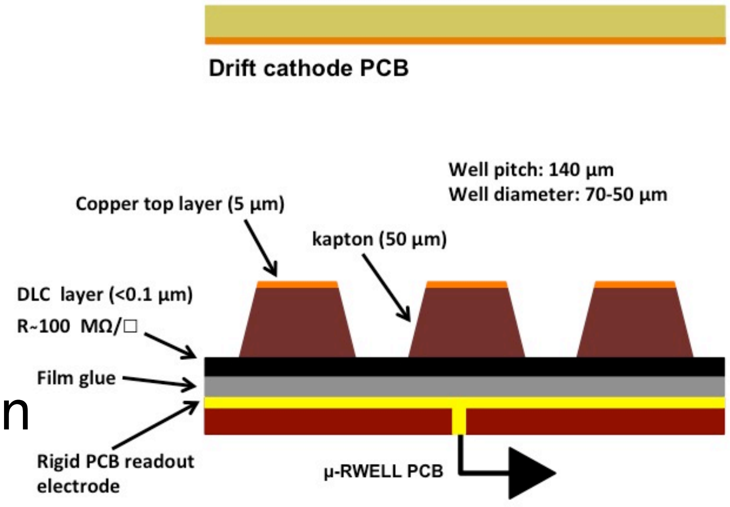
Status of the R&D on the μ-RWELL technology

G. Bencivenni[a], R. de Oliveira[b], M. Gatta[a], G. Morello[a], A. Ochi[c], M. Poli Lener[a]

a. INFN-LNF
b. CERN
c. Kobe University

The μ-RWELL detectors



- They are composed of two elements: a **cathode** glued on a **frame**, working as spacer and as limit for the conversion gas volume, and the **μ-RWELL_PCB**
- Nothing to say about cathode: a longer discussion could be held about its coating for photon/neutron conversion, but it is not the purpose of this talk
- The **μ-RWELL_PCB** is the core of the detector: this talk reports about its different versions developed taking into account the requirements of applications/experiments*

* No studies dedicated to the gas mixture have been performed

The μ-RWELL_PCB

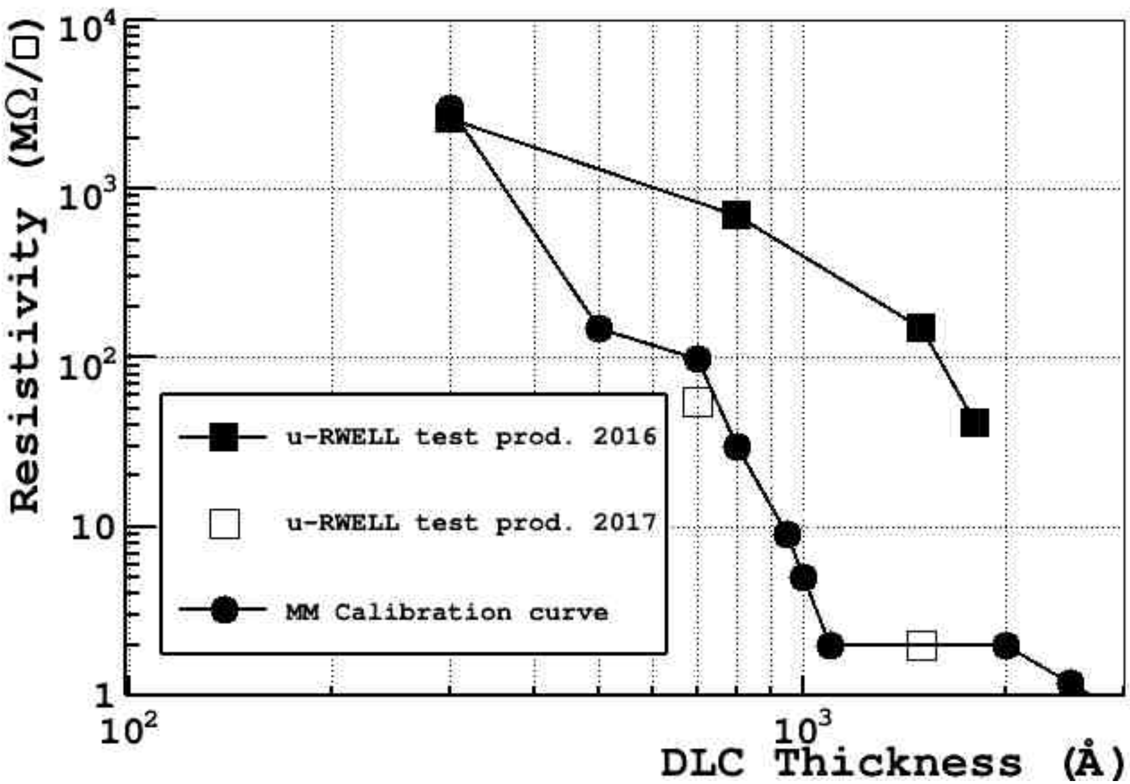
- The main element of the device is furthermore constructed coupling the **amplification stage** to **the readout plane** through an **insulating layer**
- The **amplification stage** is a kapton foil covered on one side by few microns Cu, and on the other side **sputtered with DLC** (Diamond-like Carbon). The amplification channels are created by etching, exploiting the consolidated technique used for GEMs
- The **resistive stage** can be adapted to the required performances of the detector in terms of rate capability

DLC

The foils sputtered with DLC are provided by Be-Sputter Co., Ltd. in Japan

The carbon is sputtered on the kapton foil as an amorphous diamond like carbon (a-DLC) using a pure graphite target

The resistivity dependence as a function of the carbon thickness for two different sputtering batches



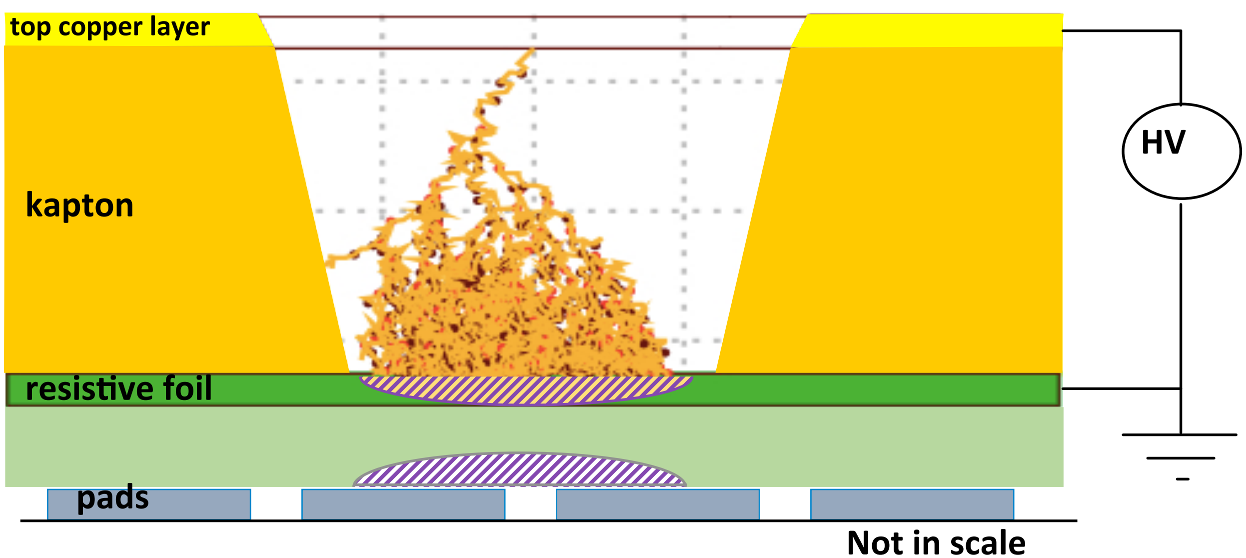
The different trend for the two curves is supposed to be related with the humidity trapped by the Kapton before the sputtering process: higher humidity implying higher resistivity.

Thanks to A. Ochi

The single resistive layer

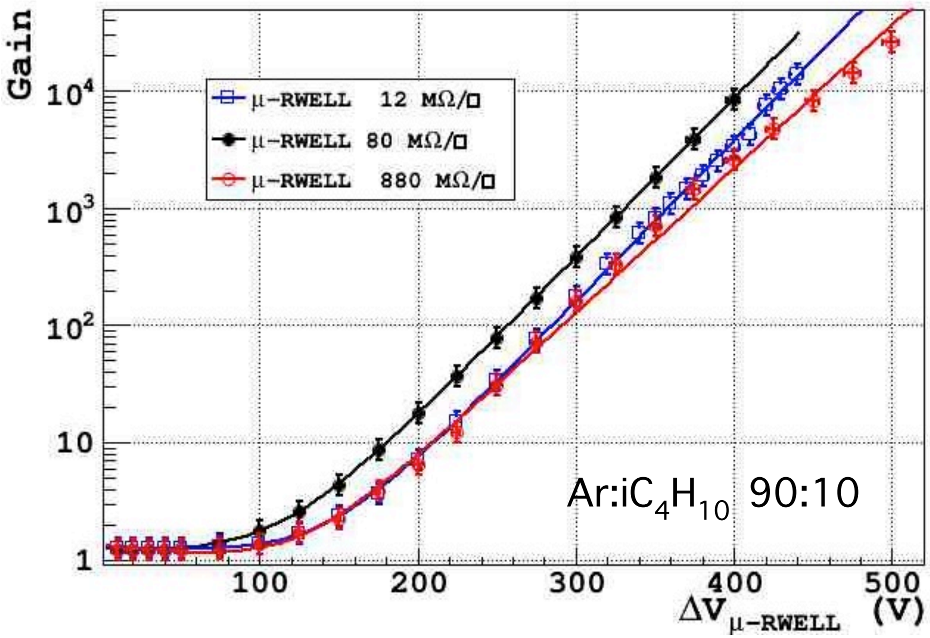
- The simplest version of the detector, actually the first one, has been extensively studied with several prototypes each characterized by different surface resistivities [JINST 10 P02008, NIM A 824 (2016) 565]
- In this case the etched kapton foil, sputtered with DLC, is coupled through an insulating layer to the readout plane

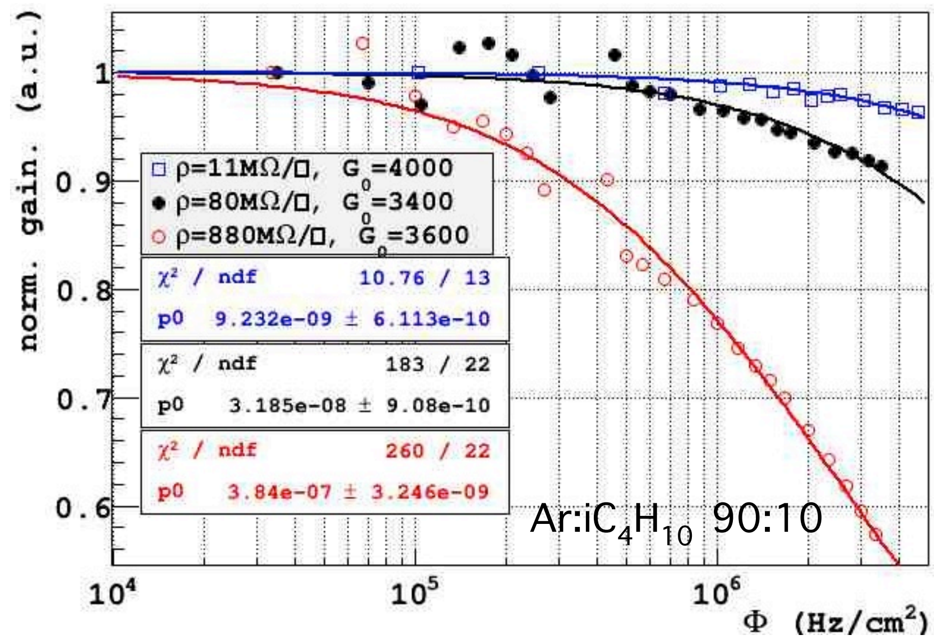
5 μm CU
50 μm Kapton
500 – 700 nm DLC
50 μm pre-preg



The single resistive layer: first tests

- Three prototypes with **10x10 cm^2 active area** have been realized and first tested with X-ray (**local irradiation**) at LNF





The **single resistive layer** layout is suitable for **low rate applications**

3% gain drop at

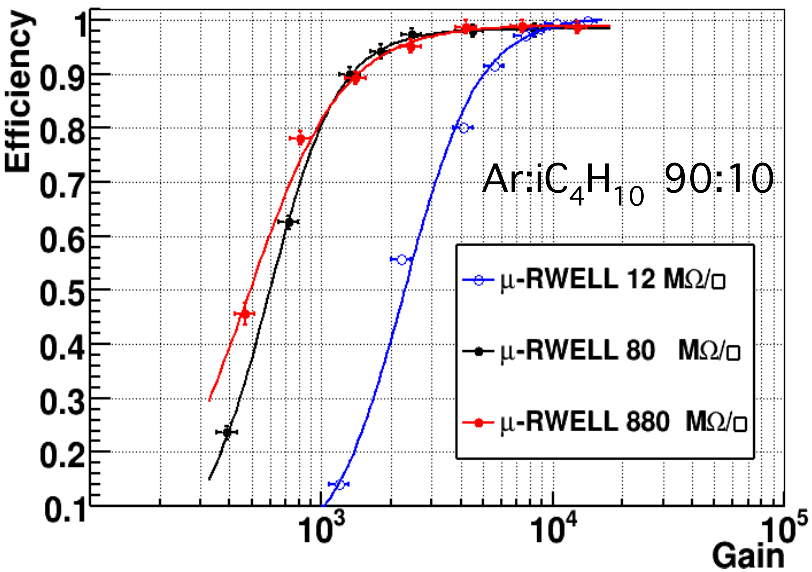
$\Phi_{0.97}$ = 850 kHz/cm^2;

$\Phi_{0.97}$ = 77 kHz/cm^2;

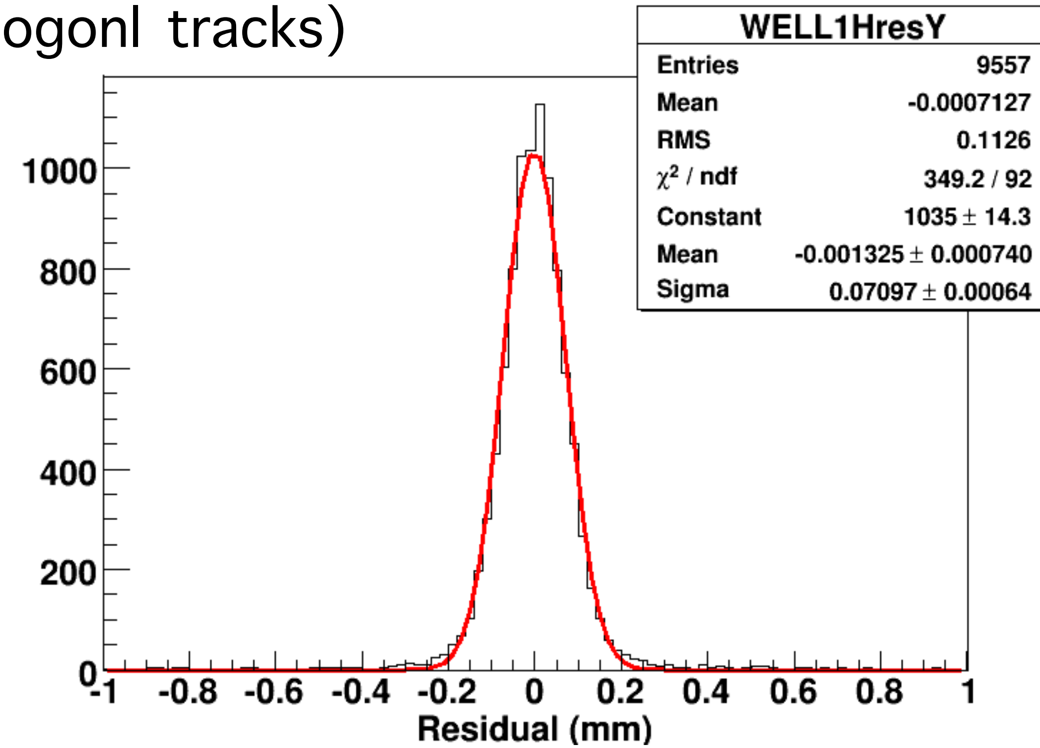
$\Phi_{0.97}$ = 3.4 MHz/cm^2;

