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The μ-RWELL detector

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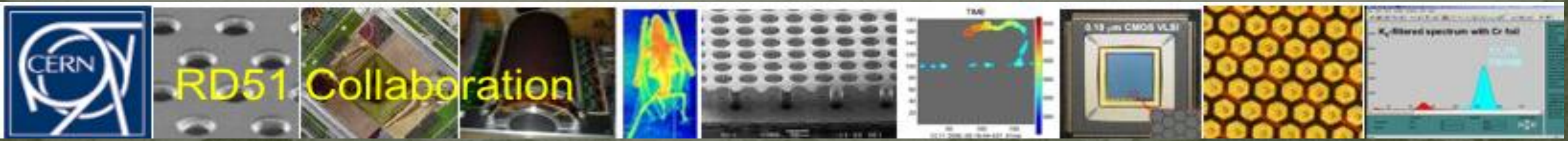


Outline

- MPGD: state of the art
- The μ-RWELL: a novel micro-structure
- Detector performance
- Summary

MPGDs: state of the art

MicroPattern Gas Detectors (MPGD) due to their performance (high rate capability and fine space resolution) 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 a long way to go by dedicated R&D studies towards:

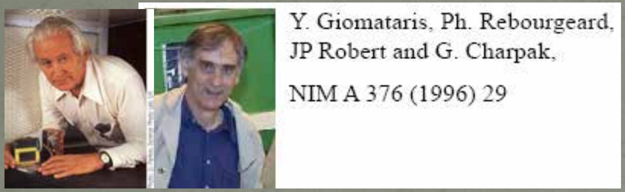
- stability under heavy irradiation (discharge containment)
- simplified construction technologies, a MUST for
  - very large scale applications in fundamental research
  - technology dissemination beyond HEP

Possibly improving their performance in terms of time and space resolution

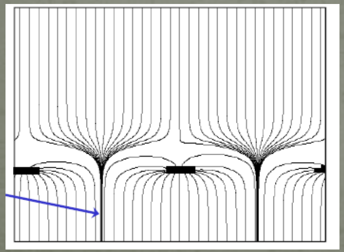
MPGDs: state of the art

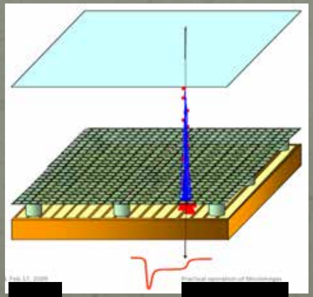
<u>MPGDs</u> are realized by means <u>photolithography technology</u>, on <u>rigid or flex substrates</u>, the same used for standard PCBs. The two most important micro-structures are:

Micromegas (Micro-MEsh Gaseous Structure) have been invented in the 1996 by Y.Giomataris and G. Charpak.



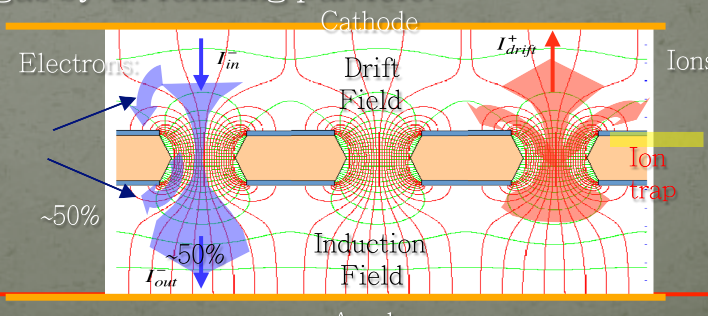
A parallel-plate chamber where the amplification (up to 10^4) takes place in a thin gap, separated from conversion region by a fine metallic micro-mesh, supported by 50-100 µm insulating pillars. Charge is collected on the anode readout board, a suitable segmented standard PCB.





The **GEM** (Gas Electron Multiplier) has been invented in the 1997 by F.Sauli [NIM A386 (1997) 531].

The GEM foil, is a thin (50 µm) metal coated kapton foil, perforated by a high density of holes (70 µm diameter, pitch of 140 µm).
By applying 400-500 V between the two copper sides, an electric field as high as ~100 kV/cm is generated into the holes which act as multiplication channels for electrons produced in the gas by an ionizing particle.

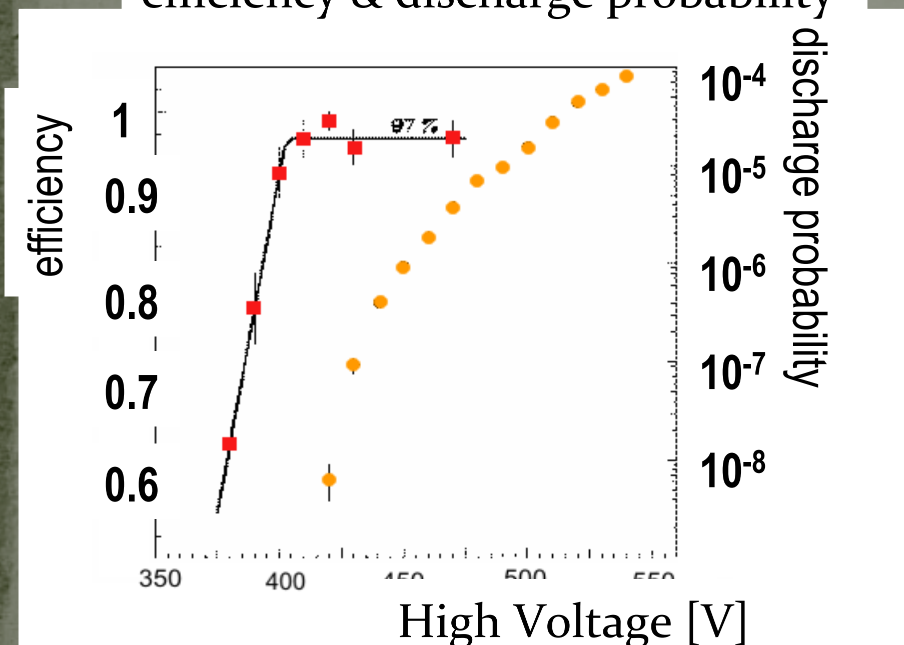


MPGDs: stability

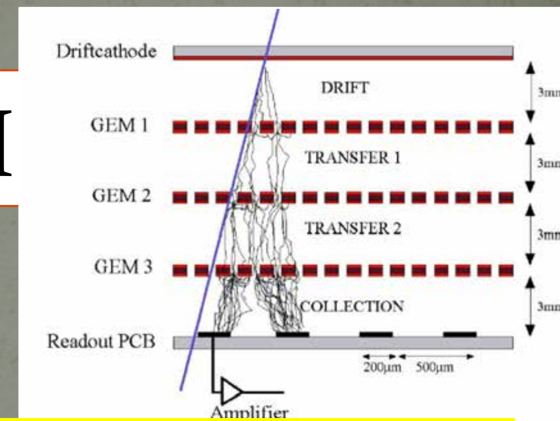
The biggest "enemy" of MPGDs are the discharges.
Due to the fine structure and the typical micrometric distance of their electrodes, MPGDs generally suffer from spark occurrence that can eventually damage the detector and the related FEE.

MM

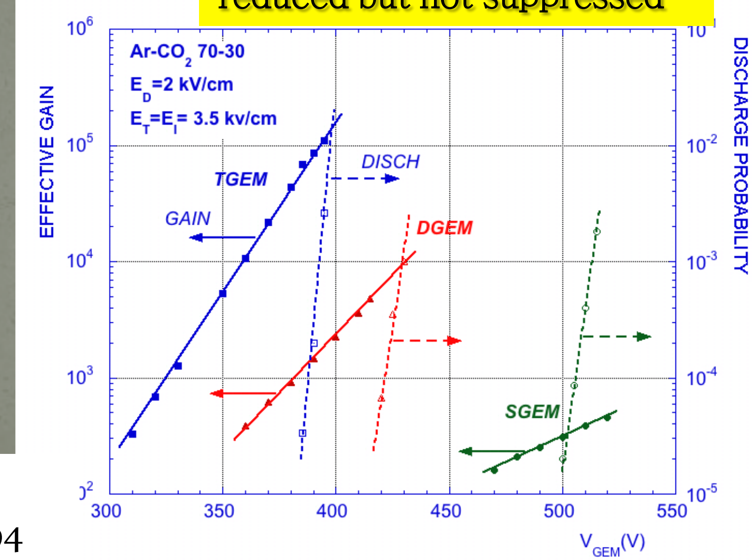
efficiency & discharge probability



GEM



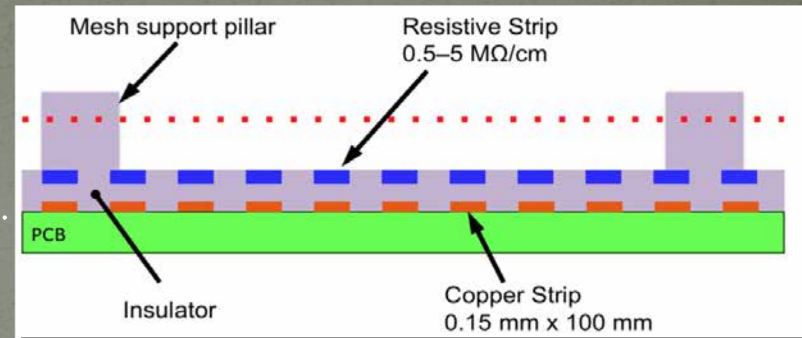
reduced but not suppressed



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

Technology improvements: resistive Micromegas

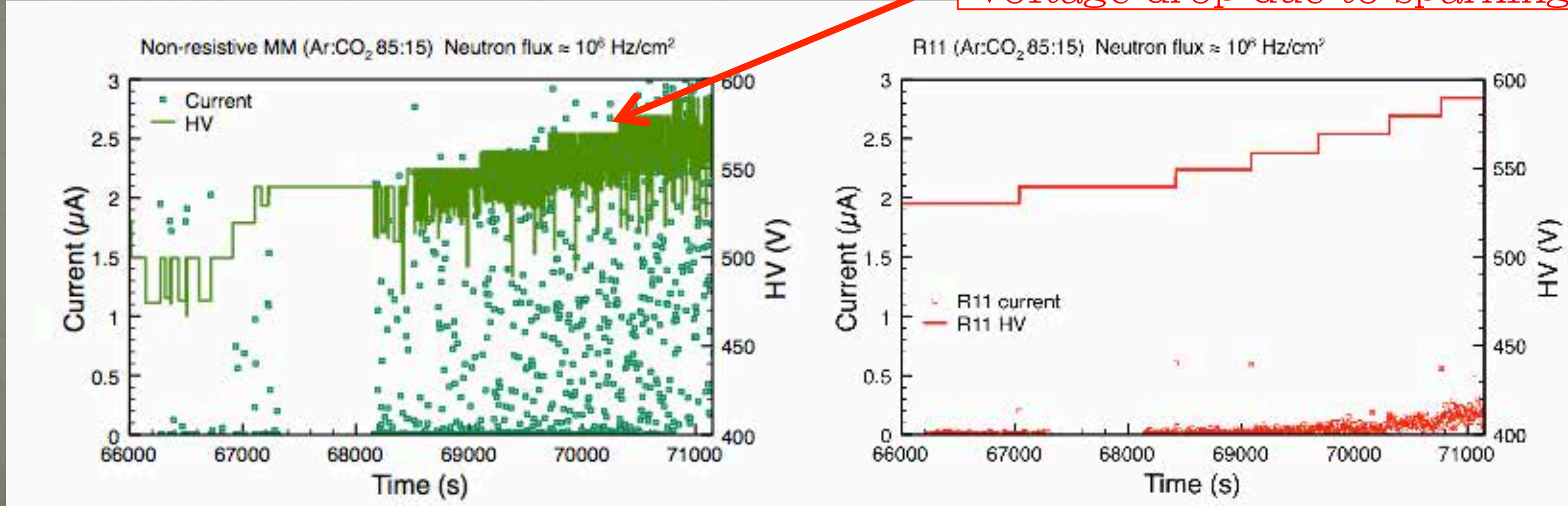
For MM, the spark occurrence between the metallic mesh and the readout PCB has been overcome with the implementation of a "resistive layer" on top of the readout itself . The principle is the same as the resistive electrode used in the RPCs: the transition from streamer to spark is strongly suppressed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



