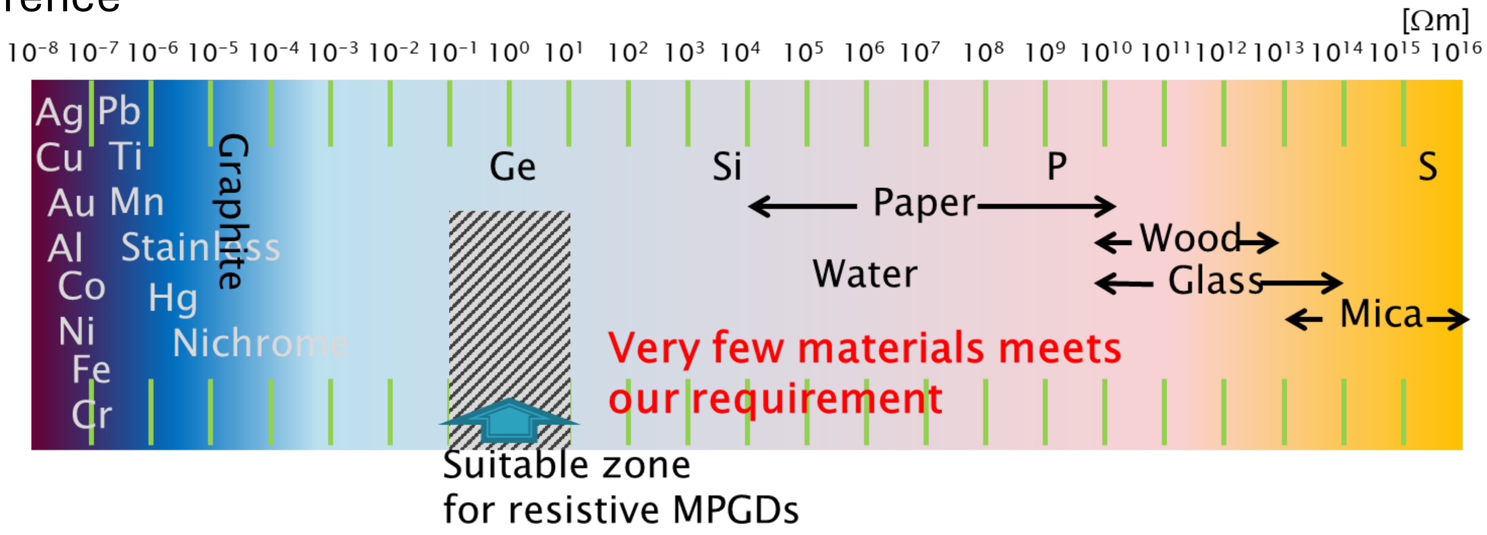
Resistive Electrodes

G. Morello on behalf of WG3

DRD1 Meeting, January 31st 2024

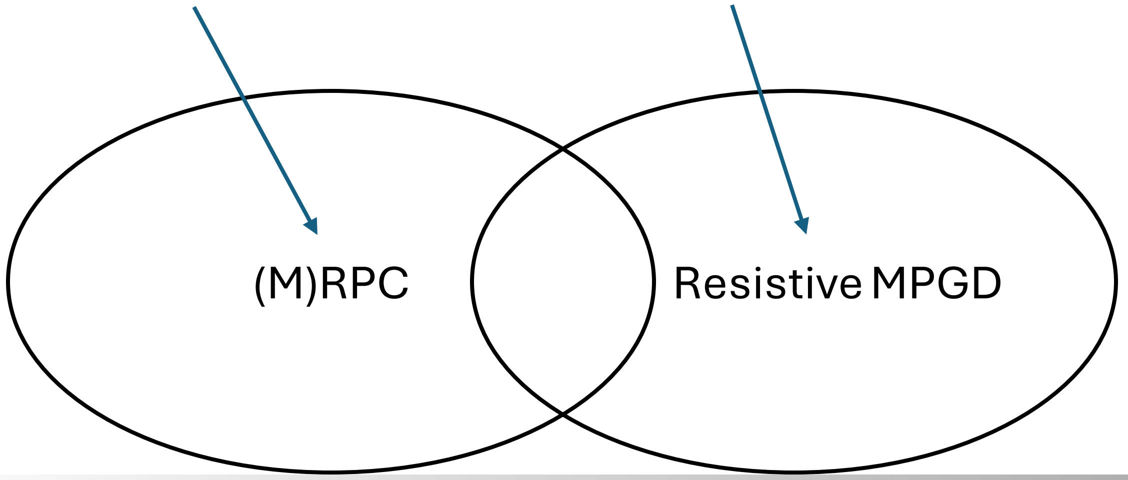
Resistivity

The resistive electrodes were introduced in particle detectors with the aim to localize the reduction of the electric field due to a discharge occurrence

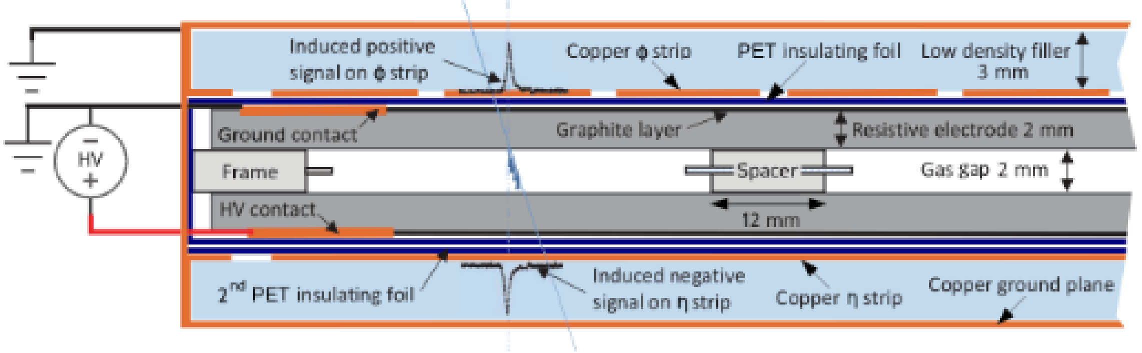


https://agenda.infn.it/event/18156/timetable/?view=standard

Several technologies for particle detectors are nowadays based on resistive electrodes.
It is worth distinguish between **bulk resistivity (Ωm)** and **surface resistivity (Ω/□)** when H<<W,L



Resistive Plate Counter



arXiv:2103.01029v1

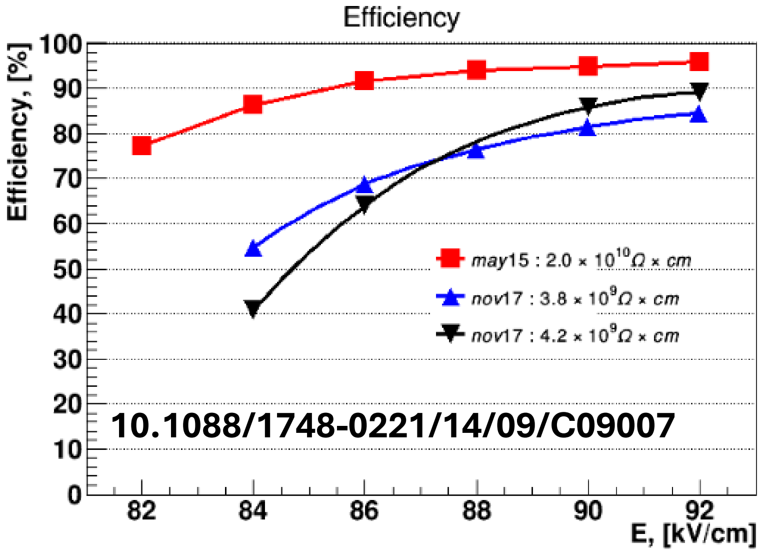
<u>FEW EXAMPLES</u> of resistive materials used in RPCs

Experiment	Resistive electrode	Gas mixture
L3	Oiled Bakelite 2E11 Ωcm	$Ar/iC_4H_{10}/C_2H_2F_4$ 59/35/6
Belle	Float glass 1E12 ÷ 1E13 Ωcm	$Ar/iC_4H_{10}/C_2H_2F_4$ 30/8/62
Alice TOF	Soda-lime glass 1E13 Ωcm	$C_2H_2F_4/SF_6$ 93/7

Source: M. Abbrescia, V. Peskov, P. Fonte, Resistive Gaseous Detectors, Wiley-VCH, 2018

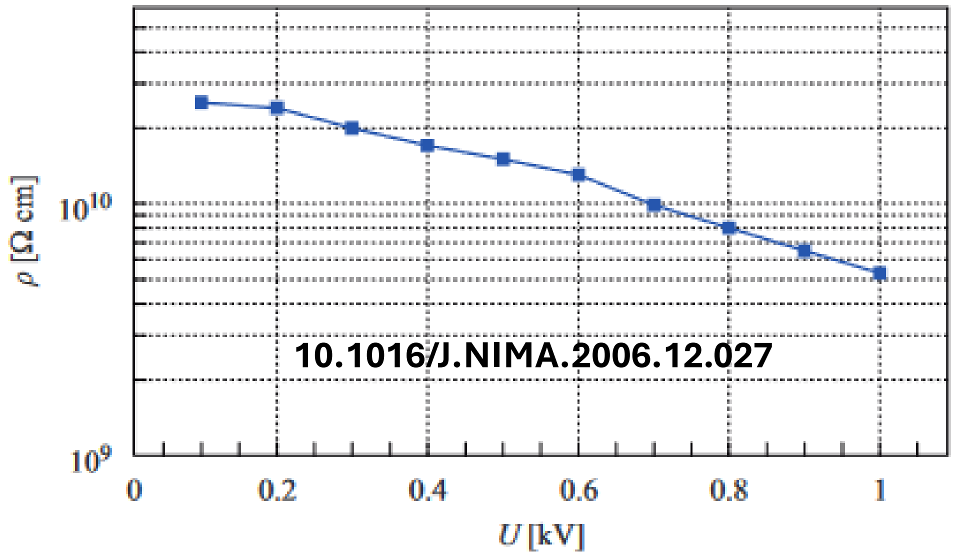
Other alternative materials under study are lower resistive glasses , ceramics, plastic with resistivity around 1E10 Ωcm (see Wang Yi and Giulio Aielli talks)
Semi-conductors (ex. GaAs) are good candidates as the resistivity is lower (1.4E8 Ωcm) →G. Aielli's talk

Resistive Plate Counter



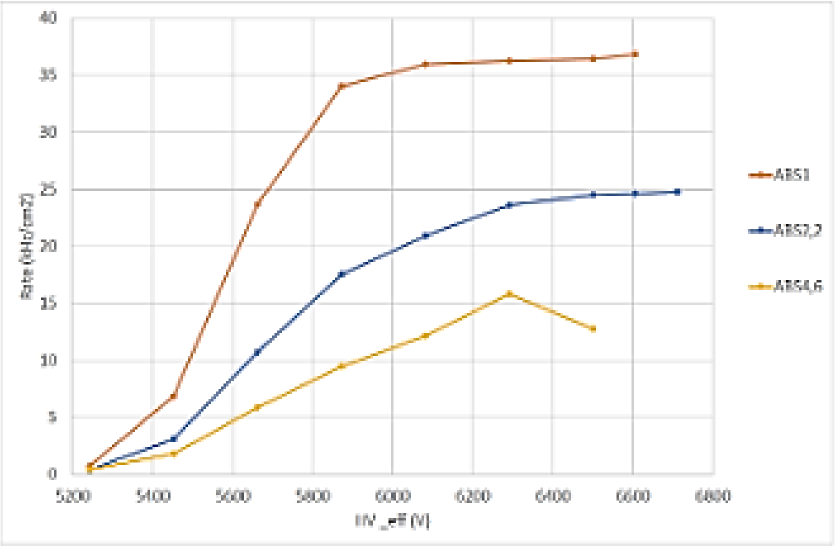
10.1088/1748-0221/14/09/C09007

Figure 3. RPC efficiency as function of the field strength for three RPC detectors performed with two readout systems: squares — MAXIM3760+CAEN TDC, triangles — PADI-10. The corresponding bulk resistivities of the ceramic plates on floating potential are given in the legend.