The single resistive layer: H4 test beam (2015)

- The devices have been then tested at H4-SPS North Area, equipped with **strips-segmented readout** (400 µm pitch) and **APV25** (CC method, orthogonl tracks)



The different behaviour can be assigned to a **different geometry** of the amplification holes, that have not been inspected

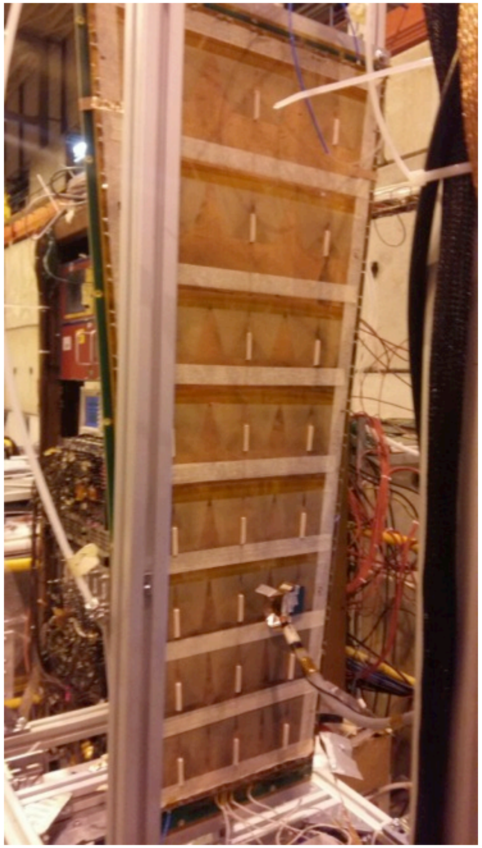


σ_{RWELL} = (52±6) µm

@ B= 0T after TRKs contribution subtraction

The single resistive layer: towards large area detectors

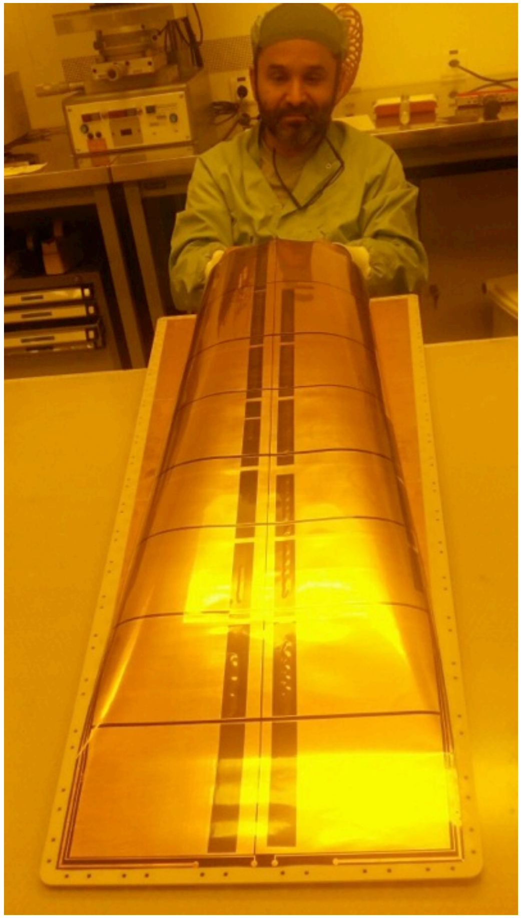
In the framework of CMS-phase2 muon upgrade we developed large size μ-RWELL in strict collaboration with **Italian industrial partners** (**ELTOS & MDT**)

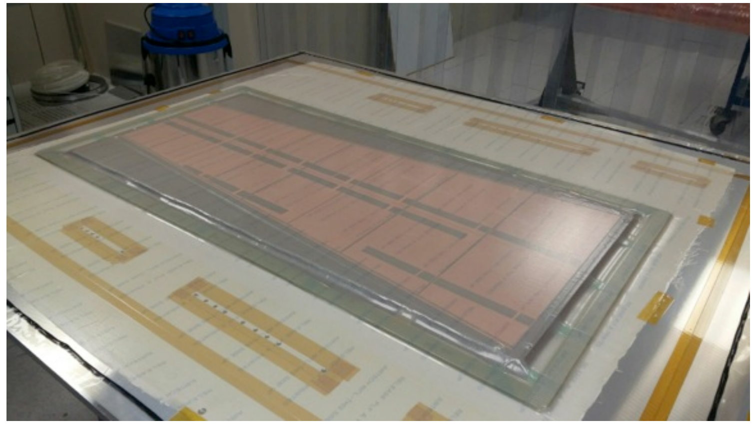


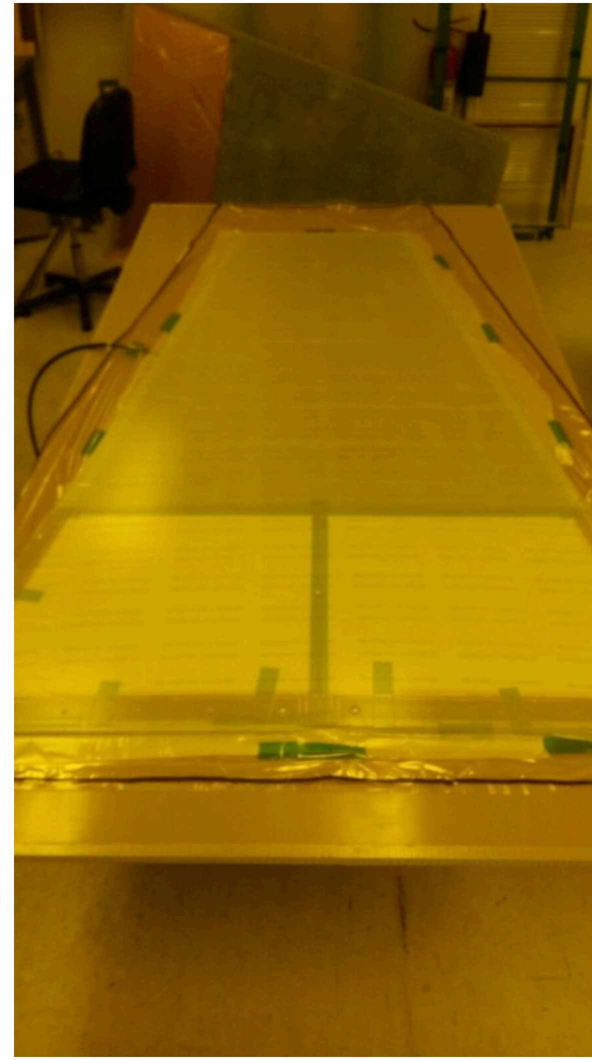
GE1/1 (1.2x0.5 m^2). Active area segmented in 16 sectors which 4 were working.

GE2/1-like chambers. Only the lower part (1.2x0.6 m^2) is active. It has been obtained splicing two μ-RWELL_PCBs

The single resistive layer: towards large area detectors

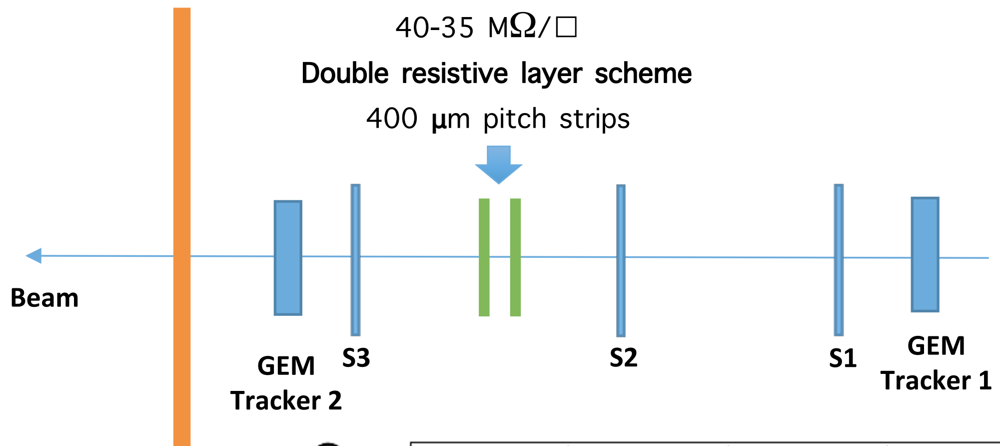




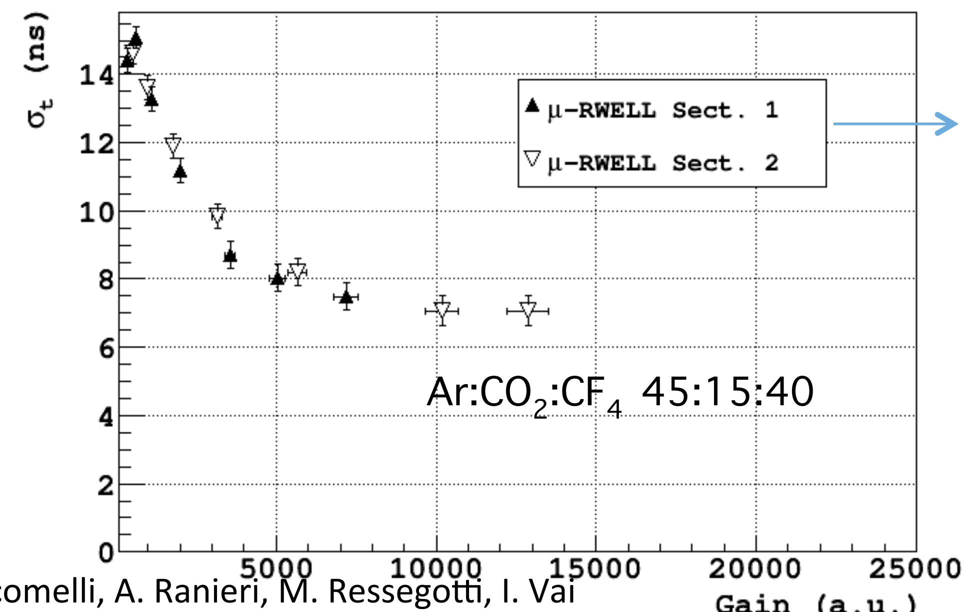


The single resistive layer: H8C (2016) test beam

N° 2 μ-RWELL protos
10×10 cm^2
40-35 MΩ/□
Double resistive layer scheme
400 μm pitch strips



N° 1 μ-RWELL proto
100×50 cm^2
70 MΩ/□
Single resistive layer scheme
800 μm pitch strips

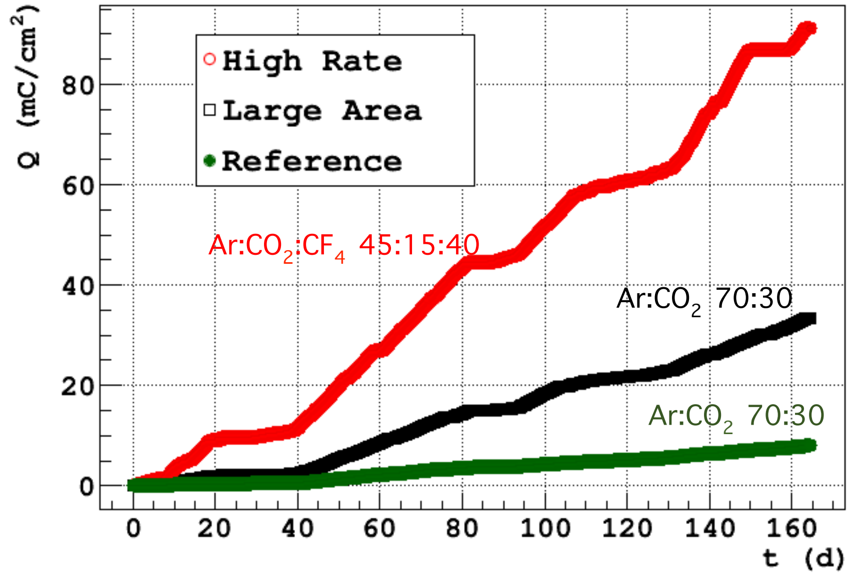


→ size ~ 10 x 30 cm^2

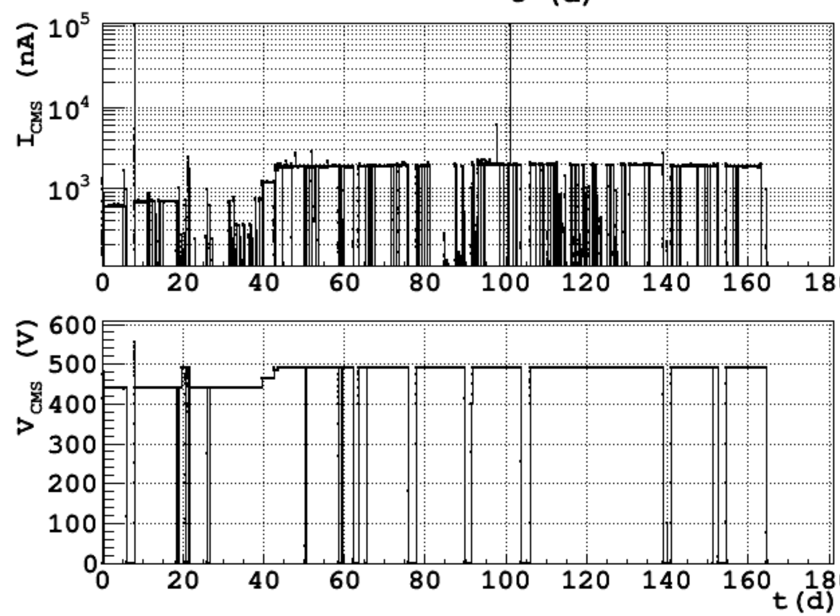
- Detectors equipped with **VFAT2**
- Analysis performed asking for **TDC coincidences**

Thanks to L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

The single resistive layer: GIF++ exposure (2017)



