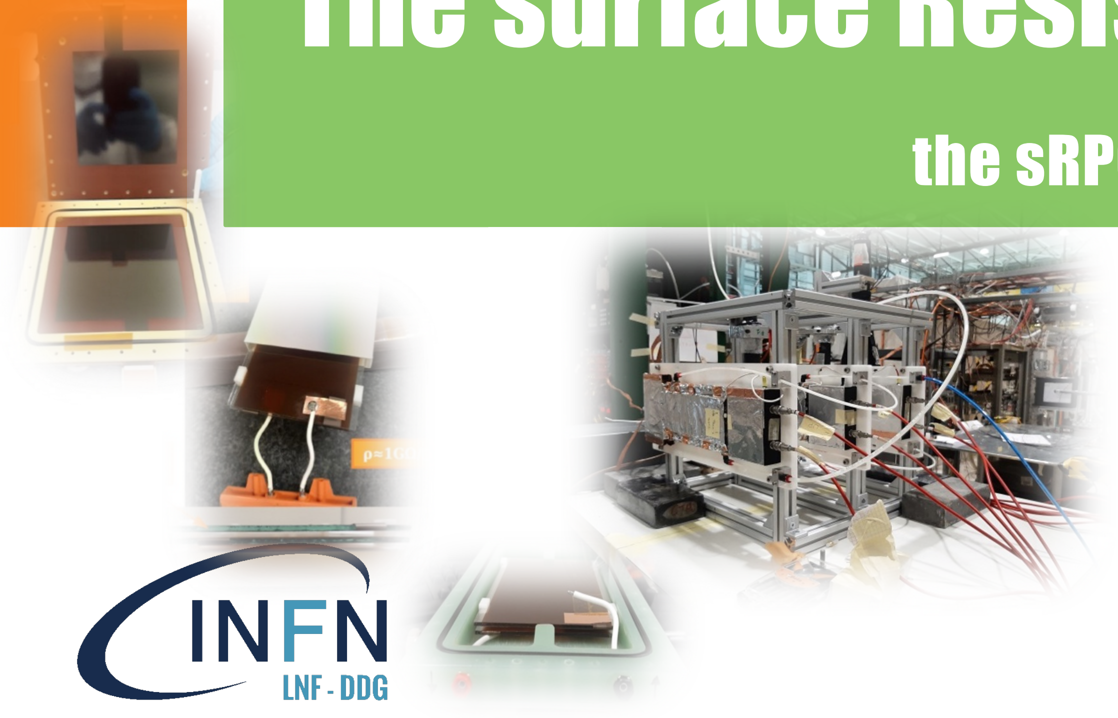
The surface Resistive Plate counter

the sRPC: an MPGD technology based RPC

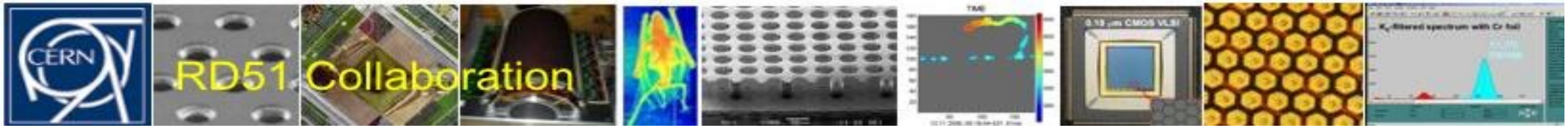


IPRD 2023- Siena, 25 – 29 Set 2023

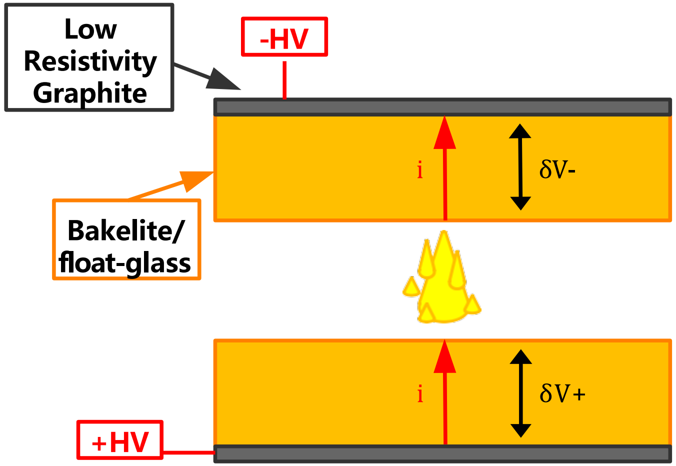
M. Poli Lener[1]
G. Bencivenni[1], R. De Oliveira[2], G. Felici[1], M. Gatta[1], M. Giovannetti[1], G. Morello[1], G. Papalino[1]

[1] LNF– INFN
[2] CERN

INFN
LNF - DDG

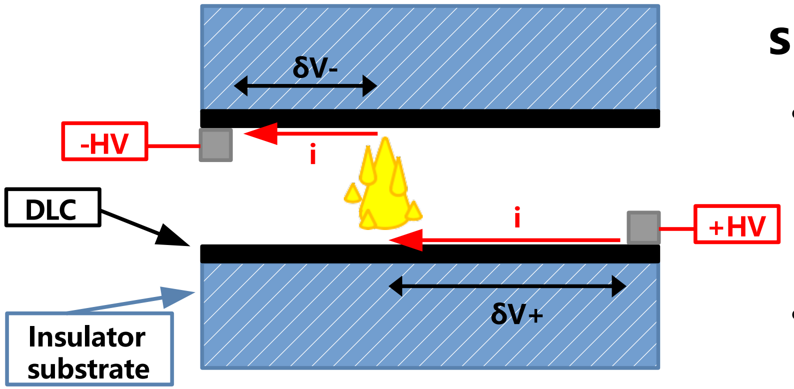


Bulk RPC vs Surface RPC



Classical RPCs

- Bulk resistivity electrodes (bakelite, float-glass, ...)
- Recovery time proportional to **volume resistivity, electrode thickness**
    - $\tau = \rho_V \varepsilon_0 (\varepsilon_r + 2d/g)$
    - Low volume resistivity and thin electrodes, together with the reduction of the gas gain (⊕high gain low noise pre-amp) is the standard recipe to increase the detector rate capability.