10.1016/J.NIMA.2006.12.027

Fig. 3. Dependence of the bulk resistivity of phosphate glass on high voltage.

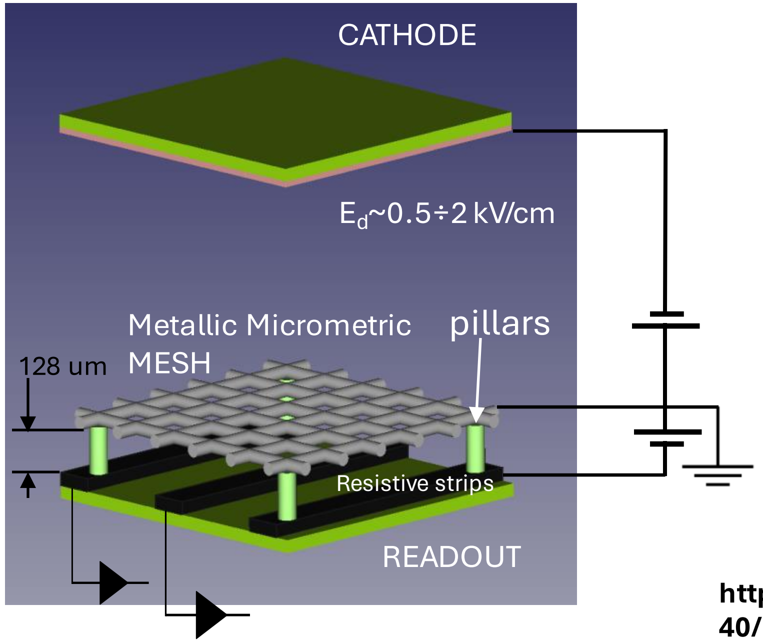


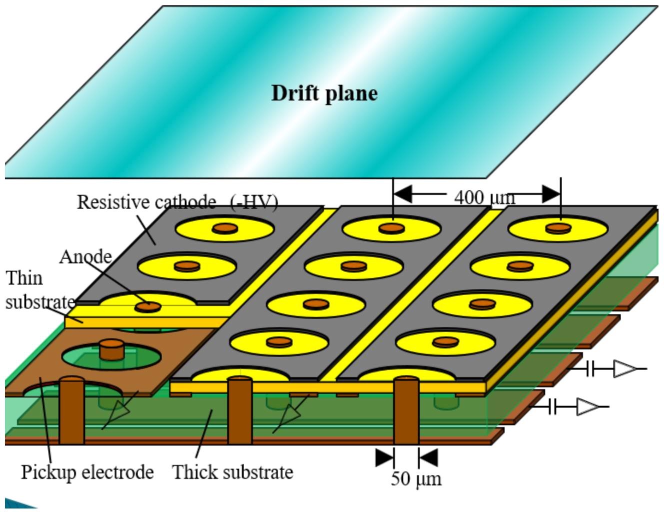
10.1088/1748-0221/15/12/C12004

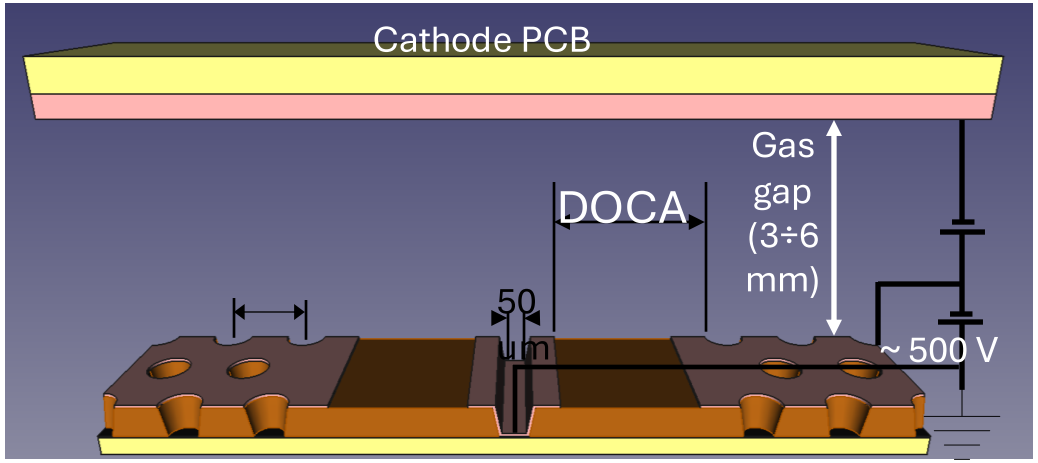
Figure 7. Measured counting rate for three different value of the absorption factor as a function of the high voltage.

Further interesting developments in HTTP://CDS.CERN.CH/RECORD/2319919

Resistive MPGDs







https://indico.cern.ch/event/756297/contributions/3149140/attachments/1723844/2783880/u-PIC_ochi_180927.pdf

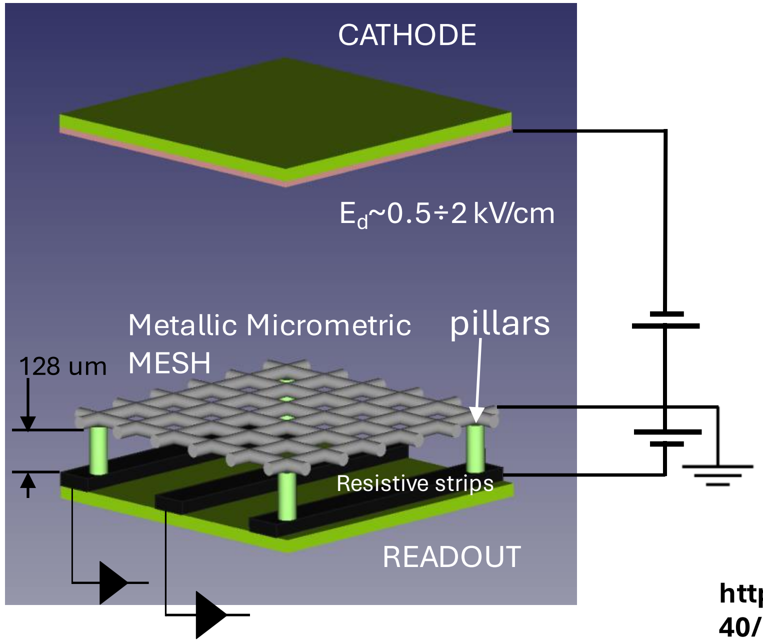
ATLAS MicroMegas were the firstg MPGD introducing a resistive stage by screen printing (O(1MΩ/☐)), example recently followed for RETGEM detectors.

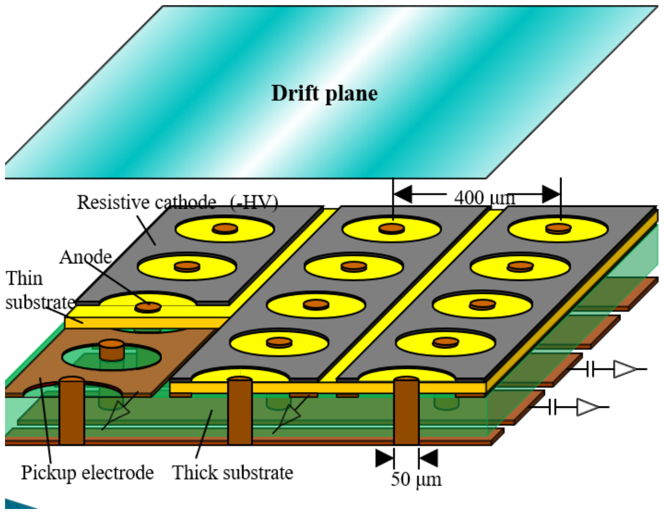
Other MPGDs start exploiting the properties of Diamond-Like Carbon (DLC), an amorphous layer of graphite, already extensively used in industry for its mechanical properties. In our case we care the electrical properties.

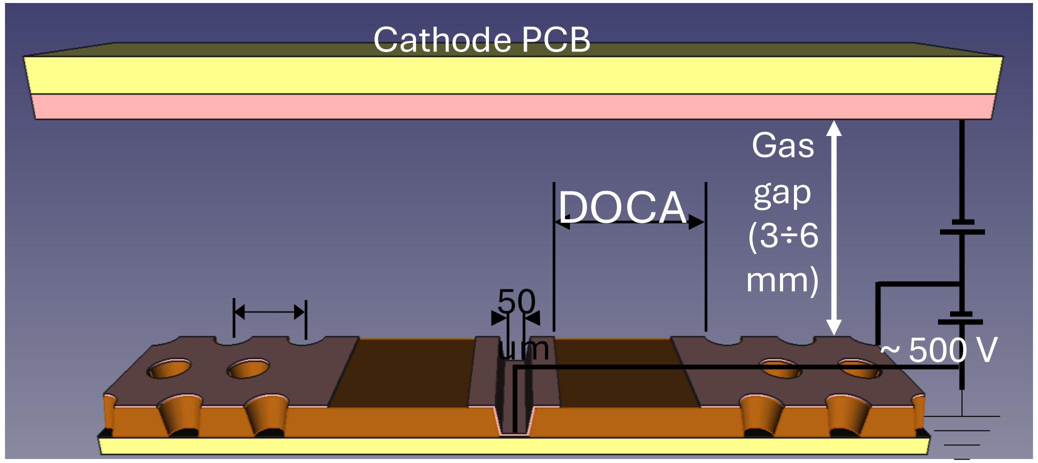
Needing different values of surface resistivity: around 10 MΩ/☐ for the MM and around 100 MΩ/☐ for the u-RWELL

The segmentation of the resistive layer and/or a more dense grounding network brings to larger rate capability