by R.de Oliveira TE MPE CERN Worksho

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

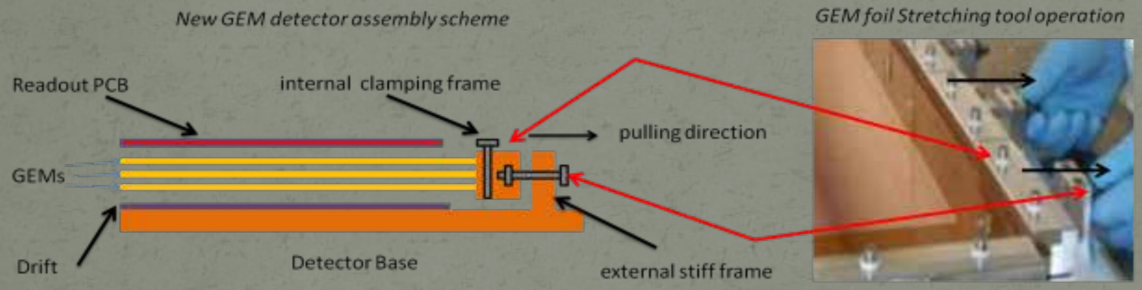
voltage drop due to sparking

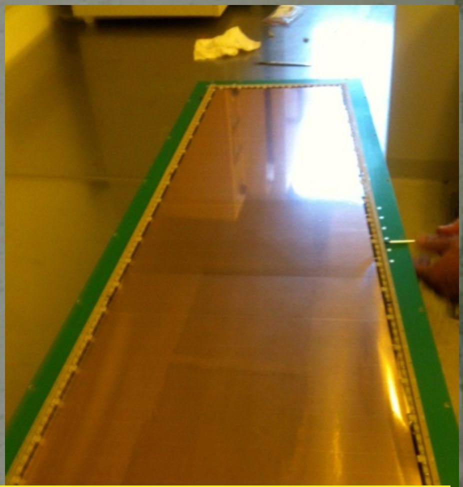


MPGDs: construction issues (I)

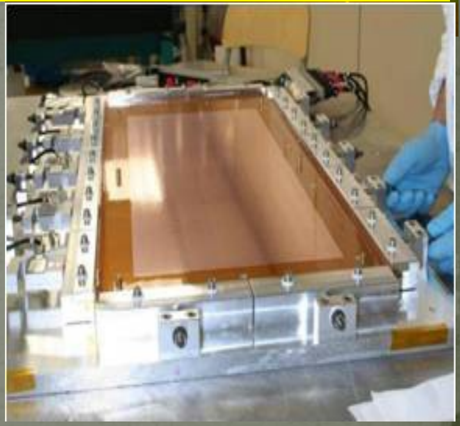
A further limitation of such MPGDs is correlated with the complexity of their assembly procedure, particularly evident in case of large area devices.

- The construction of a GEM chamber requires some time-consuming (/complex) assembly steps such as the stretching (with quite large mechanical tension to cope with — 1 kg/cm) and the gluing of the GEM foil (on frames)





NS2(CERN): no gluing … but still stretching …



- A 2 m long detector requires a 200 kg mechanical tension that must be sustained by suitable mechanical structures (large frames, rigid panels …). While the max width of the raw material is about 60 cm.
- The splicing/joining of smaller detectors in order to realize large surfaces (as used for silicon detectors) is difficult unless introducing not negligible dead zones .

MPGDs: construction issues (II)

Similar considerations hold for MM:

- the splicing /joining of smaller PCBs is clearly possible, opening the way towards the large area covering.

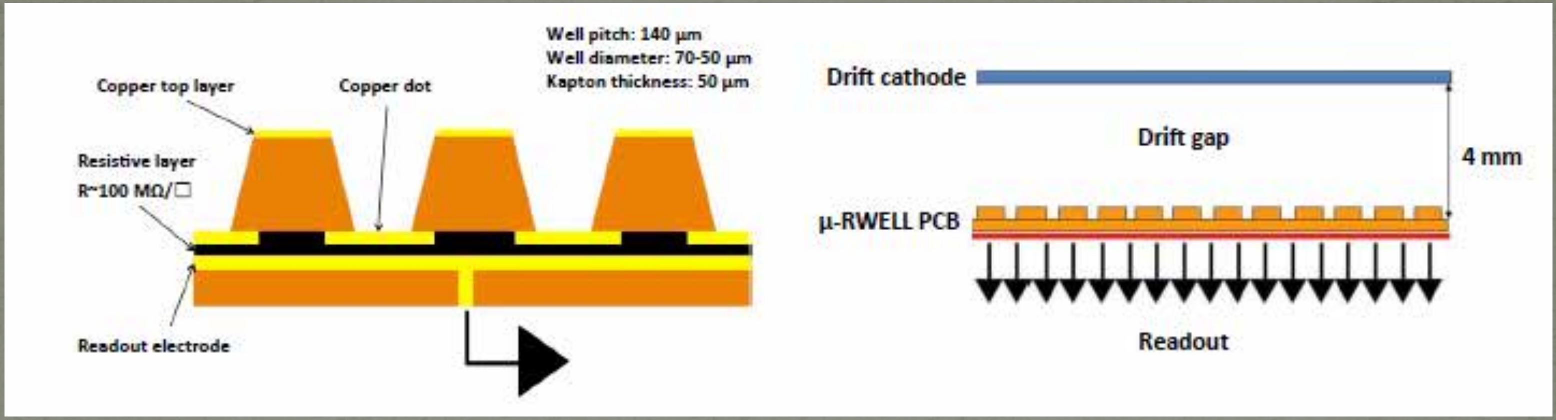
BUT

- the fine metallic mesh, that defines the amplification gap, is a "*floating component*", because it is stretched on the cathode (@ 1 kg/cm) and electrostatically attracted toward the PCB ($P=\epsilon_0 \times (\Delta V/d)^2$).

- this could be a source of instability because a "not well defined" amplifying gap could generate gain non-uniformity.
- In addition the handling of large meshes is clearly "not trivial".

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).

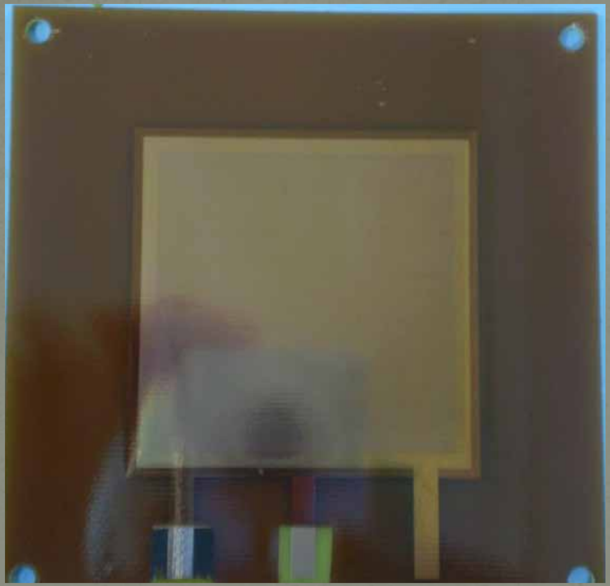


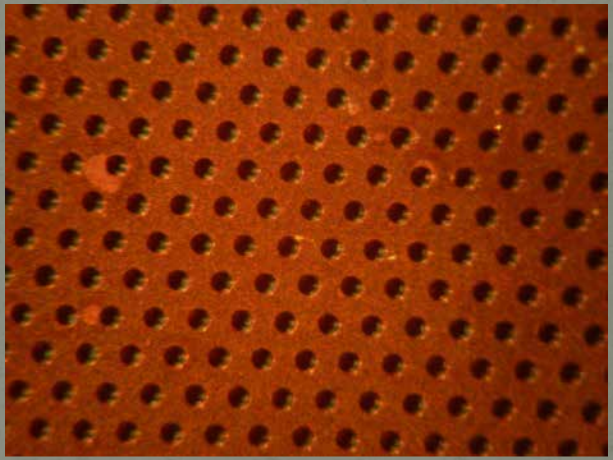
- The μ-RWELL is realized by coupling a "suitable patterned GEM foil" with the readout PCB plane coated with a resistive deposition.
- The resistive coating is performed by (cheap) screen printing technique.
- The WELL matrix is realized on a 50 μm thick polyimide foil, with conical channels 70μm (50 μm) top (bottom) diameter and 140μm pitch.
- A cathode electrode, defining the gas conversion/drift gap, completes the detector.

The µ-RWELL: a novel architecture (II)

The proposed detector is:

- ❑ compact: < 5mm thickness
- ❑ robust against discharges: amplification through resistive coupling
- ❑ simple to build , only two components:
  - a single-amplification stage embedded with the readout
  - a cathode plane





The prototype described in this presentation has been designed at LNF and built in the 2009 at the CERN PCB Workshop (preliminary tested and then put in a box of our lab ...)

The micro-structure has some characteristics in common with two MPGDs developed by the end of last century (J. P. III France 6 (1996) 337, NIMA 423 (1999) 125).

The μ-RWELL vs GEM

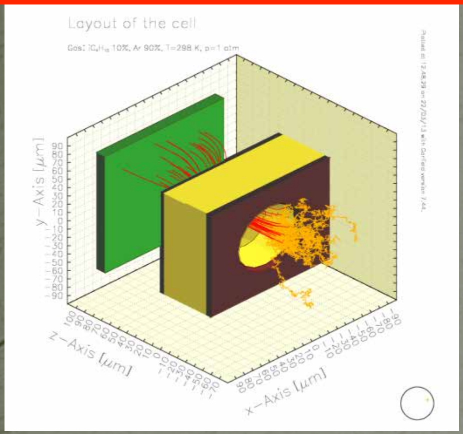
The μ-RWELL is expected to exhibit a gas gain larger than a single-GEM.

