59th International Winter Conference on MPGD - January 26th , 2023

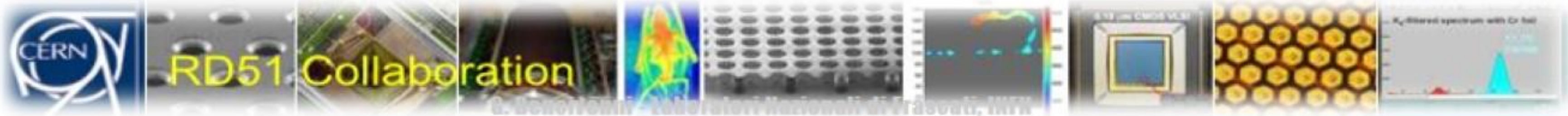
sRPC: an RPC based on resistive MPGD technology

G. Bencivenni[1]

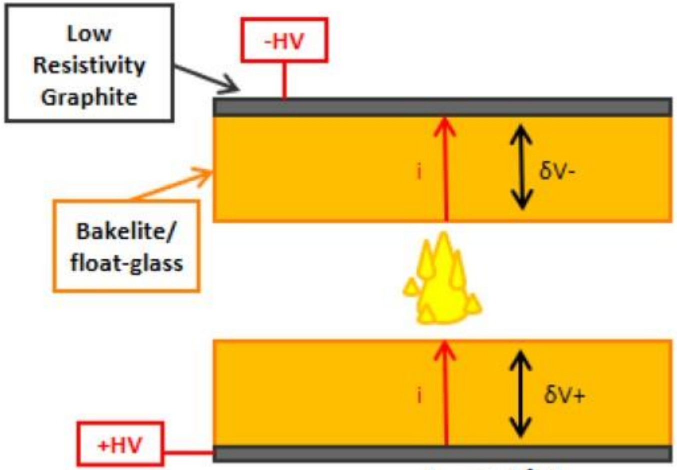
R. De Oliveira[2], G. Felici[1], M. Gatta[1], M. Giovannetti[1]
G. Morello[1], G. Papalino[1], M. Poli Lener[1]

[1] LNF– INFN
[2] CERN

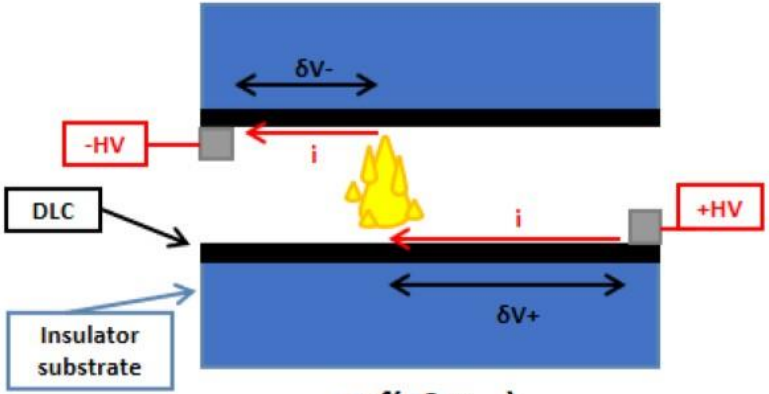
INFN
LNF - DDG



Bulk RPC vs Surface RPC



$\tau=\rho_v\varepsilon_0(\varepsilon_r+2d/g)$



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

Classical RPC

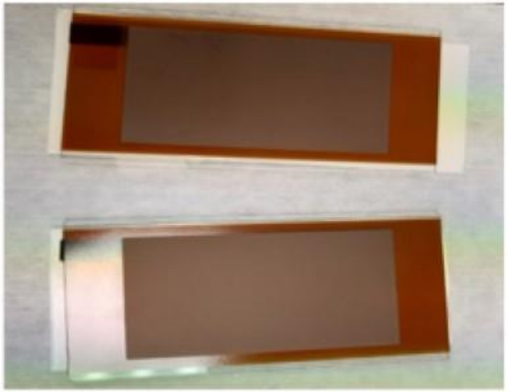
- Bulk resistivity electrodes (bakelite, float-glass, semiconductive glass, ... SI-GaAs)
- Recovery time proportional to **volume resistivity, electrode thickness, gas gap → $\tau=\rho_v\varepsilon_0(\varepsilon_r+2d/g)$**
- **Low volume resistivity** and **thin electrodes**, together with the **reduction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

Surface RPC

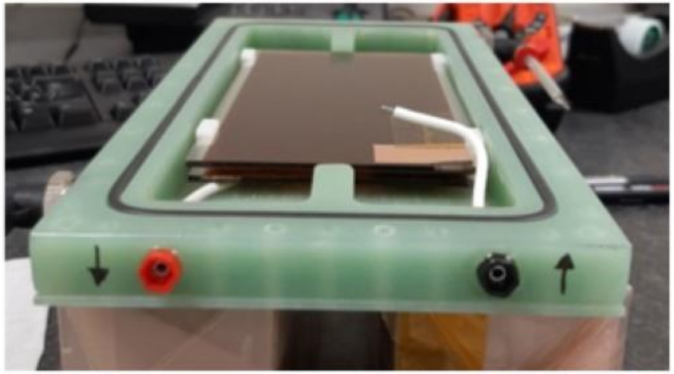
- **Surface resistivity electrodes** manufactured by sputtering **Diamond-like-carbon** (DLC) on flexible supports
- The technology allows to realize large electrodes with a **surface resistivity** in a **very wide range: 10 MΩ/□ ÷ 10 GΩ/□**
- **High density current evacuation schemes**, similar to those 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 **for mechanical purpose:** excellent planarity and very smooth surface
- The **2 mm gas gap** between the two electrodes is ensured by E-shaped spacers made of Delrin®
- The electrode stack is inserted in a FR4 box that acts as gas volume container



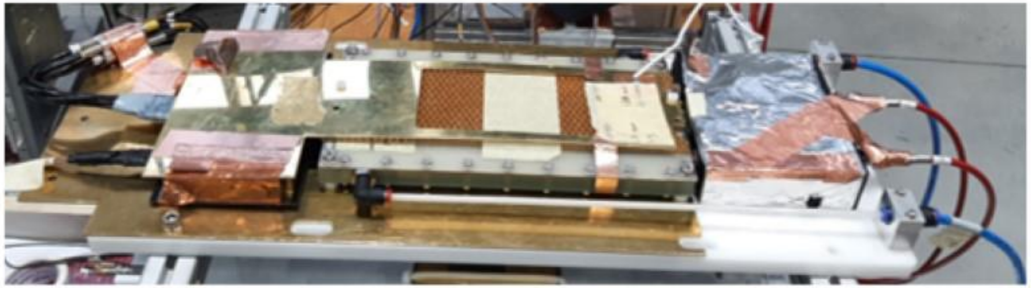
Glass 140×78 mm^2
DLC 120×64 mm^2



Patent: Brevetto-Italia N. 102020000002359 (submitted to INFN 10 Sept 2019 - registered at the patent office 6 Feb 2020)
INFN – "ELETTRODO PIANO A RESISTIVITÀ SUPERFICIALE MODULABILE E RIVELATORI BASATI SU DI ESSO."