Micro-Pattern Gaseous Detectors







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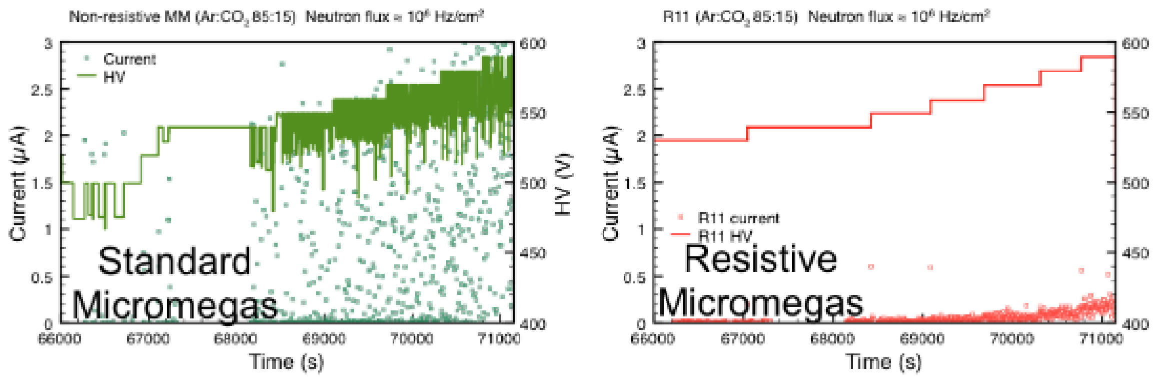
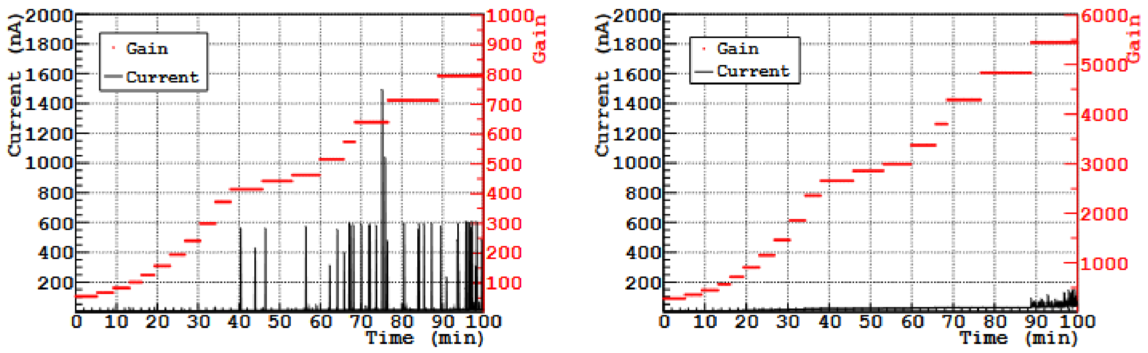


https://cds.cern.ch/record/1395690/files/EPS-HEP2011_406.pdf



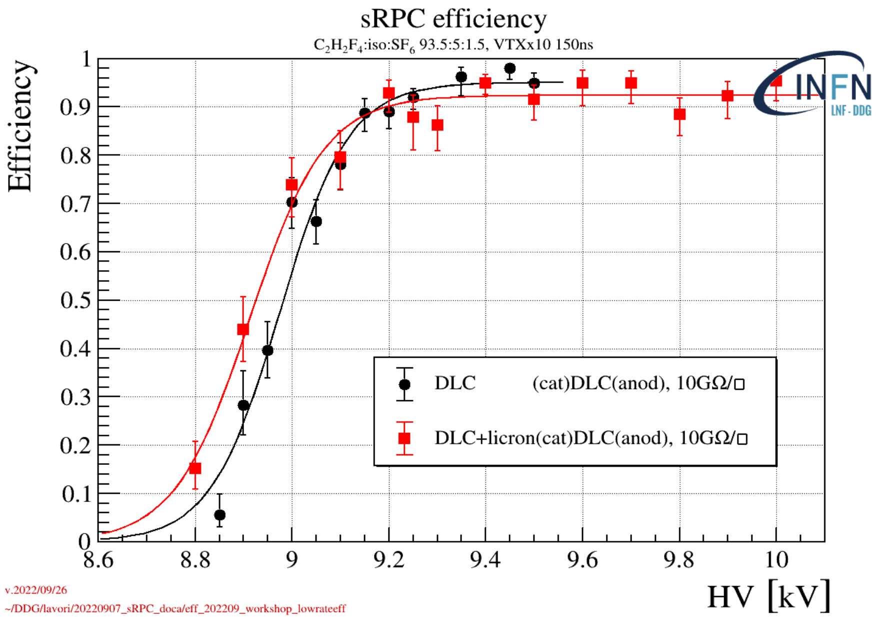
https://iopscience.iop.org/article/10.1088/1748-0221/10/02/P02008/pdf

Surface Resistive Plate Counter

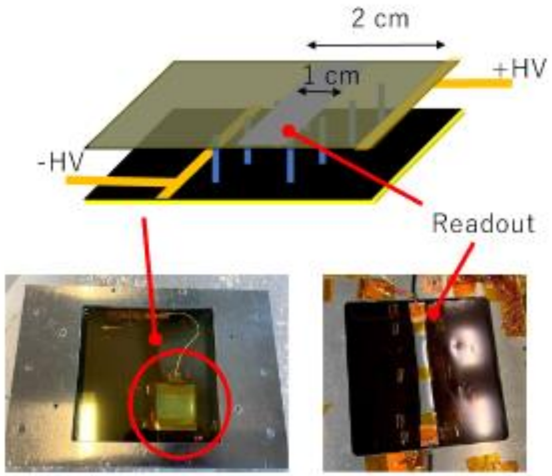
DLC-based RPC:

- **From bulk resistivity to surface resistivity**: easy tunable resistivity w.r.t. bakelite or glass
- µ-RWELL inspired **High Rate schemes**
- Flexible substrate

A promising novel technology, from MPGD material and technology experience.



M. Giovannetti, RD51 Coll. Meeting, June 2023



https://arxiv.org/pdf/2401.13553.pdf

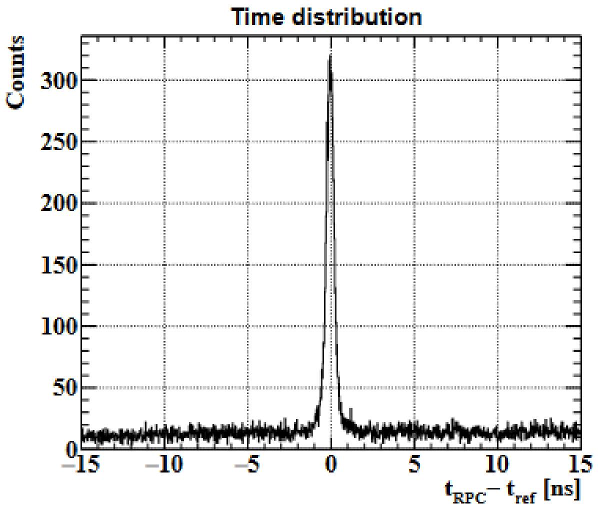
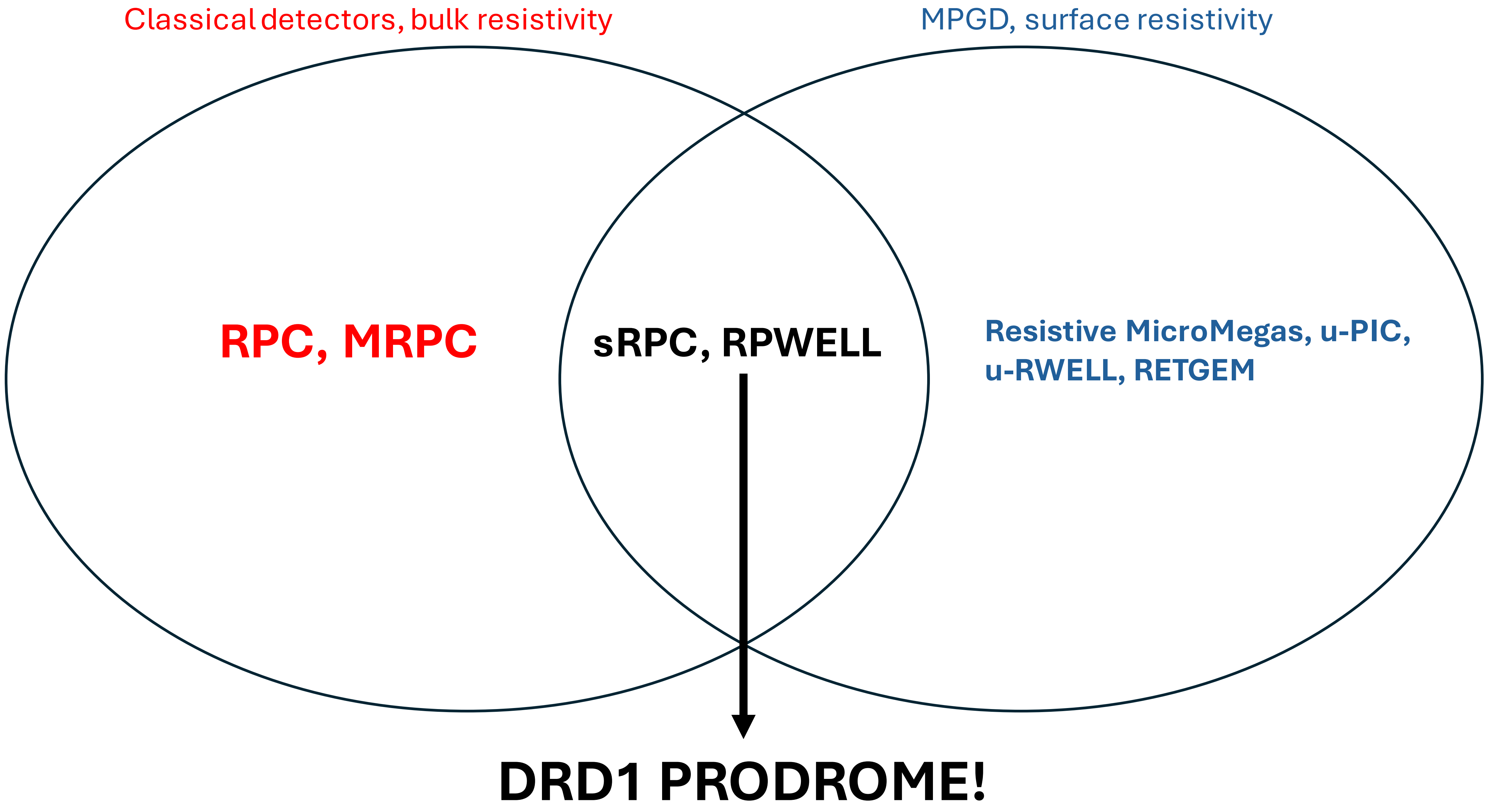


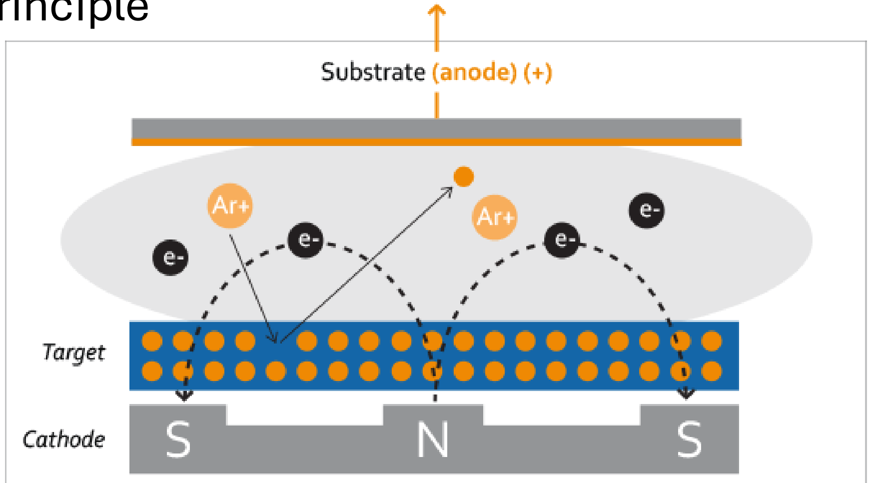
Figure 13: Time difference between the RPC and the trigger counter in the high-rate measurement. The peak comes from detected positrons and the baseline comes from accidental muon hits.

My personal view...



