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Status of the R&D/TT on µ-RWELL

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OUTLINE

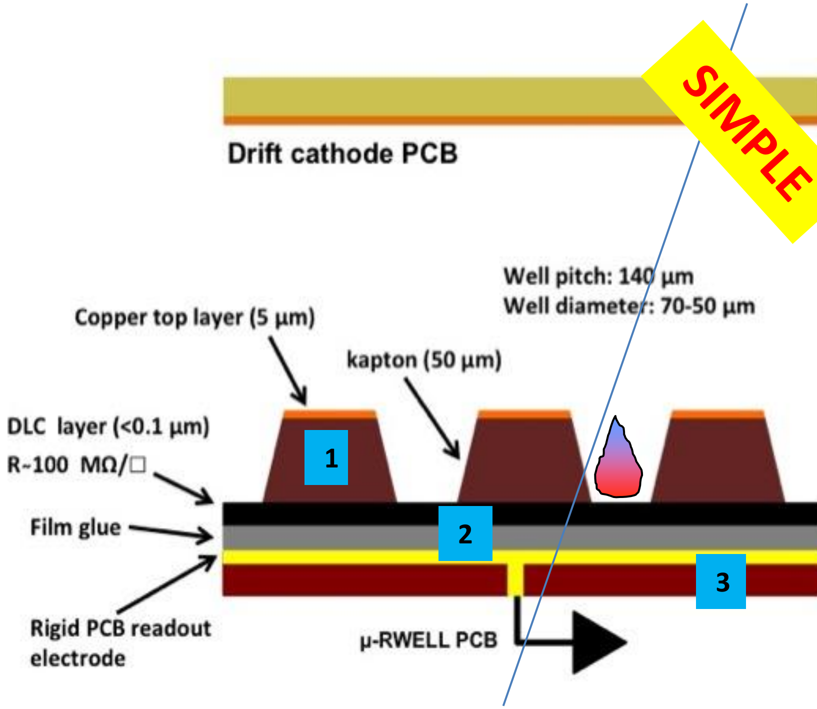
- ❑ Detector architecture
- ❑ Activity sharing between G5 & G1
- ❑ Activity report:
  - ❑ Low rate layout: the single-resistive layer scheme
  - ❑ High rate layouts: design & performance
- ❑ 2019 – Tentative Activity Plans & Group Composition
- ❑ Summary

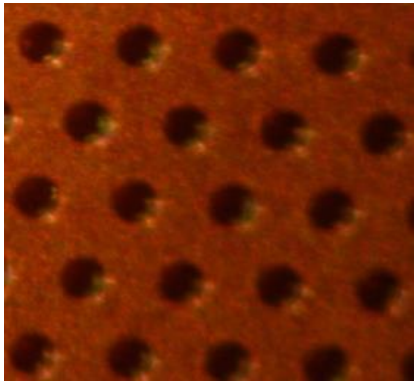
The μ-RWELL: the detector architecture

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** as **amplification stage**
2. a **resistive layer (*)** for discharge suppression & current evacuation:
   i. **Single-resistive layer (SRL) <100 kHz/cm²:** surface resistivity ~100 MΩ/☐ (SHiP, CepC …)
   ii. **Double-resistive layer (DRL) >1 MHz/cm²**: for LHCb-Muon upgrade & future colliders (CepC, Fcc-ee/hh)
3. a **standard readout PCB**

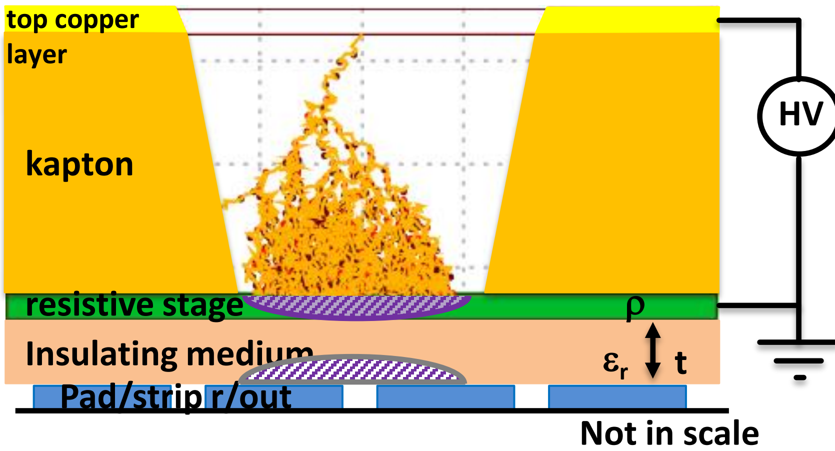




(*) DLC = Diamond Like Carbon mechanical & chemical resistant

Principle of operation

Applying a suitable voltage between **top copper layer and DLC** the "**WELL**" **acts as multiplication channel for the ionization.**



The charge induced on the resistive foil is dispersed with a ***time constant, τ = ρC ,*** determined by:

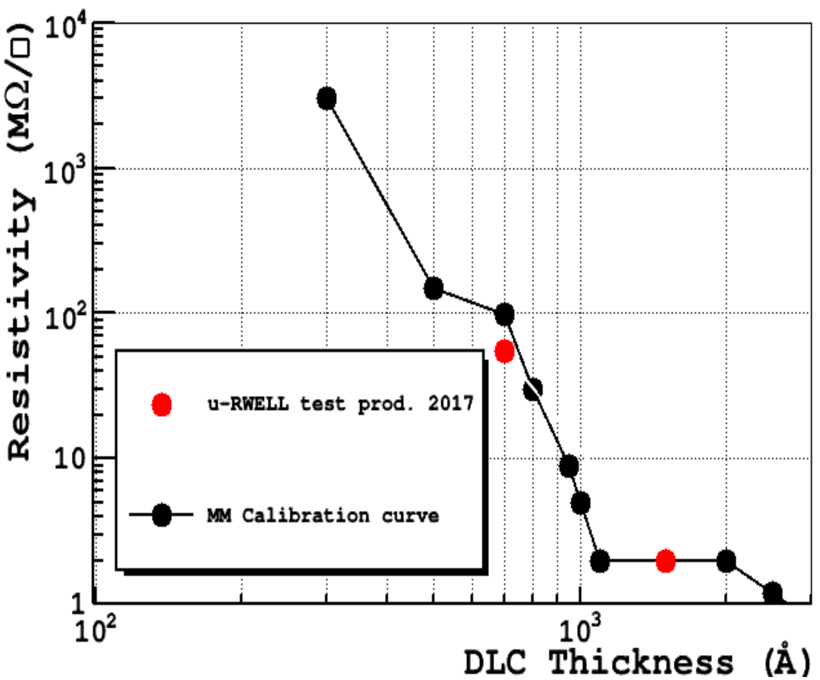
- the **DLC surface resistivity,** ρ
- the **capacitance per unit area,** which depends on the **distance between the resistive foil and the pad/strip readout plane, t**
- the **dielectric constant** of the insulating medium, ε_r **[M.S. Dixit et al., NIMA 566 (2006) 281]**

- **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 an appropriate grounding of the resistive layer with a suitable pitch solves this problem (see High Rate scheme)**

The resistive layer: DLC sputtering

The **kapton foil** copper etched on one side **is sputtered with DLC** (by **Be-Sputter Co., Ltd. in Japan)**. Simultaneous sputtering of 6 foils (1.2x0.6 m^2) per production batch is possible.

The **resistivity depends** on several manufacturing conditions, but can be parametrized as function of the **DLC thickness**. The **resistivity uniformity is at level of 20-30%.**



A collaboration with USTC – Hefei (PRC) for the manufacturing of improved DLC foils (DLC+Cu), has been started.

NEW

A (2 years) CP-RD51 among Hefei, Kobe, CERN and LNF has been recently approved with three main objectives:

- define manufacturing procedure
- define QC/QA procedures
- perform long term stability tests

The DLC+ Cu technology has great advantages:
- high performance HR - µRWELL
- full resistive HR - µRWELL (very low material budget)

Activity G5 vs G1

Activity in Commissione Scientifica Nazionale 5:

The R&D on µ-RWELL in **CSN5** started in the **2016** in the framework of **the 3-years project MPGD_NEXT (WP1):**

- **R&D on single-resistive layout** and **spatial detector performance** measurements
- **Test on DLC sputtering** in collaboration with Kobe
- **High rate version** study: **double-resistive layout** with small pad readout (**LHCb oriented)**
- **Time performance** studies (**LHCb oriented)**
- **New simplified HR layouts** based on **single-resistive layer**: conductive-grid, resistive-grid, conductive-dashed-grid (**LHCb oriented**)
- **High spatial resolution** studies: **micro-TPC** mode (**SHiP oriented …)**
- **Aging studies at GIF++ (in progress)**
- **discharge test with alpha-source (in preparation)**

Activity in Commissione Scientifica Nazionale 1:

The activity in **CSN1** has been mainly developed in the framework of the **RD_FA project started in the 2017 (WP7):**

- **TT to industry of single-resistive layout (ELTOS)** – small/large size
- **TT to industry of the etching of the amplification layer** for single-resistive layout **(TECHTRA)**
- **Construction at CERN (Rui) of an M4 prototype for 2nd phase CMS upgrade with floating techn. (Bologna resp. – not financed by RD_FA)**

External collaboration/projects participation

External collaborations/contacts

- **RD51** & EP-DT-EF – CERN (Rui de Oliveira)
- **Kobe Universitiy**, Kobe, Japan
- **USTC – Hefei, China**
- **UCAS – Beijing, China**
- **INFN – Ferrara BESIII**
- **INFN – Bologna/Bari CMS**
- **Budker Institute Akademgorodok – Novosibirsk, Russia**
- **European Spallation Source – Lund, Sweden**

