Status of the R&D on μ-RWELL

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OUTLINE

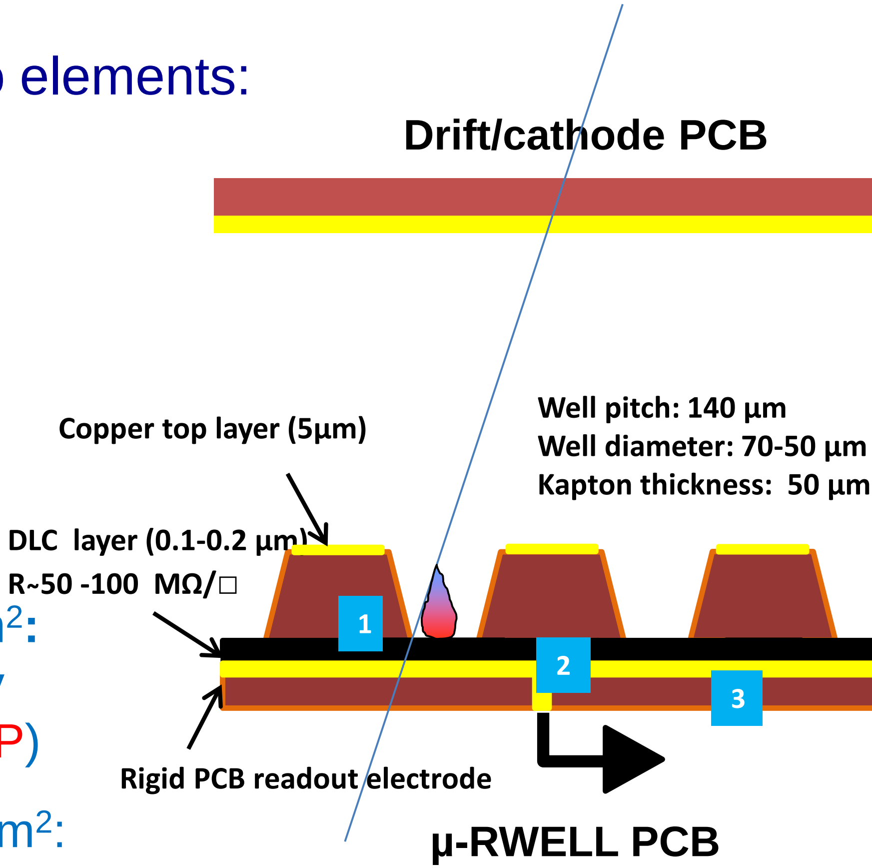
- The μ-RWELL
- Detector performance
- Towards the large area
- Summary

The μ-RWELL architecture

The μ-RWELL detector is composed by two elements:
the **cathode** and the **μ-RWELL_PCB .**

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

1. a "**suitable WELL patterned kapton foil** as "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/□ (CMS-phase2 upgrade - SHIP)
   - **ii. "High particle rate" (HR)** >> 100 kHz/cm^2: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF & LHCb-muon upgrade)
3. a **standard readout PCB**



G. Bencivenni et al., 2015_JINST_10_P02008

Main features of the μ-RWELL detector

the **μ-RWELL** is intrinsically a spark protected detector and it has a very simple construction procedure:

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

cost effective:

- 1 PCB r/o, 1 μ-RWELL foil, 1 DLC, 1 cathode and low man-power

easy to operate:

- very simple HV supply → 2 independent channels or a trivial passive divider (3GEM detector → 7 HV channels)

The µ-RWELL: a GEM-MM mixed solution

The **µ-RWELL** has features in common either with **GEMs** or **MMs:**

- **MMs** are realized on **rigid** substrate
- **GEM** on **flex** substrate
- **µ-RWELL** exploits both technologies, **rigid and flexible (**but also **full-flex)**

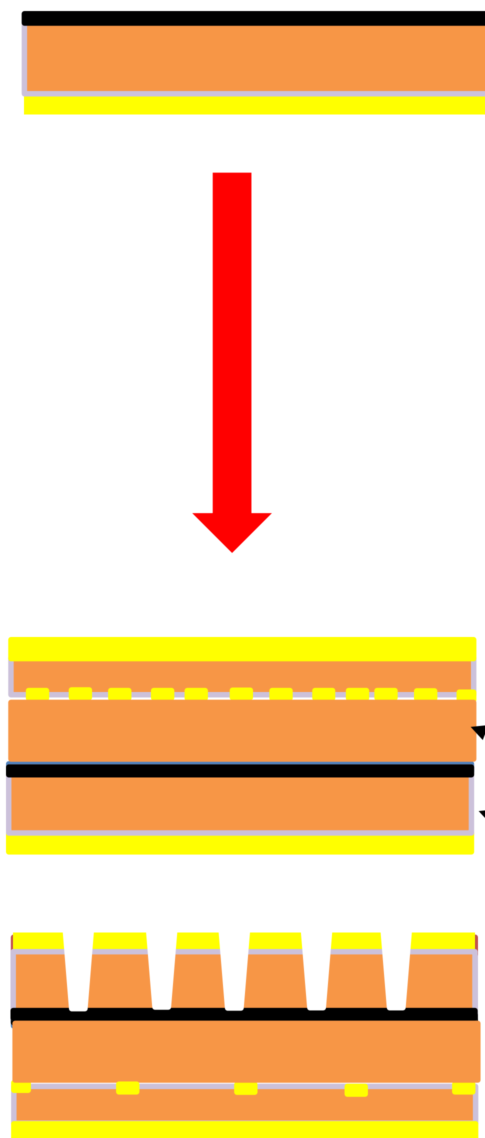
The **µ-RWELL** :

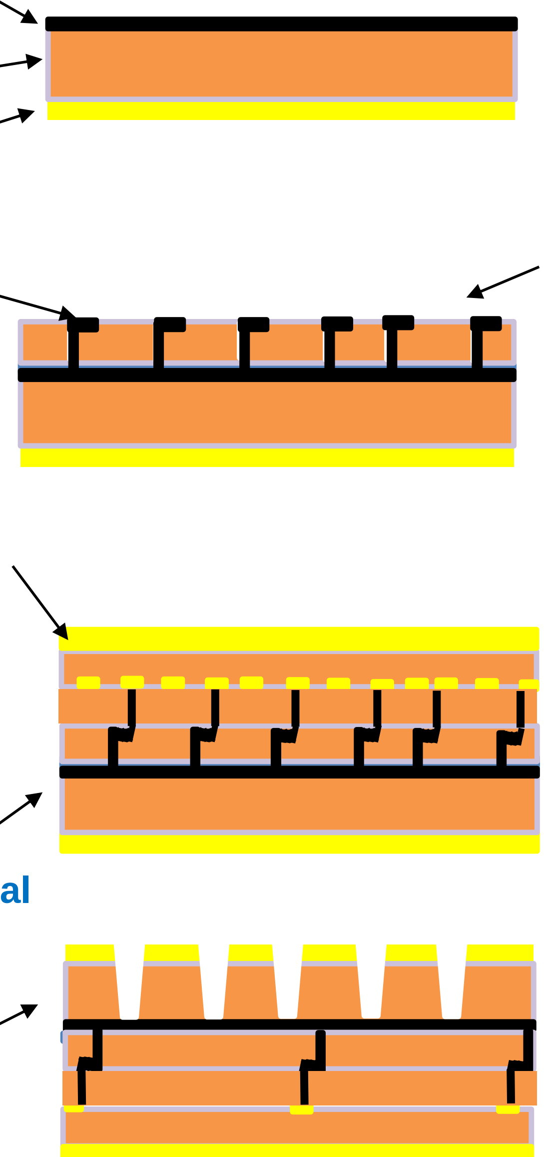
- inherits and improves the **GEM amplifying scheme** with the peculiarity of a "**well defined amplifying gap**", but ensuring **higher and more uniform gas gain,** with no transfer/induction gaps whose non-uniformity can affect the detector gain

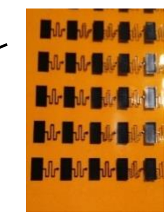
- inherits the **MM resistive readout scheme** that allows a "**strong suppression**" of the amplitude of the **discharges.**

LR scheme: single resistive layer

HR scheme: double resistive layers







DLC-coated kapton base material: DLC layer ~ 0.1-0.2 µm (50-100 MΩ/□)

Kapton layer 50 µm

Copper layer 5 µm

Kapton layer (12-25 µm) with
$1/cm^2$ vias density .
Screen printed with a
"buried-resistances" pattern

Strip kapton layer (50 µm)

pre-preg #106 (50 µm)

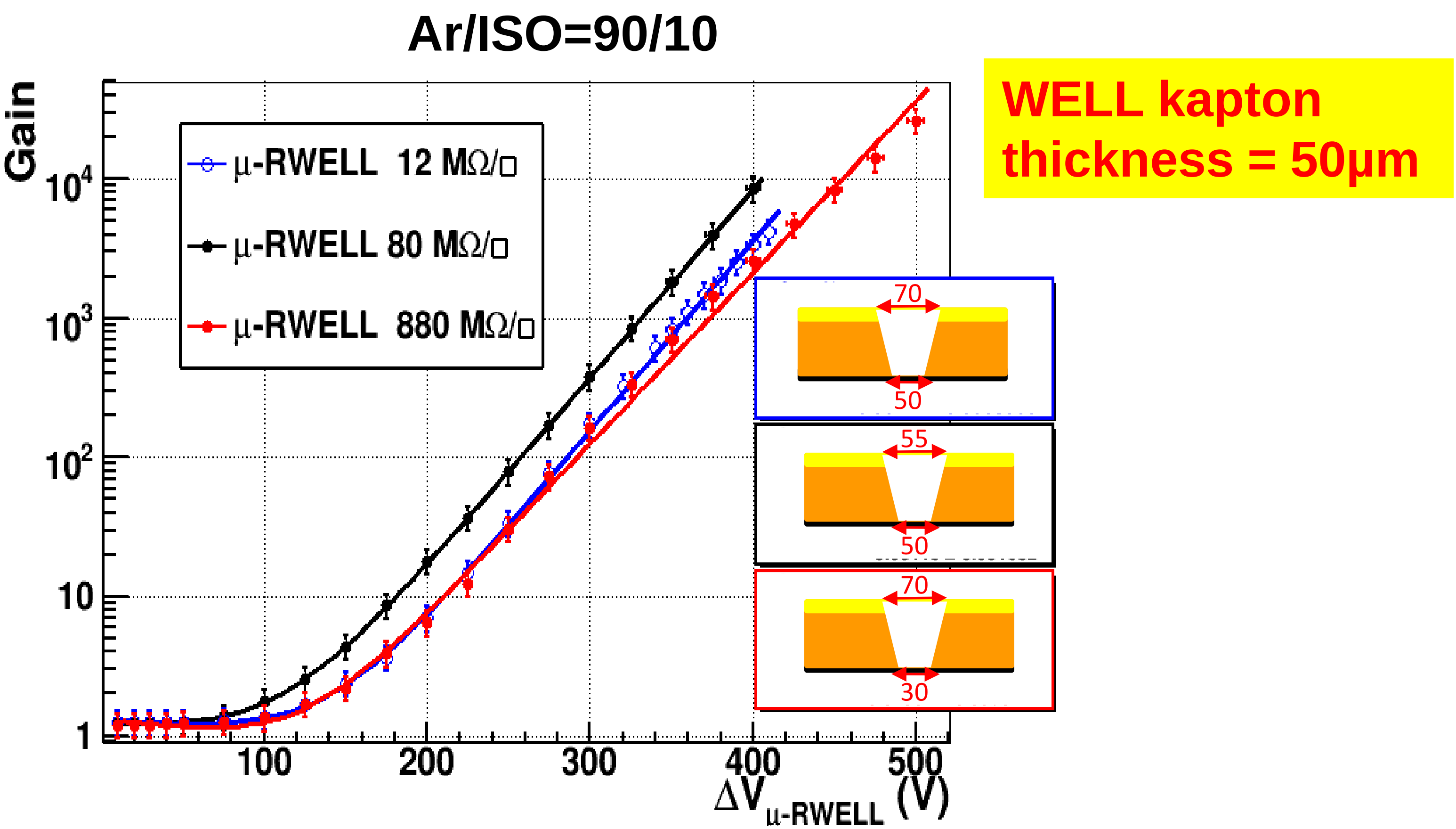
DLC-coated kapton base material

DLC-coated base material
after copper and kapton
chemical etching

The µ-RWELL performance: Lab Tests

gas gain

prototypes with different resistivity (12-80-880 MΩ/☐) have been tested with an **X-Ray** gun (5.9 keV), with **Ar/iC$_4$H$_{10}$= 90/10** gas mixture, and characterized by measuring the **gas gain** in **current mode**.