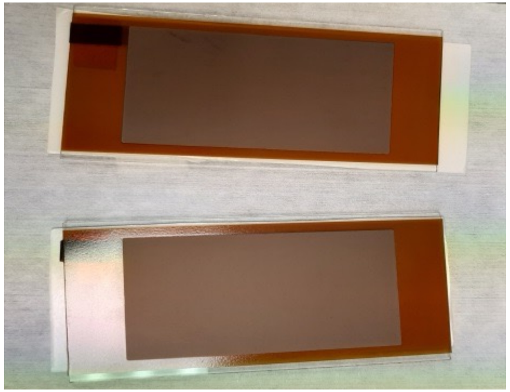


sRPCs – surface RPC

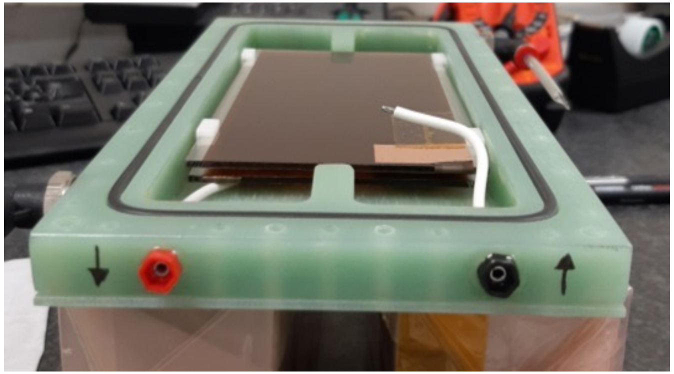
- Surface resistivity electrodes manufactured with sputtering techniques of Diamond-like-carbon (DLC) on flexible supports
    - The technology allows to realise large electrodes with a DLC **surface resistivity** in a **very wide range: 10 MΩ/□ ÷ 10 GΩ/□**
- High density current evacuation schemes, similar to those used for resistive MPGD (μ-RWELL and MicroMegas), can be implemented to improve the rate capability of the detector

Prototype layout (I)

- The **baseline** version of the detector is built with **patterned DLC electrodes** sputtered on **Apical®** foil then **glued** on **float-glass substrates**
- The **glass support** is used due its **excellent planarity and very smooth surface** (*use of standard PCB in future not excluded*)
- The **2 mm gas gap** between the two electrodes is ensured by **E-shaped spacers made of Delrin,** ensuring a good gap uniformity
- The **electrodes stack** is inserted in a **FR4 box** that acts as **gas volume container**

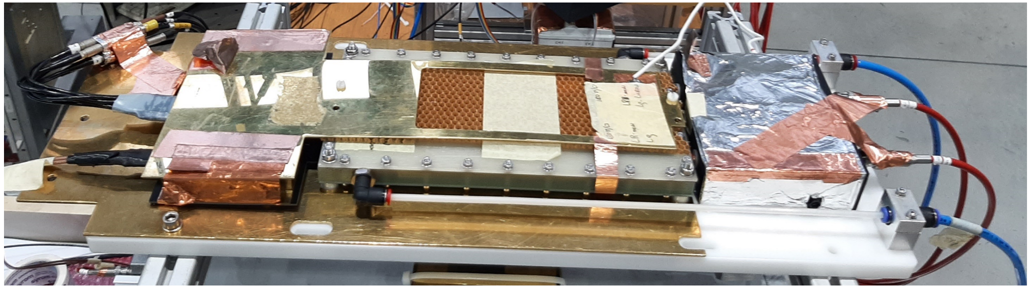


glass 140x78 mm² - DLC 120x64 mm²



Prototype layout (II)

- The **HV** to **DLC electrodes (baseline version)** is supplied through a **dot-like connection** realized on **DLC tails** bent on the **external side of the glass** support
- **External strip-patterned** boards are used to pick-up the **induced signals**
- The **readout** is based on the **six-channels VTX pre-amplifier** with analog output, **10mV/fC sensitivity**
- Detectors have been operated with the **$C_2H_2F_4$/iso-C_4H_{10}/SF_6 = 93.5/5/1.5** gas mixture

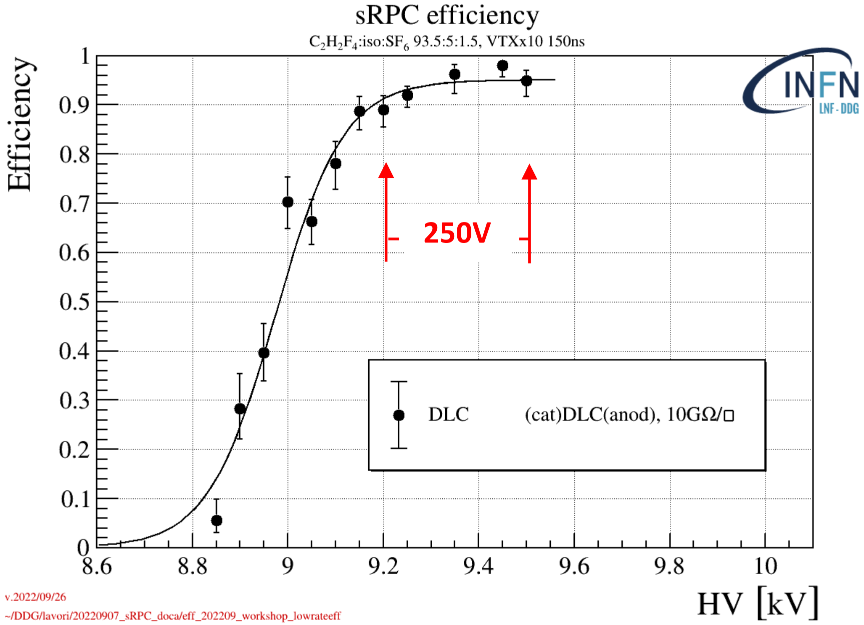


The cathode puzzle (I)

The **efficiency plateau** is **not** as **large** as the one obtained with standard RPC(*) with bulk resistivity electrodes (≥ 1kV).

Instability correlated **with a constant current drawn** has been observed **over a certain HV threshold.**

Since the **DLC has a work function of few eV**[1] and exhibits a **non-negligible sensitivity to UV-photons**[2], **secondary electron emission due to photon-feedback and/or field emission**[3] may occur at the **cathode surface.**



(*) RPCs with cathode electrode made of float-glass (*that don't exhibit secondary electron emission*) exhibit plateau larger than 1kV.

[1]A. Valentini, RD51-NOTE-2020-006.
[2] Kordas, et al., 15*th* Vienna Conference on Instrumentation, Feb. 18-22, 2019.
[3] S.A. Korff, Electron and Nuclear Counters, D. Van Nostrand Company -Inc, Fourth Avenue, New York, USA, 1955.

The cathode puzzle (II)

A **possible solution** of this problem is the production of a **thin barrier on the cathode surface** in order to **suppress the electron extraction from DLC.**

Several **passivation coatings of the DLC cathode** surface have been tested, among these the **Licron** led to **positive results** by significantly **improving the stability** of the detector.

In order to do not affect the correct behavior of the electrode, the **passivation film** should have a **surface resistivity comparable with the DLC one.**