Prototype layout (II)

- The **HV** to **DLC electrodes** is supplied through a **dot-like connection** realized on **DLC tails** bent on the **back 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

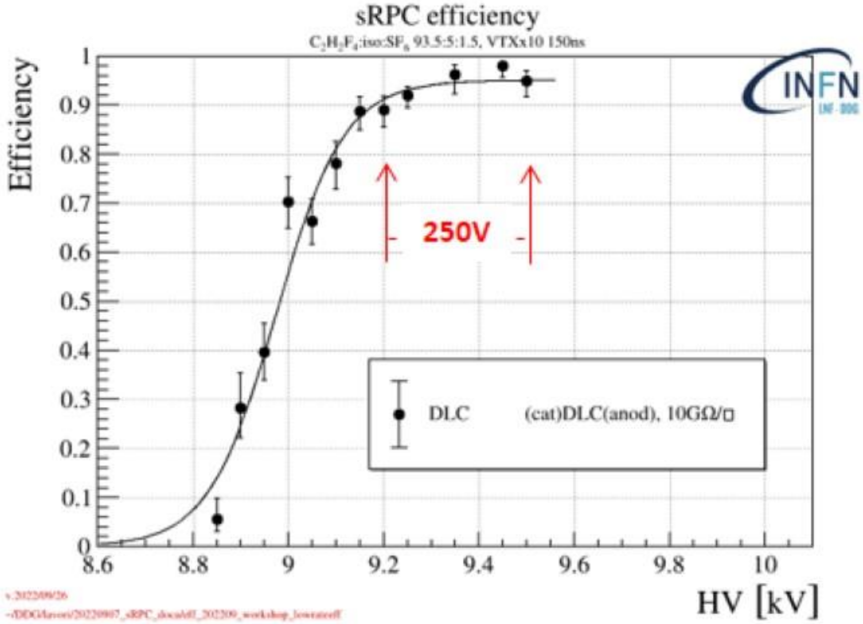


The cathode puzzle (I)

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.**



Hypothesis: is the DLC cathode the source of the instability?

[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 (III)

Possible solution: create 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.**

