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Advances in μ-RWELL technology

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OUTLINE

- Introduction
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- Detector performance
- Towards a large area μ-RWELL
- Summary

Introduction

MicroPattern Gas Detectors (MPGD) due to their performance are ideal tools for :

- **fundamental research** (*Compass, LHCb, Totem, KLOE, Jlab, LHC experiments upgrades*)
- **applications beyond science** (*medical, industrial, neutron ...)*

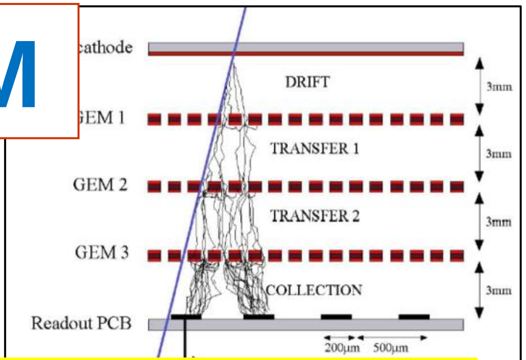
In spite of the recent relevant progress in the field, **still dedicated R&D studies are required** for:

- **stability under heavy irradiation** (discharge containment)
- **simplified construction technologies**, a MUST for
    - very large scale applications in fundamental research
    - technology dissemination beyond HEP

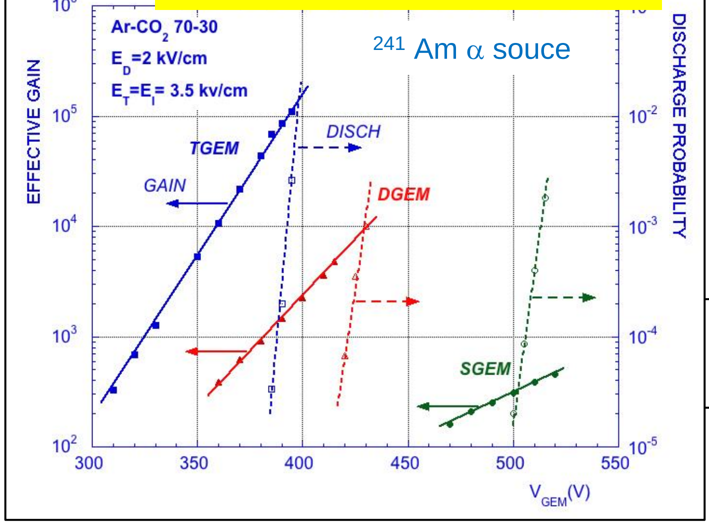
MPGDs: stability

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

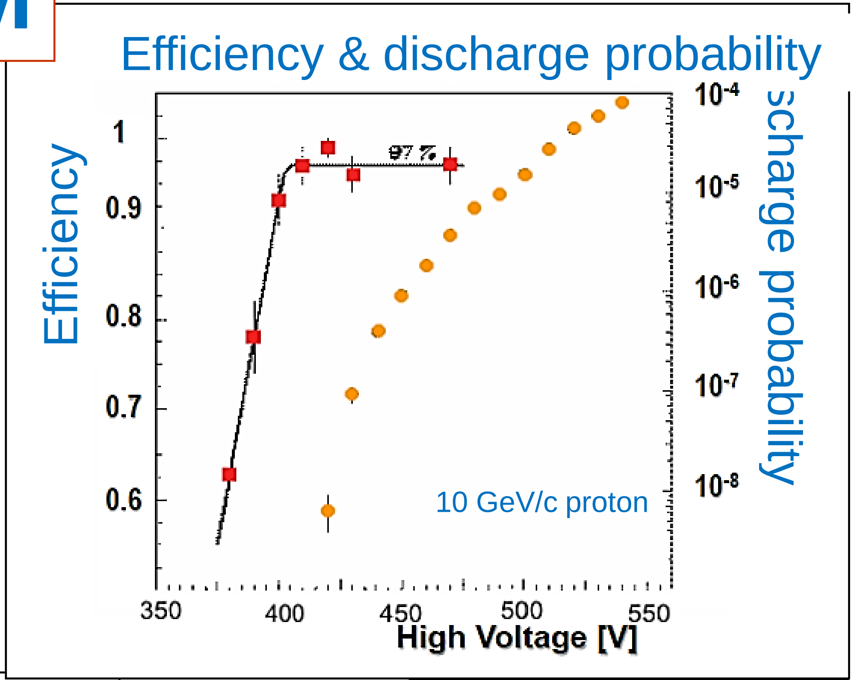


Strongly reduced but not completely suppressed



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

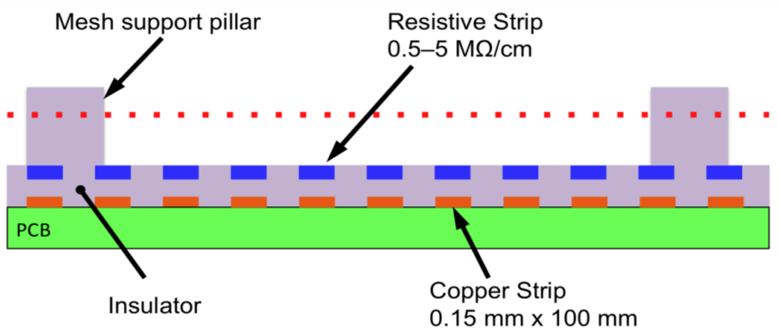
MM



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

Technology improvement: resistive MPGD

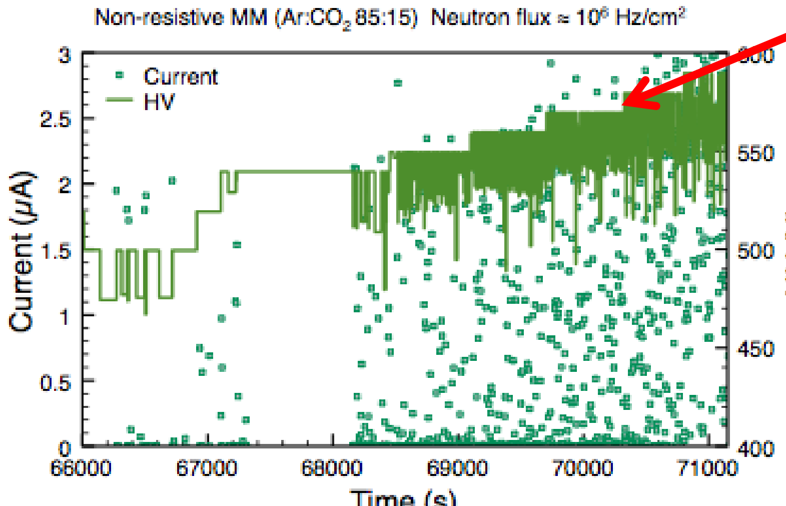
For **MM,** the spark occurrence between the metallic mesh and the readout PCB has been overcome with the **implementation** of **a "resistive layer"** on top of the readout itself . The principle is the **same as the resistive electrode used in the RPCs: the transition from streamer to spark is strongly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

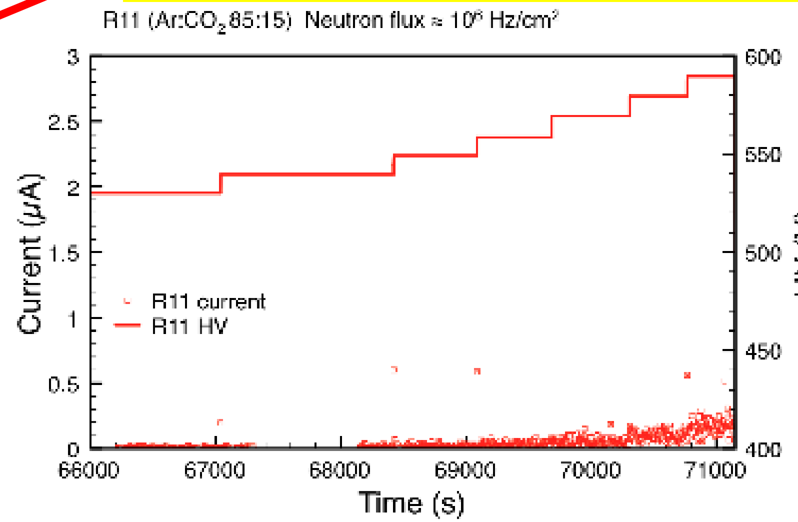


by R.de Oliveira TE MPE CERN Workshop

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**, especially in view of their applications in the large HEP experiments, is the **large area:**

- 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 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**

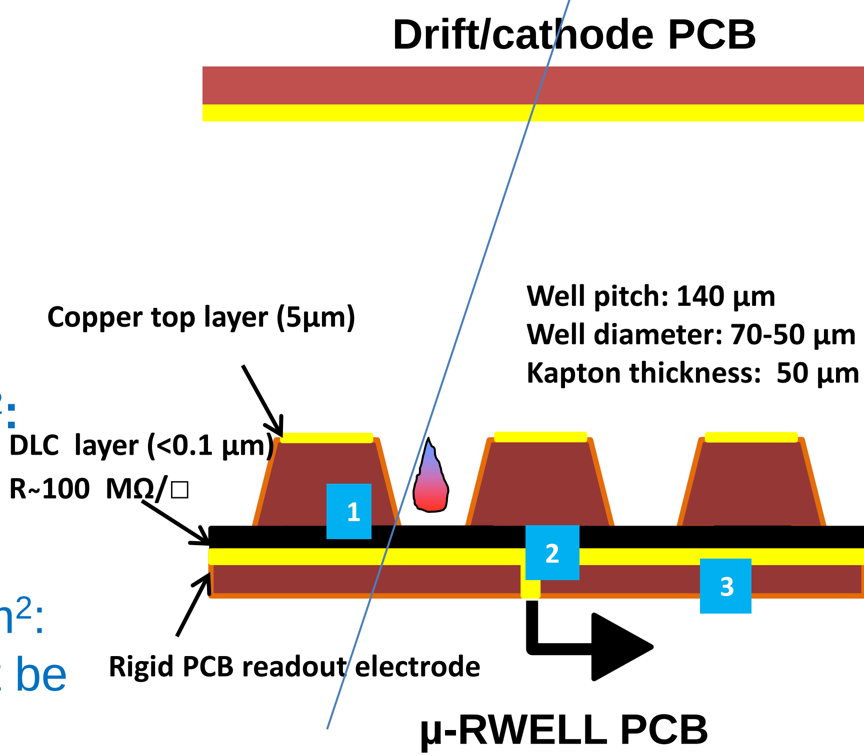
NS2(CERN): no gluing but still stretching …

Handling of a stretched mesh

The µ-RWELL architecture

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)
   - **ii. "High particle rate" (HR)** >> 100 kHz/cm^2: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF)
3. a **standard readout PCB**