→ **Improved DLC+Cu technology**

External projects

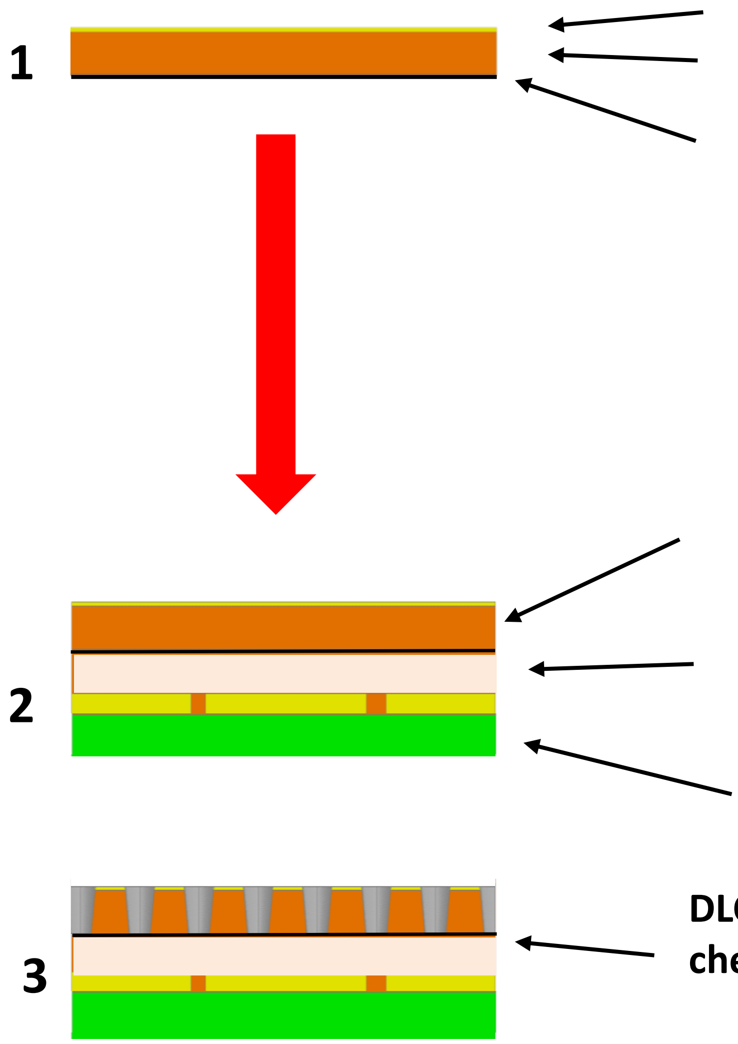
- **MAECI with USTC, China** - 2017 (rejected)
- **MAECI with ESS, Sweden** - 2017 (rejected)
- **PRIN 2017 – submitted 2018** (waiting for evaluation)
- **Common Project RD51 – 2018** w/CERN,Kobe,USTC **(approved – 2 years)**
- **ATTRACT 2018** – to be submitted after summer
- **CREMLIN2 -** Call deadline 14th November 2018

Industrial Partners: ELTOS SpA (Arezzo – Italy), TECHTRA (Wroclaw – Poland)

R&D on single-resistive layout (MPGD_NEXT - G5)

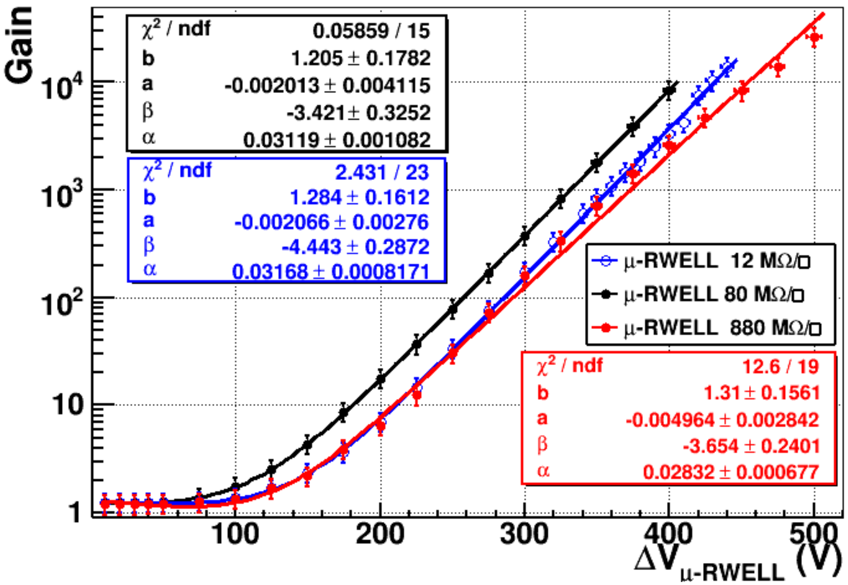
R&D on Low Rate Layout

single resistive layer w/edge grounding



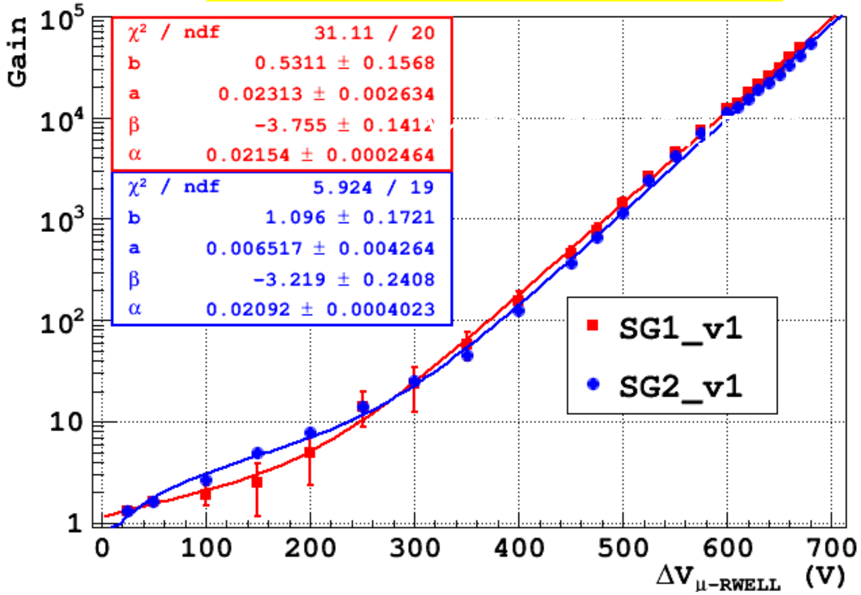
Detector Gain

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**

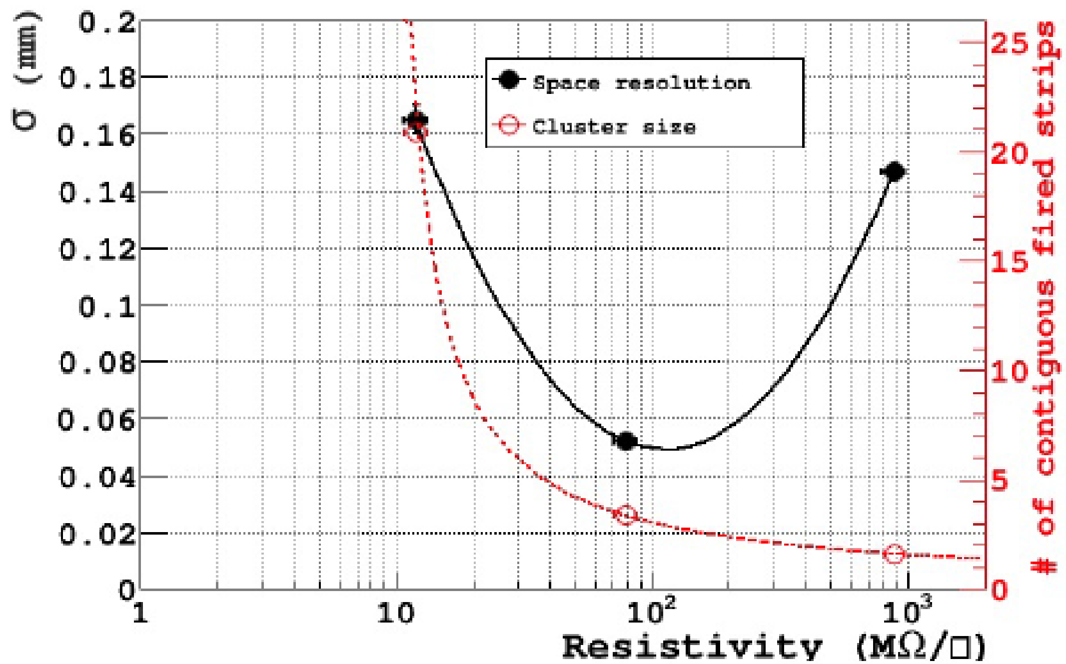
$Ar/CO_2/CF_4$= 45/15/40



Recent prototypes showed Gain ~10^5 in $Ar/CO_2/CF_4$= 45/15/40

Space resolution *vs* DLC resistivity

Charge Centroid analysis (orthogonal tracks)



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 (Cluster-size → 1 fired strip)** then the **Charge Centroid method** becomes **no more effective (σ → pitch/√12)**

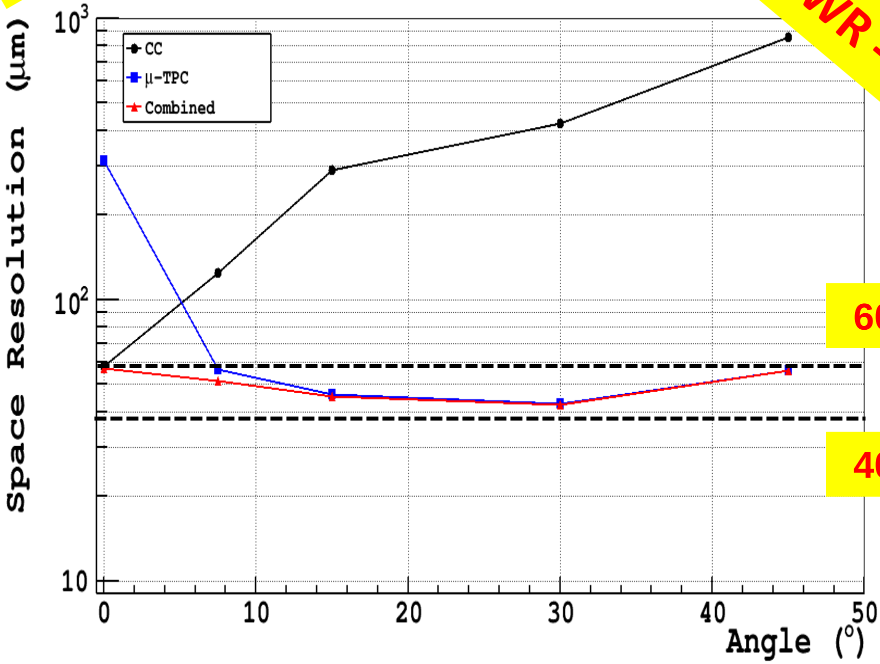
Space resolution vs inclined tracks: μ-TCP mode

