Update on μ-RWELL technology

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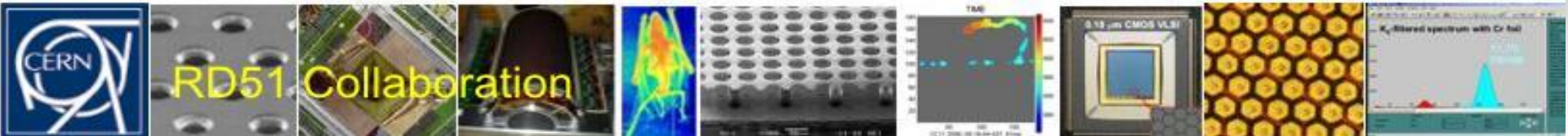


OUTLINE

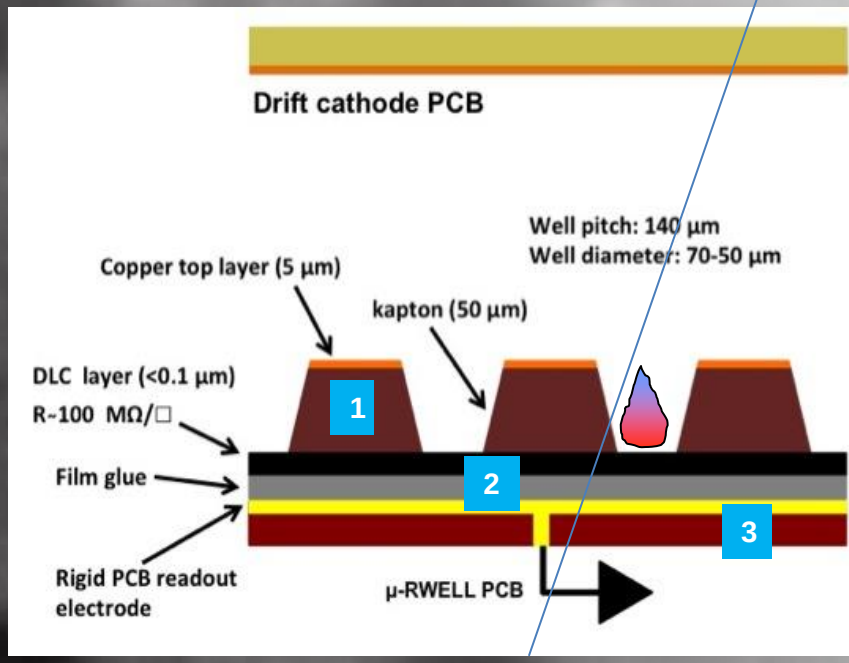
- Detector architecture & principle of operation
- Low rate layout: the single-resistive layer
  - performance & Technology Transfer to industry
- High rate layouts: design & performance at PSI
- Cylindrical IT based on μ-RWELL technology
- Summary

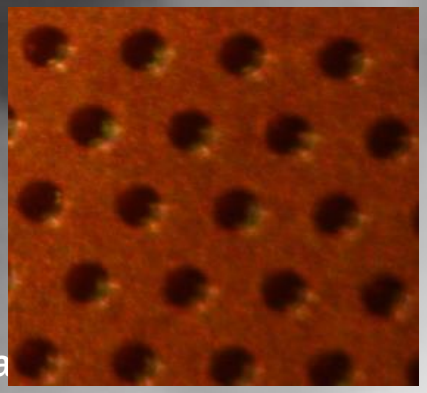
The μ-RWELL: the detector architecture

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

The **μ-RWELL_PCB, the core of the detector,** is realized by **coupling:**

1. a **WELL patterned kapton foil** acting as **amplification stage**
2. a **resistive layer (*)** for discharge suppression w/surface resistivity ~ 50-100 MΩ/□ - with different current evacuation schemes:
   - **i. LR,** < 100 kHz/cm^2 - SHiP, CepC, STCF, EIC, HIEPA
   - **ii. HR,** >1 MHz/cm^2 - LHCb-Muon upgrade & future colliders - CepC, Fcc-ee/hh
3. a **standard readout PCB**

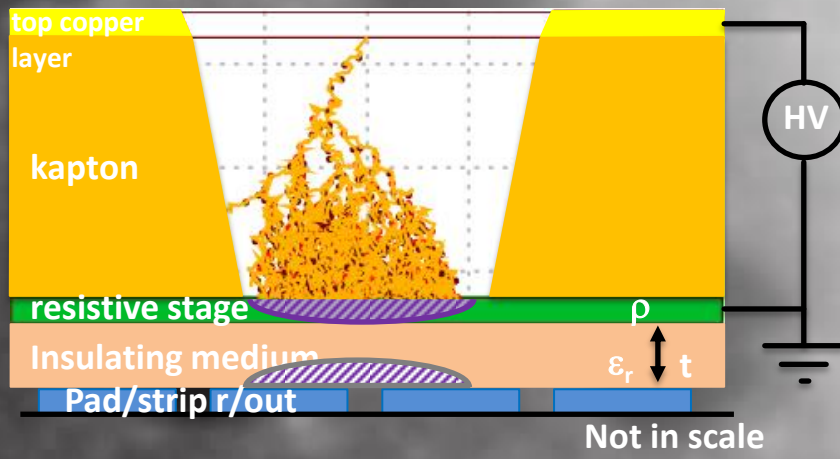




(*) DLC = Diamond Like Carbon high mechanical & chemical resista

Principle of operation

Applying a suitable voltage between the **top copper layer and the DLC** the "**WELL" acts as a multiplication channel for the ionization produced in the conversion/drift gas gap**



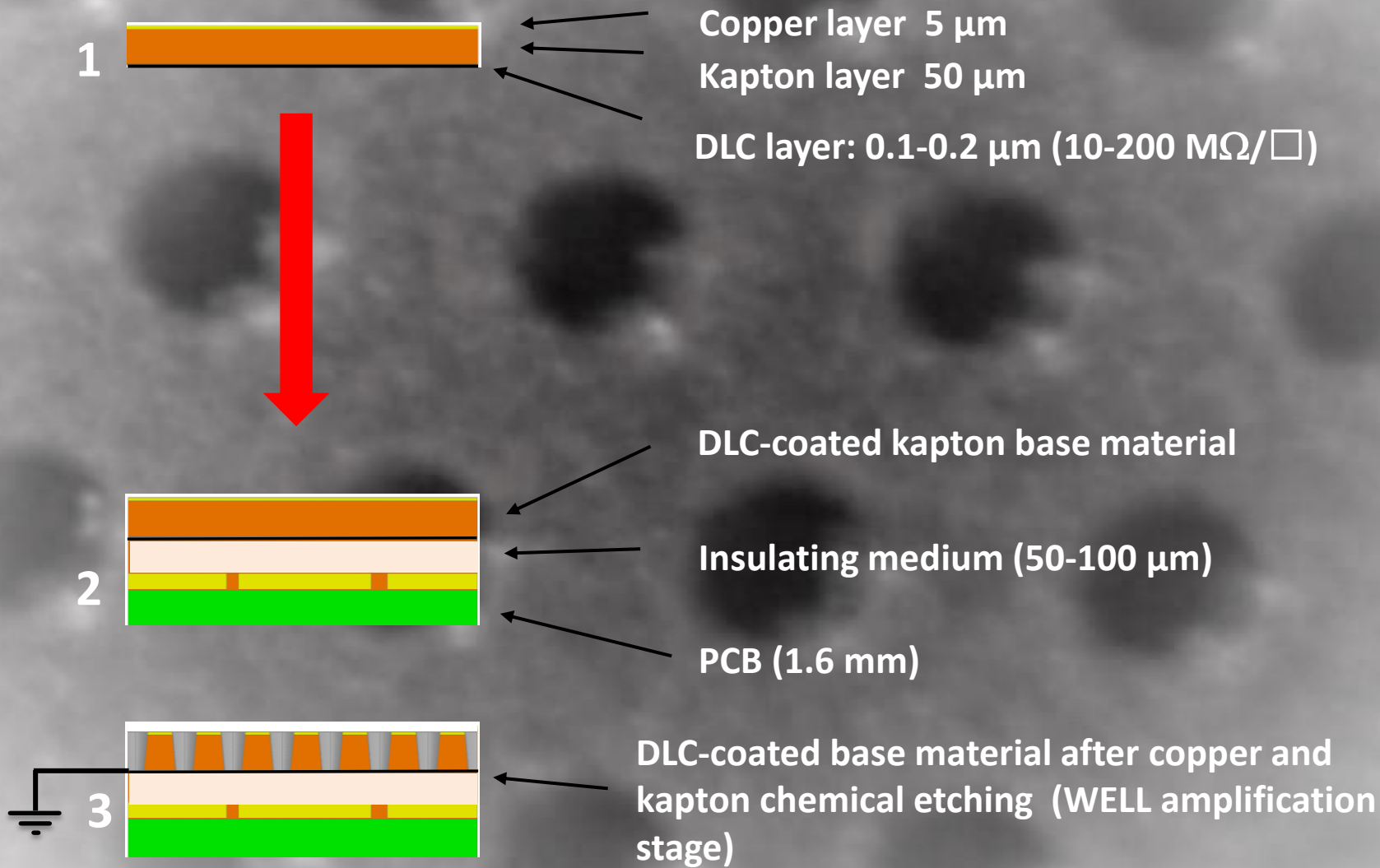
The charge induced on the resistive foil is dispersed with a *time constant, τ = ρC ,* determined by **[M.S. Dixit et al., NIMA 566 (2006) 281]:**

- the **DLC surface resistivity** → ρ
- the **capacitance per unit area,** which depends on the **distance between the resistive foil and the pad/strip readout plane** → **t**
- the **dielectric constant** of the insulating medium → ε_r