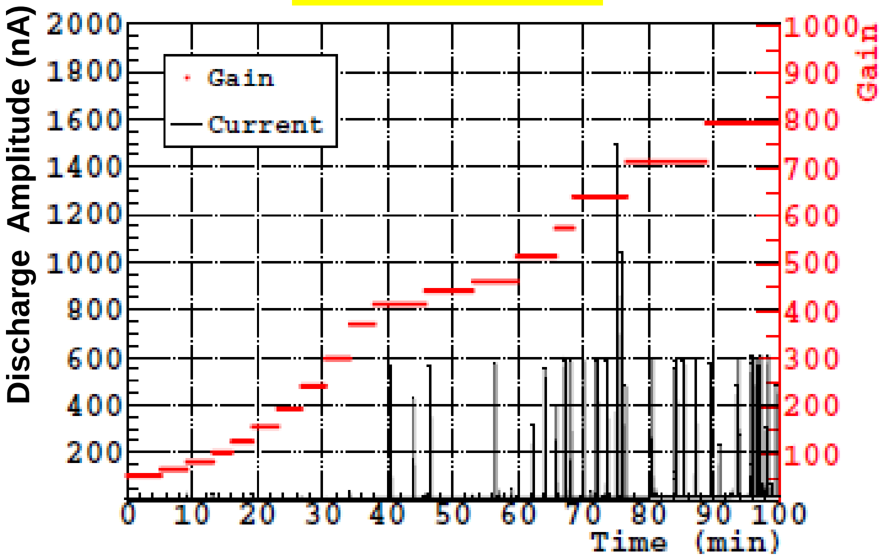


discharges: μ-RWELL vs GEM

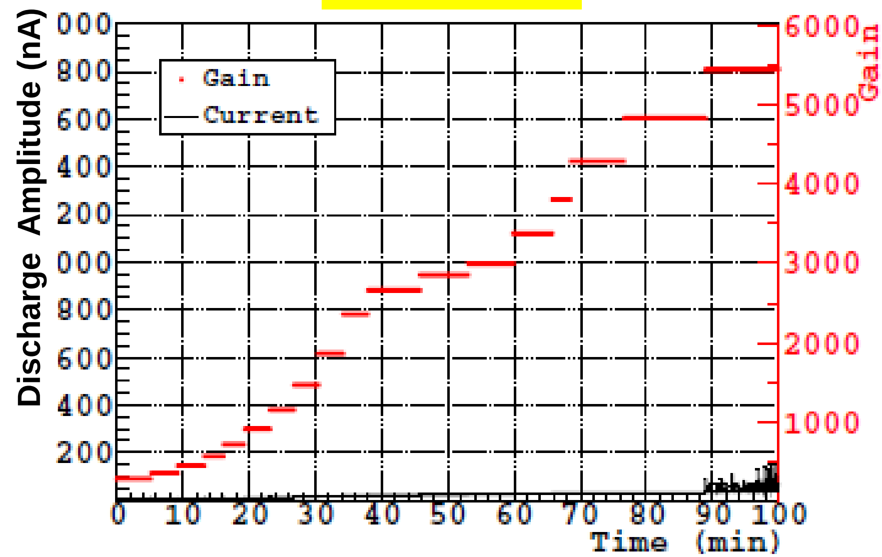
test with X-ray

Ar/CO_2 = 70/30

single-GEM



μ-RWELL

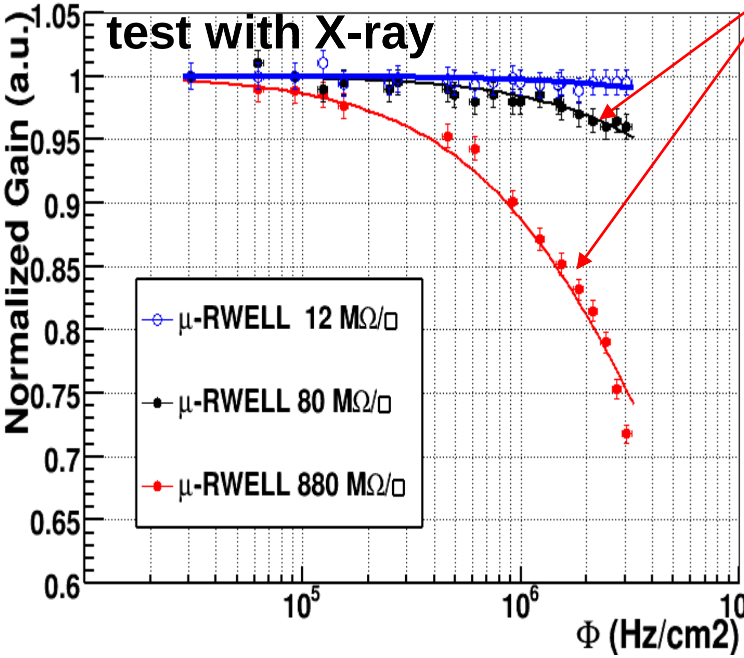


- the **μ-RWELL** detector reaches discharge amplitudes of **few tens of nA, <100 nA @ max gain**
- the **single-GEM** detector reaches discharge amplitudes of **≈ 1μA** *(of course the discharge rate is lower for a triple-GEM detector)*

More quantitative studies must be clearly performed

rate capability vs layer resistivity

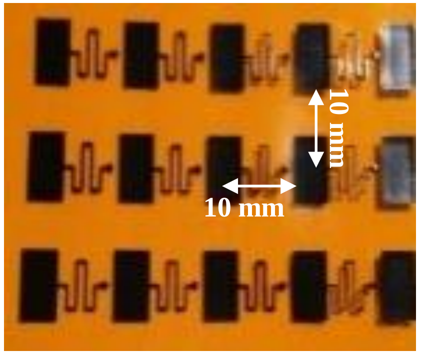
Ar/ISO =90/10, G = 1000

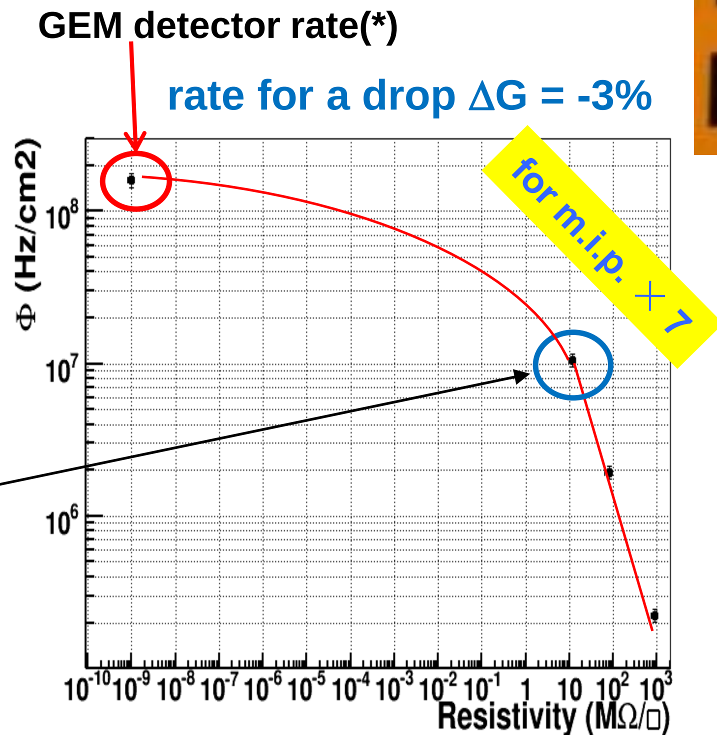


the **gain decrease** is correlated with the voltage drop due to the **resistive layer**

<u>Solution for high rate</u>: local evacuation of the current through embedded resistors on a kapton layer and connected by vias directly to the strips of the detector

➔ **grounding pitch**





a re-scaling with the right gain would be required

with a **1×1 cm² grounding pitch** & a resistivity of **≈10 MΩ/□**
a rate capability of **≈10 MHz/cm²** can be achieved.

(*) Bellazini et al. NIMA 423 (1999) 125
Sauli et al., NIMA 419 (1998) 410

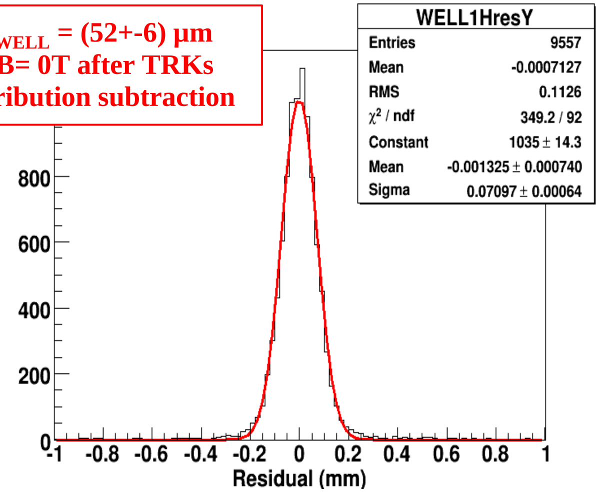
The μ-RWELL performance: Beam Tests

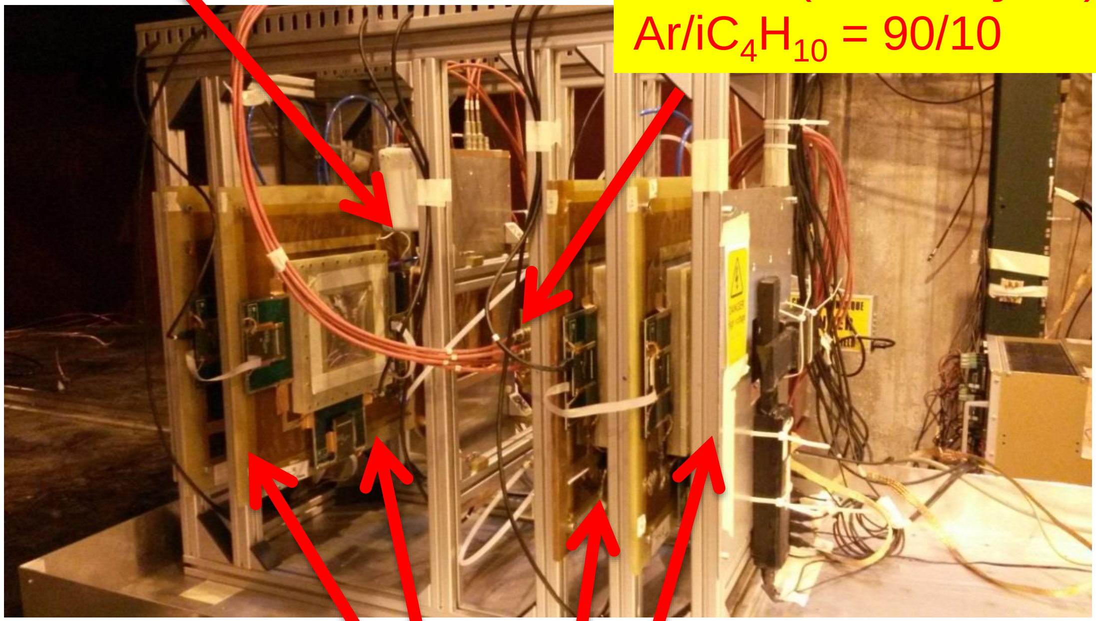
H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

