Construction and Stability of the µ-RWELL

Challenges and possible solutions

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LNF – INFN, Frascati, IT [1]
CERN, Meyrin, CH [2]

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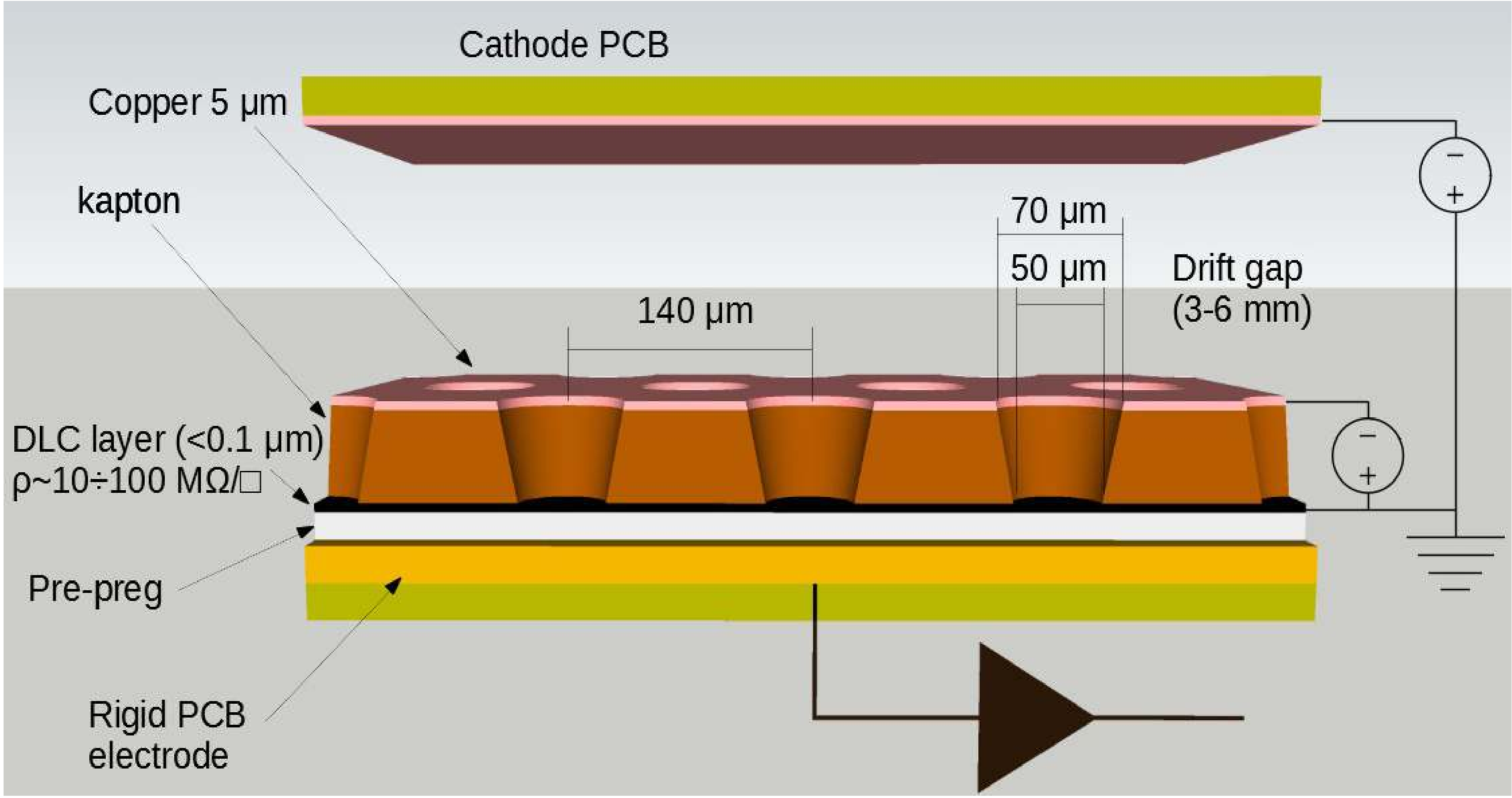
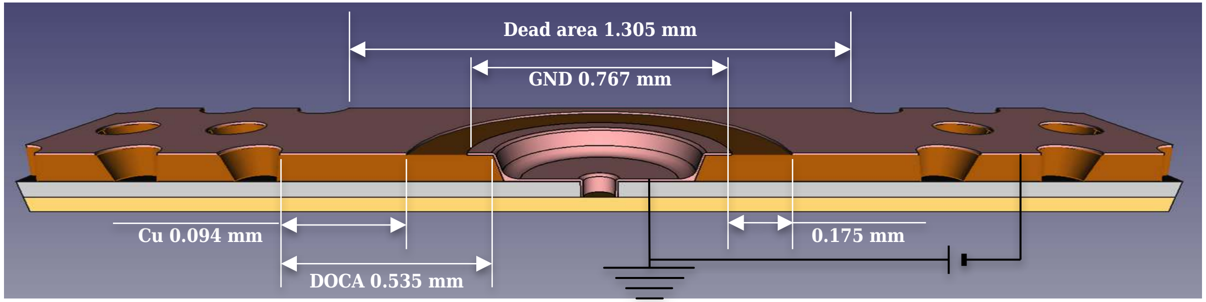
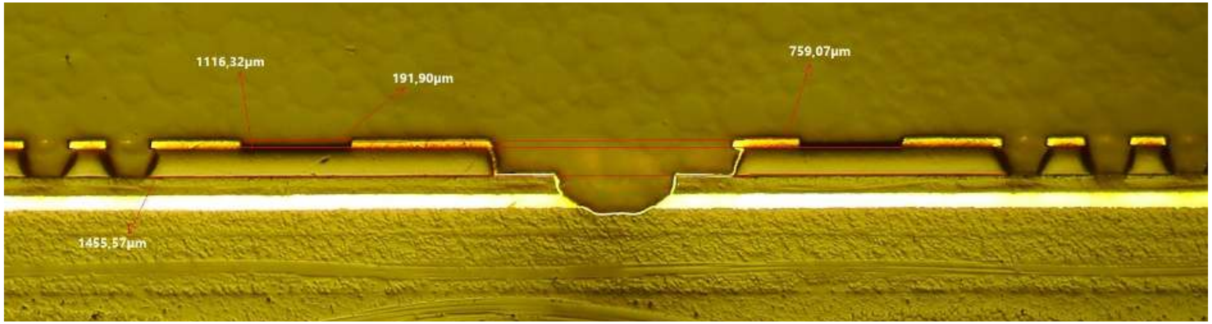
The µ-RWELL


Cathode PCB
Copper 5 µm
kapton
70 µm
50 µm
Drift gap
(3-6 mm)
140 µm
DLC layer (<0.1 µm)
ρ~10÷100 MΩ/□
Pre-preg
Rigid PCB
electrode

The PEP-DOT µ-RWELL

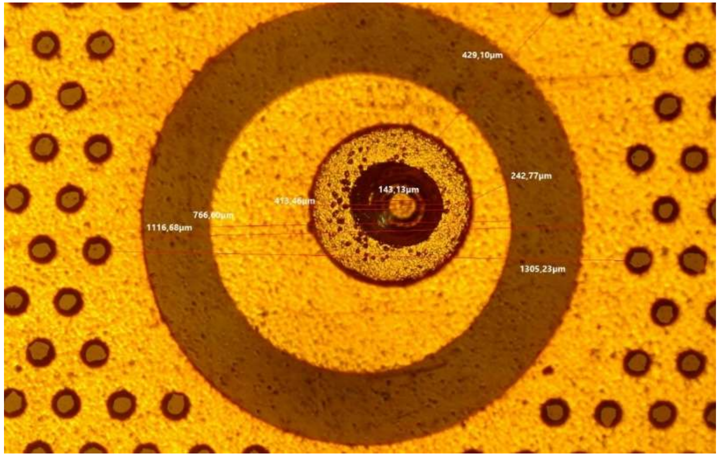
DLC-GND pitch [mm]	Dead Zone [mm]	GND width [mm]	Insulation gap [mm]	DOCA [mm]
9	1.3 (1.6%)	0.767	0.175	0.535





- The most recent high rate layout
  - **P**atterning–**E**tching–**P**lating
- The DLC ground connection is established by creating **metalized vias from the top Cu layer through the DLC**, down to the pad-readout of the PCB
- The dead zone is ~2%

Our main activity is R&D on **high-rate µ-RWELL with pad R/O** for LHCb U2.



Detector warm up and operation

Initial power-up procedure:

At CERN, detectors undergo the Electrical Cleaning, a conditioning procedure at a temperature of 90°C where the HV is increased step by step from 100 V up to 680 V, essentially without current limitation.
This procedure allows for curing potential manufacturing defects by exploiting the current draw. Critical areas are deactivated by burning the thin layer of DLC at defect sites **(Rui will surely show some photos).**

Detectors are closed with their cathode at CERN and then delivered.