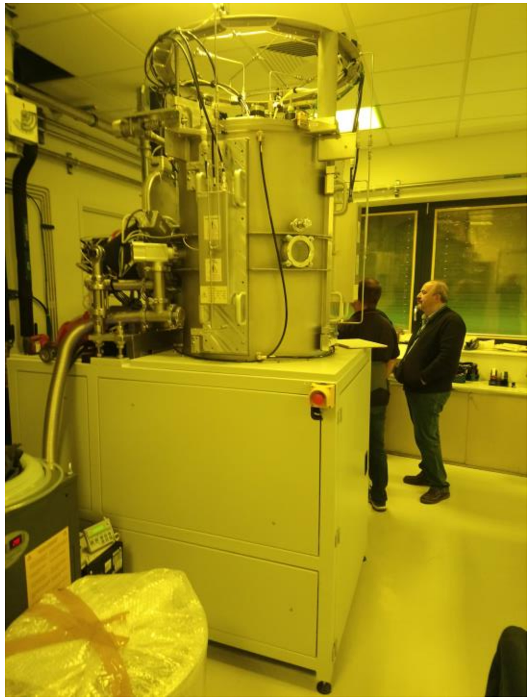
The magnetron sputtering machine

Working principle



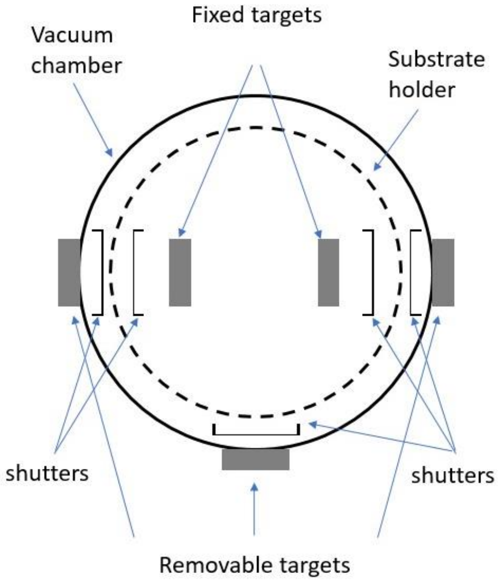
https://www.dentonvacuum.com/products/discovery/

- The field creates ion-electron pairs in the plasma
- The electrons area accelerated and furtherly ionize the plasma generating new ions
- A magnetic field concentrate the ions in a peculiar region of the targer (speed track)
- The ions drift towards the target and by collision the material is extracted flying all over the vacuum chamber



The graphite target

The three external cathodes



Machine co-funded by CERN and INFN. R&D led by INFN LNF, Roma3 and Na

DLC tests: modus operandi

SAMPLES

- APICAL foil dried in the oven (at least 16h at 100°C)
- Three rectangular samples, 15 x 10 cm2 (machine operating in oscillation mode), to check the uniformity of the deposition along z
- A small 1.5 x 1.5 cm2 glass next to each sample for thickness measurement

RUN

- Pure Ar-based plasma surface treatment (plasma etching)
- Pure Ar-based pre-sputtering process
- Sputtering process

POST RUN

- Resistivity measurements
- Baking of one sample from each run (2h at 220°C) to simulate the thermal shock during detector manufacturing
- Monitoring of the resistivity during the following days (stability check)

Repetitivity and stability with N2

First tests with N2 answered to two urgent questions:

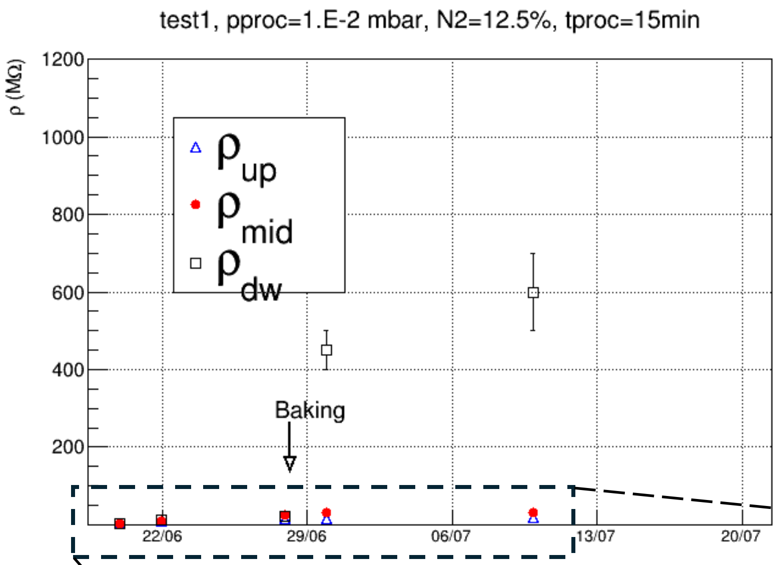
1) Standing the same deposition parameters, will the resisitivity be the same or will it change?
2) How does the resistivity change along the time?

1)

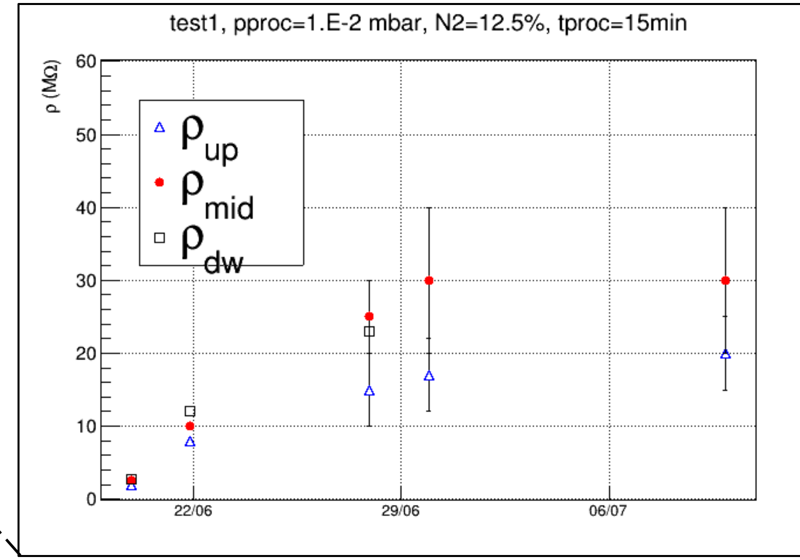
Test			20/06	22/06
1	P_{proc}=1.E-2 N_2 = 12.5% T_{proc} = 15min	ρ_{bot} ρ_{mid} ρ_{up}	2.7 2.5 2	
2	P_{proc}=1.E-2 N_2 = 12.5% T_{proc} = 15min	ρ_{bot} ρ_{mid} ρ_{up}	2.5 3 2	
3	P_{proc}=1.E-2 N_2 = 12.5% T_{proc} = 15min	ρ_{bot} ρ_{mid} ρ_{up}		3 3 4

Measurements in Mohm/sq.
Quite satisfactory repetition capability
Further confirmations for other dep. conditions

2)



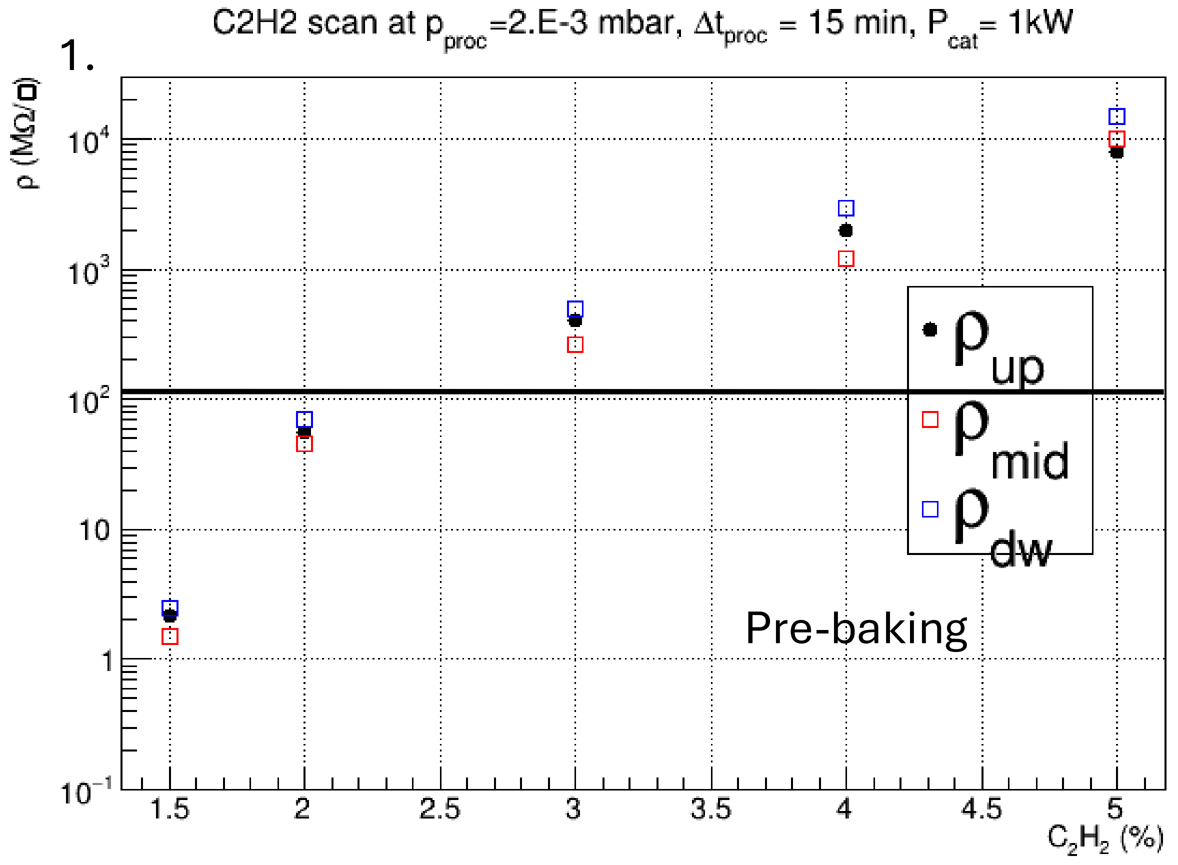
We baked one of the three sample and the resistivity jumped up of a factor 200

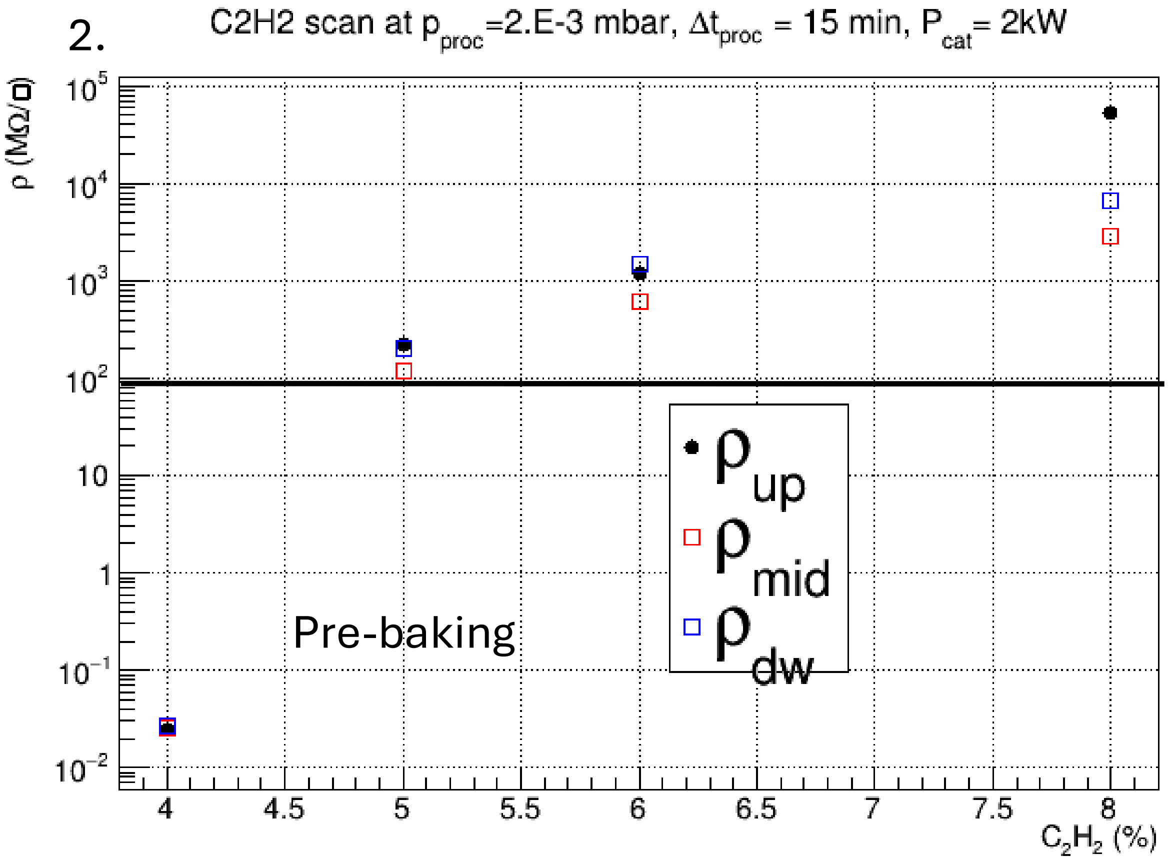


Anyway a drift towards upper values of resistivities is observed after few days
WE NEED STABLE VALUES

