rho_s') \text{ x } d/3d'$$

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

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

The High Rate scheme (LHCb)

1

Copper layer 5 μm

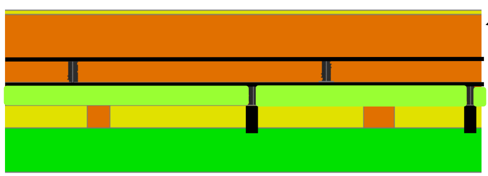
Kapton layer 50 μm

DLC layer: 0.1 – 0.2 μm
(10-200 MΩ/☐)

2

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

3



DLC-coated kapton base material

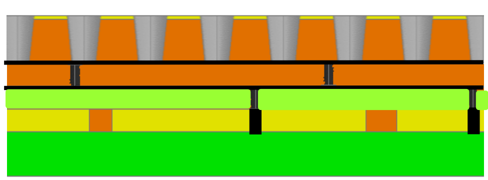
2^{nd} resistive kapton layer

insulating layer

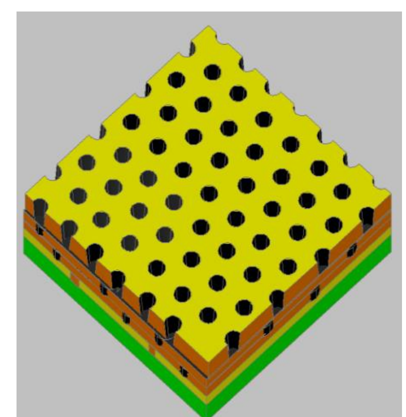
pad/strips readout on standard PCB

"through vias" for grounding

4

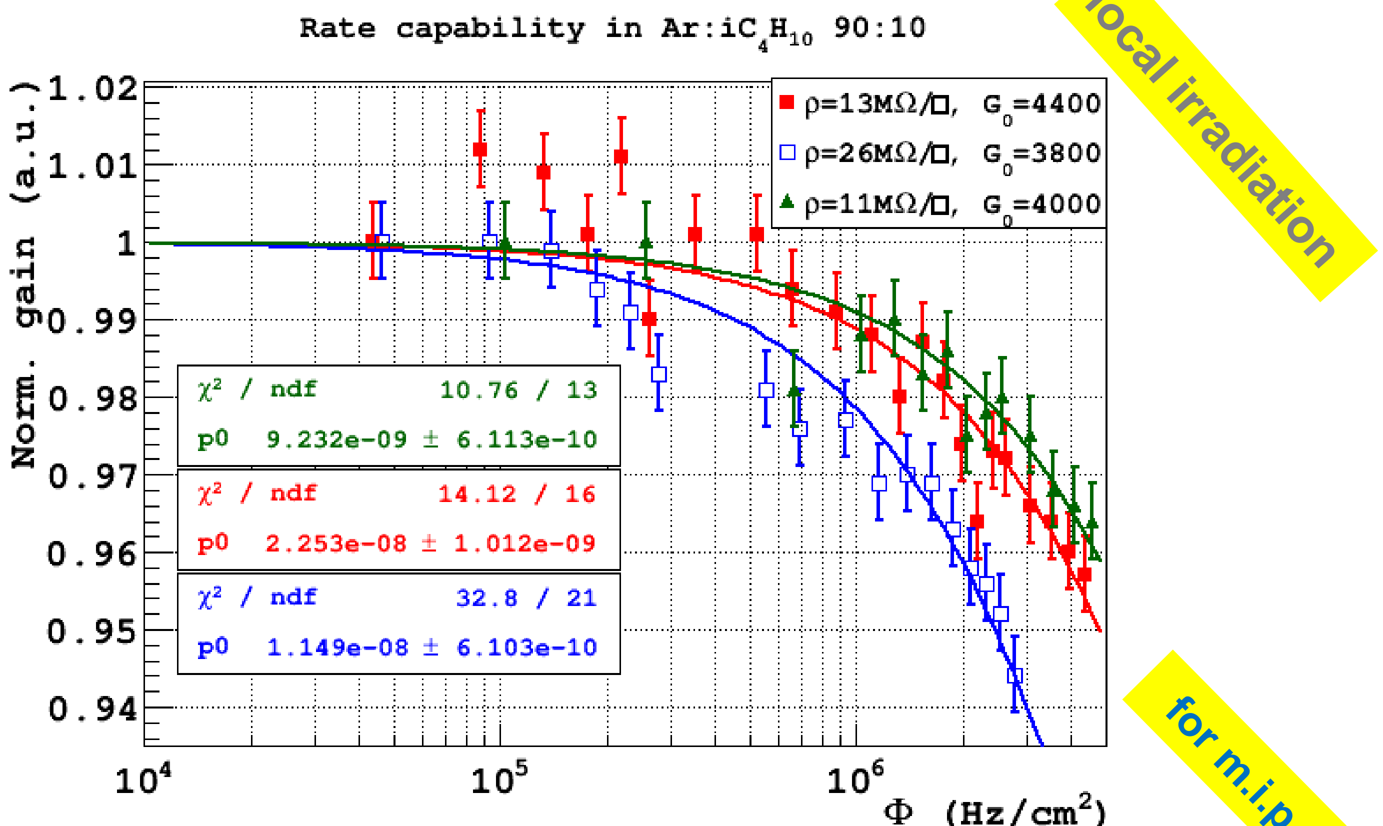


DLC-coated base material after copper and kapton chemical etching (WELL amplification stage) →