At LNF, an initial power-up procedure is followed according to the following steps:
- Test with a MEGGER up to 500V
- Flushing with the gas mixture at 100 cc/min for approximately 24-48 hours (depending on detector size) monitoring the humidity (ppm or %)
- Ramp-up of the HV: 100, 200, 300, 400, 450, 500, 520, ... 660 V
- Measuring gas gain with X-ray
- Readout test with APV with X-ray (using internal trigger)

<u>See spare for additional info on both the Megger test and the first operation</u>

Some critical construction aspects

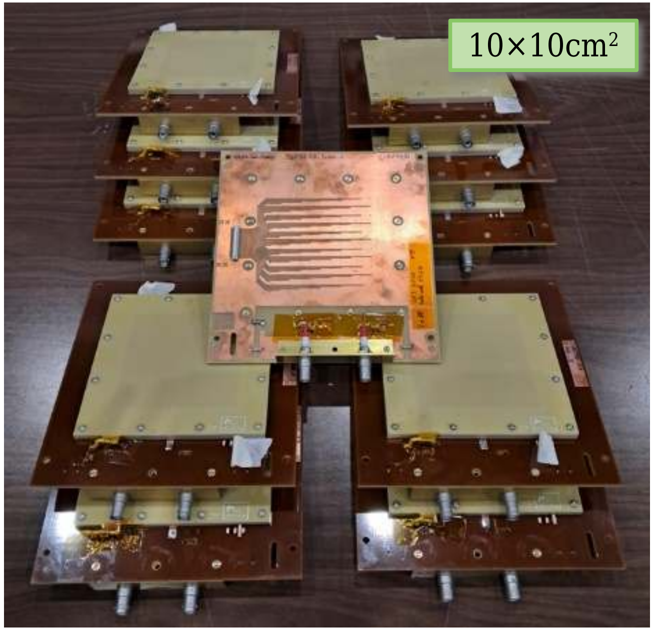
The **main parameters** of the detector, crucial **for stable and efficient operation**, are:

- The **resistivity of the DLC**, which is closely related to the quenching of the discharge amplitude.
- The **DOCA** (Distance of Closest Approach): the distance between conductive grounding elements of the DLC and the nearest amplification region (the wells of the amplification stage). This parameter is related to the DLC resistivity. **Optimizing this parameter ensures the safe operation of the detector.**
- The **distance between the DLC and the readout stage** (pads or strips), coinciding with the **prepreg thickness**, which determines the amplitude of the charge induced on the readout**. By maximizing this charge, the detector can operate at a low gas gain**, increasing the stability of the detector.

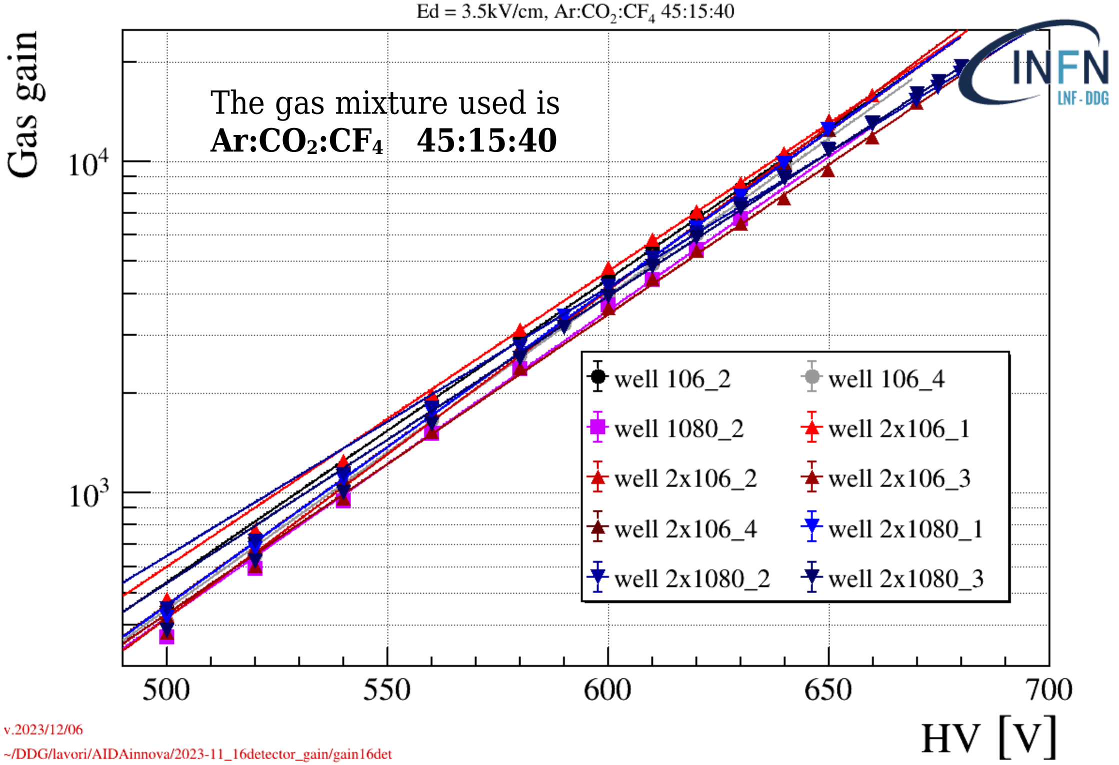
Further possible improvement of the detector stability can be done **optimizing the amplification stage** by **reducing the well pitch: 140µm, 110µm, 90µm** (work in progress)

Other important construction aspects include the **choice of materials**, such as using **PEEK instead of FR4** for frames, thus **minimizing hygroscopic and outgassing materials.** Since the base material for the cathode **must be made of FR4**, we have recently produced cathodes where **copper covers the entire surface facing the active area**, up to the inner edge of the PEEK frame.

Co-production pilot test – results



- **16** co-produced protos have been **produceded**
- **15/16 are fine → 94% yield**
- 1 should be re-cleaned



- Characterized with **X-ray gun → Gas gain** measurement
- **Next** step: measure of the **pulse amplitude** (APV25) vs Gas gain

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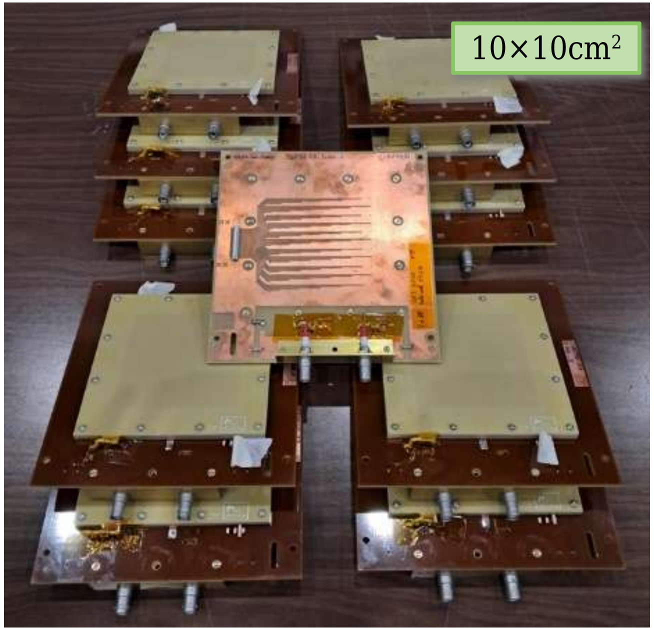

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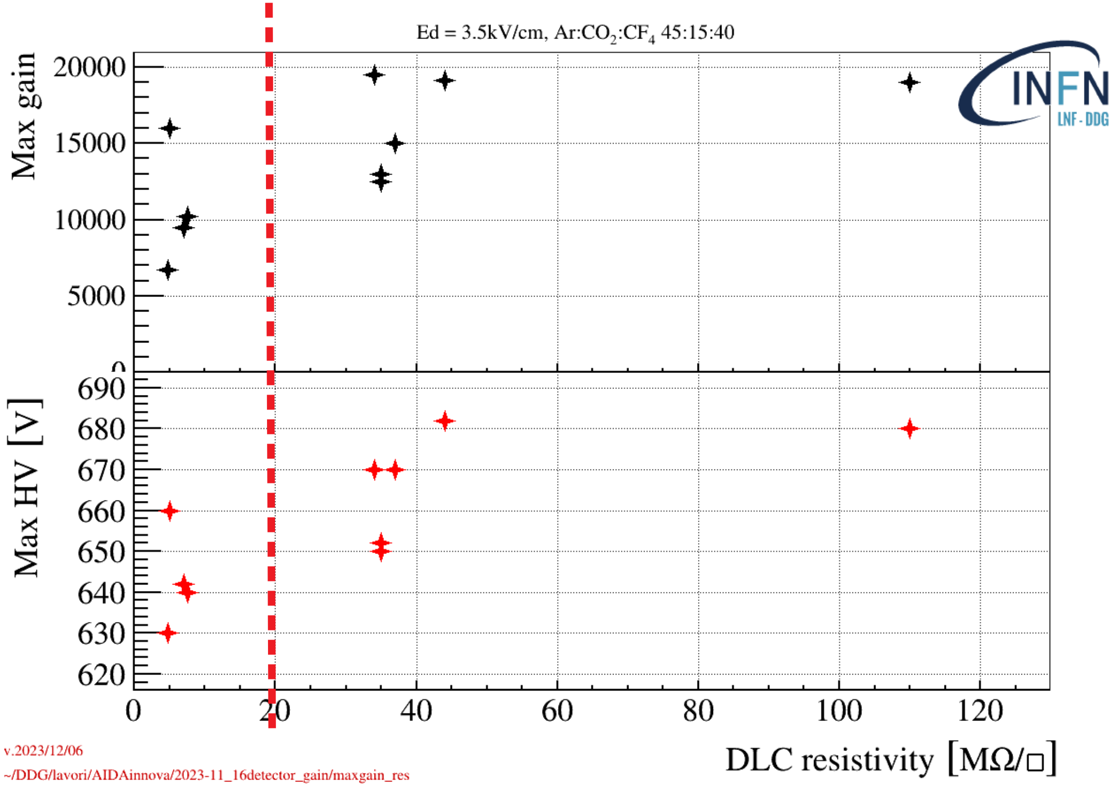