- **The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark**
- As a drawback, the **capability to stand high particle fluxes is reduced, but appropriate grounding schmes of the resistive layer solves this problem (see High Rate scheme)**

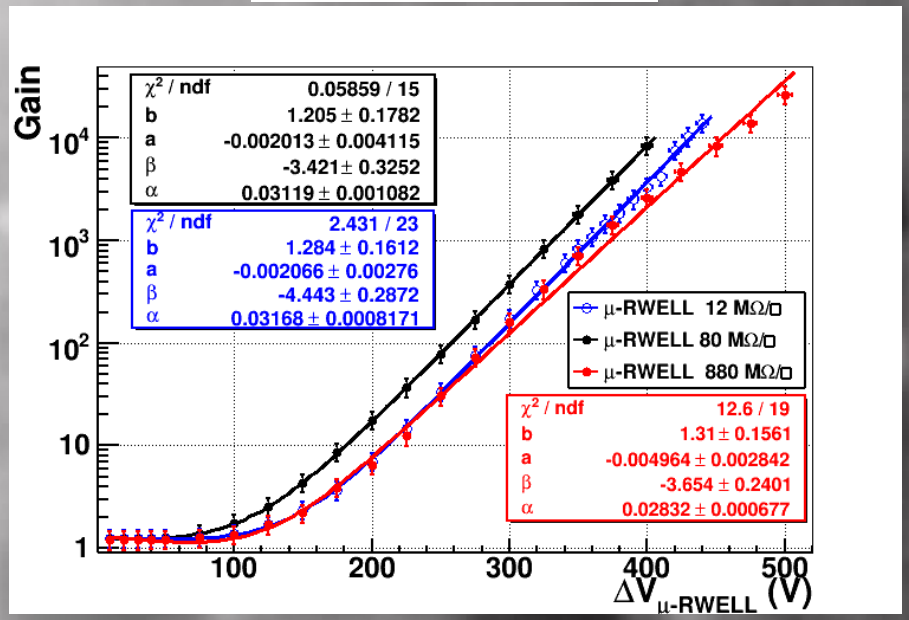
The Low Rate Layout

single resistive layer w/edge (2-D) grounding scheme



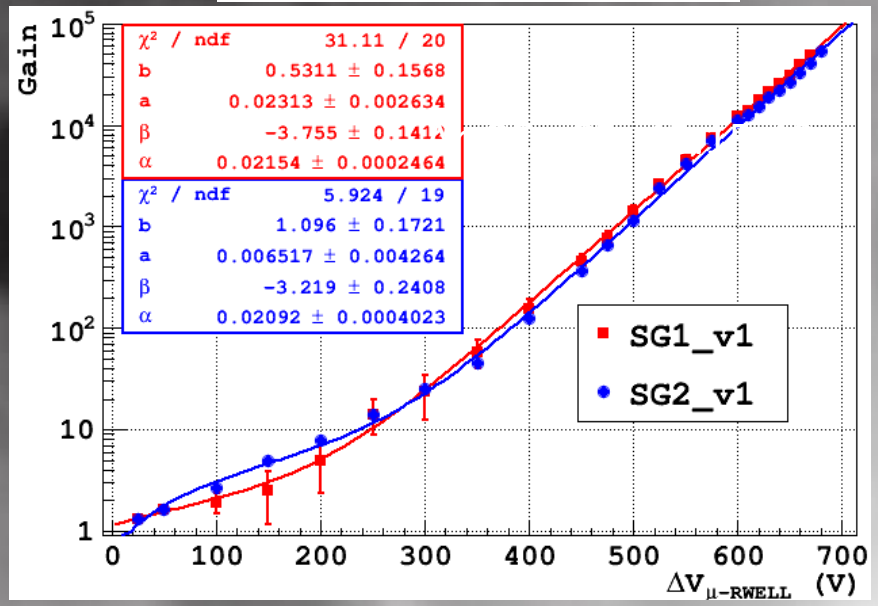
Detector Gain

Ar/iC_4H_{10}= 90/10



Single Resistive Layer prototypes with different resistivity have been tested with **X-Rays** (5.9 keV), with several gas mixtures, and characterized by measuring the **gas gain** in **current mode**

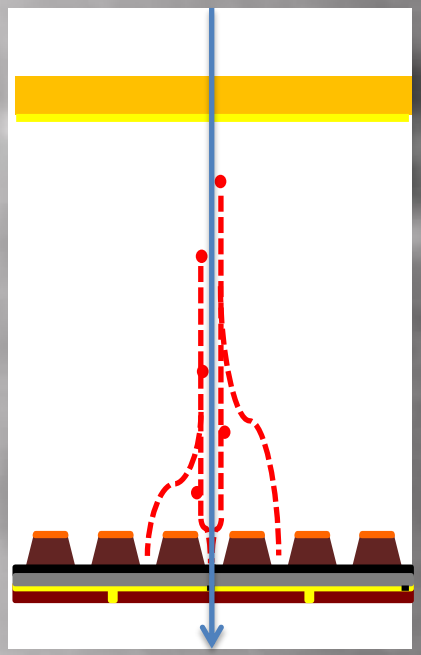
$Ar/CO_2/CF_4$= 45/15/40

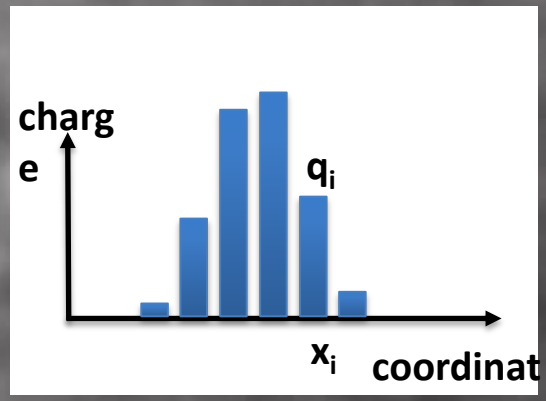


Recent prototypes showed Gain >10^4 in $Ar/CO_2/CF_4$= 45/15/40

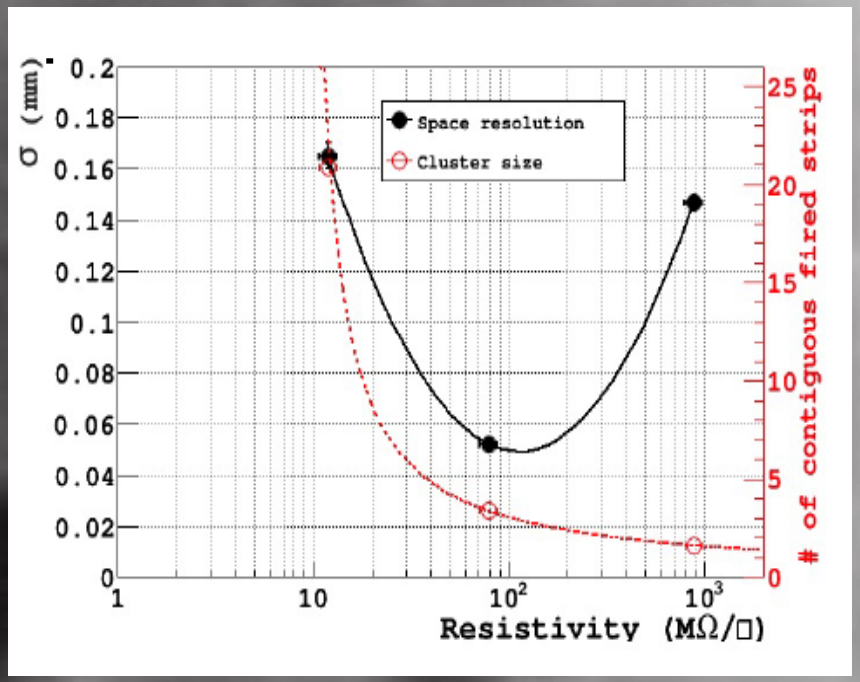
Space resolution *vs* DLC resistivity

Charge Centroid analysis (for orthogonal tracks) uses the charge to weigh the position of the fired strips. The track position is determined as a weighted average of fired strips.





$$x_{hit} = \frac{\sum x_i * q_i}{Q_{TOT}}$$

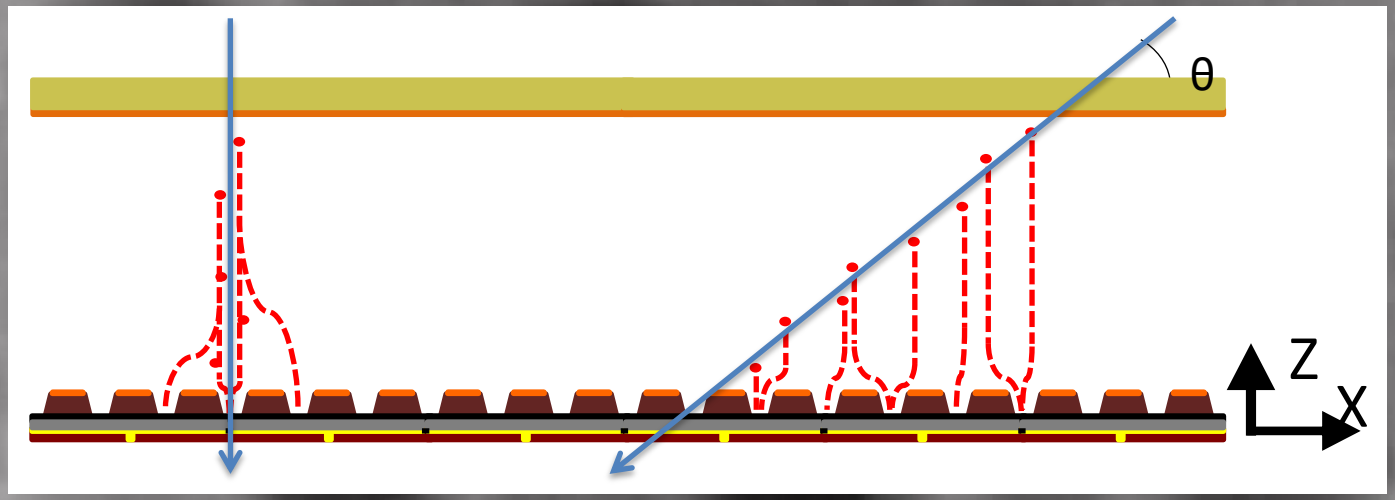


The **space resolution** exhibits a **minimum around 100 MΩ/□**

- at **low resistivity** the **charge spread increases** and then **σ is worsening**
- at **high resistivity** the **charge spread is too small (Cluster-size → 1 fired strip)** then the **Charge Centroid method** becomes **no more effective (σ → pitch/√12)**