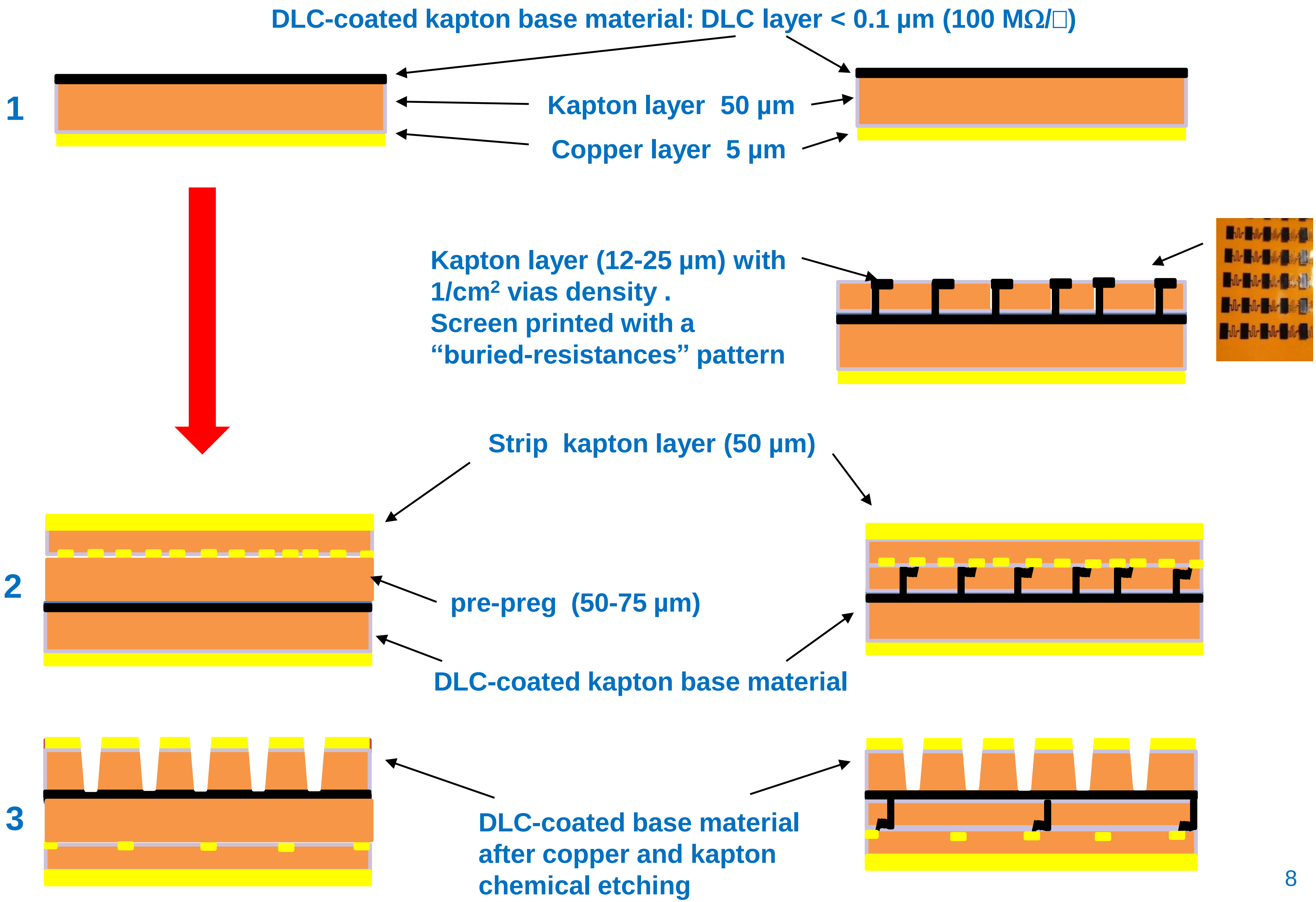


G. Bencivenni et al., 2015_JINST_10_P02008

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

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

LR scheme: single resistive layer | **HR** scheme: double resistive layers



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** :

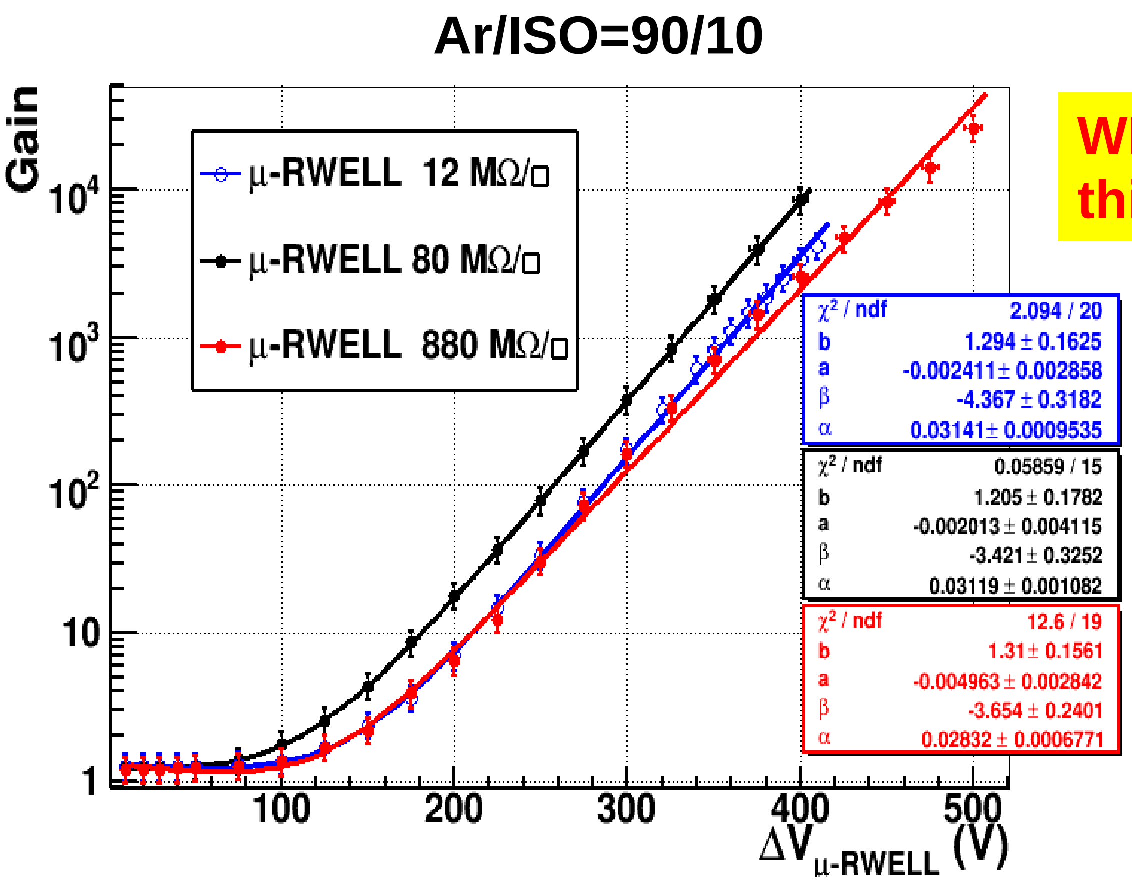
- inherits and improves the **GEM amplifying scheme** with the peculiarity of a "**well defined amplifying gap**", but ensuring **higher and more uniform gas gain,** with no transfer/induction gaps whose non-uniformity can affect the detector gain

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

The μ-RWELL performance: Lab Test

μ-RWELL: gas gain

The prototypes have been tested with an **X-Ray** gun (5,9 keV) with **Ar/CO_2 =70/30, Ar/i-C_4H_{10} =90/10** gas mixtures and characterized by measuring the **gas gain, rate capability** and studying the **discharge** behaviour in **current mode**.

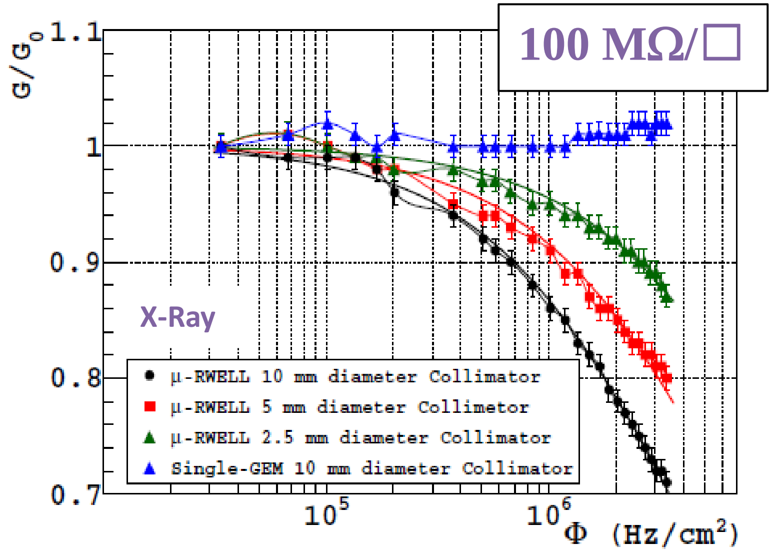


WELL kapton thickness = 50μm

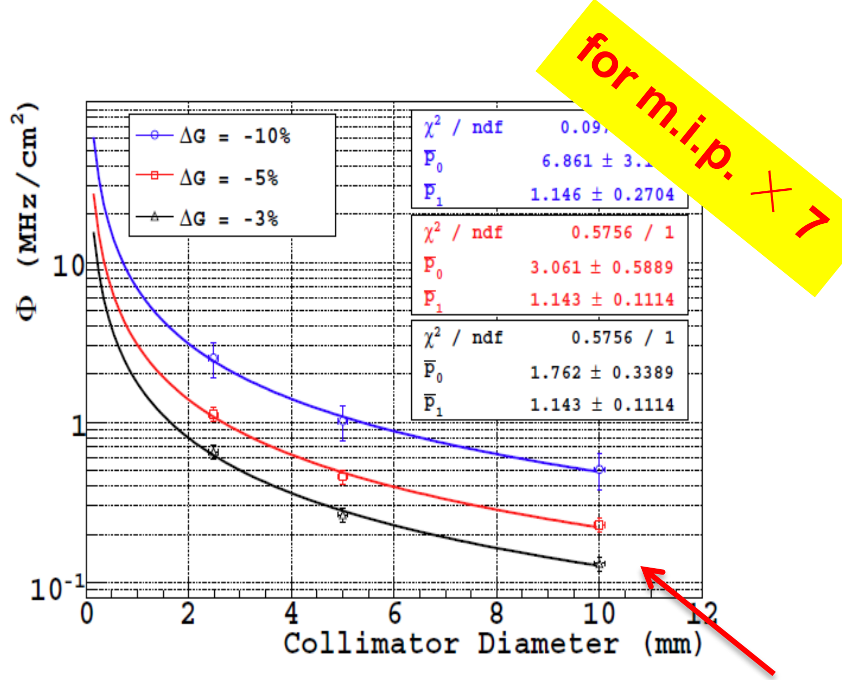
μ-RWELL: rate capability(I)

A **drawback** correlated with the implementation of a **resistive layer** is the **reduced capability** to **stand** high **particle fluxes**

Ar/CO_2 – $G_{\mu\text{-RWELL}}$ = 2000, G_{GEM} ~ 1000



collimator aligned with the center of the detector



150-200 kHz/cm² with X-Rays corresponding to 1 – 1.5 MHz/cm² m.i.p.