$\rho_{DLC} \sim 10^8 \div 10^9\ \Omega/\square$

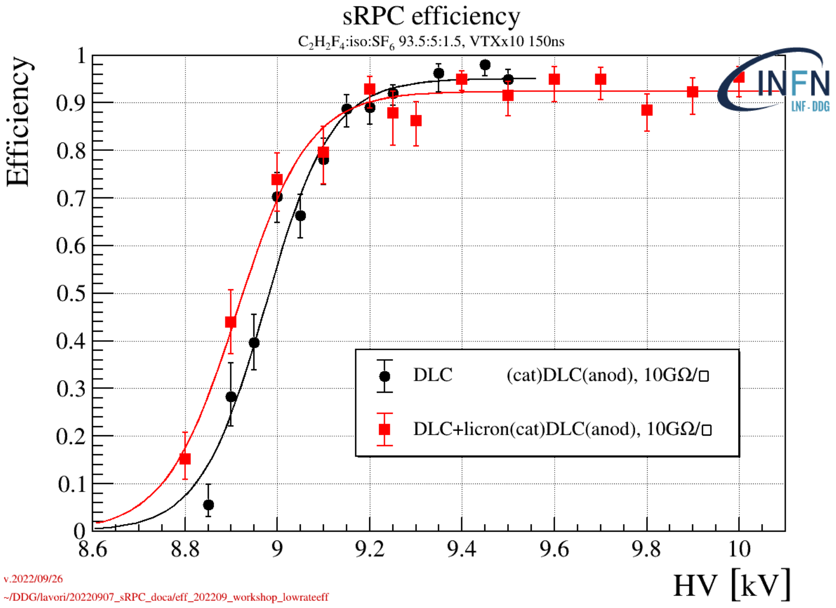
$\rho_{film} \sim \rho_{DLC}$

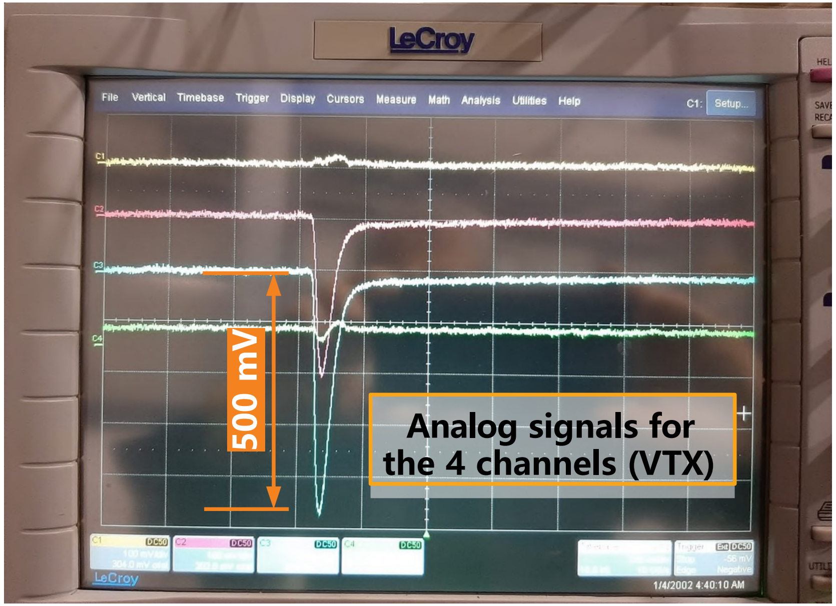
At the moment the **cathode passivation is done manually**. Looking for **SBU technology.**

Features / Benefits

- Rugged static dissipative coating
- Surface Resistivity of 10^6 To 10^9 ohms
- Operating temperature range up to 302°F (155°C)
- Humidity independent
- Superior adhesion to variety of surfaces: glass, plastic, etc.
- Coverage - 1 gallon @ 1 mil wet film will cover ~1600 sq. ft., @ 2 mil ~800 sq. ft.
- Non-ozone depleting

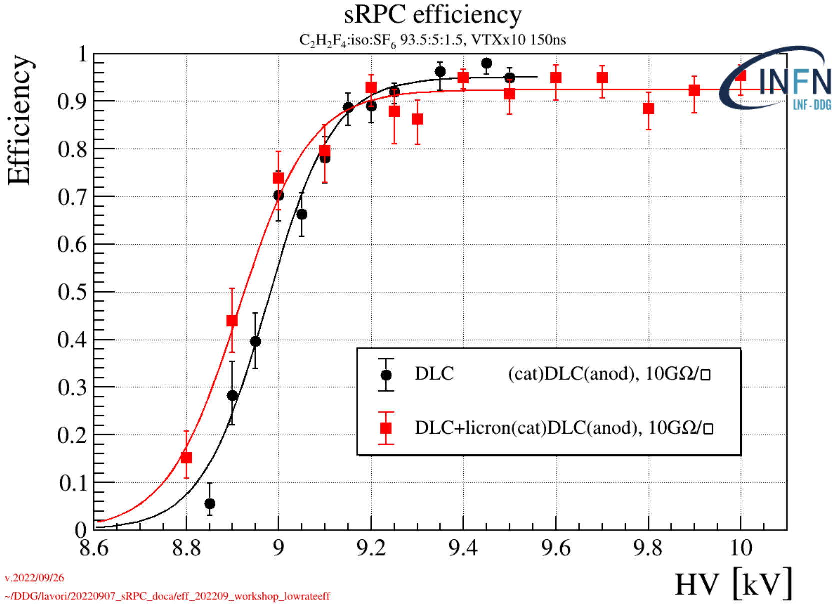
The Cathode Puzzle – IV

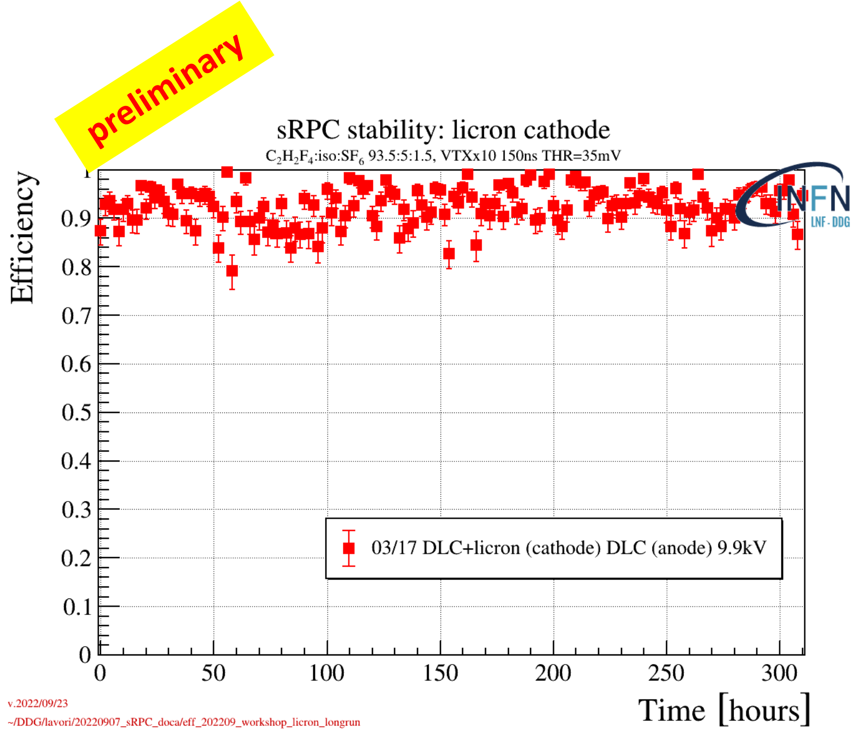




Detectors with **Licron** cathode passivation **show an efficiency plateau** of the order (or larger than) **of 1 kV**, while a long-term test to verify the detector stability is in progress.