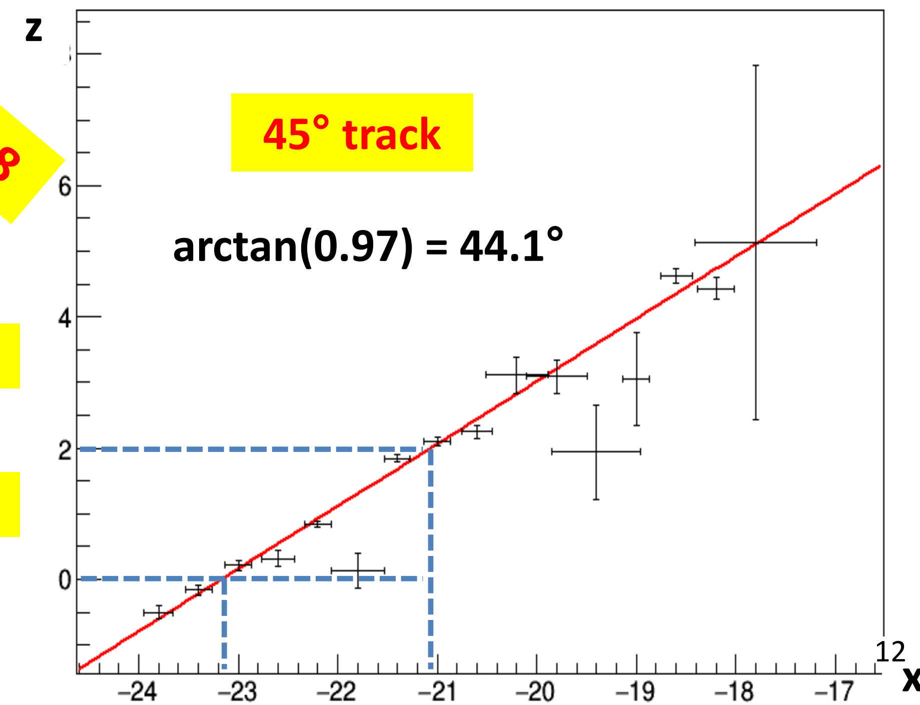
Collaboration DDG-LNF & BESIII-CGEM - R.Farinelli (INFN-Fe) & L.Lavezzi (INFN-To)

NEW

Ar:CO_2:CF_4 45:15:40 - HV=600V, Ed=0.5kV/cm, Gain ~10^4

WR - 2018



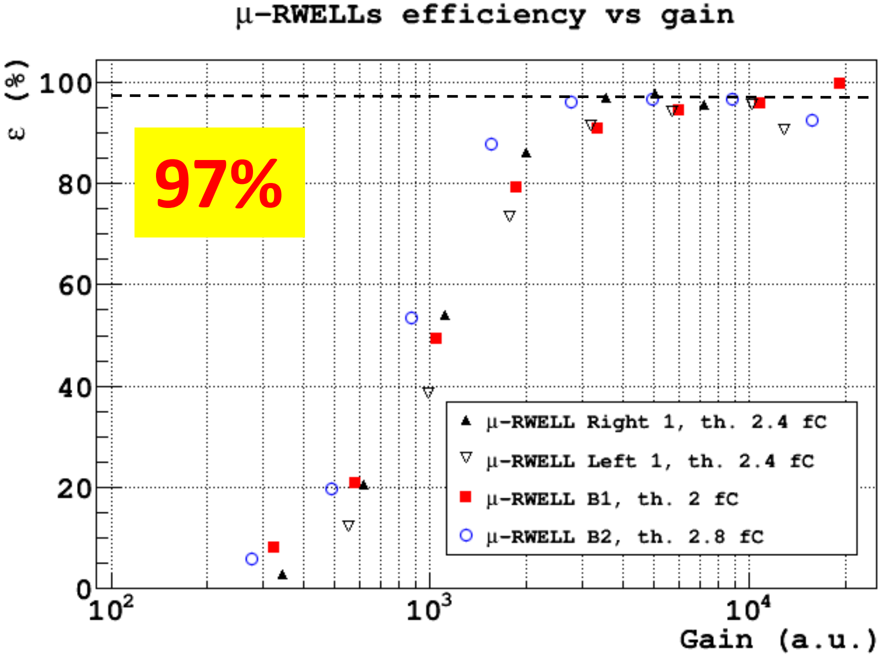


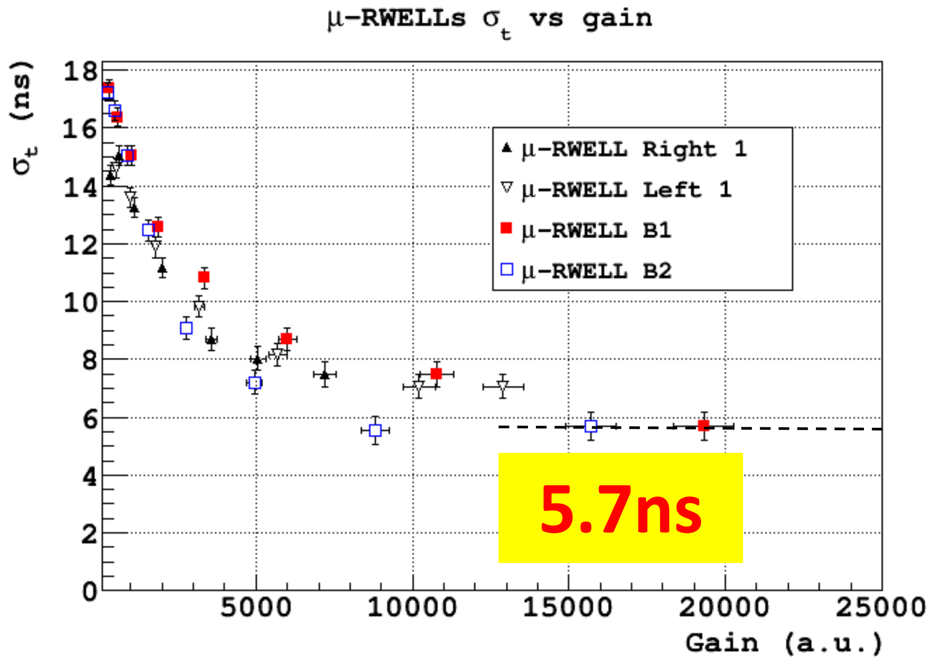
CC and the μ-TPC mode with E_d= 0,5 kV/cm

Combined space resolution over a wide range of incidence angles well below 60μm

Time Performance

Ar/CO2/CF4 = 45/15/40





Different chambers with different dimensions and resistive schemes exhibit a <u>very similar behavior</u> 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

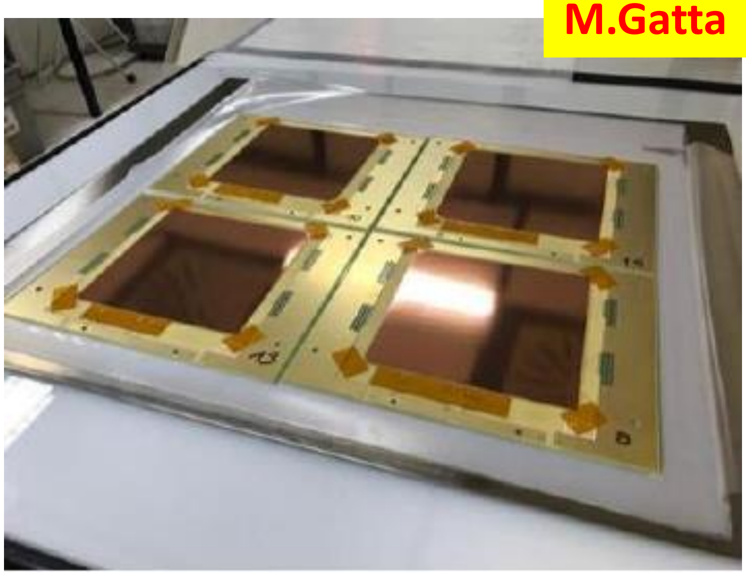
Single-resistive layout:
Technology Transfer to industry
(RD_FA – G1)

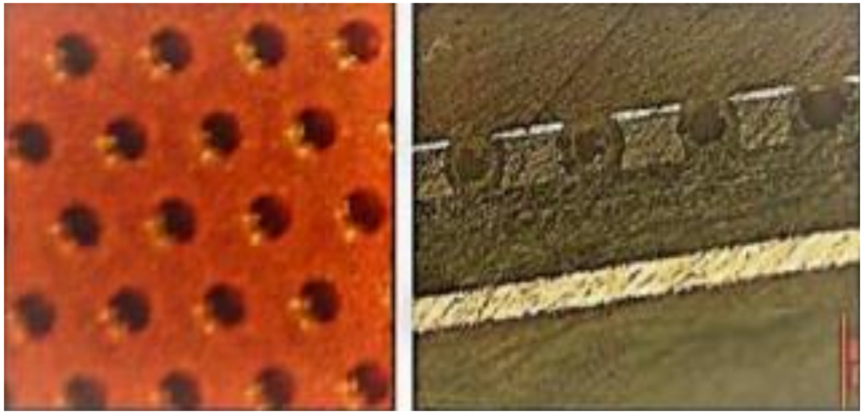
Technology Transfer to Industry (I)

M.Gatta

The **engineering and industrialization** of the μ-RWELL technology is one of the **main goals of our research program**.
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)**