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

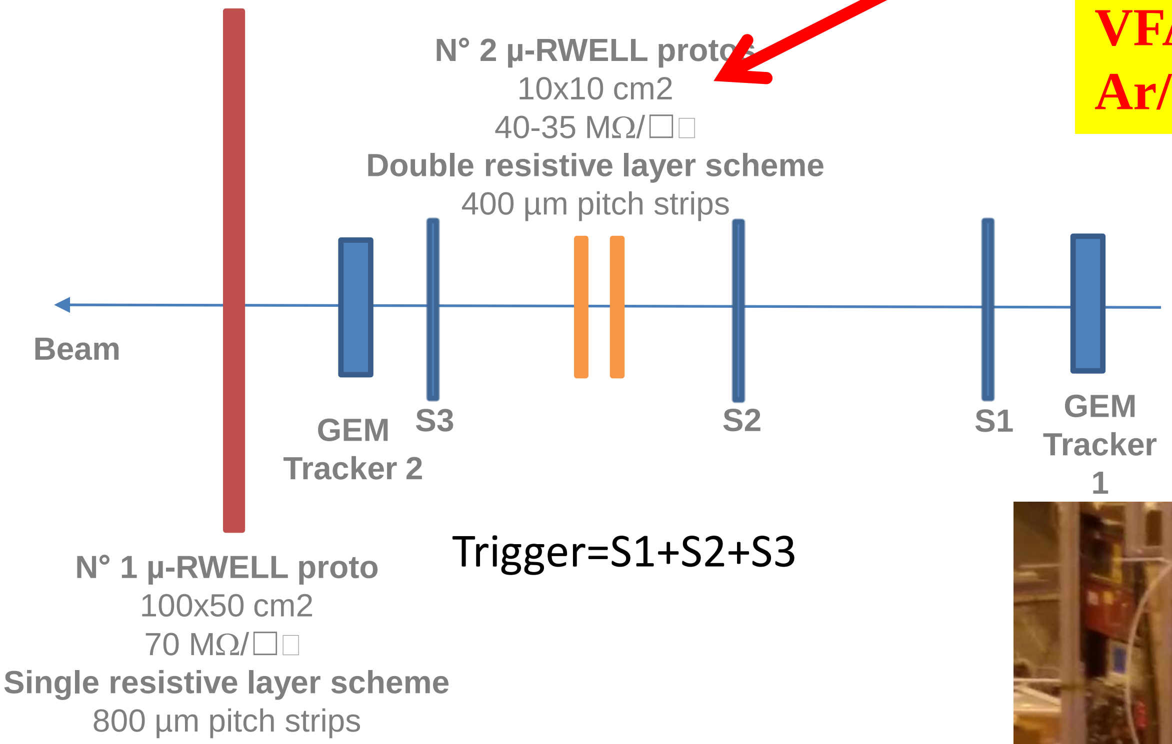
Local irradiation is practically equivalent to global irradiation

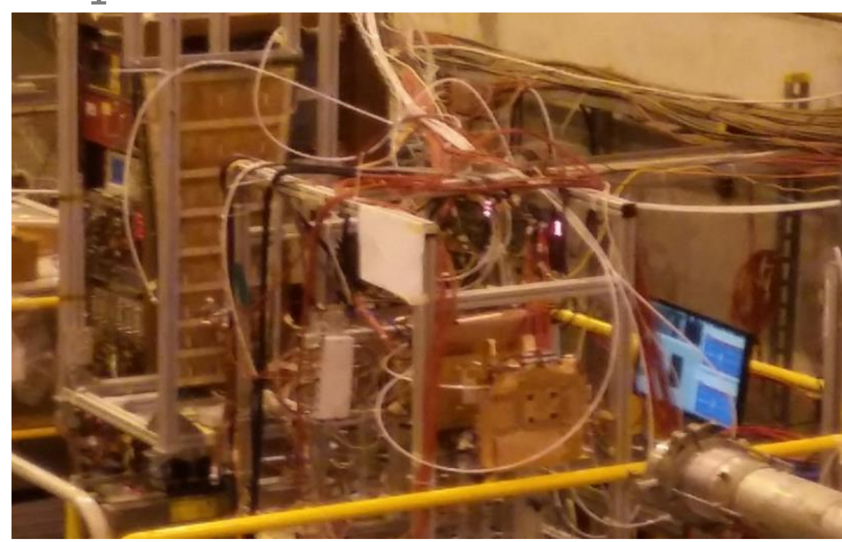
Beam Test (CMS/LHCb collaboration)