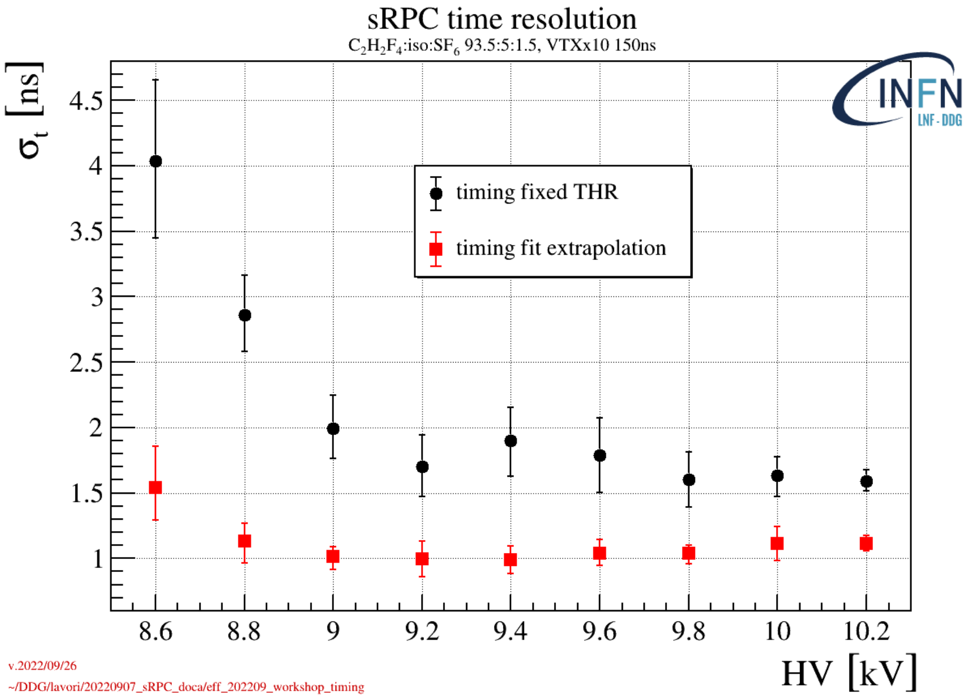
The cathode puzzle (III)

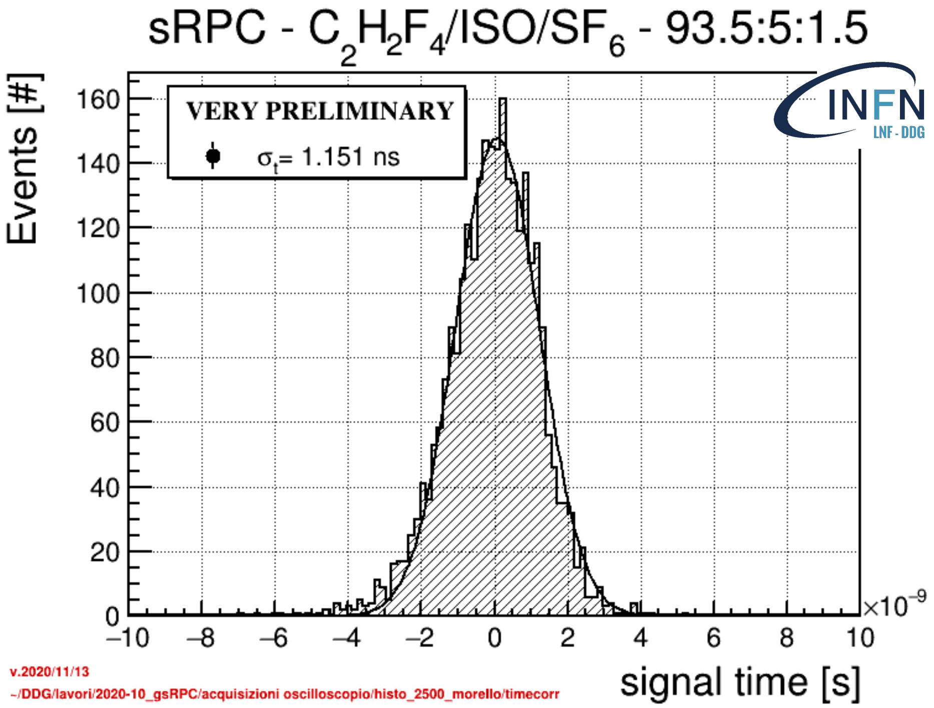




Detectors with **Licron cathode passivation** show an **efficiency plateau of the order (or larger than) of 1 kV,** while a **long-term test** to verify the **detector stability** is in progress.

Time resolution

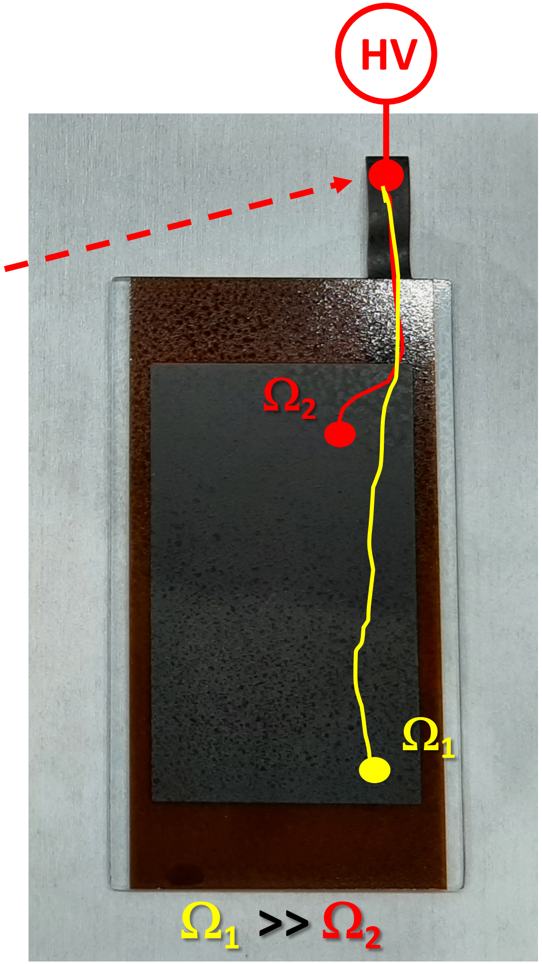




LR (baseline) layout limitation

A **drawback** of the **surface resistivity electrode** with **single dot-like current evacuation scheme** is that, beside the **reduced capability to stand high particle fluxes,** the **detector response is not uniform** over its surface.

This is more evident as the **size of the detector increases**. This effect is correlated to the **average resistance (Ω)** faced by the charge/current produced in the avalanche that **depends on the distance between** the **particle incidence position** and the **current evacuation point** on the electrode.