Space resolution vs inclined tracks: μ-TPC mode

For **inclined tracks and/or in presence of high B field, the charge centroid method** gives a **very broad spatial distribution** on the anode-strip plane. In the **u-TPC mode each ionization cluster is projected inside the conversion gap**, then, from the knowledge of the **drift time of primary electrons, the track segment in the gas gap can be reconstructed.**



The method has been introduced for MMs by T. Alexopoulos (NIM A 617 (2010) 161):

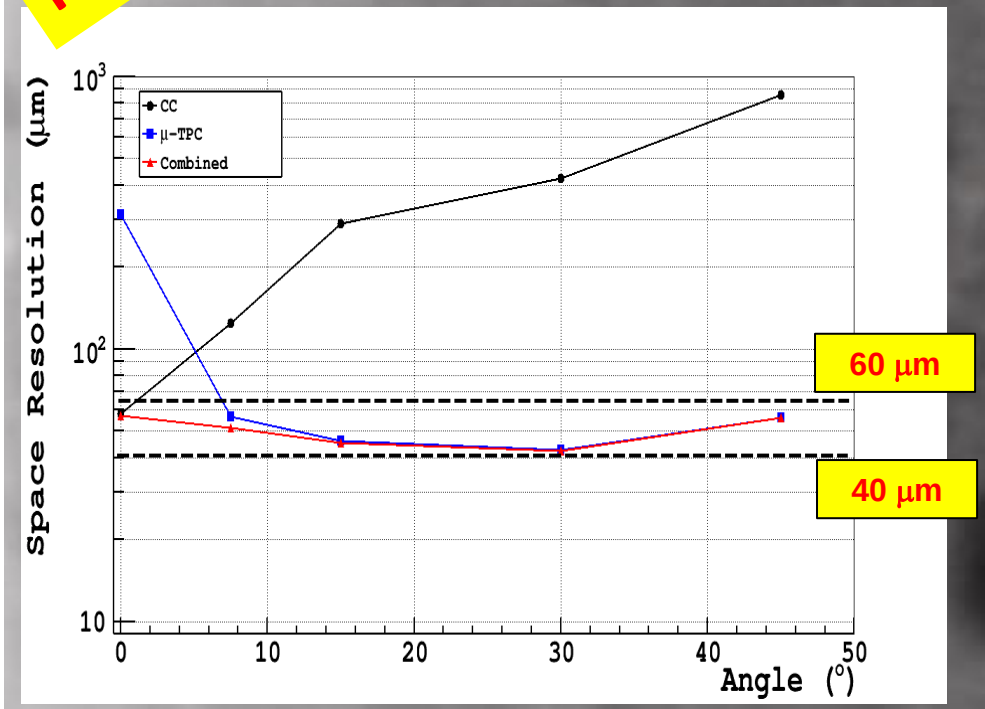
- the information of the **arrival time of primary electrons** can be extracted from the **time sampling of the APV signal**
- a **fast time reference (t_0)** must be provided **to define the intercept of the track-segment on the z-axis inside the gas gap**

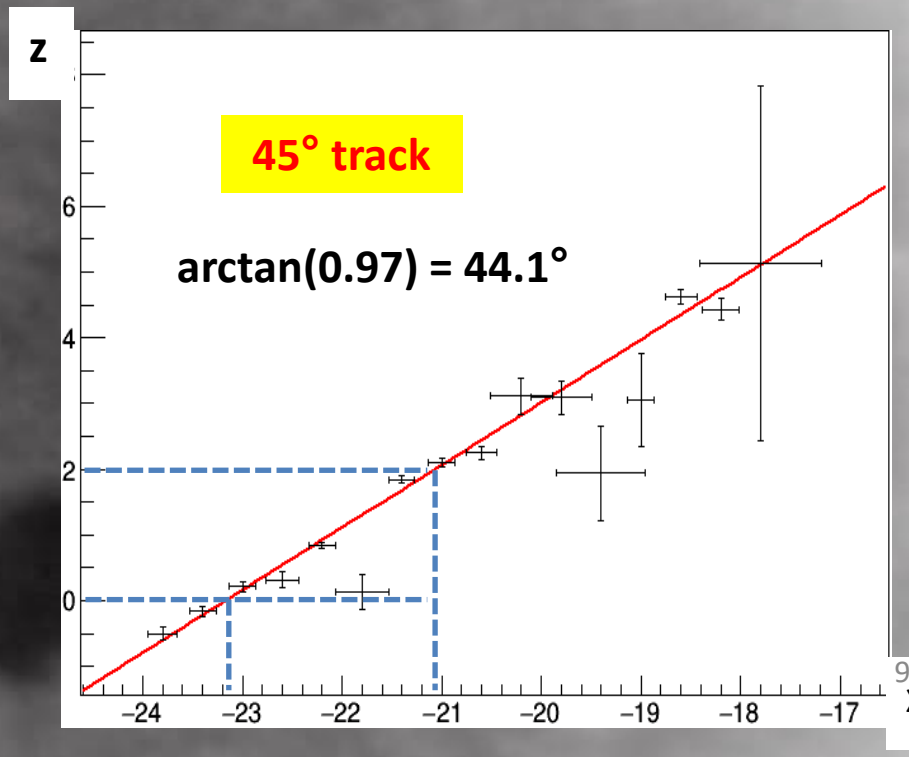
Space resolution vs inclined tracks: μ-TCP mode

Thanks to the collaboration with BESIII-CGEM, G. Cibinetto, R.Farinelli (Ferrara) & L.Lavezzi (To)

NEW

$Ar:CO_2:CF_4$ 45:15:40 - HV=600V, Ed=1kV/cm, Gain ~10^4



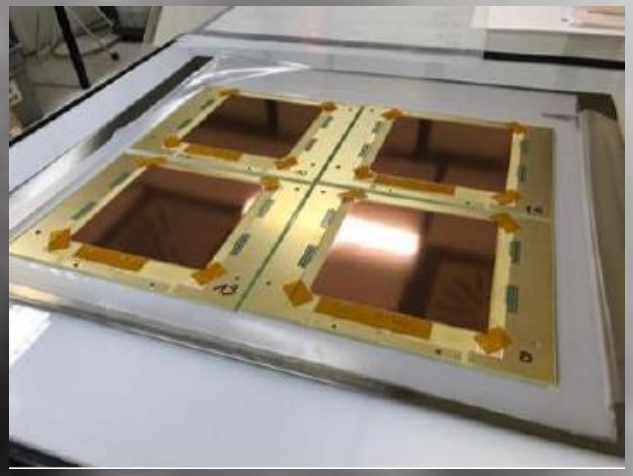


The **combination of the CC and the μ-TPC mode** with **E_d= 1 kV/cm**

The **combined spatial resolution is almost flat over a wide range of incidence angles**

Technology Transfer to Industry

The **engineering and industrialization** of the **μ-RWELL technology** is one of the **main objective of the project**.
TT to industry can open the way towards **cost-effective mass production.**
Manufacturing process of the **single resistive layer has been extensively tested at the ELTOS SpA (http://www.eltos.it)**



Production Tests @ ELTOS:
- **10x10 cm² PCB – (PAD r/o)**
- **10x10 cm² PCB – (strip r/o)**

coupled with kapton/DLC foils
but also large detectors (in coll. w/CMS)