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

Muon/Pion beam: 150 GeV/c

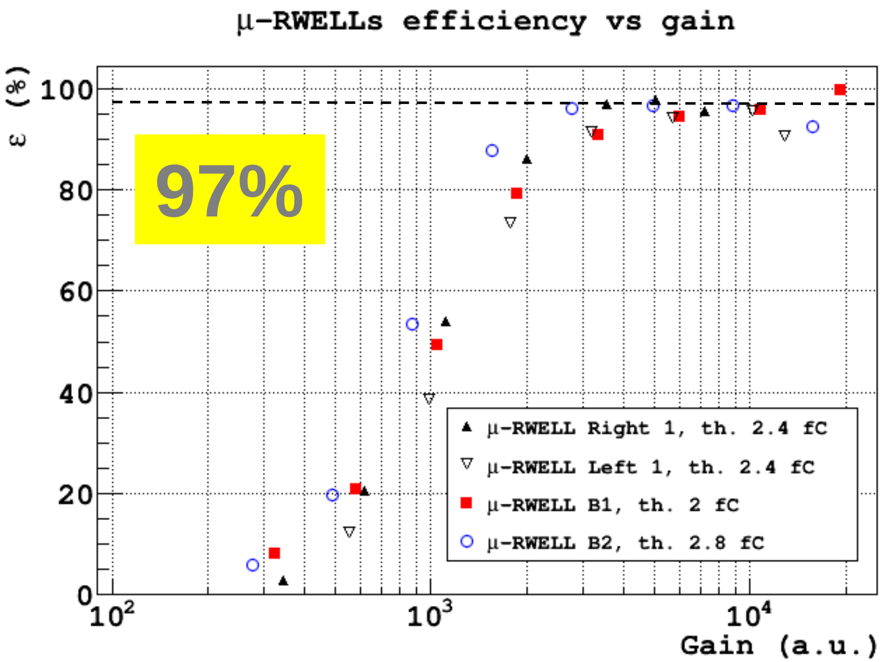
3 μ-RWELL prototypes
40-35-70 MΩ /☐
VFAT (digital FEE)
$Ar/CO_2/CF_4$ = 45/15/40