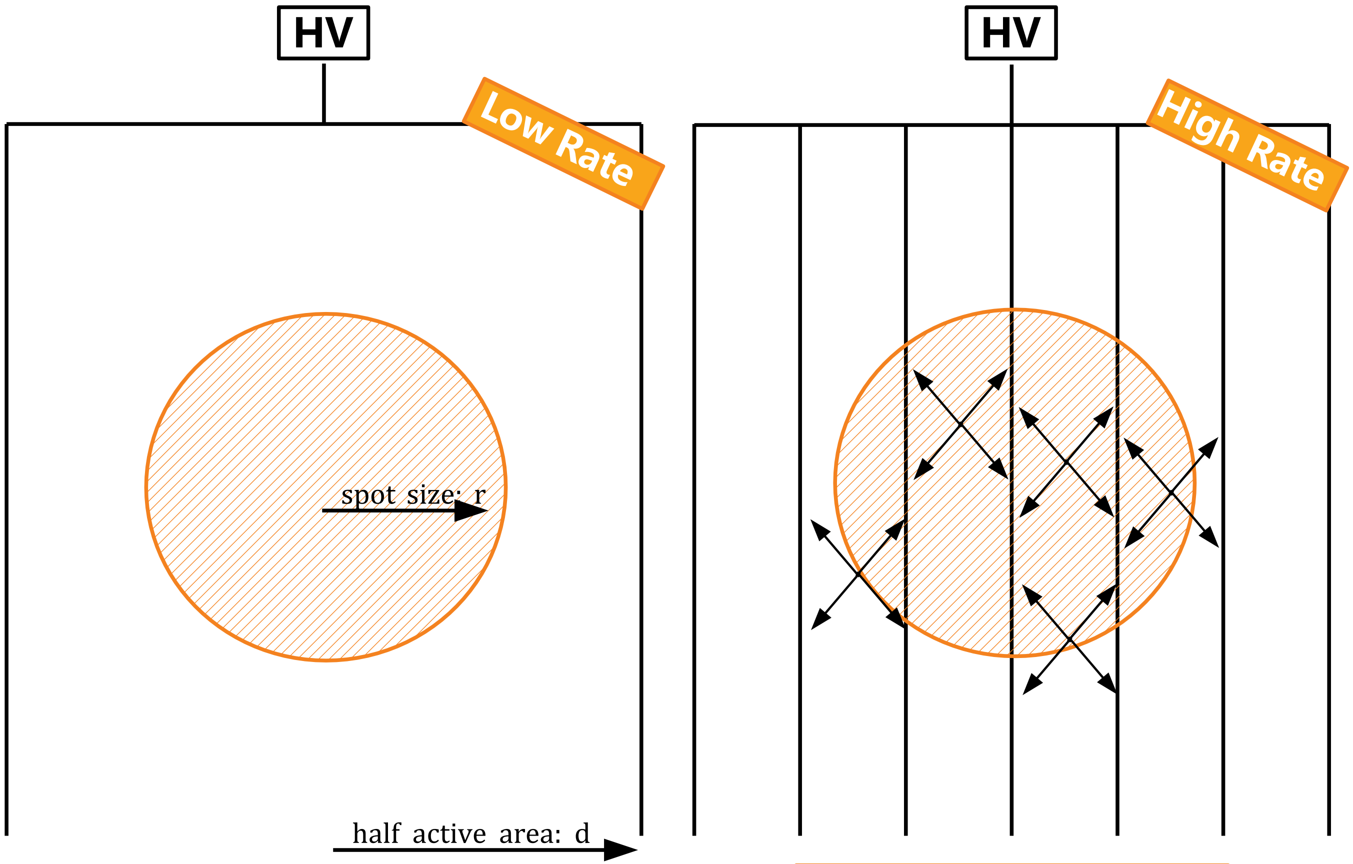


High Rate layout – design

Exploiting **our experience** done **with the R&D of the μ-RWELL**, the solution could be the implementation of a "dense" conductive network on the resistive electrode.

In this way the average path of the current towards the evacuation connection is reduced thus improving the rate capability of the detector, while increasing the detector response uniformity.

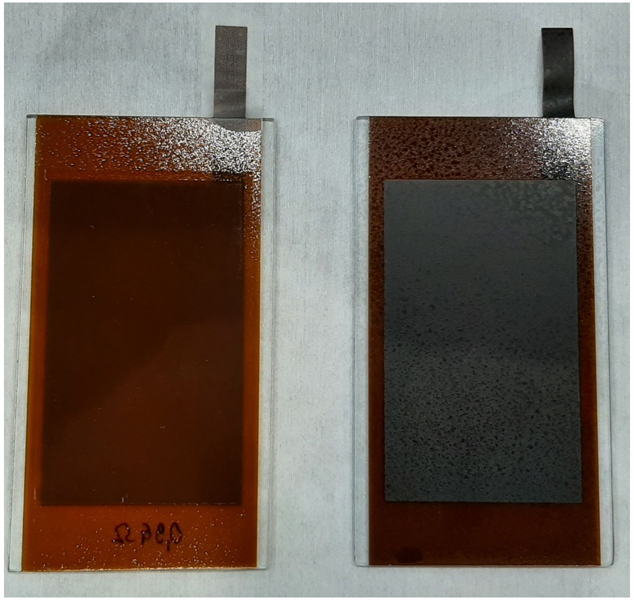
The performance of such a HR layout depends on the **DLC resistivity** as well as the **pitch of the conductive network**.



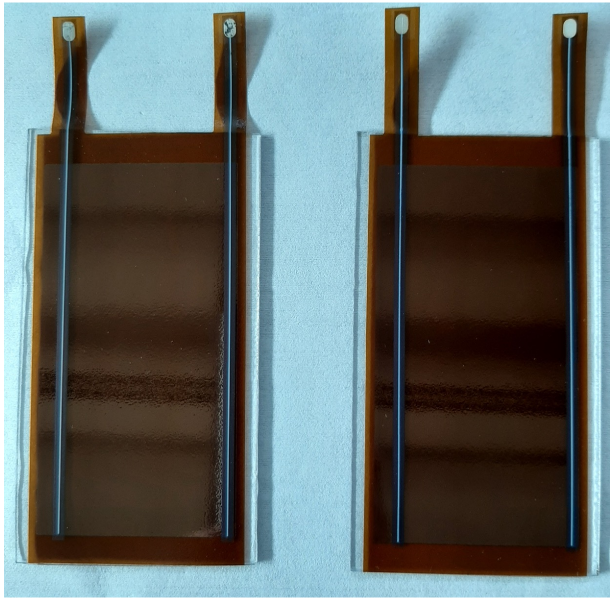
A sort of tassellation with smaller low rate schemes.

LR vs HR layout (II)

High-rate: same structure **as Low-rate electrode ⊕ conductive grid** acting as a **fast current evacuation** scheme

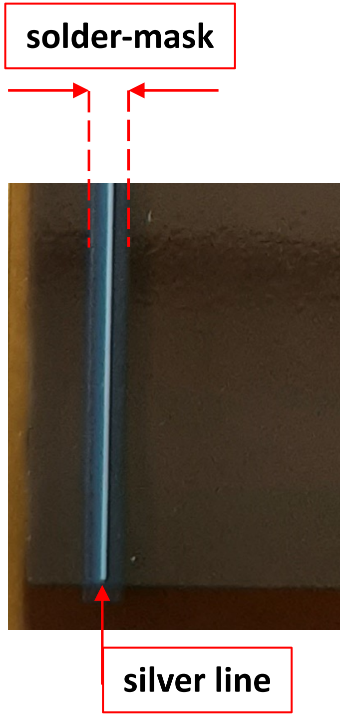


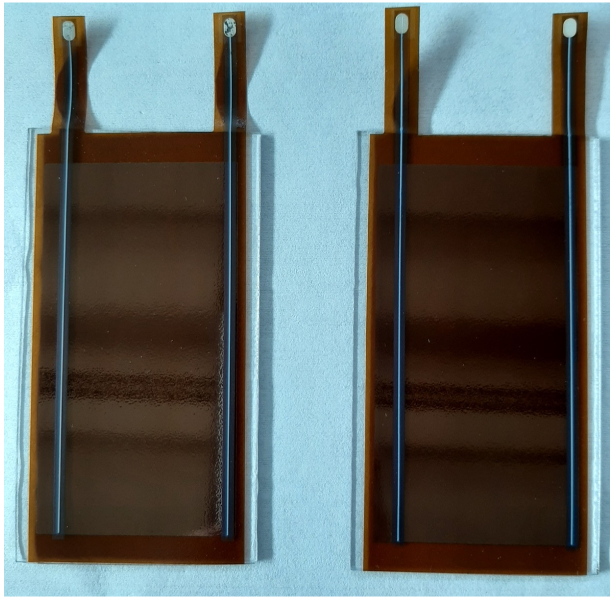
Low-rate: DLC sputtered **on Apical® foil** then **glued** on **2 mm thick float glass**