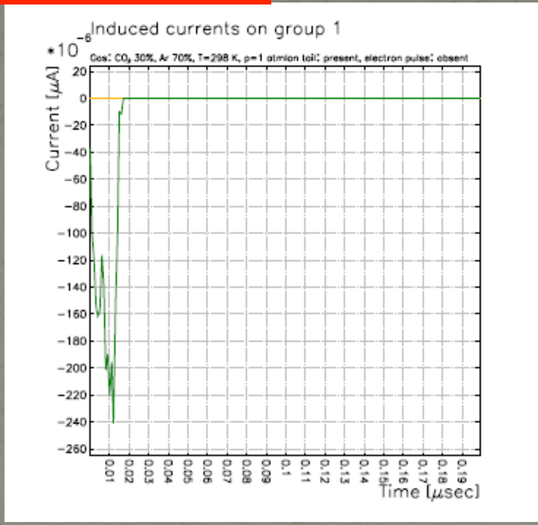
- Single-GEM:
  - only 50% of the electron charge produced into the hole contributes to the signal, the rest of the electron charge is collected by the bottom side of the GEM foil
  - the signal is mainly due to the electron motion, the ion component is largely shielded by the GEM foil itself

- 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

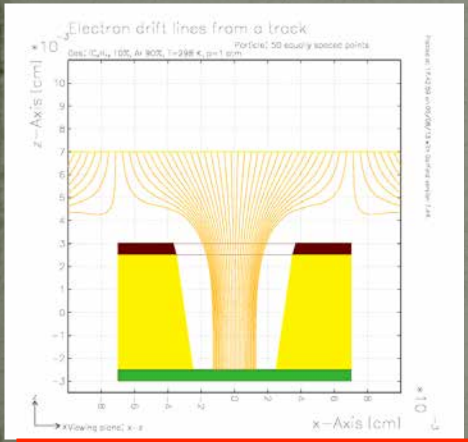
The μ-RWELL vs GEM (Garfield simulation)

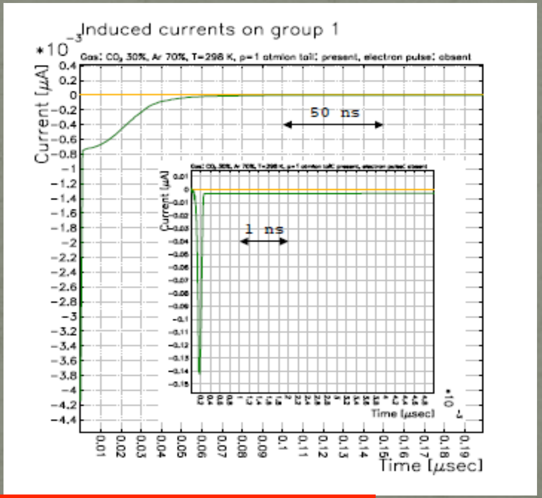
GEM – Ar:CO2 70:30 gas mixture





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.



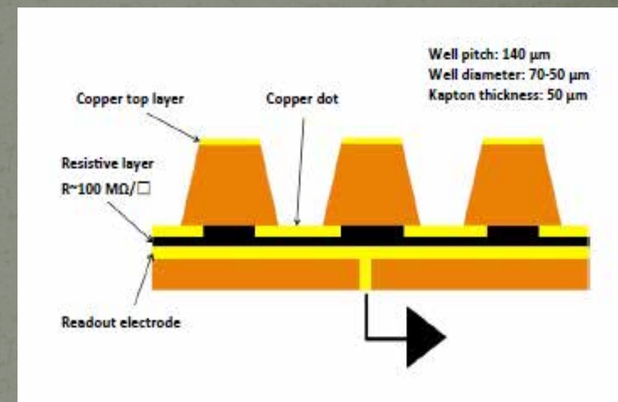


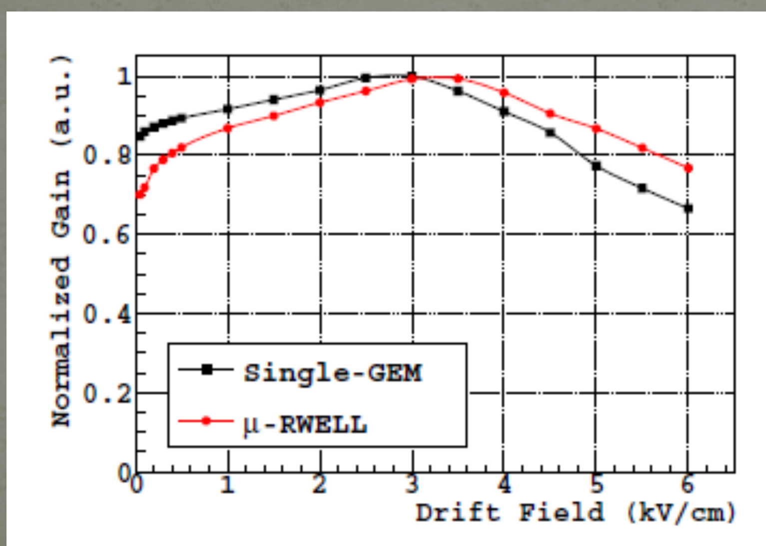
Signal from a single ionization electron in a μ-RWELL.
The absence of the induction gap is responsible for the fast initial spike, about 200 ps, induced by the motion and fast collection of the electrons and followed by a ~50 ns ion tail.

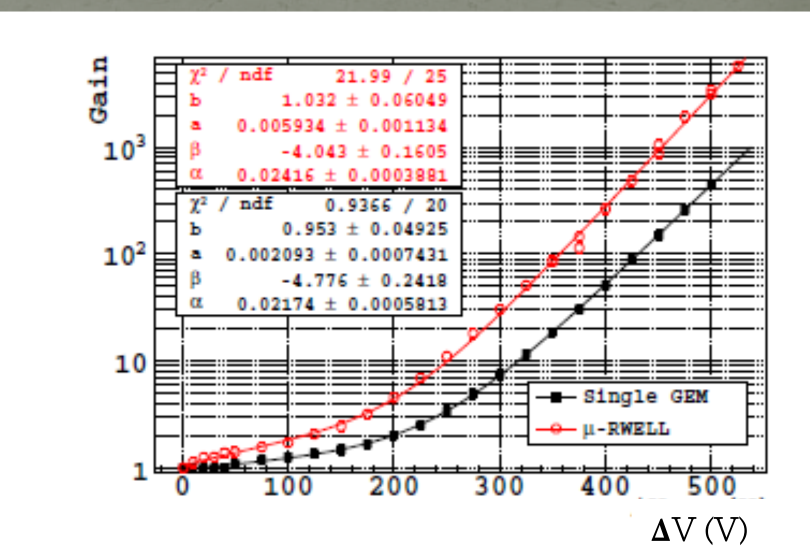
μ-RWELL – Ar:CO2 70:30 gas mixture

The μ-RWELL performance (I)

- 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*.
- The device has been irradiated with a collimated flux of 5.9 keV X-rays generated by a PW2217/20 Philips Tube.
- The gain has been measured vs potential applied between the top of the electrode of the amplification stage and the resistive layer.

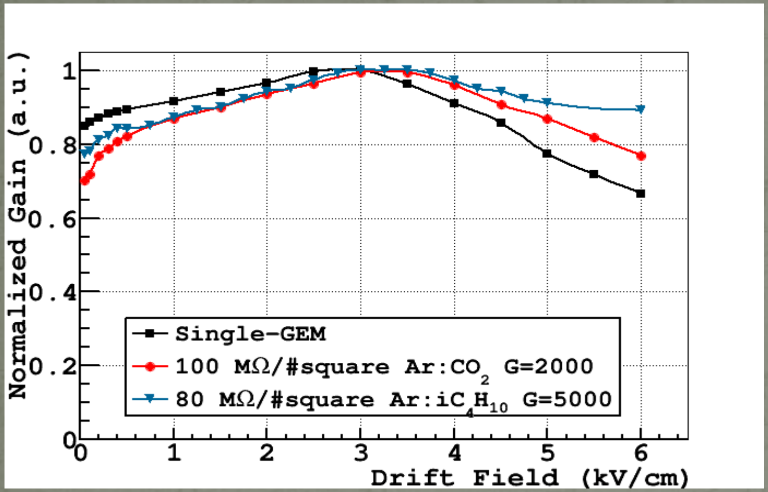




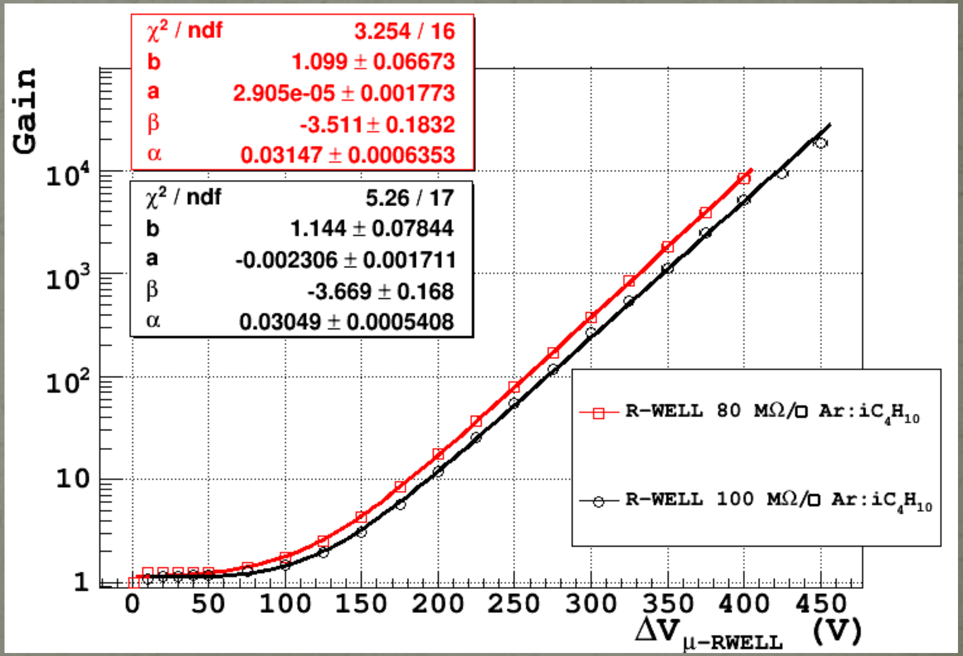


The μ-RWELL performance (II)

Gain with Ar/i-C_4H_{10} =90/10



The use of isobutane (better quencher) based gas mixtures, allows to achieve higher gas gain (10^4).