- **1.2x0.5m² (strip r/o)**
- **1.9x1.2m² (strip r/o)**

Etching of the kapton done by Rui @ CERN

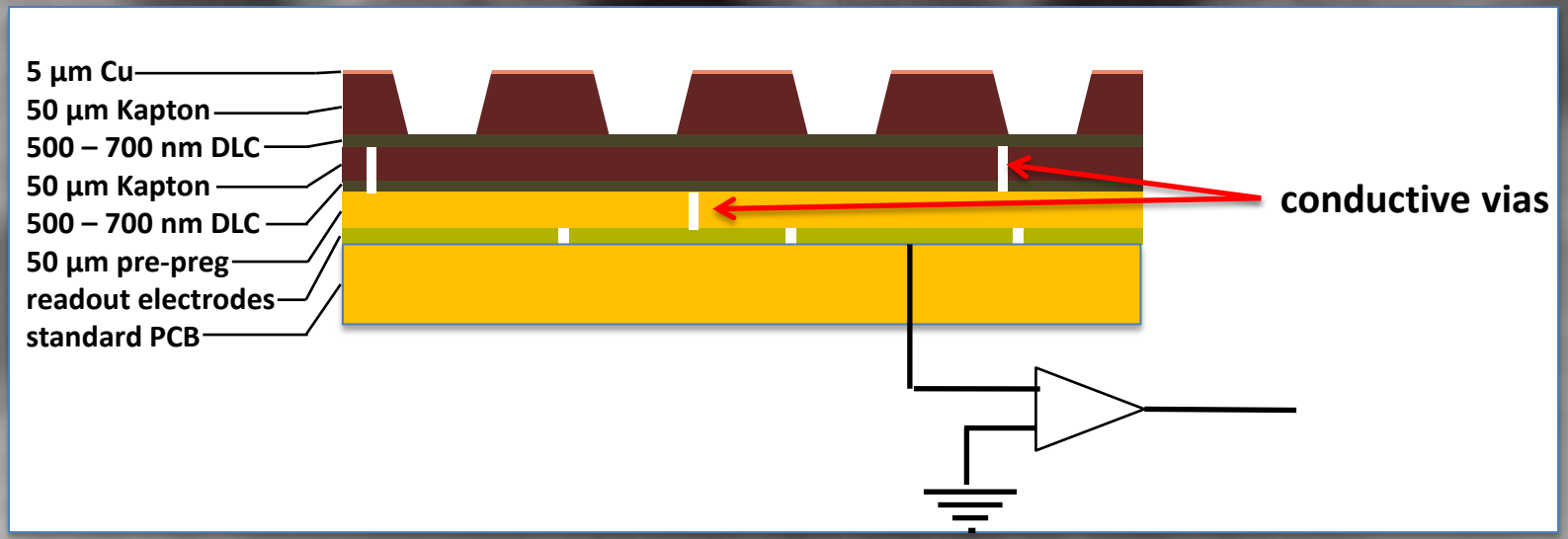
Kapton etching test @TECHTRA (Poland) planned for the near future.

High rate layouts

High rate layout: the double-resistive layer

The **idea is to reduce the path of the current on the DLC implementing** a **matrix of conductive vias** connecting **two stacked DLC layers.** A second **matrix of vias** connects the **second resistive layer to ground** through the readout electrodes (**3-D grounding scheme**)

The **pitch of the vias is typically of the order 1/cm²** (or less).

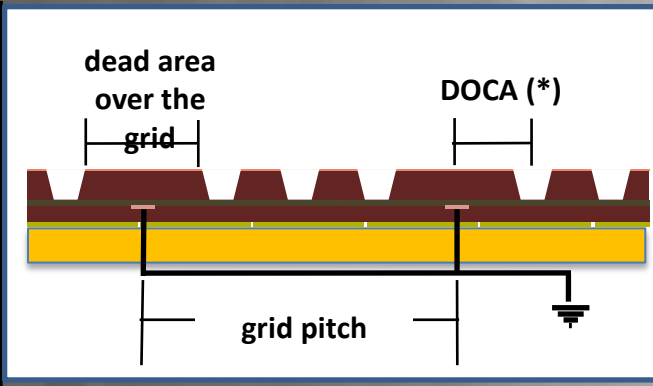


WARNING: *The **engineering/industrialization of the double-resistive** layer seems to be **difficult** due to the **manufacturing of the conductive vias on kapton foil***

New ideas for the HR layout

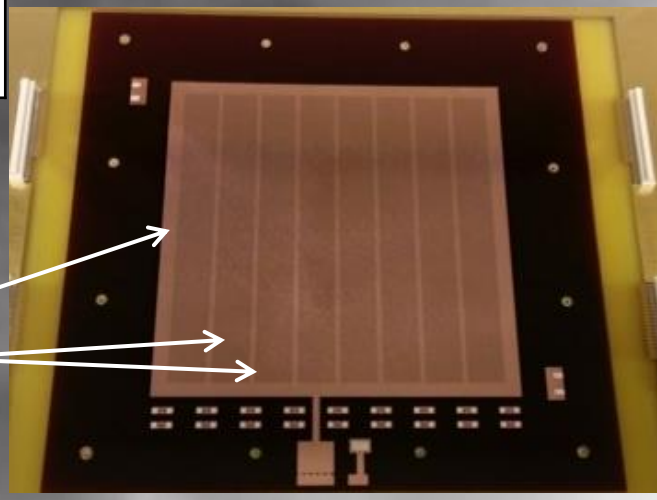
Simplified HR schemes are based on the **Single Resistive layout** with **surface grounding** by **conductive strip lines realized on the DLC layer**. The **conductive grid can be screen-printed as well as etched (if a Cu deposition is done on top of the DLC layer)**

High Rate layout	Resistivity [MΩ/□]	Dead Area over grid	Grid Pitch	Geometrical acceptance [%]	Type
SG1	70	2 mm	6 mm	66	conductive grid
SG2	65	1,2 mm	12 mm	90	conductive grid
SG2++ (*)	64	0,6 mm	12 mm	95	condcutive grid

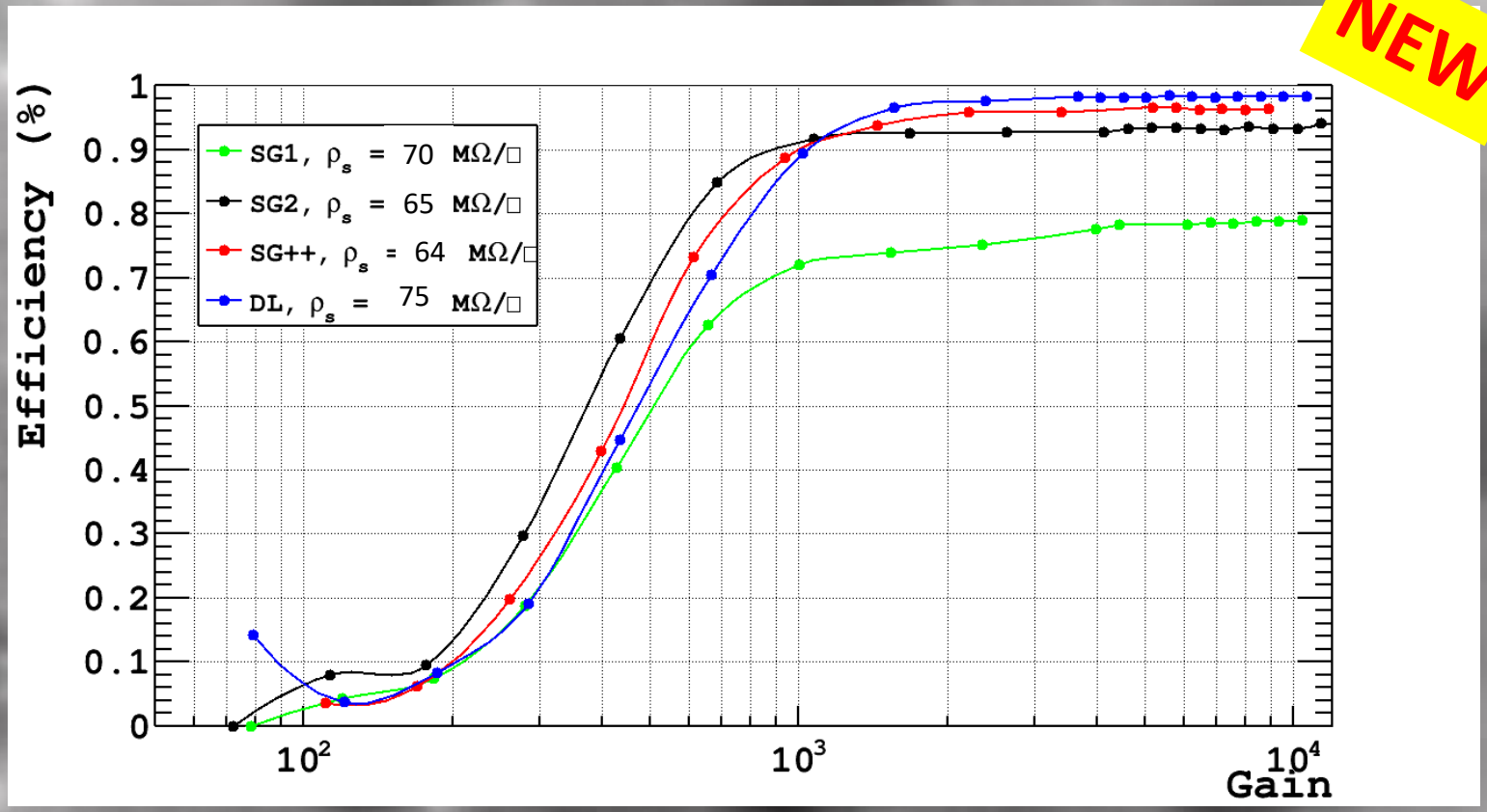


(*) the base material of the SG2++, DLC+Cu polyimide foil, has been produced by Zhou Yi – USTC, Hefei (PRC).