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

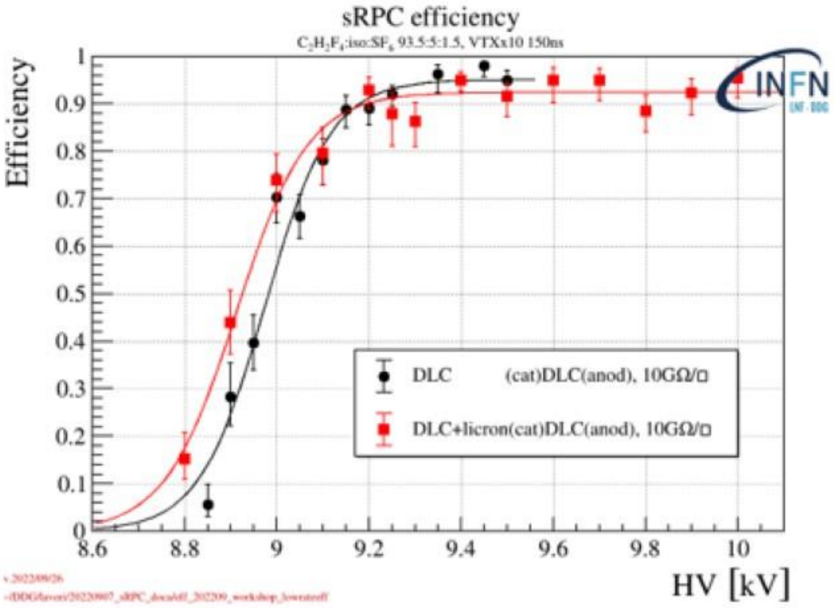
$\rho_{DLC} \sim \rho_{film}$

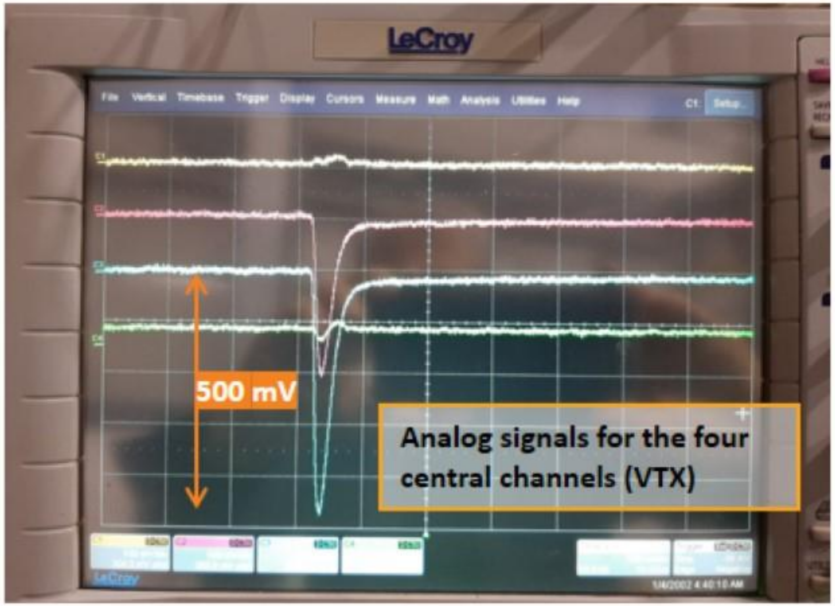
Features / Benefits

- 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

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

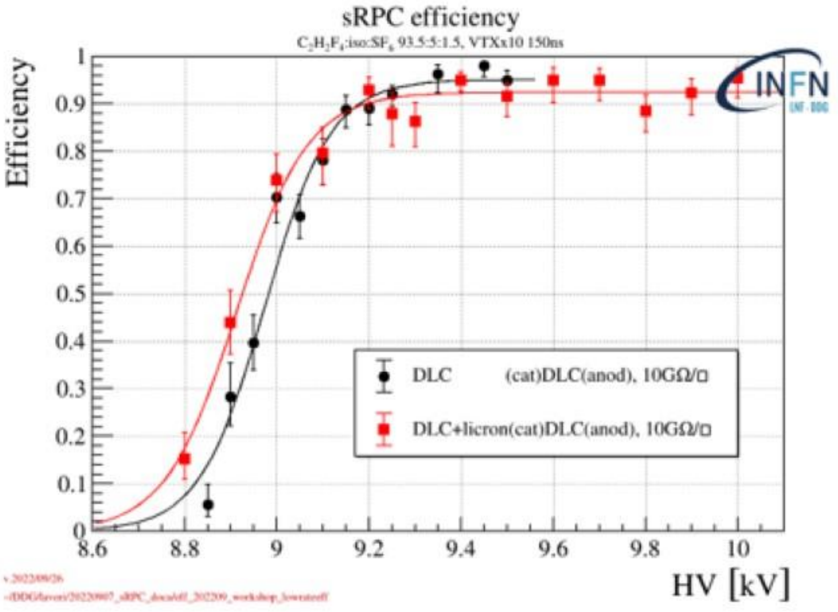
The Cathode Puzzle (IV)

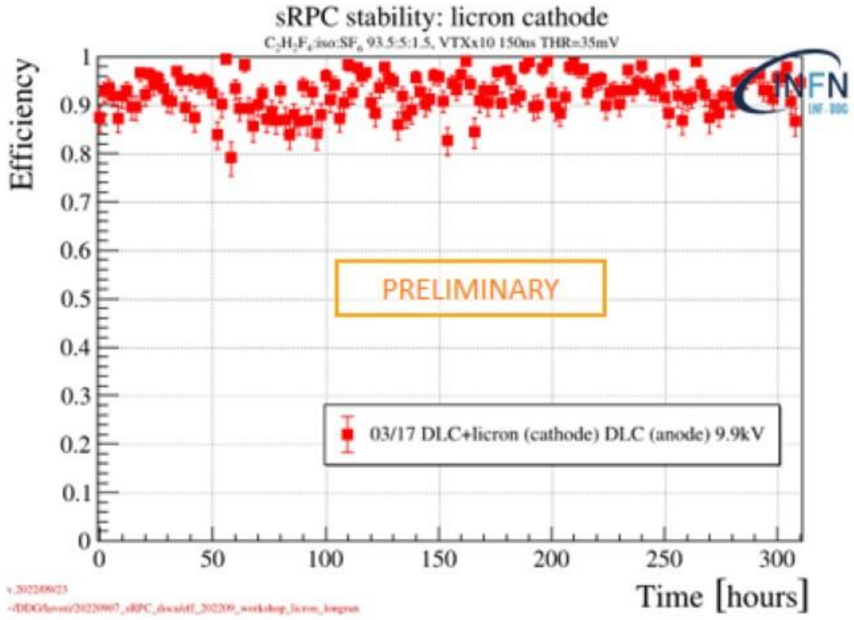




Detectors with **Licron** cathode passivation **show an efficiency plateau** of the order (or larger than) **of 1 kV**, while a long-term test to verify the detector stability is in progress.

The Cathode Puzzle – IV



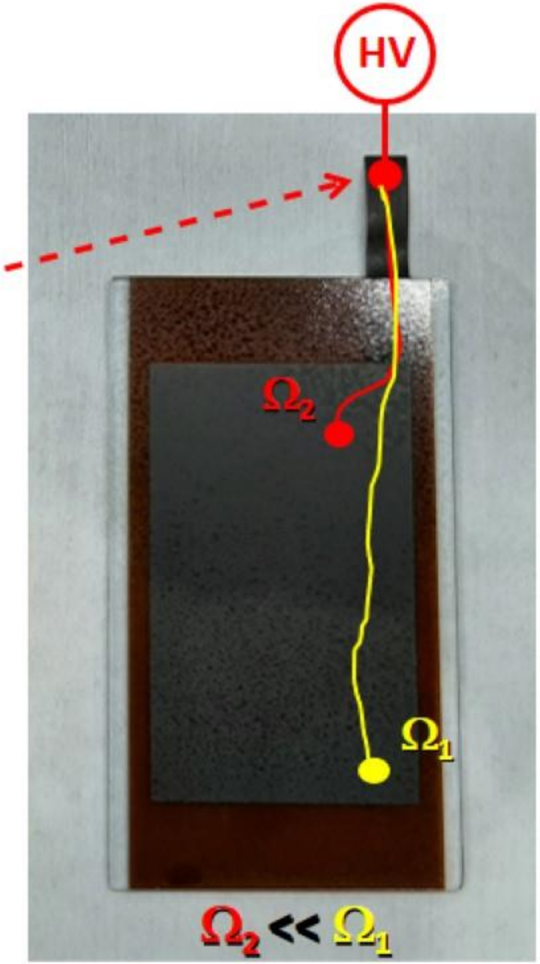


Detectors with **Licron** cathode passivation **show an efficiency plateau** of the order (or larger than) **of 1 kV**, while a long-term test to verify the detector stability is in progress.

Low-rate 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.

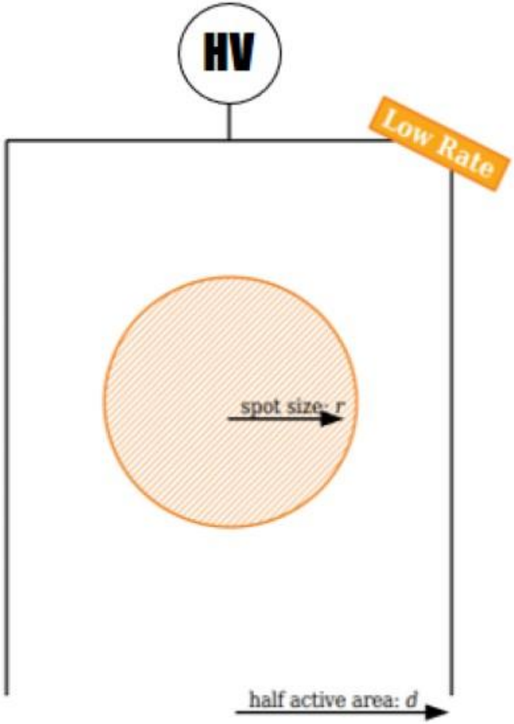


LR vs HR layout (I)