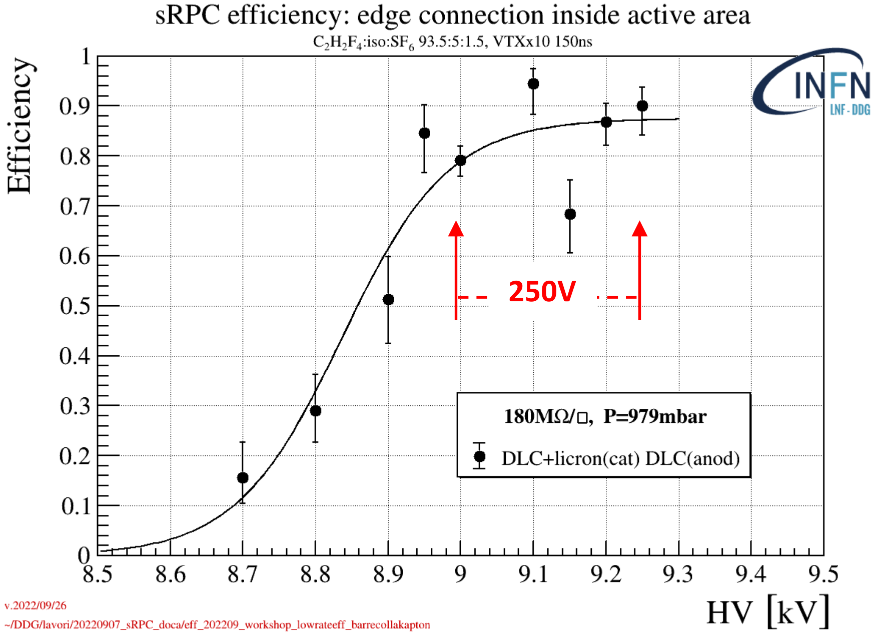


The **conductive grid** is realized by **0.3 mm wide silver screen-printed lines.** A **5 mm wide solder-mask** strip deposited **on the silver lines** ensures the **insulation. Width** and **thickness** of the **solder-mask** still **to be optimized.**

High-rate layout (I)



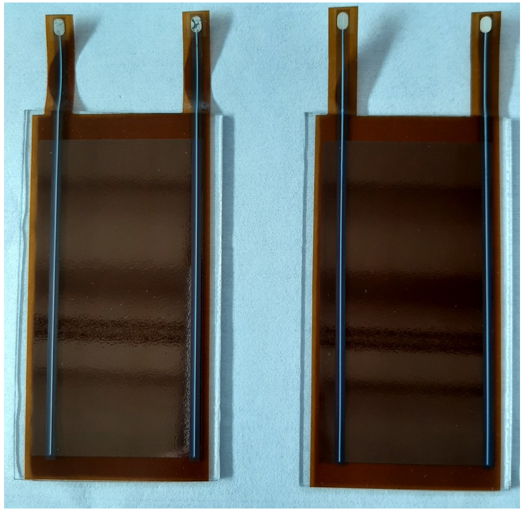




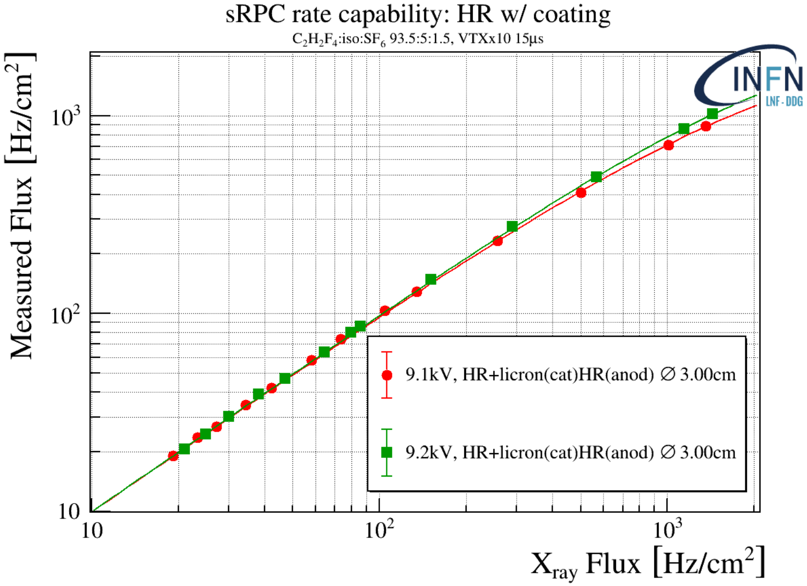
The implementation of **conductive lines** on the DLC, even though protected with **solder-mask**, seems to introduce an **instability at higher voltage,** sensibly **reducing the plateau width wrt the baseline** version.
The problem is still to be solved, discussion about solder-mask characteristics is in progress.

High-rate layout: preliminary rate capability

A preliminary measurement of the **rate capability** *(defined as the radiation flux corresponding to an efficiency drop of 20%)* of the **high-rate layout** has been performed by irradiating the detector with **a 5.9 keV X-ray gun** with a **spot size comparable with the pitch of the conductive grid** realized on the **DLC** (ρ_{DLC}~200 MΩ/□).



Layout still to be optimized (resistivity, grid-pitch, insulation …)



Rate capability of ~**1 kHz/cm^2 with X-ray,** corresponding to ~ **3 kHz/cm^2 m.i.p.**

sRPC behind HEP: thermal neutron detection

WHY

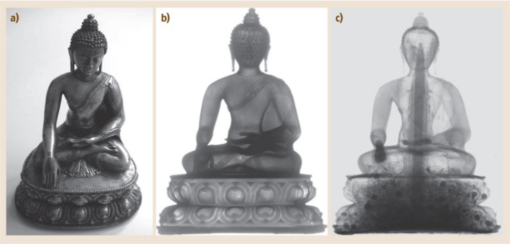
- **Probing heavy structure in motion**
- High penetration power

- **Radioactive waste monitoring**
- **Radiation Portal Monitor** (homeland security)
- **Neutron tomography**

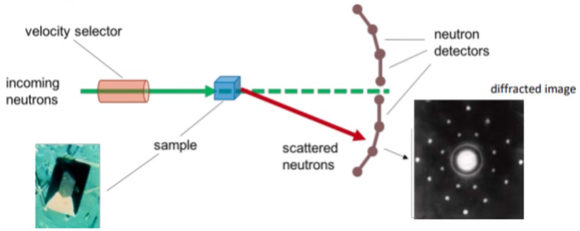
→ see M. Giovanetti poster – **Thermal neutron detection based on resistive gaseous devices**