<u>Production Tests @ ELTOS</u>:

- **10x10 cm^2 PCB – μ-RWELL (PAD r/o)**
- **10x10 cm^2 PCB – μ-RWELL (strip r/o) coupled with kapton/DLC foils**

The etching of the kapton done by Rui (CERN)

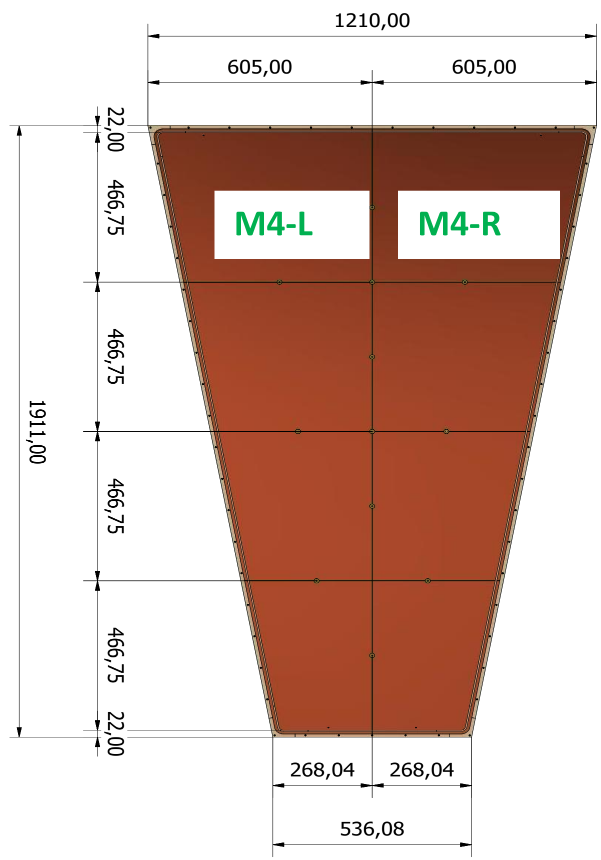
<u>On last tests done in Feb. 2018 the yield was 100%</u>. More statistics needed.

Technology Transfer to Industry (II)

In the framework of the **CMS-phase2 muon upgrade** different prototypes of **large size single-resisitive layer μ-RWELLs** have been **built at ELTOS**:

- **1.2x0.5m² μ-RWELL**
- **1.9x1.2m² μ-RWELL**

1.2x0.5m² (GE1/1) μ-RWELL



1.9x1.2m² (GE2/1) μ-RWELL

M.Gatta

TESTS done at ELTOS in the 2016/17. Yield ~ 50-60%
To be repeated asap after 2018 successful tests @ELTOS

Technology Transfer to Industry (III)

- The **etching of the amplification stage** (= DLCed Kapton foil) of the micro-RWELL, is done **at CERN by Rui. The operation is quite similar** to the **manufacturing of GEM** foil
- The **TT of the GEM etching** has been done by Rui during the last years towards Industries specialized in the flex technology: **TECHTRA in Poland and MECARO in South Corea**
- **TECHTRA produce all 10x10 cm^2 GEM foils for CERN**, and it is also involved in the production of medium size (**up to 50x50 cm^2**) GEM for several experiments
- **We are collaborating with TECHTRA since the 2017: during the last months they were able to manufacture 3/3 high quality detectors. Further kapton etching test will be done asap**

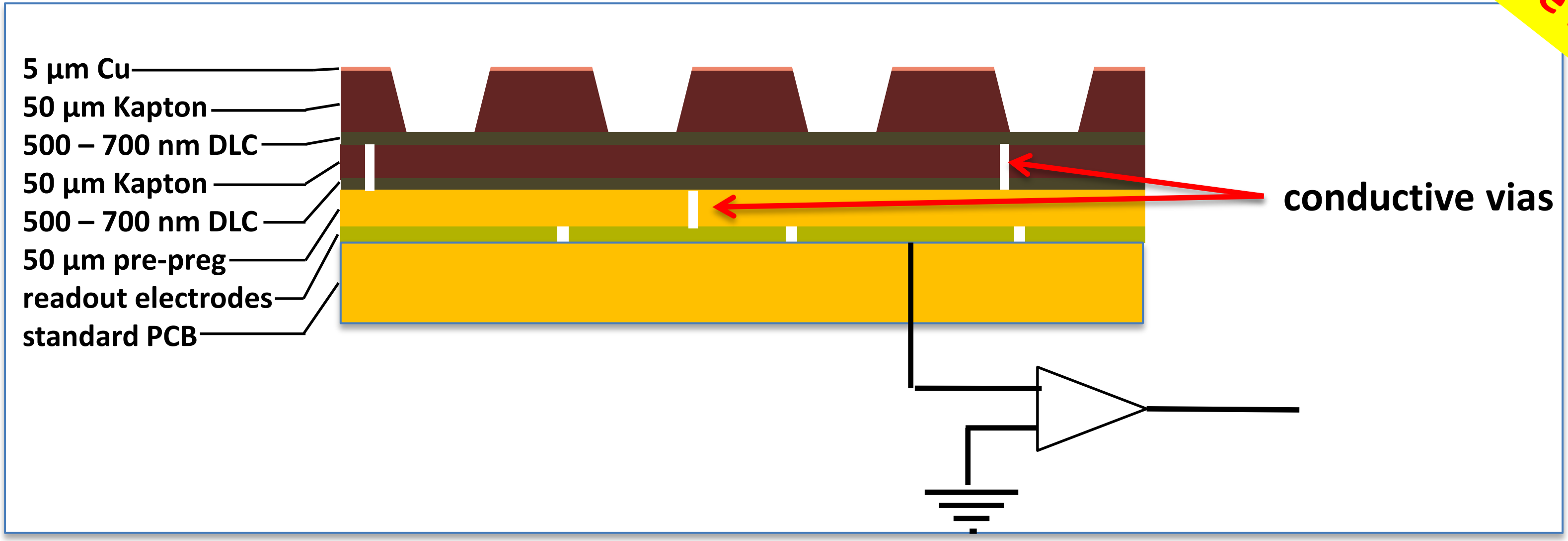
High-Rate layouts
(MPGD_NEXT - G5)

1 - HR layout: the double-resistive layer

The **idea is to reduce the path of the current on the DLC surface implementing** a **matrix of conductive vias** connecting **two stacked resistive 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).

baseline solution

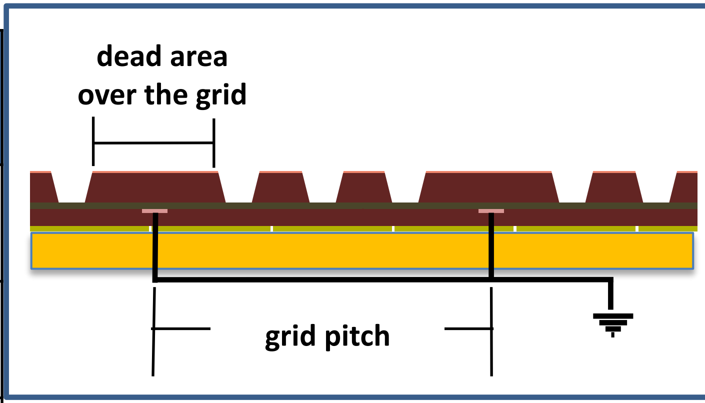


WARNING: The **engineering/industrialization of the double-resistive** layer is **difficult** due to the **manufacturing of the conductive vias on kapton foil.**

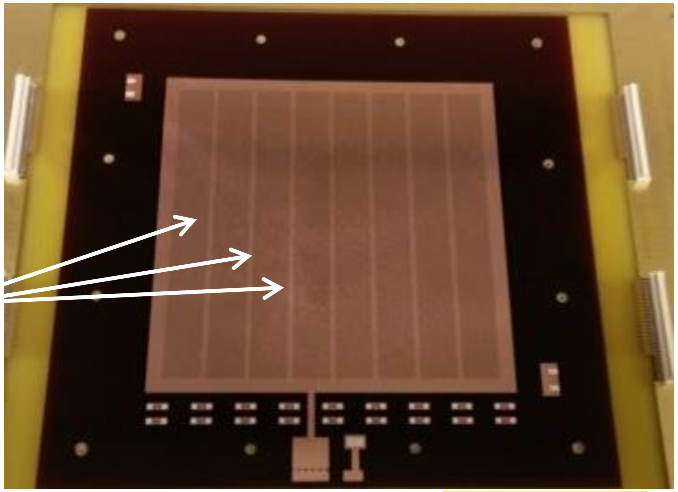
2 - HR layout: new ideas

New simplified grounding schemes are now under study, both based on **Single Resistive Layout**: **silver-grid & resistive-grid with the grid screen printed on the DLC side.**

High Rate layout	Resistivity [MΩ/□]	Dead Area over grid	Grid Pitch	Geometrical acceptance [%]	Type
Silver Grid 1 (SG1)	60-70	2 mm	6 mm	66	conductive grid
Silver Grid 2 (SG2)	60-70	1,2 mm	12 mm	90	conductive grid
Resistive Grid (RG)	60-70	-	6 mm	Full	resistive grid



The **conductive grid** on the bottom of the amplification stage **can induce instabilities due to discharges over the DLC surface, thus requiring the introduction of a dead zone on the amplification stage. This is not the case for the resistive grid layout.**