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

BES III-GEM chambers

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

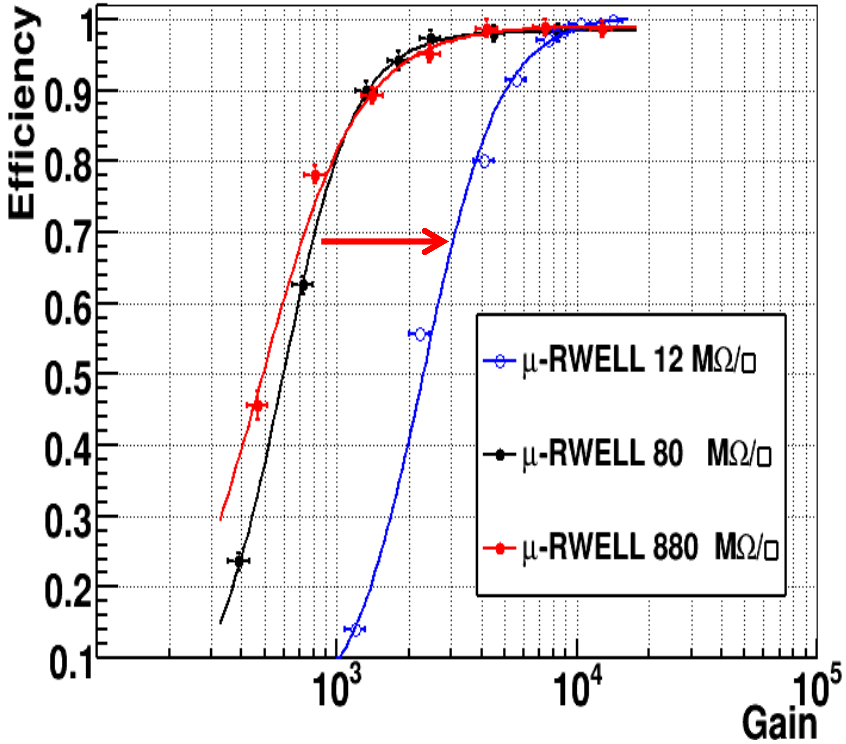




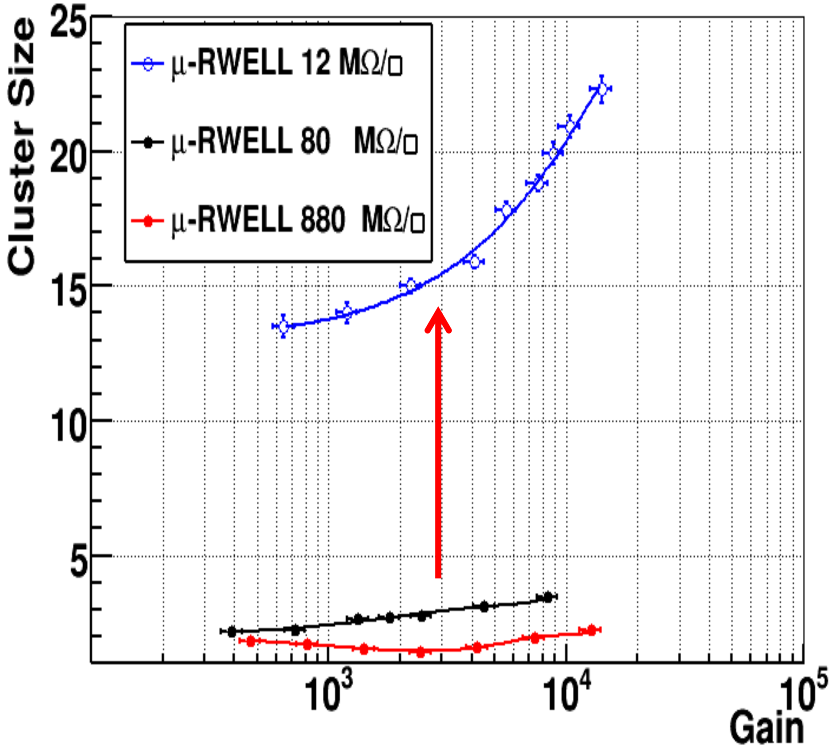
GEMs Trackers

µ-RWELL: tracking efficiency

Ar/ISO=90/10



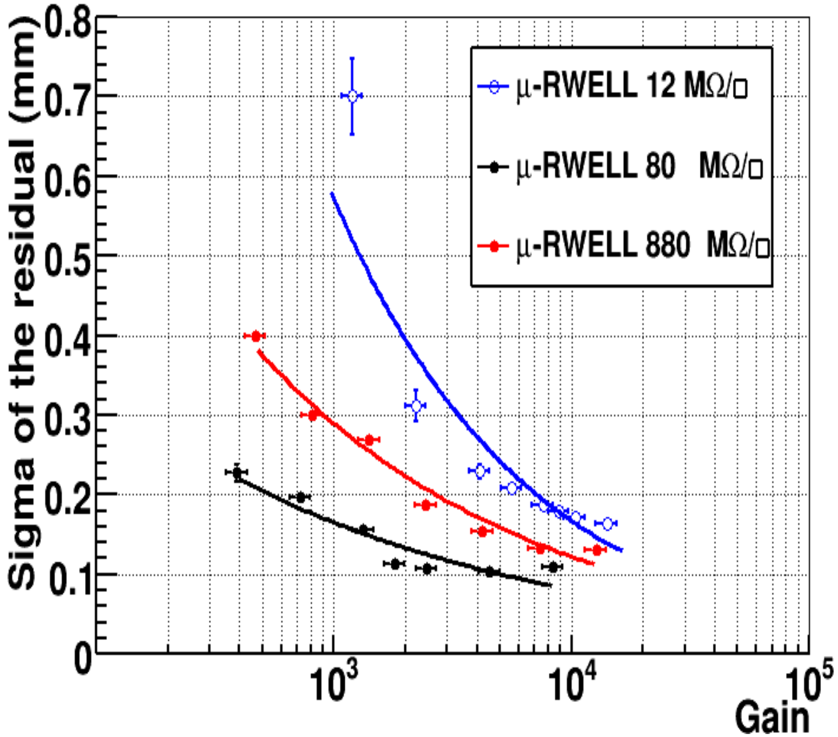
Ar/ISO=90/10

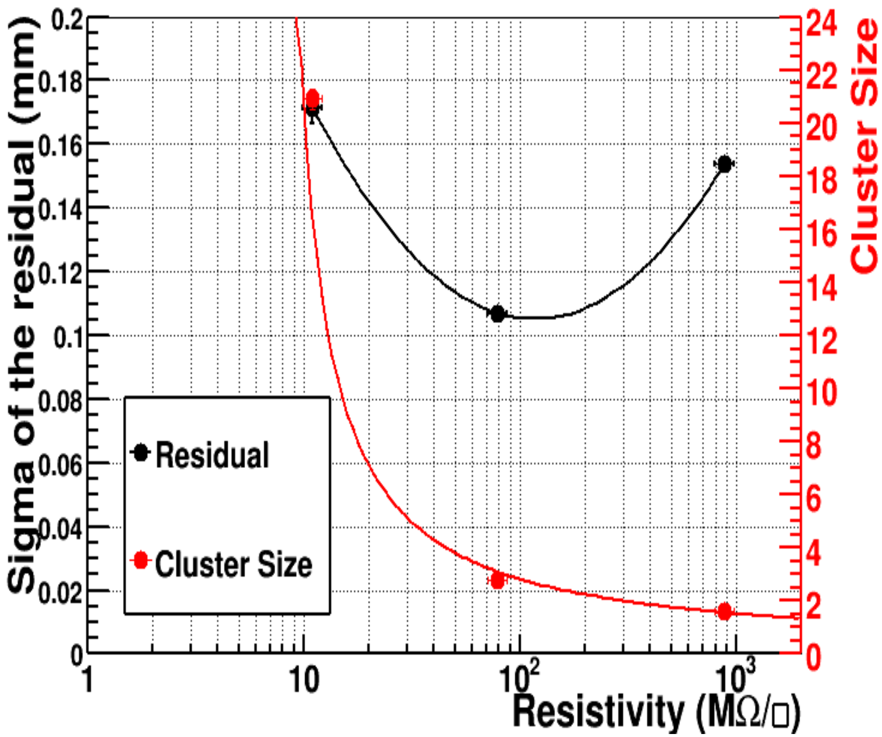


At **low resistivity the spread of the charge** (cluster size) on the readout strips **increases**, thus requiring a **higher gain** to reach the **full detector efficiency.**

Space resolution: orthogonal tracks

CC analysis





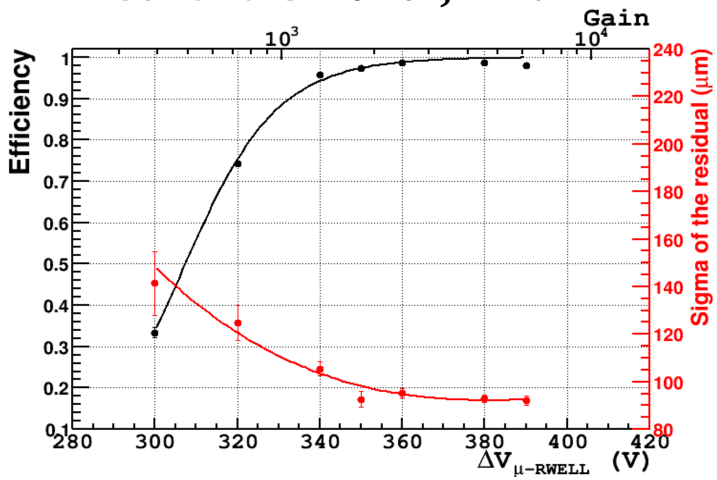
The **space resolution** exhibits a **minimum around 100MΩ/□.**