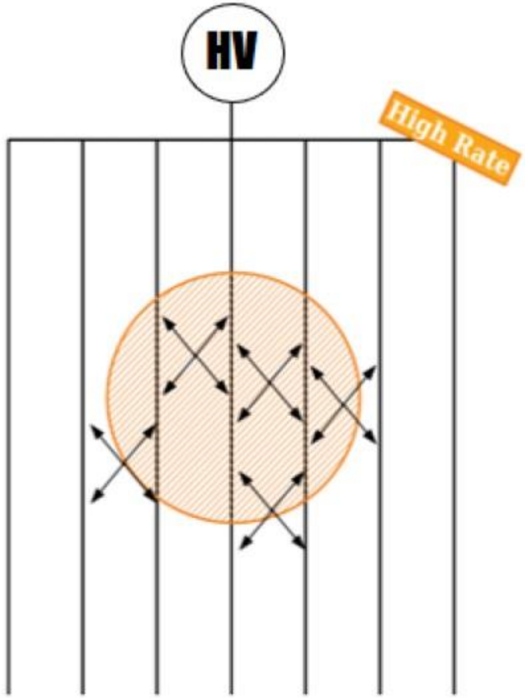
Exploiting the **R&D on the μ-RWELL**, the solution could be the implementation of a **“dense” conductive network** on the **resistive electrode.**

In this way the **average path** of the **current towards the evacuation connection is reduced** thus **improving the rate capability** of the detector, as well as its **response uniformity.**

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



LR layout

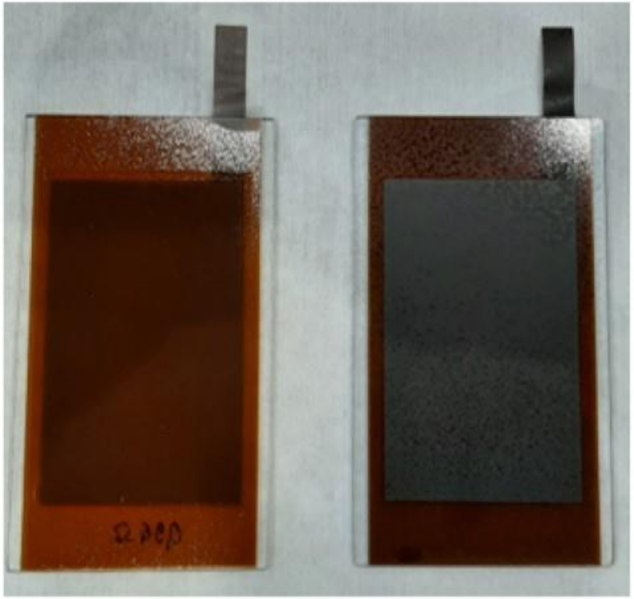


A sort of tassellation with little low rate schemes.

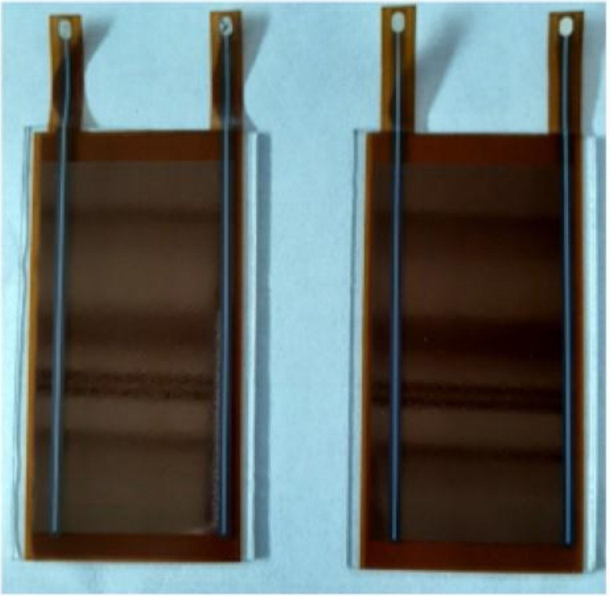
HR layout

LR vs HR layout (II)

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



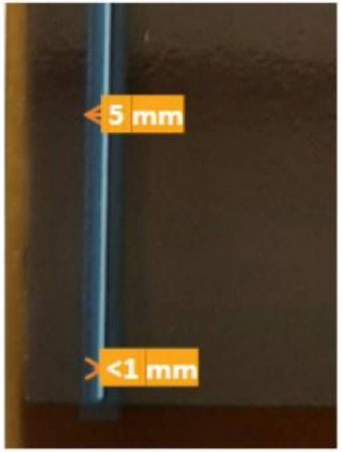
Low-rate: DLC sputtered **on Apical® foil** then **glued** on **2 mm thick float glass**

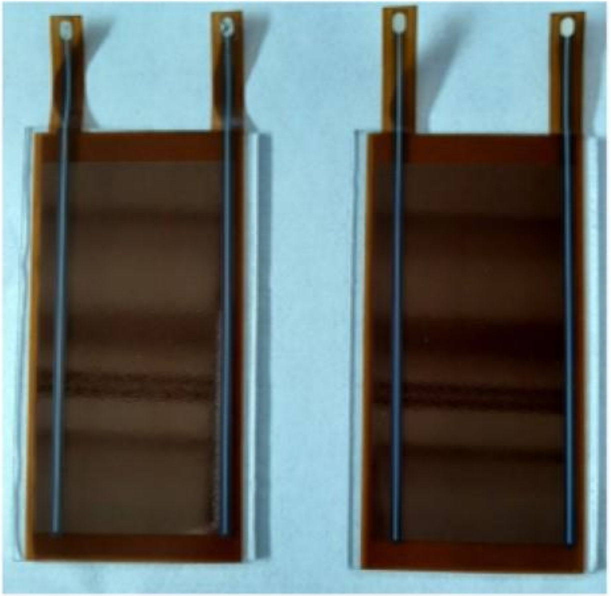


The **conductive grid** is realized by **1 mm wide screen-printed silver lines.** A **5 mm wide solder-mask** strip deposited **on the silver lines** ensures the **insulation. Width** and **thickness** of the **solder-mask** still **to be optimized.**