Taking into account that:

- the ionization of a **m.i.p. is a factor 7 smaller than X-rays**
- the resistive stage can be **suitably segmented** in order to evacuate the current every **~ 1x1 cm²** (a sort of **"matrix of resistive pads put at ground" → HR scheme)**

a rate of **~1 MHz/cm² for m.i.p. should be easily achieved (tbd)**

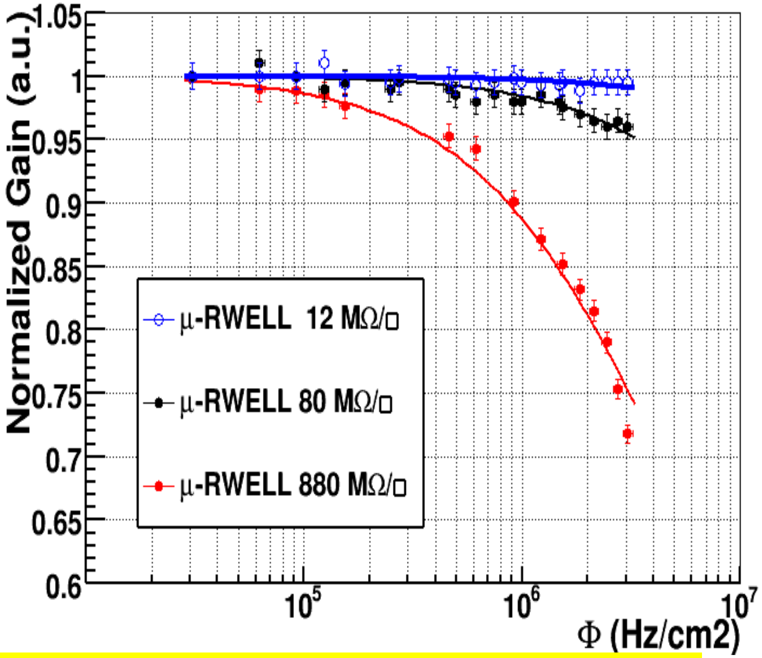
μ-RWELL: rate capability(II) vs layer resistivity

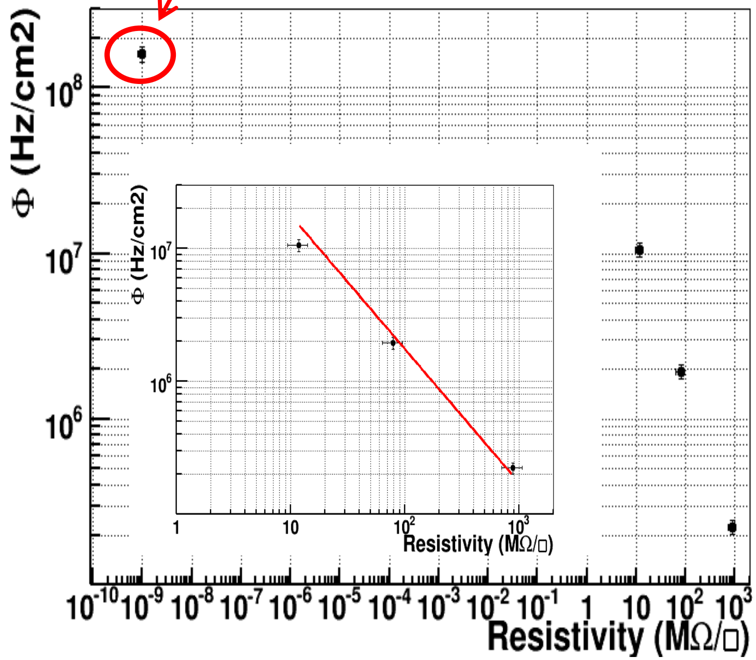
Bellazini et al. NIMA 423 (1999) 125
Sauli et al., NIMA 419 (1998) 410.

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

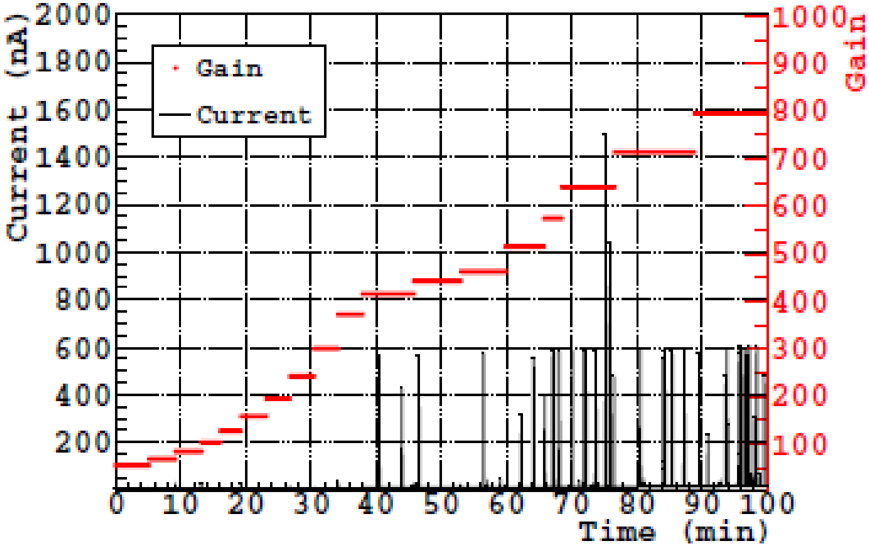
Resistivity declared by the deliverer: 80 MOhm/square
Resisivity=79.2628 MOhm/square +- 15.8526

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

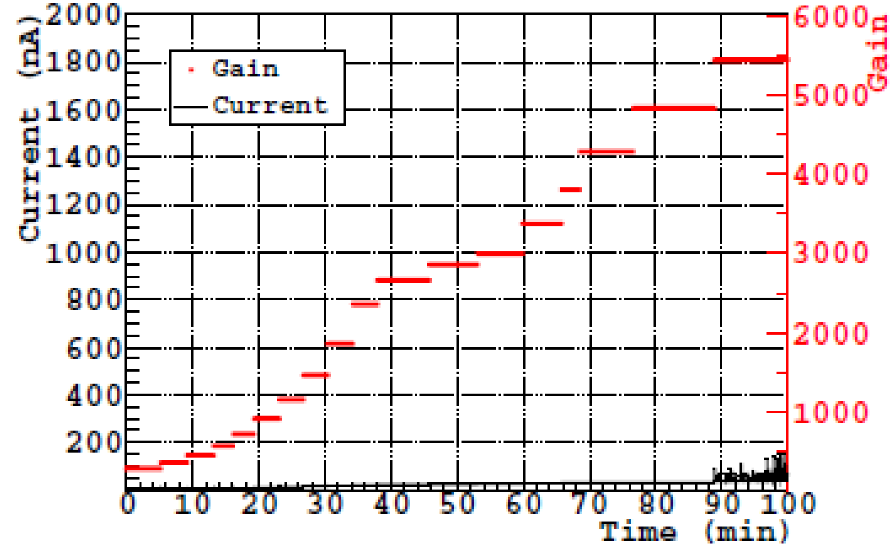
µ-RWELL: discharge study

Discharge study (qualitative): µ-RWELL vs GEM

Single-GEM



µ-RWELL



- for **µ-RWELL** discharge amplitude of the order of **few tens of nA (<100 nA @ max gain)**

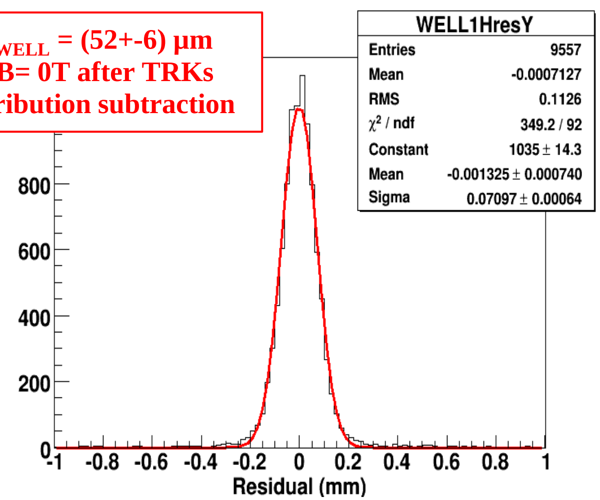
- for **GEM** discharge amplitude of the order of **1µA**

More quantitative studies must be clearly performed

The μ-RWELL performance: Beam Tests

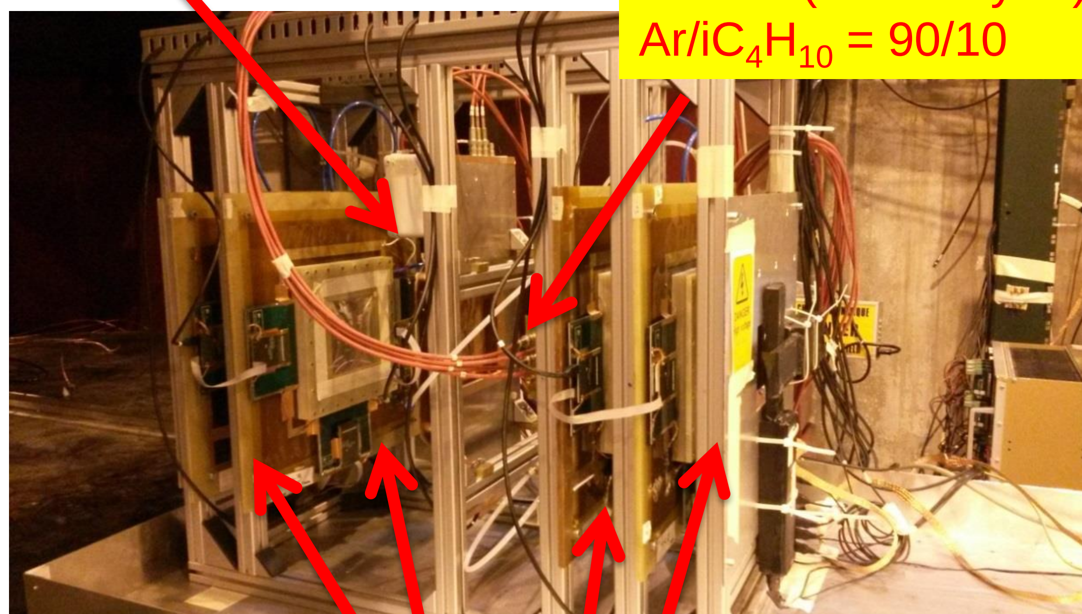
H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