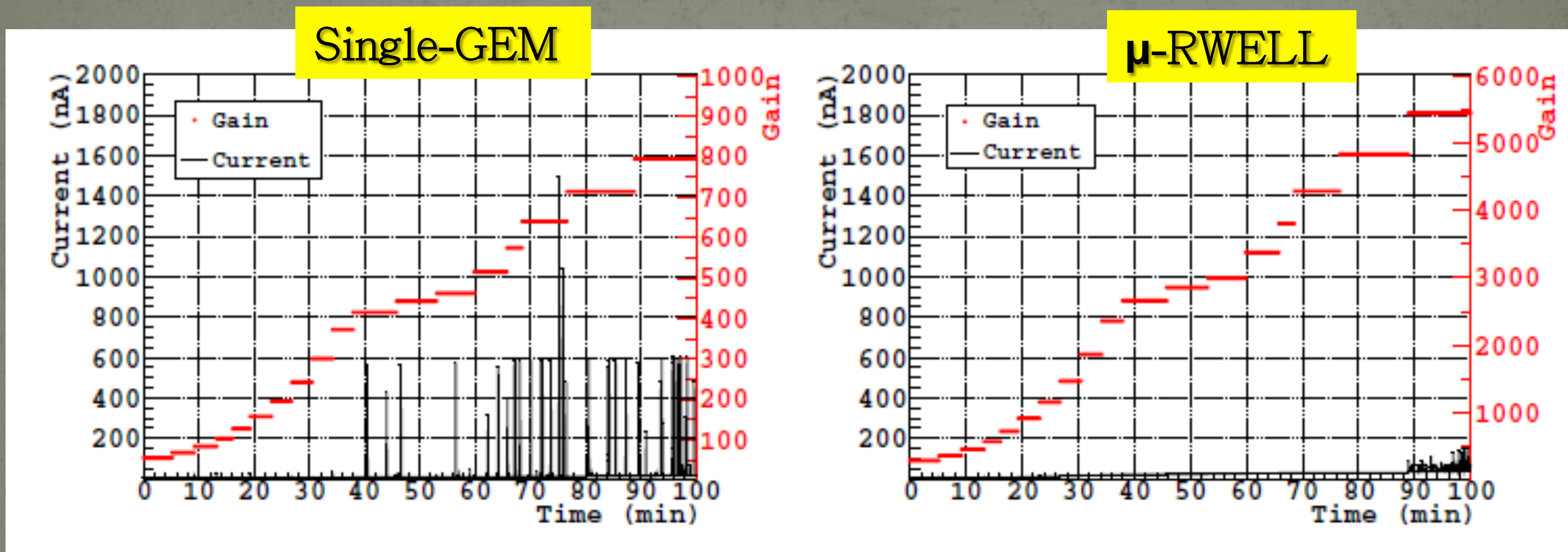


The main difference between the two prototypes is the coupling between the top-layer of the well and the resistive-plane:

- for the 100MΩ/□ is through the copper-dots;
- for the 80MΩ/□ is without the copper-dots;

The μ-RWELL performance (III)

Discharge study: μ-RWELL vs GEM



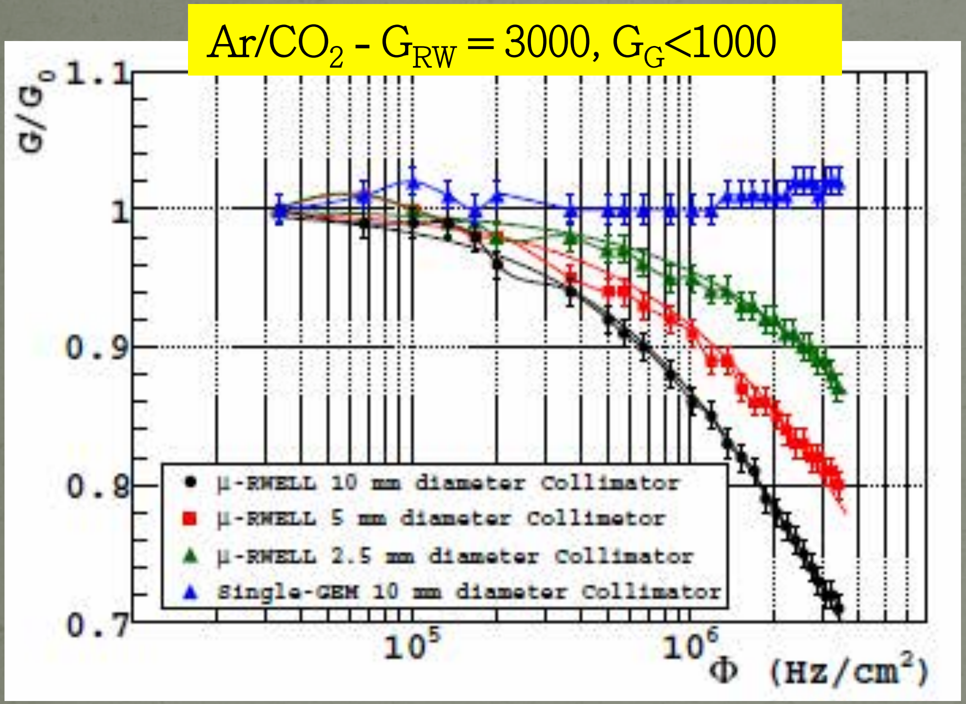
The max. ΔV achieved for the gain measurement is correlated with the onset of the discharge activity, that, comes out to be substantially different for the two devices:

- ❑ 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

Further systematic and more quantitative studies must be clearly performed

The μ-RWELL performance (IV)

A drawback correlated with the implementation of a resistive layer is the reduced capability to stand high particle fluxes: larger the radiation rate, higher is the current drawn through the resistive layer and, as a consequence, larger the drop of the amplifying voltage.



The curves are fitted with the function:

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

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

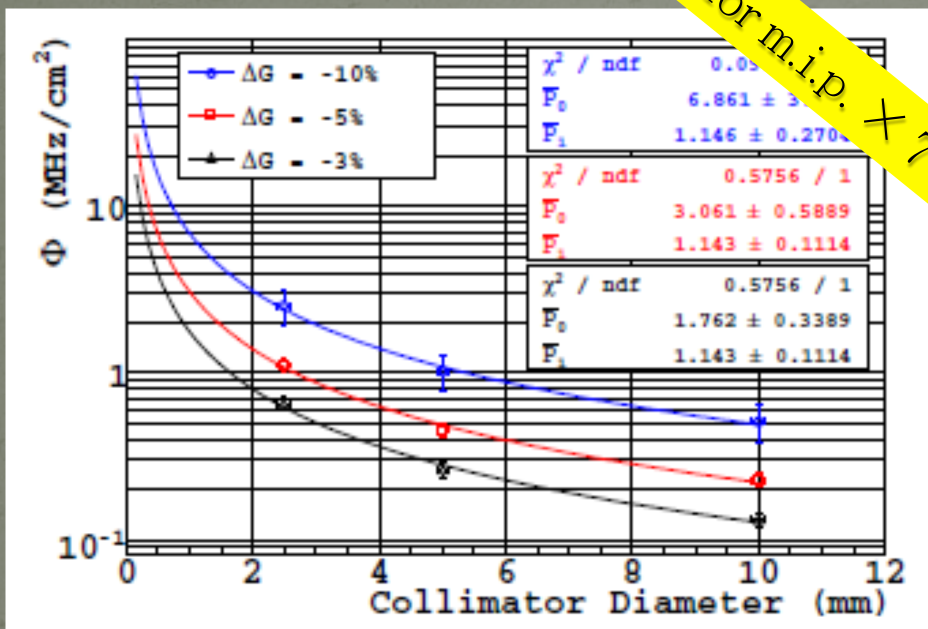
The function allows the evaluation of the radiation flux for a given gain drop of 3%, 5% and 10% for all the collimators.

Normalized gain vs X-ray flux for GEM and μ-RWELL for irradiation at the center of the active area, with three different collimator diameters: 10 mm, 5 mm and 2.5 mm.

The μ-RWELL performance (V)

The particle flux that the μ-RWELL is able to stand, in agreement with an Ohmic behavior of the detector, decreases with the increase of the diameter of the X-ray spot on the detector.

for m.i.p. × 7

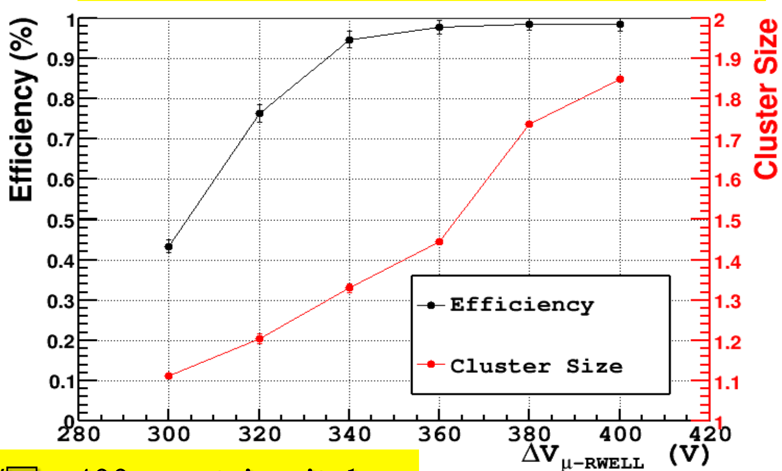


The rate capability of the detector, for a fixed surface resistivity, can be tuned with a suitable segmentation (NIMA 732(2103)199) of the resistive layer (under study): a "*matrix of resistive pads*" each one independently connected to ground (~1 MHz/cm^2 for m.i.p. seems achievable)

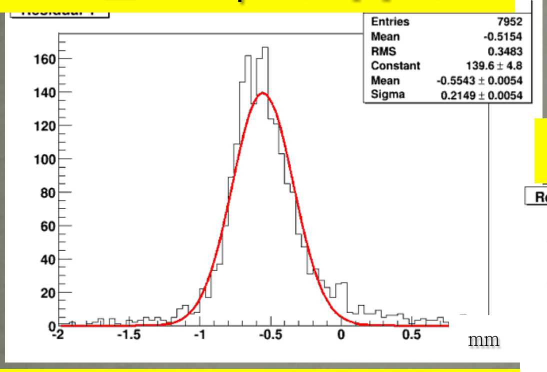
The µ-RWELL performance (VII)

Test beam results (VERY PRELIMINARY)

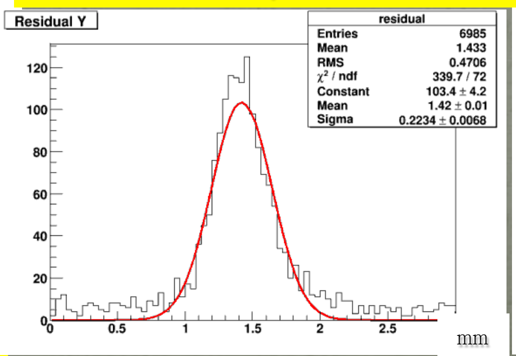
80 MΩ/□; 55-50µm dia., 100 µm pitch



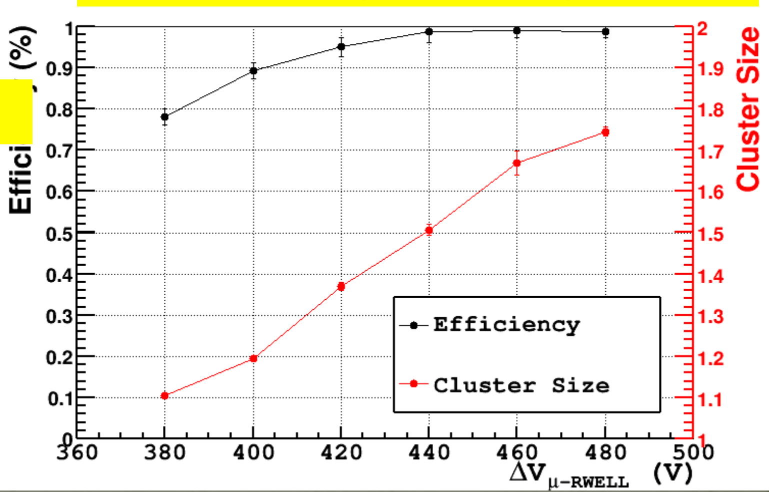
80 MΩ /□ - 400 µm strip pitch



1 GΩ /□- 400 µm strip pitch



1 GΩ /□ ; 70-30µm dia., 100 µm pitch



NO alignment
NO fine tracking

SUMMARY

The μ-RWELL shows several advantages with respect to the GEM and MM:

- very compact device → *large area tracking in magnetic field, Compact Digital Calorimetry*
- effective spark quenching → *safe high reliable operation*
- very simple assembly procedure → *large area (splicing easiest than MM)*
- gas gain ~10^4 → *larger gain increasing the WELL thickness, good gain uniformity with "segmented-resistive layer"*
- rate capability ~1 MHz/cm^2 for m.i.p. → *enough for many applications (SHIP, LHCb, position-sensitive neutron detection …)*
- suitable for multi-μ-gap device → *for high time resolution (<100 ps)*

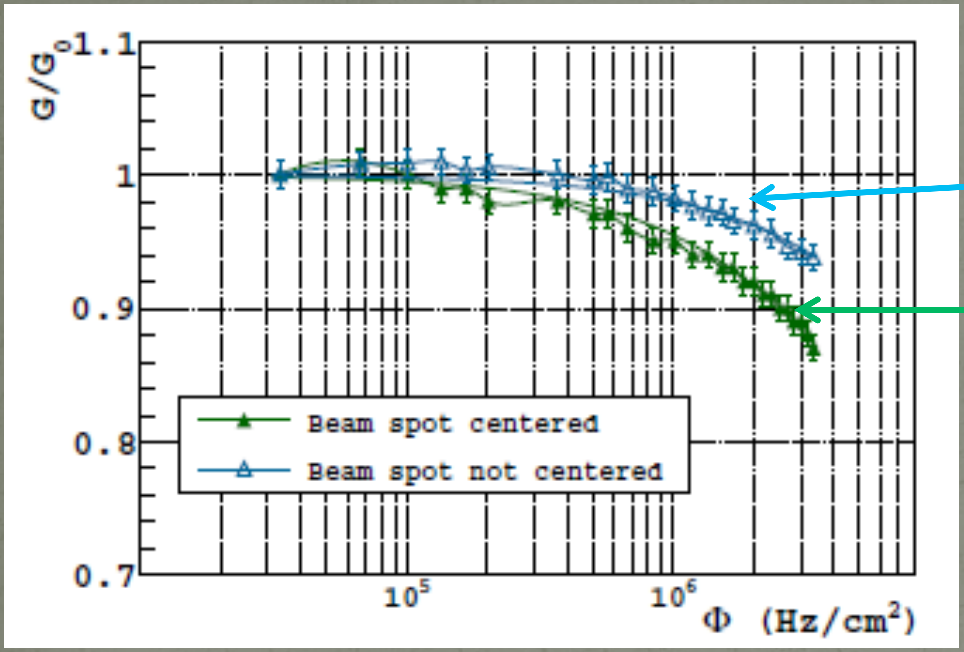
… a large set of measurements & work to be done to become a reliable solution for the suggested applications …

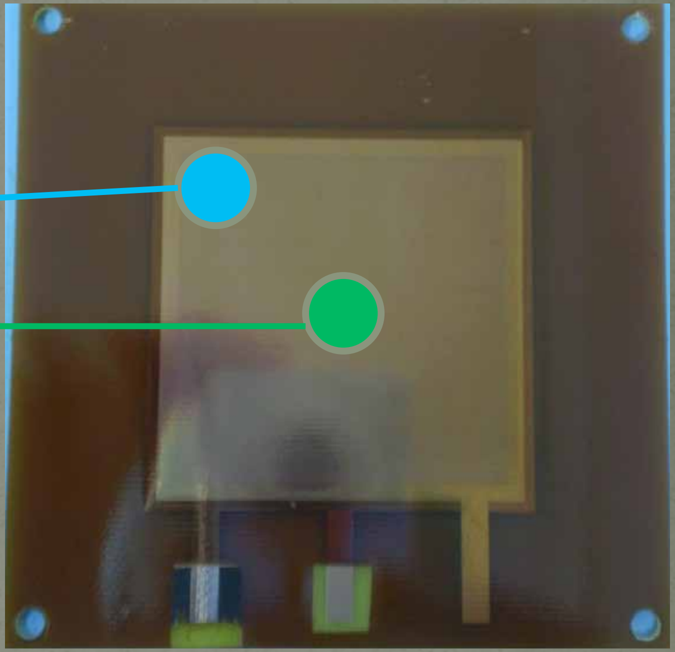
Thanks for the attention

Spares Slides

The μ-RWELL performance (VI)

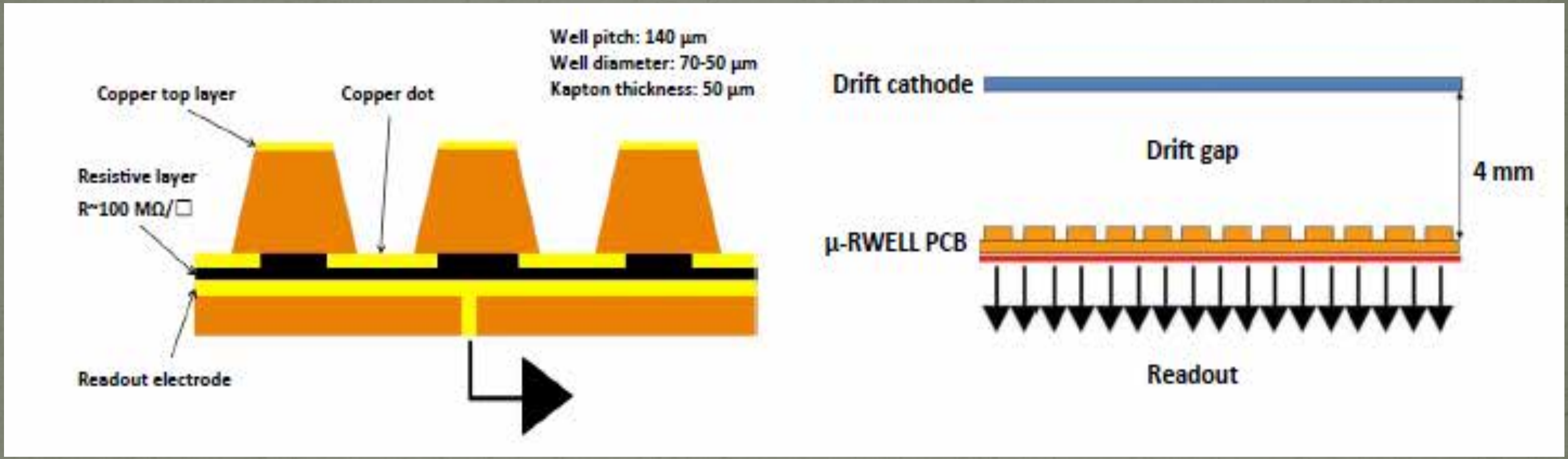
Gain vs beam position





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>.

μ-RWELL vs MM



Compared to MM structure μ-RWELL offer the big advantage that the cleanness of the device is much easier.
Large area can be therefore covered with a structure with a well defined amplifying gap.
MM lost this last property moving to large area.
Uniform and constant gap was given by the bulk method. Large MM now uses *floating meshes* because it is not possible to have clean and cleanable large mm.

The Ohmic model for the Gain of a μ-RWELL

The gain variation of a μ-RWELL depends on the radiation flux and the observed drop is supposed to be due to the resistive layer. The gain of a μ-RWELL can be written as follows:

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

A gain drop corresponds to a decrease of the voltage V_0:

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

Following the Ohm first law: $\delta V = i \cdot \Omega$

where "*i*" is the current measured on the resistive layer and **Ω** is the average resistance faced by the charges to reach the ground frame. The current "*i*" can be written as follows:

$$i = eN_0 GR$$

per cui:

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

ovvero:

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

expanding the exponential using the Maclaurin serie up to the first order we obtain:

$$\frac{G}{G_0}\left[1 + \alpha e N_0 G \Phi \pi r^2 \Omega\right] = 1$$

ovvero:

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

which admits the following solution:

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

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

Principle of operation: single-GEM

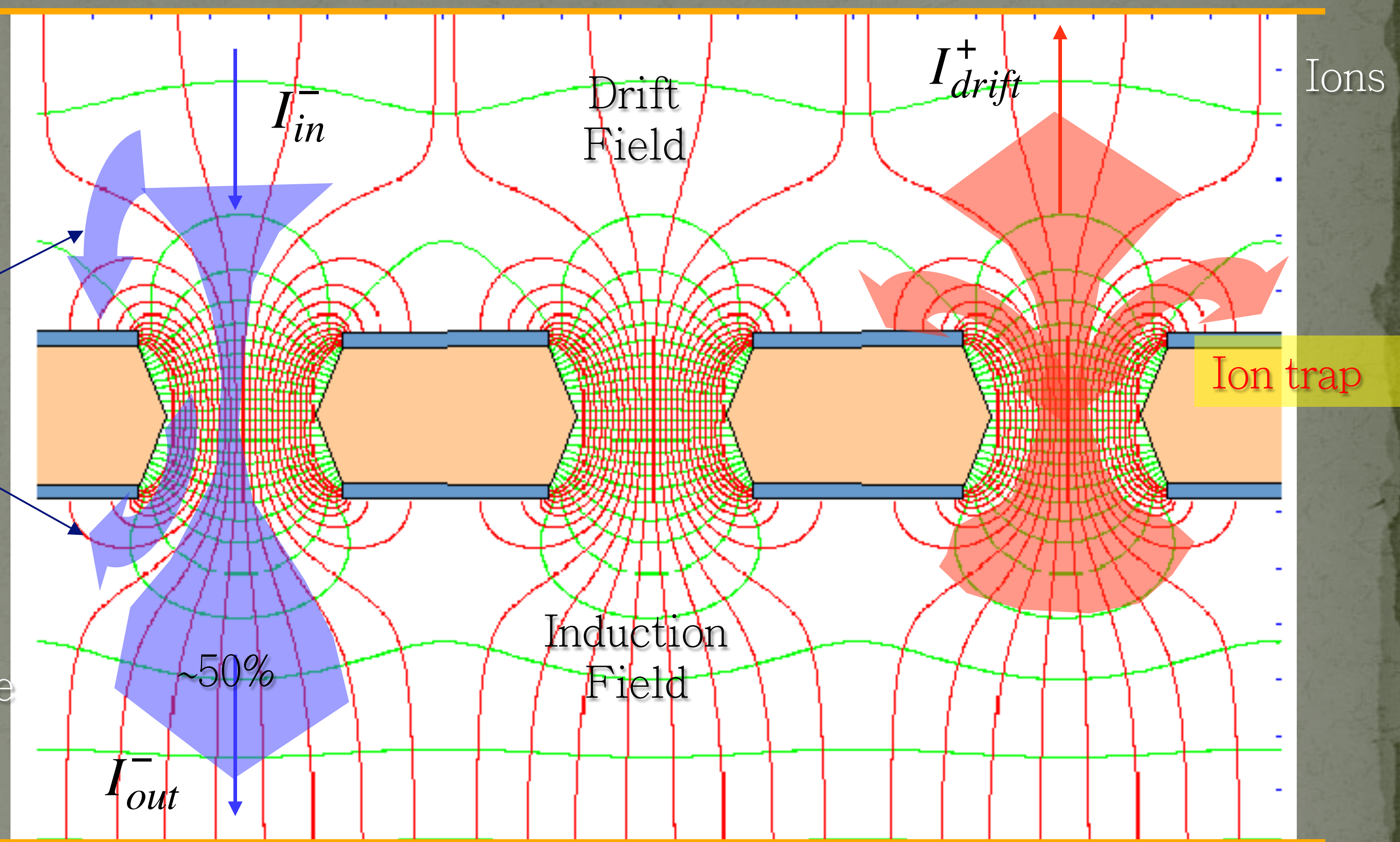
Cathode

Electrons:

Diffusion Losses

~50%

signal only due to electron motion

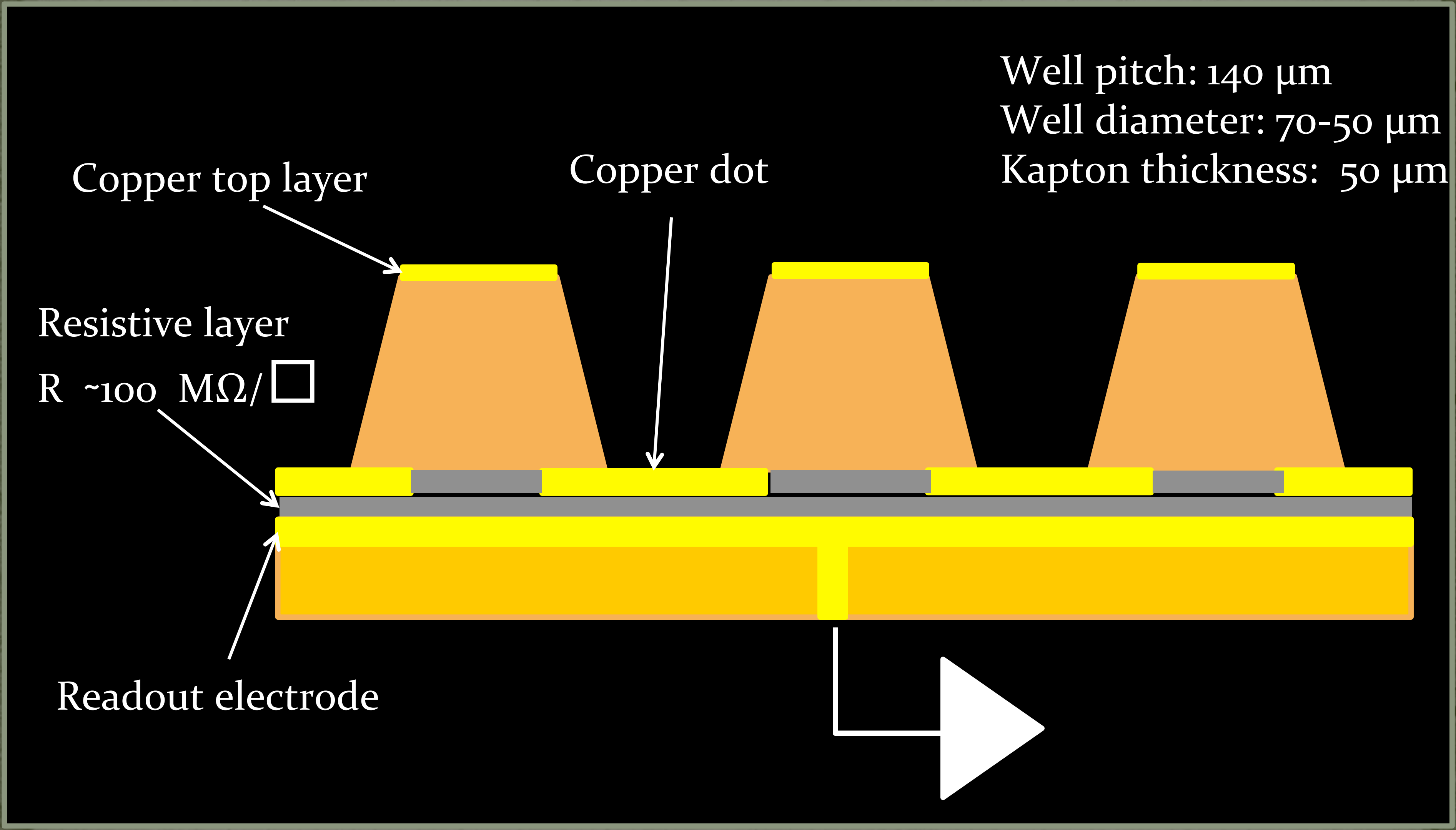


Anode

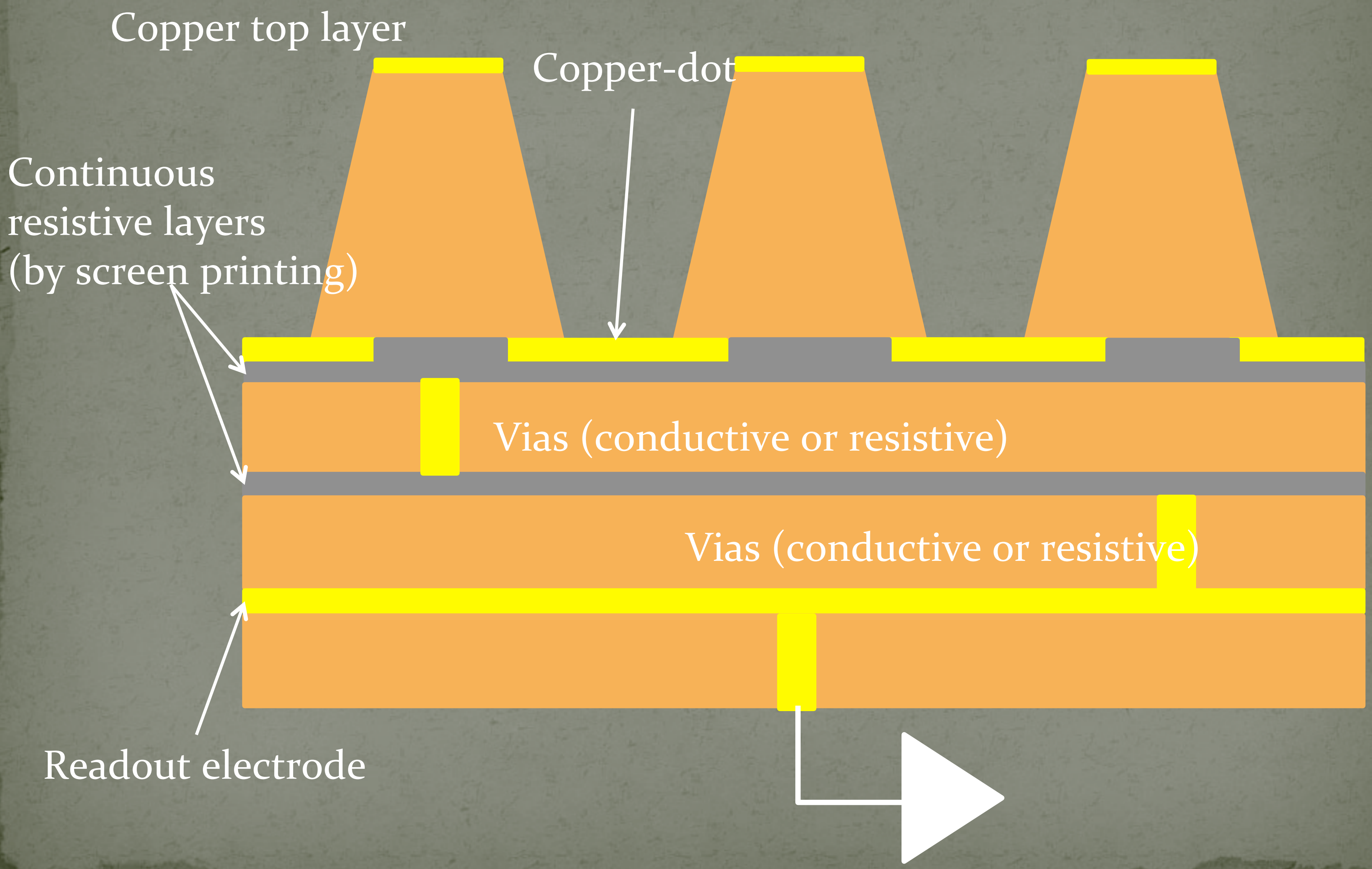
$I^-_{out} = I^-_{in} \cdot G \cdot T$
(gain **x** transparency)