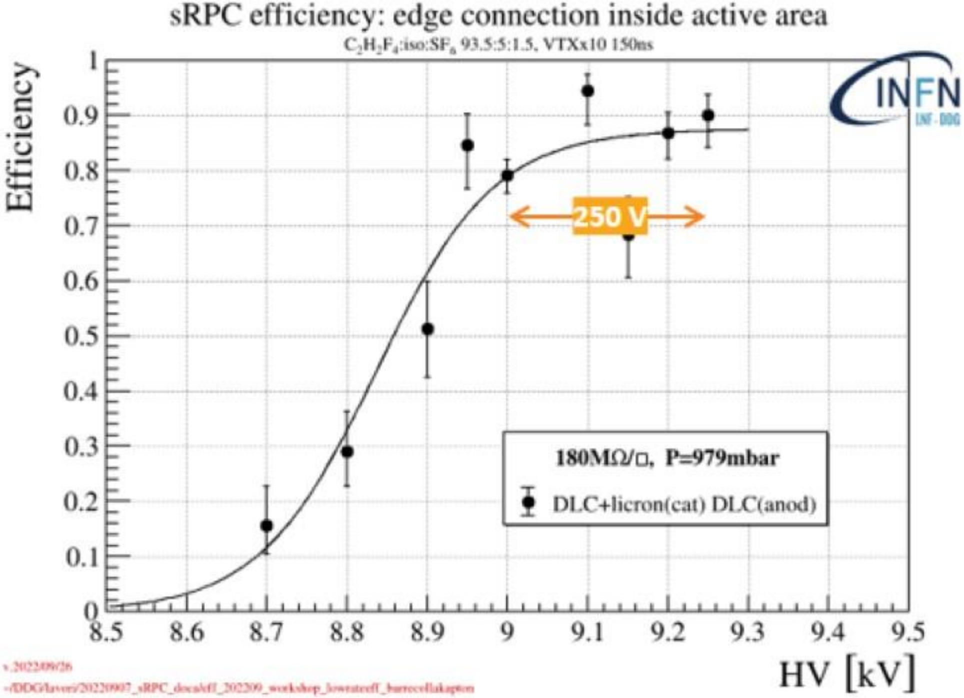
High-rate layout: preliminary results (I)

soldermask





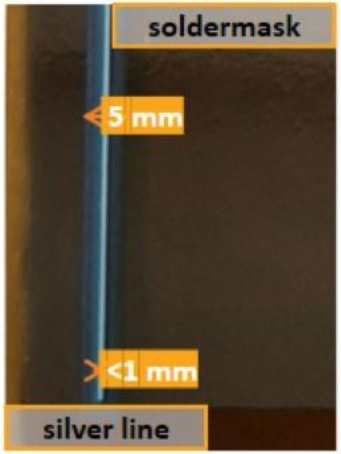
silver line

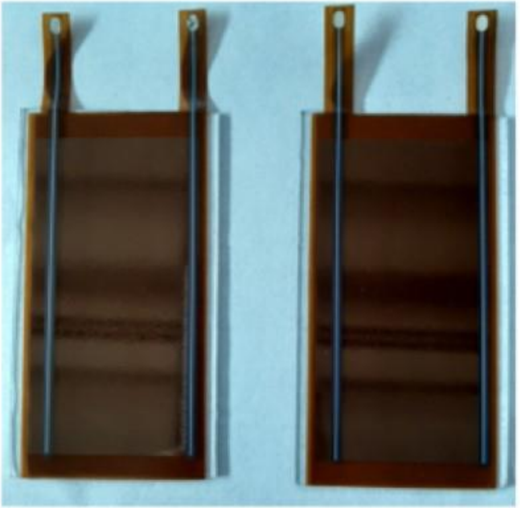


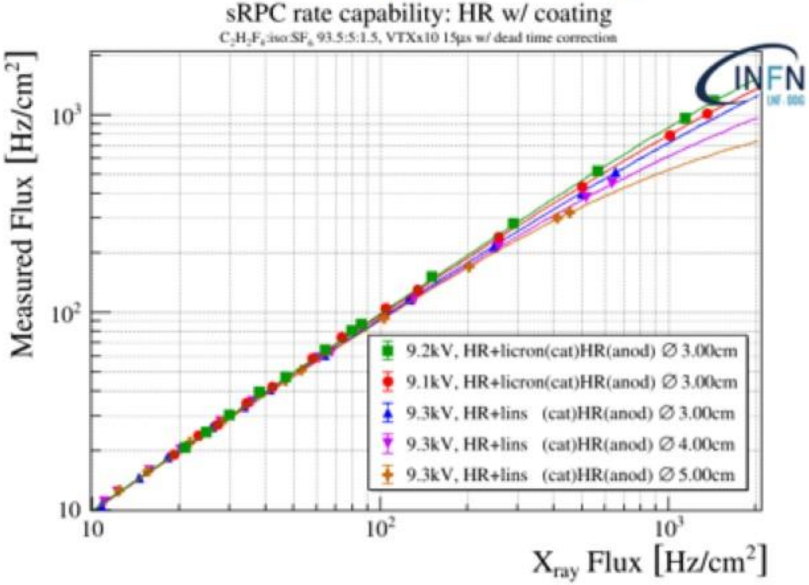
The implementation of **conductive lines** on the DLC, even though protected with solder-mask, **seems to introduce an instability at higher voltage,** sensibly reducing the plateau width w.r.t. the baseline version. The problem has **still to be solved** (solder-mask insulation, DOCA, etc ...)