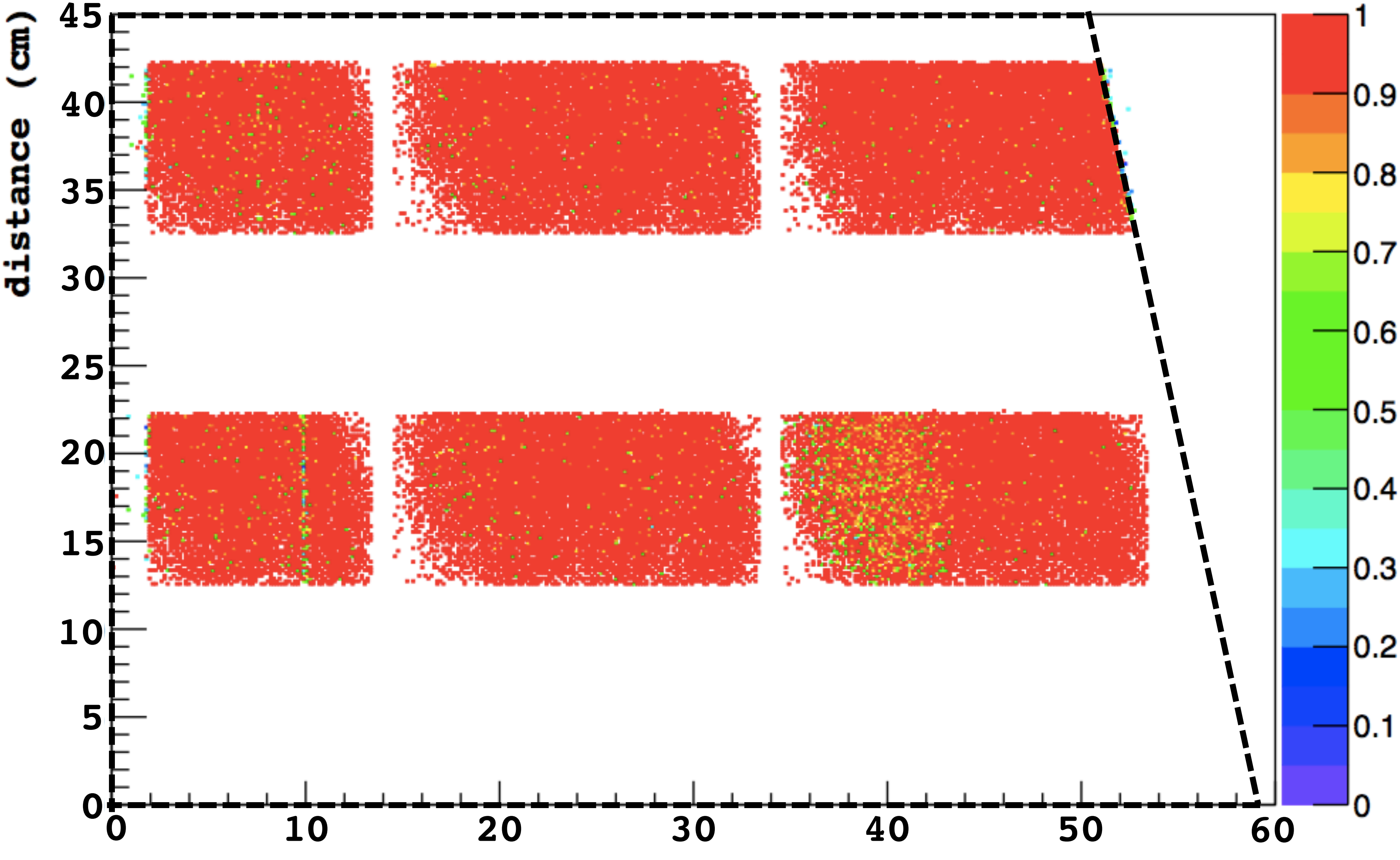
m.i.p. equivalent rate ~10 kHz/cm²



The study of ageing effects on DLC has been done by integrating the charge expected in 10 years of operation in the CMS GE2/1 region (1 kHz/cm^2).

At a gain of 4000 the total charge expected is **2.6 mC/cm^2**

The single resistive layer: H4 test beam (July 2017)

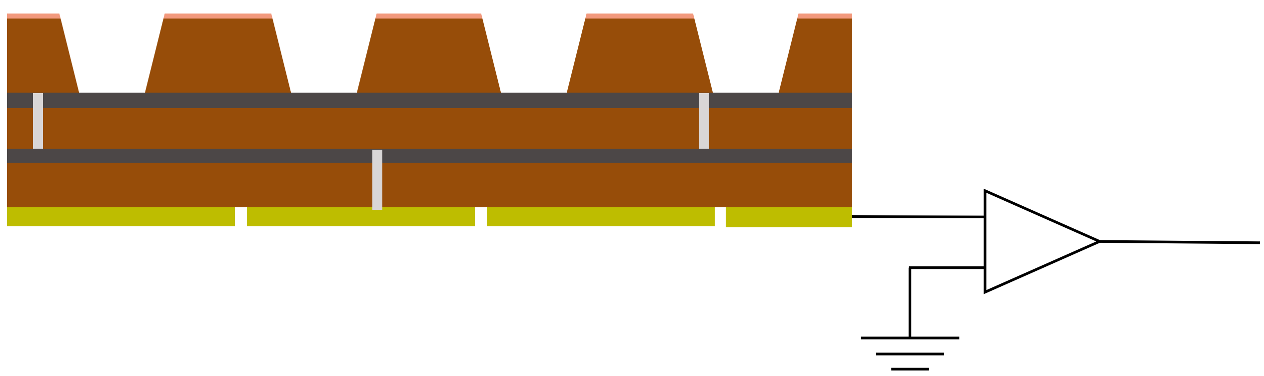


Thanks to L. Borgonovi, L. Benussi, P. Giacomelli

The double resistive layer

- The charges collected on the resistive layer move towards the ground with a characteristic time τ(R,C) [Dixit et al, NIMA 518 (2004) 721, NIMA 566 (2006) 281].
- The idea is to reduce the pattern covered by the electrons on the DLC

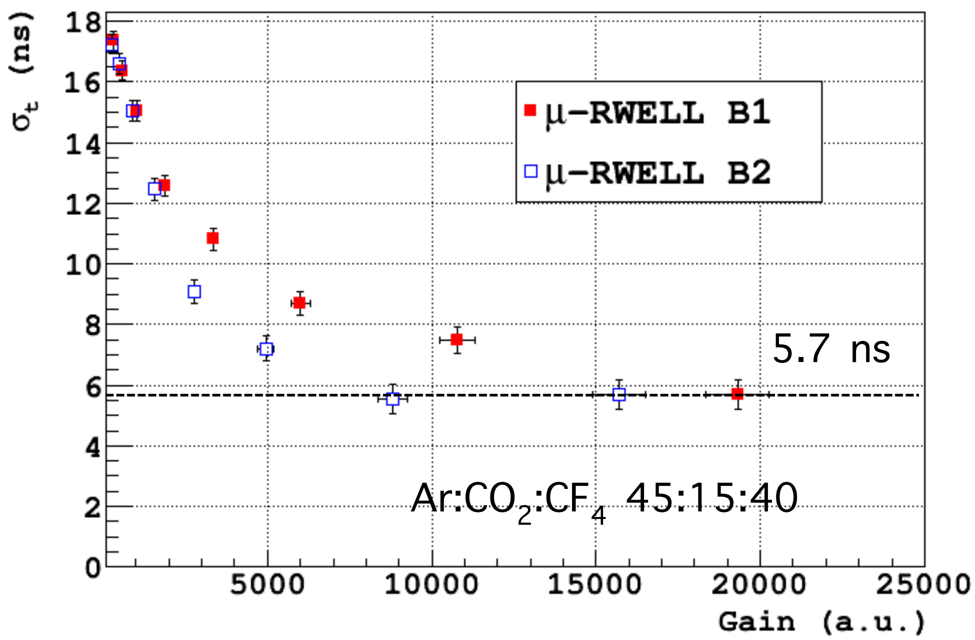
5 μm CU
50 μm Kapton
500 – 700 nm DLC
10 μm epoxy
500 – 700 nm DLC
20 μm epoxy



A matrix of conductive vias connects the two resistive layers. Another matrix of vias chains the second resistive layer to ground through the readout

The double resistive layer: H8C test beam (2016)

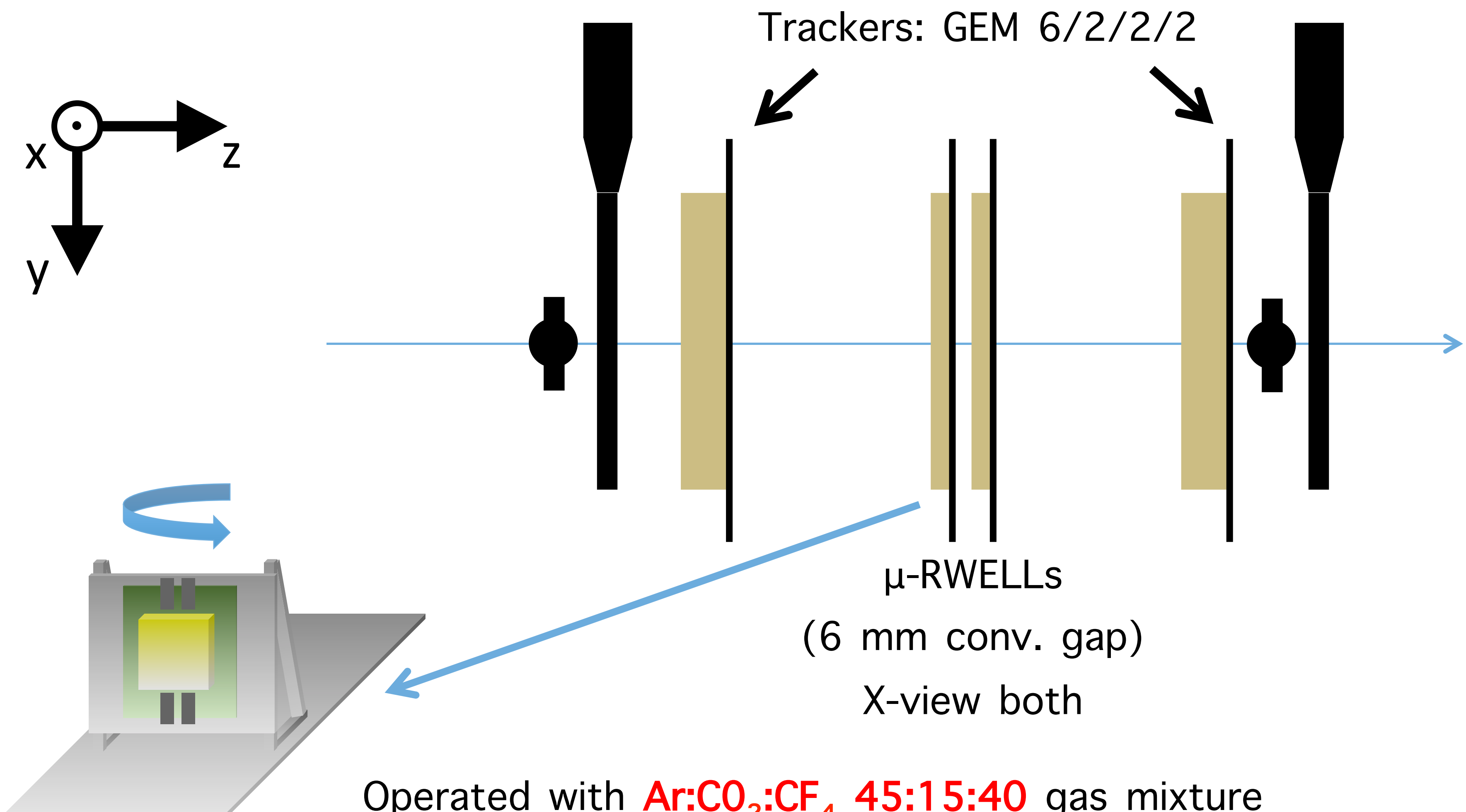
Two double resistive layer prototypes have been tested with muon beam and equipped with VFAT2



Same saturation observed in GEM detectors operated with the same FEE in the same test beam, while with GEM a time resolution of 4.8 ns has been obtained by LHCb [G. Bencivenni et al., NIM A 494 (2002) 156]

Thanks to L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai

The double resistive layer: H8C test beam (Oct. 2017)



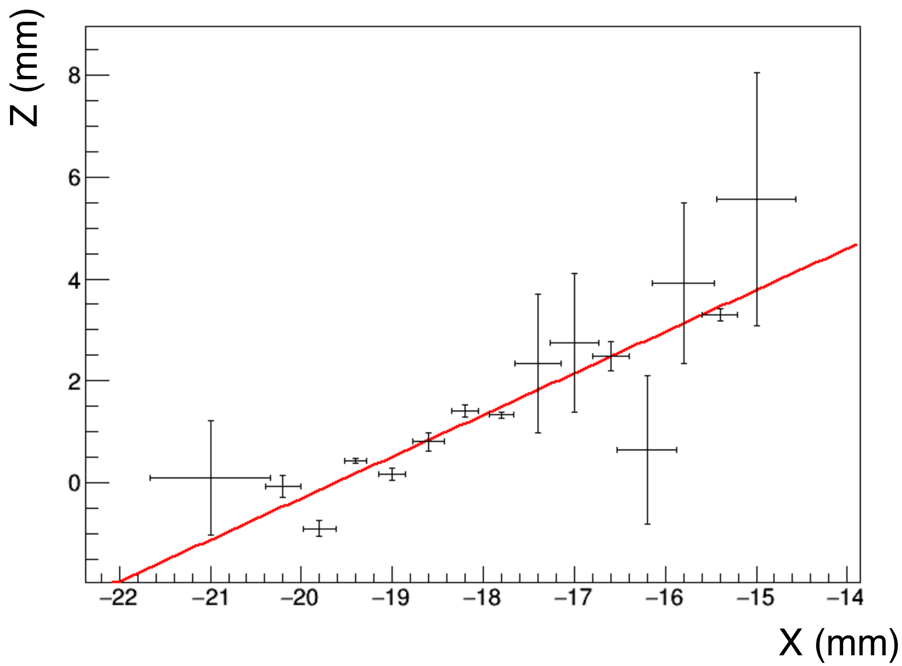
Rotatable plate

Operated with **$Ar:CO_2:CF_4$ 45:15:40** gas mixture

All the detectors equipped with **APV25 boards** handled by an **SRS system**

The double resistive layer: H8C test beam (Oct. 2017)