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).**

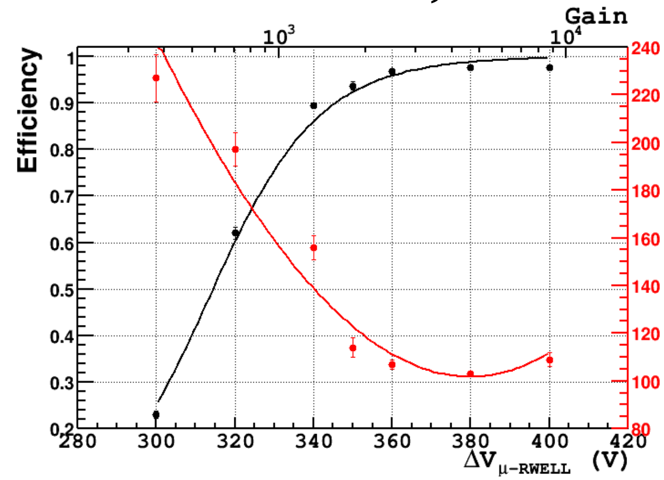
CC analysis

µ-RWELL: B≠0 with Ar/ISO=90/10

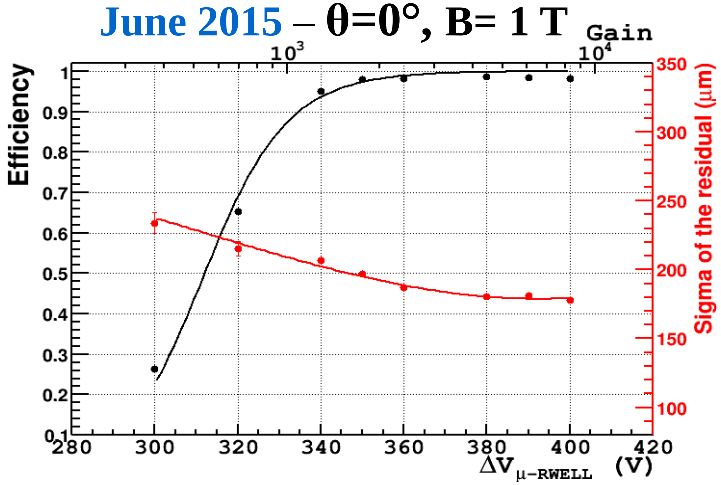
June 2015 – θ=0°, B= 0 T



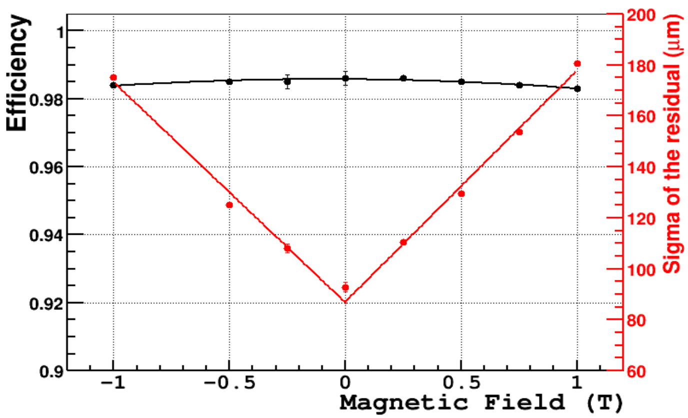
Dec 2014 – θ=0°, B= 0.5 T



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%**

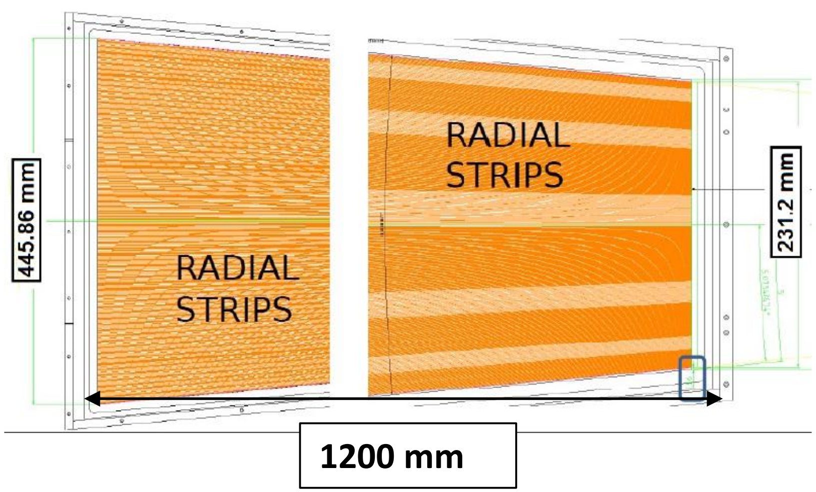
Towards large area & detector engineering

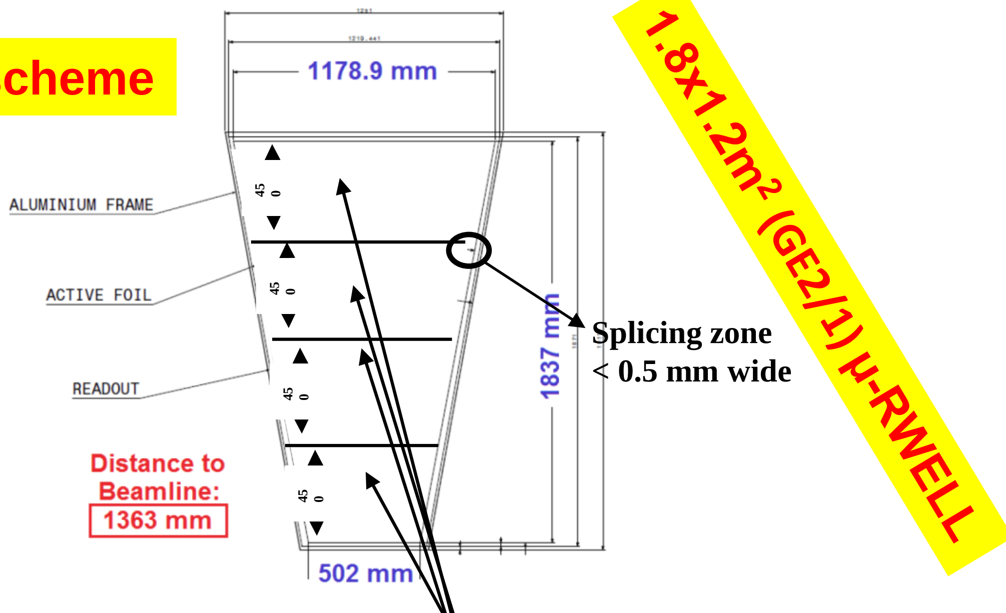
In the framework of the **CMS-phase2 muon upgrade** we are developing **large size µ-RWELL**. The **R&D** is performed in strict collaboration with Italian industrial partners (**ELTOS SpA & MDT**). The work will be performed in **two years** with following schedule:

1. Construction & test of the first **1.2x0.5m^2 (GE1/1) µ-RWELL** **2016**
2. Mechanical study and mock-up of 1.8x1.2 m^2 (GE2/1) µ-RWELL **12/2016**
3. Construction & test of the first **1.8x1.2m^2 (GE2/1) µ-RWELL** **12/2017- 6/2018**

1.2x0.5m^2 (GE1/1) µ-RWELL

LR scheme





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

Milestones & schedule for G1/1 μ-RWELL (2016)

- ✓ **January.: drawings of the G1/1 μ-RWELL**
- ✓ **10 Feb:** ELTOS send formal offer for n.2 kit μ-RWELL (GE1/1 type)
- ✓ **25 Feb:** order for n.3 kit μ-RWELL completed

- ✓ **5 April:** PCB-readout (type GE1/1) completed at ELTOS
- ✓ **2 May:** DLC sputtering on large Kapton foils (w/copper on one side) completed

- ✓ **12 May:** discussion at ELTOS about the gluing/pressing of the kapton foil w/DLC(amplification stage of μ-RWELL) on the readout-PCB
- ✓ **12 May:** the DLCed Kapton foils have been delivered at the LNF

- ✓ **17 May:** preliminary test at MDT-Milano of the gluing/pressing of nake-kapton foils on one of the final PCB-readout; the goal of the test is to tune the parameters of the gluing/pressing and verifying the absence of air bubbles between the DLC surface and the prepreg
- ✓ **26 May:** quality check (by Rui) of the sample prepared @ MDT
- ✓ **6-8 june:** gluing the DLCed foils on the readout -PCBs @ MDT

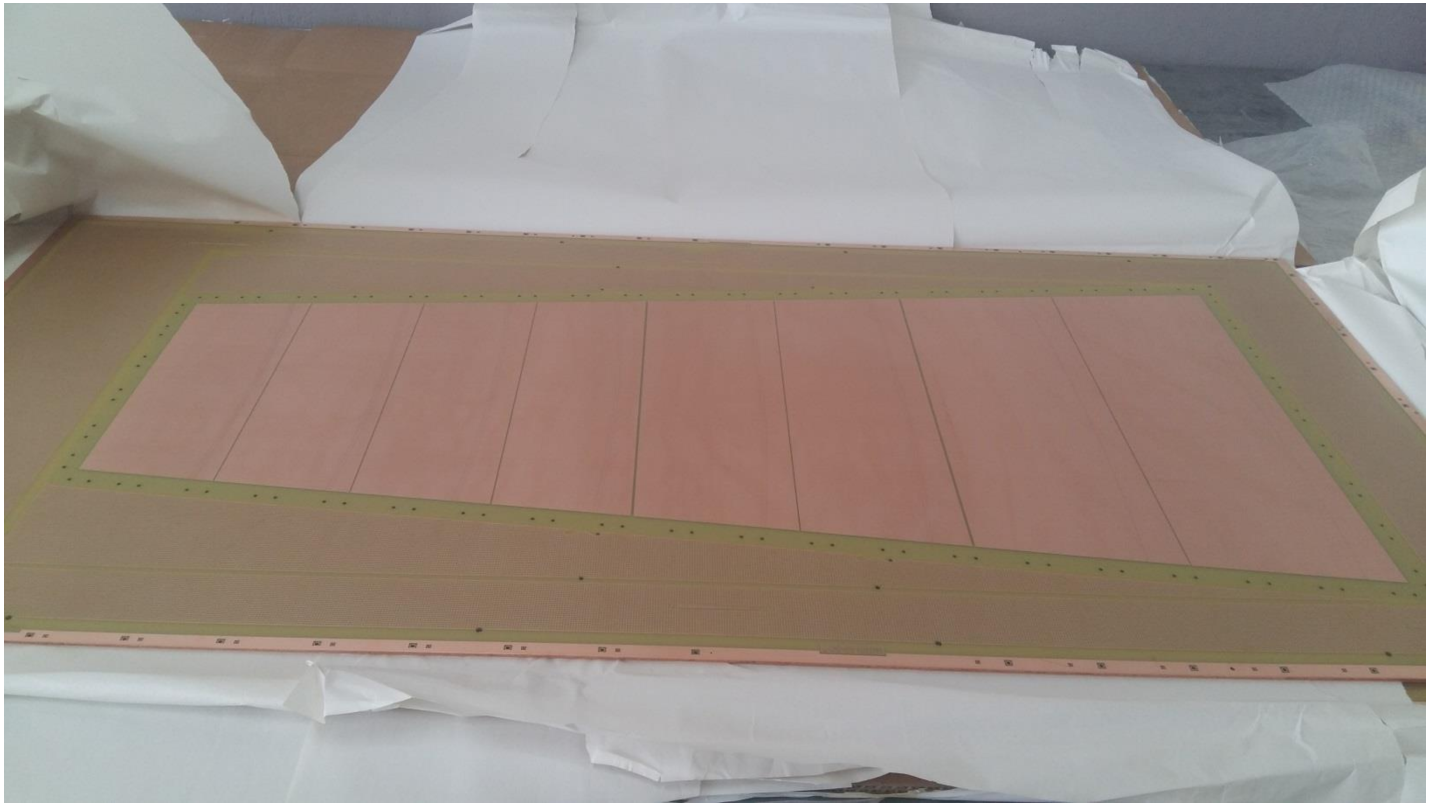
- ○ **13-30 June:** etching at CERN of the kapton foils to produce the WELL-pattern