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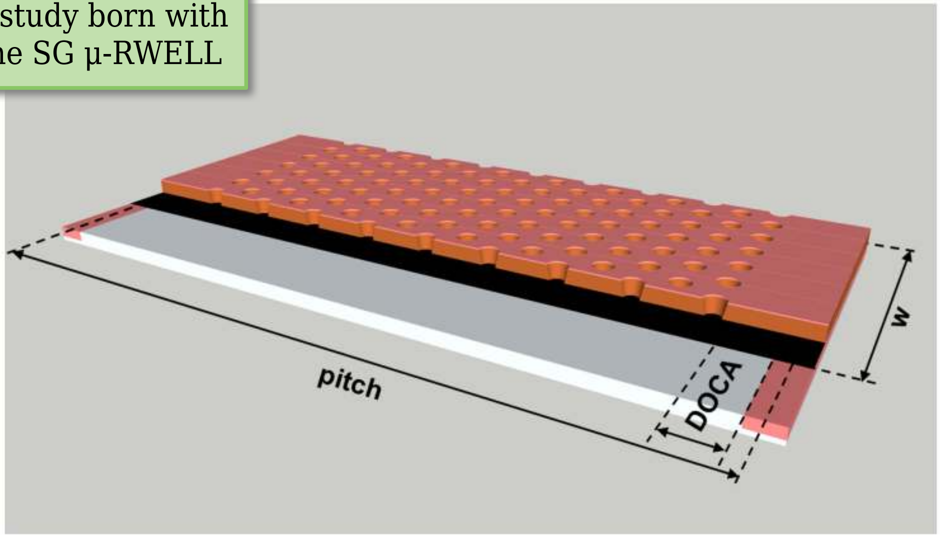
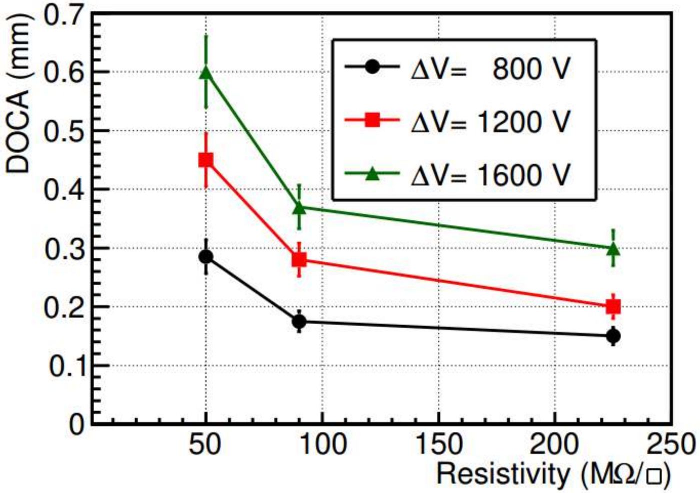
The DOCA

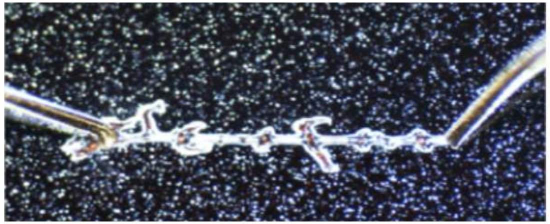
A study born with the SG µ-RWELL



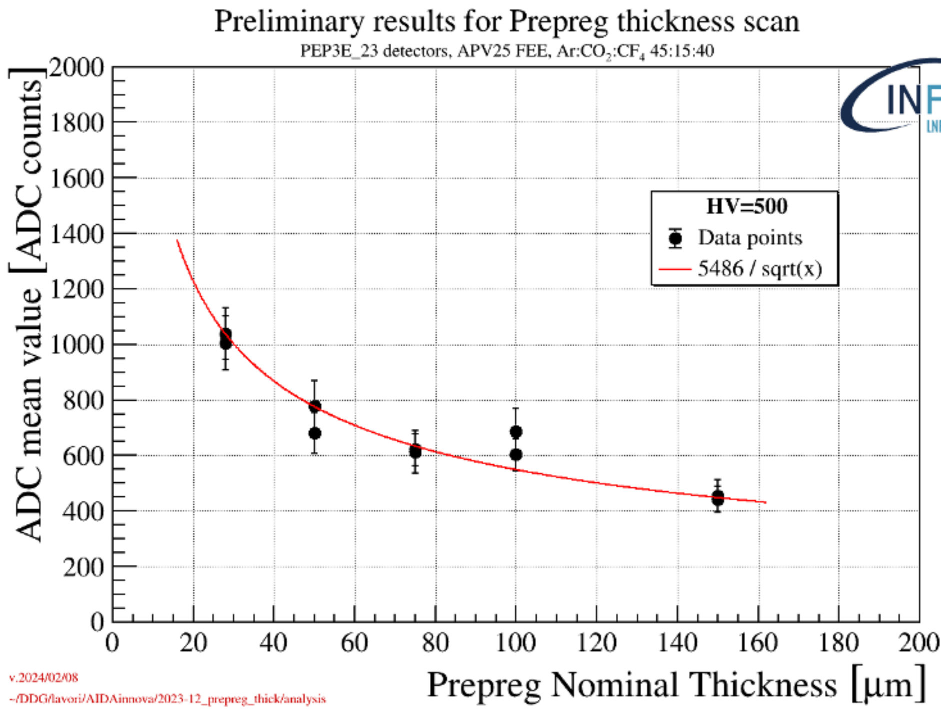
Cross-section of a µ-RWELL with a conductive line on the DLC (High-Rate scheme).
The concept of **DOCA** (Distance-Of-Closest-Approach) before discharge is fundamental for the **stability** of the detector.
The **DOCA** is defined as the **distance between** the edges of the **conductive lines** and its **closest amplification hole**.

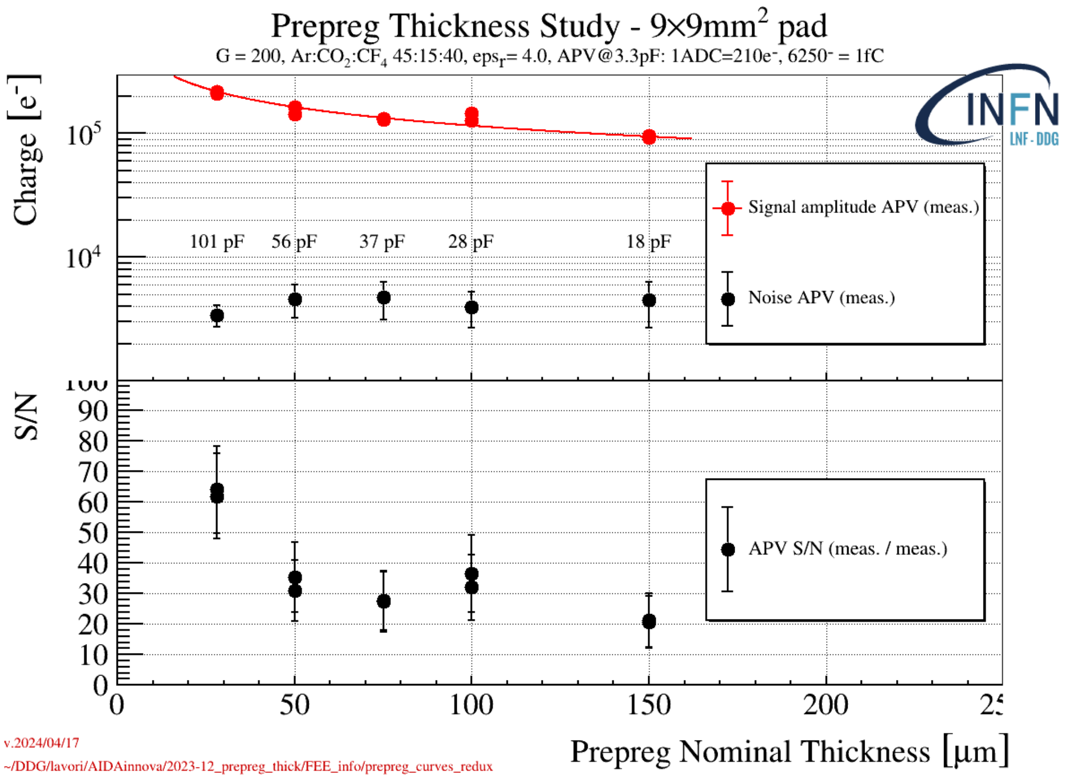


The **DOCA (before discharge)** as a function of the DLC **resistivity**, for different **voltages**.
The study has been performed with a custom tool, with two thin conductive movable tips.



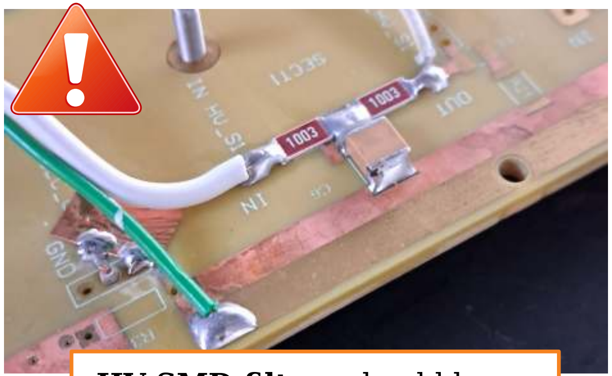
Prepreg thickness optimization



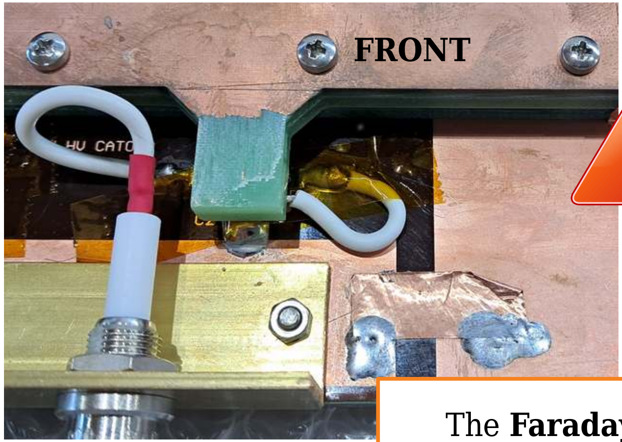


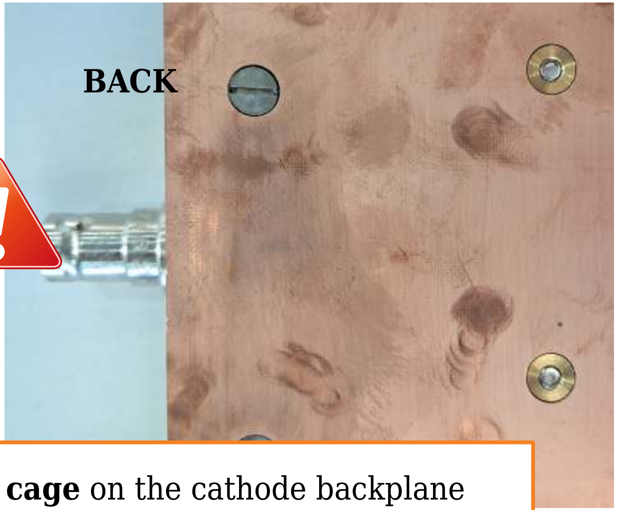
28μm thick prepreg maximize both the **amplitude of the signa**l induced on the pad readout, and **S/N ratio** (measurement done with APV25)