HOW

Low Energy: Exoenergetic Nuclear Processes
Use **converter medium** with large capture cross-section



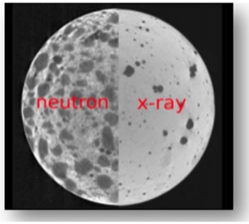
- Neutron diffraction imaging

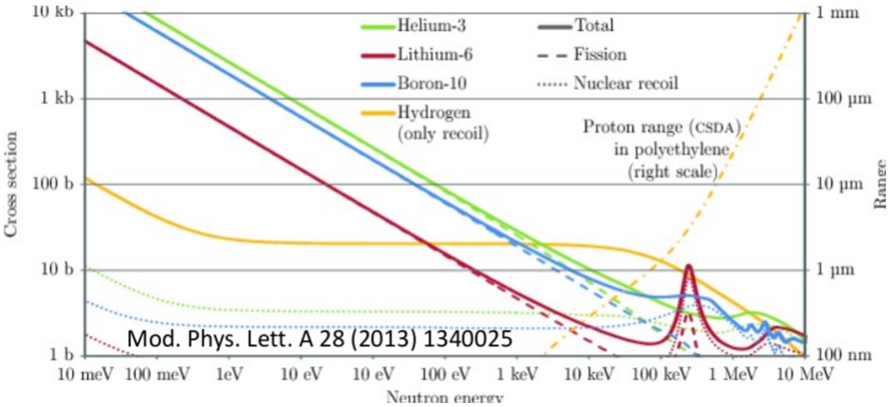


- Radioactive waste monitoring (PuO_2 or PuF_4)

- Radiation Portal Monitor (RPM) for homeland security

- Complementary to X-ray imaging





Cross section for common conversion materials

Summary

By exploiting the technology based on the **industrial DLC sputtering procedure** developed for **resistive MPGDs** we realized **electrodes** with **different surface resistivity** for a **new promising RPC concept**

- The **baseline version** of the detector (*dot-like HV connection* ⊕ *cathode passivation with Licron*) exhibits **high stability (ΔV ≥ 1kV)** and **good performance** in terms of **efficiency (~95%)** and **time resolution (~1 ns)**

- The **High-rate** version based on **current evacuation** schemes realized **with conductive grids** shows **some instability,** while a **rate capability** of **~3kHz/cm²** with **m.i.p,** has been measured

- Detector **stability** (*grid insulation and geometry …*) and **optimization** studies in terms of **DLC resistivity, grid-pitch** (…) are the **priorities** for the near future

- **Engineering** studies, replacing glass support with **standard PCB** (SBU tech.)

- **The DLC** sputtering process is a **scalable technology** allowing to realize **large area electrodes at low cost:** the **CERN-INFN DLC** sputtering facility allows the manufacturing of ~**2x0.5 m DLC foils**

SPARE SLIDES

Diamond Like Carbon

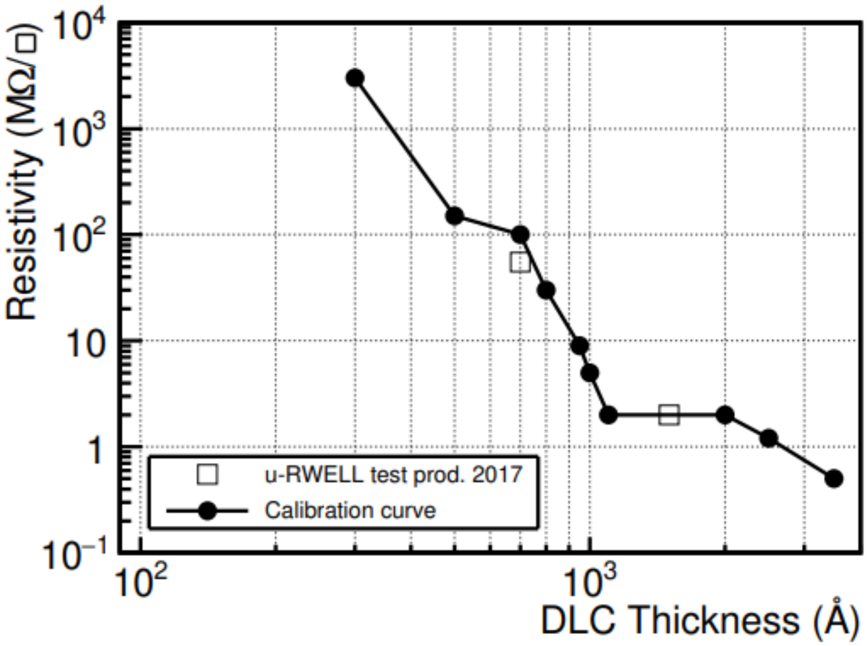
The **DLC sputtering technology** is used in many **industrial applications** (mechanics, automotive and medical industry) that require **surface hardening and reduced abrasive wear.**

The **DLC is a class of carbon material** that contains both the **diamond** as well as **the graphite structure** in different fractions, depending on sputtering parameters.

The **DLC film (typically 0.1 μm thick) is deposited** by sputtering **graphite** on one side of a **large Apical® foil.** The resistivity depends on the DLC thickness and gas atmosphere used in the process.

The production of **DLC Apical® foils for our detectors (μ-RWELL, MicroMegas, sRPC**) has been done by the **Be-Sputter Co., Ltd. in Japan (size ~1.2x0.6 m²).**

In the near future a **DLC machine, co-funded by CERN and INFN,** will enter in operation at the **CERN MPT- Workshop (size ~2x0.6 m²).**