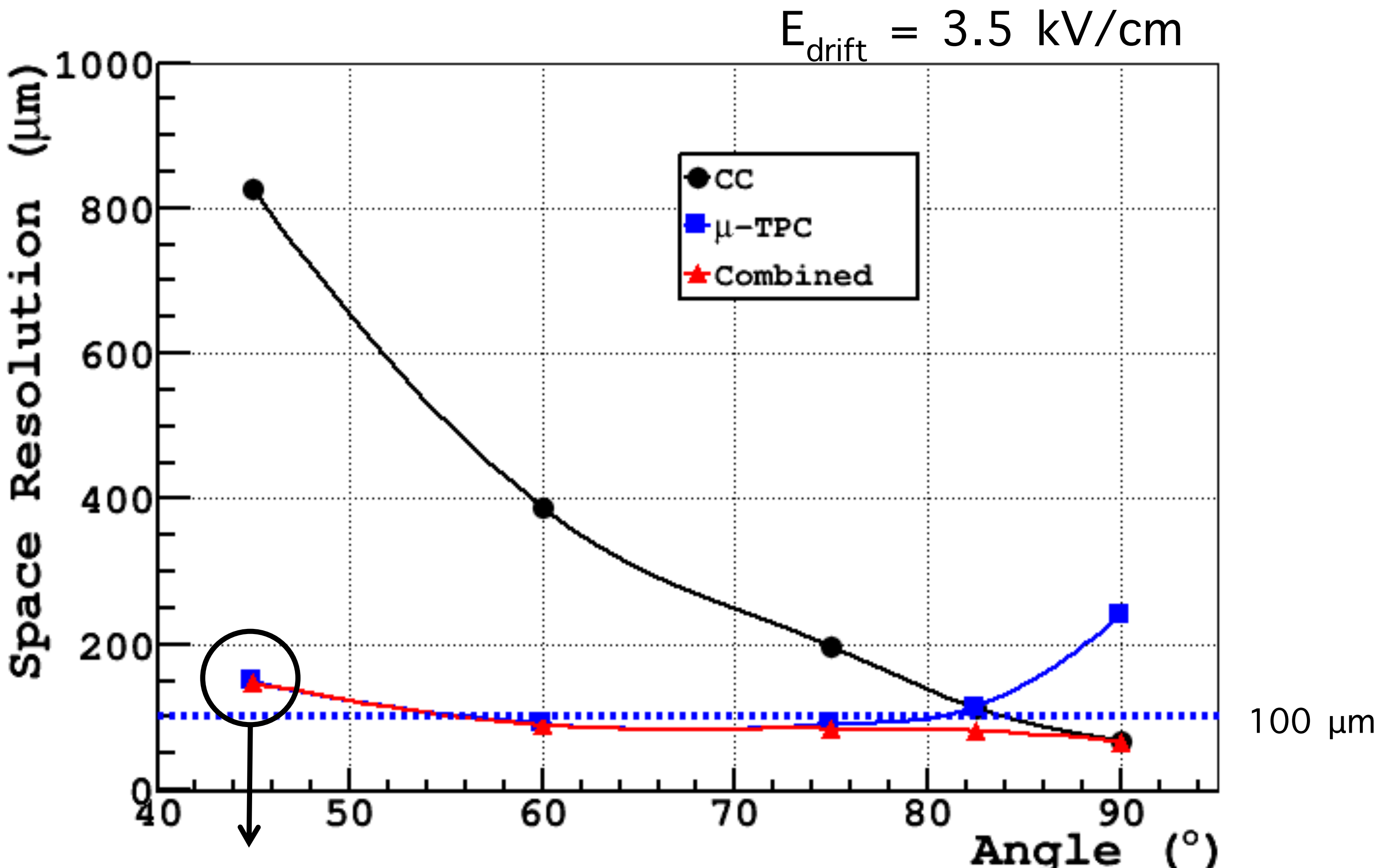
- Purpose of the test beam in the SHiP framework was the measurement of the spatial resolution vs. the track angle with respect to the readout plane
- We implemented the **μ-TPC algorithm** (T. Alexopoulos et al., NIMA 617 (2010) 161)



"Event display": hits projected in the conversion gap

More details will be given tomorrow

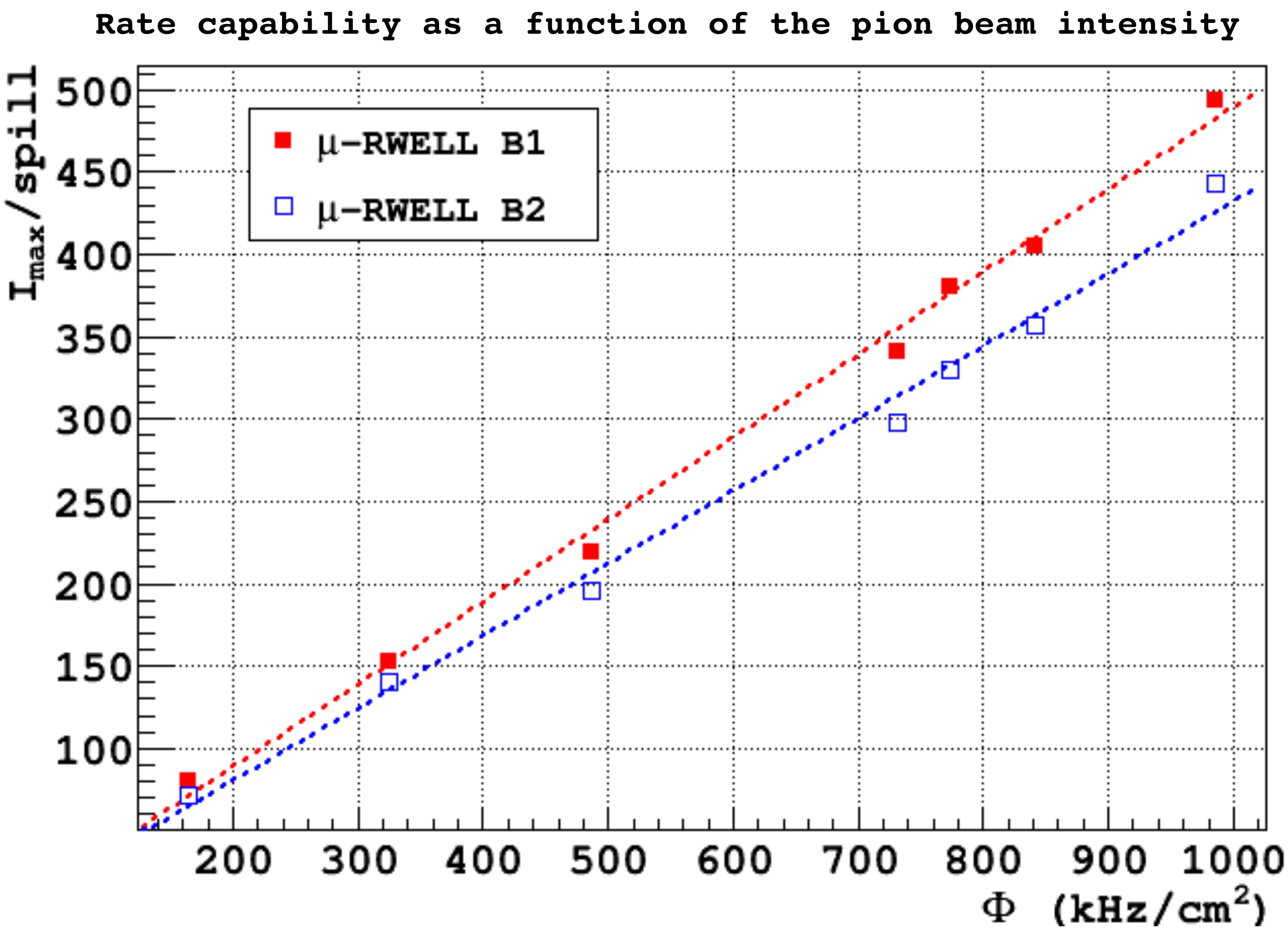
The double resistive layer: H8C test beam (Oct. 2017)



To be understood: analysis is ongoing

Thanks to M. Giovannetti, L. Lavezzi, R. Farinelli

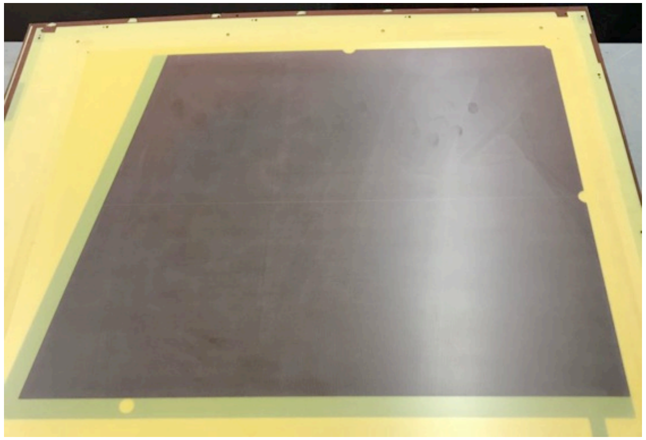
The double resistive layer: H8C test beam (Oct. 2017)



Detectors operated at a gain of 10^4. Particle fluence estimated by the current drawn by a GEM detector. Beam spot ~2 cm^2

Status of the technological transfer

- As already mentioned, the strict collaboration with **ELTOS** made possible the construction of large area detectors with single resistive layer (GE1/1-, GE2/1-like)



- This allowed us to well define the coupling procedure of the amplification stage with the readout
- ELTOS is now producing other μ-RWELL_PCB to be etched at CERN
- The industrialization of the double resistive layer construction is much more difficult
- Other (simpler) layouts must be developed in order to be included in an industrial process

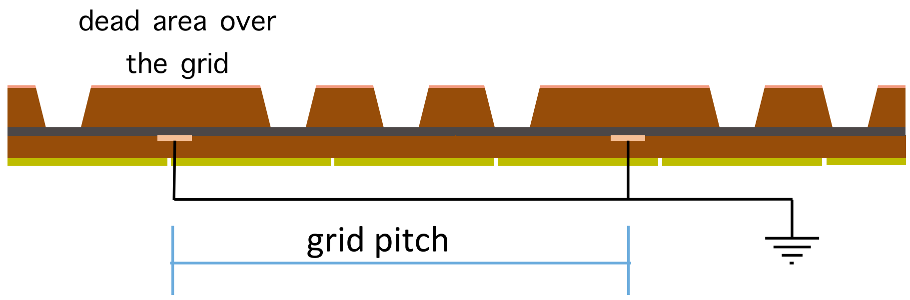
New layouts, new ideas, new challenges

The aim is to maintain a very short pattern for charges drifting on the resistive layer, while simplifying the construction process.

Two ideas are now under development: silver grid and resistive grid

Silver Grid (SG)

Small conductive strips are screen-printed on the bottom part of the DLC

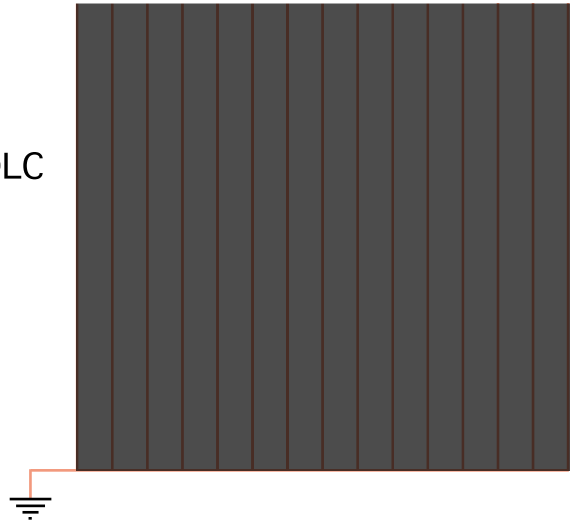


5 µm CU

50 µm Kapton

500 – 700 nm DLC

pre-preg 50 µm

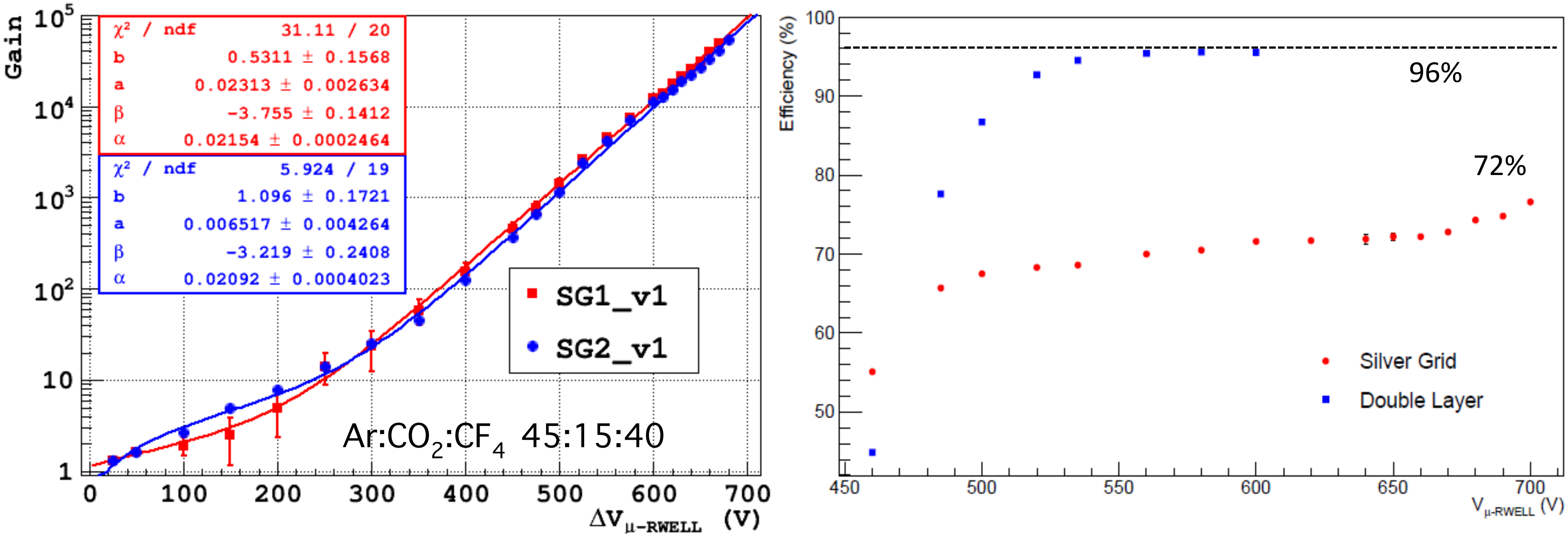


Clearly the introduction of a conductive strip on the bottom layer of the amplification stage can induce strong instabilities due to surface discharges.

First prototypes of SG delivered in July and tested: grid pitch 6 mm, dead area around 1/3 of the total area

Silver Grid v1:
X-rays and H4 test beam (July 2017)

- A SG μ-RWELL has been installed inside the RD51 tracking system and characterized together with a Double Layer chamber



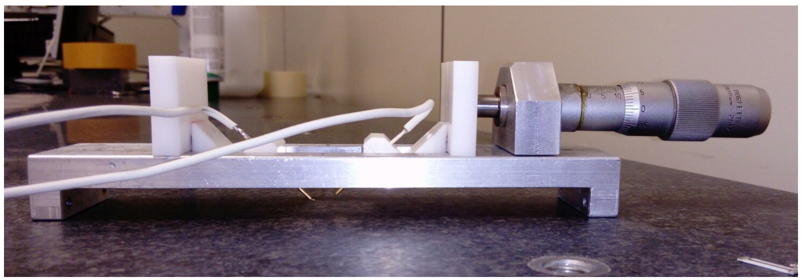
At the H4 test beam we could supply **up to 700 V** without instabilities. The reason of a so high breakdown voltage is **under investigation**.