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 (1.6 GOhm/sq)**



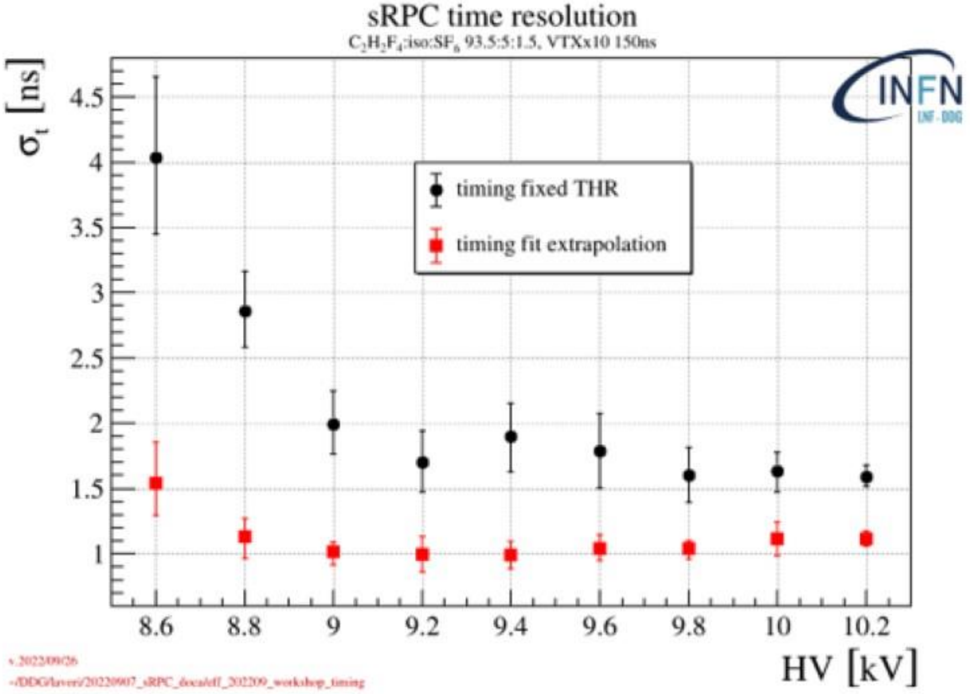


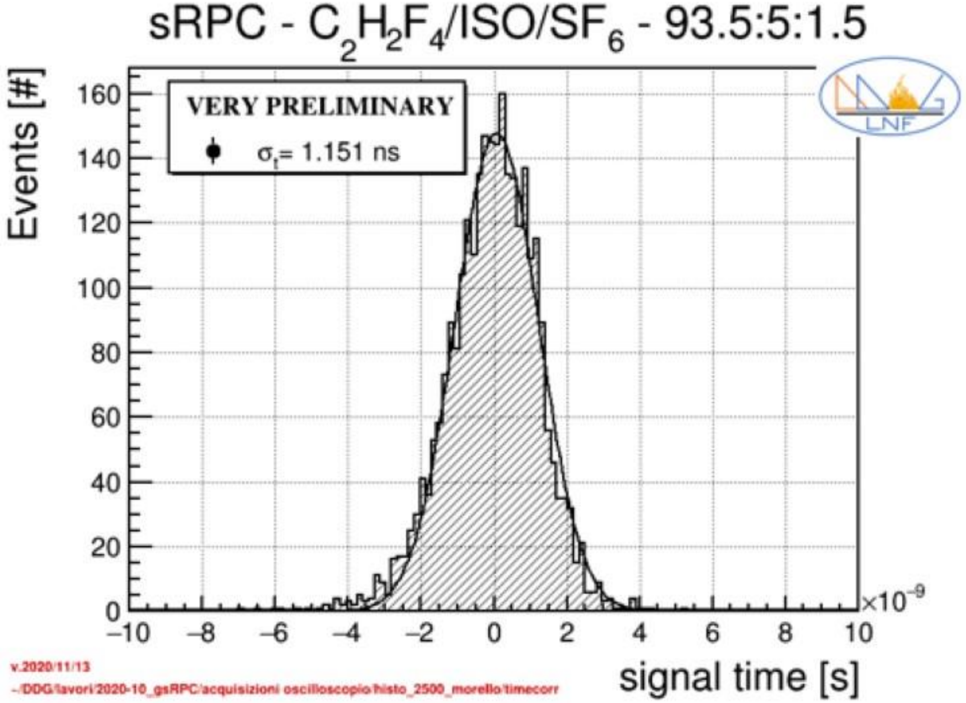


Layout still to be optimized (resistivity, grid-pitch, insulation …)

Rate capability of ~**1 kHz/cm² with X-ray,** corresponding to ~ **3 kHz/cm² m.i.p.**

Time resolution





$\sigma_t \sim$ 1ns → typical for 2 mm gas gap RPC

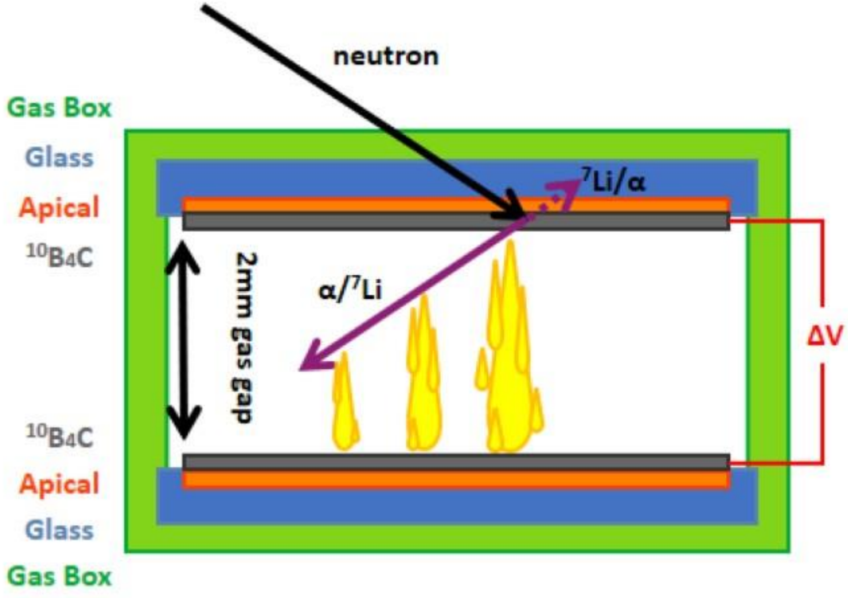
sRPC for thermal neutron detection (I)

Detecting thermal neutrons (E_k ~25meV) **with sRPC:**

- ^{10}**B$_4$C** deposition (*) on one or both detector electrodes
- Neutron interacting with ^{10}**B converts** in **back-to-back α/^{7}Li**

$$\mathrm{n}+{}^{10}_{5}\mathrm{B}\begin{cases}{}^{7}_{3}Li(1.02MeV)+\alpha(1.78MeV) & 6\% \\ {}^{7}_{3}Li(0.84MeV)+\alpha(1.47MeV)+\gamma(0.48MeV) & 94\%\end{cases}$$

- **2.5 µm** thick ^{10}**B$_4$C** planar converter → ~ 4% **neutron detection efficiency**



- α/^{7}Li emission is **isotropic**
  ⇒ they enter the gas gap with a random angle
- α/^{7}Li **mean path** is **shorter than 2mm**
  ⇒ cathode and anode have different behaviour

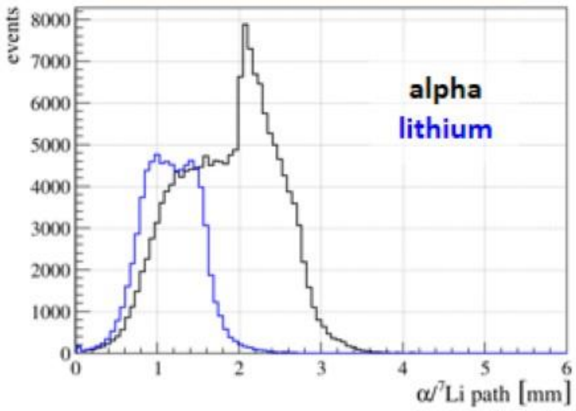
Advantages of the device:

- **simple technology** → high efficiency **multi-stack structure** easy to be implemented
- **scalable technology →** exploitable for Radiation Portal Monitor (homeland security)