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



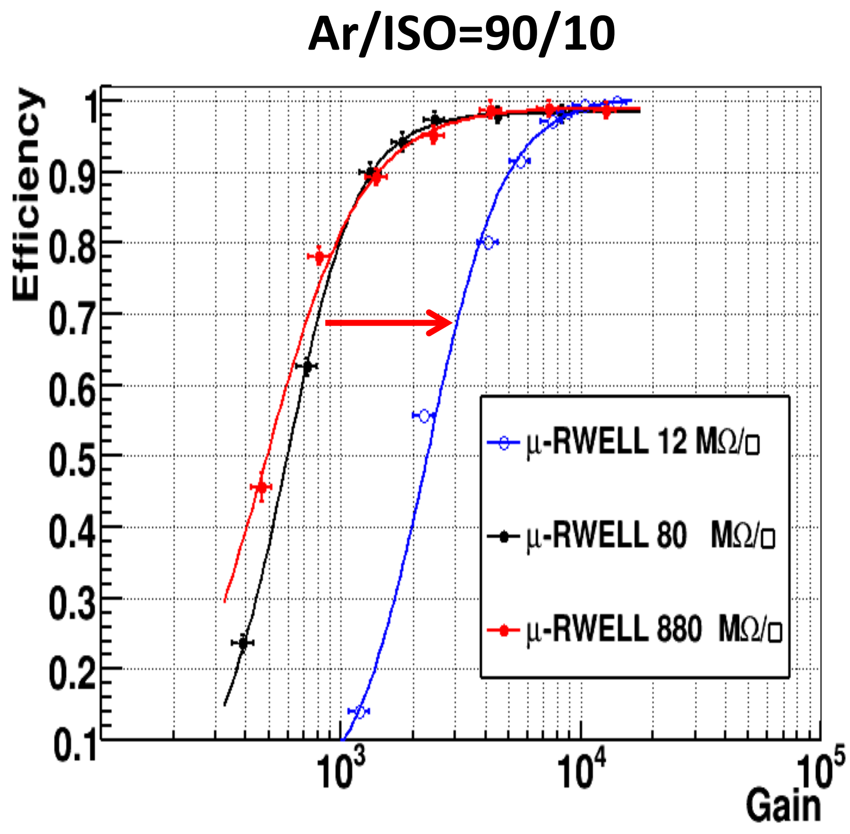
BES III-GEM chambers

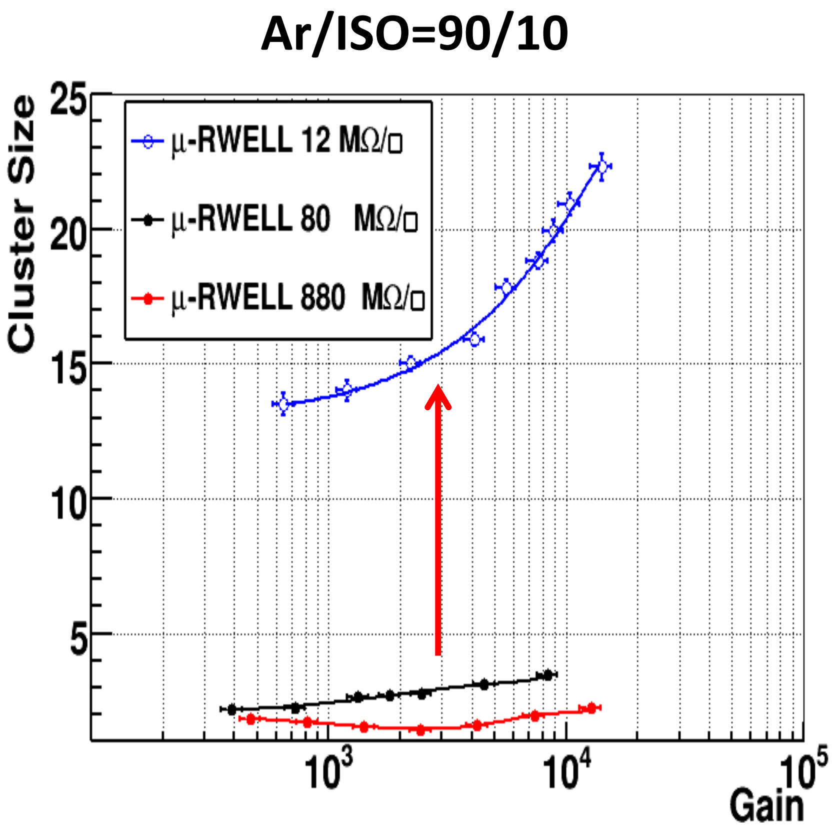
μ-RWELL prototype
12-80-880 MΩ /□
400 μm pitch strips
APV25 (CC analysis)
Ar/iC_4H_{10} = 90/10



GEMs Trackers

μ-RWELL: tracking efficiency

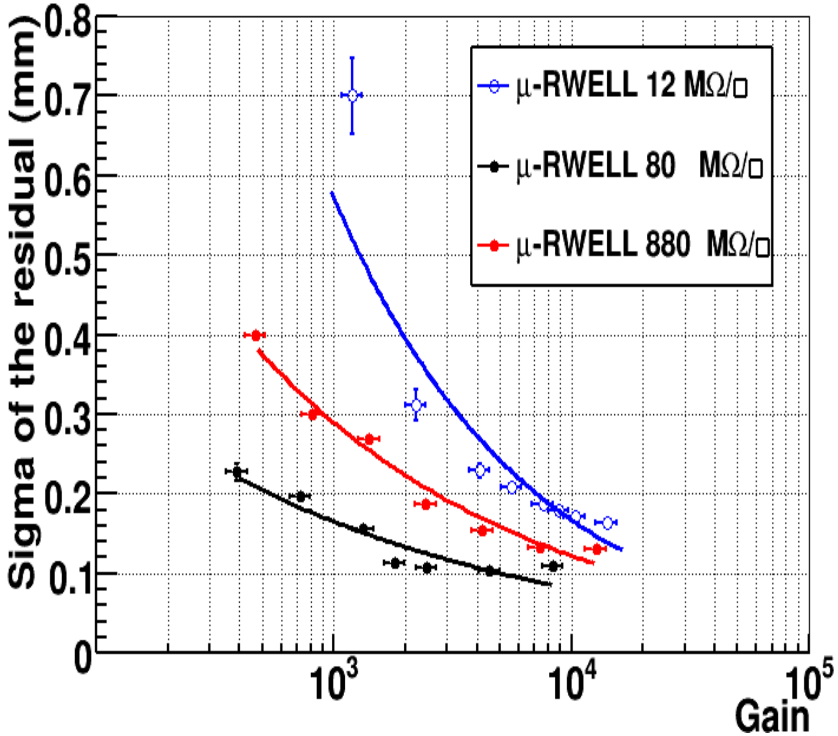




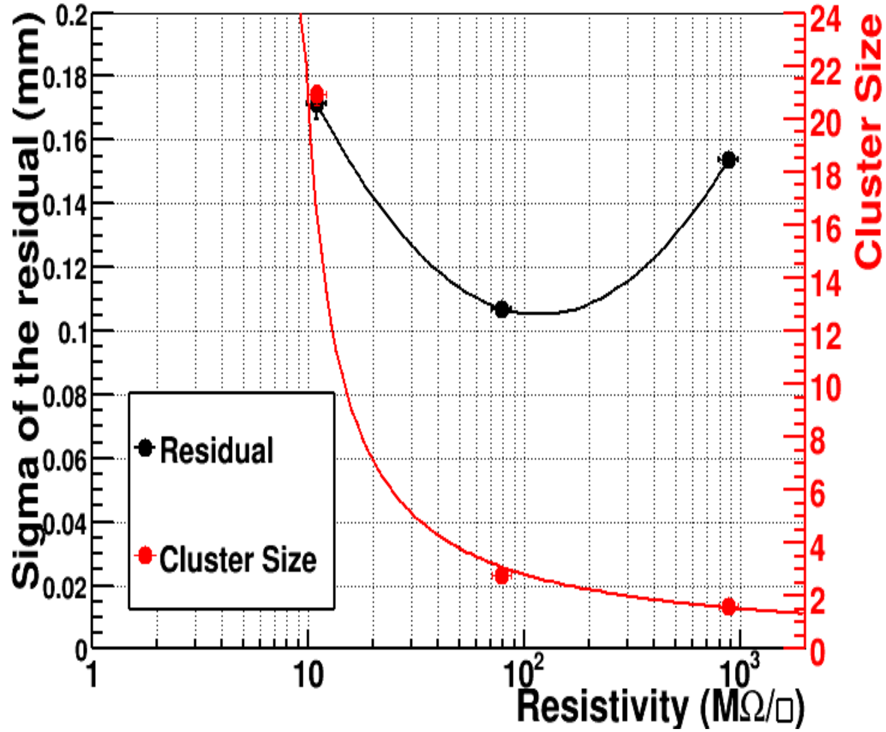
At **low resistivity the spread of the charge** (cluster size) on the readout strips **increases**, thus requiring a **higher gain** to reach the **full detector efficiency.**

Space resolution: orthogonal tracks

Ar/ISO=90/10



Ar/ISO=90/10



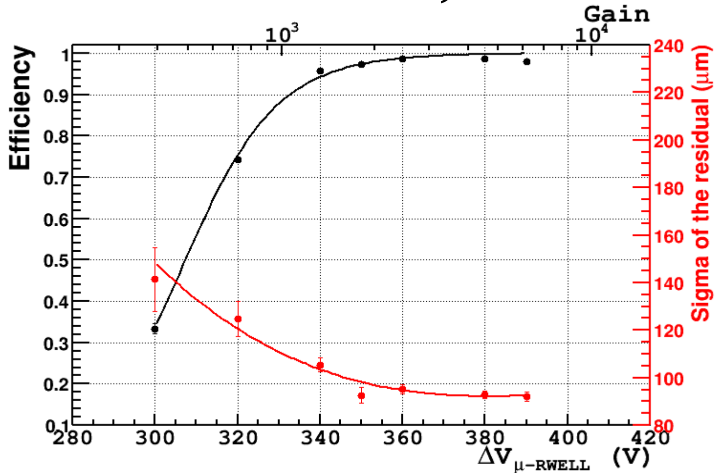
The **space resolution** exhibits a **minimum around 100MΩ/□.**

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

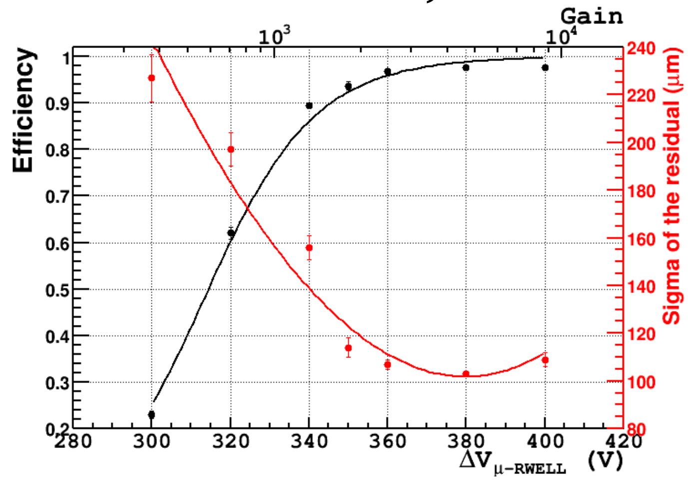
At **high resistivity** the **charge spread is too small (Cl_size → 1)** then the Charge Centroid method becomes no more effective **(σ → pitch/√12).**