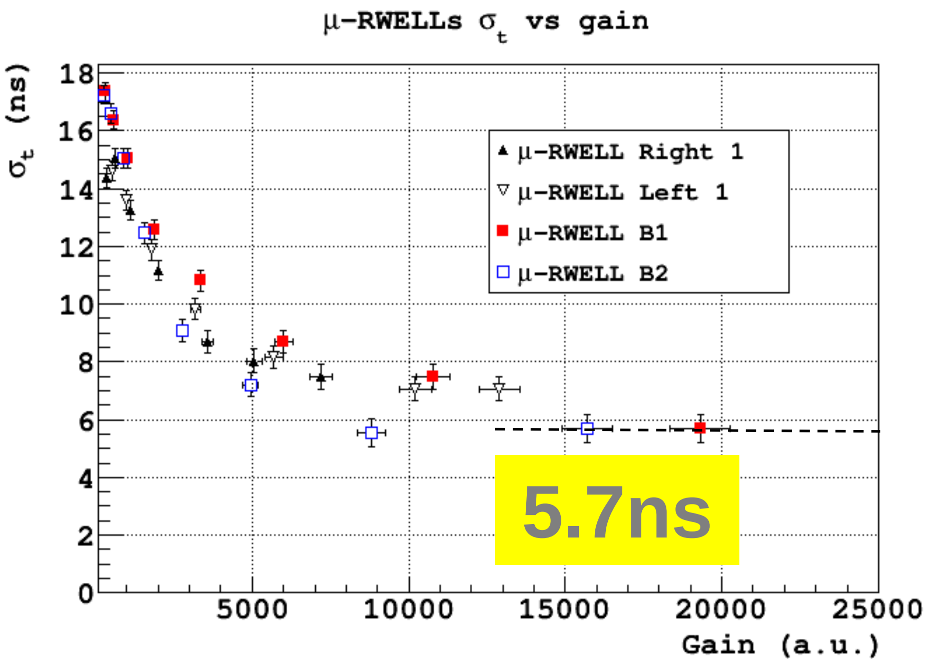




GOAL: <u>time resolution measurement (never done before)</u>

Time Performance





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

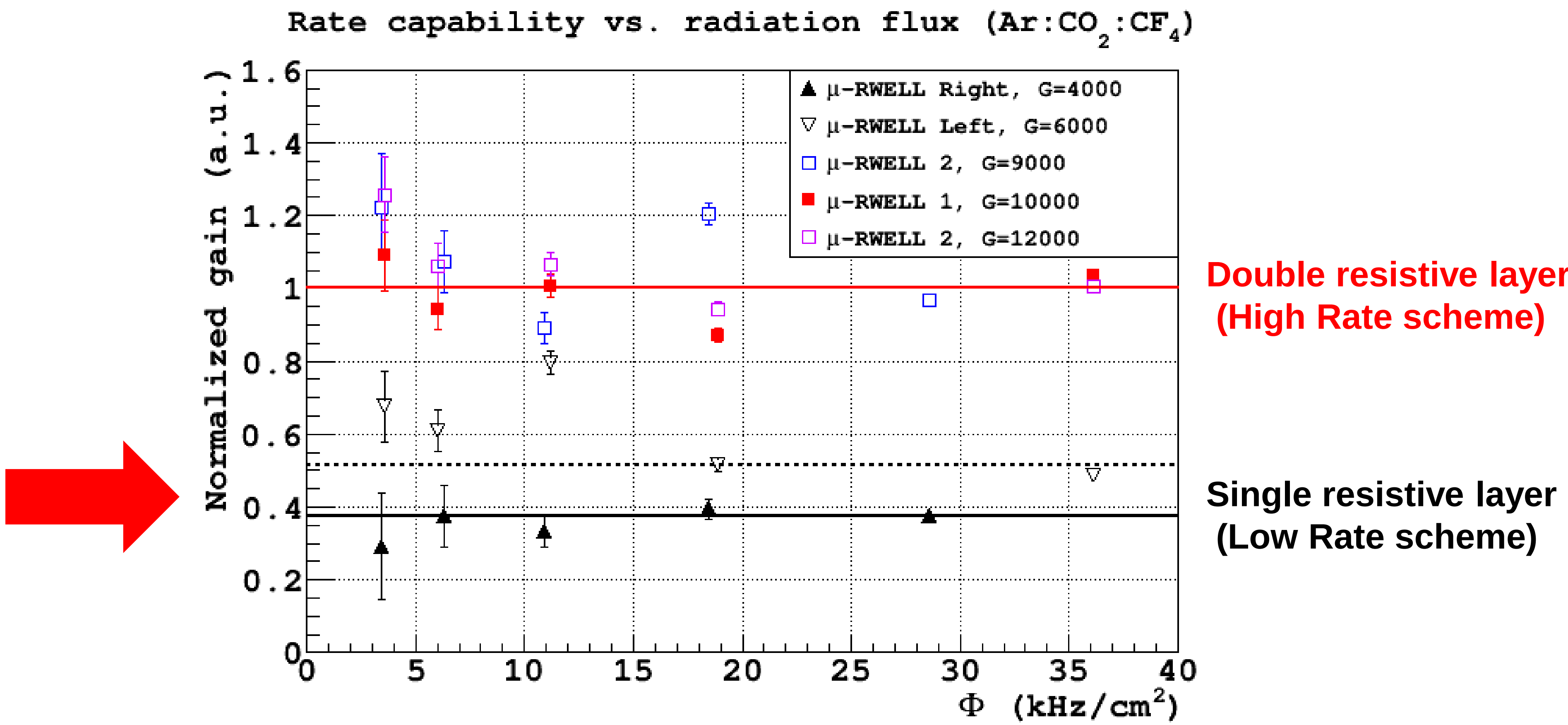
The **saturation at 5.7 ns** is dominated by the fee (measurement done with VFAT2).

To be **compared** with a measurement done with **GEM by some of us in 2004 (LHCb) giving a σ_t = 4.5 ns** with VTX chip **[1].**

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

Performance vs Rate

The detectors 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) (medium size irradiation, ~10 cm^2 spot)



SUMMARY of WP13.2.4

The **μ-RWELL R&D in AIDA2020 is matching the schedule, with very good results.**
The most important performance of the detector have been measured:

- ✓ gas gain > 10^4
- ✓ intrinsically spark protected
- ✓ rate capability >> 1 MHz/cm^2 (HR version)
- ✓ space resolution < 60μm
- ✓ time resolution < 6 ns

The 1st milestone has been succesfully fulfilled:

- ✓ **MS13.3:** Small-size prototype of the μ -RWELL (built and qualified prototype - M24)

The 2nd milestone foreseen for M44:

- ❖ **D13.4 :** Large-size prototype of μ-RWELL (a large-size fully engineered and validated prototype of the μ-RWELL - demonstrator)

WP 13.4.5:
tools for readout PCB QC

Preparation of tools for large series production

Task 13.4.5
Design of an automatic system to check the electrical integrity of electrode patterns by pulse reflection method

Activity 2016-2017 subdivided in two sub-tasks:

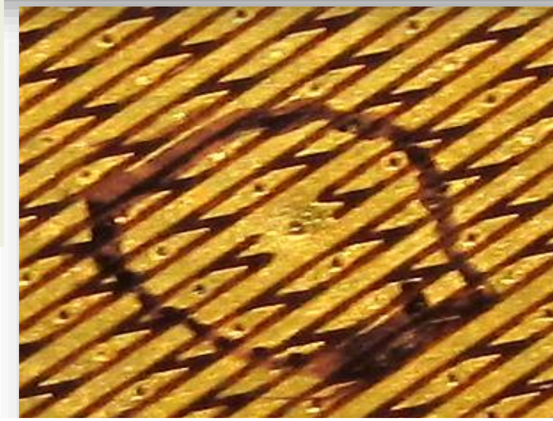
1. Design and implementation of a TDC embedded structure in the Time Domain Reflectometer (TDR) control logic
2. Construction of the prototype chamber with μ-RWell technology & related readout PCB for CMS R&D phase_2, as proof of concept for the TDR

Partecipants: INFN-Bari, INFN-LNF

Design of a TDC embedded structure in control logic (I)

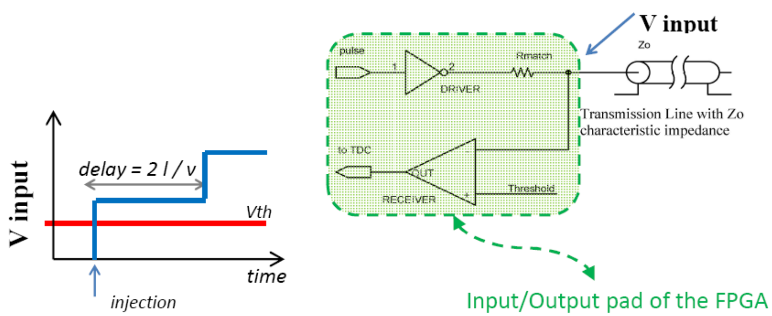
TDR exploits time measurements -> TDC

The aim of this work is the development of a **device capable to find defects on a micro-strips readout plane of a MPGD** under test through the **search of discontinuities in the impedance profile which cause reflection of injected pulses**.