M.Gatta

3 – HR layout: next prototypes

Next step

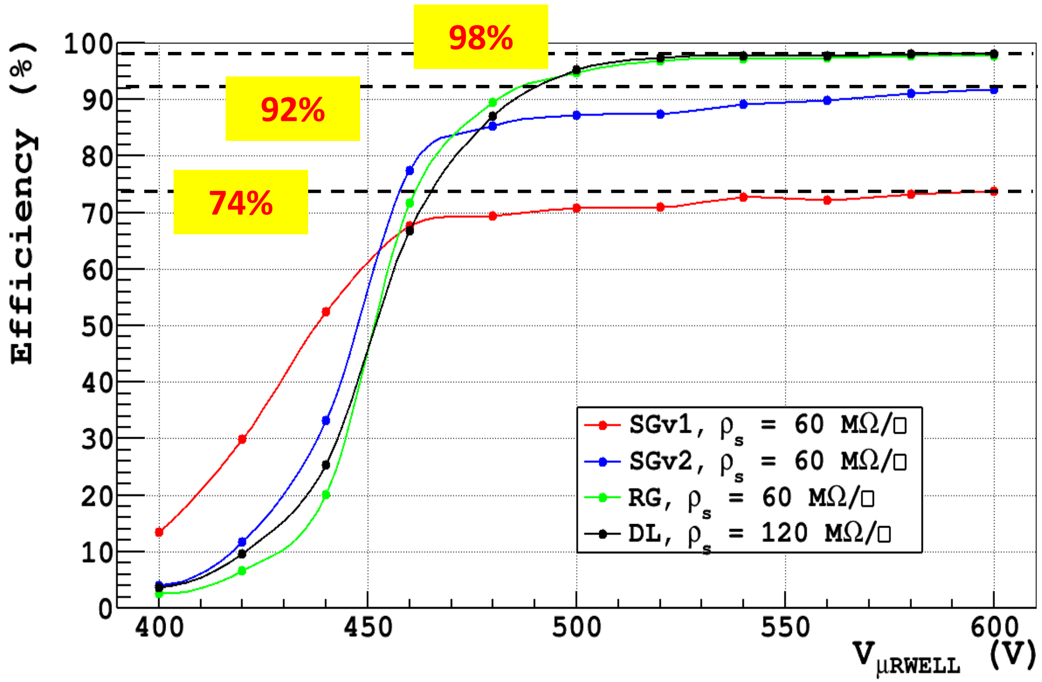
Following the **recipe adopted for Silver Grid (SG1 & SG2)** layouts (based on the definition of the **grid-pitch, grid-width)** we would like to **minimize as much as possible the dead zone** (for a given **DLC resistivity around 60-80 MΩ/□**)

HR Layout	Resistive layer	Grounding grid-pitch	Grounding	Dead-zone	Grid width	DOCA
SG2++	single	12 mm	Conductive grid + edge grounding	0,3 + 0,3 mm	100 um	250 um

The very fine grid structure is made possible thanks to the DLC+Cu technology under study at USTC-Hefei (CP-RD51): with a geometric acceptance of the order of 95% an almost full efficiency, 97-98%, is expected with the new prototypes.

HR layouts performance: the efficiency

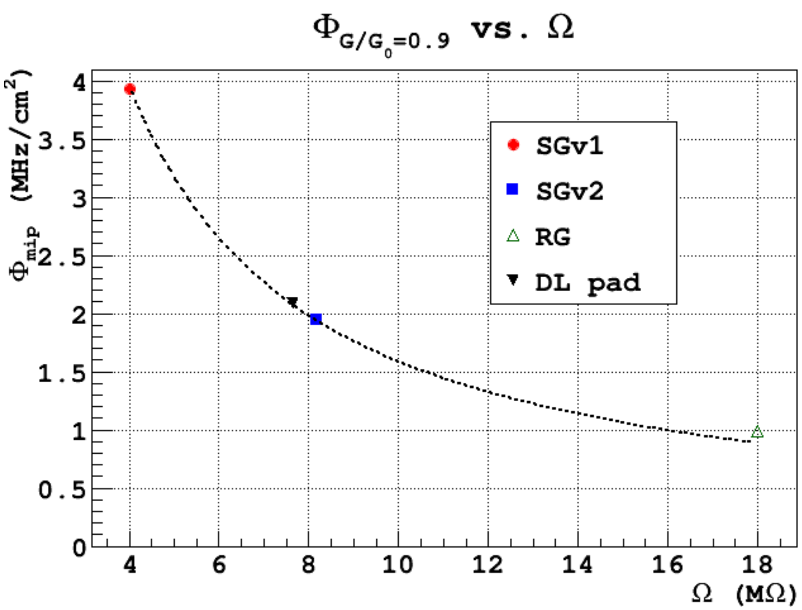
$Ar:CO_2:CF_4$ 45:15:40 – Muon Beam



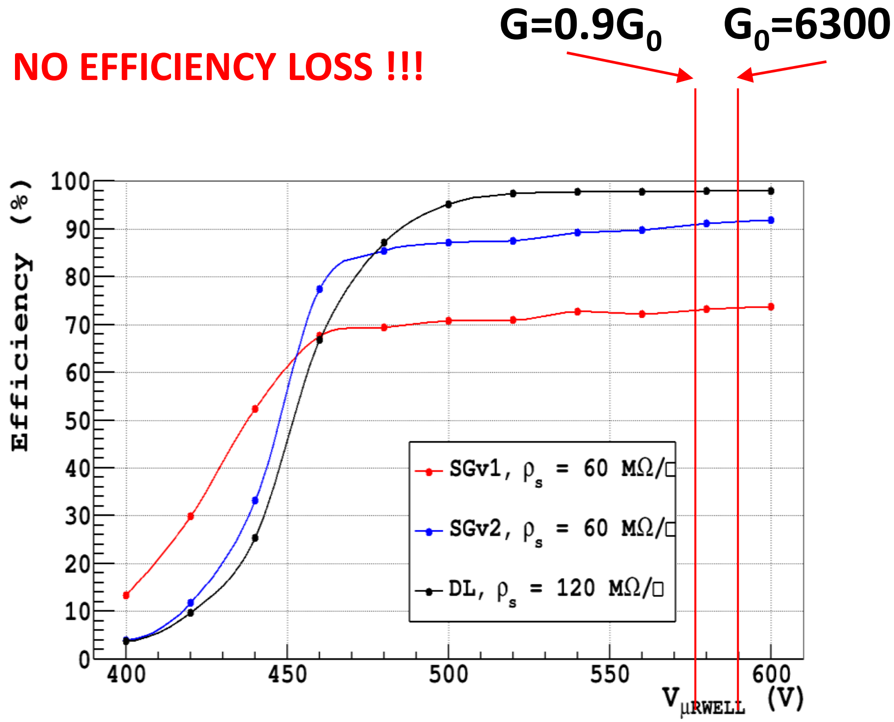
- **RG & DL prototypes** reach **full tracking efficiency, 98%** (NO DEAD ZONE in the amplif. stage)
- **SG1 & SG2** show lower efficiency **(74% -92%) BUT higher than their geometrical acceptance** (**66% and 90%** respectively), thanks to the **efficient electron collection mechanism** that **reduce the effective dead zone.**
- **With optimized SG2 version ($SG2^{++}$ w/95% geometrical acceptance) we should achieve almost full efficiency (97-98%).**

Rate Capability vs Ω (for m.i.p)

rate capability for m.i.p. accepting 10%gain drop



NO EFFICIENCY LOSS !!!

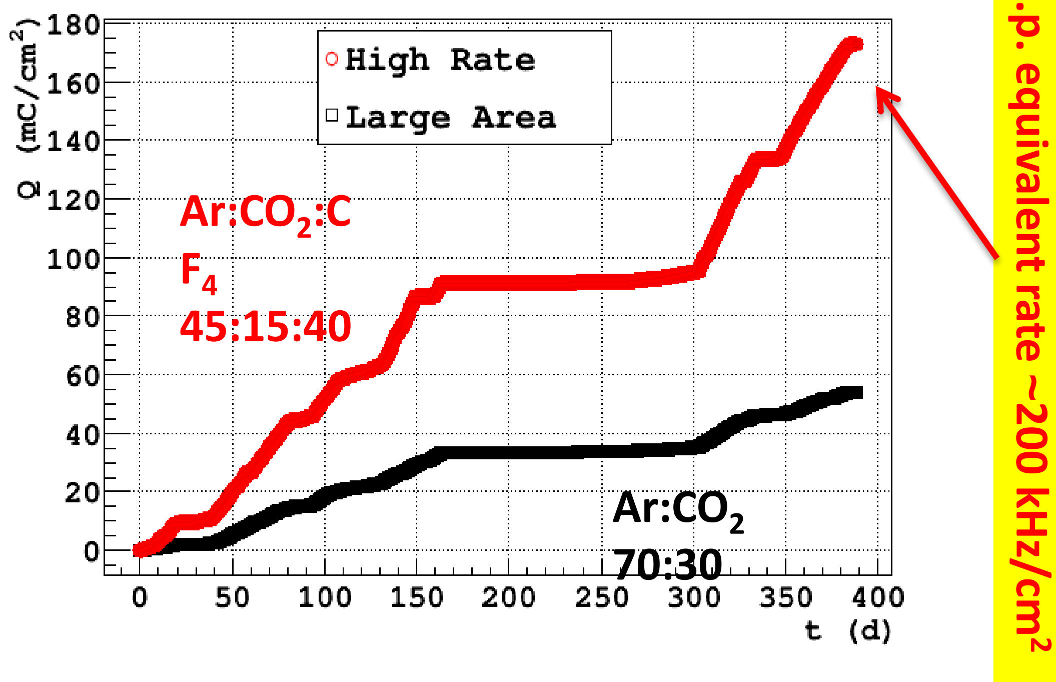


Detectors stand particle fluxes O(MHz/cm^2)

Aging

wrt to a GEM detector the **only new component in the μ-RWELL is the DLC**, so that the **aging studies** for μ-RWELL should mainly be **focused on DLC behaviour under irradiation and current drawing**

Ageing test at GIF^{++} (I)



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/cm^2 m.ip. equivalent) a charge of ~180 mC/cm^2 has been integrated (in about 240 days up-time of the source). No degradation observed till now.

Further tests to be done: localized 5.9 keV X-rays, gamma source (660 keV from ^{137}Cs), alpha particles (5.4 MeV from ^{241}Am) or thermal neutrons.

G5 vs G1: 2018 vs 2019 (LNF)

Experiment	afferenza	# of people 2018	Fte -2018	# of people 2019	Fte -2019
MPGD_NEXT	CSN - 5	6	1,15	0	0
RD_FA	CSN - 1	3	0,40	7	2,05
AIDA2020	CSN - 1	1	0,05	1	0,05

Nominativo	RD_FA (LNF)
bencivenni	45
poli lener	40
Morello	40
Domenici	30
de lucia	20
felici	20
bertani	10
TOTALE	205

Interessati in particolare alla RWELL cilindrica

2019 – RD_FA: new entry ?