µ-RWELL: B≠0 with Ar/ISO=90/10

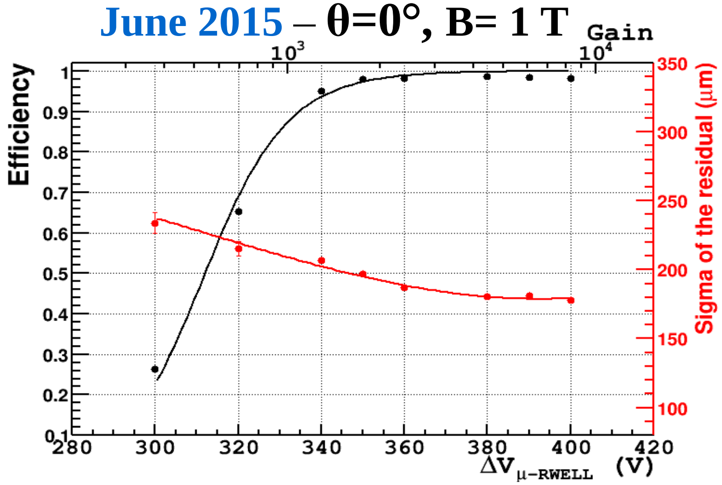
June 2015 – θ=0°, B= 0 T



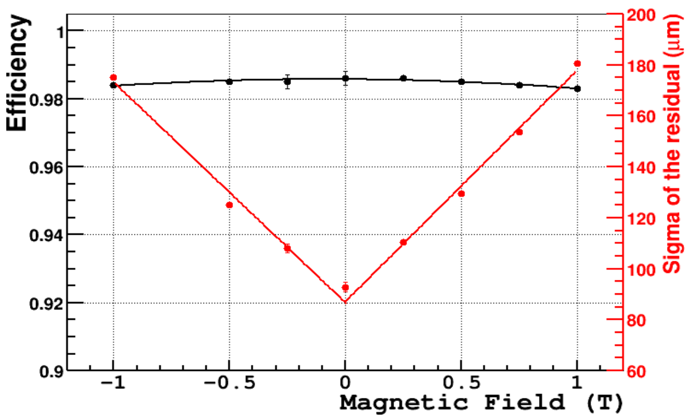
Dec 2014 – θ=0°, B= 0.5 T



June 2015 – θ=0°, B= 1 T



June 2015 - θ=0°

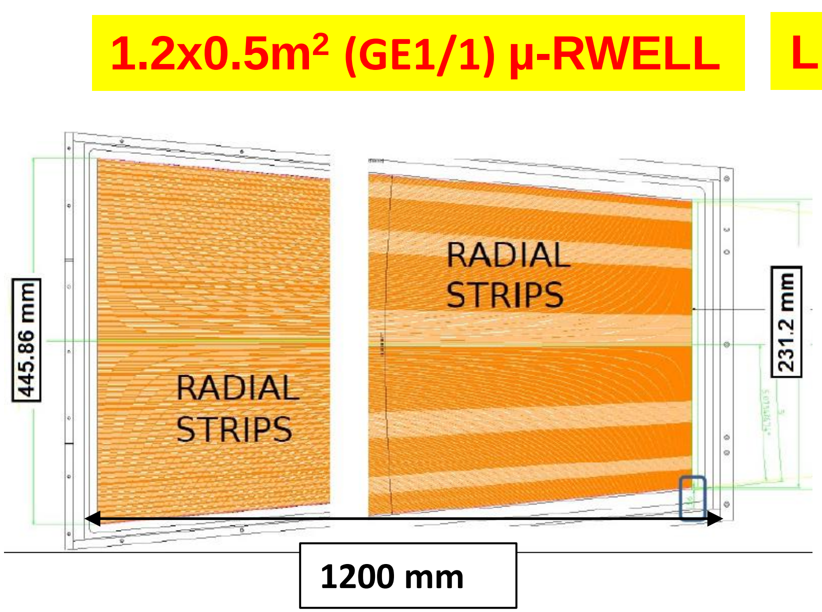


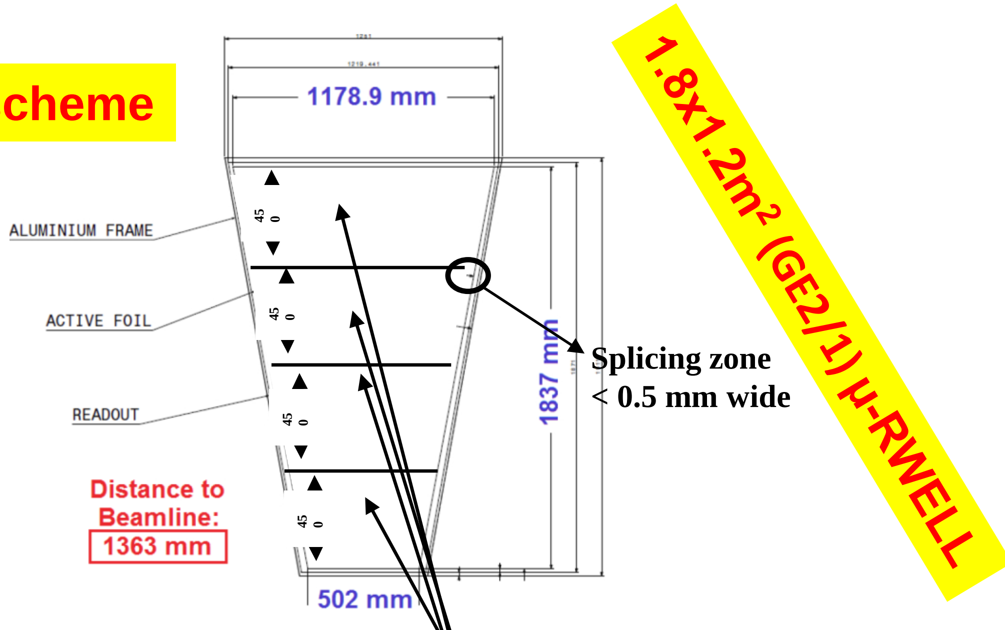
For **θ=0° and 0 < B < 1 T** ➡ **σ < 180 µm** and **ε > 98%**

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 an Italian industrial partner (**ELTOS SpA**). The work will be performed in **two years** with following schedule:

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





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

Summary

The **μ-RWELL is the new frontier of MPGD**:

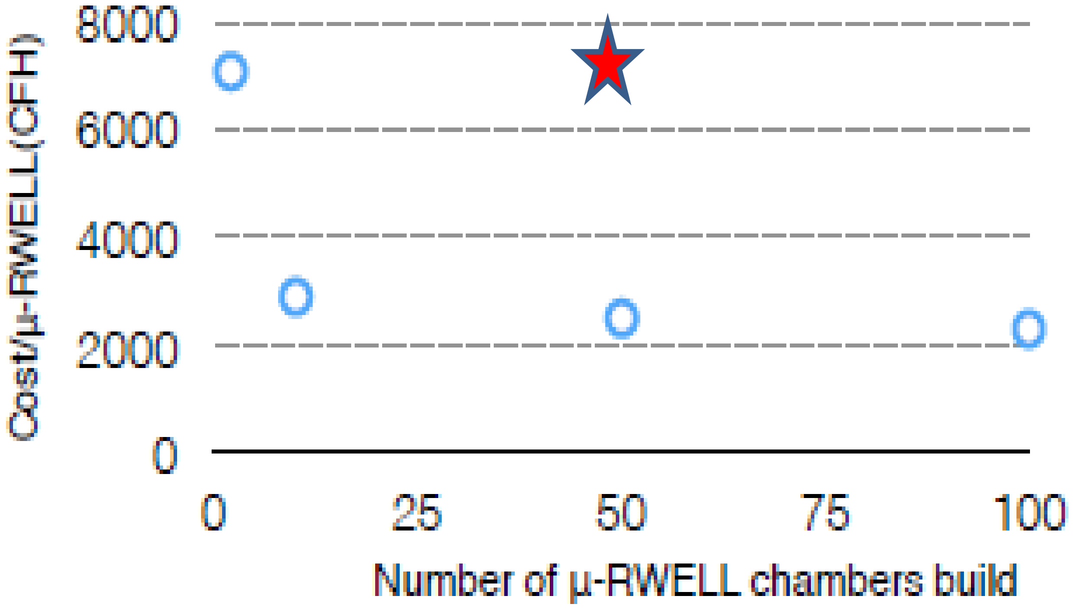
- **compact**
- **simple to assemble & suitable for large size**
- **gas gain ~10^4**
- **intrinsically spark protected**
- **rate capability ~1 MHz/cm^2 for m.i.p**
- **space resolution < 60μm**
- **work in progress**: *large area (CMS, SHIP); high rate with HR scheme(LHCb); larger gain with 125μm thick WELL amplification stage (MPGD_NEXT)* → *PHD position opening in Frascati Lab*

Spare slides

Cost of μ-RWELL and GEM for large volume production

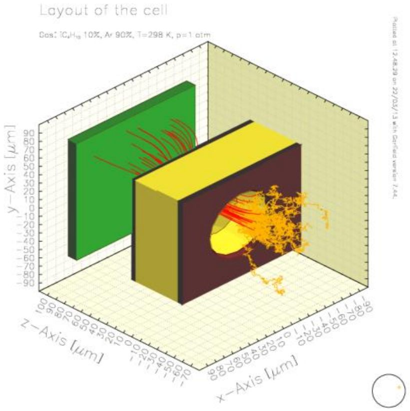
Open dots: cost estimate (by ELTOS SpA) of a1.2x0.5m^2 μ-RWELL

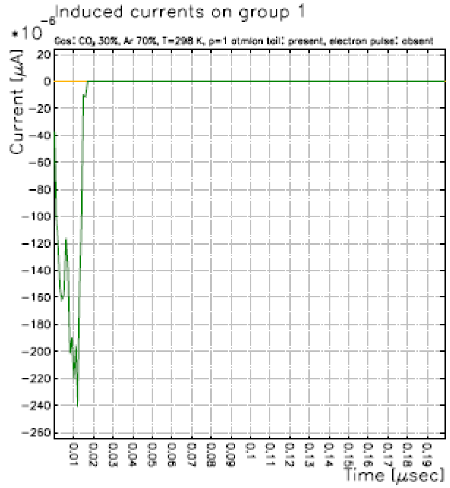
Star: cost (by CERN) of a 1.2x0.5 m^2 GEM



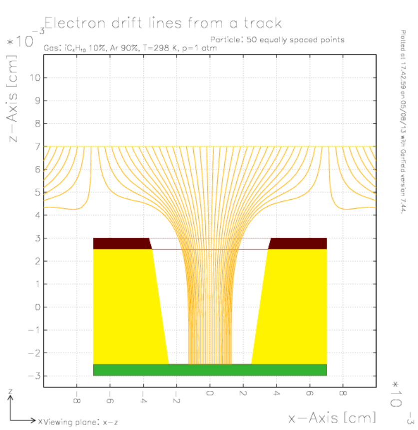
The μ-RWELL vs GEM (Garfield simulation)

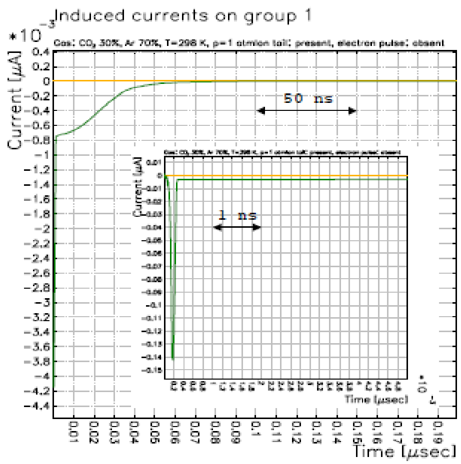
GEM – Ar:CO2 70:30 gas mixture





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.