- ○ **1- 30 July:** closing and preliminary test of the detectors
- ○ **1 sept – 19 oct**: Beam Test preparation
- ○ **19 oct – 8 nov:** Beam Test at H8-B area (LHCb area)

Readout-PCB production @ ELTOS

- ✓ **10 Feb:** ELTOS send formal offer for n.2 kit μ-RWELL (GE1/1 type)
- ✓ **25 Feb:** order for n.3 kit μ-RWELL completed

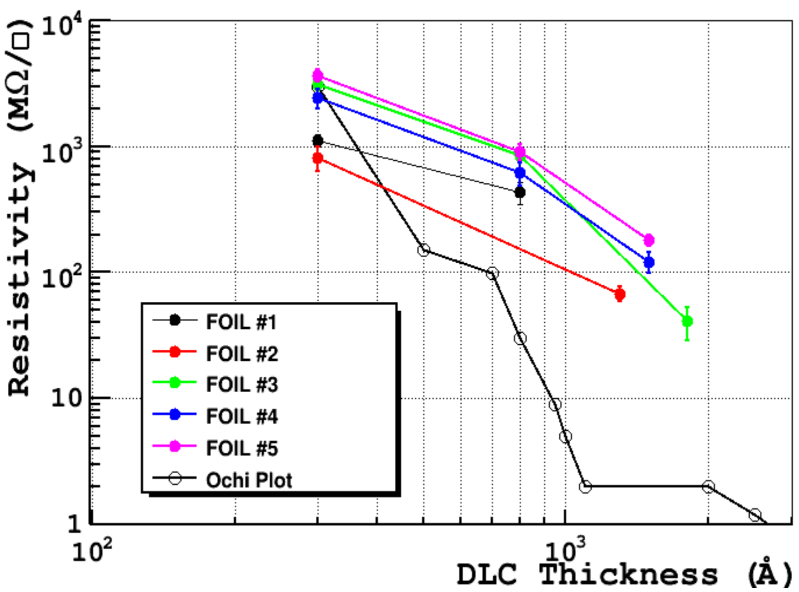
- ✓ **5 April:** PCB-readout (type GE1/1) completed at ELTOS



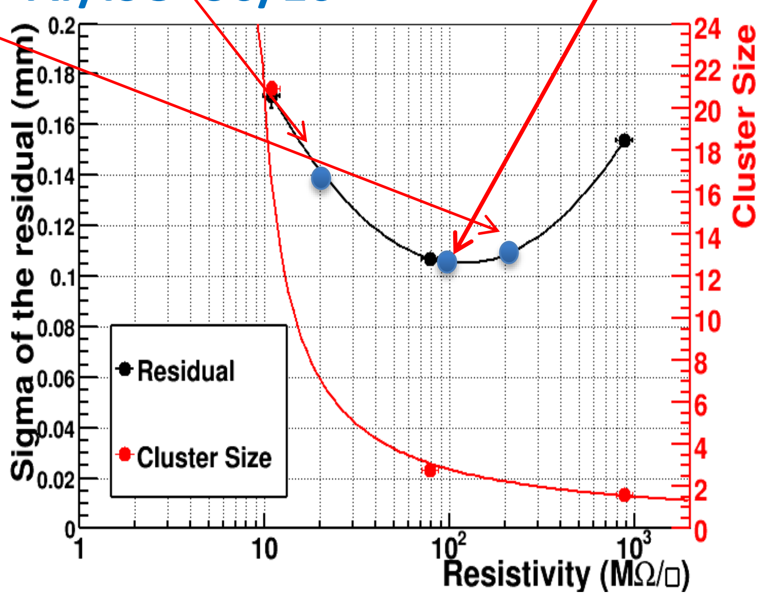
DLC sputtering on Kapton foils (supervised by Ochi)

- ✓ **2 May:** DLC sputtering on large Kapton foils (w/copper on one side) completed @ Be-Sputter Co., Ltd (Japan)
- ✓ **12 May:** DLCed Kapton foils have been delivered at the LNF

	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

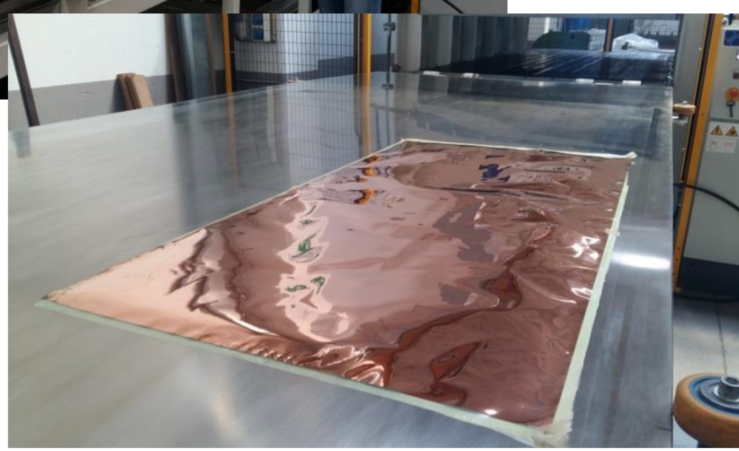


Ar/ISO=90/10



Coupling the DLCed Kapton with r/o-PCBs

- ✓ **17 May:** preliminary test at MDT of the gluing/pressing of **nake-kapton foils** on one of the **final PCB-readout;** the goal of the test is **to tune the parameters** of the gluing/pressing and verifying the absence of air bubbles between the DLC surface and the prepreg
- ✓ **26 May:** quality check (by Rui) of the sample prepared @ MDT
- ✓ **6-8 june: gluing the DLCed foils on the readout -PCBs @ MDT**



Nest steps

- **13-30 June:** etching at **CERN** of the kapton foils to produce the **WELL-pattern**
- **1- 30 July:** closing and preliminary test of the detectors
- **1 sept – 19 oct**: Beam Test preparation
- **19 oct – 8 nov:** Beam Test at H8-B area (LHCb area)

Summary & Outlook

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

- **gas gain ~10^4**
- **intrinsically spark protected**
- **rate capability ~1 MHz/cm^2 for m.i.p (with HR scheme)**
- **space resolution < 60μm**
- **Lot of work/R&D in progress**:
  - ***large area (CMS, SHIP) with LR detector scheme;***
  - ***HR scheme(LHCb) with double resistive layer;***
  - ***large gain with 125μm thick WELL amplification stage (MPGD_NEXT)***

SPARE SLIDES

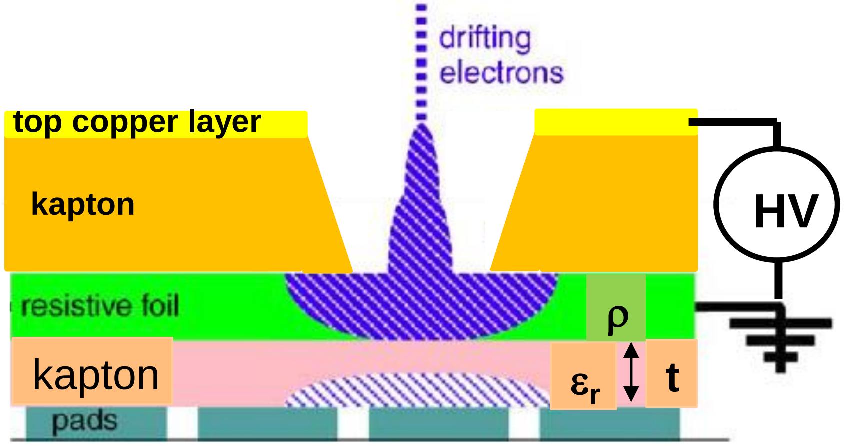
The Goal

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

- **stability under irradiation**
- **construction/assembly procedures**

Principle of operation

A voltage of 400-500 V between the top copper layer and the grounded resistive foil, generates an an electric field of ~100 kV/cm into the **WELL which acts as multiplication channel**



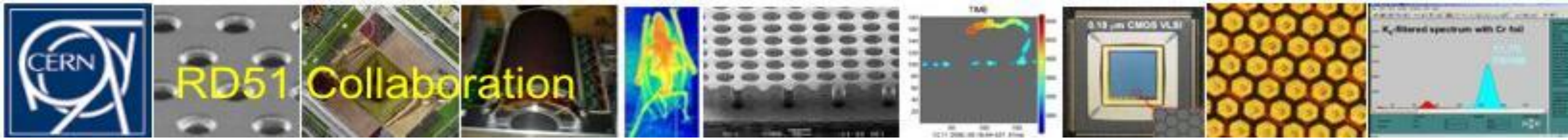
the charge induced on the resistive foil is dispersed with a time constant, RC, determined by

- 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 kapton, $\boldsymbol{\varepsilon_r}$ *[M.S. Dixit et al., NIMA 566 (2006) 281]*

the effect of the introduction of the resistive foil is the suppression of the transition from streamer to spark by a local voltage drop around the avalanche location

the μ-RWELL option for the Muon detector @ $2\times10^{34}cm^{-2}s^{-1}$

G. Bencivenni, M. Poli Lener
LNF - INFN



requirements @ 2×10^{34} cm^{-2} s^{-1}

- ✓ **Rate** up to 3 **MHz/cm²** **with an additional filters in front of M2**
- ✓ **Efficiency** for single gap **> 95%** within a BX (25 ns)
- ✓ **Long stability** up to **6 C/cm²** accumulated charge in **10 y** of operation
- ✓ **Pad cluster size < 1.2**

	Expected max rate MHz/cm² (*)	Active area cm²	Pad Size cm² (*)	Rate/Pad MHz	# pad/gaps	# gaps	#chamber 2 gaps
M2R1	3	30x25	0.63x0.77	1.5	1536	24	12
M2R2	0.5	60x25	1.25x3.15	0.5	384	48	24
M3R1	1	32.4x27	0.67x1.7	1	768	24	12
M3R2	0.15	64.8x27	1.35x3.4	0.15	384	48	24

(*) **average rate is about 50% of maximum rate**

(*) X, Y/4 w.r.t. present logical pads in M2R1; **a factor 2 more in Y, to halve the rate/Pad**
X, Y/2 w.r.t. present logical pads in M2R2, M3R1 and M3R2

in this framework the **GEM detector** is still **a valid option,**
however we are proposing a new detector ➔ **the μ-RWELL**