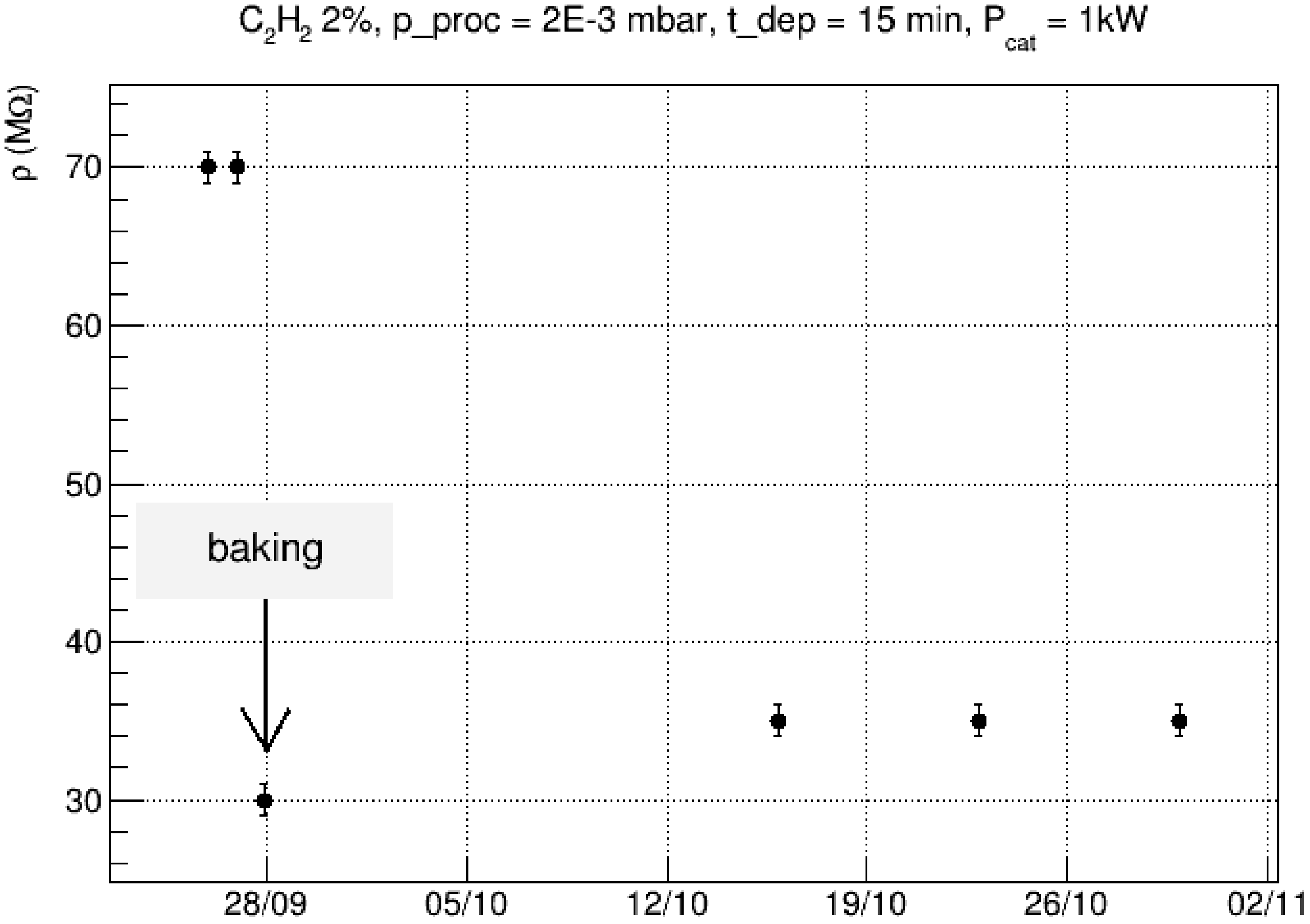
Summary of the test with C_2H_2 (Sept. 2023)

1. Scans in acetylene percentage (1.5% - 5%) at p_proc = 2.E-3 mbar, t_dep = 15 m and P_cat = 1 kW
2. Scans in acetylene percentage (4% - 8%) at p_proc = 2.E-3 mbar, t_dep = 15 m and P_cat = 2 kW
3. Test at different deposition time (15 m – 240 m) with 4% of C2H2 at p_proc 8.E-3 and P_cat = 1 kW
4. Repetitivity tests (C2H2 3%, p_proc = 2.E-3, P_cat = 1kW, t_dep = 22.5 m)
5. Uniformity tests



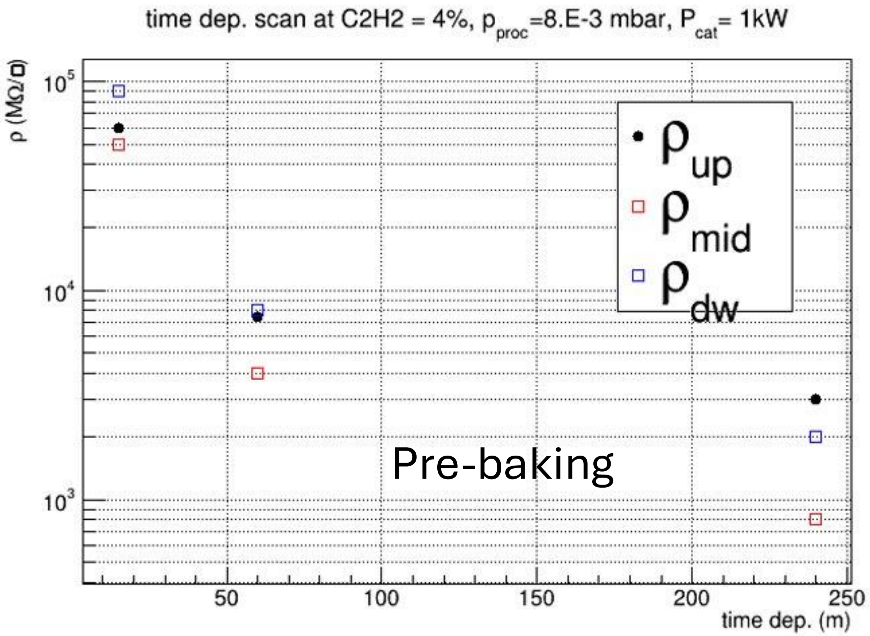


Stability with C_2H_2 (Sept. - Oct. 2023)