Two design good habits



HV SMD filters should be on external board and not on kapton (FR4 is even worse) → possible leakage currents



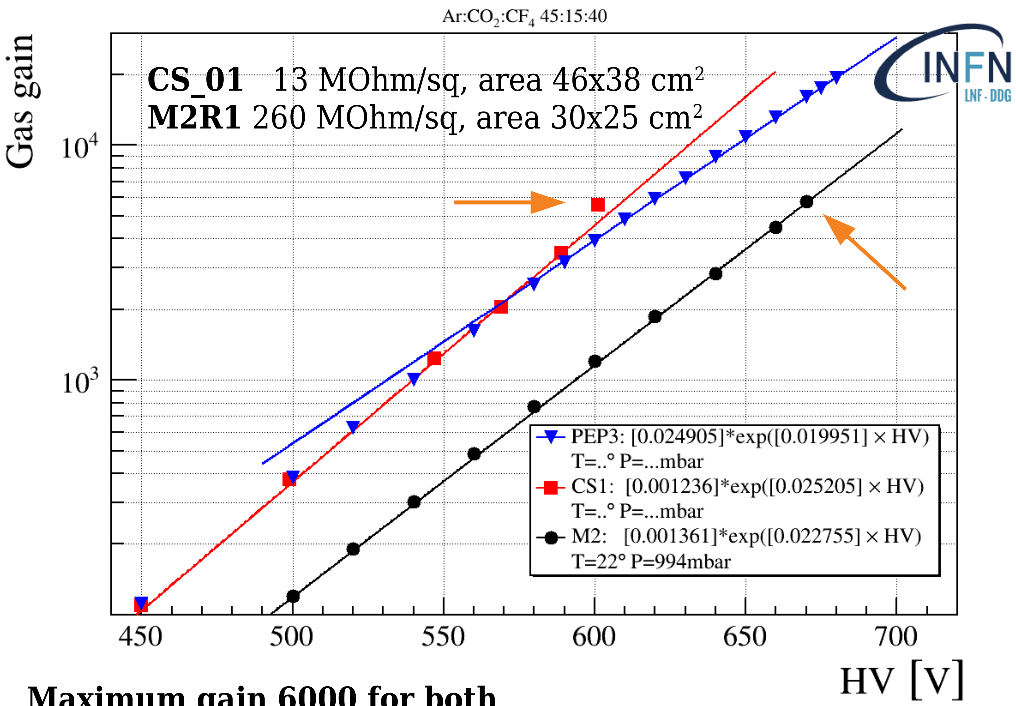


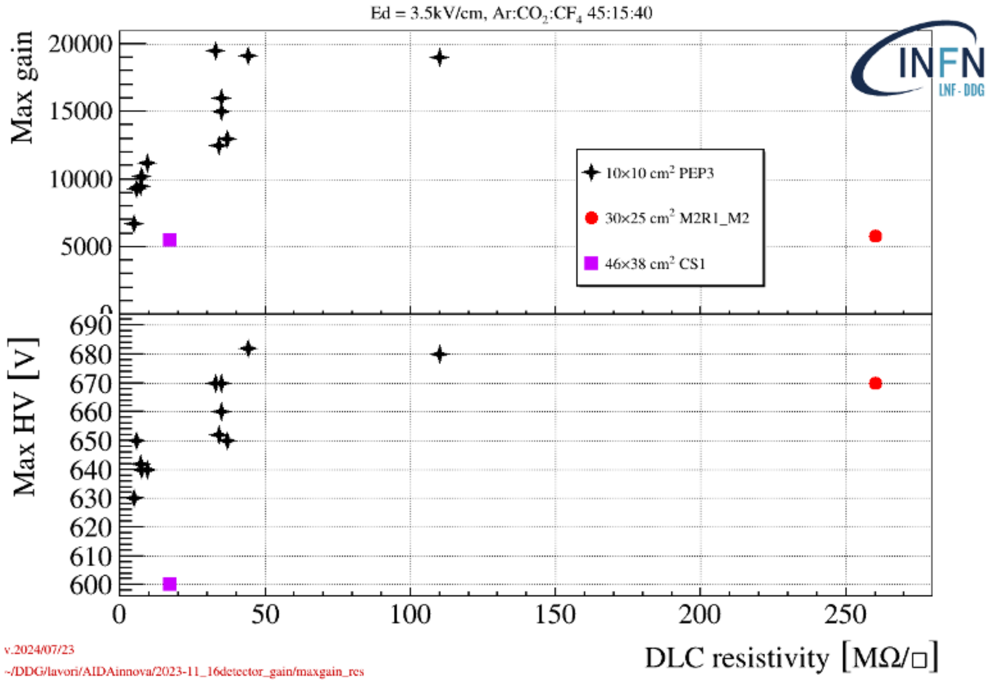
The **Faraday cage** on the cathode backplane should have rims around the bolts passing through the frame. Such bolts could be very close to the HV traces → possible leakage currents or discharges

Detector washing and electrical cleaning @ LNF

At LNF, we are installing a **detector washing station** with a stainless-steel tank and a high-pressure car-washing machine using deionized water.
After washing, the detector is placed in an **oven at 90°C**. After 24 hours, it is gradually powered by increasing voltage from 300V to 680V, following Rui's guidelines.

OPEN POINTS – maximum gas gain for the last production





Maximum gain 6000 for both
- hypothesis: CS_01 not stable due to the resistivity
- M2R1 → to be investigated

HV shift for M2R1 (50V)
- hypothesis: Kapton overetching

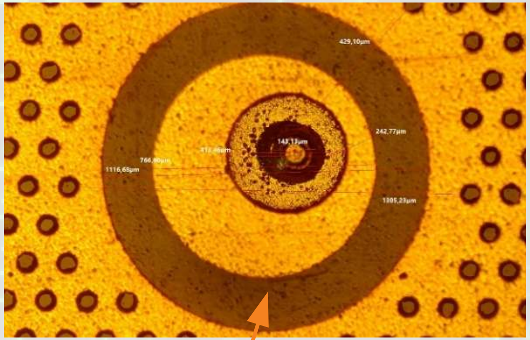
These issues with low-gain detectors could be strongly correlated with the use of **low-resistivity DLC** as well as **inadequate etching** chemistry of the Kapton: it is necessary to rigorously **standardize all manufacturing steps and the choice of components (DLC).**

OPEN POINTS – SG reloaded

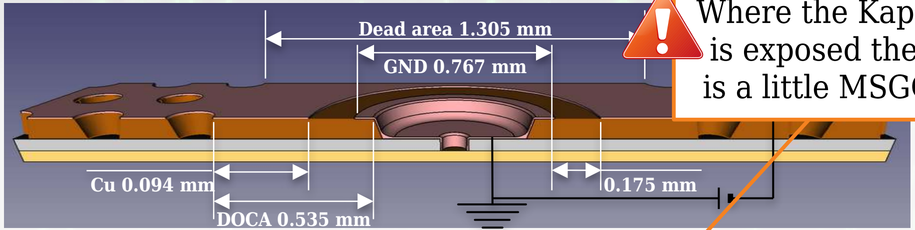
Focusing on the detector design for the LHCb experiment, **the layout currently in use is the PEP-DOT**.
From the recent positive results on the sputtering of DLC+Cu, we would like to **reconsider the use of the SG layout:** we think that from a manufacturing perspective, the SG layout could be simpler and more stable than the PEP (to be discussed with Rui).

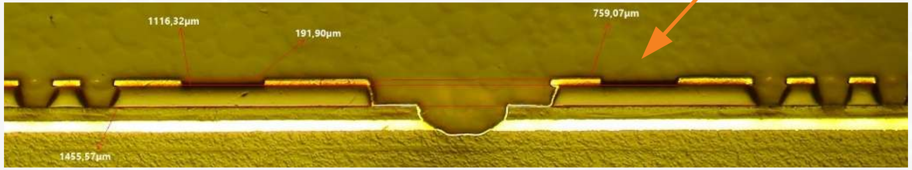
PEP-DOT

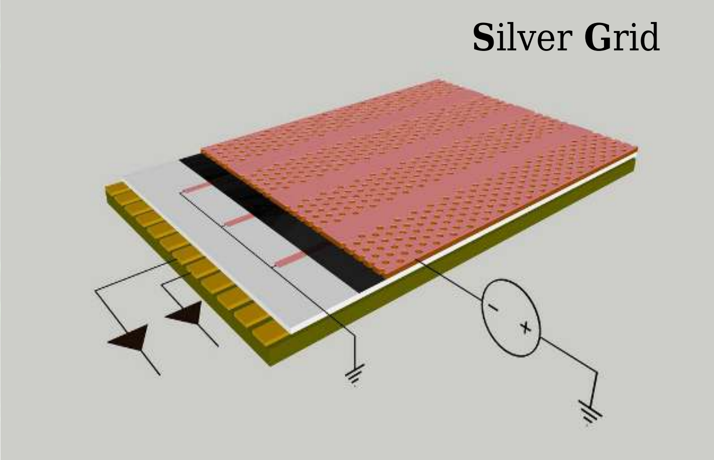
DLC grounding through conductive dots connecting the DLC with pad r/o
Pad R/O = 9×9mm^2
Dot pitch = 9mm
Dot rim = 1.3mm
DOCA = 0.5 – 0.6mm
ρ ≥ 50 Mohm/sq



Where the Kapton is exposed there is a little MSGC!!