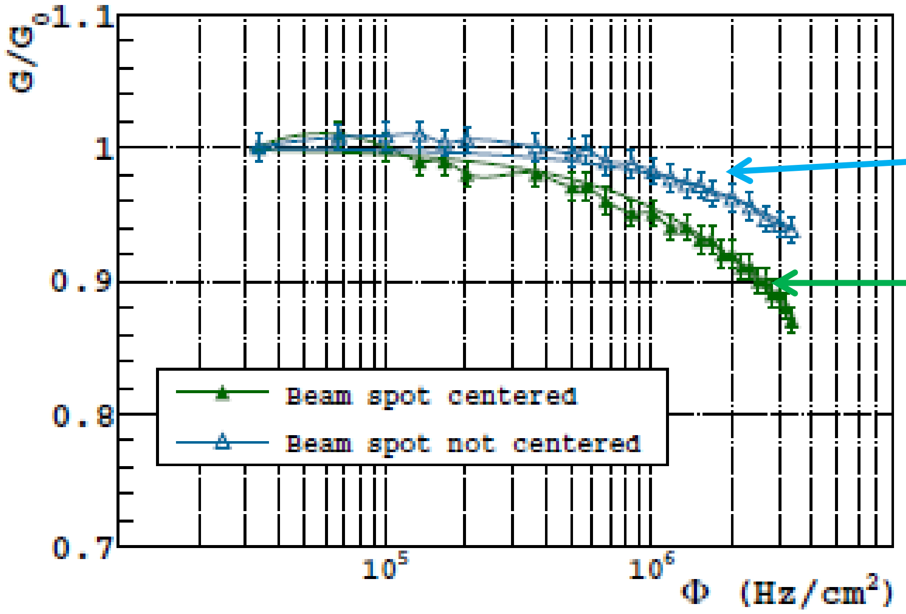


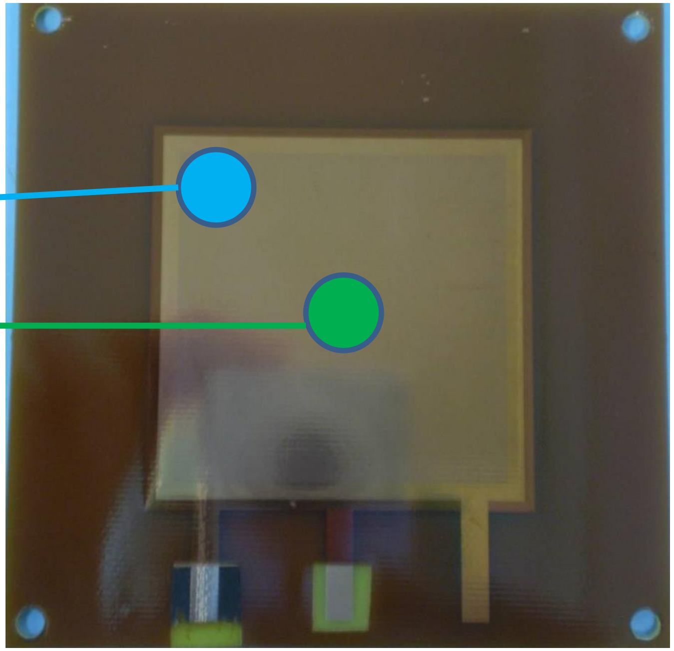
Signal from a single ionization electron in a μ-RWELL.
The absence of the induction gap is responsible for the fast initial spike, about 200 ps, induced by the motion and fast collection of the electrons and followed by a ~50 ns ion tail.

μ-RWELL – Ar:CO2 70:30 gas mixture

The μ-RWELL performance (VI)

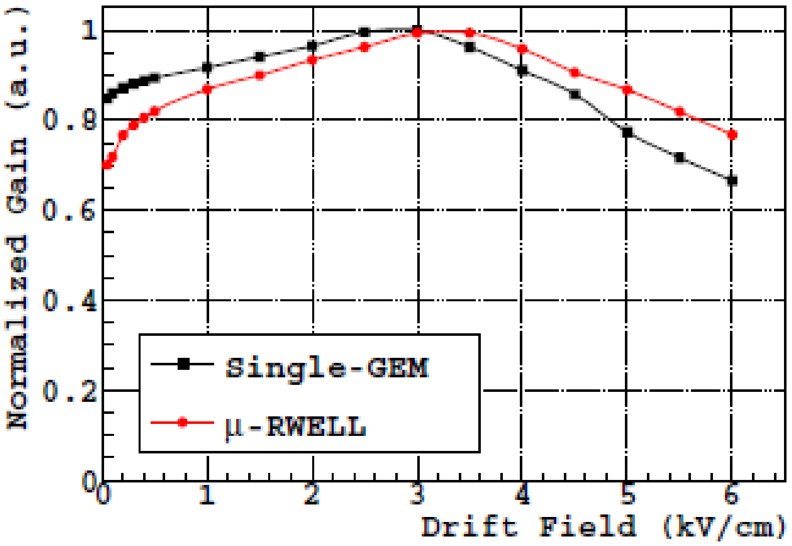
Gain vs beam position

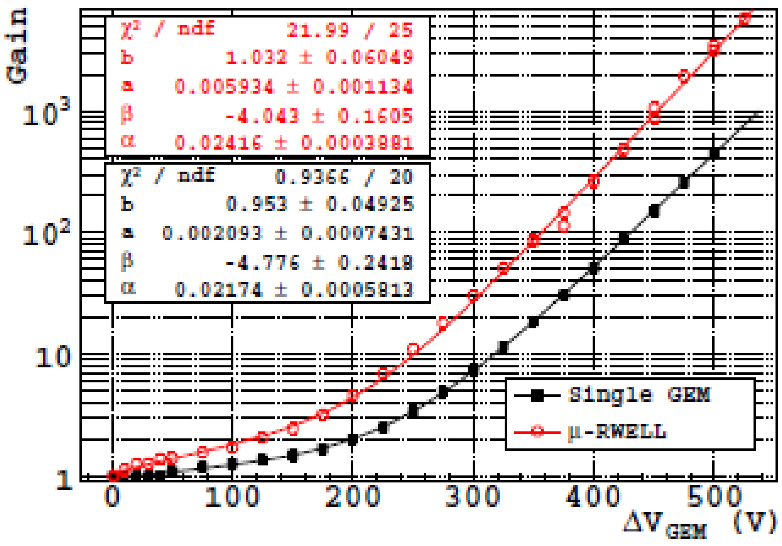




The <u>gain</u> (*vs particle flux*) <u>depends on the beam position</u>: the <u>larger is the distance covered by electrons</u> in the resistive layer (green curve) to reach the ground, the <u>greater is the average resistance</u> and the <u>lower is the rate capability</u>.

The prototype has been tested with Ar:CO_2 (70:30) gas mixture and characterized by measuring the gas gain, rate capability and discharge behavior in *current mode*.

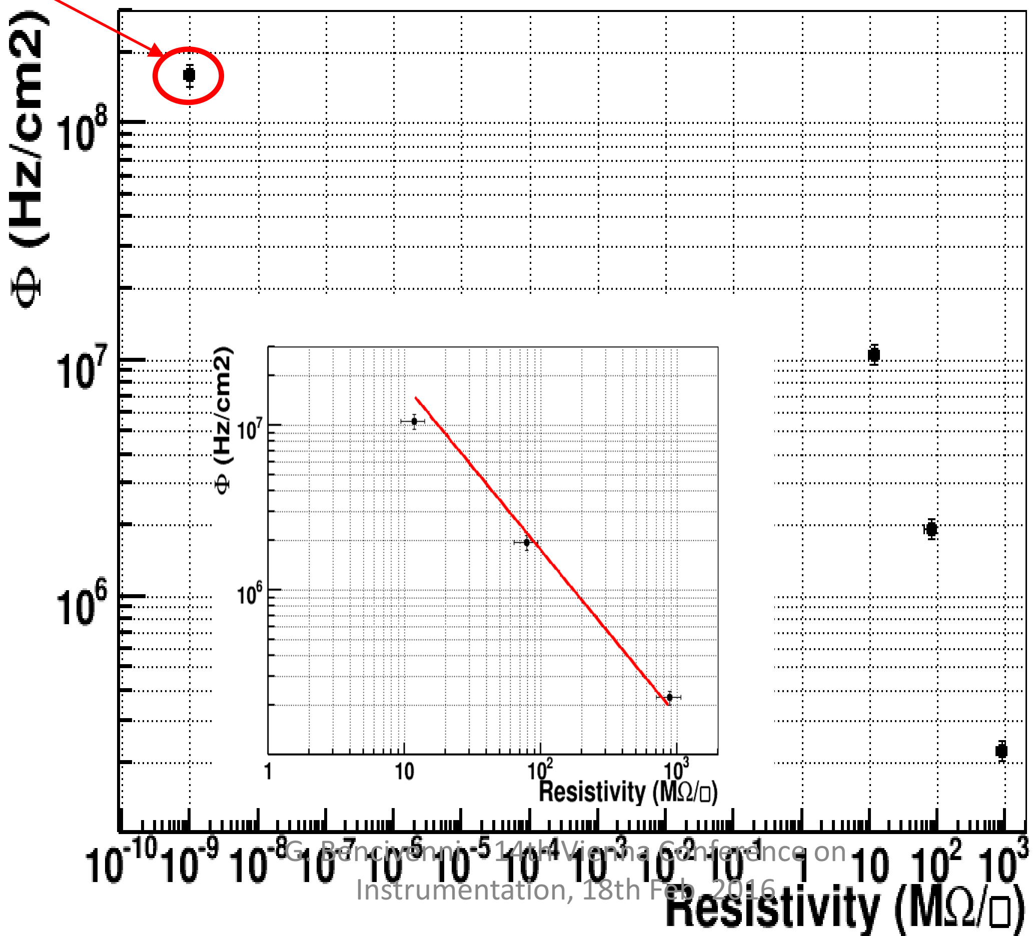




μ-RWELL Rate Capability in Ar/ISO=90/10 with an X-Ray tube

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

Rate capability for ΔG=-3%
Ar/Iso=90/10 & X-ray



TB June 2015:

AR/CO2=70/30 vs AR/ISO=90/10

Rate Capability Ar/CO2 vs Ar/ISO

Ar/CO2 & ρ= 100 MΩ/□
α=0.024
N_0 =209 (Garfield simulation);
G_0 =2000;
Ω = 600 MΩ;
r= 0.125 cm;

$$p_0 = \alpha e N_0 G_0 \Omega \pi r^2$$ = 5.6*10^-8

$$\frac{G}{G_0} = \frac{-1+\sqrt{1+4p_0\Phi}}{2p_0\Phi}$$ = 0,907 (Φ=2MHz/cm2)

Ar/ISO & ρ= 80 MΩ/□
α=0.031
N_0 =225 (Garfield simulation);
G_0 =1000;
Ω = 480 MΩ (estimated $\Omega = \rho_S \frac{d - \frac{r}{2}}{\pi r}$
r= 0.125 cm;

$$p_0 = \alpha e N_0 G_0 \Omega \pi r^2$$ = 2.5*10^-8

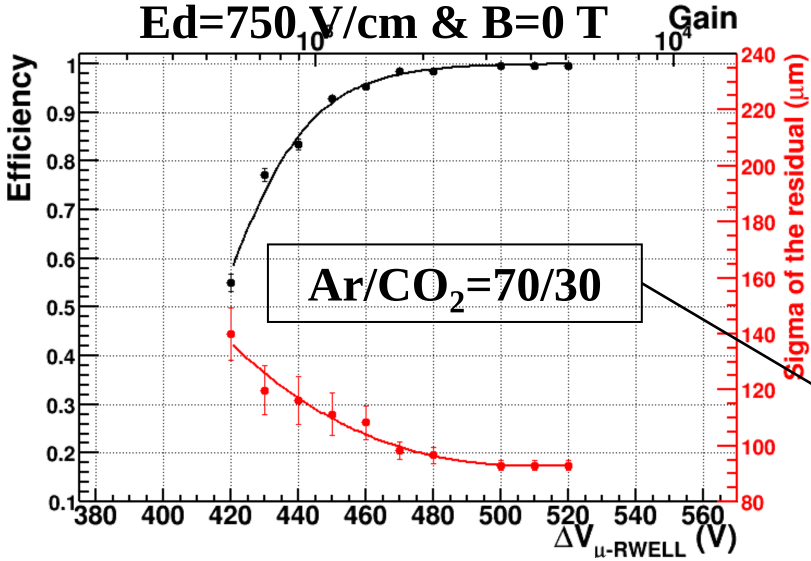
$$\frac{G}{G_0} = \frac{-1+\sqrt{1+4p_0\Phi}}{2p_0\Phi}$$ = 0,954 (Φ=2MHz/c

TB June 2015 B=0T & θ=0°

Efficiency & Residual vs gas mixture

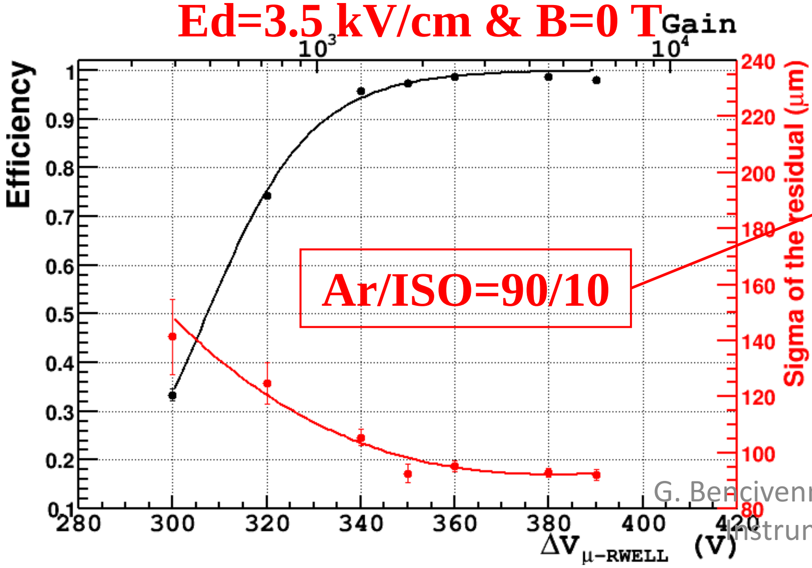
σ-Residual w/out TRK subtraction

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

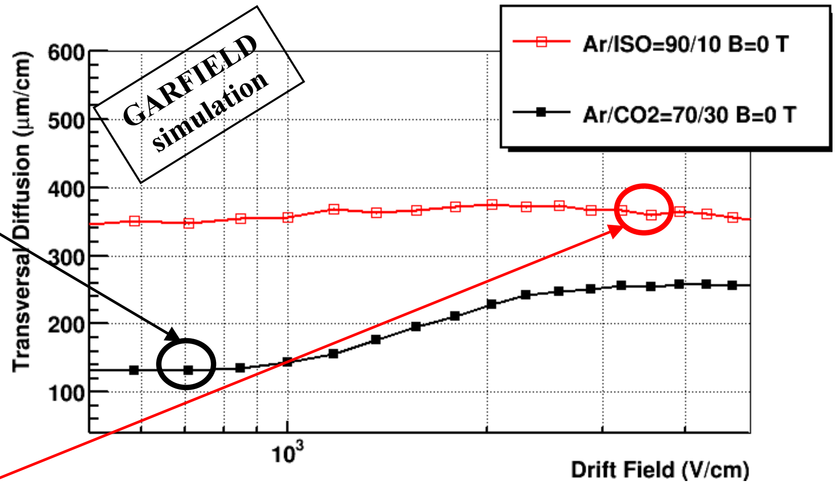


~60 μm on 4 mm gap

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:

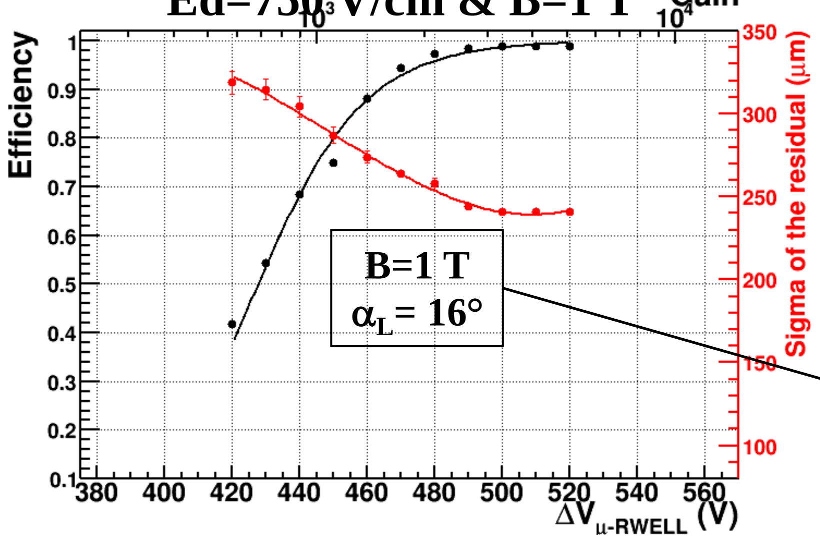
- μ-RWELL compactness
- relatively large strip pitch (400 μm)