The **conductive grid** on the bottom of the amplification stage **can induce instabilities due to discharges over the DLC surface, thus requiring for the introduction of a small dead zone (2xDOCA) on the amplification stage.**



HR layouts performance: the efficiency

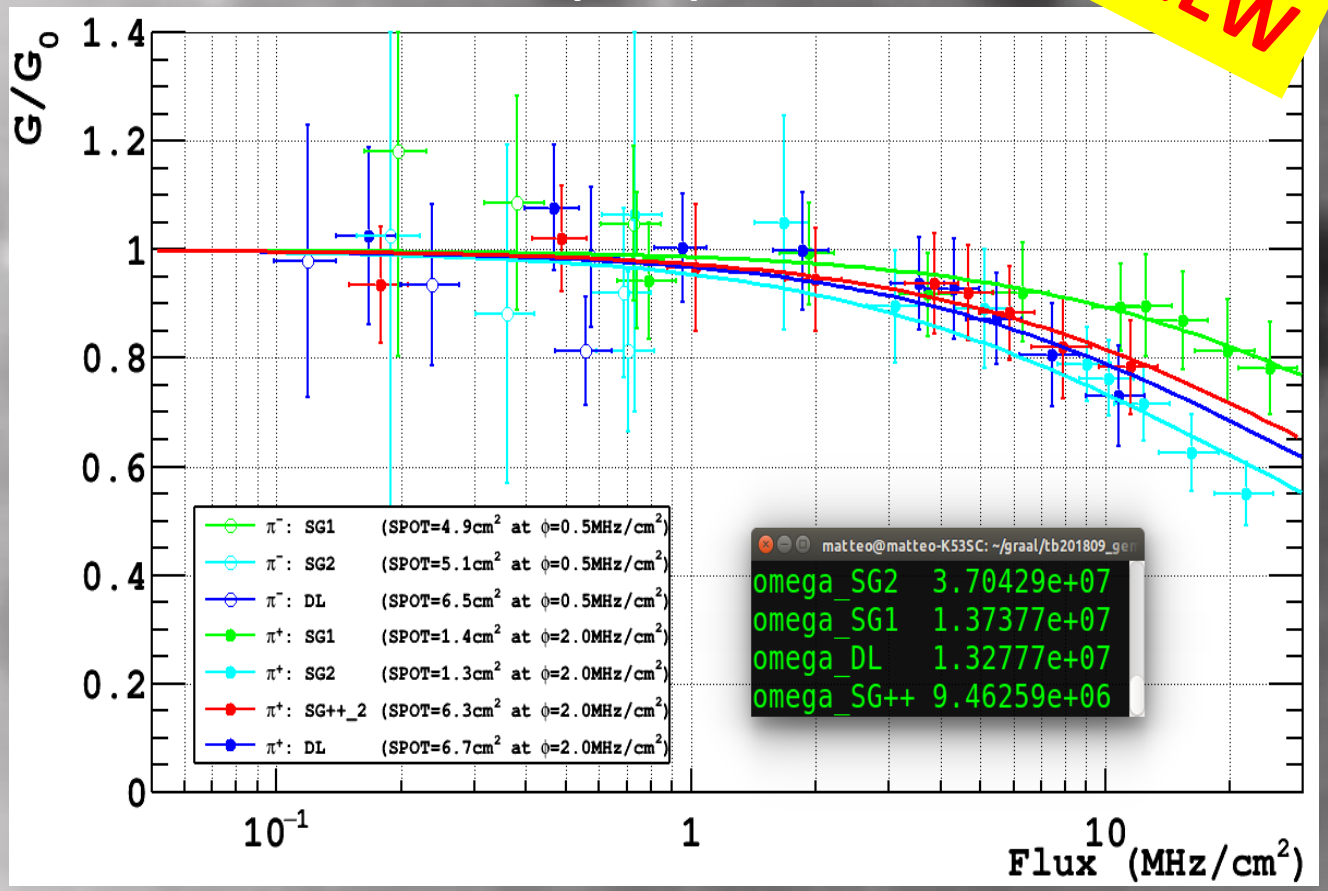


As expected the **DL prototype** reaches **full tracking efficiency – 98%** (NO DEAD ZONE). The **SG1, SG2 and SG2++** show lower efficiency **(76% -94% - 97%) BUT higher than their geometrical acceptance** (**66% - 90% - 95%** respectively), thanks to the **efficient electron collection mechanism** that **reduce the effective dead zone.**

Rate Capability for HR Layout

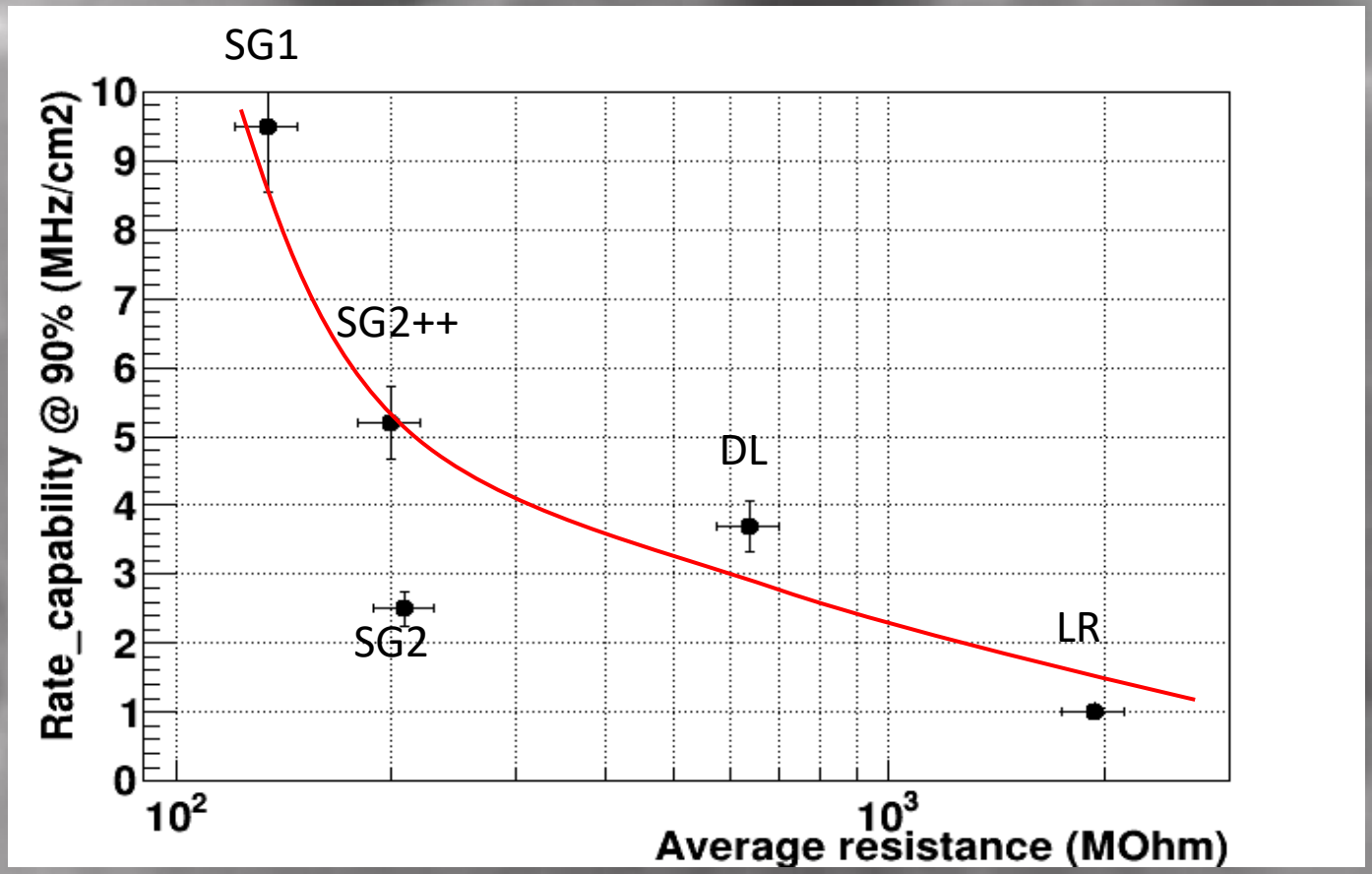
Gain=5000, beam spot up to 7 cm² FWHM

NEW



The **gain drop** is due to the **Ohmic effect** on the resistive layer: the **currents collected on the DLC drift** towards the **ground** facing an **effective average resistance Ω**, depending on the **evacuation scheme geometry (i.e effective pitch) and the DLC surface resistivity.**

Rate capability vs Ω



Lower the *effective average resistance* (Ω) higher the rate capability

$$\Omega = \frac{\rho}{2} \times (pitch/2 + DOCA)$$

(under the assumption of uniform irradiation)

Cylindrical μ-RWELL

KLOE – CGEM–IT

The Cylindrical MPGD concept, introduced the first time with GEMs (KLOE & BESIII), can be applied also to μ-RWELL (C-RWELL), with several advantages wrt CGEMs:

- **lower material budget, down to 1-1,2% X_0 for n. 4 C-RWELL layers (tbc with 2% X_0 for KLOE2-CGEM)**
- **more simple construction/assembly** and **cheaper**: **less cylindrical electrodes (2 instead of 5), less toolings are required (2 molds instead of 5)**
- the concepts of **"openable detector"**, **"floating-amplification", "reversed conical hole shape" (increasing the gain), can be easily implemented** for the **μ-RWELL making** the **C-RWELL more reliable & performing than CGEM** (*great advantages for detector debug & fixing – when needed, while the spark suppression mechanism of the* **μ-***RWELL make the operation of the detector more safe*)
- **μ-RWELL operated in micro-TPC mode** exhibits a **spatial resolution down to 40-60 μm over a wide track incidence angular range (0-45°)**

Summary

The μ-RWELL is a breakthrough technology suitable for **large area planar tracking devices** as well as **ultra-light high space resolution Cylindrical Inner Trackers:**

The detector has been extensively characterized

- **gas gain ≥ 10^4**
- **rate capability > 1 MHz/cm²** *(w/HR layouts)*
- **space resolution < 60μm** *(over a large incidence angle of tracks)*
- **time resolution ~ 5.7 ns**