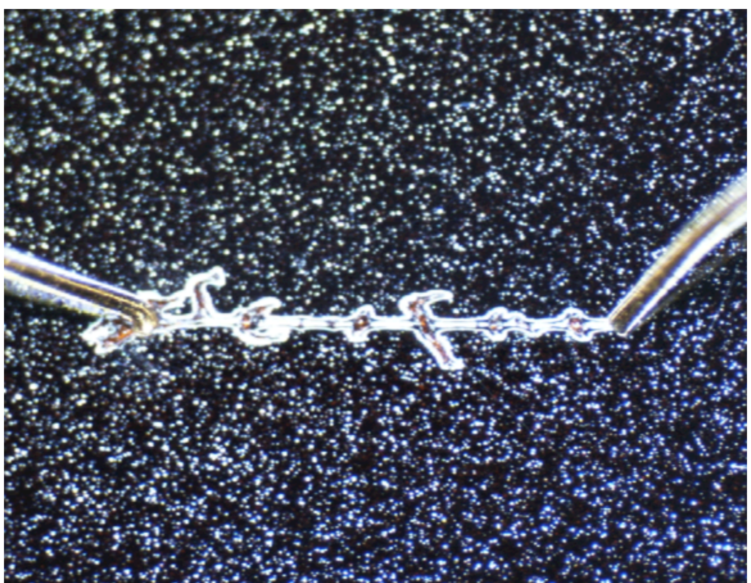
The lower efficiency is due to the geometrical effects. The increasing gain improves the collection efficiency partially compensating this leak.

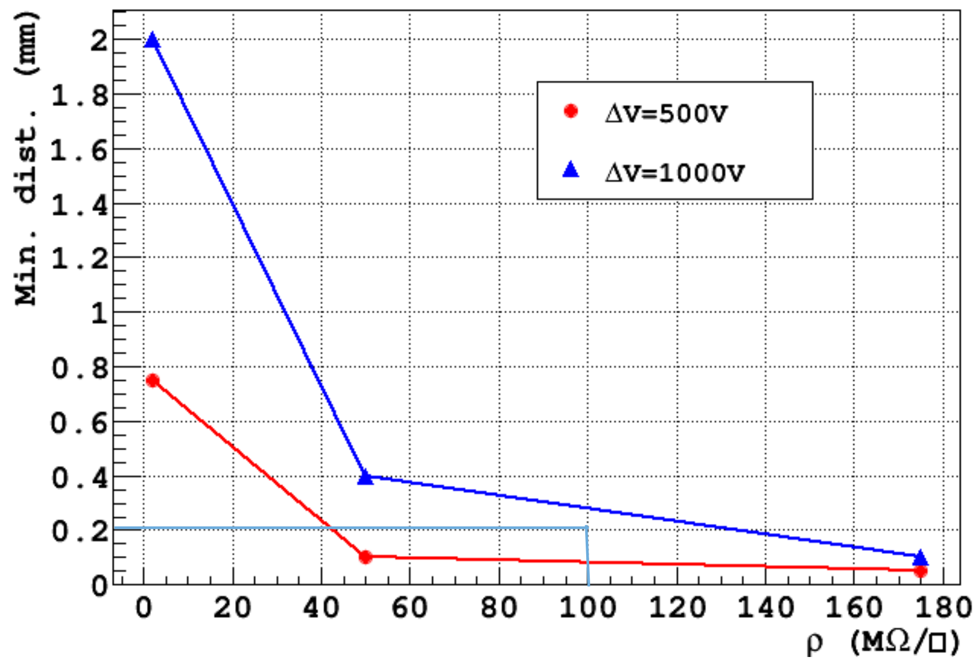
A dedicated study on the minimum distance between the strip and the holes has been done to increase the efficiency

Silver Grid: optimization

In order to reduce the dead area, we measured the Distance Of Closest Approach between two tips connected to a PS. We recorded the minimum distance as a function of the ΔV supplied for different foils before a discharge on the DLC occurs



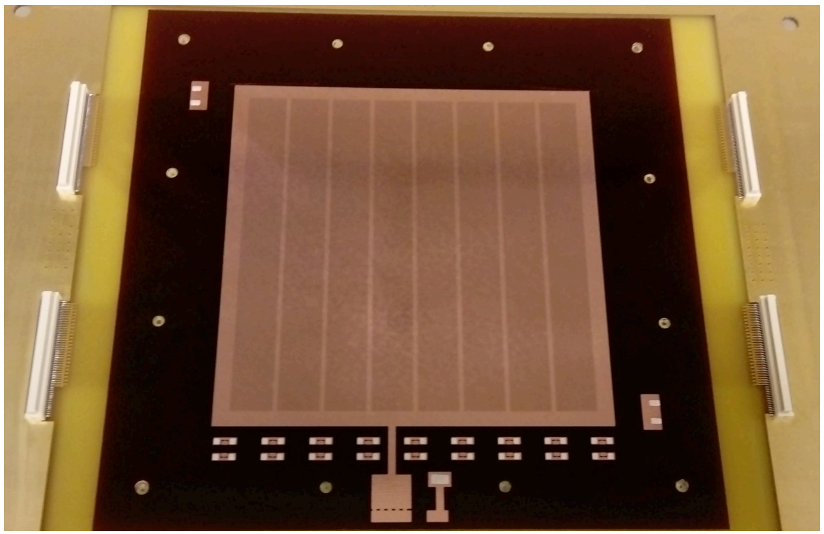




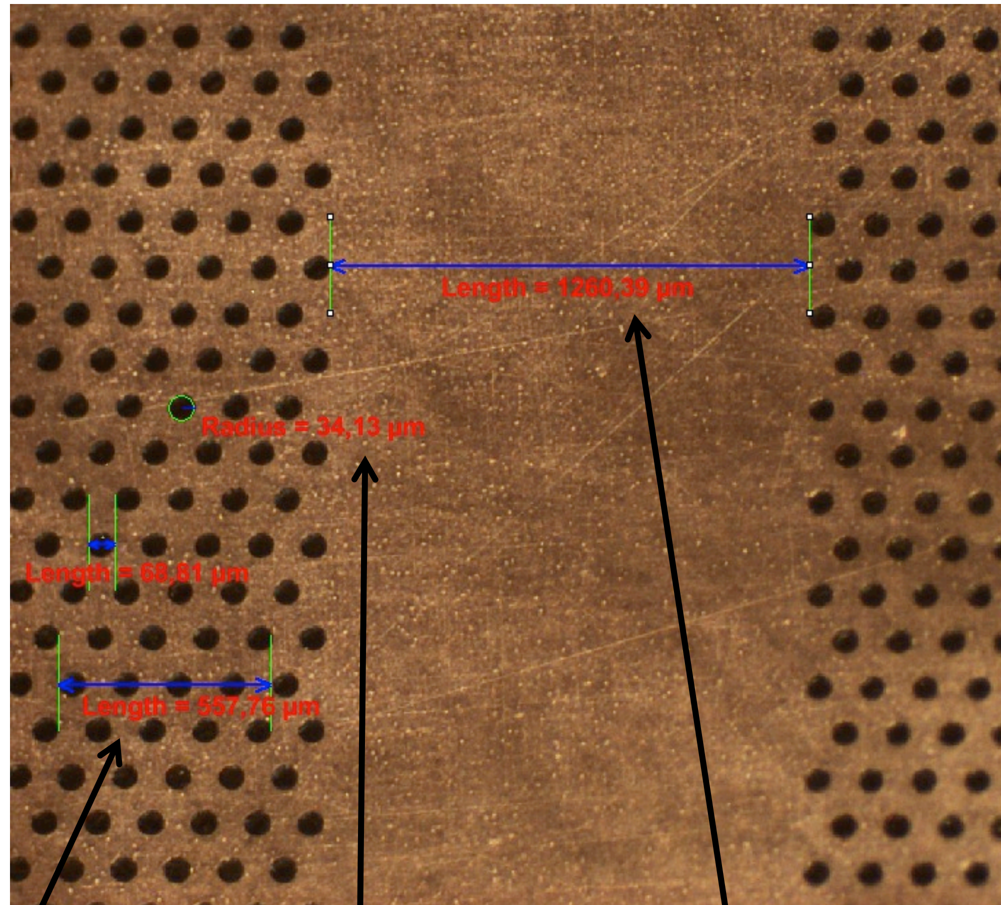
Two more prototypes delivered in November, with grid pitch 12 mm, dead area 1/10 of the active area

Silver Grid: 2nd generation

The two detectors have been equipped with 6 x 8 mm^2 pad-segmented readout

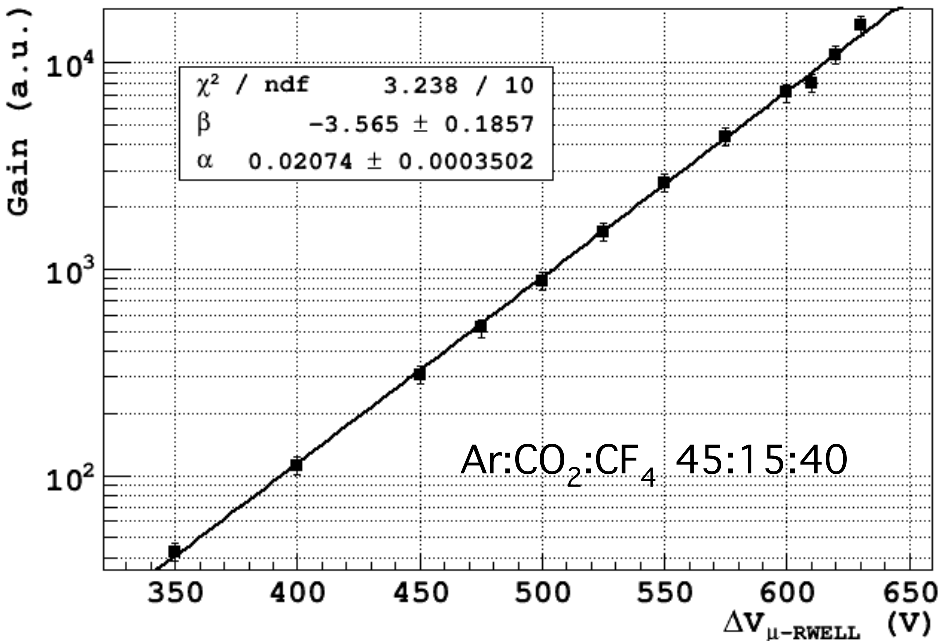


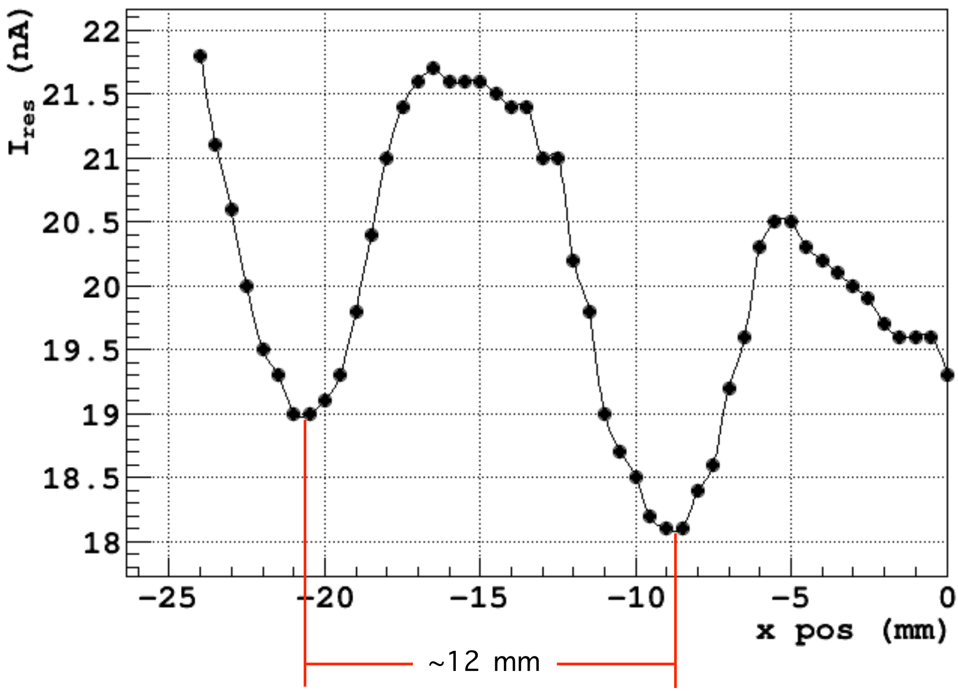
The grid lines are connected to the ground through the resistance provided by the DLC itself (9-10 MΩ)

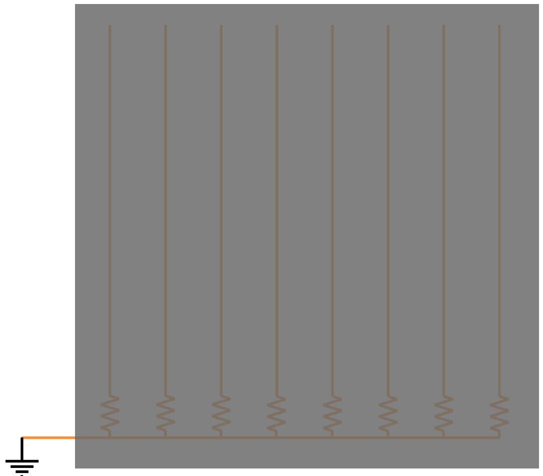


557.76 µm 34.13 µm 1260.39 µm

Silver Grid: 2nd generation





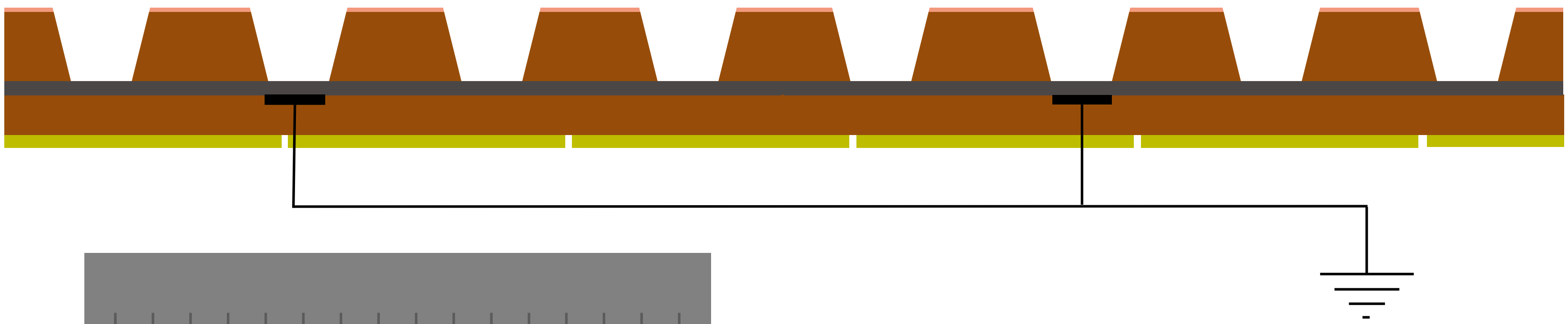


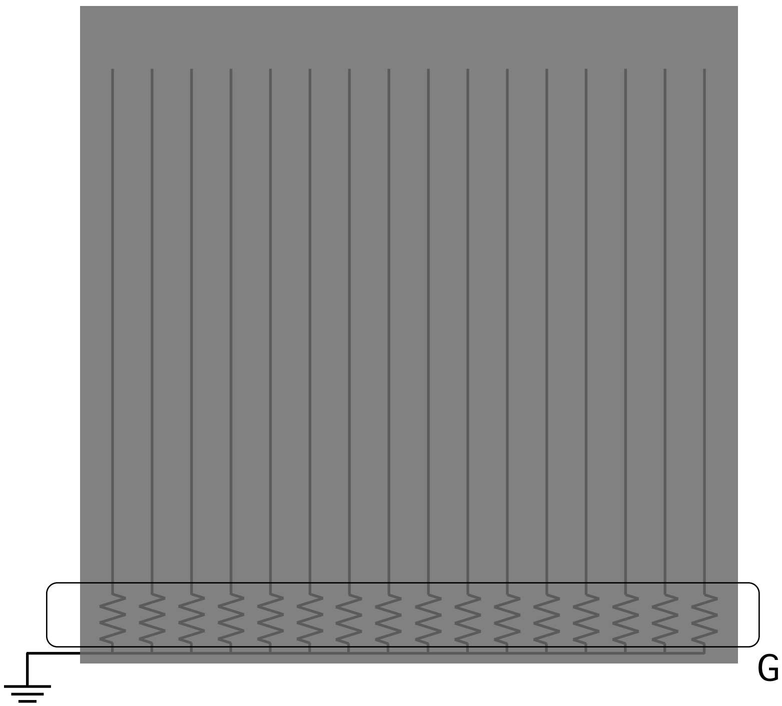
The detectors is mounted on a support moved by a stepper motor. The position is given within few tenths of millimeter.