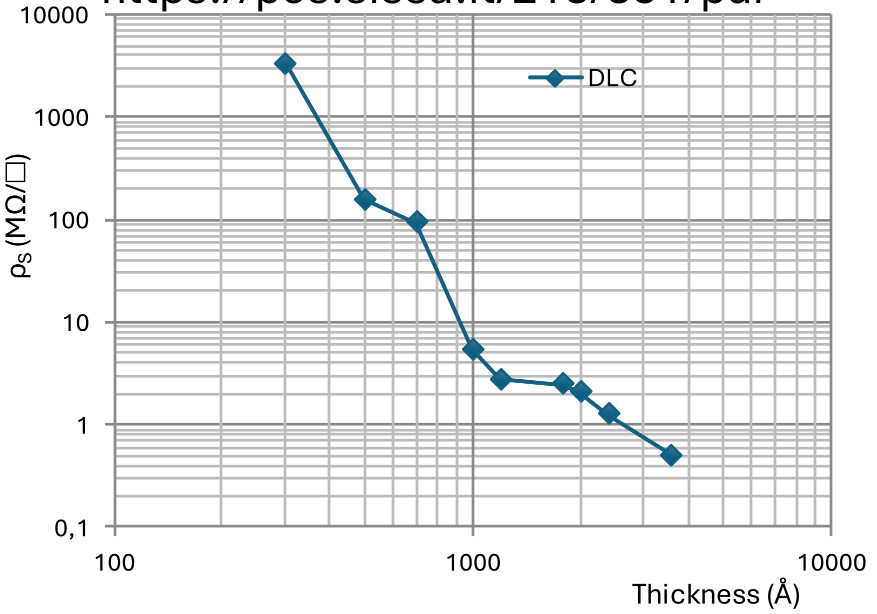


A drop after the baking and a small drift, but then very stable values

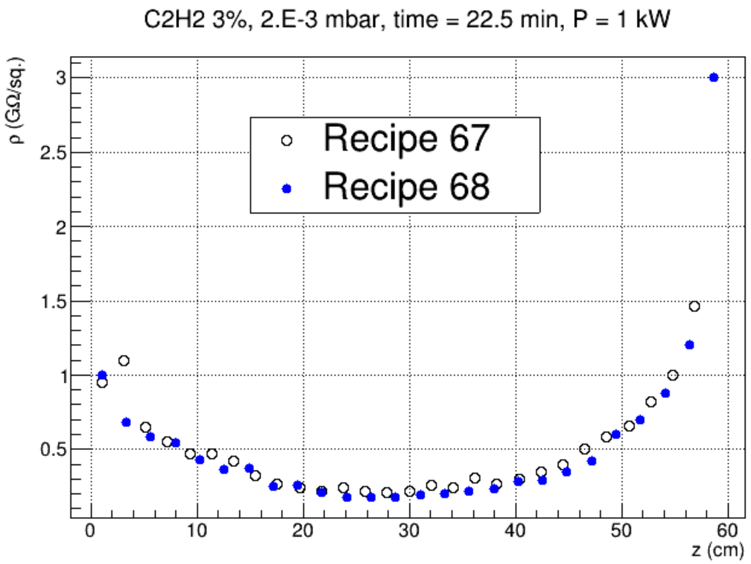
Deposition time and repetitivity test

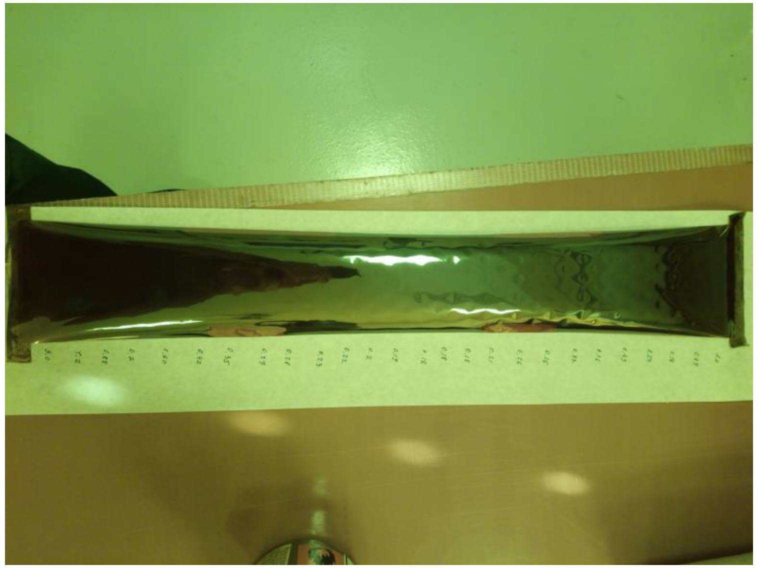


https://pos.sissa.it/213/351/pdf



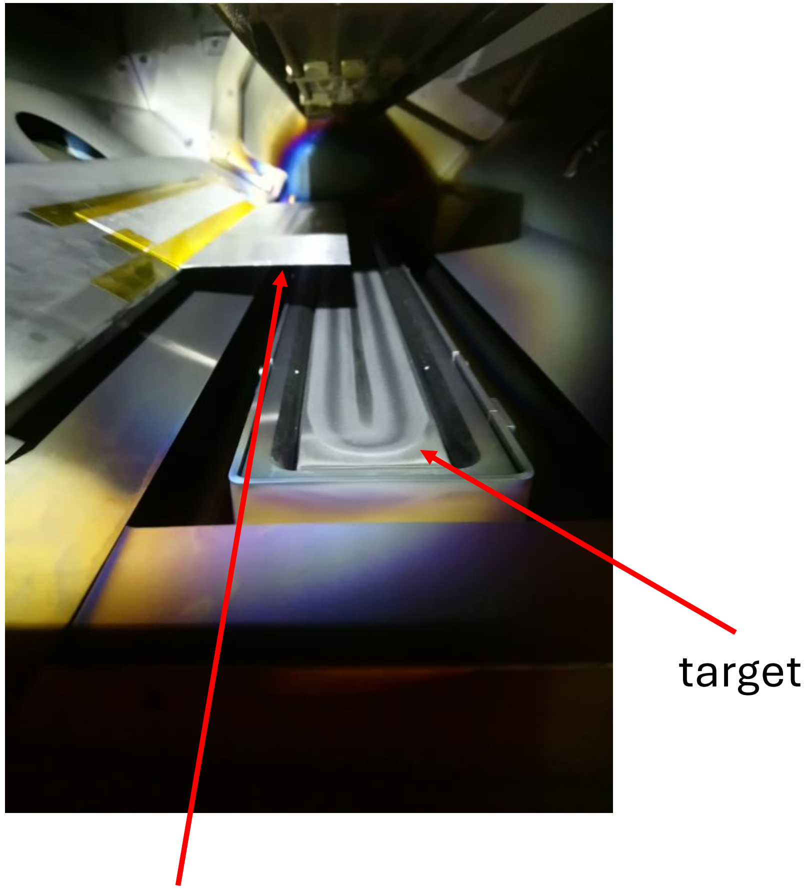
Confirmed the behaviour f(1/t)
Time can be an important parameter for the resistivity adjustment
WARNING = evidence of non-uniformity along z!

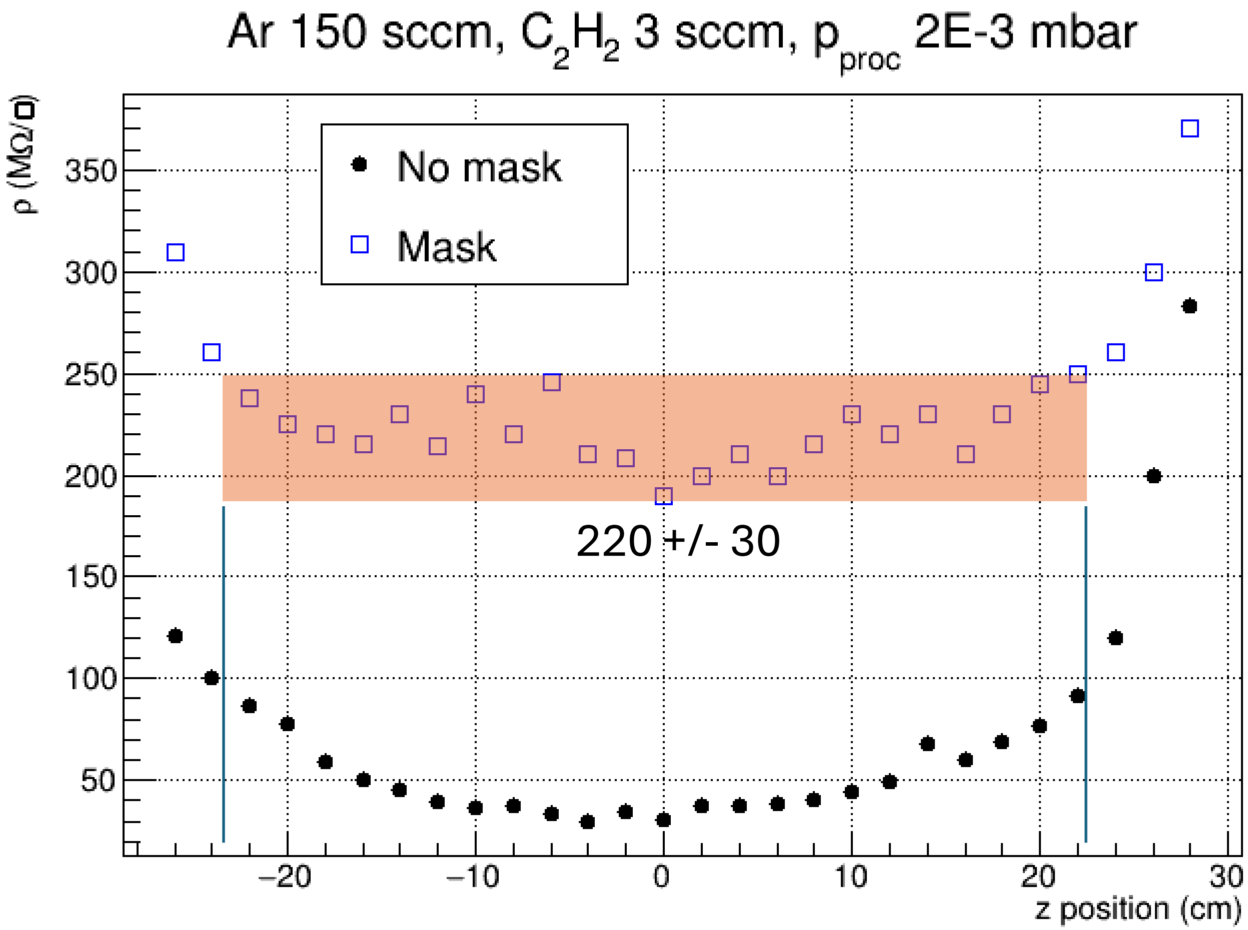




From now on, we use a single APICAL sample 60 x 10 cm2
We measure the resistivity along the longitudinal axis

Summary of the test with C_2H_2 (Nov. 2023)





The mask seems promising. The uniformity region has been extended to about 45 cm. Further improvements con be achieved with a different mask shape

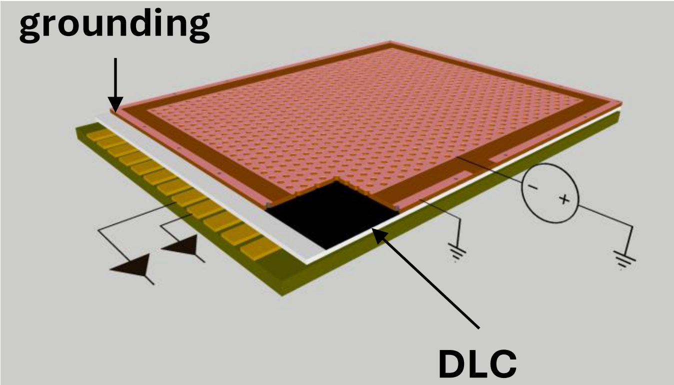
Conclusions

- The community shows a huge interest in resistive materials, since they can improve the stability of the detectors
- In RPCs field new lower bulk resistive materials have been introduced to improve the rate capability keeping the other features unchanged
- A link from bulk resistive material borrowed by MPGDs with the birth of RPWELL
- The DLC created another strong link between the MPGD technologies and the RPC world with the introduction of the sRPC technology

- The presence of the CID machine at CERN should provide a remarkable production of this resistive material for the early mentioned applications
- The tests done so far are very promising
- The production is likely to start in 2024

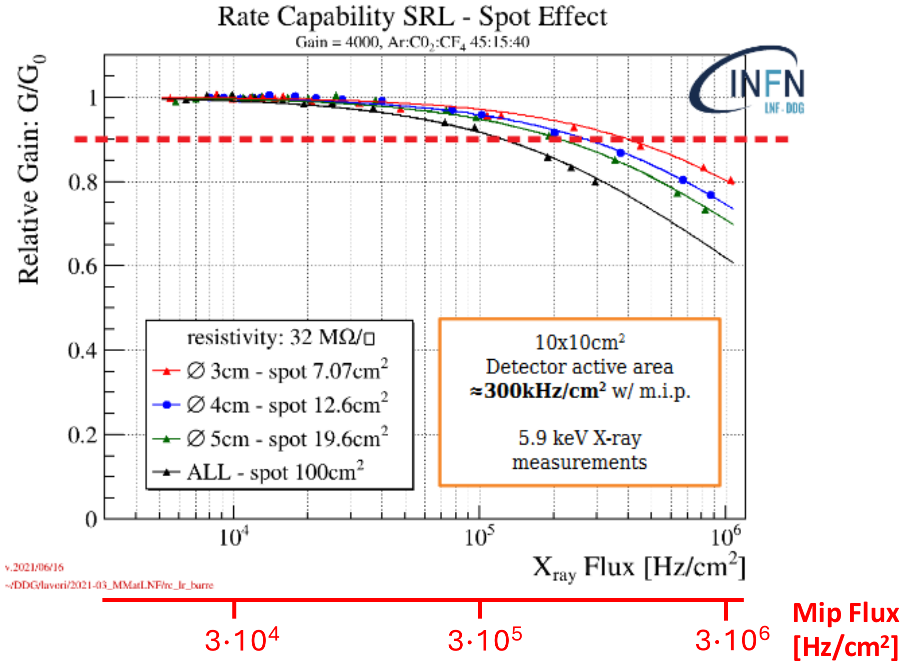
Spare

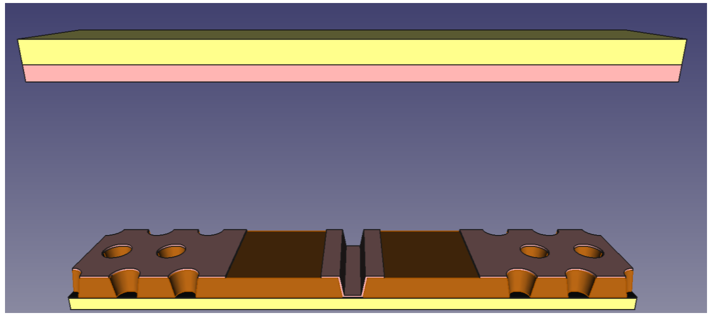
Micro-Pattern Gaseous Detectors

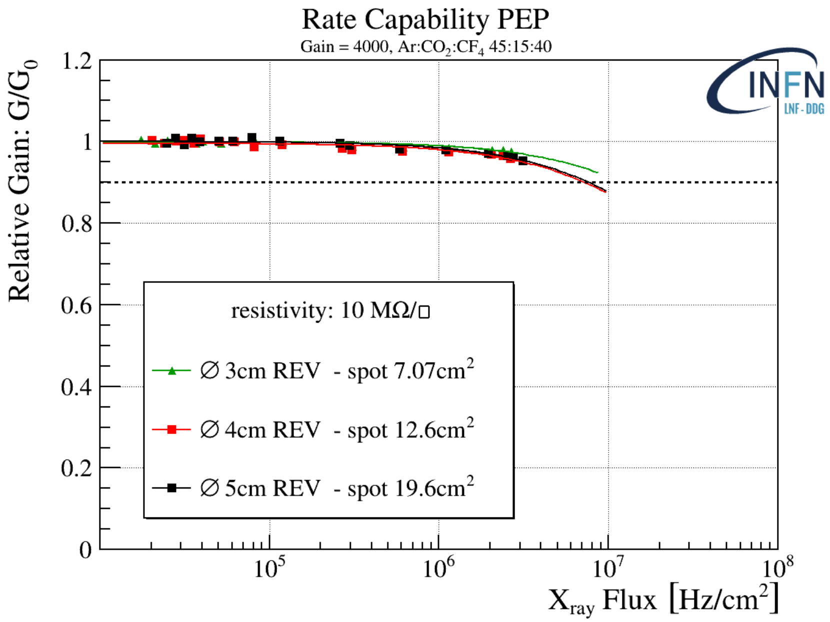


Single Layer

- **Single DLC layer**
- **Large *d* (~active area size)**
- **Low rate purposes (up to 100 kHz/cm²)**
- **Easy for industry**