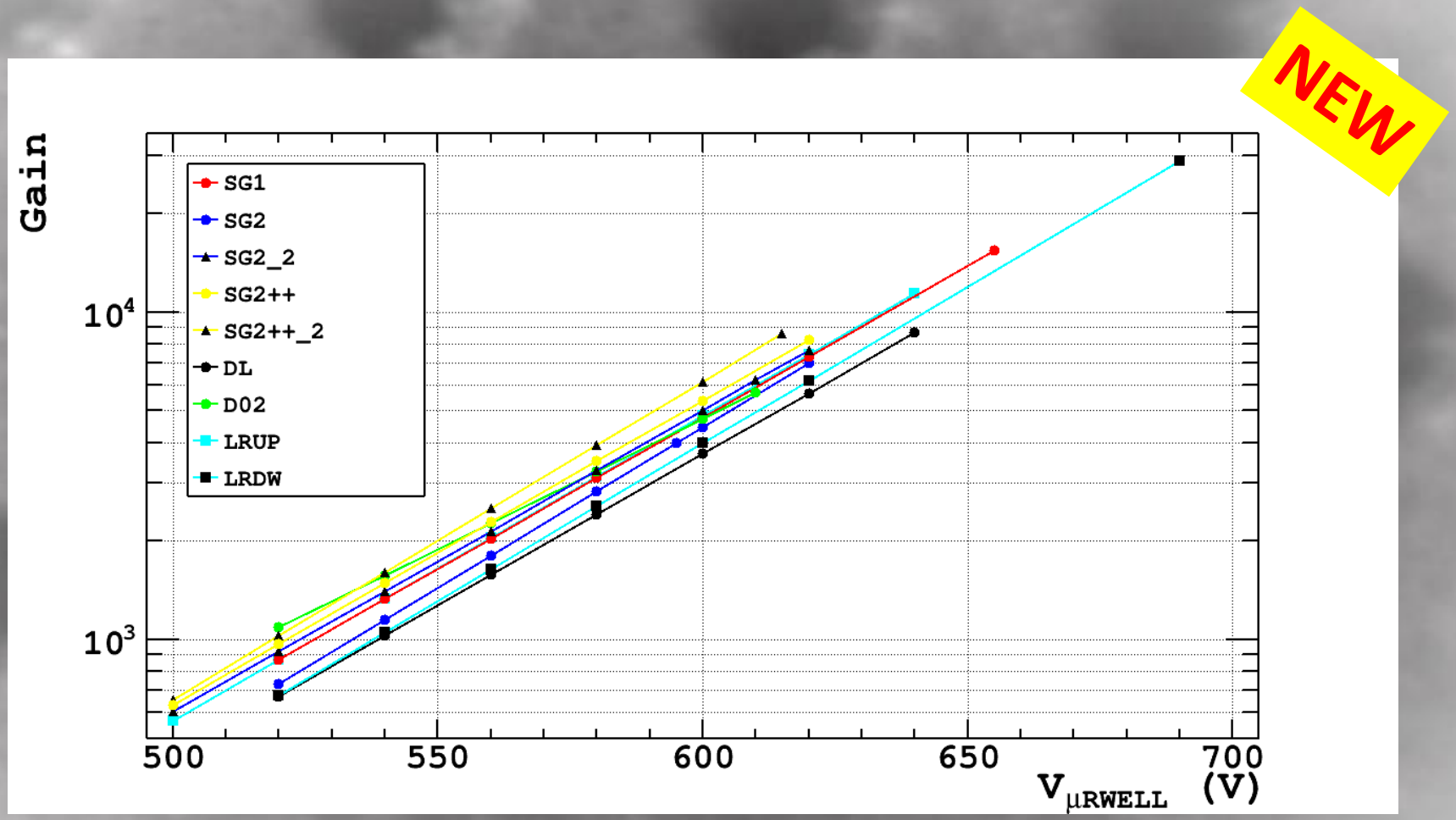
The technology is ready for TT to industry

- **low rate version is already partially built outside CERN at ELTOS, while test at TECHTRA is going to be started**
- **the R&D on new high rate layouts is almost completed & for TT to Industry**

Exploiting the μ-RWELL technology for Cylindrical IT seems to have many advantages with respect to what has been done till now with standard GEM technology

SPARES SLIDES

Maximum Gain under heavy irradiation

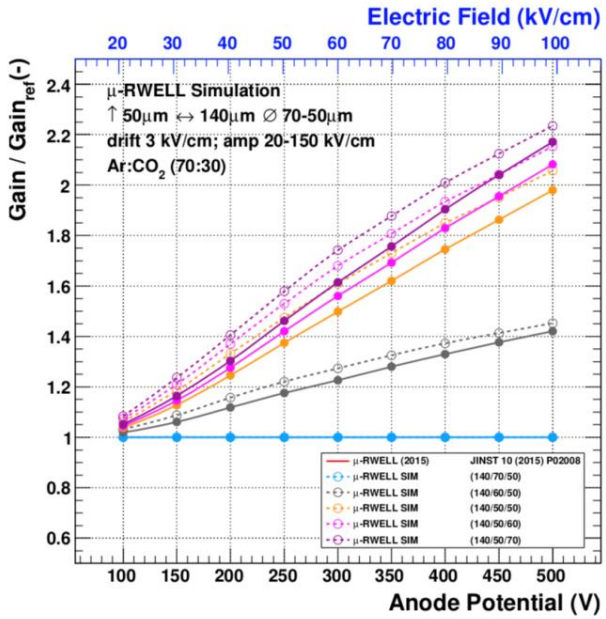


Increasing the Gain of a factor of 2 (I)

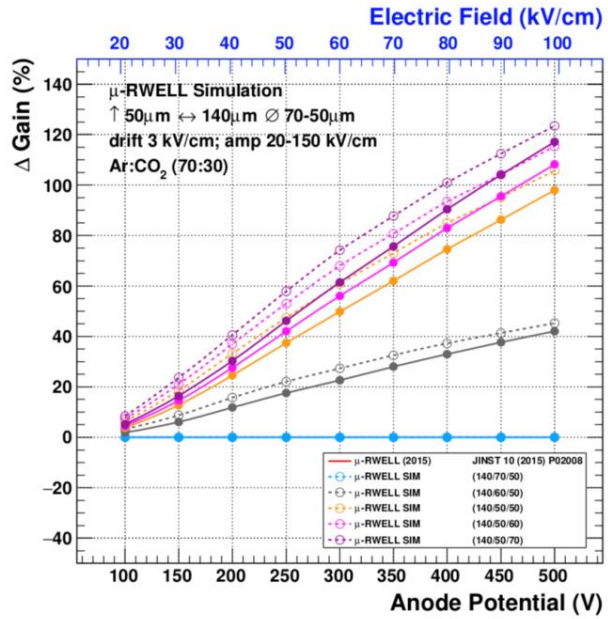
Courtesy of P. Verwilligen

Gain for different hole shapes

FTM (140/50/70) vs μ-RWELL (140/70/50)



(a) Ratio of $G_{\text{FTM}}/G_{\mu\text{-RWELL}}$



(b) $\Delta G = (G_{\text{FTM}} - G_{\mu\text{-RWELL}})/G_{\mu\text{-RWELL}}$

Figure: Gain ratio for different hole shapes (70/50 = μ-RWELL; 60/50; 50/50; 50/60; 50/70 = FTM) in Ar:CO_2 70:30 (left) and the percentual difference of the gain ΔG (%) (right).

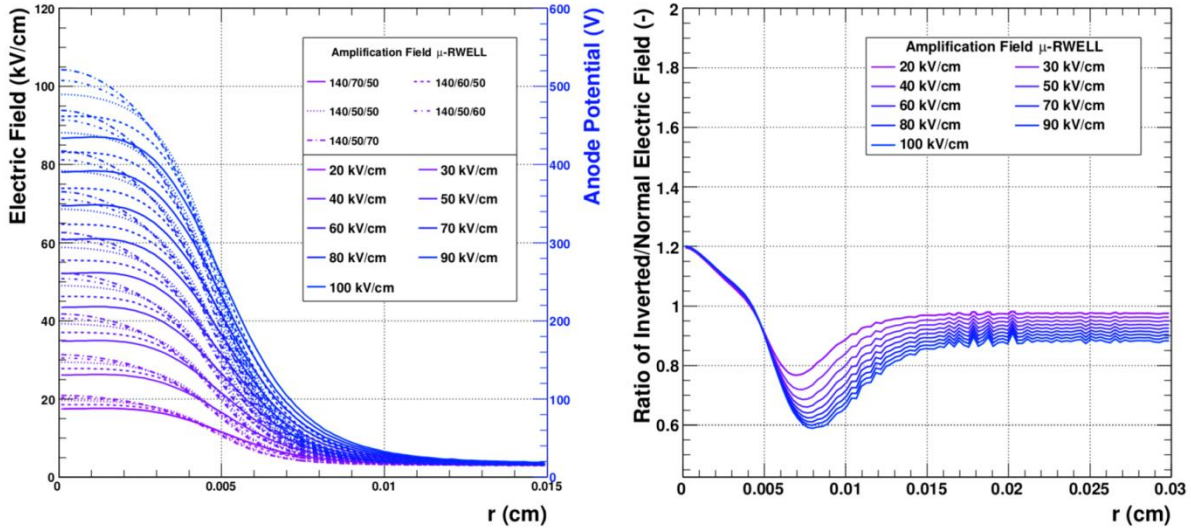
Simulation Studies for the fast timing mpgd (FTM)

(Dashed= no Penning, Full= Penning included)

Increasing the Gain of a factor of 2 (II)