NEW

WP7.2 - see presentation G. Cibinetto:

- **proposal for a NEW R&D line in RD_FA: "Ultra-light high space resolution IT based on Cylindrical RWELL technology** " (**SCTF*,** HIEPA, but also FCC-ee)

(*) CREMLIN2: **EU Call – INFRASUPP-01-2018-2019:**

NEW

- Opening of the topic: **14 November 2018**
- Deadline of the topic: **20 March 2019**

WP7.1 - μ-RWELL plans for 2019-20

2019 (continuing the TT to Industry – small size):

- **Technology transfer of SG2++ layout for HR @ELTOS**
- **TT of the etching process of the DLCed Kapton foil for SG2++ HR @TECHTRA**
- **R&D on improved DLC+Cu (in the framework of CP-RD51 – 3 years project)** with the duty of construction of protos with DLC+Cu and **long-term tests**

LNF: TT to ELTOS+TECHTRA & construction HR - prototypes + basic tests + DLC+Cu R&D
Ferrara/Bologna/LNF: test on beam of HR - prototypes

2020 (finalizing the TT to Industry – large size)

- **construction of large size HR-Layouts @ELTOS**
- **etching of the large size HR-Layouts @TECHTRA**
- **Finalizing R&D on improved DLC+Cu (in the framework of CP-RD51 – 2 years project)**

LNF: TT to ELTOS+TECHTRA & construction HR - prototypes + basic tests + DLC+Cu R&D
Ferrara/Bologna/LNF: test on beam of HR - prototypes

Funds requests

2019 – TT on small size HR-layouts + DLC+Cu R&D:

- TT of SG2++ layout for HR @ELTOS **12 k€ (LNF)**
- TT of SG2++ layout for HR @TECHTRA **10 k€ (LNF)**
- R&D on improved DLC+Cu (CP-RD51 – 2 years project) **5 k€ (LNF)**
- missioni per contatti (ELTOS+TECHTRA) **3 k€ (LNF)**
- Missioni per test beam **6 k€ (Ferrara+Bologna+LNF+…)**

2020 – TT on large size HR-layouts + DLC+Cu R&D:

- TT of large size layout for HR @ELTOS TBD (LNF)
- TT of large size layout for HR @TECHTRA TBD (LNF)
- R&D on improved DLC+Cu (CP-RD51 – 2 years project) **5k€ (LNF)**
- Missioni per contatti (ELTOS+TECHTRA) TBD (LNF)
- Missioni per test beam TBD (LNF+Ferrara+Bologna…)

Summary (I)

The µ-RWELL is a very promising MPGD technology

- **large area planar tracking devices**
- **ultra-light high space resolution Cylindrical Inner Trackers** NEW
- **non-HEP applications (X-ray & neutron imaging and gamma environment monitoring) to be investigated**
- **Beam monitor & luminometer**

The detector has been extensively characterized

- **gas gain > 10^4**
- **rate capability > 1 MHz/cm^2** *(w/HR layouts)* NEW
- **space resolution 40- 60µm** *(w/uTPC - mode - over a large incidence angle)*
- **time resolution ~ 5.7 ns**

Summary (II)

Status of the R&D/engineering:

- **Low rate:**
  - ✓ R&D on small/large area prototypes built/tested (completed)
  - ✓ Technology Transfer to ELTOS well advanced
  - Technology Transfer to TECHTRA for Kapton etching in progress with very promising results – to be continued in 2019

- **High rate:**
  - several layouts under study showing very promising performance (G5)
  - the engineering and the TT to industry will be started in 2019

NEW

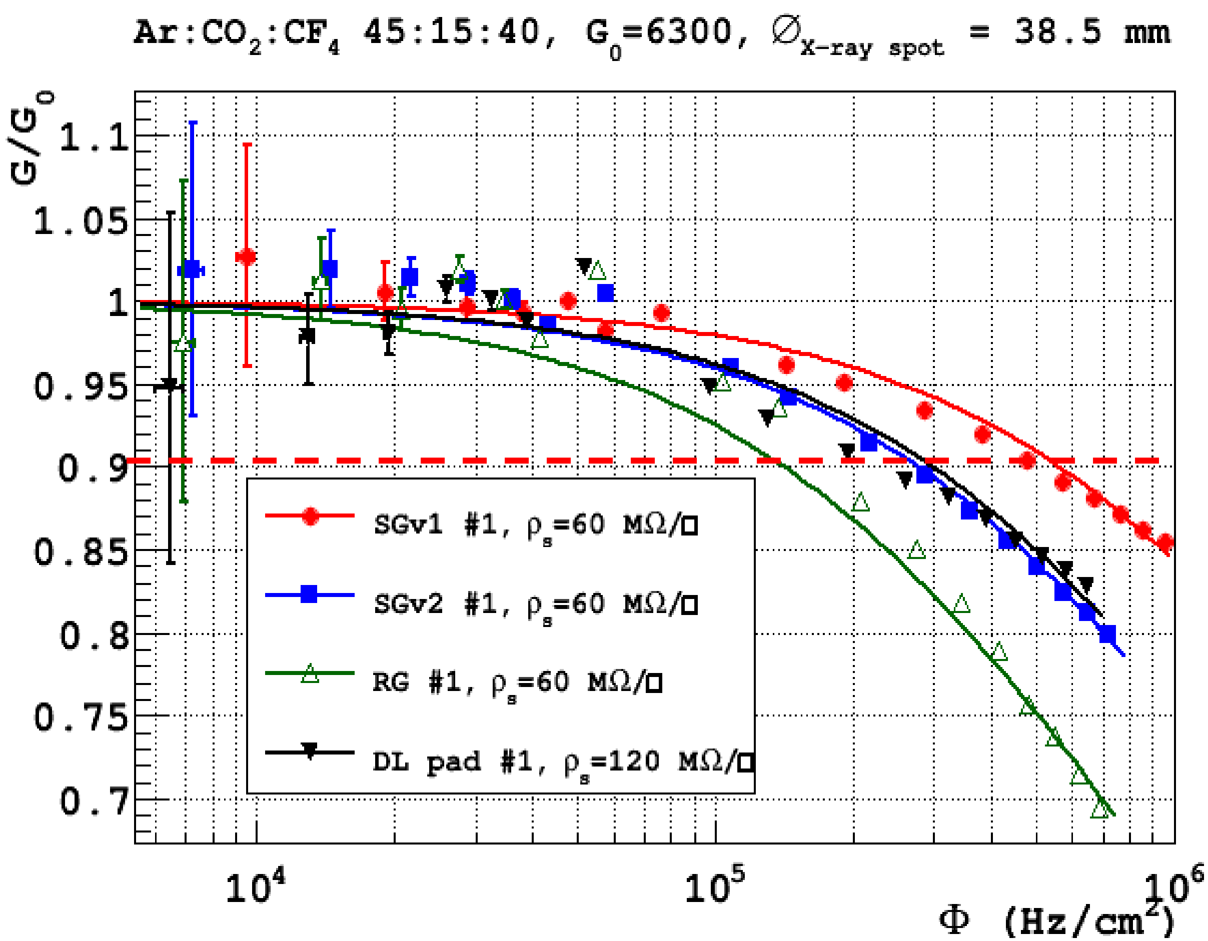
- R&D on improved DLC+Cu manufacturing processes, long term stability under irradiation and current flow strongly required (in the framework of CP-RD51)

NEW

- for 2019 the whole R&D activity on μ-RWELL, including the Cylindrical μ-RWELL, will be included in RD_FA program

SPARES SLIDES

Gain drop measurement w/5.9 X-ray



The **gain drop** is due to the **Ohmic effect** on the resistive layer: **charges collected on the DLC drift** towards the **ground** facing an **effective resistance Ω**, depending on the **evacuation scheme geometry and DLC surface resistivity.** **Ω** is computed by the **parameter** p_0 coming from the **fit of the Gain curve.**

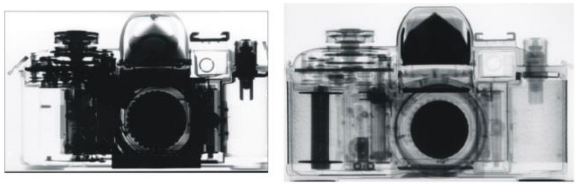
$$\frac{G}{G_0} = \frac{-1+\sqrt{1+4p_0\Phi}}{2p_0\Phi}$$

Non – HEP applications

The **TT of the -RWELL to industry** allows to **exploit the technology for applications beyond HEP:**

- detection of **gamma from Cs-137** for **environmental monitoring**
- fine **X-ray imaging** for medical, industrial, material science, archeology diagnostics
- **thermal neutrons imaging** for the monitoring of the tanks for radioactive disposal as well as for industrial applications as complimentary to the X-ray imaging

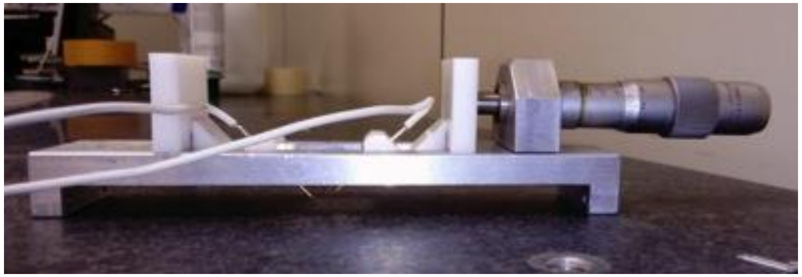
Comparison of X-ray and Neutron Radiographs