Scan along the coordinate orthogonal to the grid lines direction

Resistive grid

Small resistive strips are screen-printed on the bottom side of DLC



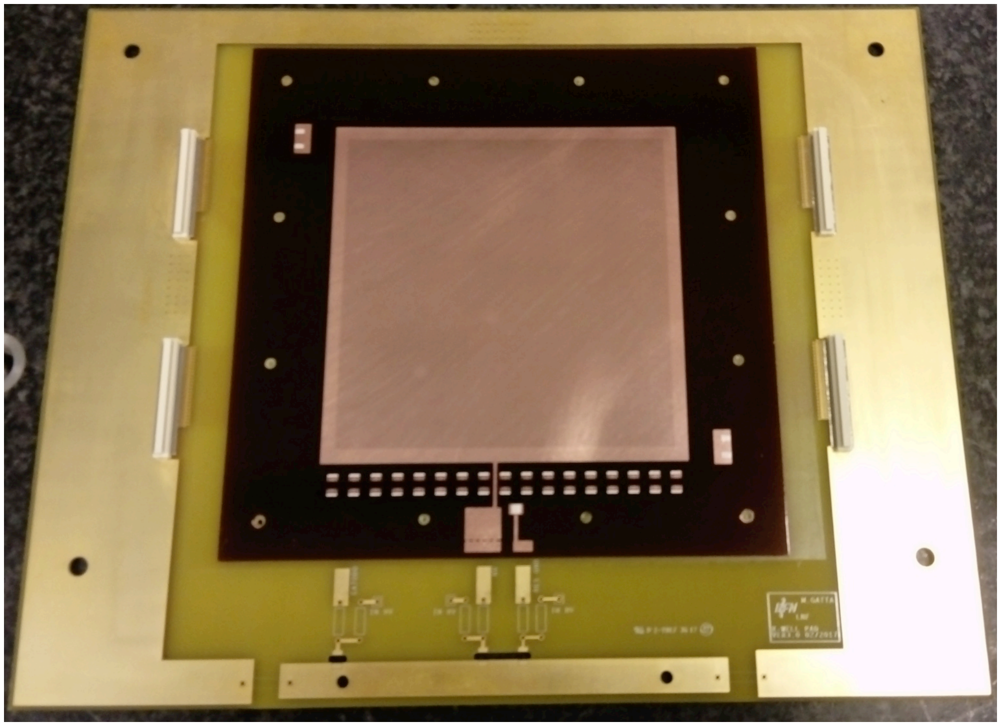


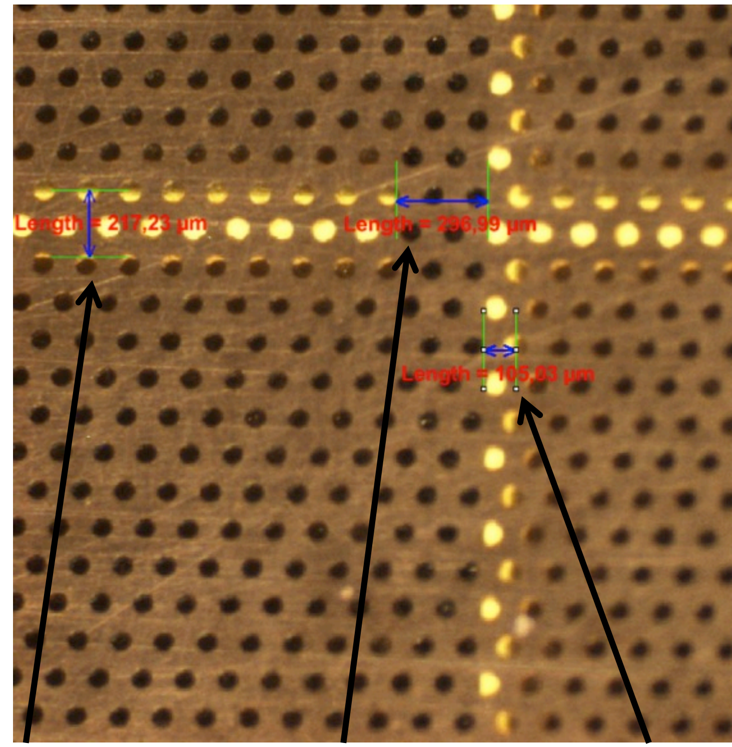
Grounding through DLC

The grid grounding is similar to the one used for the 2nd generation SG, as well as the readout segmented in pads.

Two prototypes delivered in November, with 6 mm grid pitch

Resistive grid



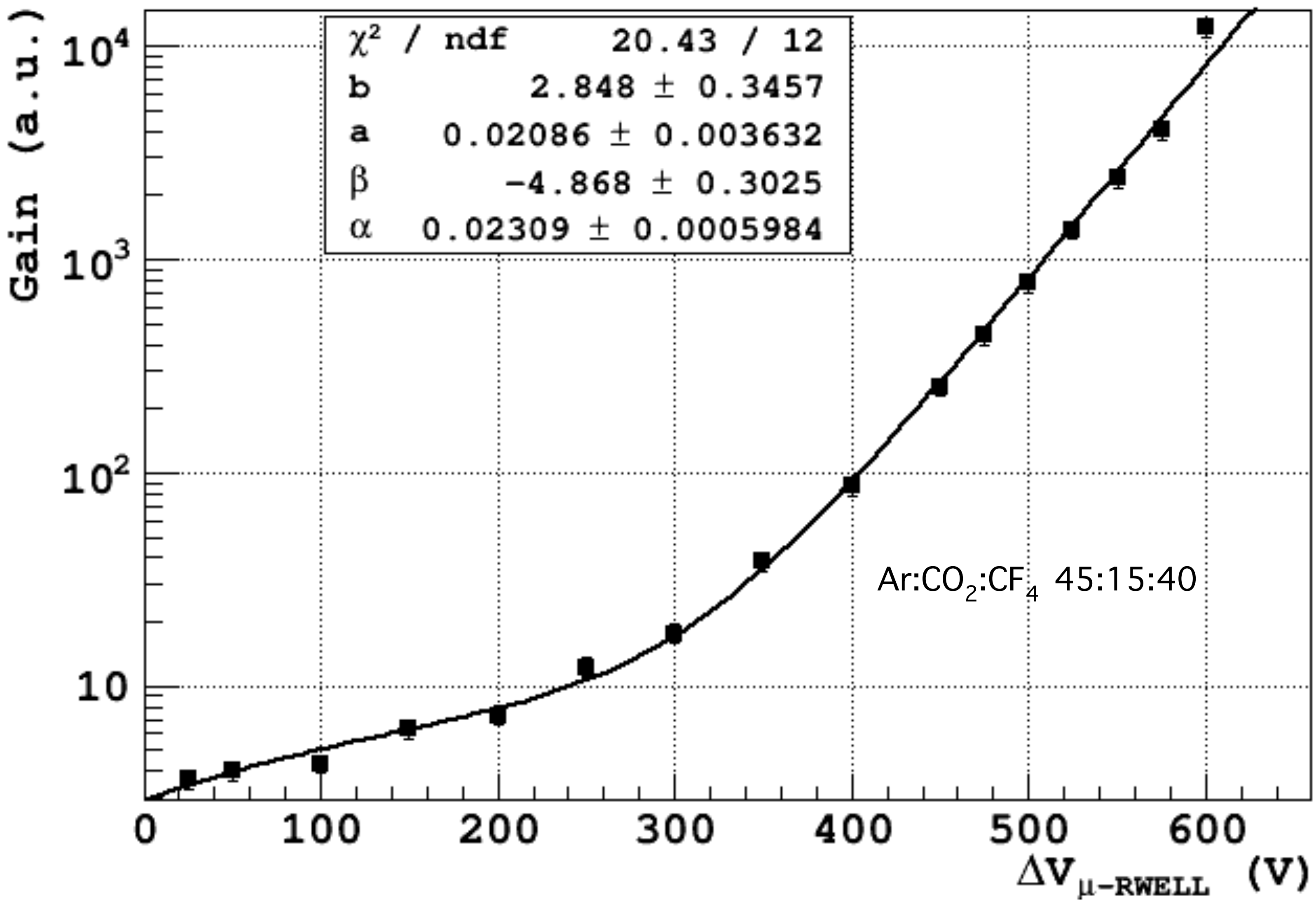


217.23 µm 296.99 µm 105.03 µm

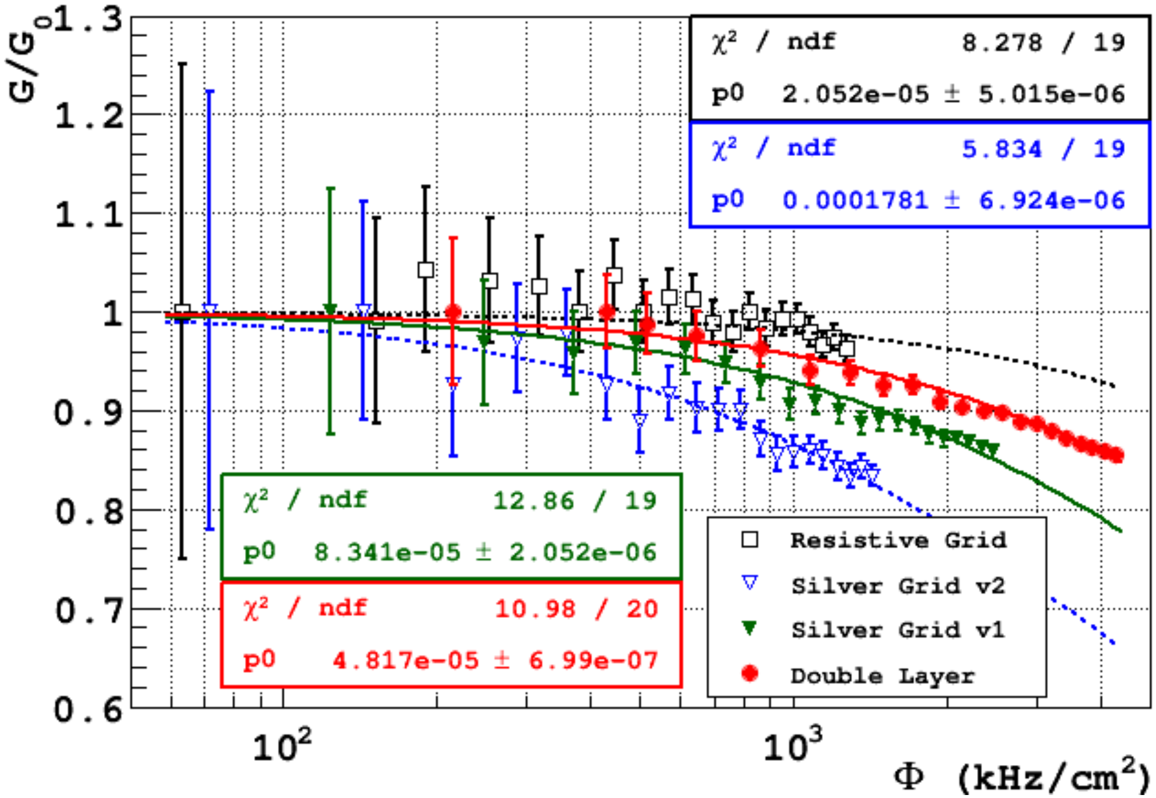
No dead areas

Grounding resistance: between 12 and 16 MΩ

Resistive grid



Gain drop measurement: a comparison



With the X-ray tube we measure the gain drop of four versions of µ-RWELL.

The voltage have been set at 590 V, corresponding to a gain of

- 6300 for the RG
- 5800 for the SG_v2
- 7700 for the SG_v1
- 7000 for the DL

rate capability measured at the tests beam with m.i.p.

The primary ionization of 5.9 keV is ~7 times the one created by a m.i.p.

The SG_v1 and the DL shown gain linearity up to 1 MHz/cm^2 with m.i.p. equivalent to a X-rays flux of about 140 kHz/cm^2.