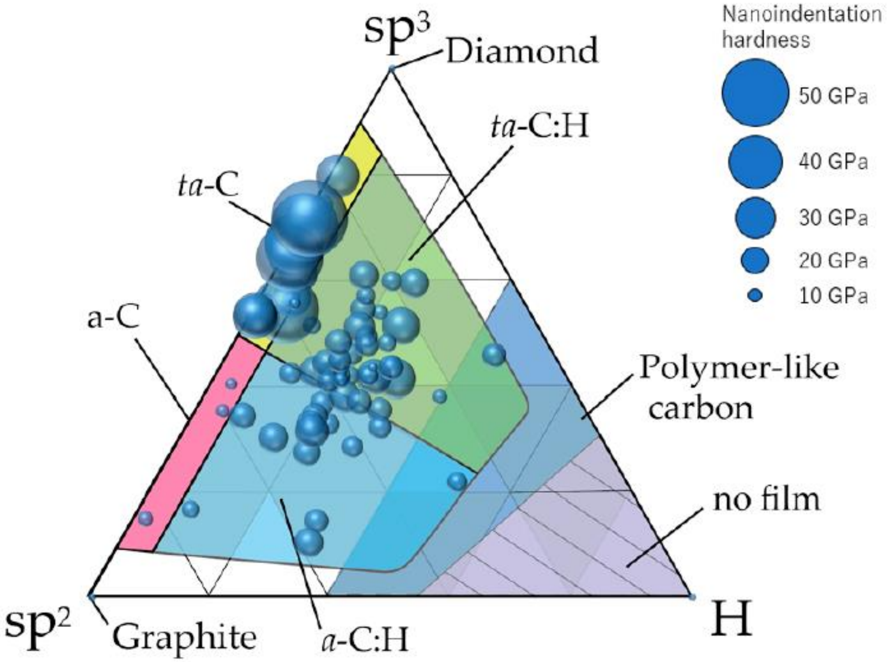


A rate capability under X-rays irradiation of 10 MHz/cm² (to be scaled by three for mip) is **extrapolated.**

The flux is limited by the capability of the X-ray gun

DLC tests

The machine phase-space is quite huge; the plan for the tests have been focused to few parameters.



QUICK GLOSSARY

Pressure limit: *the pressure of the vacuum at which the run starts. Typically 2.E-5 mbar*

Pressure process: *the pressure of the plasma during the sputtering phase*

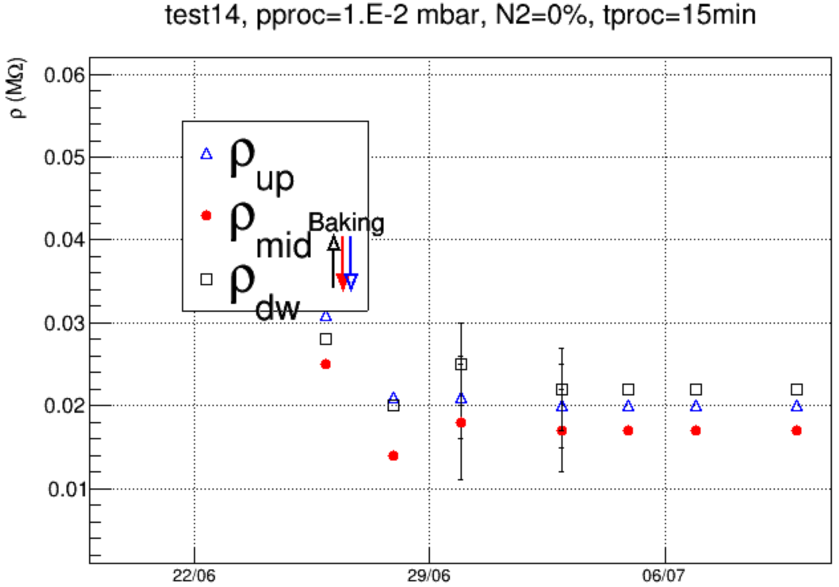
Power: *the maximum power limit output from the DC PS on the cathode*

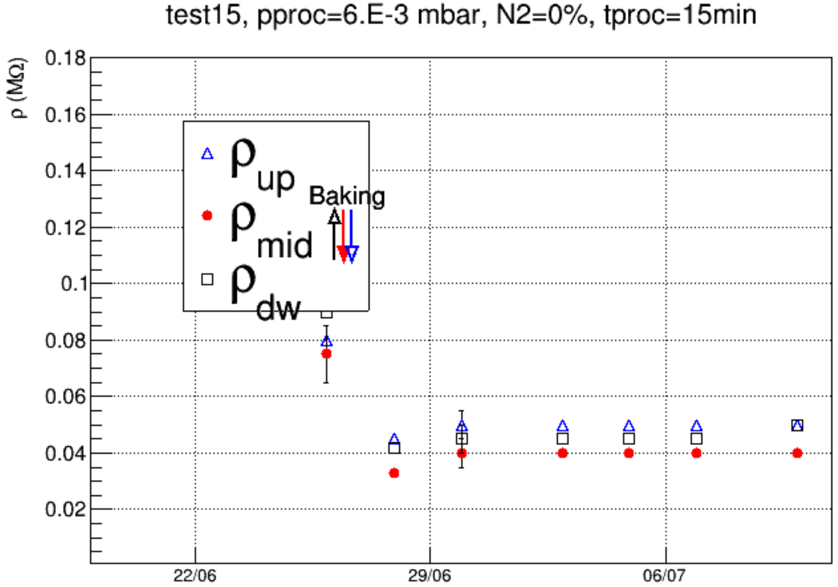
Time deposition: *the duration of the sputtering process*

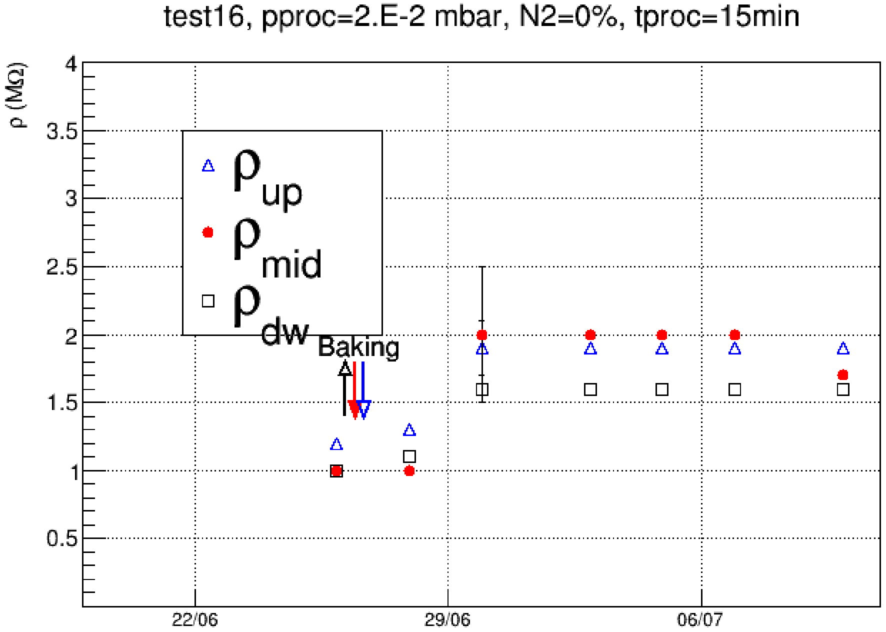
- Ar-N_2 plasma tests
  - Scan in nitrogen percentage at a given pressure process
  - Scan in pressure process at a given nitrogen percentage
  - Tests with different time deposition

- Ar-C_2H_2 plasma tests
  - Scan in acetylene percentage at a given pressure process and power
  - Scan in time deposition at a given pressure process, acetylene percentage and power
  - Uniformity tests