Ion Feedback = I^+_{drift} / I^-_{out}

The μ-RWELL: single resistive-layer

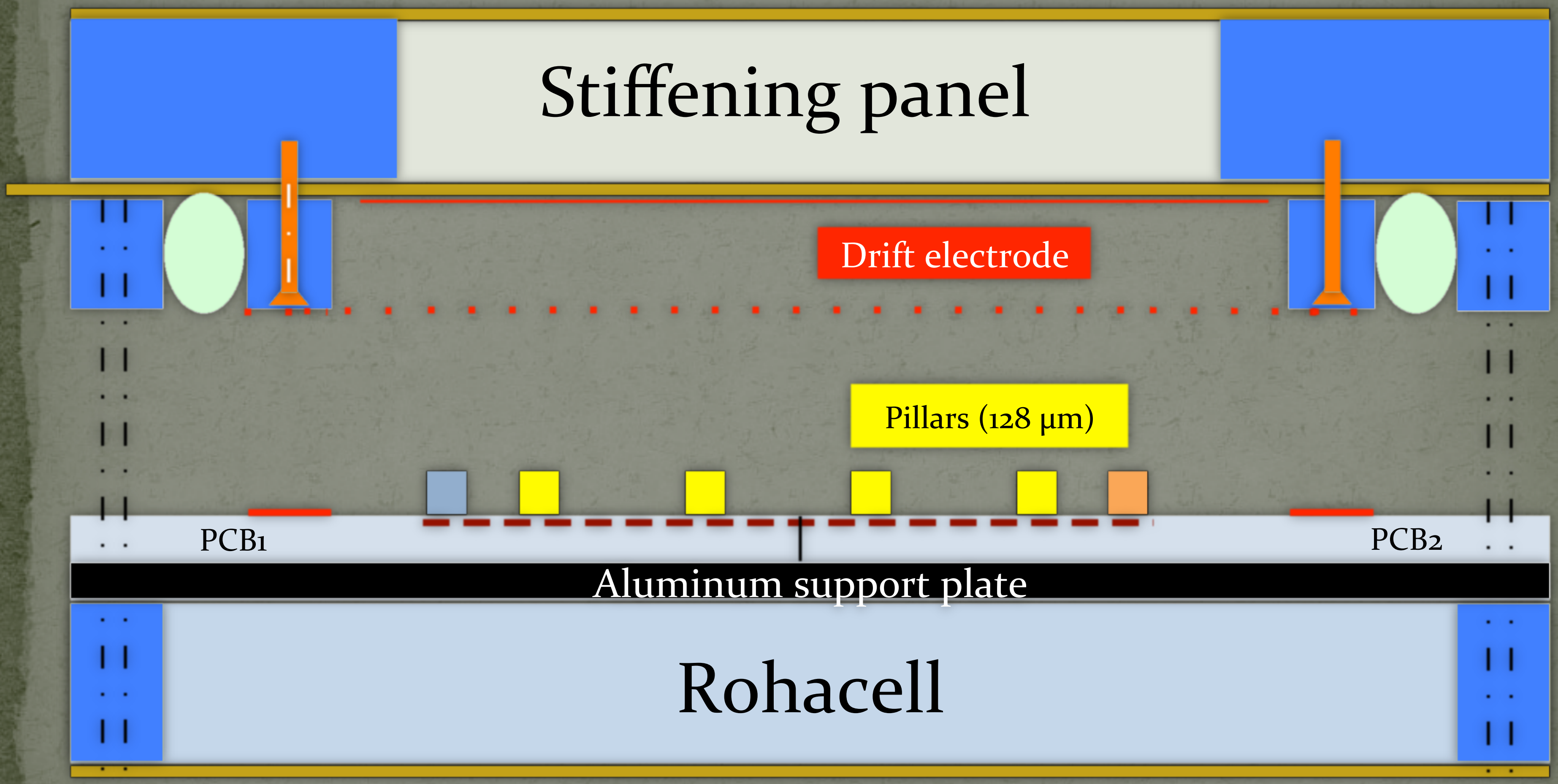


The μ-RWELL: double-segmente resistive-layer



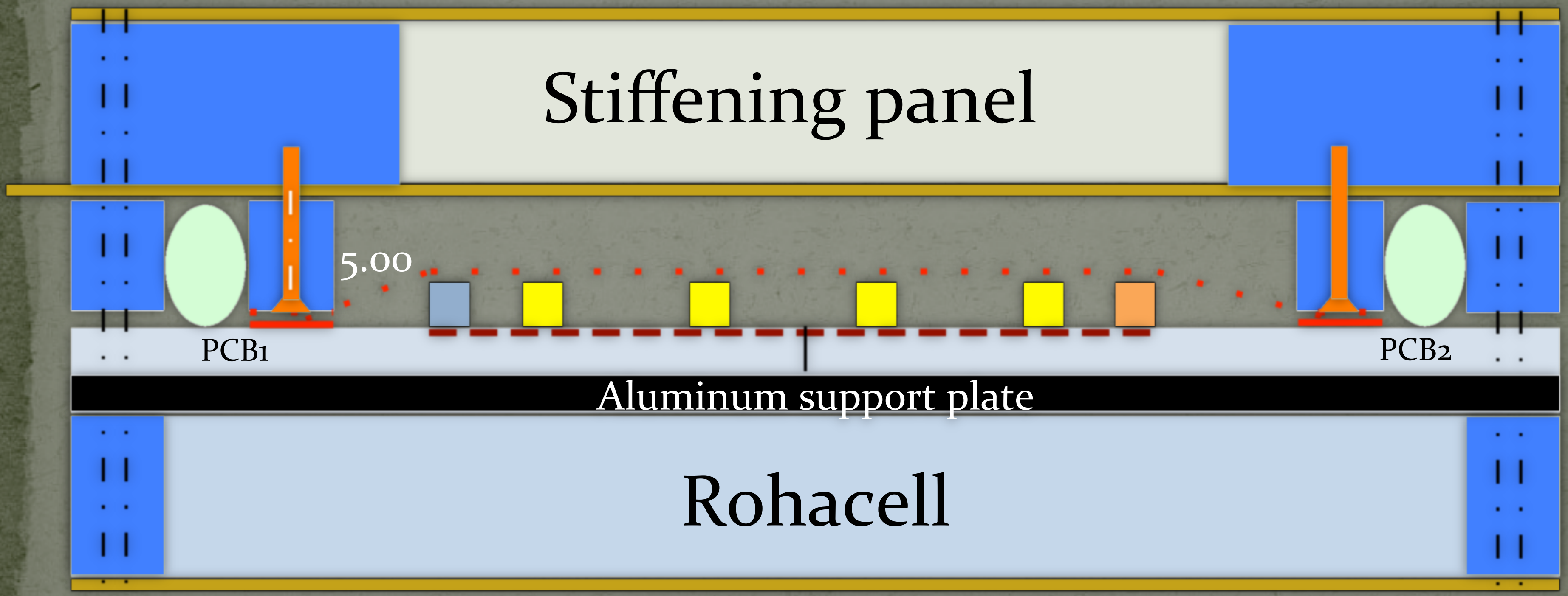
Resistive-MicroMegas with *floating mesh*
(positioning rely only on the electrostics of the cell)

not to scale detector opened



Resistive MicroMegas with *floating mesh* (positioning rely only on the electrostics of the cell)

not to scale detector closed



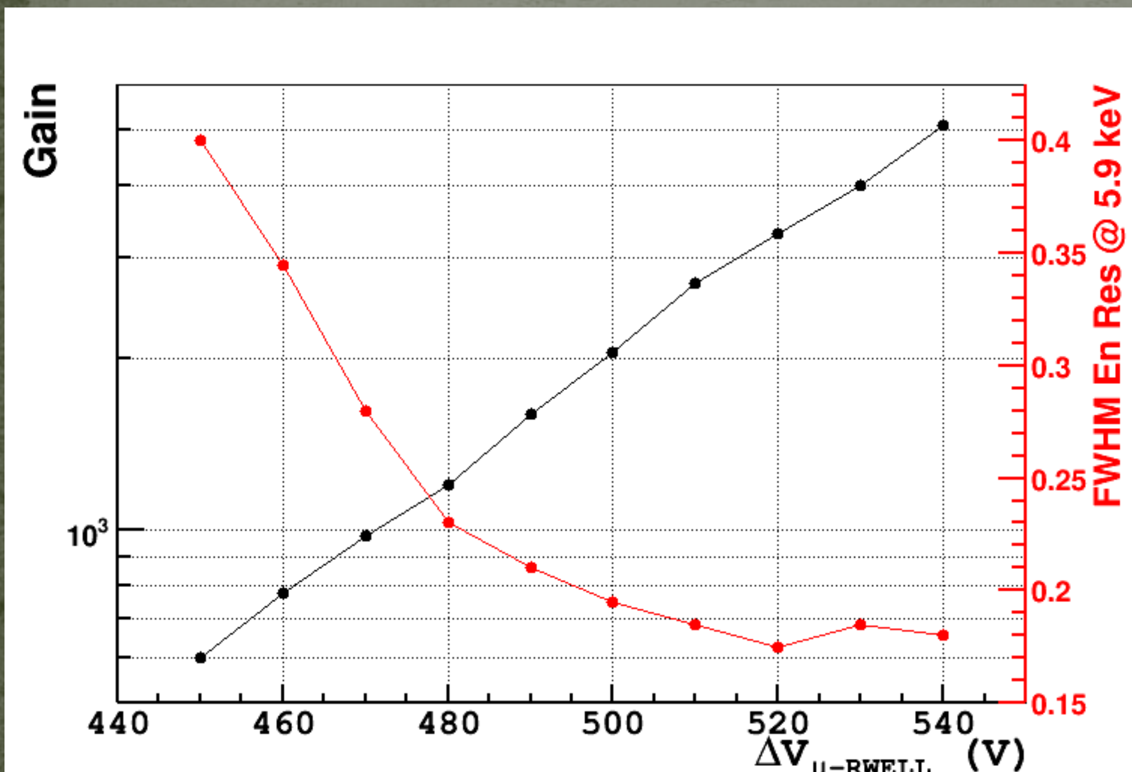
MPGDs: construction issues (II)

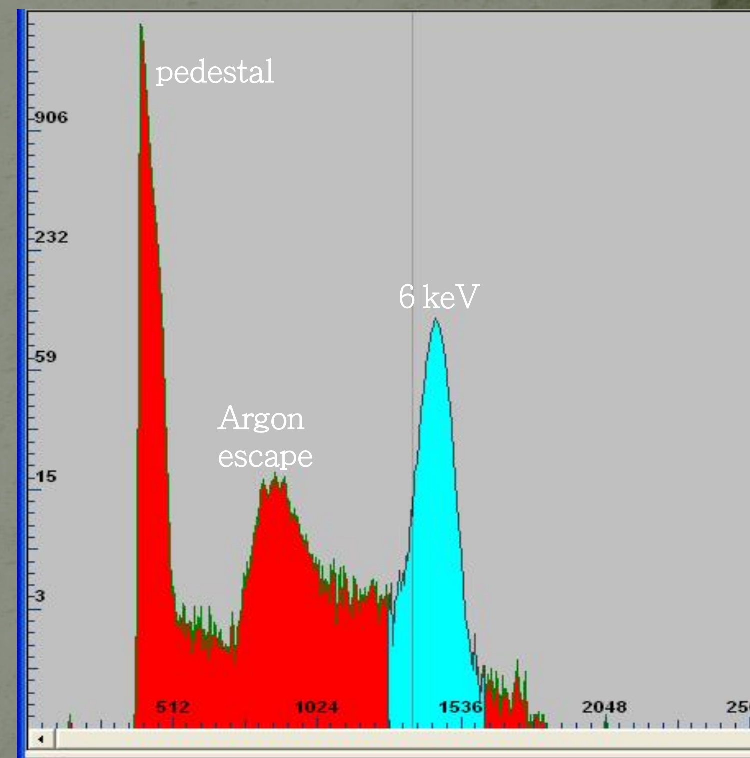
- For MM the fine metallic mesh requires for precise stretching (1 kg/cm), and, since must be assembled on the cathode (!!!), its positioning wrt the PCB-readout mainly rely on the electrostatics of the amplification/conversion gap ($P=\epsilon_0 \times (\Delta V/d)^2$) → *floating mesh.*

- Also in this case the mechanical tension [O(100kg)] applied on the mesh must be supported by very stiff mechanical structures in order to avoid deformations of the gas gaps. Even though patching of the readout PCBs is possible, the handling of the framed mesh and its positioning wrt the PCB-readout it is an issue: a not well defined amplifying gap → gain non-uniformity.