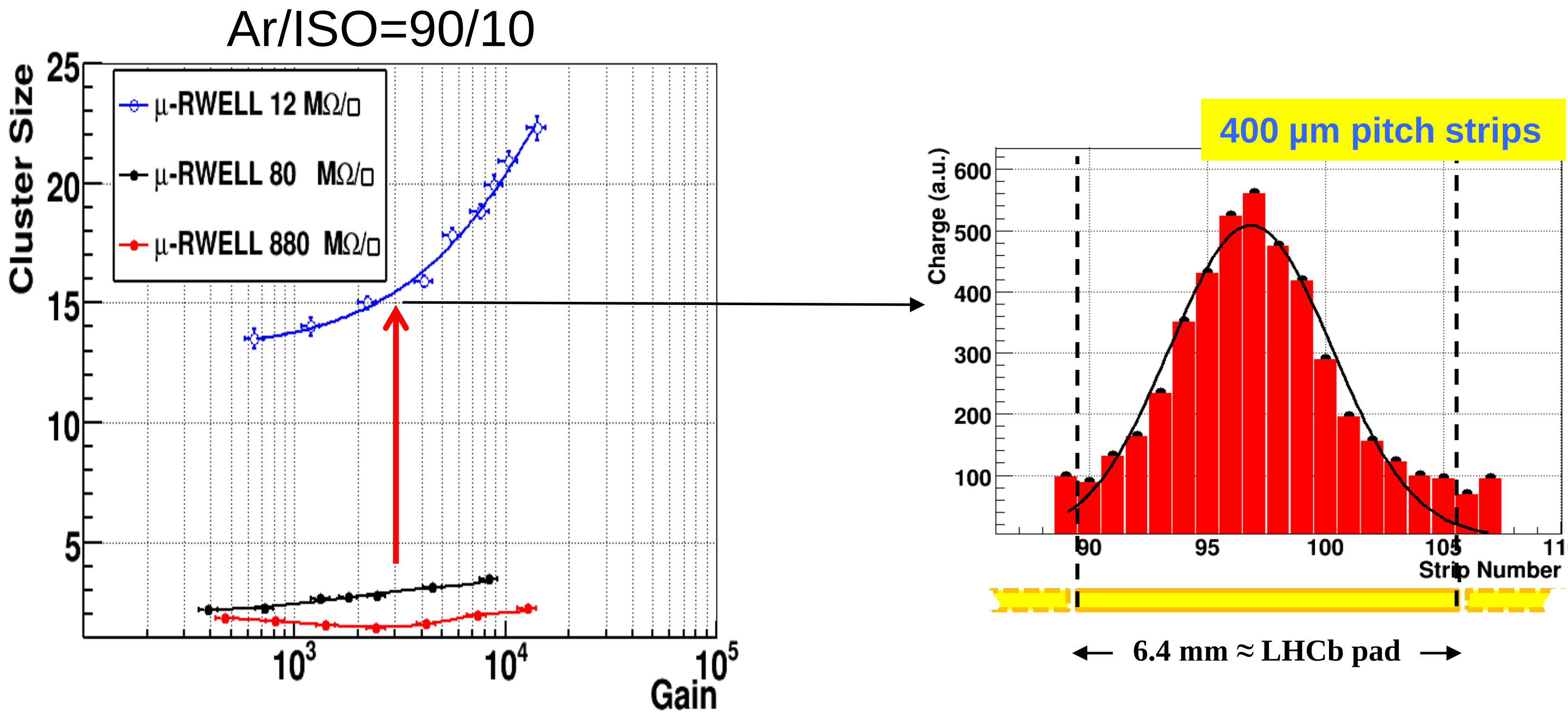
cluster size vs layer resistivity

G. Bencivenni et al., presented @ 13th Pisa Meeting on Advanced detectors & in press on NIMA

test beam measurements:

H4 Beam Area (RD51), $P_{\mu\text{-beam}}$ = 150 GeV/c, B up to 1.4 T

μ-RWELL prototypes with 12-80-880 MΩ /☐, readout 400 μm pitch strips



use of **low resistivity increases the charge spread (cluster size)** on the readout strips

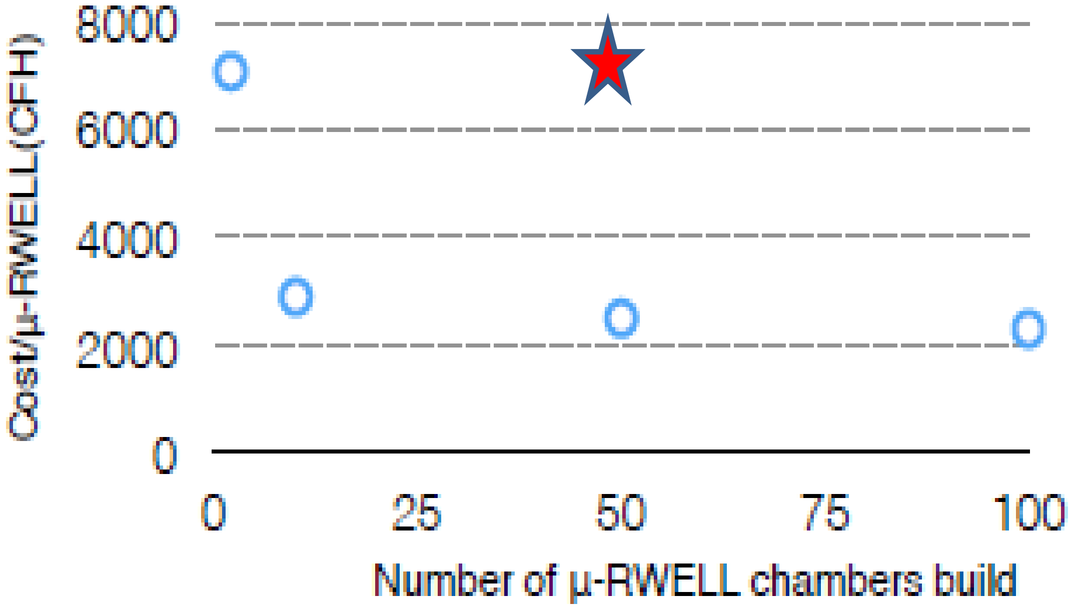
but ➔ measured charge spread ≈ 16 strips = 6.4 mm ≈ X_{PAD_LHCb}

and the expected cluster size for LHCb is ≈1

Cost of μ-RWELL and GEM for large volume production

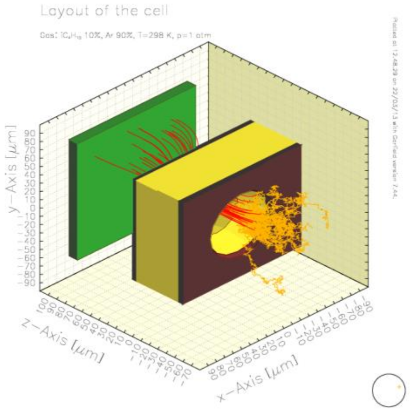
Open dots: cost estimate (by ELTOS SpA) of a1.2x0.5m^2 μ-RWELL

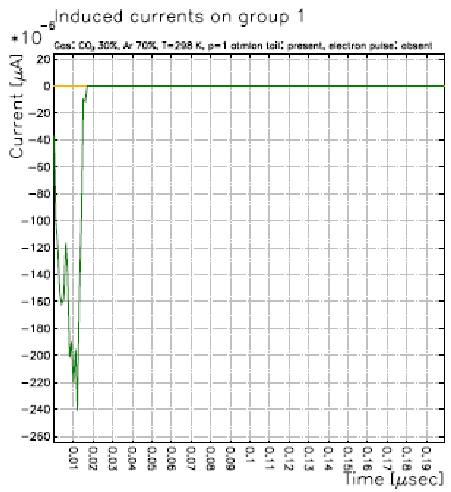
Star: cost (by CERN) of a 1.2x0.5 m^2 GEM



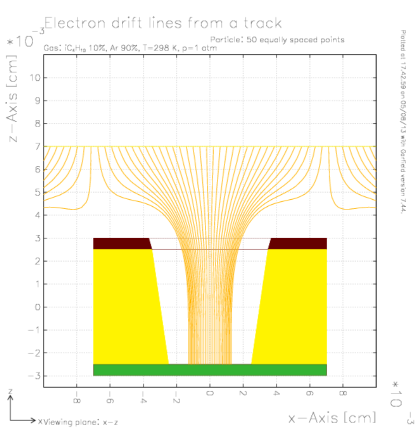
The µ-RWELL vs GEM (Garfield simulation)

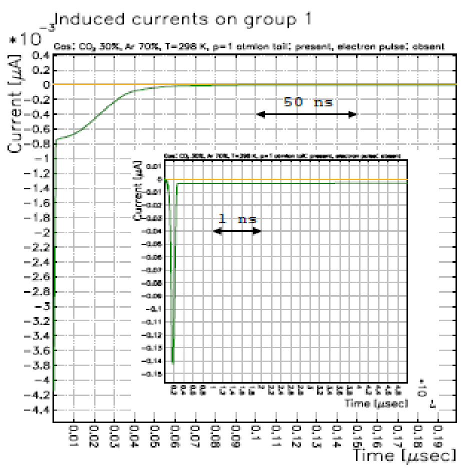
GEM – Ar:CO2 70:30 gas mixture





Signal from a single ionization electron in a GEM.
The duration of the signal, about 20 ns, depends on the induction gap thickness, drift velocity and electric field in the gap.





Signal from a single ionization electron in a µ-RWELL.
The absence of the induction gap is responsible for the fast initial spike, about 200 ps, induced by the motion and fast collection of the electrons and followed by a ~50 ns ion tail.