Example: 2D readout geometry

- The drawing shows the run of a signal, in this case **a transition from low to high state, injected into an un-terminated transmission line**
- **The first edge occurs when the signal is injected** at the input while the **second edge is observed after that the signal reflected comes back** (in red a threshold level)



A time resolution **of about 100 ps** is required to appreciate **length differences of about 1 cm**

1'st TDR proto's

ISSUE: Temperature stability:

- The only reliable method is to put one TDC/channel

Design of a TDC embedded structure in control logic

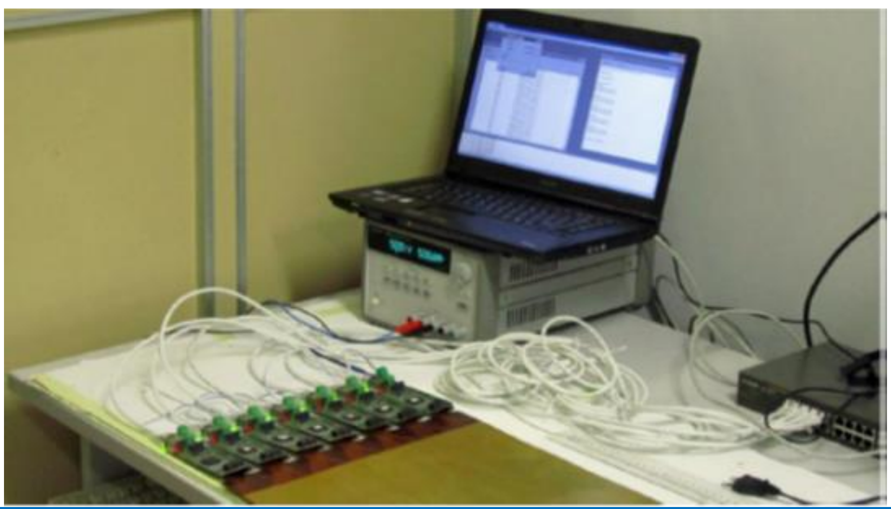
TDR exploits time measurements -> TDC

By analysing the **delay of the reflected signal, it is possible to evaluate the length of a transmission line,** a micro-strip in the device under test. This **length will be as expected** by design **if the micro-strip is intact,** then **shorter if there is an interruption somewhere** along the strip and **longer or shorter, due to multiple reflections, whether some close strips are shorted together**

A **2nd release of the TDR board has** foreseen **n.4 TDCs per FPGA** , so that **each TDC sequentially read/out n.32 strip channels**. Wrt the previous version, the new board is **more stable** and precise and **doesn't require tedious repeating calibration procedures**, having **solved the problem of thermal instability**.

Temperature stability issue solved with new release:

- The only reliable method is to put one TDC/channel
- The new release contains one TDC per channel



Workbench with 7 TDR modules connected to an anodic sheet under test and through Ethernet to PC for logging and control

2'nd TDR electronics card

Summary
Milestones & Deliverables

- **MS13.10 - Quality control system to ensure the electrical integrity of readout electrode for MPGDs (prototype of a Time Domain Reflectometer: M24) → succesfully fulfilled**

MS13.7	Mechanical structure and supports for large, thin-gap RPCs	13	M30	Prototype
MS13.8	Optical system for the quality assessment of MPGD foil/mesh mechanical tensioning	13	M12	Demonstrator
MS13.9	Integrated FBG sensors for monitoring the mechanical tension of MPGD films and meshes	13	M24	Prototype
MS13.10	Quality control system to ensure the electrical integrity of electrode patterns	13	M24	Prototype
MS13.11	Protocol and specifications for MPGD production and quality control	13	M36	Report to StCom
MS14.1	Commissioning of Fibre Testbenches	14	M24	Running system results
MS14.2	Specification of systems for highly granular scintillator tests	14	M12	Report to StCom
MS14.3	Assembly and QA chain demonstration for highly granular silicon calorimeters	14	M12	2-3 operational layers produced
	Design specifications of test stations for irradiated silicon sensors and LHC oriented front-end			

- Designed a **new TDC scheme inside the FPGA (firmware) to overcome the temperature instability**
- As soon as **new anodic foils will be delivered for a GE2/1 CMS** chamber based on the **µ-RWell technology, tests with TDR device will be performed** and results will be reported

backup

WELL amplification stage: thickness studies

The increase of the thickness of the amplification stage (Kapton base material thickness) from the standard (GEM like) 50 µm up to 125 µm should result in a **increase of the detector gain.**