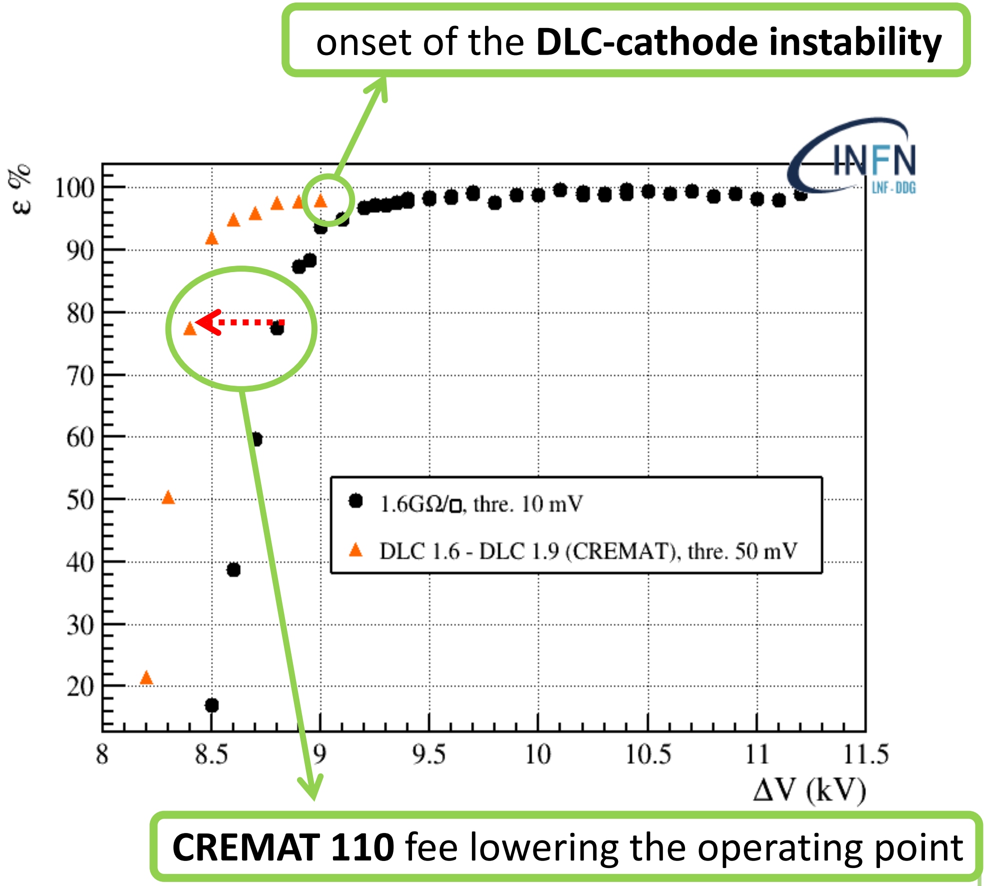
DLC-DLC vs DLC-float_glass layout

Symmetrical

- **DLC (anode) – DLC (cathode)** electrodes shows **instability at high voltage**
- possible **photon-feedback or/and field emission effects** on the **DLC surface** of the cathode
- with more sensitive electronics **few hundreds of Volts of stable operation can be found**

Hybrid

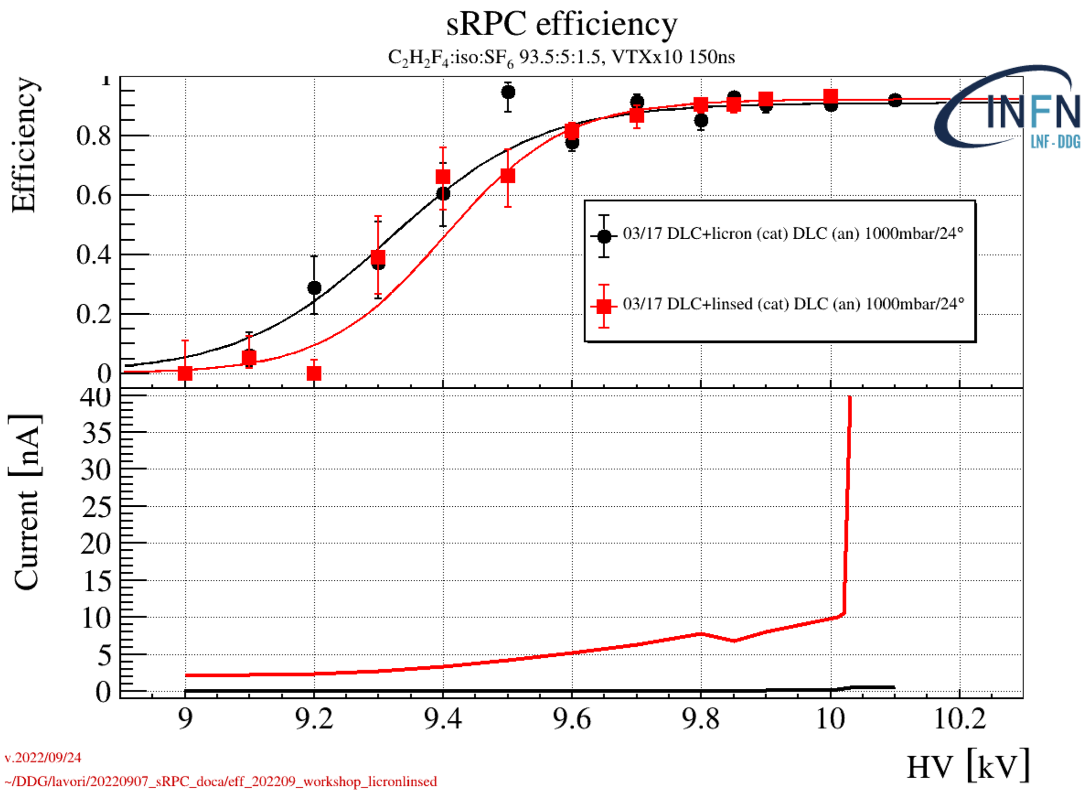
- **DLC (anode) – float glass (cathode)** electrodes shows high stability (plateau larger than to 2 kV)
- **Float-glass cathode** does **not** suffer of **photon-feedback or field emission effects**
- **not a solution for high-rate** because limited by the relatively **high resistivity of the float-glass**



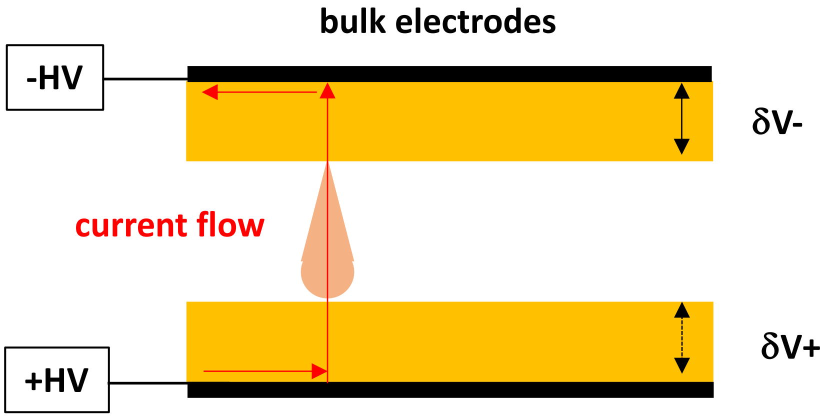
Linsed-oil vs Licron (dot-like HV connection)

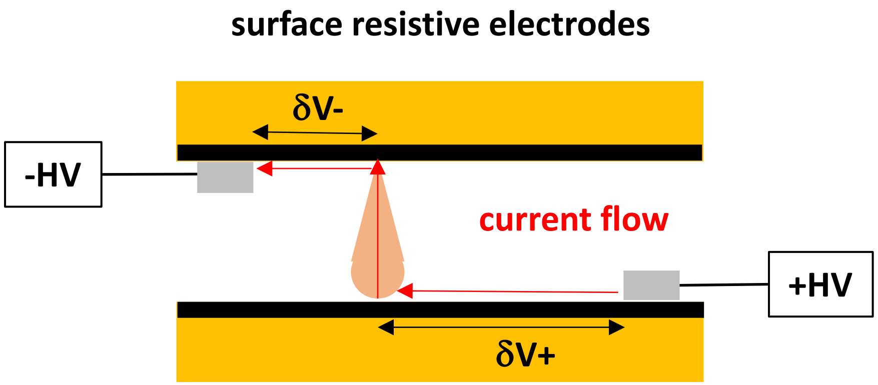
Main **differences** between **linsed-oil** and **Licron:**

- $\rho_{\text{linsed-oil}} >> \rho_{\text{Licron}}$
- **Licron is easier to apply/engineering**
- Detectors with DLC cathode passivated with **linsed-oil** show **dark current** and **breakdown at high voltage**



Bulk-RPC vs Surface-RPC





$\tau = f(\rho_b, \varepsilon_r, d, g)$

$\tau = f(\rho_S, p, \ldots)$