∝-RWELL: Energy Resolution

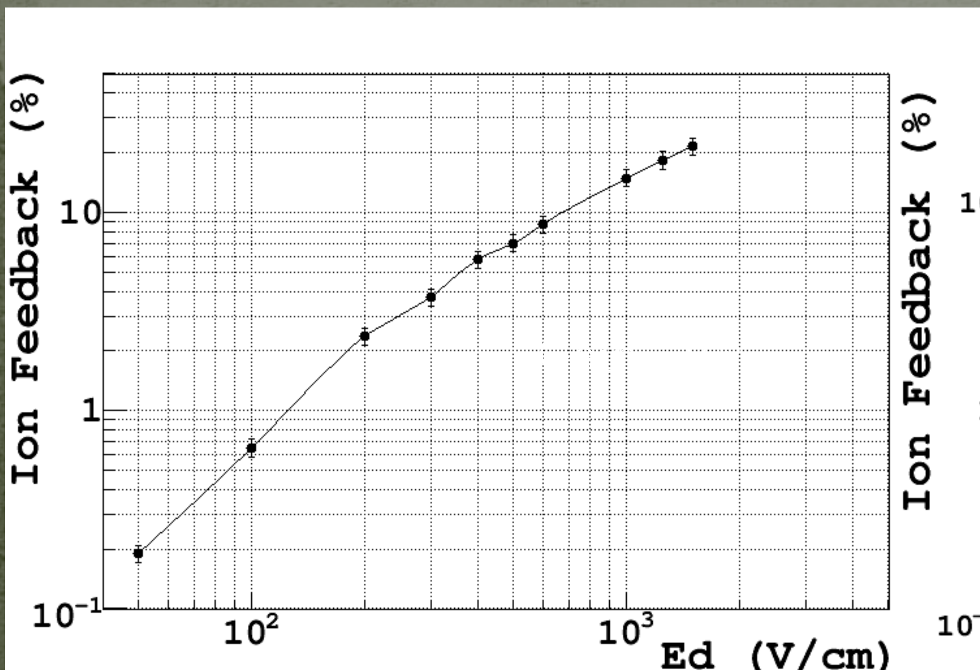
The prototype of ∝-RWELL (100 MΩ/□) has been tested with X-rays tube (6keV) (Ar/CO_2=70/30) & the signal has been readout vith an ORTEC amplifier

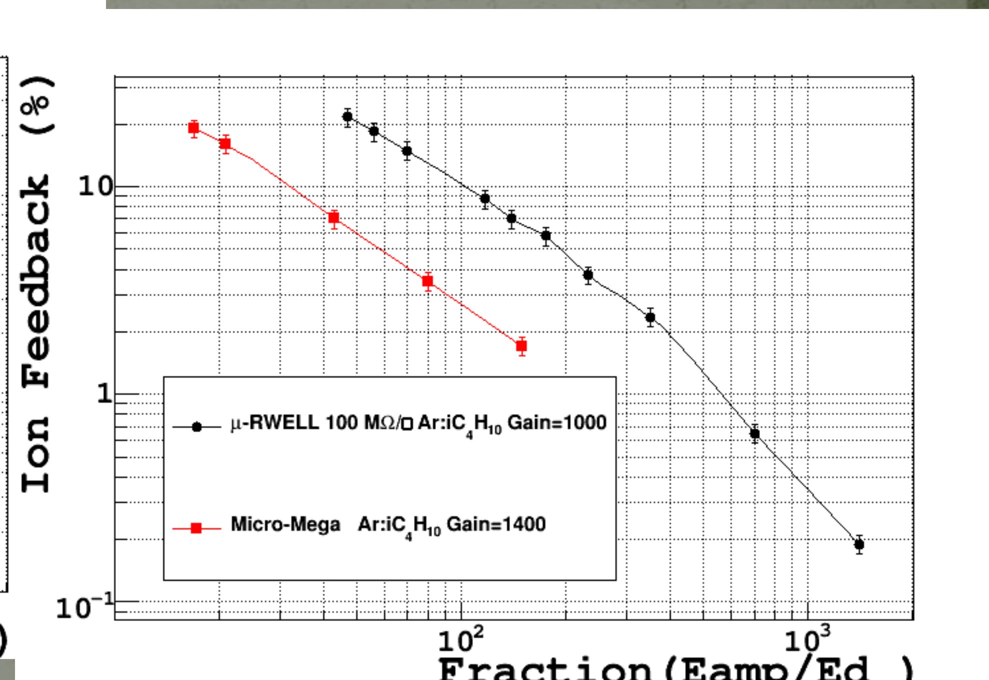




∝-RWELL: Ion Feed-Back measurement

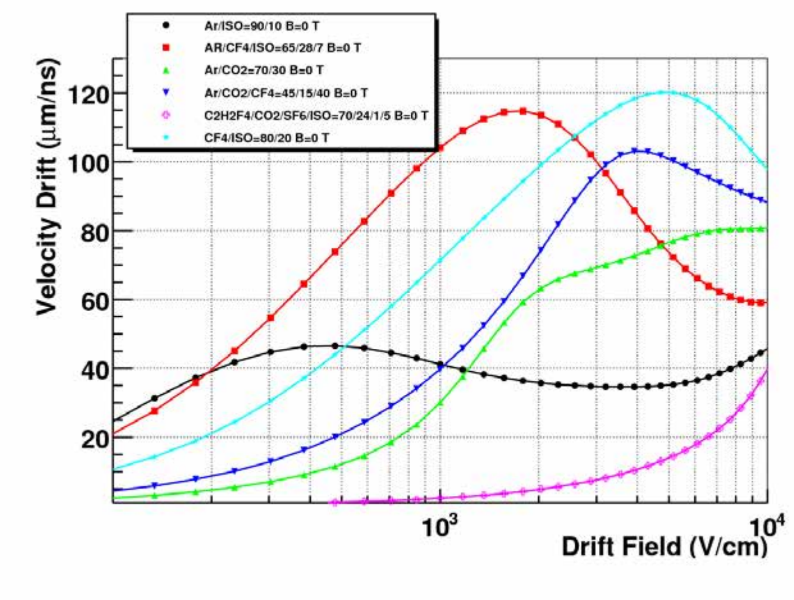
The prototype of ∝-RWELL (100 MΩ/□) has been tested in current mode with X-rays tube (6keV) (Ar/ISO=90/10)



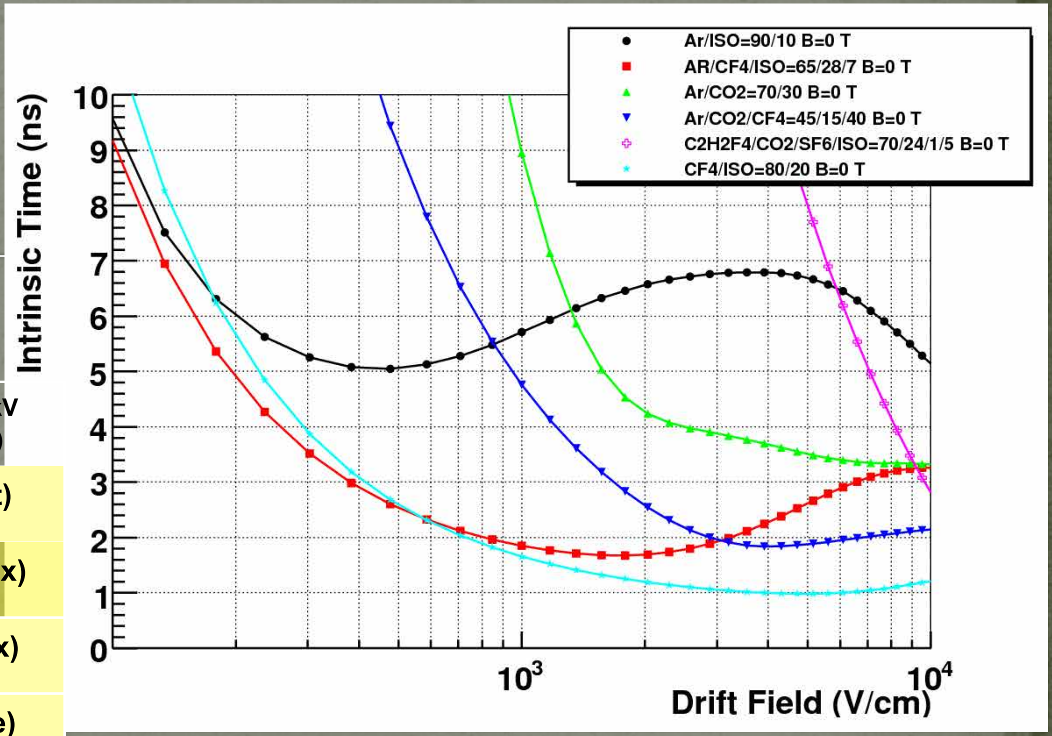


MM IBF measurement: NIMA 535 (2004) 226

Gas mixtures properties for triggering & tracker detectors



$\sigma_T \sim 1 / n_{clu} * vel_{drift}$



Gas Mixture	Cluster/cm (μ 10 GeV)	Vd @ 2 kV (μm/ns)
Ar/ISO = 90/10	42.52±0.06	36 (flat)
AR/CF4/ISO = 65/28/7	52.00±0.07	113 (max)
Ar/CO2 = 70/30	37.22±0.06	64 (max)
Ar/CO2/CF4 = 45/15/40	52.85±0.07	74 (rise)
C2H2F4/CO2/SF6/ISO = 70/24/1/5	89.49±0.09	4.9 (rise)
CF4/ISO = 80/20	84.66±0.09	99 (rise)

Gas mixtures properties for triggering & tracker detectors

Gas Mixture	Cluster/cm (μ 10 GeV)	Vd @ 2 kV (μm/ns)	σt = 1/nv (ns) @ 2 kV	σlong @ 2 kV (μm/√cm)	σtra @ 2 kV (μm/√cm)	Lorentz Angle (degree) @ 2 kV	Town@ 80 kV (1/cm)	Att @ 80 kV (1/cm)	e-/clu
			MAGNETIC FIELD = 0. T						
Ar/ISO = 90/10	42.52±0.06	36 (flat)	6.57	163 (flat)	376 (flat)		1695	0.0716	2.073± 0.001
AR/CF4/ISO = 65/28/7	52.00±0.07	113 (max)	1.69	73.6 (drop)	133.8 (flat)		1565	13.9	1.815± 0.001
Ar/CO2 = 70/30	37.22±0.06	64 (max)	4.24	150 (flat)	228 (rise)		1229	2.17	1.966± 0.001
Ar/CO2/CF4 = 45/15/40	52.85±0.07	74 (rise)	2.55	90.6 (drop)	91.3 min		1207	18.9	1.884± 0.003
C2H2F4/CO2/SF6/ISO = 70/24/1/5	89.49±0.09	4.9 (rise)	22.9	60.4 (drop)	55.9 (drop)		797	23.1	2.361± 0.006
CF4/ISO = 80/20	84.66±0.09	99 (rise)	1.2	58.0 (drop)	76.0 (flat)		1300	47.45	2.400± 0.005