The program for THICK µ-RWELL was started by the end of 2016

BUT

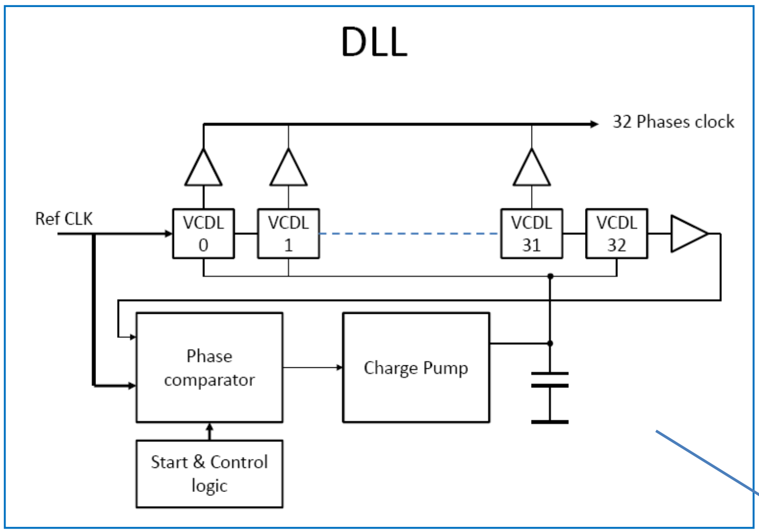
We discovered etching problem with single mask technique (the natural one for µ**-RWELL): the needed etching along the whole thickness (125** µm) **results in a too large diameter hole (> 100** µm) thus **strongly affecting the effective GAIN** of the hole itself (exactly the opposite of the desired goal)

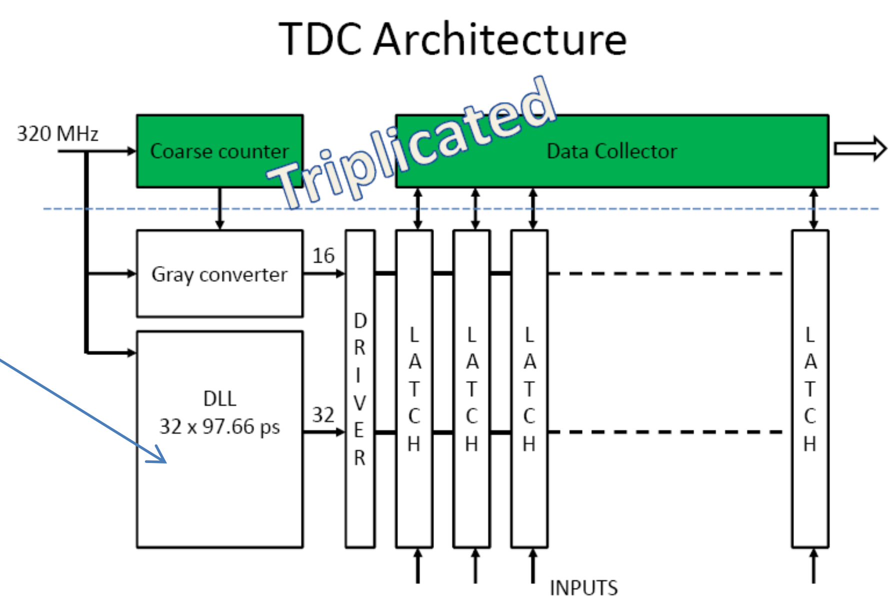
THEN
Some change in the manufacturing of the high gain detector is clearly required (→ double mask etching + floating amplification stage; …)

Anyway we have demonstrated that using suitable gas mix the detector achieve a Gain 2-3 x 10^4

New architecture characteristics

- Reference clock 320 MHz (better than that previous version: 250MHz)
- Measured (after simulation) timing resolution: ≤ 100ps
- 5 bits fine counter + 16 bits coarse counter
- 33 channels (32 comparator + 1 test input)