(*) see G. Morello's talk , 27/01 – micro-RWELL in HEP and beyond

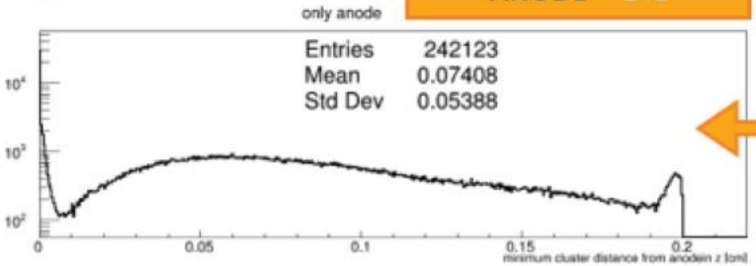
sRPC for thermal neutron detection: simulation

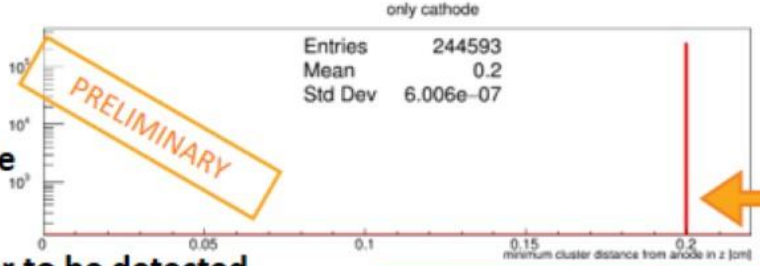
Path in gas for α and ^{7}Li



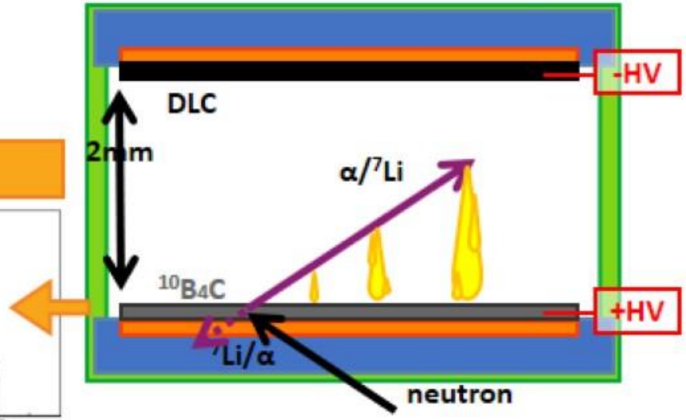
GEANT4/Garfield++ simulations for α: closest e^{-} to the cathode

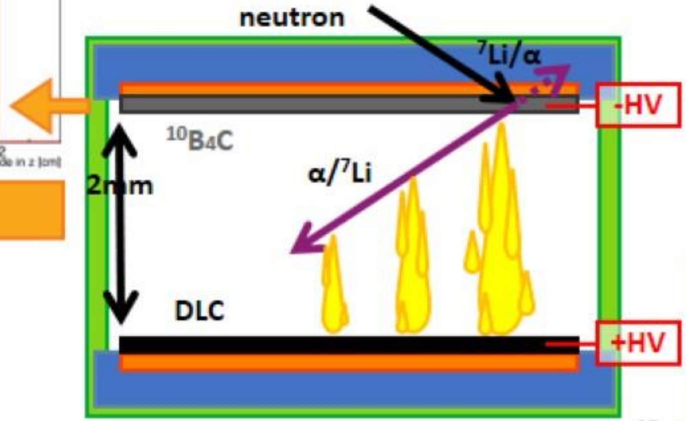
ANODE $^{10}B_4C$





CATHODE $^{10}B_4C$





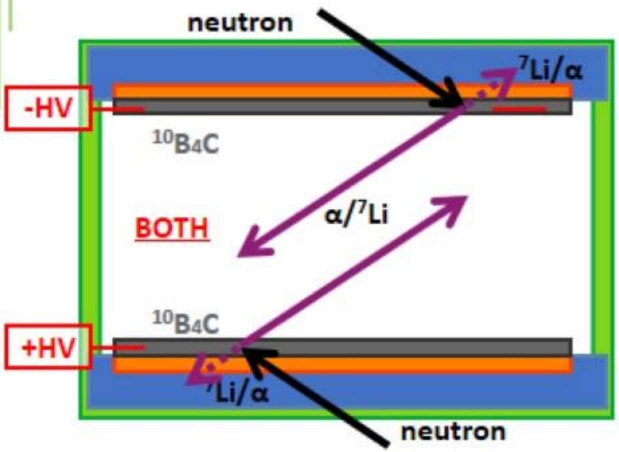
- **RPC principle of operation**: signal **amplitude strongly depends on the distance** of the ionization **e^{-} from the cathode**
- mean path of α/^{7}Li in gas ≤ gas gap

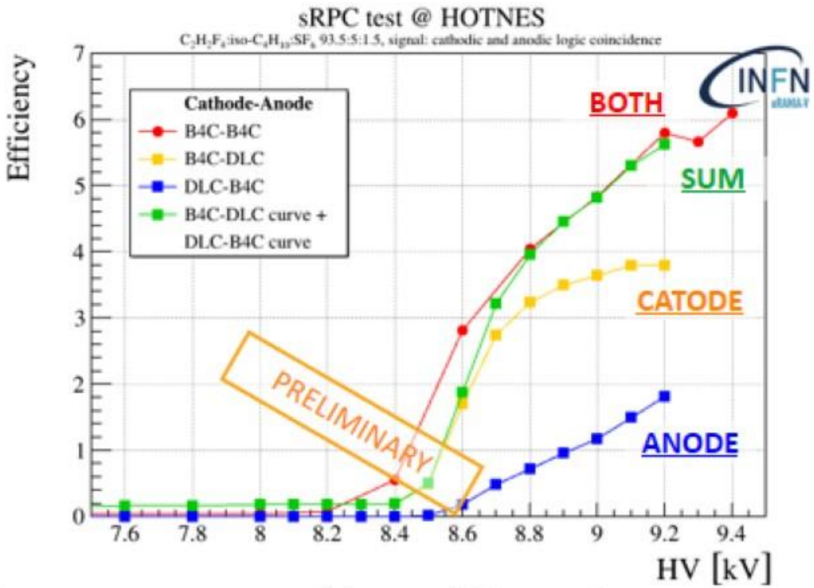
⇒ **α/^{7}Li produced on the anode are harder to be detected than those generated on the cathode**