By the fit function we expect a G/G$_0$ of:

99.7% for the RG; 97.6% for the SG_v2; 98.8% for the SG_v1; 99.3% for the DL

Conclusions & outlook

- Several prototypes have been realized, with different evacuation charge scheme
- The new resistive layout have the following parameters

	grid pitch	dead zone (2*DOCA-line/2)	Grid line width (mm)	Resistivity
SG_v1	6	2	0.2÷0.25	100 MΩ/☐
SG_v2	12	1.2	0.2÷0.25	100 MΩ/☐
RG	6	-	0.3	100 MΩ/☐

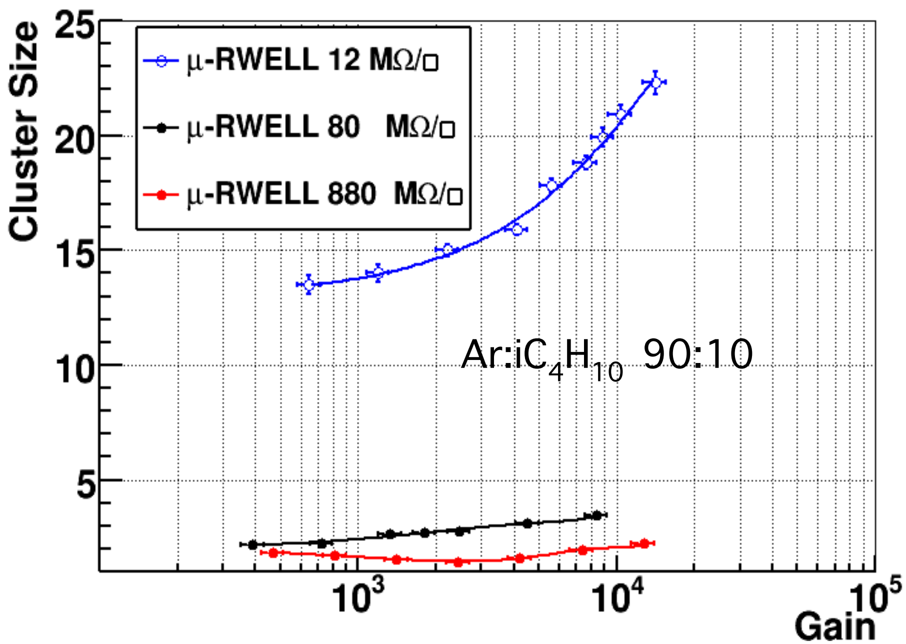
- So far the best measured performances are:
  - space resolution **52 ± 6 μm** (80 MΩ/☐, orthogonal tracks, no B field)
  - below **100 μm** with non-orthogonal tracks, with the **μ-TPC** mode
  - time resolution **5.7 ns** (with FEE saturation)
  - **1 MHz/cm^2** rate capability with pion beam (Double Layer working at G=10000)
  - Both the Silver Grid v1 reached a gain of almost **10^5 (to be understood)**

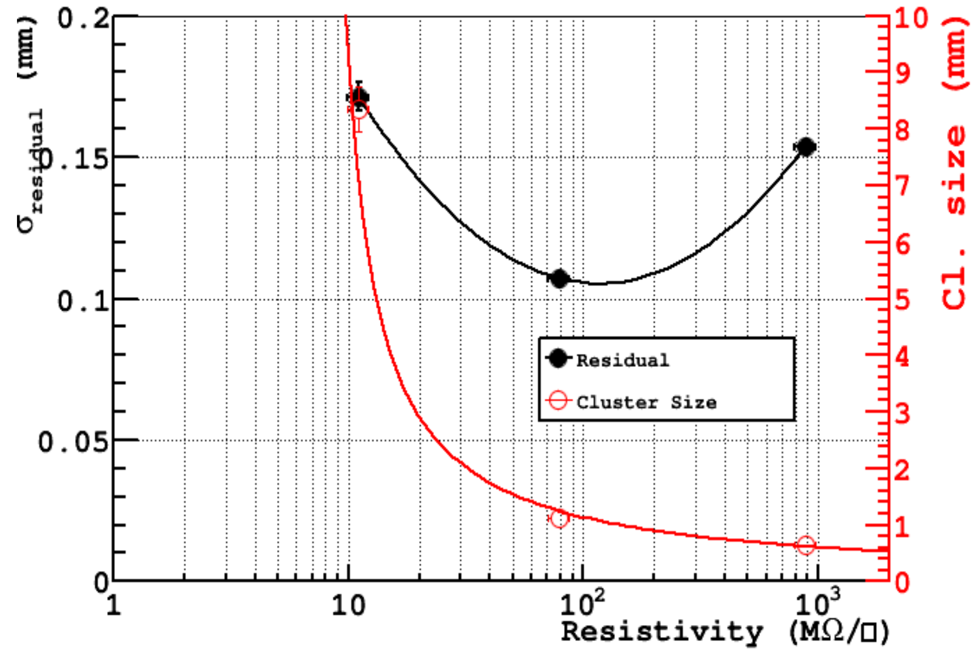
Conclusions & outlook

- The single layer layout has been exploited to build large area detectors (**~1/2 m^2**), but we also demonstrated that even larger detectors can be realized with the splicing technique
- This is done in strict collaboration with ELTOS company, within the Technological Transfer process
- In 2018 we plan to complete the technological transfer to industry of the single resistive layer µ-RWELL
- In the same year we wish to complete the R&D of the high rates (DL, SG and RG) detectors (in order to be ready for TT in 2019)

Spare

The single resistive layer: H4 test beam (2015)





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

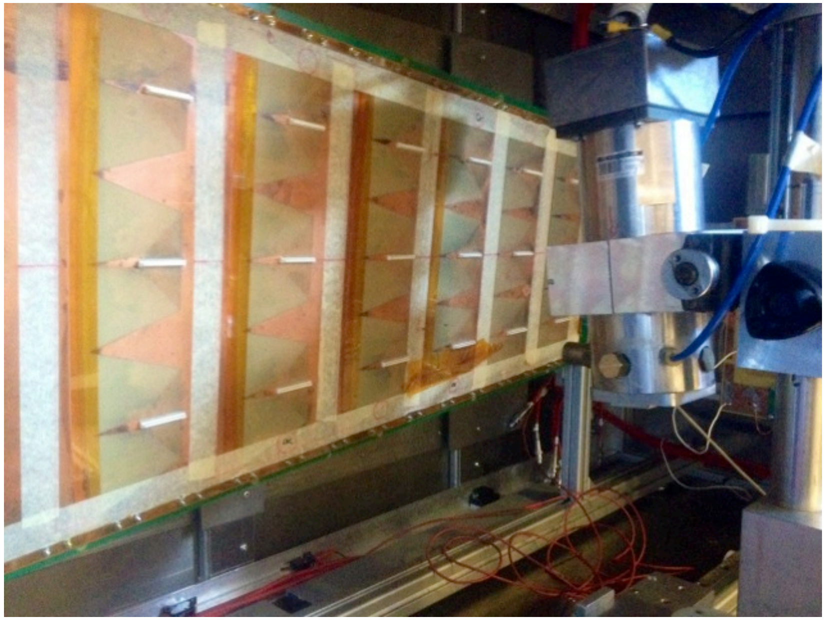
The residuals exhibit a minimum width around 100 MΩ/☐.

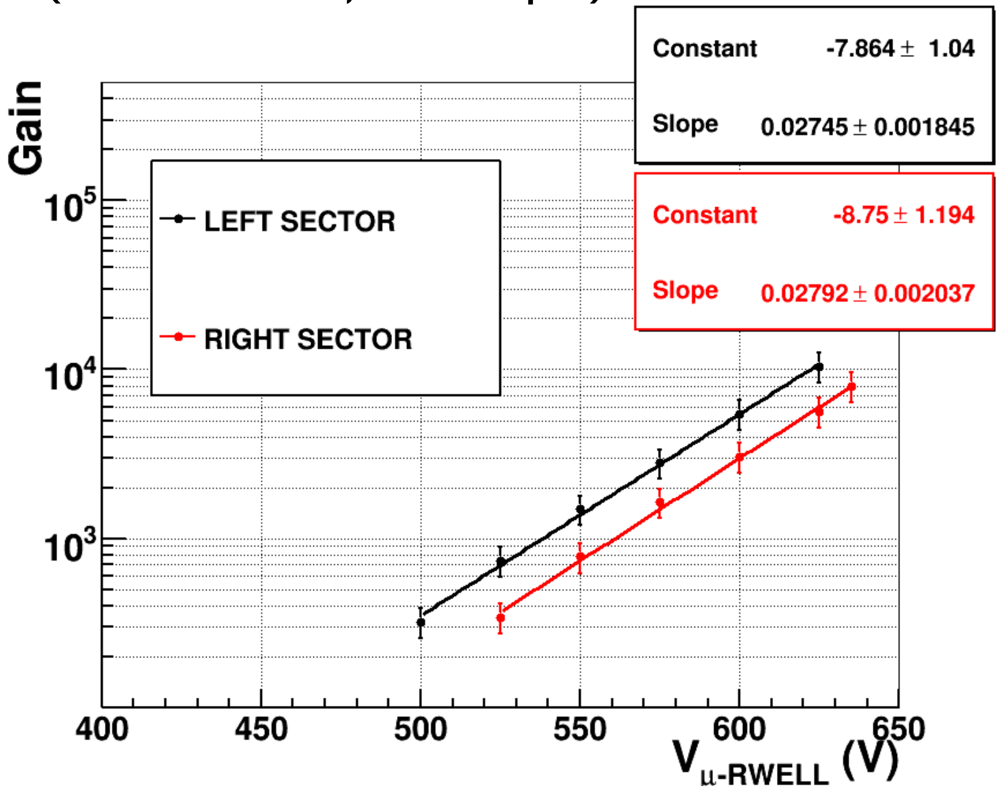
At low resistivity the charge spread increases → worse spatial resolution

At higher resistivity → ~ 1 fired strip

GE1/1 Detector Gain

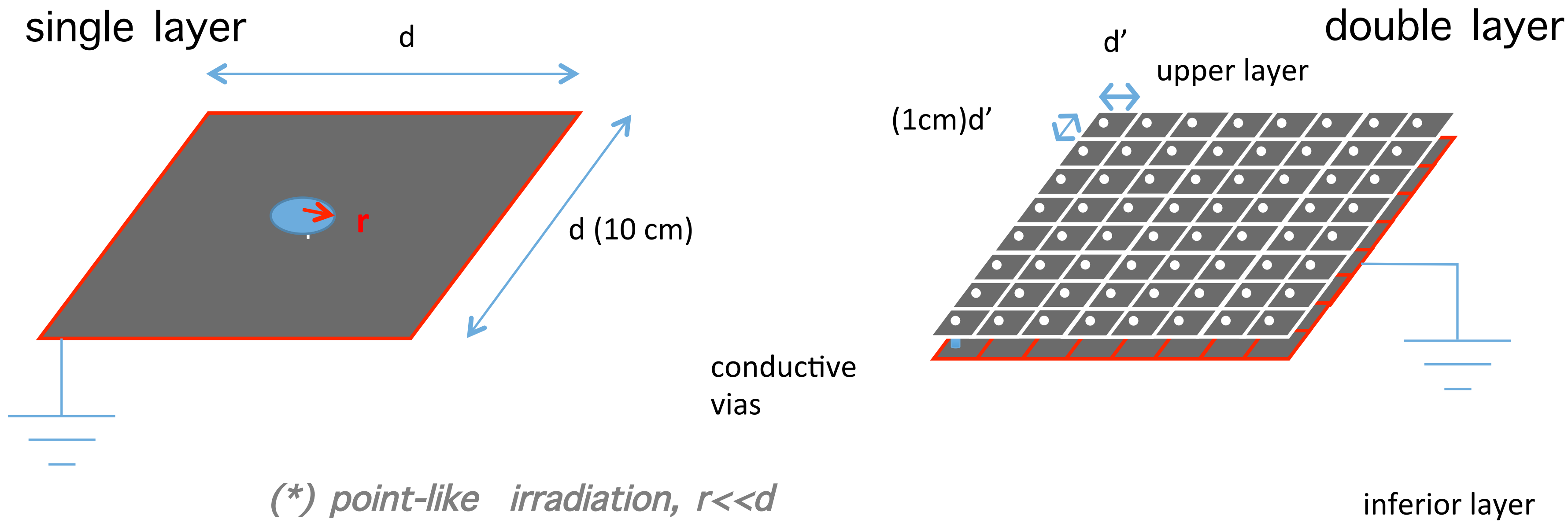
The prototype has been characterized by measuring the **gas gain, rate capability** in **current mode** with an **5.9 keV X-rays (local irradiation, ~1cm^2 spot).**





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

The two layouts



(*) point-like irradiation, r<<d

Ω is the resistance seen by the current generated by a radiation incident in the center of the detector cell

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

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

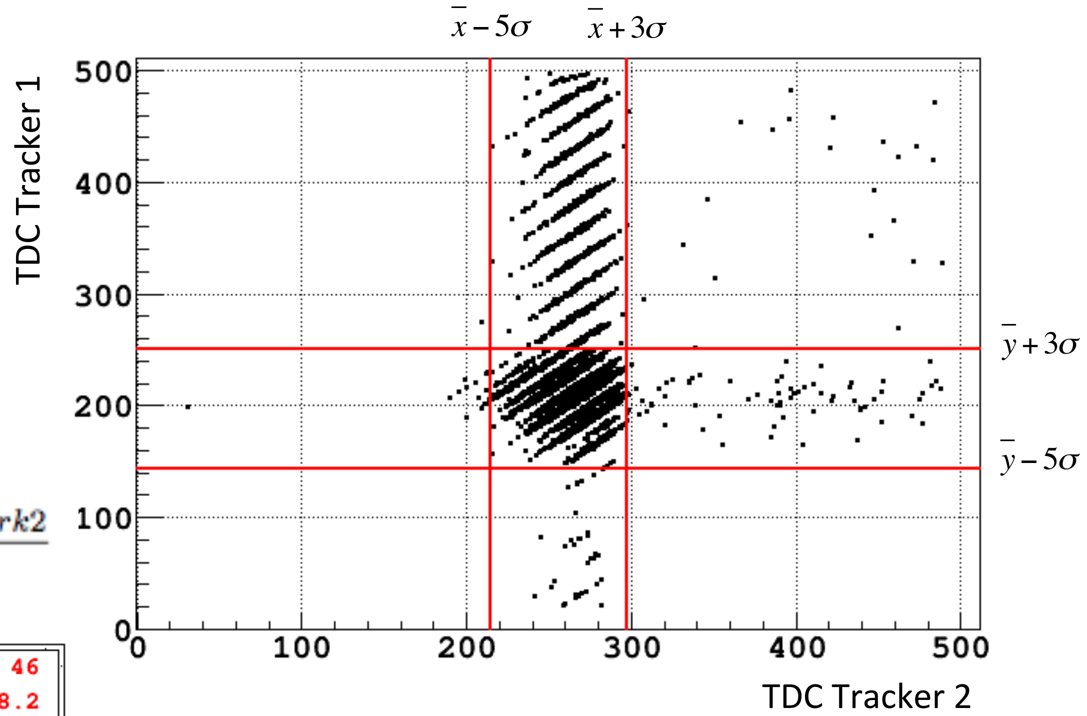
$$\text{If } \rho_s = 2\rho_s' \rightarrow \Omega/\Omega' \sim \rho_s/\rho'_s * d/3d' = 2 * 5/3 = 3.3$$

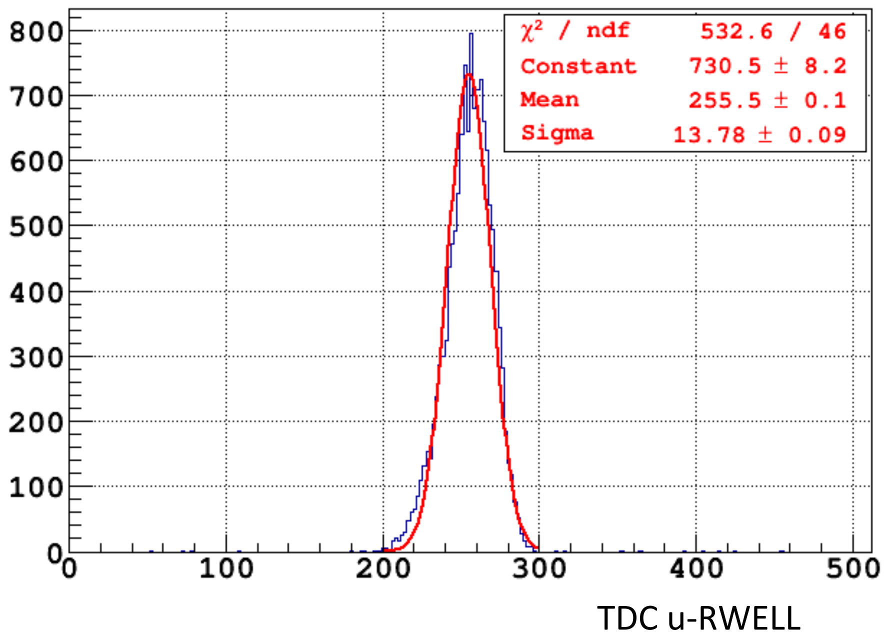
(*) Morello's model: appendix A-B (G. Bencivenni et al., 2015_JINST_10_P02008)

Efficiency & time resolution measurement

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

$$\varepsilon = \frac{TDC_{\mu-RWELL} \wedge TDC_{trk1} \wedge TDC_{trk2}}{TDC_{trk1} \wedge TDC_{trk2}}$$