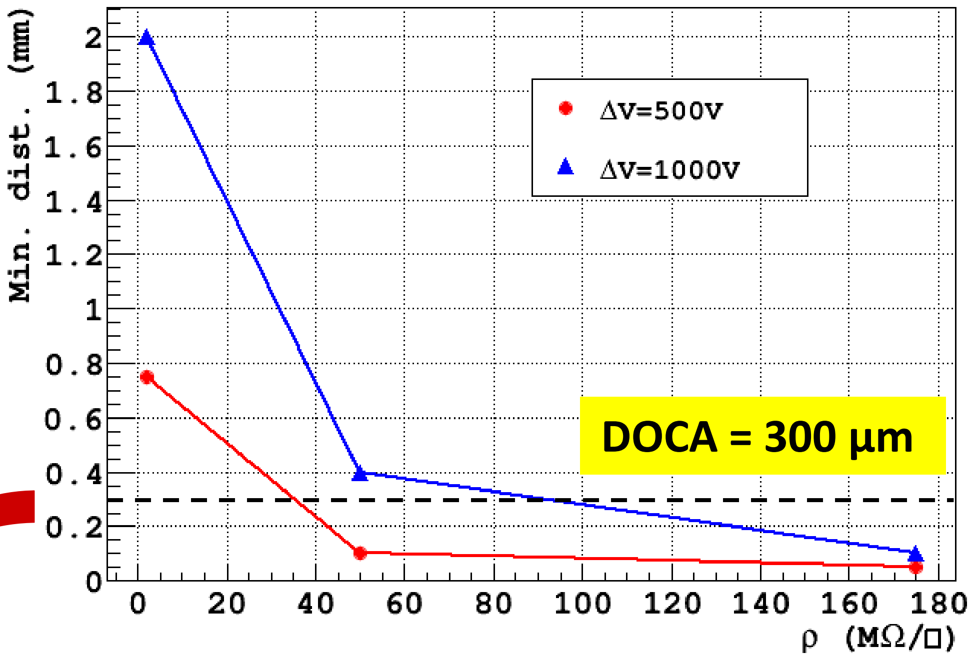


- **beam monitors/luminometers**

Conductive Grid: optimization

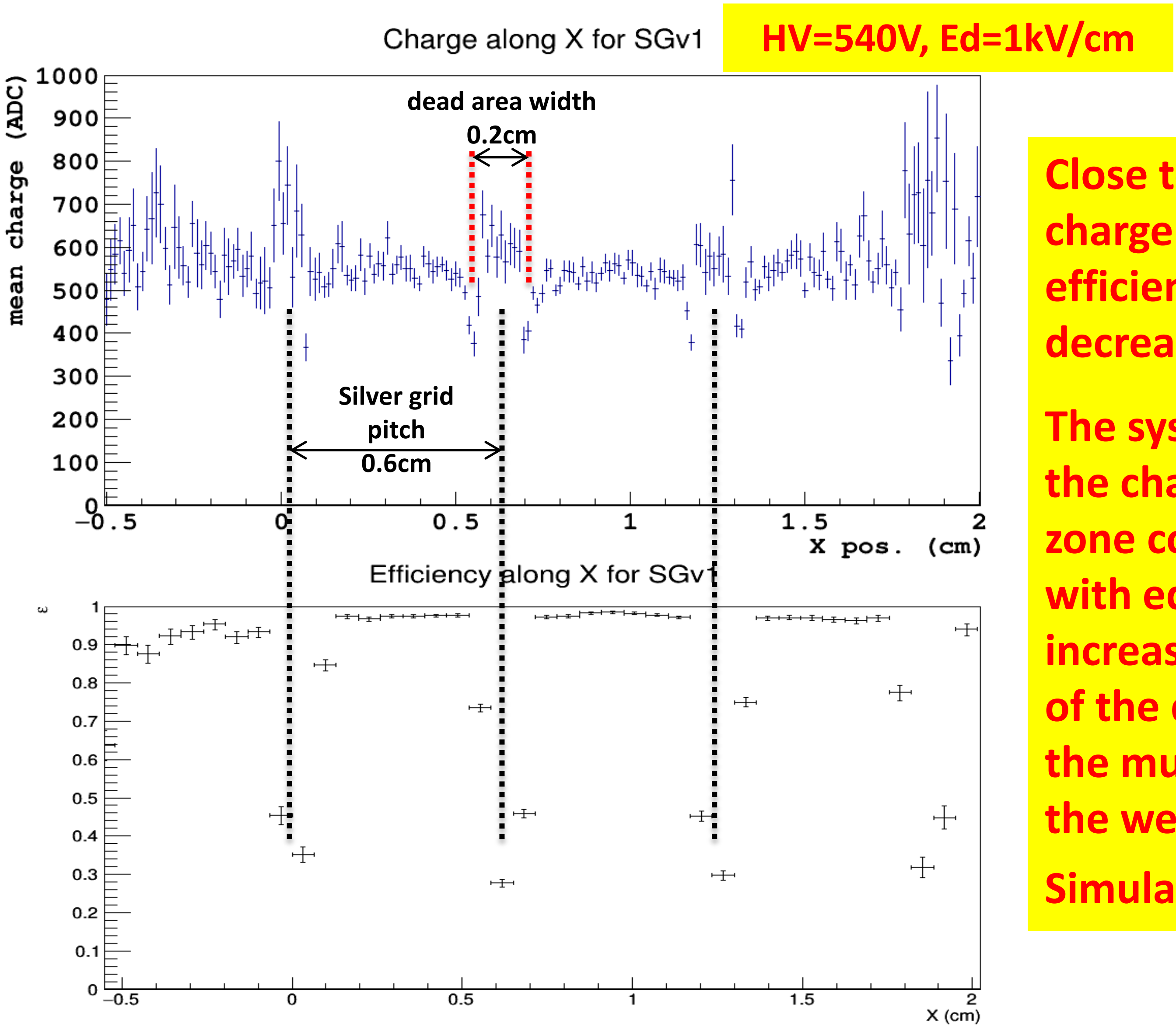
In order **to reduce the dead area,** we studied the **Distance Of Closest Approach** (***without discharges***) between **two tips connected to an HV power supply**. We recorded the **minimum distance before a discharge on the DLC** occurred *vs* the **ΔV supplied** for foils with different surface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





ρ ~ 60-80 MΩ/□ → DOCA < 300 µm

Charge & Efficiency profiles of SG1 (w/pions)



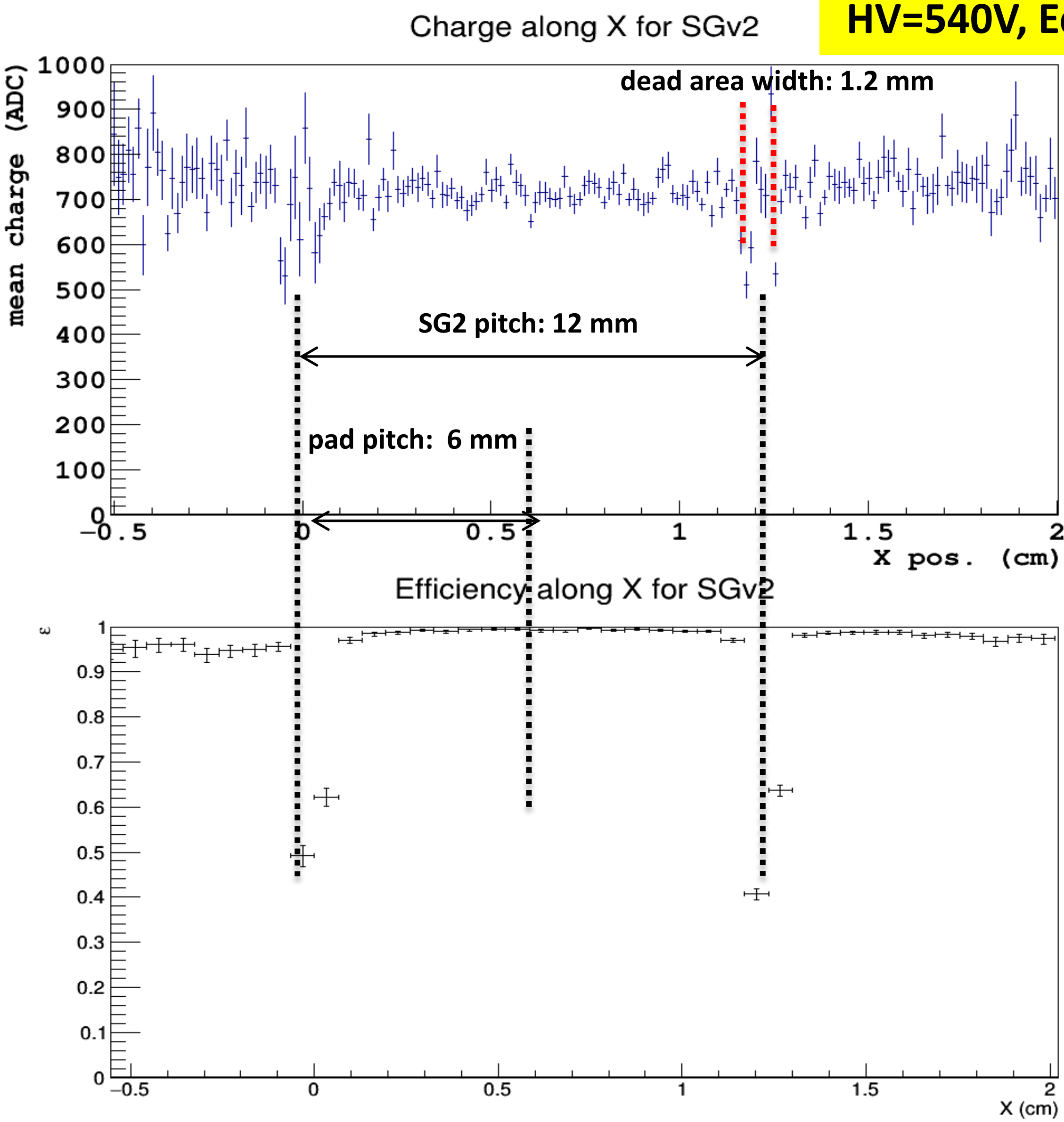
Close to dead zone the charge increases while the efficiency (obviously) decreases.

The systematic increase of the charge close to the dead zone could be correlated with edge effects locally increasing the amplification of the detector, extending the multiplication outside the wells.

Simulation needed !!!