TB June 2015, B=1T & θ=0°

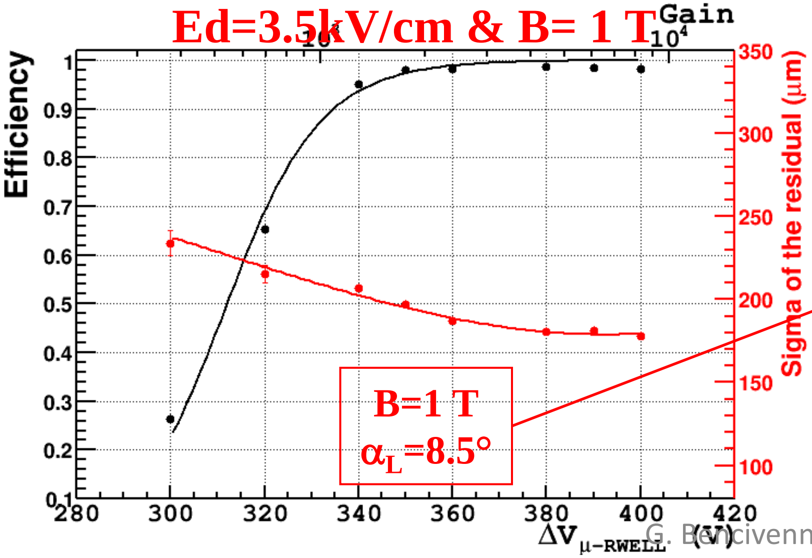
Efficiency & Residual vs gas mixture

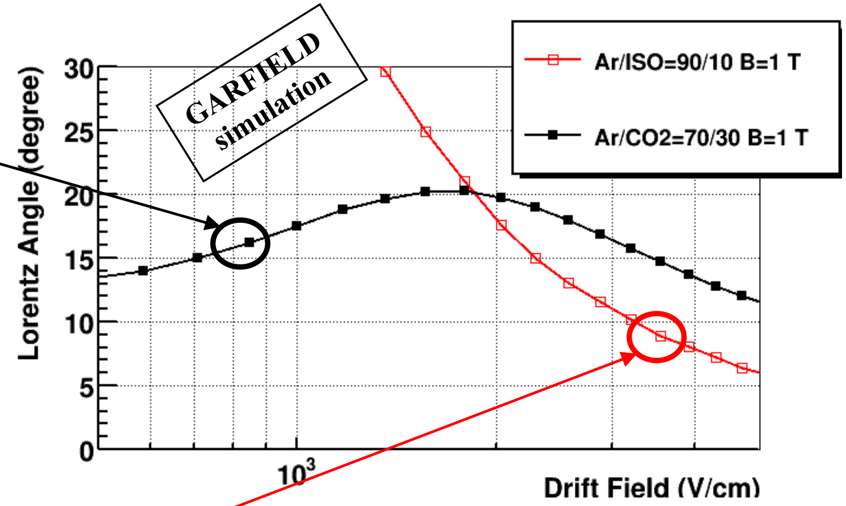
σ-Residual w/out TRK subtraction

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



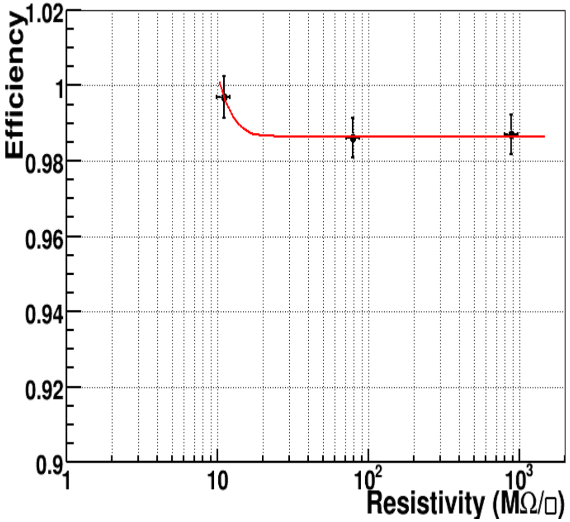
Ar/ISO=90/10
Ed=3.5kV/cm & B= 1 T



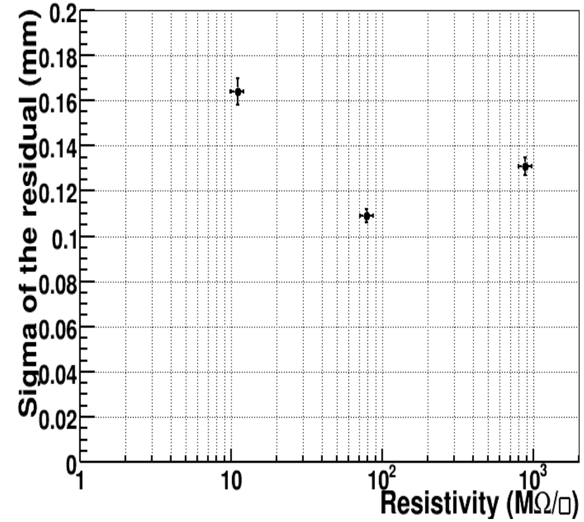


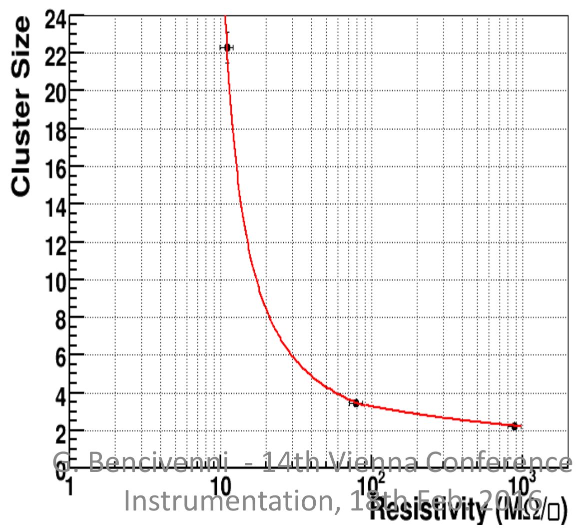
The difference on the residual is probably due to the diverse Lorentz angle

μ-RWELL Summary in Ar/ISO=90/10 @ SPS beam test



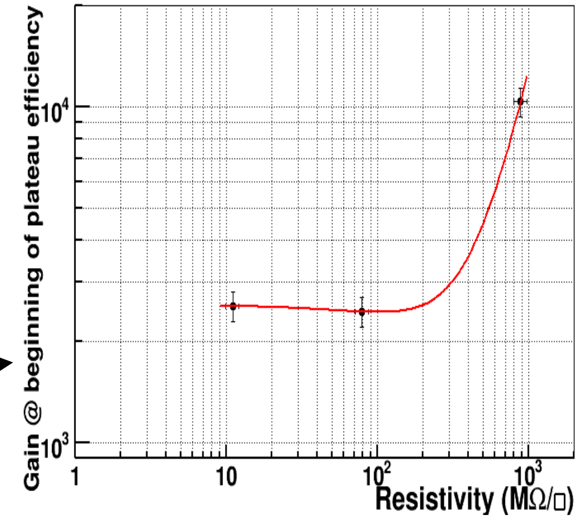
I punti nei plot presentati (efficienza, residui, clu size) sono riferiti al massimo valore del guadagno raggiunto per ogni rivelatore con mip

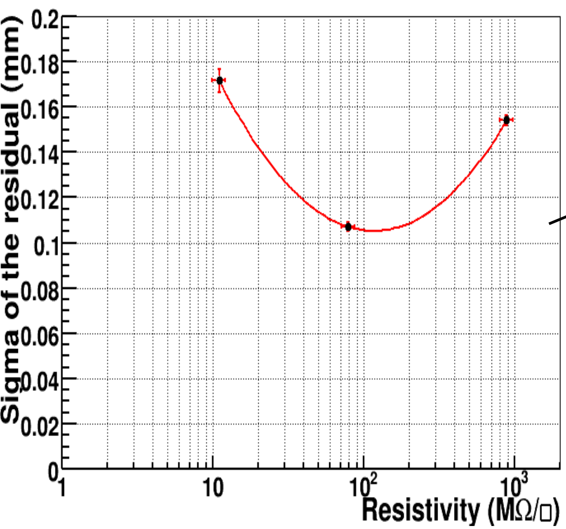


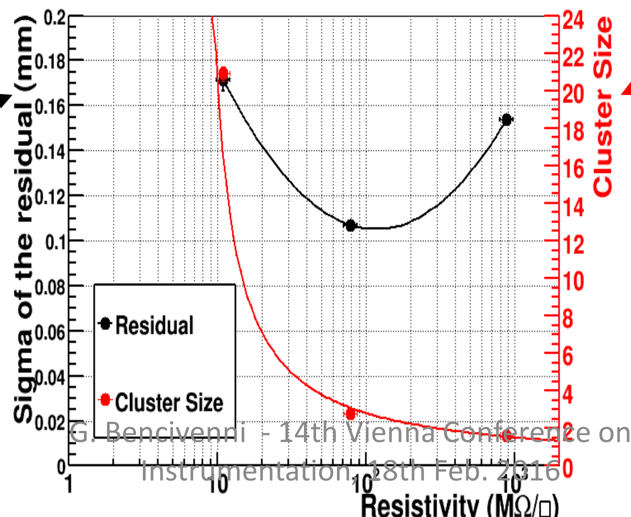


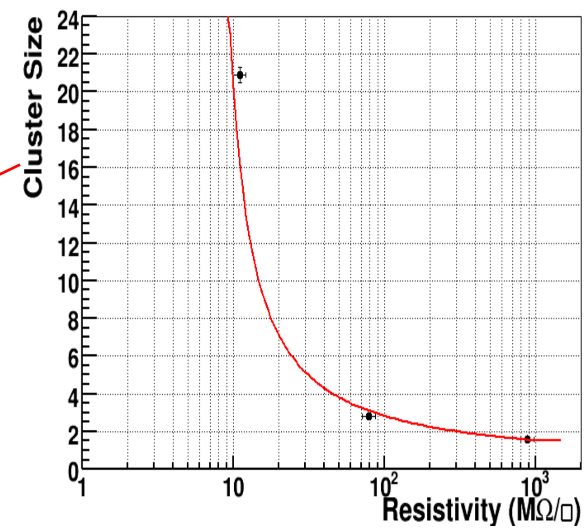
μ-RWELL Summary in Ar/ISO=90/10 @ SPS beam test

I punti nei plot presentati (residui, clu size) sono riferiti al <u>guadagno</u> a cui si raggiunge il <u>plateau di efficienza</u> per ogni prototipo



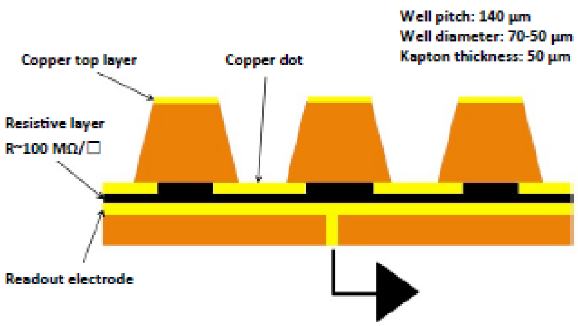


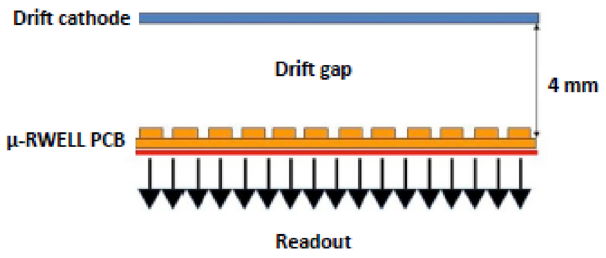


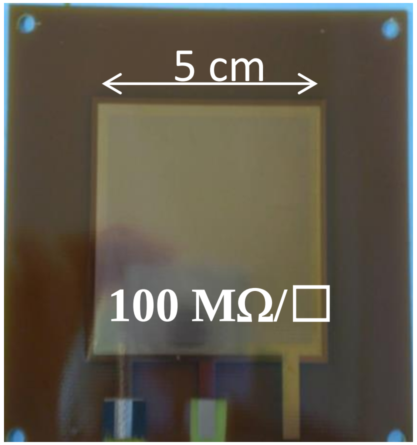


The µ-RWELL: a novel architecture (I)

The goal of this study is the development of a novel MPGD by combining in a unique approach the solutions and improvements proposed in the last years in the MPGD field (RD51).



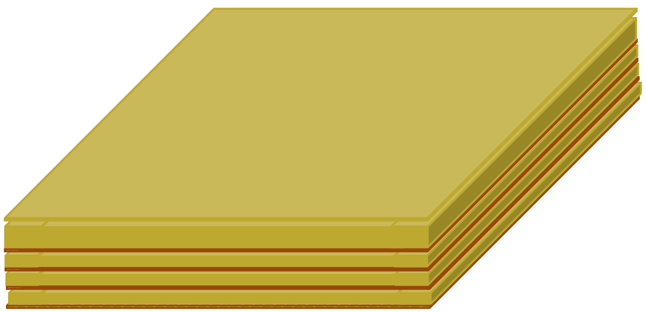


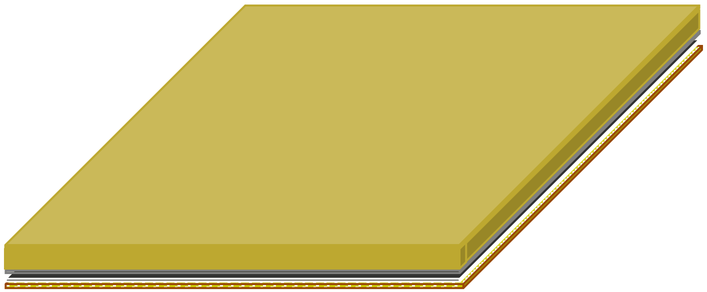


- The µ-RWELL is realized by coupling a "suitable patterned kapton foil" with the readout PCB plane through a resistive layer (100 MΩ/□).
- The resistive coating is performed by screen printing or DLC → robust against discharges.
- The WELL matrix is realized on a 50 µm thick polyimide foil, with conical channels 70µm (50 µm) top (bottom) diameter and 140µm pitch.
- A cathode electrode, defining the gas conversion/drift gap, completes the detector

→ compact & simple to build .

The µ-RWELL: a GEM-MM mixed solution





µ-RWELL

GEM detector sketch

MM detector sketch