Single DLC layer

2-D current evacuation: conductive grid on the DLC layer
Grid pitch 9mm
DOCA = 0.6mm
ρ ≥ 50 Mohm/sq
NO plating
NO Kapton exposure on the active area
NO ground element in the active area (NO MSGC effect)

Summary

CERN: µ-RWELL production + electrical cleaning
LNF: quality control w/ X-ray - gas gain measure + R/O control with APV25
in case of minor problems -> whashing station + oven

A great effort in R&D has been made in recent years. We are confident that we can set many of the detector's parameters to maximize its stability.

Detector parameters have been set to **maximize stability and gain**:
- **ρ_S > 50 MOhm/sq.** (taking into account 30% uniformity during sputtering)
- **DOCA** depending on ρ_S, **O(500µm)**
- **prepreg thickness 28µm** (depending on the FEE)
- (w.i.p.) ampl. stage optimization → protos under production

Detector materials optimization:
- **PEEK instead of FR4** whenever possible (e.g. frames) to minimize hygroscopic materials
- copper cathode closer as possible to the frame to minimize exposed FR4 in the active area
- metallic bolt: patterned faraday cage
- **HV filter NOT onboard** (passable for R&D, not suitable for experiment production)

Detector production:
- **Standardizing** the production processes, including the **etching chemistry** and the selection of **parameters and materials**, is crucial because it ensures consistent quality, enhances reliability, and maximizes stability.
- **high rate** layout: The **PEP layout provides excellent results**, but the **SG layout**, already successfully characterized in terms of stability and high-rate performance, is likely to be **simpler and more reliable from a manufacturing process perspective** (less manufacturing steps, no exposed kapton, no ground electrodes in the active area, no plating holes yield)

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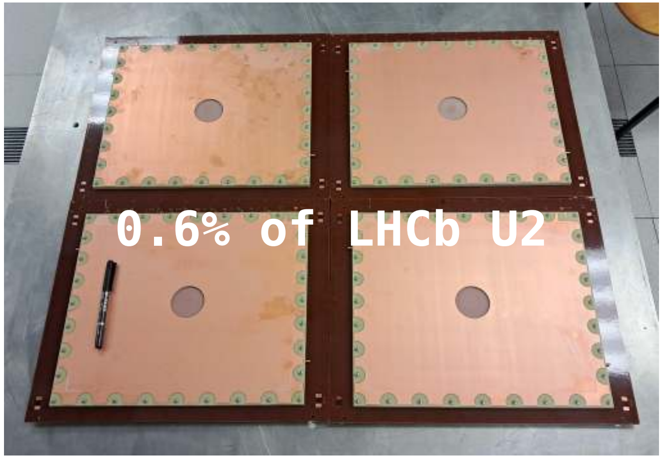

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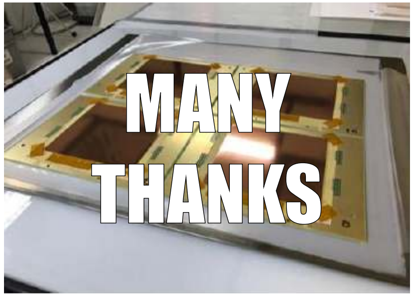

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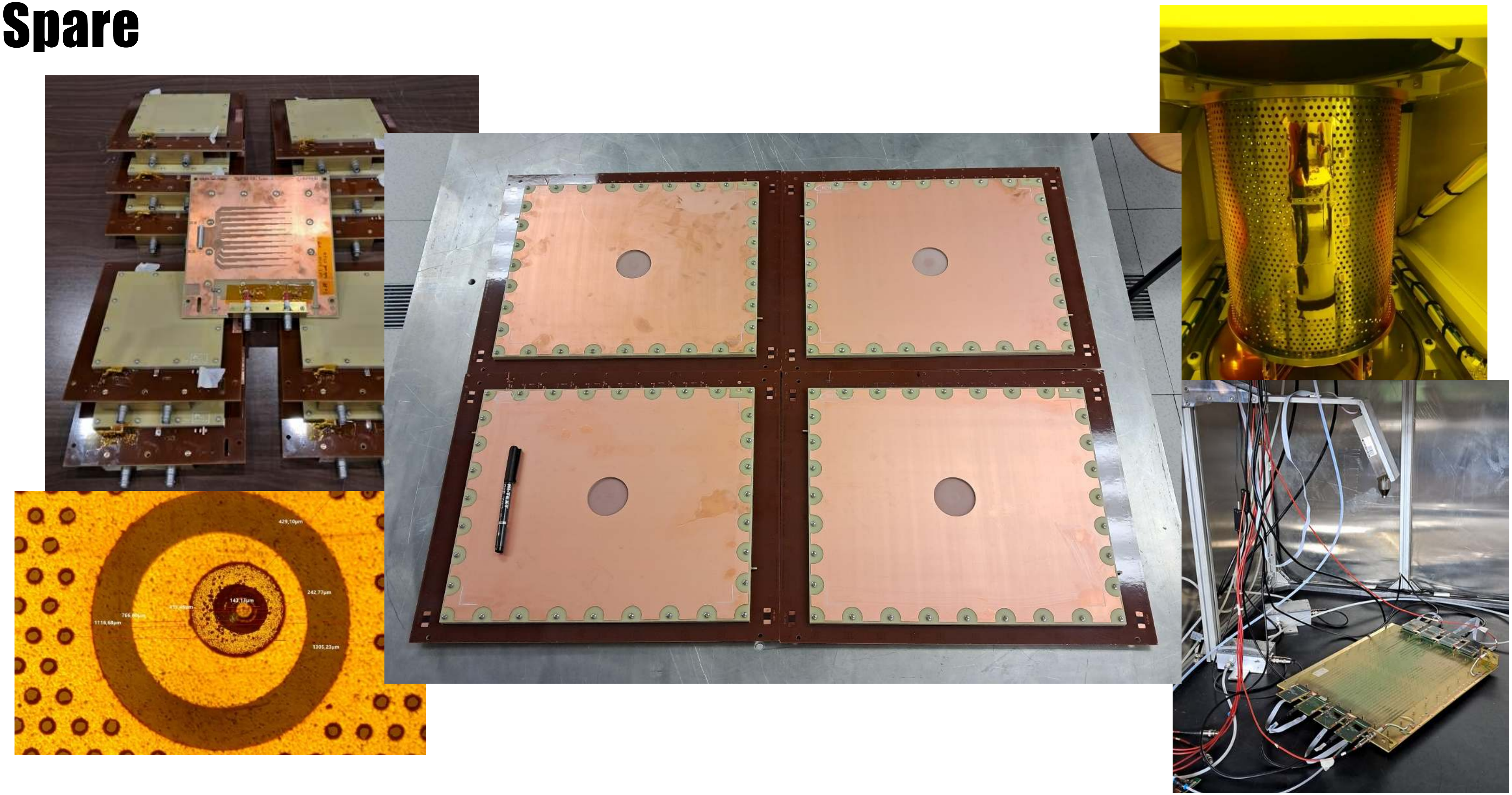
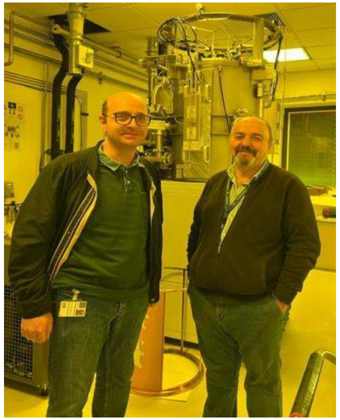
Spare



DLC Sputtering



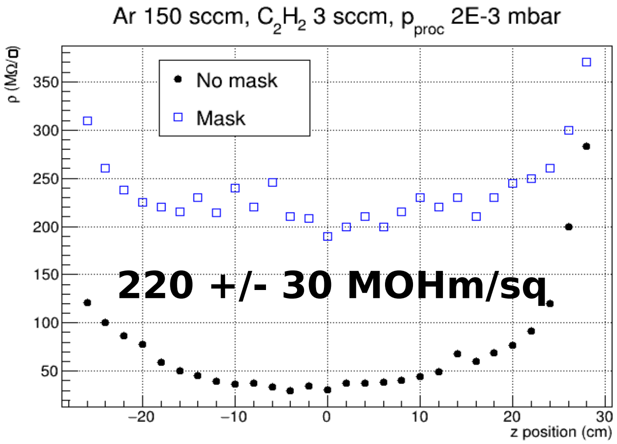
The **CID** (CERN-INFN-DLC) sputtering machine, a **joint project between CERN and INFN**, is used for preparing the **base material of the detector**. The potential of the DLC sputtering machine is:

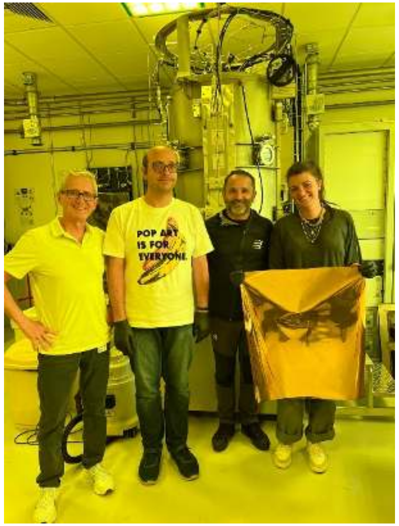
- **Flexible substrates** up to **1.7×0.6m2**
- **Rigid substrates** up to **0.2×0.6m2**

In **2023,** the activity on CID focused on the **tuning** of the **machine on small foils: good** results in terms of **reproducibility and uniformity.**

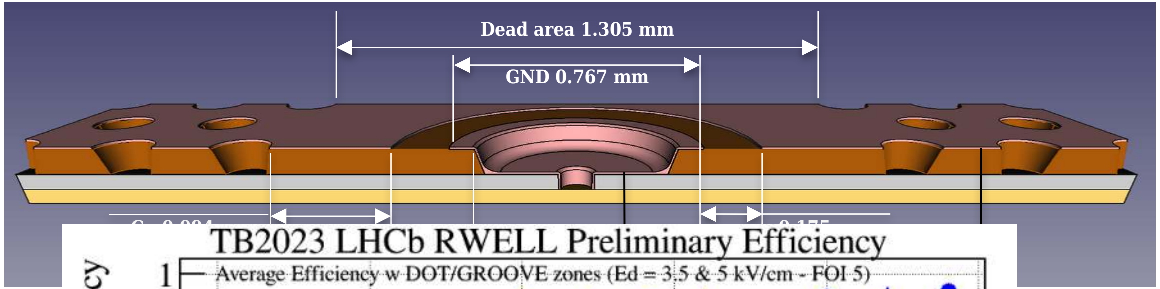
In **2024**, the challenge is the **sputtering of large foils:**

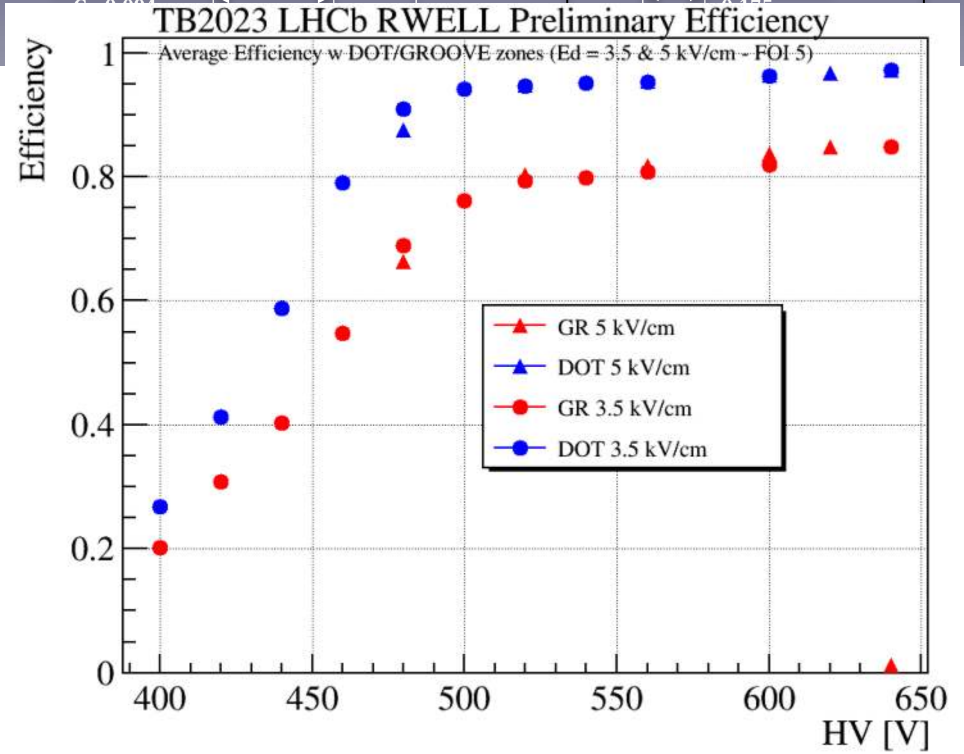
- **DLC+Cu sputtering on 0.8×0.6m2 successfully done (May/June 2024)**
- **DLC on 1.7×0.6m2 large 0/50/0 Apical foils successfully done (June 2024)**
- **DLC on 1.7×0.6m2 large 5/50/0 Apical foils still to be done (July 2024)**