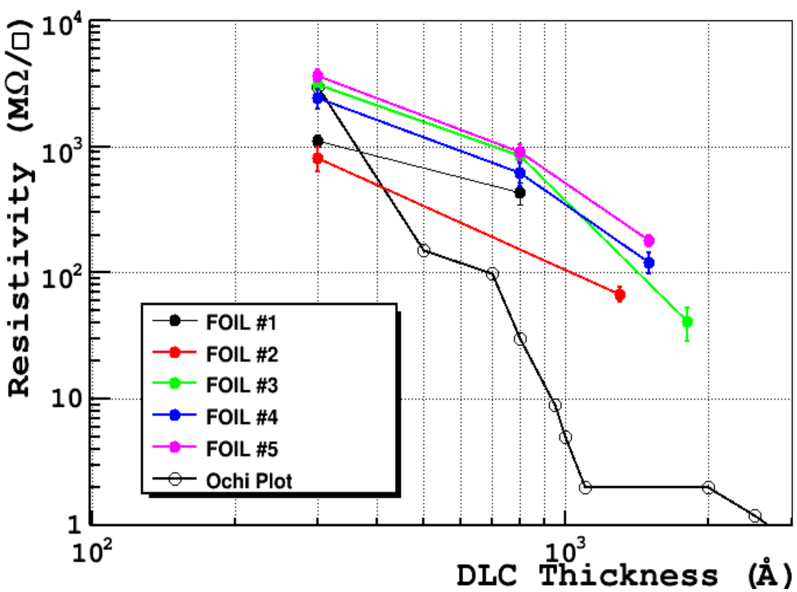




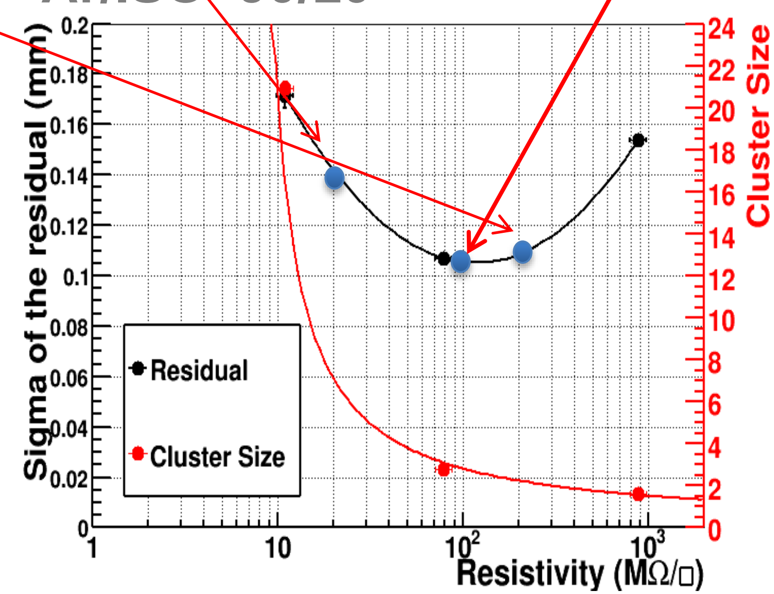
DLC sputtering on Kapton foils (supervised by A.Ochi)

DLC sputtering on large Kapton foils (w/copper on one side) completed @ Be-Sputter Co., Ltd (Japan)

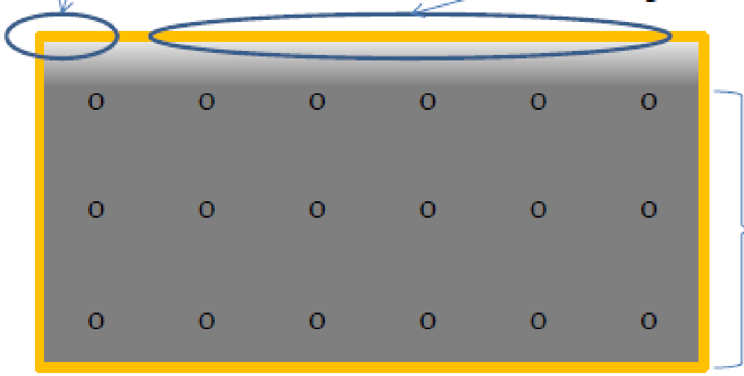
	Foil 1 (800A)	Foil 2 (1300A)	Foil 3 (1800A)	Foil 4 (1500A)	Foil 5 (1500A)
Average Surface Resistivity MΩ/□	433±90	68±9	41±12	122±22	180±17



Ar/ISO=90/10



Surface resistivity map (A. Ochi, Kobe – Univ., Japan)



Surface resistivity measured on a 18 points of the 600x1200 mm2 kapton base material

- Unit is Mohm/sq.

No.1

70.2	82.6	75.3	73.1	73.9	73.2
76.8	86.2	87.0	85.6	86.6	71.7
65.4	71.5	72.4	66.7	69.2	65.8

No.2

42.4	48.0	45.6	46.3	49.4	40.0
39.4	41.5	40.6	42.1	40.7	36.3
48.4	53.4	51.7	51.6	51.8	39.5

No.3

65.7	73.4	73.8	66.6	63.8	50.9
79.2	90.9	83.5	79.4	76.6	61.4
67.8	75.4	65.5	57.8	57.4	51.6

No.4

39.4	46.2	52.1	62.7	58.8	57.1
32.5	37.3	41.3	44.7	47.1	44.2
41.1	49.1	53.8	57.0	61.4	55.4