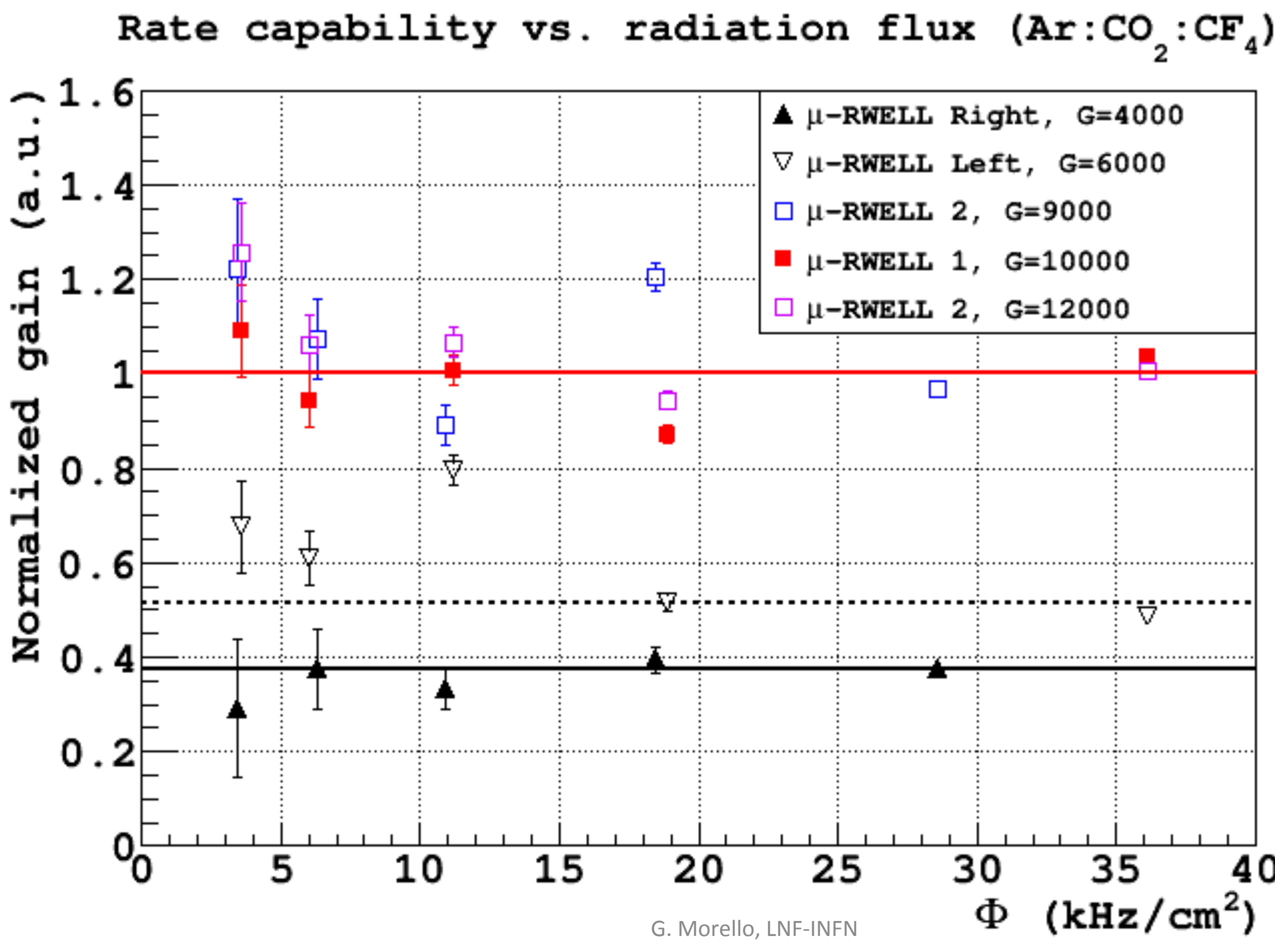
The TDC distribution is then fitted with a simple gaussian and the sigma is then **deconvoluted** by the contribution of the VFAT.

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

J. A. Merlin, Etude de fonctionnement à long terme de détecteur gazeux l'environment à haut flux de CMS, PhD thesis, 2016

Performance vs Rate

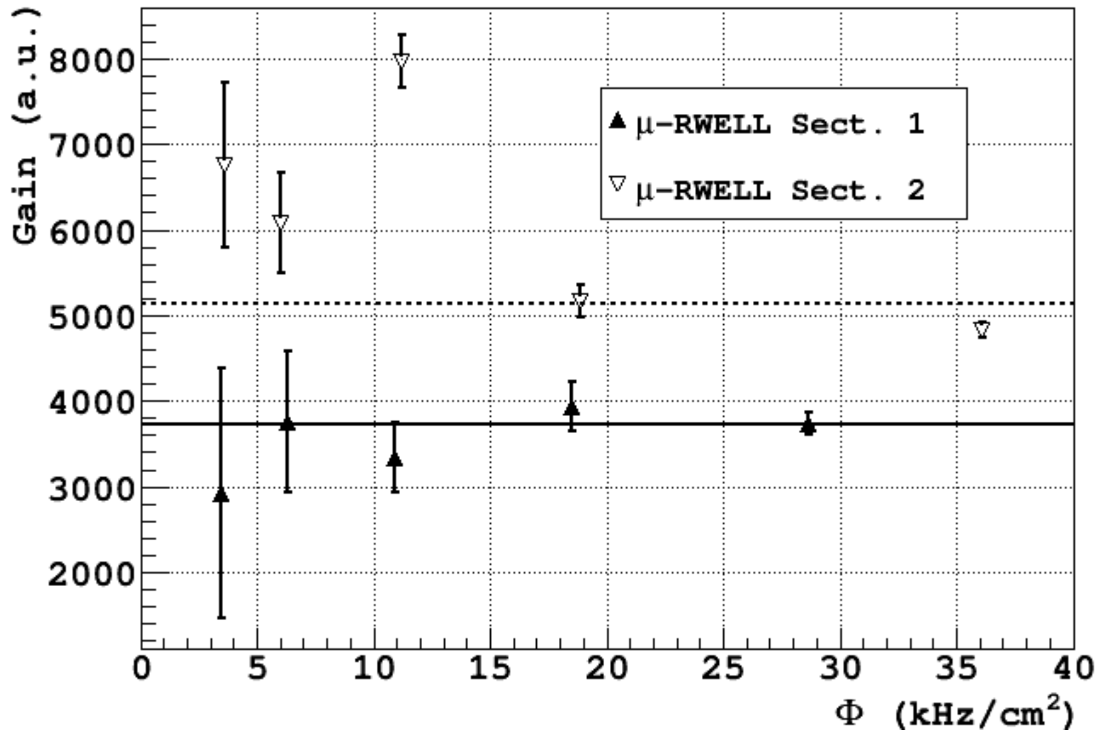
The detectors rate capability (with Ed=3.5 kV/cm) has been measured in current mode with a pion beam and irradiating an area of ~3 x 3 cm^2 (FWHM) ("local" irradiation, ~10 cm^2 spot)



Double resistive layer
(High Rate scheme)

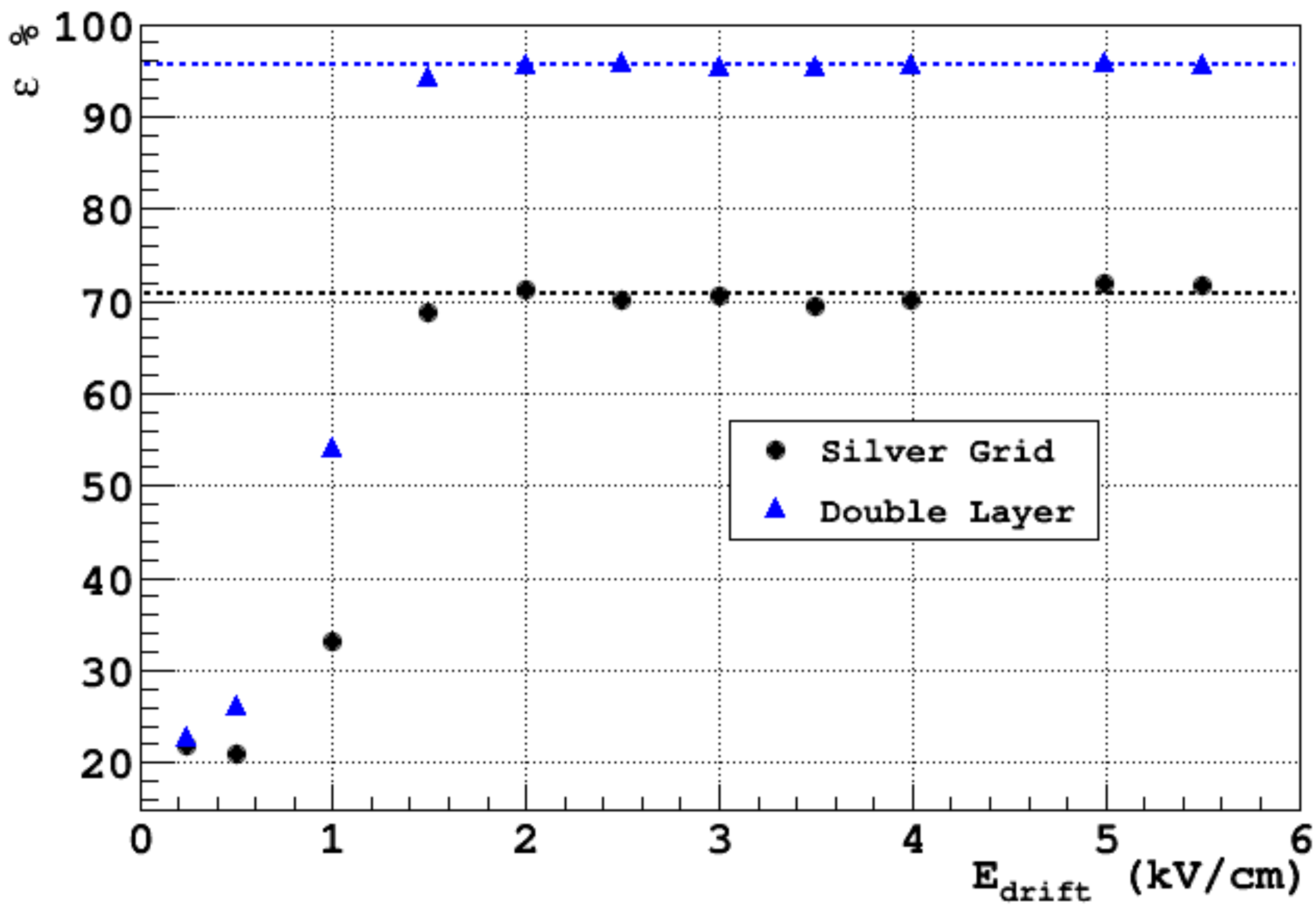
Single resistive layer
(Low Rate scheme)

The single resistive layer: H8C test beam (2016)



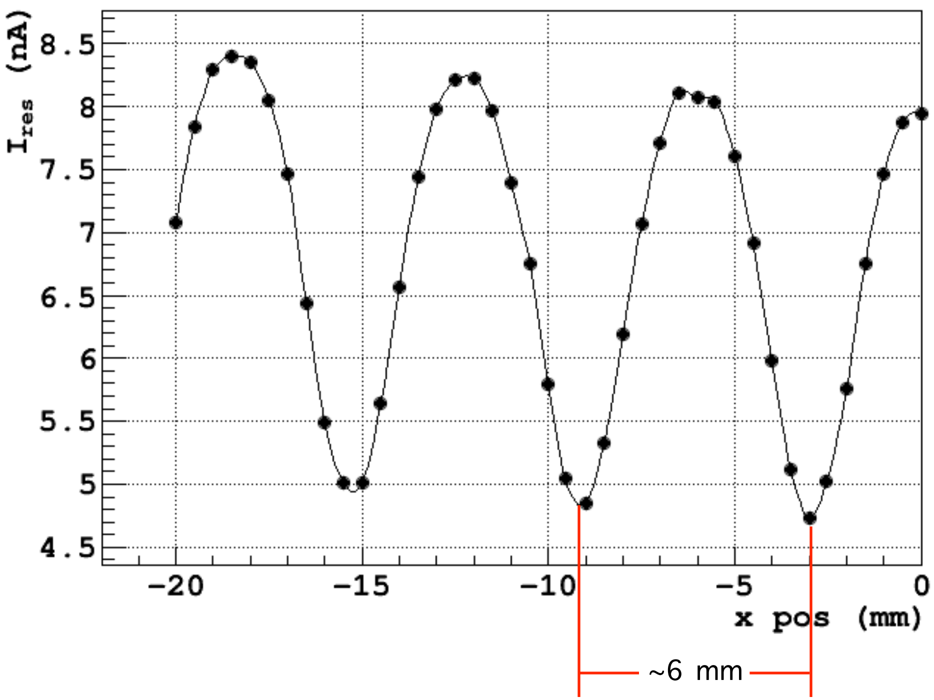
Rate capability measured with pion beam. The beam spot has a transverse section of **about 10 cm^2**, one order of magnitude larger than our X-rays spot

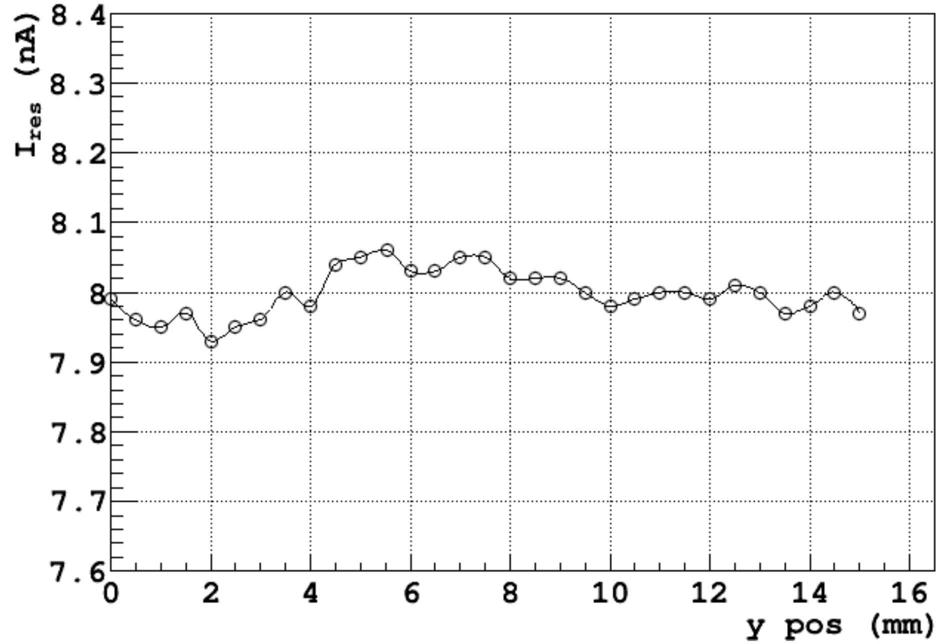
Silver Grid: H4 test beam (July 2017)



Silver Grid v1: X-rays measurements

The detectors is mounted on a support moved by a stepper motor. The position is given within few tenths of millimeter





Scan along the coordinate orthogonal to the grid lines direction

Scan along the coordinate parallel to the grid lines direction

Silver Grid v1: geometry