Charge & Efficiency profiles of SG2 (with pions)

HV=540V, Ed=2kV/cm



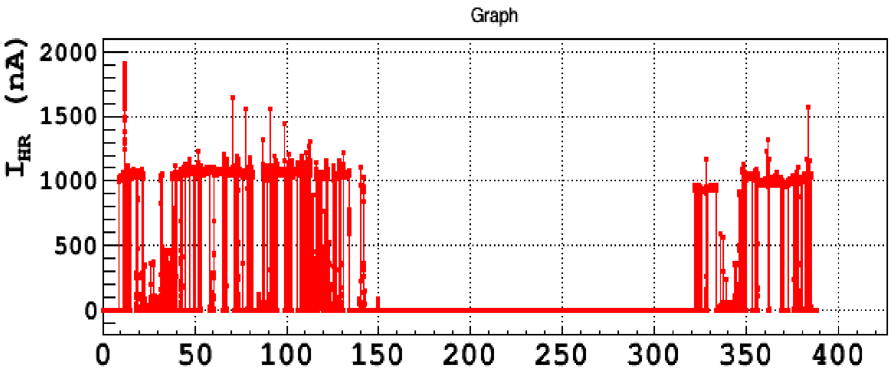
Less evident effects observed for the SG2

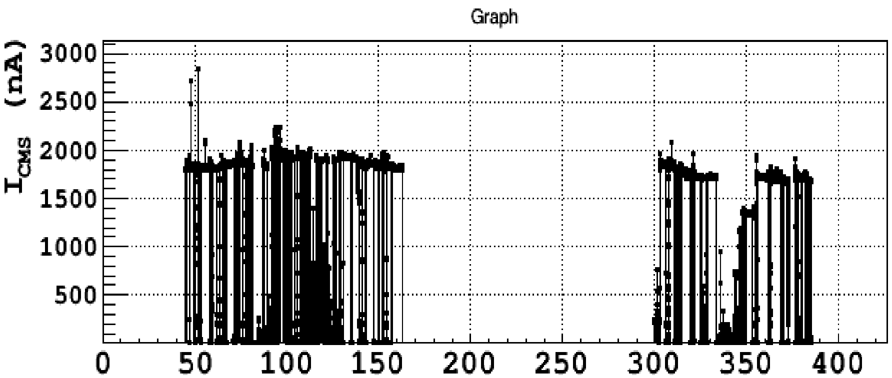
More uniform response expected with the new detector layout SG2++, under production at CERN (by Rui) for which:

- **picth = 12 mm**
- **dead zone = 0,6 mm**
- **geometrical acceptance 95%**

Ageing test at GIF^{++} (II)

Very Preliminary





HR:

- $Ar/CO_2/CF_4$= 45/15/40
- ρ_s ~ 12 MΩ/□
- 100 cm^2
- 200 kHz/cm^2 mip equivalent
- Up-time ~ 1,6x10^7 sec
- N_{spark} ~ 32

P_{spark} ~ 1x10^{-13}

LR:

- Ar/CO_2 = 90/10
- ρ_s ~ 70 MΩ/□
- 380 cm^2
- 130 kHz/cm^2 mip equivalent
- Up-time ~ 1,7x10^7 sec
- N_{spark} ~ 19

P_{spark} ~ 2x10^{-14}

sampling time 1 ms / acquisition rate every 2 seconds

Future DLC Aging/Discharge tests

A systematic **stress study of the DLC** as component of the micro-RWELL **is mandatory:**

In the framework of the RD51-CP (USTC, Kobe, CERN and LNF) we are planning:

- define a stable manufacturing process to deposit **DLC+Cu on APICAL foils, opening the way towards improved HR layouts**
- study possible surface resistivity of DLC changes during the detector manufacturing
- study the DLC stability under long-term irradiation

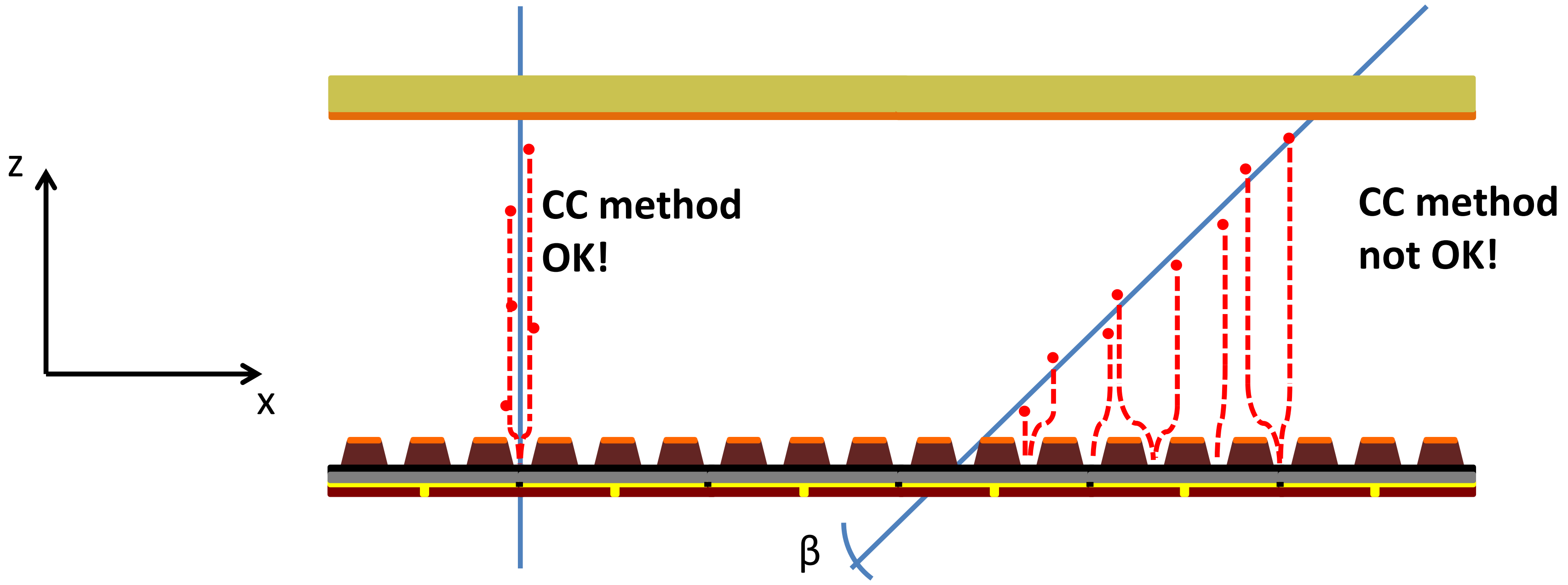
Long-term tests:

- check for **DLC aging effects** due to **current flow** inducing a **high current density, up to 10÷30 nA/cm^2 (@ GIF++ 10 nA/cm^2).**
- **aging test of DLC embedded on detectors** irradiated with different radiation sources: **localized 5.9 keV X-rays, gamma source (660 keV from ^{137}Cs), alpha particles (5.4 MeV from ^{241}Am) or thermal neutrons**

Improving space resolution: the μ-TCP mode

Thanks to the collaboration with BESIII-CGEM, see R. Farinelli 's talk

The use of an analogic front-end allows to associate a hit to a track using the charge centroid (CC) method. The space resolution associated to the hit with this algorithm is dependent on the track angle: minimum for orthogonal tracks and larger as the angle increases .



To improve the space resolution for non-orthogonal tracks the u-TPC algorithm combined with the CC method has been implemented

Improving space resolution: the μ-TCP mode

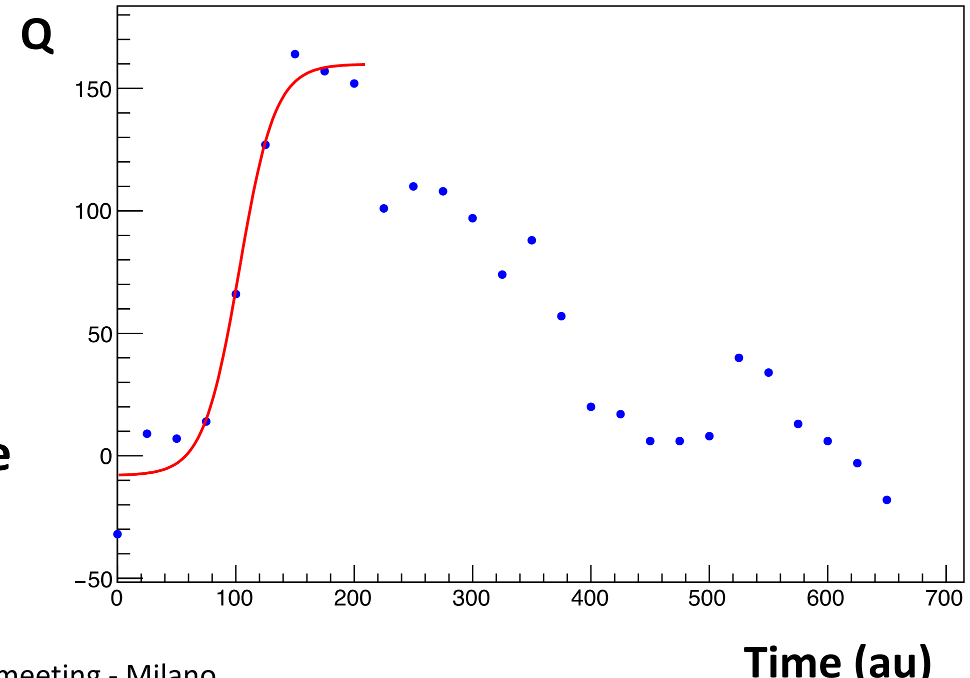
Introduced for **MicroMegas** by **T. Alexopoulos** et al. [NIM **A 617** (2010) 161] it suggests a way to overcome the **poor position reconstruction of the inclined tracks.**

Each **hit is projected inside the conversion gap**, where the ***x* position is given by each strip and the $z = v_d t$**

The drift velocity is provided by the Magboltz libraries.

The **drift time is obtained with a fit of the charge sampled every 25 ns (APV25)** from each FEE channel associated to the strip.

For each event we obtain a set of projected hits that once fitted provide a track segment



Example of µ-TPC reconstruction

Some examples where the tracks have an angle w.r.t. the readout plane

75° tracks

45° tracks