Courtesy of P. Verwilligen

E field: hole shape μ-RWELL vs FTM



(a) Electric Field calculated for different well geometries

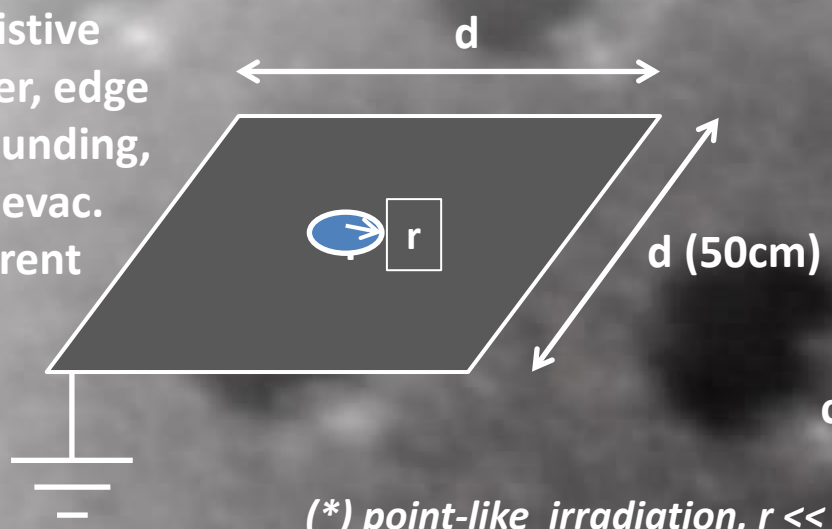
(b) Ratio Inverted / Normal geometry

Figure: Electric Field calculated for different well geometries, starting with the *Standard* geometry with a top diameter of 70 μm and bottom diameter of 50 μm, reducing first the top diameter to 50 μm with a step of 10 μm, then changing the bottom diameter to 70 μm, arriving at the *Inverted* geometry with 50 μm top diameter and 70 μm bottom diameter (left). Ratio of the *Inverted* and

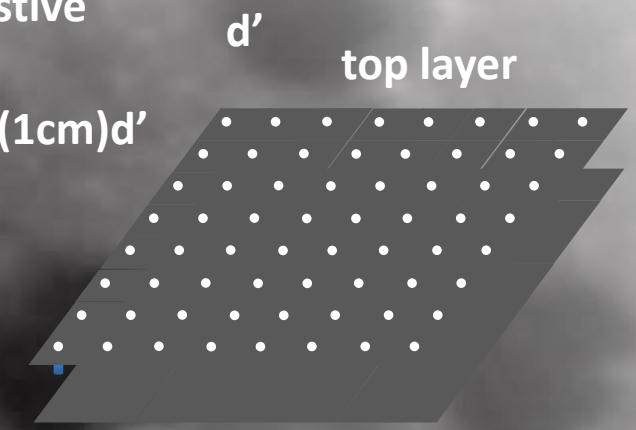
Simulation Studies for the fast timing mpgd (FTM)

Towards High Rate grounding schemes

single resistive layer, edge grounding, 2D evac. current



double resistive layer, 3D grounding



(*) point-like irradiation, r << d
Ω is the resistance seen by the current generated by a radiation incident the center of the detector cell

$$\Omega \sim \rho_s \times d/2\pi r \qquad \Omega' \sim \rho_s' \times 3d'/2\pi r$$

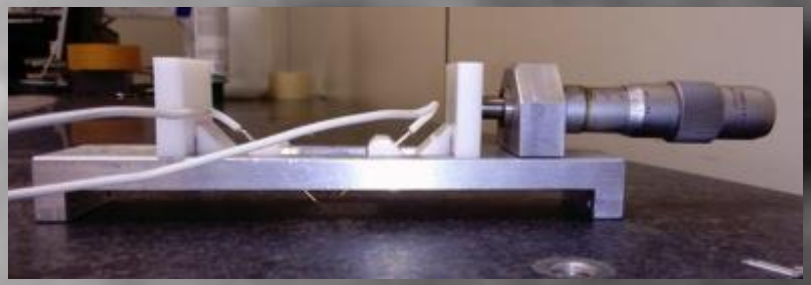
$$\Omega/\Omega' \sim (\rho_s/\rho_s') \times d/3d'$$

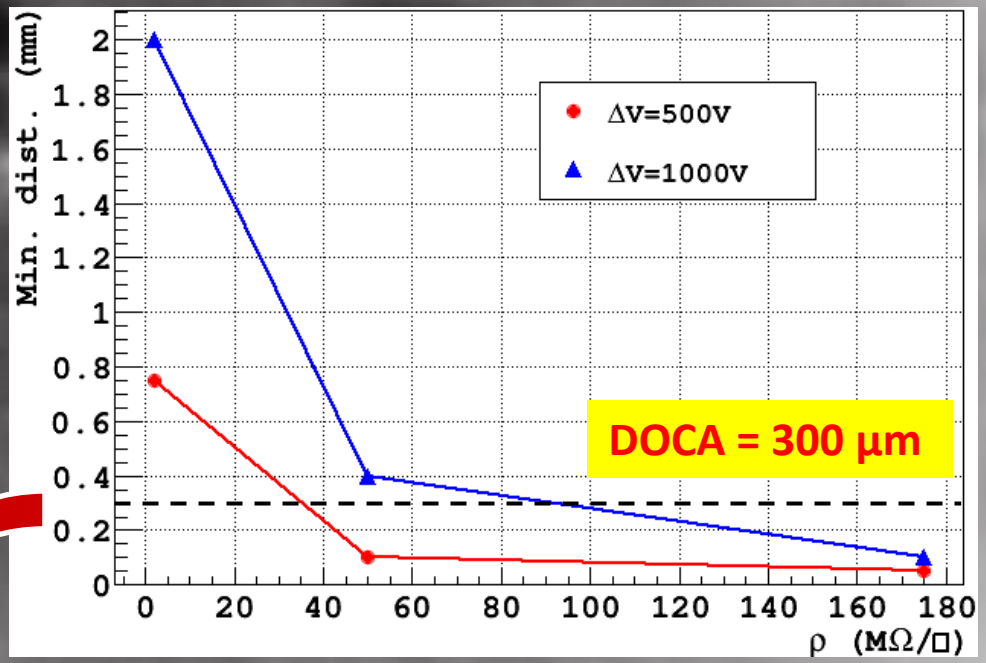
$$\text{If } \rho_s = \rho_s' \rightarrow \Omega/\Omega' \sim \rho_s/\rho'_s * d/3d' = 50/3 = 16.7$$

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

Conductive Grid: optimization

In order **to reduce the dead area,** we studied the **Distance Of Closest Approach *(DOCA) without discharges*** between **two tips connected to an HV power supply**. We recorded the **minimum distance before a discharge on the DLC** occurred *vs* the **ΔV supplied** for foils with different surface resistivity

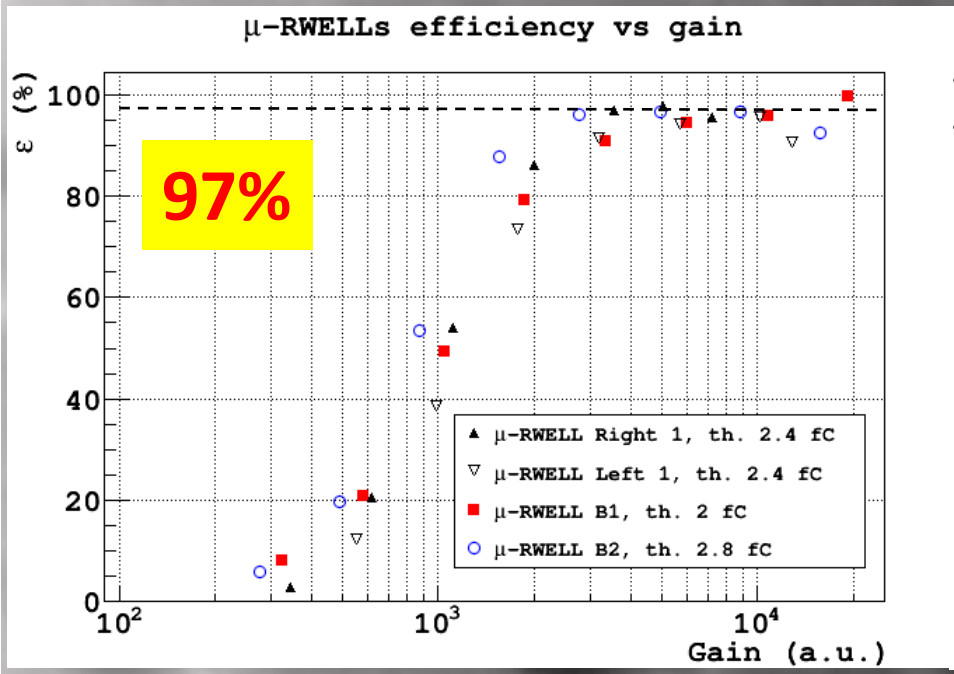


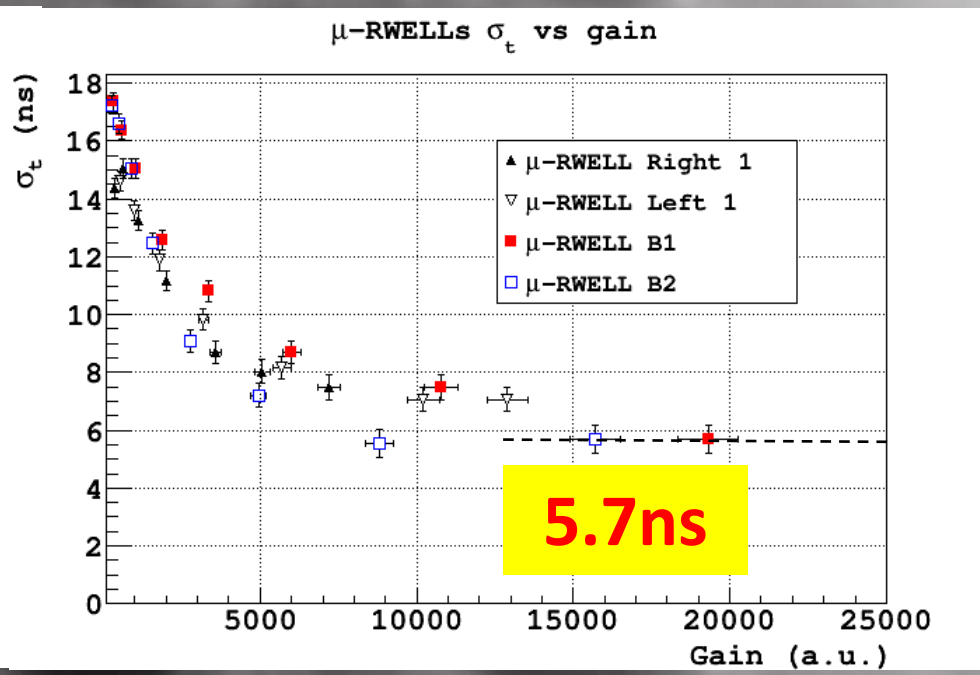


ρ ~ 60-80 MΩ/□ → DOCA < 300 µm

Time Performance

Ar/CO2/CF4 = 45/15/40





Different chambers with different dimensions and resistive schemes exhibit a very similar behavior although realized in different sites (large detector realized @ ELTOS).
The saturation at 5.7 ns is dominated by the FEE (measurement with VFAT2)