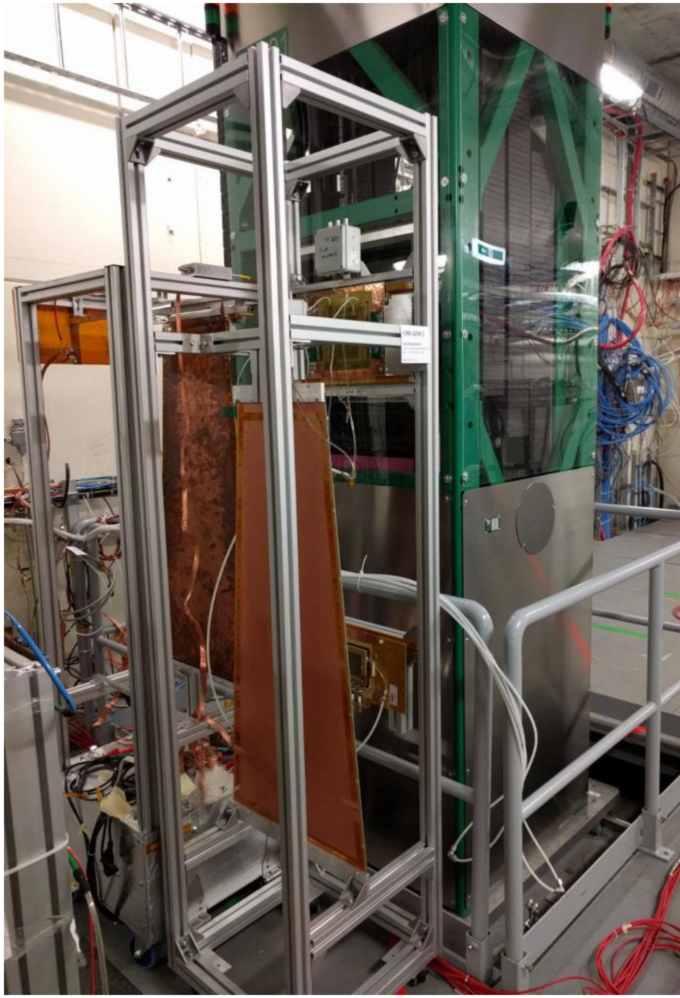
No.5

48.4	54.6	58.8	61.4	66.4	62.0
52.0	57.1	62.2	67.4	72.0	62.8
44.6	47.2	49.4	55.0	58.2	56.7

No.6

39.8	44.7	39.4	38.1	36.1	33.4
33.4	35.9	33.8	31.2	28.7	27.7
45.5	45.8	41.9	38.3	36.2	35.2

Ageing test @ GIF++



μ-RWELL detector: the AIDA2020 program (II)

2. **Detector engineering for large area tracking & digital calorimetry applications:**

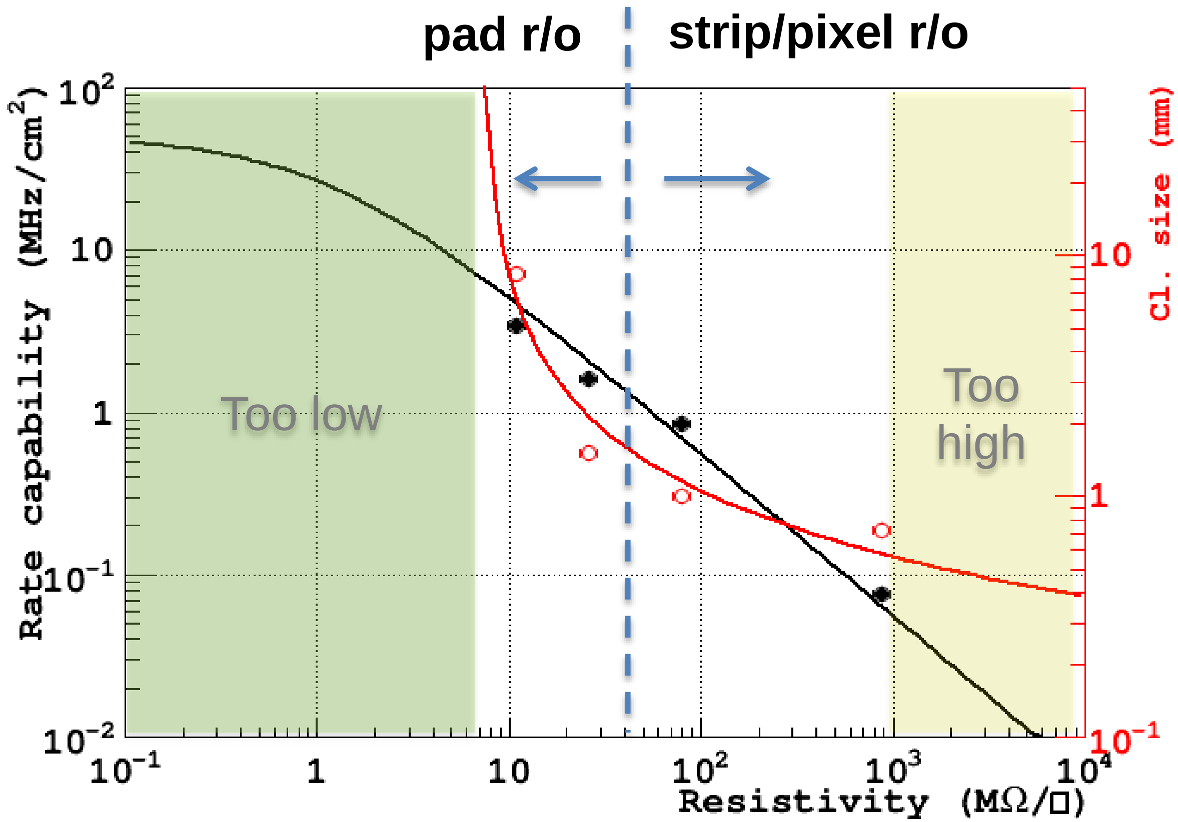
   i. Design of large area demonstrator
   ii. Large area readout design
   iii. Study of FEE-detector coupling

<u>Work to be done in the second 24 months (M24-48)</u>

MILESTONES

- **MS13.3:** Small-size prototype of the μ-RWELL (a built and qualified prototype - **M24**)
- **D13.4 :** Large-size prototype of μ-RWELL (a large-size fully engineered and validated prototype of the μ-RWELL (demonstrator - **M44**)

Combining the information



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