Tests in pure Argon

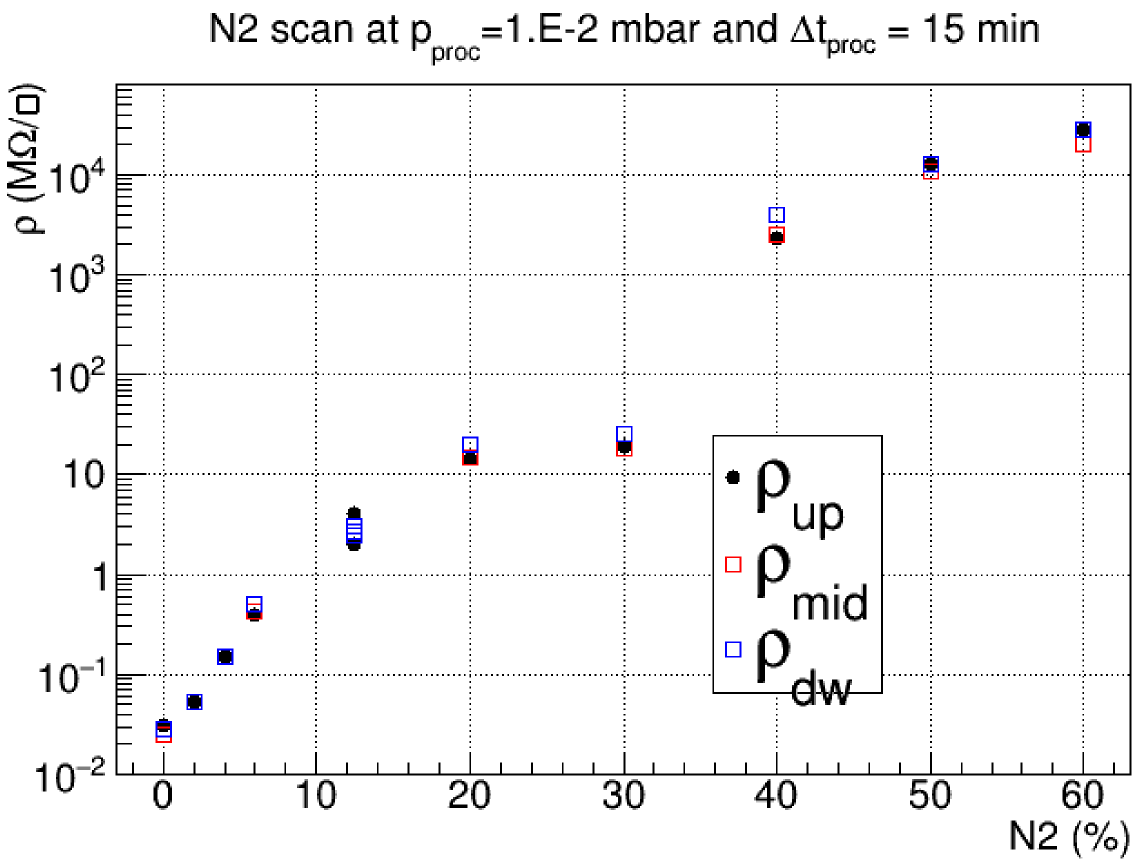


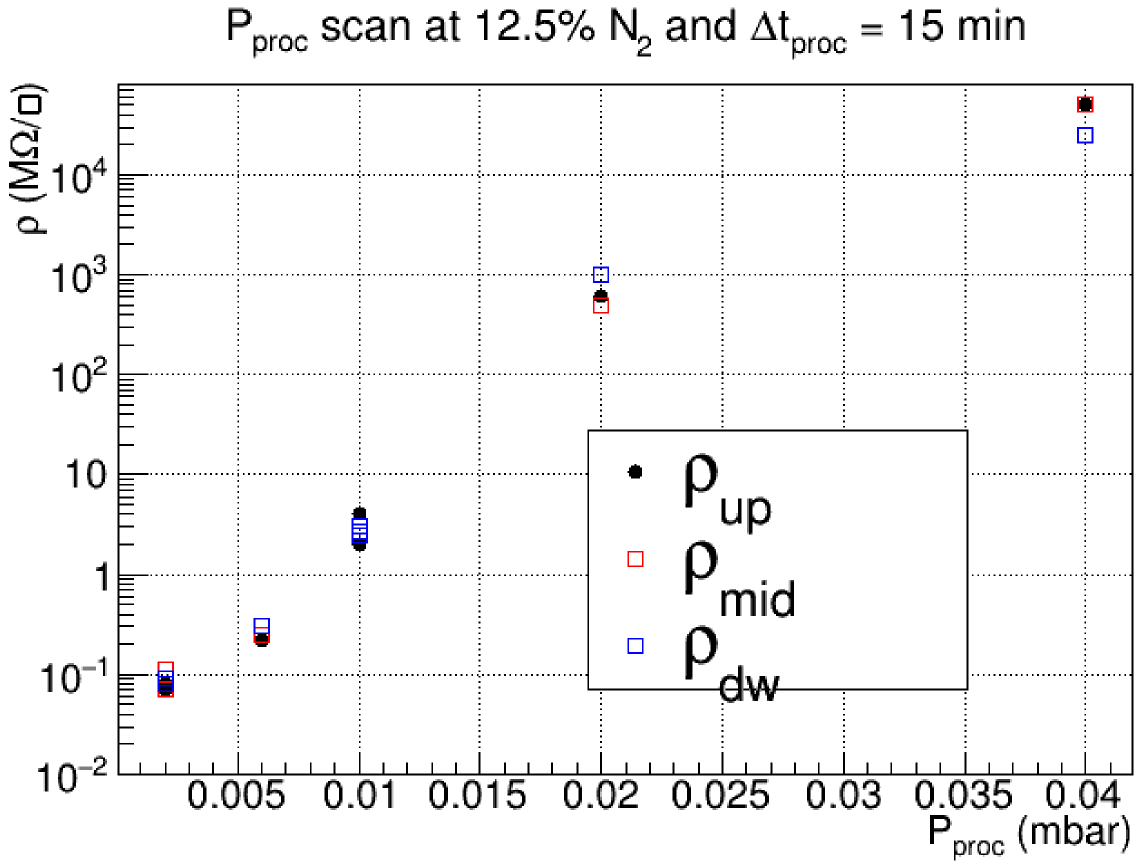




Summary of the test with N_2 (June 2023)

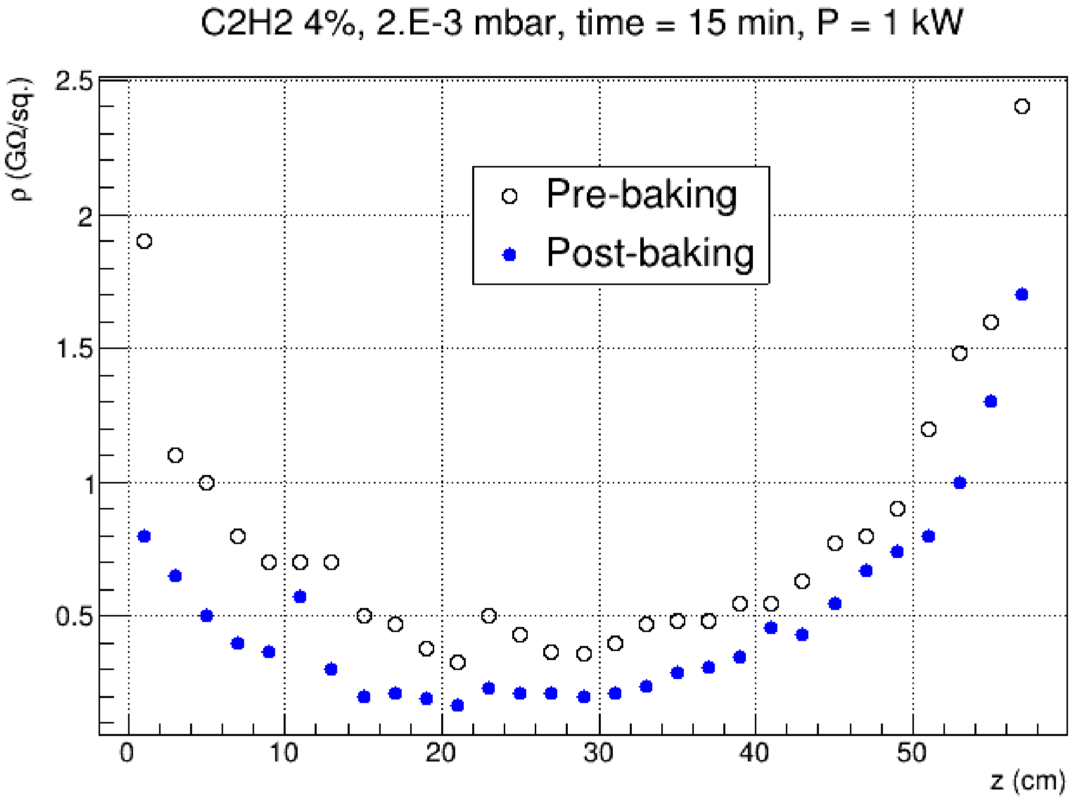
Nevertheless these tests have been helpful to understand the dependance of the resisivity on the quantity of the second component of the plasma and on the pressure process

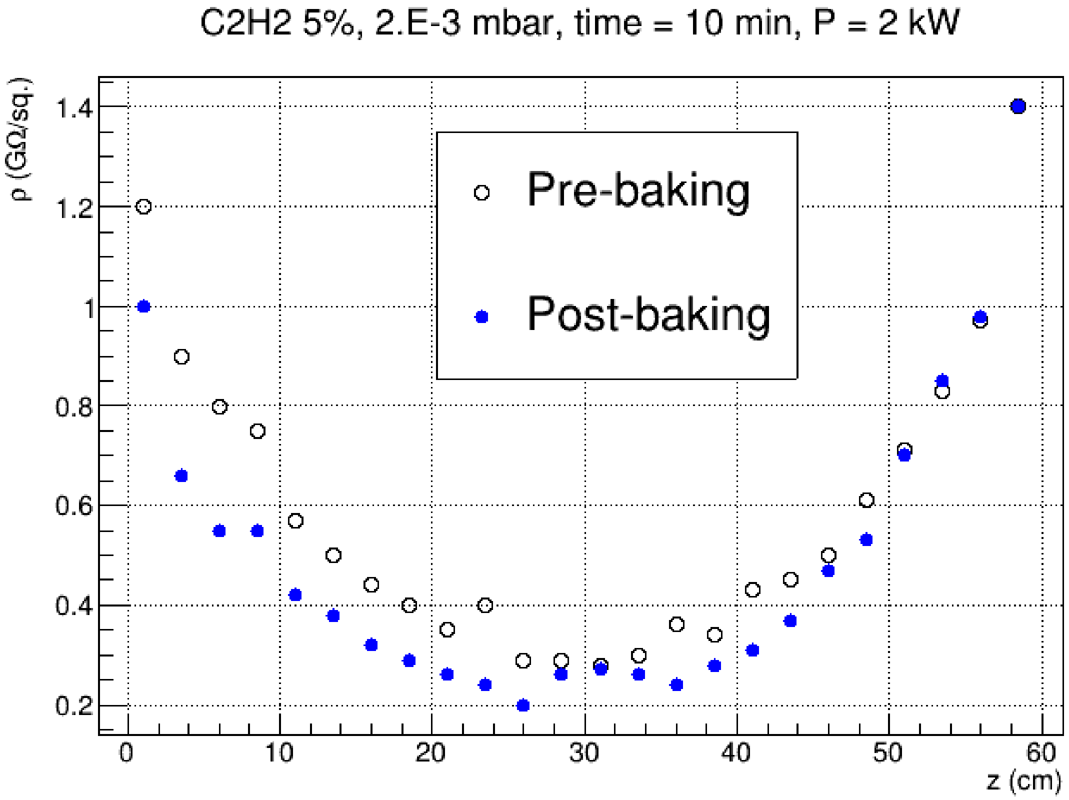




Very large amount of nitrogen to reach the target resistivity (50 – 200 Mohm/sq.)

Uniformity test





The baking, as expected, doesn't change the thickness profile

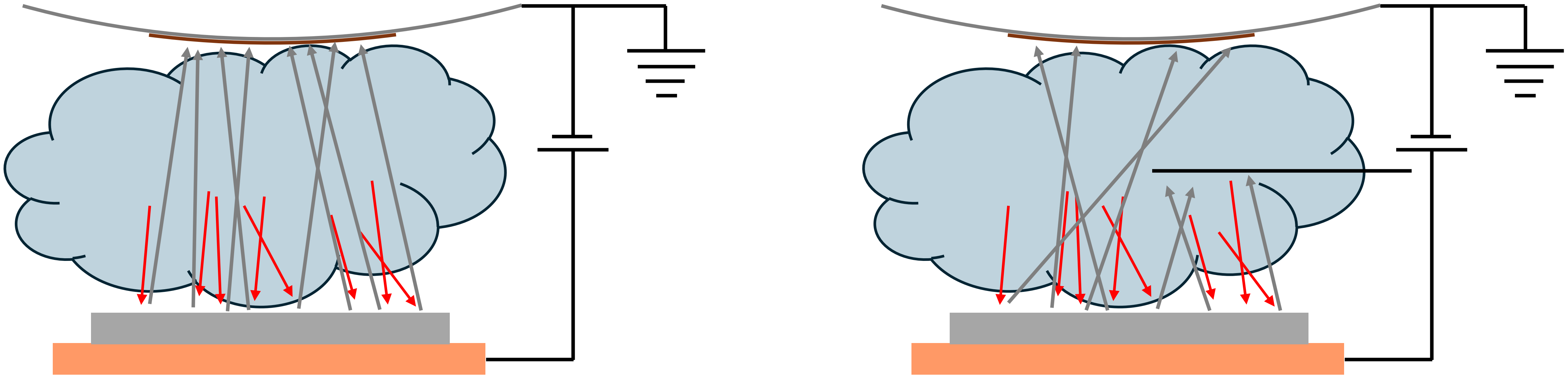
These tests pointed out that the deposition, along the axis, is uniform in a very narrow central region

We would like to have a uniformity ≤ 15%

THIS REGION MUST BE EXTENDED

Summary of the test with C_2H_2 (Nov. 2023)

To improve the uniformity, Serge's idea is to install a mask stuck to the shutter to reduce the material extraction in the central part of the target



Lower extraction → thinner deposition → larger resistivity