Collaboration with CMS-Muon group: L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai, V. Valentino

Comparing different HR Layouts

Under the assumption of uniform irradiation, we can define an **average effective resistance (Ω)** to ground as follows:

$$\Omega = \frac{1}{\int_{DOCA}^{pitch/2} \delta x} \times \rho \times \int_{DOCA}^{pitch/2} x \delta x$$

$$\Omega = \frac{\rho}{2} \times (pitch/2 + DOCA)$$

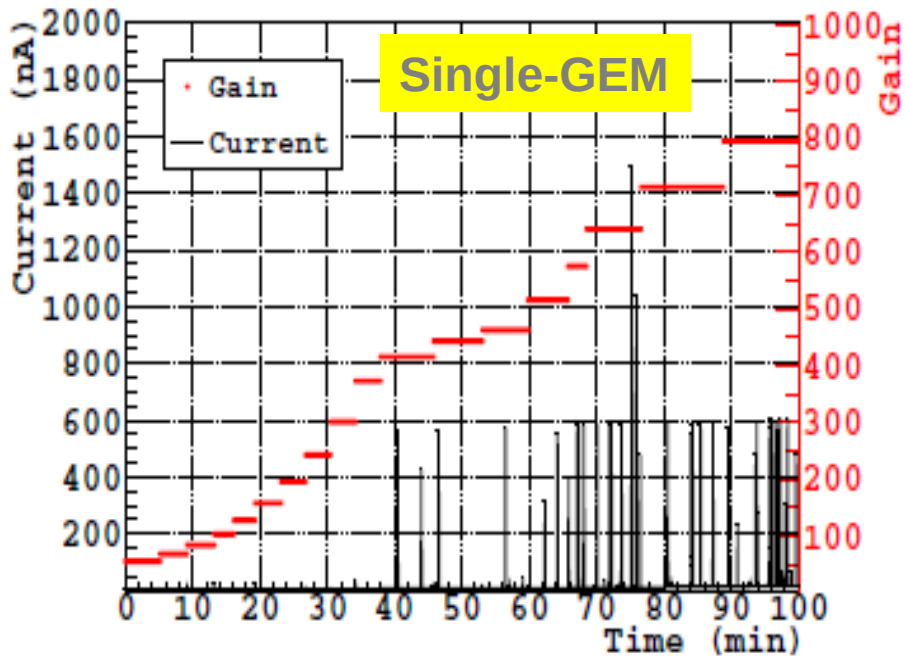
Where:

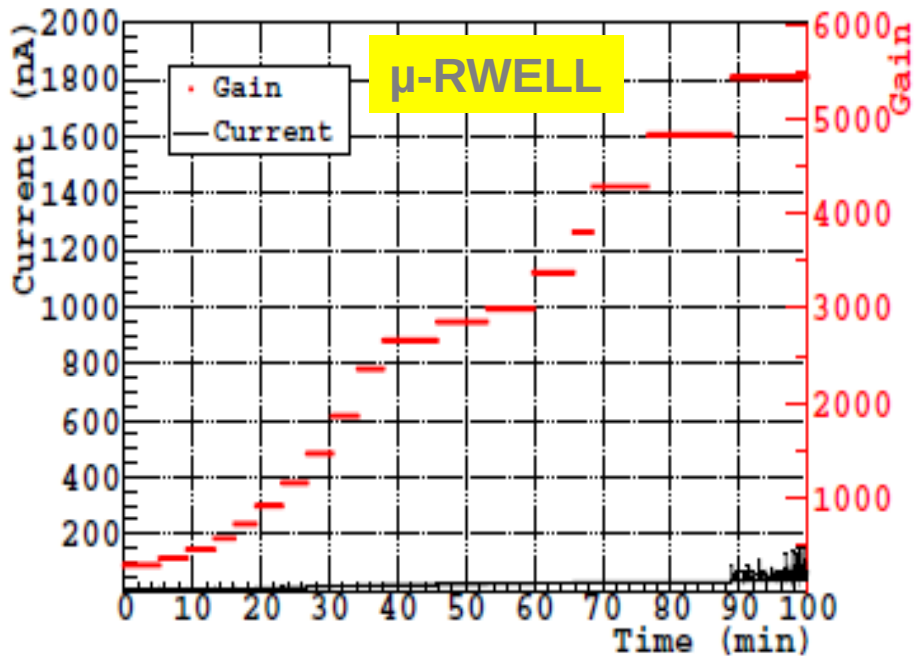
- ***pitch/2*** is half of the distance between two grounding-grid lines
- ***ρ*** is the surface resistivity of the DLC layer
- ***DOCA*** is the distance between the last (or first) amplification hole and the center of the grounding-grid line

HR proto parameters

	SG1	SG2	SG2++	DL	LR
Grid-pitch	6 mm	12 mm	12 mm	6 mm	100 mm
Dead zone	2 mm	1.1	0.6	-	-
Conductive line width	300 um	300 um	100 um	-	-
Doca (distance of close approch) between edges active area & conductive line	**0.85 mm**	**0.45 mm**	**0.25 mm**	**7 mm (path between vias on the 2nd layer)**	**5.5 mm**
Effective average resistance to ground*	**134 MΩ**	**209 MΩ**	**200 MΩ**	**640 MΩ**	**1947 MΩ**
Nominal resistivity	70 MΩ/□	65 MΩ/□	64 MΩ/□	75 MΩ/□	70 MΩ/□

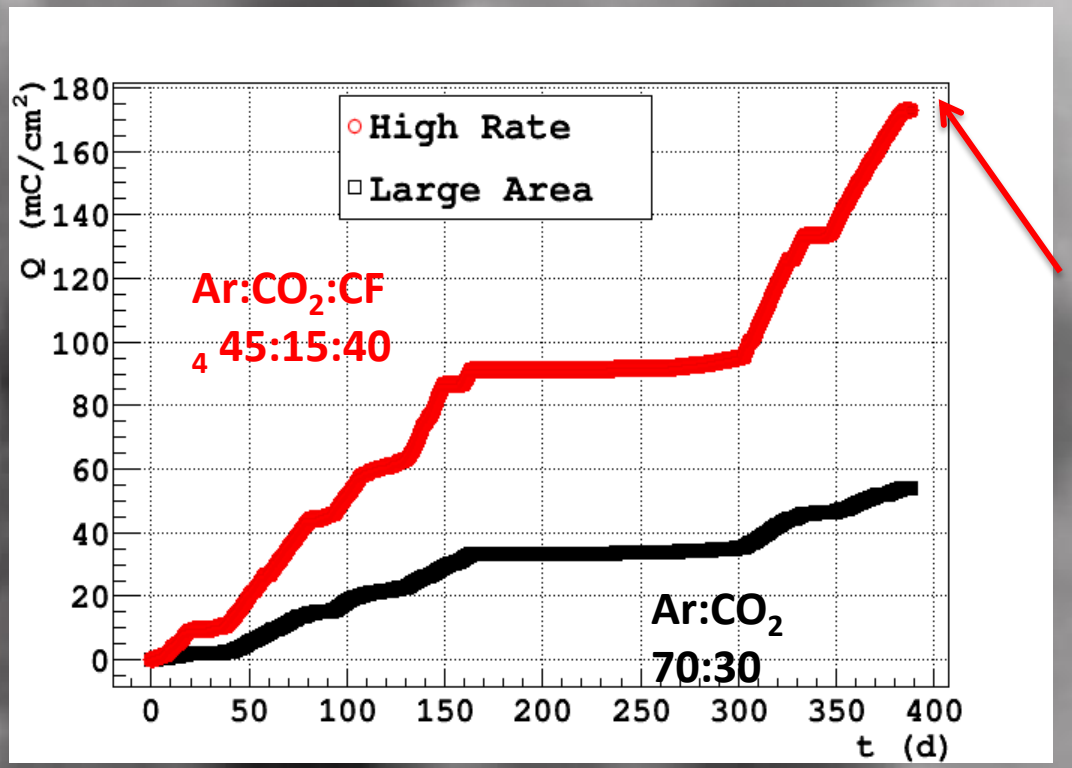
Preliminary study: μ-RWELL vs GEM





- discharges for μ-RWELL are of the order of few tens of nA (<100 nA @ high gain)
- for GEM discharges the order of 1μA are observed at high gas gain

Ageing test at GIF++ (I)



m.i.p. equivalent rate ~200 kHz/cm²

The ageing effects on DLC is under study at the GIF++ by irradiating different μ-RWELL prototypes operated at a gain of ~4000 .

On the most irradiated detector (~200 kHz/cm² m.ip. equivalent) a charge of about 180 mC/cm² has been integrated (in about 240 days up-time of the source).
No effects have been observed till now. Detectors will be opened by the end of the 2018.