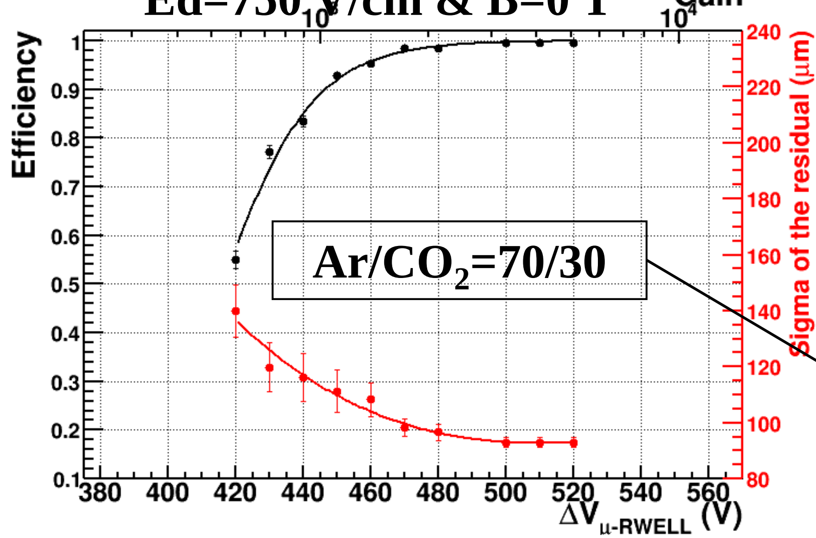
µ-RWELL – Ar:CO2 70:30 gas mixture

TB June 2015 B=0T & θ=0°

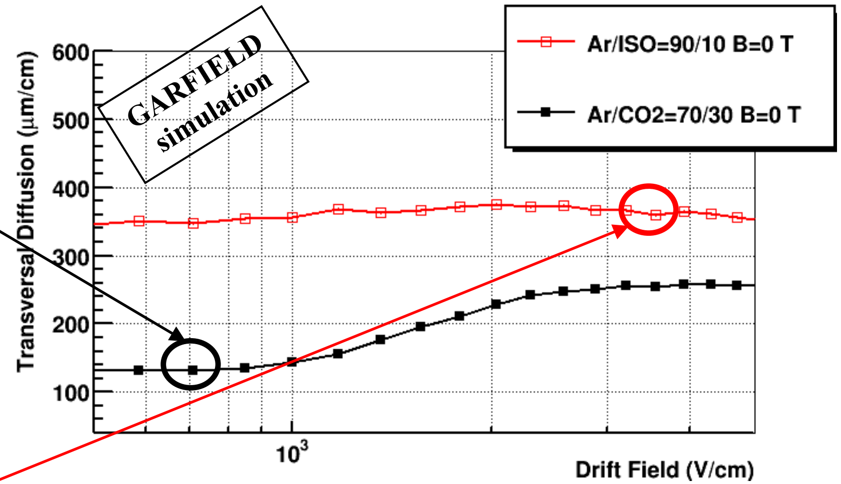
Efficiency & Residual vs gas mixture

σ-Residual w/out TRK subtraction

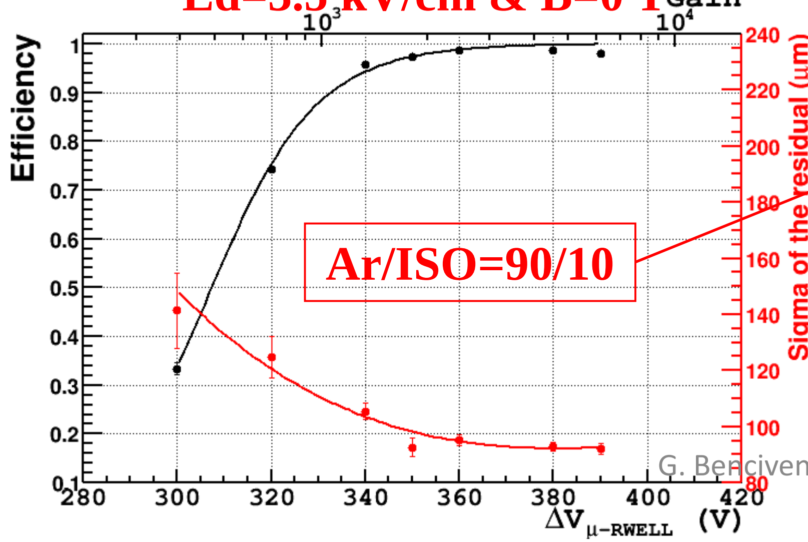
June 2015 – Ar/CO_2=70/30
Ed=750 V/cm & B=0 T



~60 µm on 4 mm gap



June 2015 – Ar/ISO=90/10
Ed=3.5 kV/cm & B=0 T



~ 140 µm on 4 mm gap

No large difference observed between Ar/CO_2 & Ar/ISO due to:

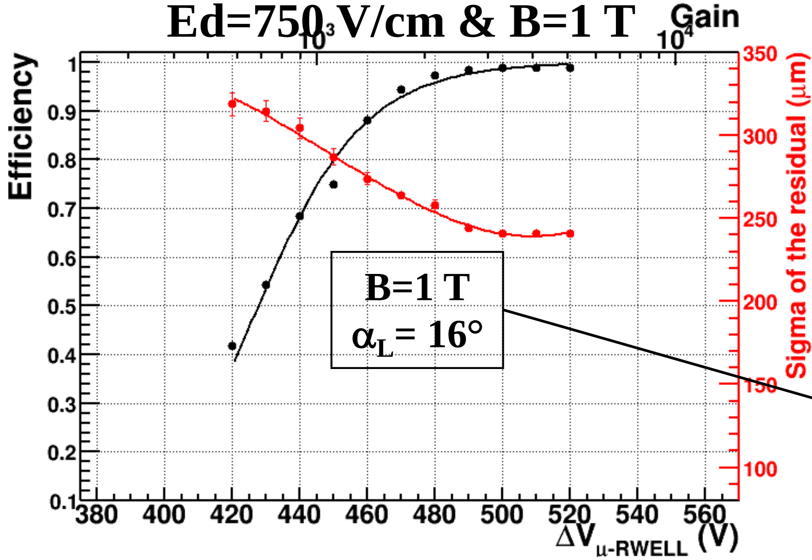
- µ-RWELL compactness
- relatively large strip pitch (400 µm)

TB June 2015, B=1T & θ=0°

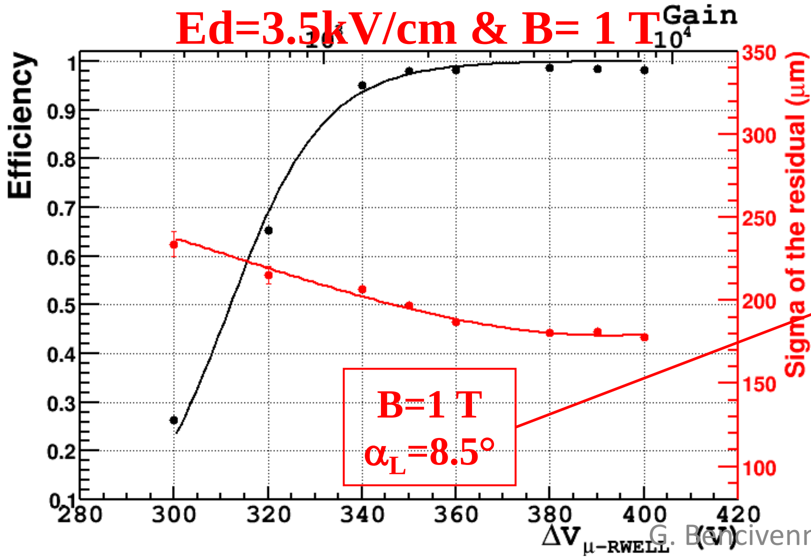
Efficiency & Residual vs gas mixture

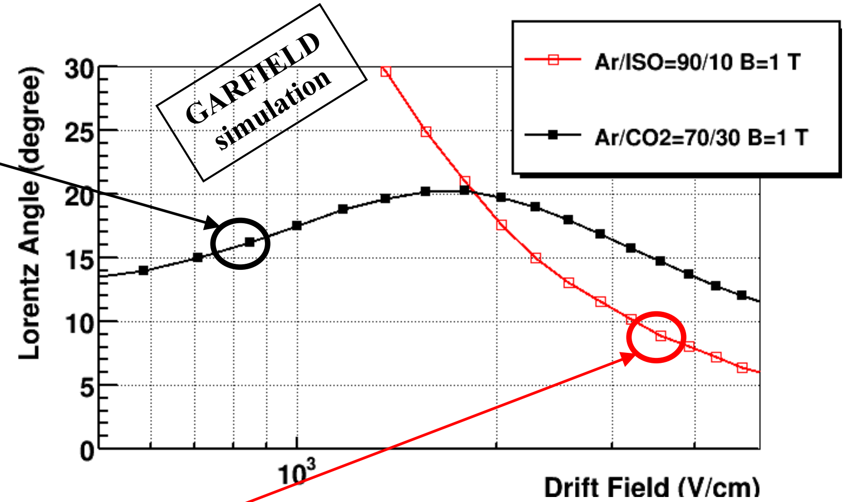
σ-Residual w/out TRK subtraction

Ar/CO_2=70/30
Ed=750 V/cm & B=1 T



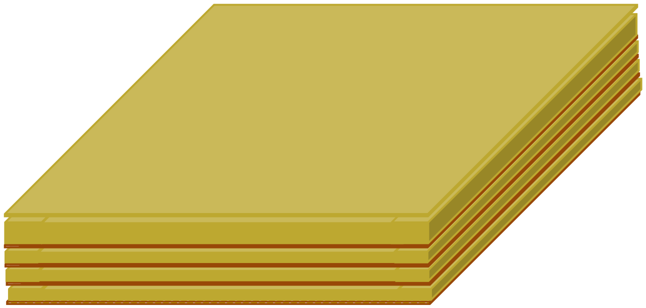
Ar/ISO=90/10
Ed=3.5kV/cm & B= 1 T

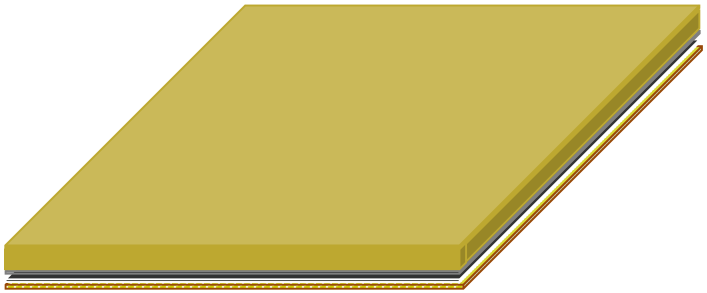




The difference on the residual is probably due to the diverse Lorentz angle

The µ-RWELL: a GEM-MM mixed solution





µ-RWELL

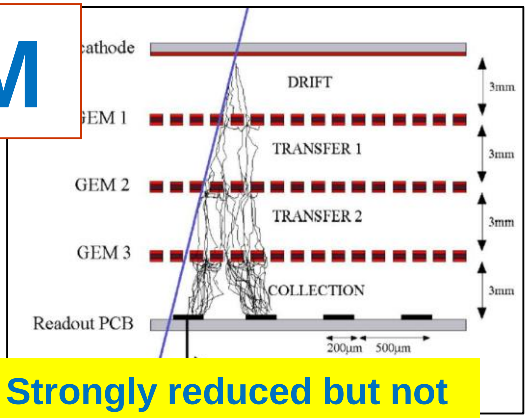
GEM detector sketch

MM detector sketch

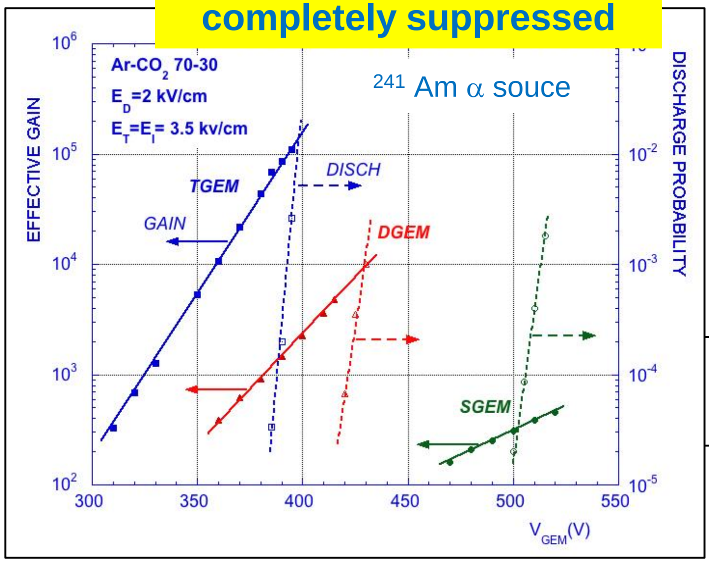
MPGDs: stability

The **biggest "enemy"** of MPGDs are the **discharges.**
Due to the **fine structure** and the **typical micrometric distance of their electrodes**, MPGDs generally suffer from **spark occurrence** that can be **harmful for the detector and the related FEE.**