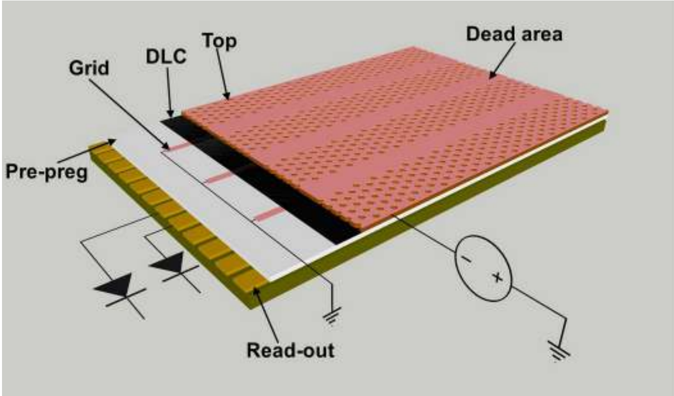


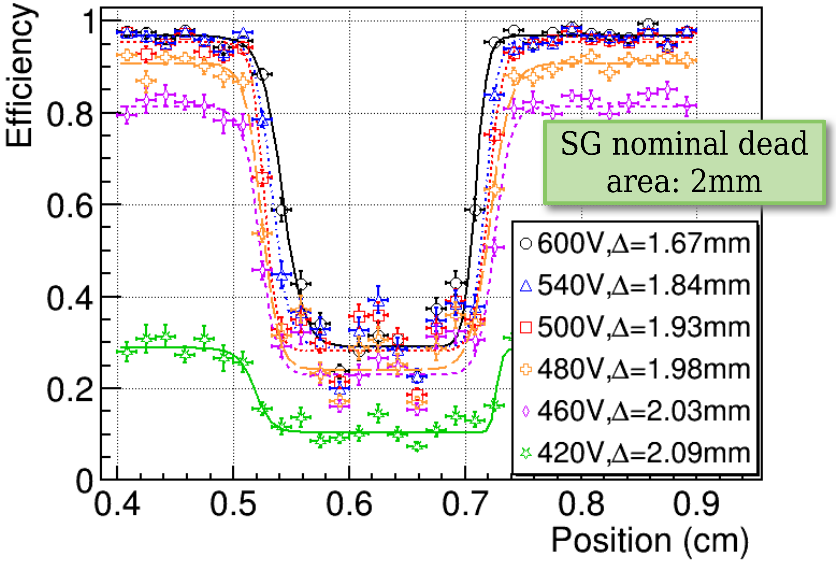


Dead Zone: PEP vs SG

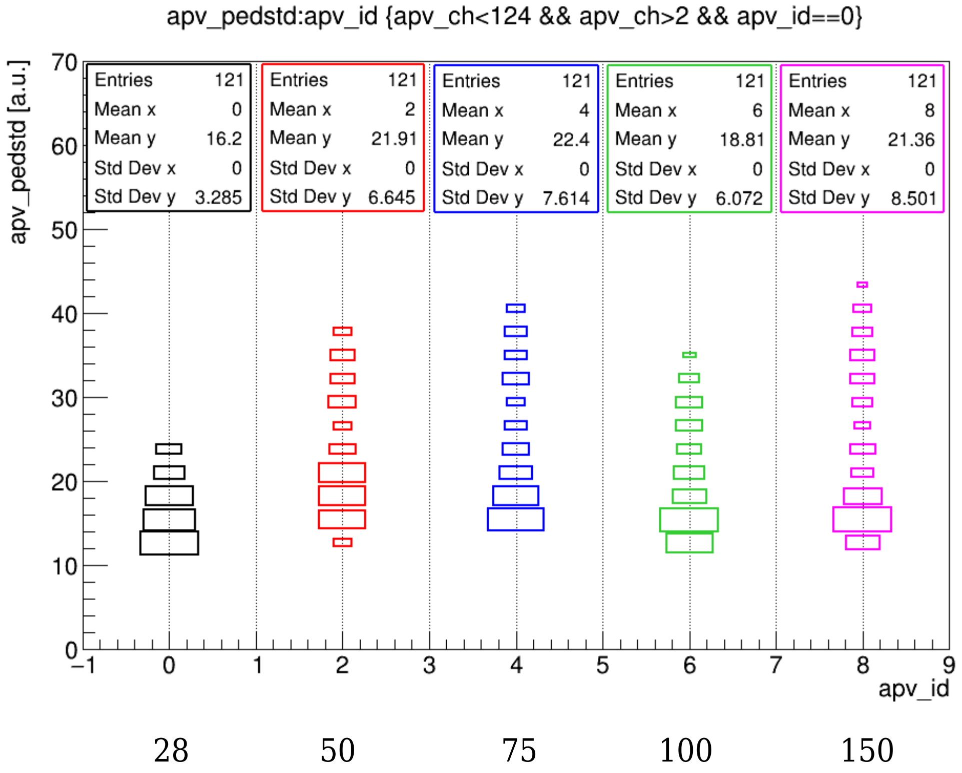


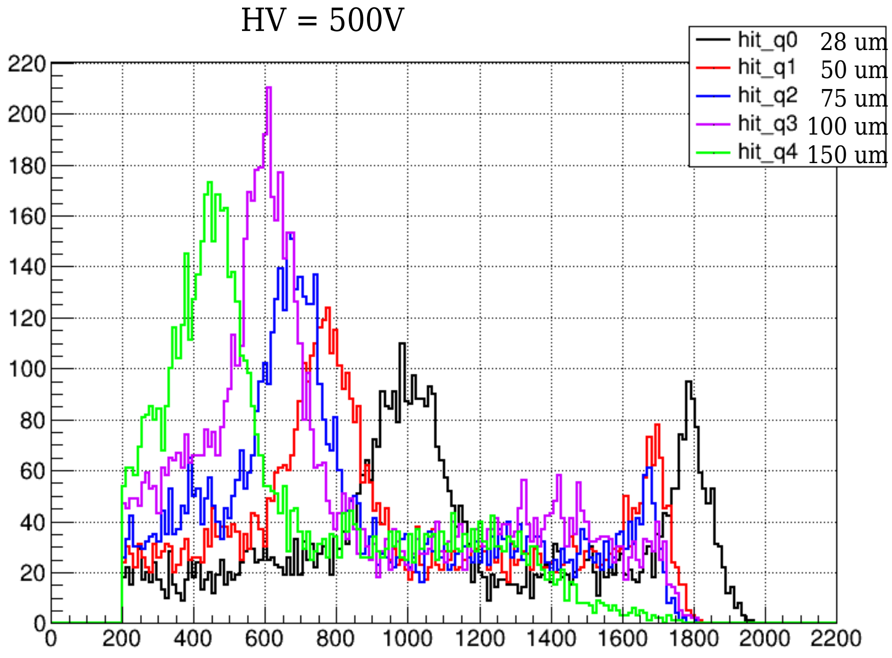




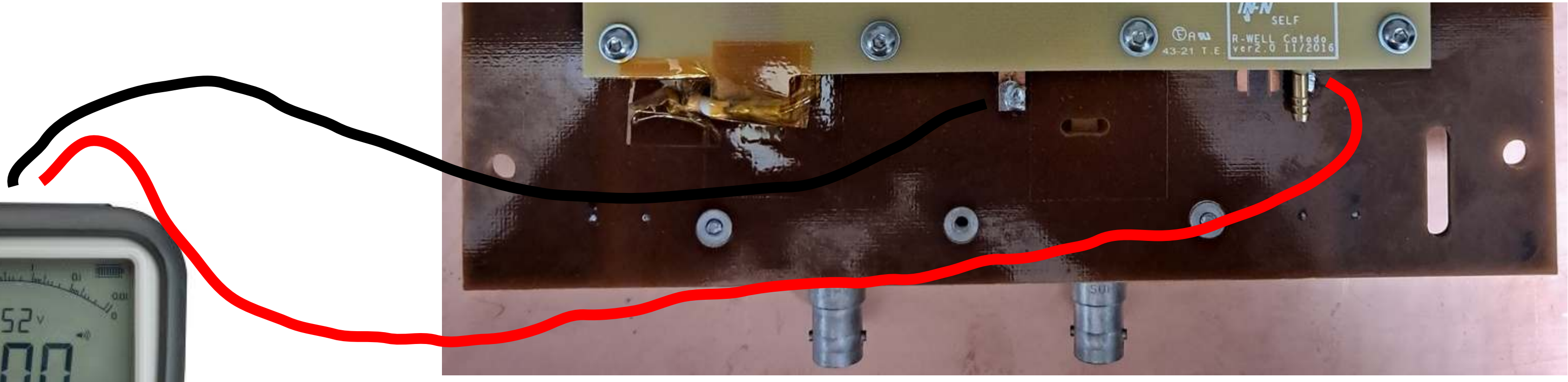


Prepreg thickness scan – noise + spectrum





Megger Quality control



MEGGER MIT420
Insulator tester

- A first quality control can be done measuring the insulation between the DLC and the TOP electrode. The resistance should be in principle infinite because the two electrodes are not connected.
- The test should be done with the **right polarisation** of the detector: during operation the TOP has a voltage hundreds of volts lower than the DLC.
  - Check that the R/O is grounded (see previous slide)
  - Connect the **RED probe to the DLC** trough one of the GROUND access
  - Connect the **BLACK probe to the TOP** electrode.
    - in the picture for example both connections are made on top of the PCB
- Start the test with 50V, waiting for it to reach >10GΩ.
  - Repeat for 100, 250, 500V. A good detector should reach **>100GΩ @ 500V**.
    - Sometimes the 500V step is slow so it is suggested to wait at least 10-20s before declaring the presence of a problem.
  - **Don’t use 1kV**: the voltage is too high and can damage the detector
- The ramp-up of the measure should last some seconds. If the GΩ limit is reached too fast it can be an hint of a bad connection of the probe (bad mechanical contact or an oxidised surface).

Power on the detector – cosmic rays

STEP 1 – the gas

- flux the gas at least 2 hours with **100 cc/min** (6 L/h), to ensure that all the volume is filled with the right gas mixture.
- it is strongly recommended to monitor the humidity inside the detector (with a humidity probe on the output gas line). We suggest a value below **500ppmv**.

STEP 2 – setting the HV (all information given w/ **$Ar:CO_2:CF_4$ 45:15:40** gas mixture as reference)

- Top electrode (TOP) and Cathode electrode (CAT) HV are NEGATIVE so absolute values will be reported
- As a safety measure set the limit for the maximum HV for the TOP: it should not go above 650V.
- The **TOP** channel should have at least a **1nA current resolution**, in order to detect possible instabilities.
- the CAT depends on the desired drift field. A value of 3.5kV/cm is suggested: for a 6mm gas gap it means that the CAT should be larger than the TOP by 2100V.
- Set:
  - RAMP-UP of 10 V/s for the TOP, of 100 V/s for the CAT. RAMP-DW of 200 V/s for both.
  - Trip: **2μA current limit** and **10s trip time** for both electrodes.
    - The TOP current during the ramp-up shouldn't be higher than 2μA. If it's not the case, increase the current limit only during the ramp-up and then set again the safe current limit.

STEP 3 – Powering up

- Set both the TOP and the CAT at **50V** in order to see the presence of possible problems. The current drawn by both should be lower than **1nA**.
- Set the CAT to the final HV value.
- Increase the TOP to **[100, 200, 300, 400]V**. Wait that the current will **drop below 2nA** before increasing the HV.
- Increase the TOP with fine steps: **[450,500,520,540,560,570,580,590,600]V**, waiting for the current to drop every time.

Spot Effect for SRL – Manufacturer plot

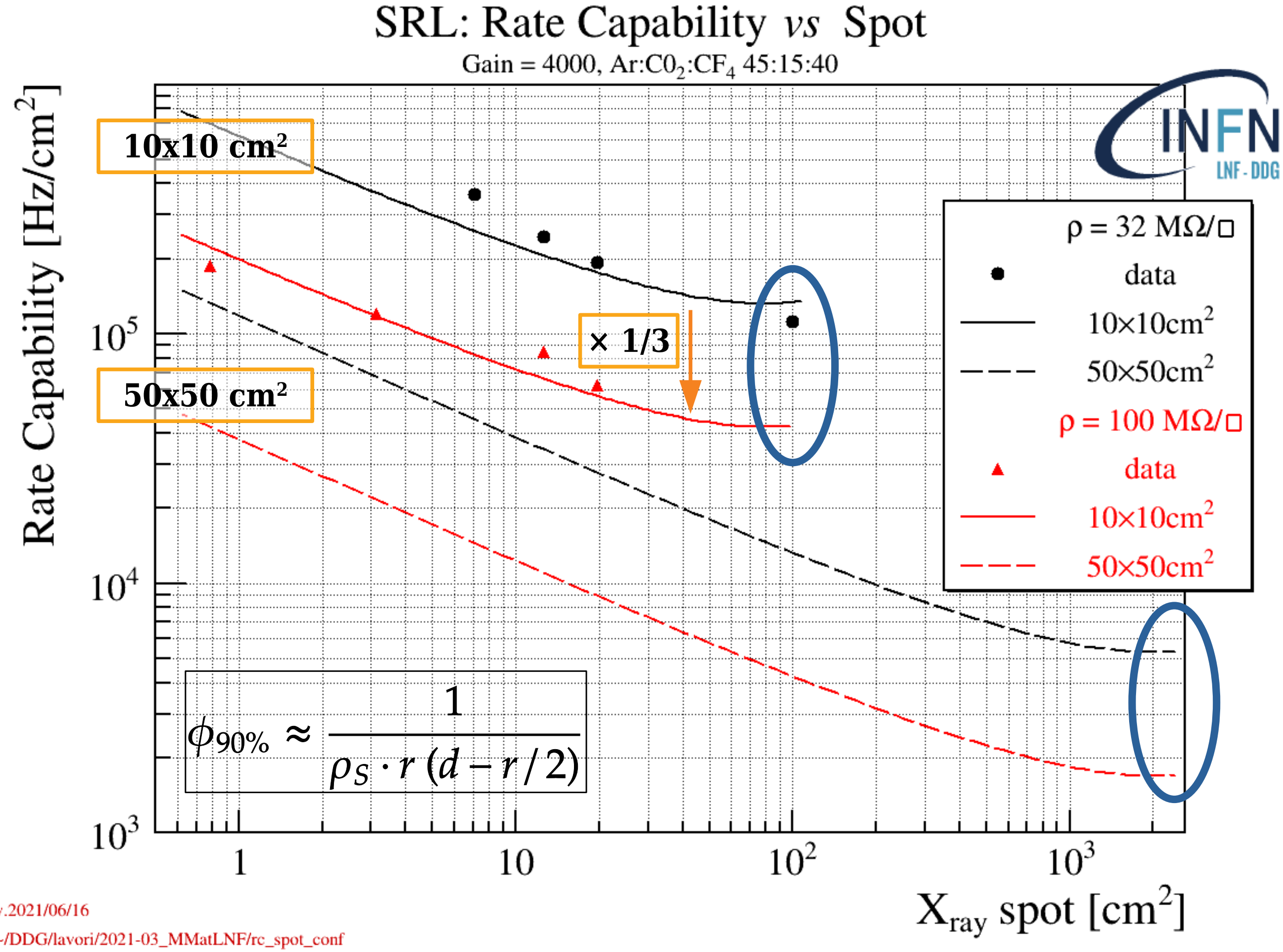
From the mathematical model:

1. detectors with same size but **different resistivity** exhibit a rate capability scaling as the inverse of their resistivity: **× 1/3**

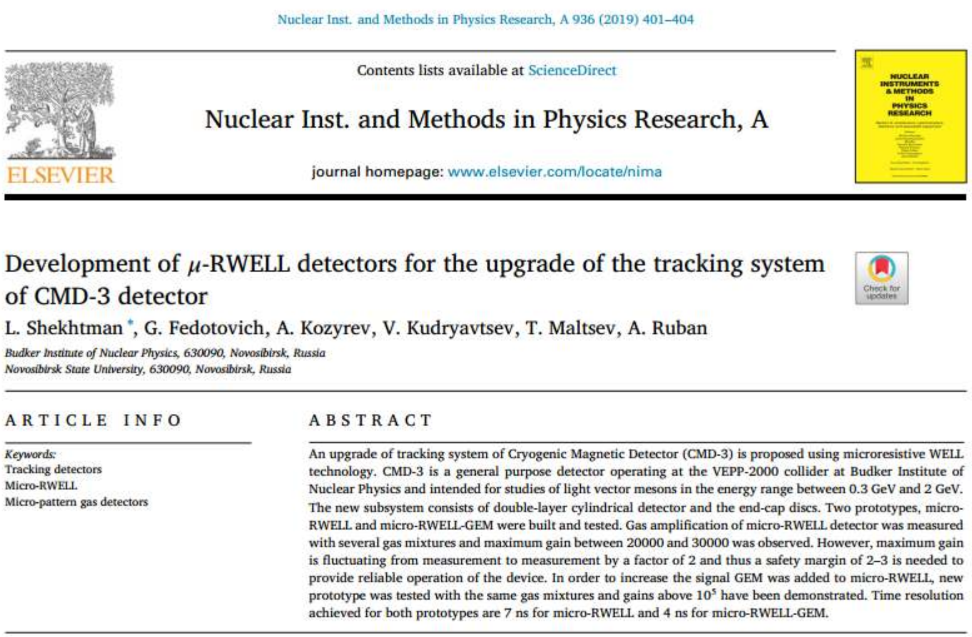
2. for the SRL, **increasing the active area** from 10×10 cm² to 50×50 cm² the rate capability should go down to few kHz/cm²

3. thus using a DLC **ground sectoring** every 10/20/30 cm, detectors could achieve rate capability up to 100kHz/cm² (with X-ray)

! **Different primary ionization ⇒ Rate Cap.$_{m.i.p.}$ = 3×Rate Cap.$_{X\text{-}ray}$**



µ-RWELL + GEM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Development of μ-RWELL detectors for the upgrade of the tracking system of CMD-3 detector

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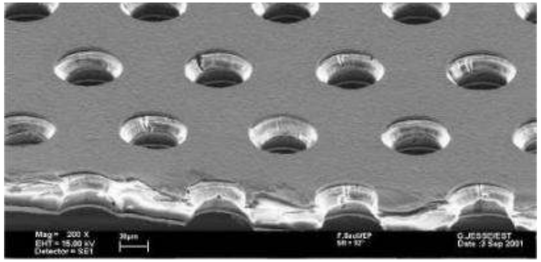
Micro-RWELL
Micro-pattern gas detectors

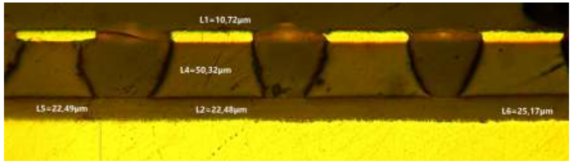
ABSTRACT

An upgrade of tracking system of Cryogenic Magnetic Detector (CMD-3) is proposed using microresistive WELL technology. CMD-3 is a general purpose detector operating at the VEPP-2000 collider at Budker Institute of Nuclear Physics and intended for studies of light vector mesons in the energy range between 0.3 GeV and 2 GeV. The new subsystem consists of double-layer cylindrical detector and the end-cap discs. Two prototypes, micro-RWELL and micro-RWELL-GEM were built and tested. Gas amplification of micro-RWELL detector was measured with several gas mixtures and maximum gain between 20000 and 30000 was observed. However, maximum gain is fluctuating from measurement to measurement by a factor of 2 and thus a safety margin of 2–3 is needed to provide reliable operation of the device. In order to increase the signal GEM was added to micro-RWELL, new prototype was tested with the same gas mixtures and gains above 10^5 have been demonstrated. Time resolution achieved for both prototypes are 7 ns for micro-RWELL and 4 ns for micro-RWELL-GEM.

Drift Gap: Shekhtman **3mm** – LNF+Roma2 **6mm**



Transfer Gap: Shekhtman **3mm** – LNF+Roma2 **3mm**



Suitable for CMD3 upgrade disks (4 sectors 50×50cm^2)

The GEM **must be** stretched: sizes larger than 50×50cm^2 could be critical (depending on the gas gaps size).

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μ-RWELL + GEM – Gain

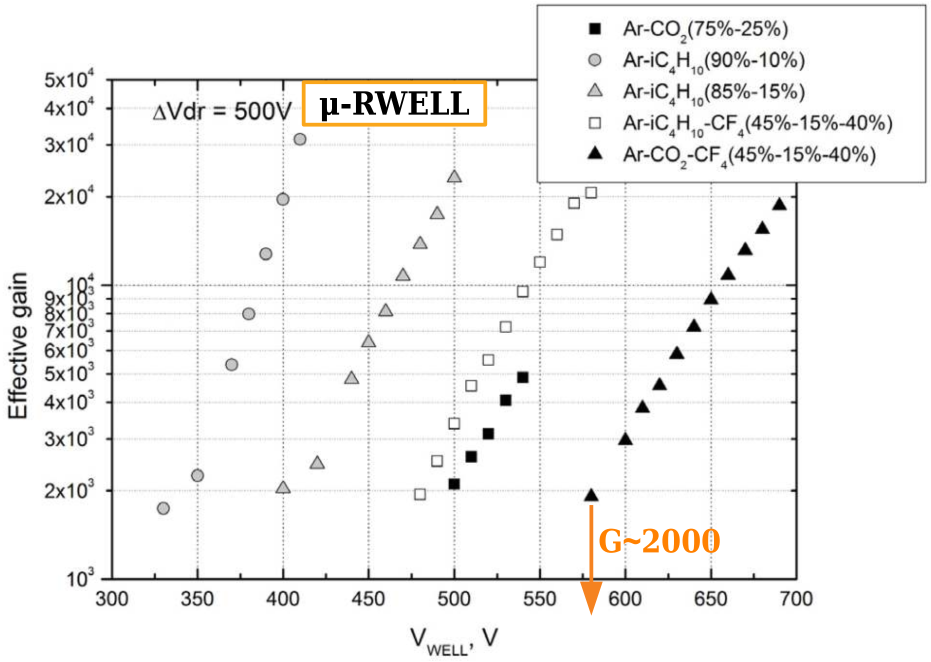

Fig. 4. Gain as a function of voltage on the top electrode of μ-RWELL for different gas mixtures. Voltage across the drift gap is 500 V.

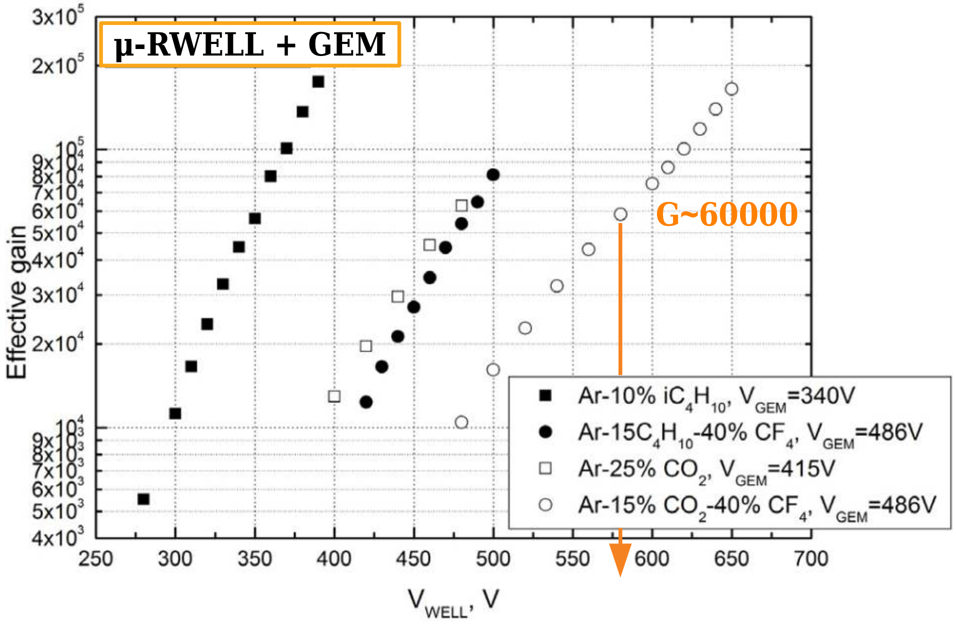

Fig. 5. Gain as a function of voltage on the top electrode of μ-RWELL for GEM voltages providing additional gain of 50–100 and for different gas mixtures. Voltage across the drift gap is 500 V.

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