GEM

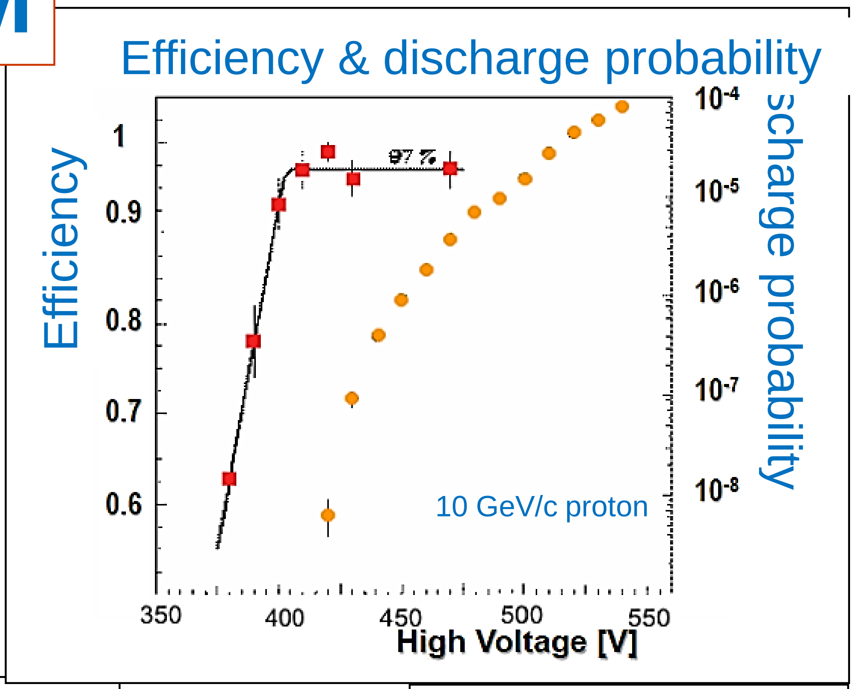


Strongly reduced but not completely suppressed



S. Bachmann et al., NIMA A479(2002) 294

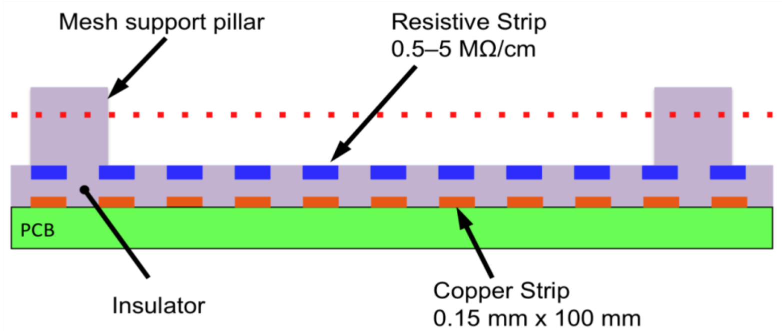
MM



A. Bay et al., NIMA 488 (2002) 162

Technology improvement: resistive MPGD

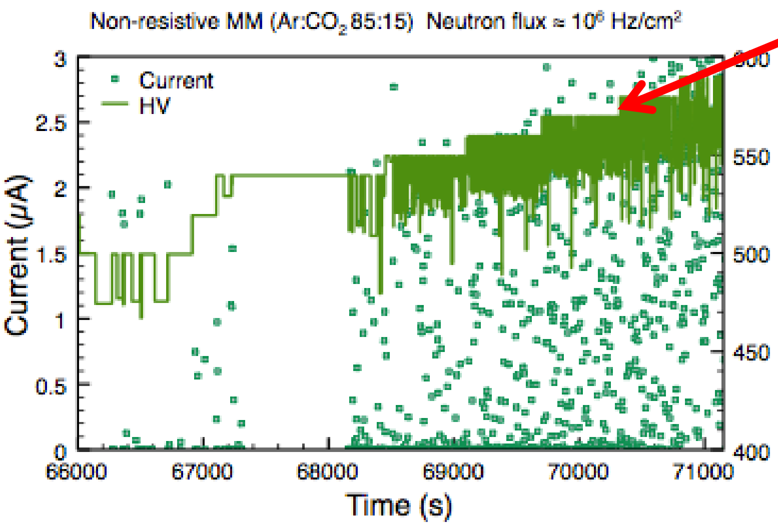
For **MM**, the spark occurrence between the metallic mesh and the readout PCB has been overcome with the **implementation** of **a “resistive layer”** on top of the readout itself . The principle is the **same as the resistive electrode used in the RPCs: the transition from streamer to spark is strongly suppressed by a local voltage drop.**

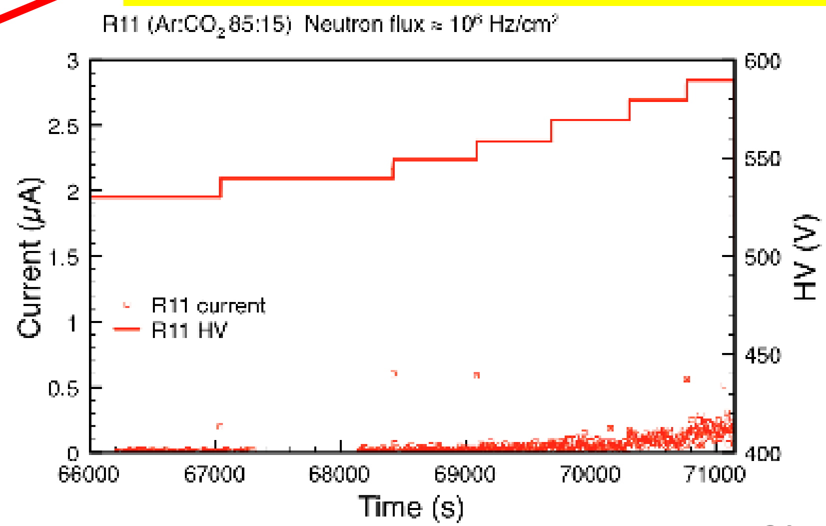


by R.de Oliveira TE MPE CERN Workshop

The resistive layer is realized as resistive strips capacitive coupled with the copper readout strips.

voltage drop due to sparking





MPGDs: the challenge of large area

A further **challenge for MPGDs** is the **large area:**

NS2(CERN): no gluing but still stretching …

- the construction of a **GEM** requires some time-consuming (/complex) assembly steps such as:
  - the **stretching of the 3 GEM foils** (with quite **large mechanical tension** to cope with, ~1 kg/cm)
  - the **splicing of GEM foils** to realize large surfaces is a **demanding operation** introducing **not negligible dead zones (~3 mm)**. The width of the **raw material is limited to 50-60 cm**.

- similar considerations hold for **MM**:
  - ✓ the **splicing of smaller PCBs is possible**, opening the way towards the large area covering (**dead zone of the order 0.3 – 0.5 mm**).
  - The **fine metallic mesh**, defining the amplification gap, is a "*floating component*" stretched on the cathode (**~**1 kg/cm) and **electrostatically attracted toward the PCB**

➡ **Possible source of gain non-uniformity**

Handling of a stretched mesh

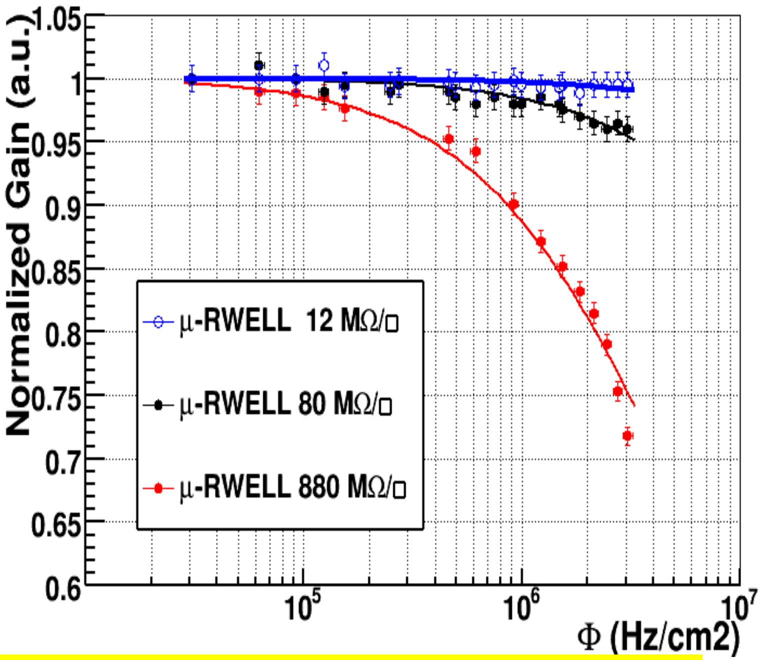
μ-RWELL: rate capability(II) vs layer resistivity

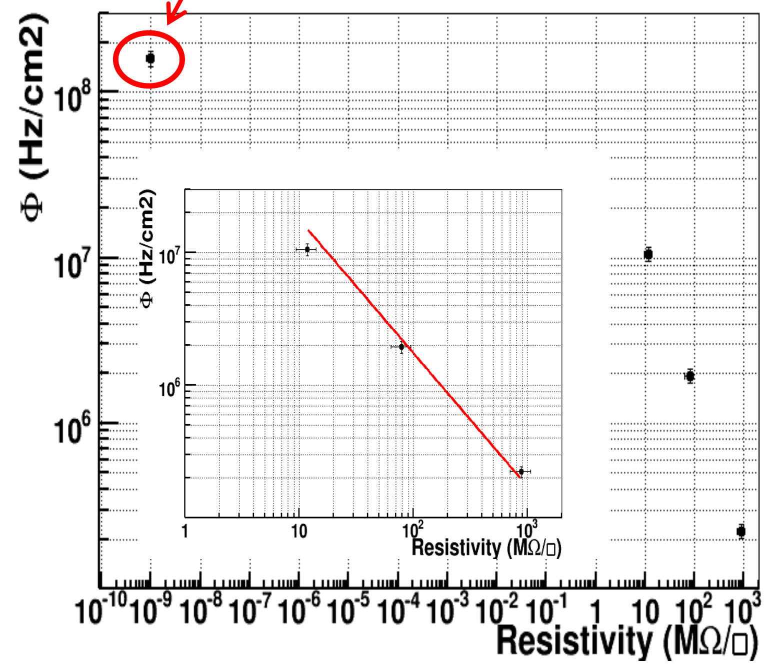
Bellazini et al. NIMA 423 (1999) 125
Sauli et al., NIMA 419 (1998) 410.

Ar/Iso - 2,5 mm Diameter Collimator

Gain =1000

Rate for a drop ΔG=-3%





Model based on a pure Ohmic behaviour

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

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

G. Bencivenni *et al.*, 2015_JINST_10_P02008

Resistivity declared by the deliverer: 1 GOhm/square
Resisivity=883.782 MOhm/square +- 176.756

Resistivity declared by the deliverer: 80 MOhm/square
Resisivity=79.2628 MOhm/square +- 15.8526

Resistivity measured by us: 7.5 MOhm/square
Resisivity=11.7345 MOhm/square +- 2.3469