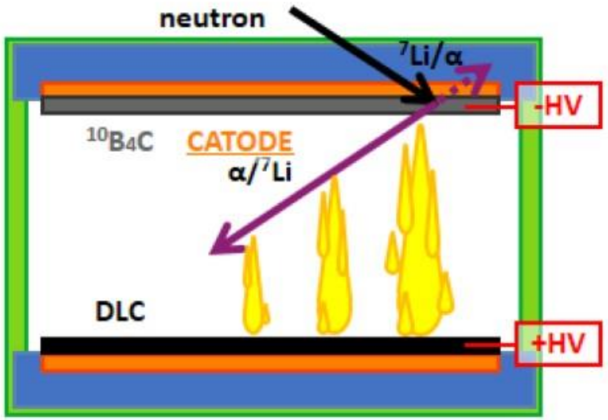
ANODE $^{10}B_4C$: smaller and spread signal → efficiency strongly depends on gain & FEE threshold

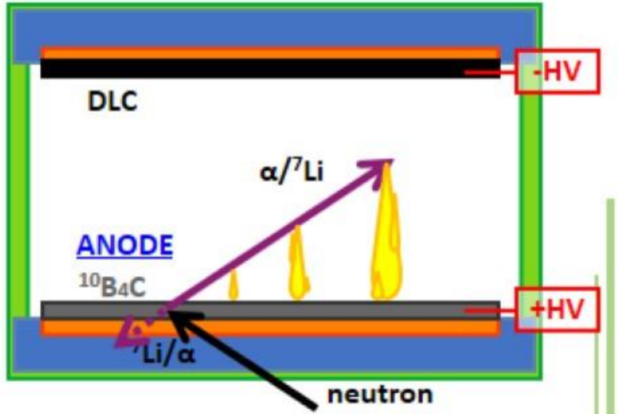
CATHODE $^{10}B_4C$: every event has maximum amplification

sRPC for thermal neutron detection (II)









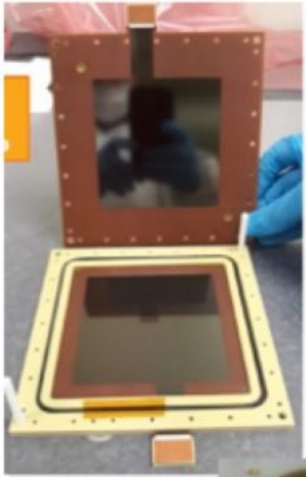
Measurements at HOTNES thermal neutron source w/three different layouts:

- $^{10}B_4C$ **(Cat)** – DLC(An) → ~ **4% efficiency** plateau achieved
- DLC (Cat) – **^{10}B4C (An)** → efficiency strongly depends on HV/gain
- **$^{10}B_4C$ (Cat) – $^{10}B_4C$ (An)** → performs as the **"SUM"** of the two, reaching ~ **6% efficiency**

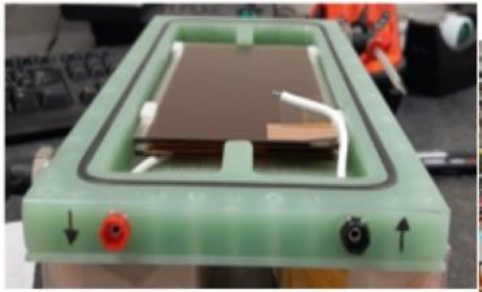
Summary & Outlook

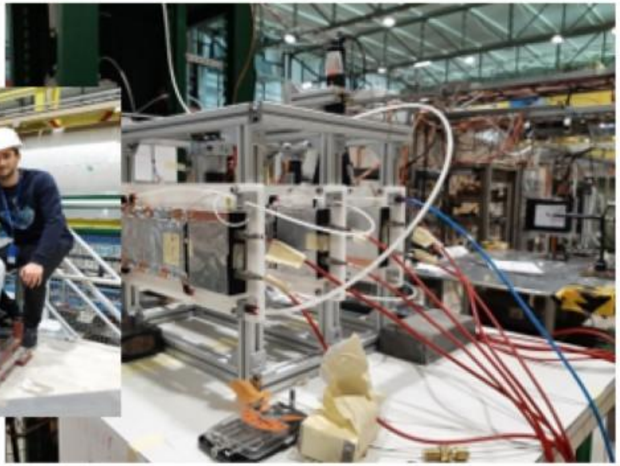
By exploiting the technology based on the **DLC sputtering** developed for **resistive MPGDs** we realized **electrodes** with **different surface resistivity** for a **new promising RPC concept**

- The **baseline version** of the detector exhibits **high stability ($\Delta V \geq$ 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/cm^2** with **m.i.p,** has been measured
  - 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.) will be performed
- The **DLC** sputtering is a **scalable technology** allowing to realize **large area electrodes at low cost:** the **CERN-INFN DLC (CID)** sputtering facility will allow the manufacturing of ~**2x0.5 m DLC foils**
- Very promising results with **boron coated sRPC** have been achieved, opening the way for a **cost effective - scalable thermal neutron detector technology** (for homeland security application)

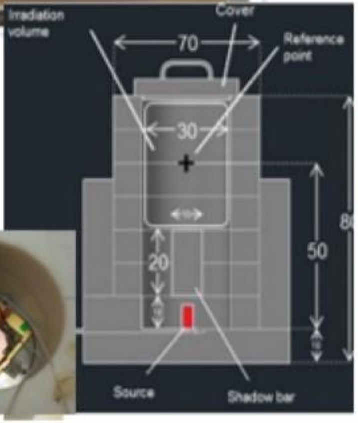



ρ≈1GΩ/□





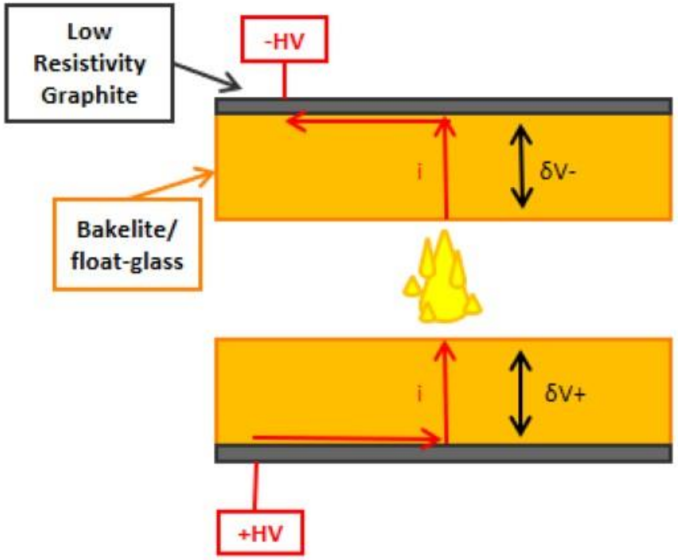
MANY THANKS


Irradiation volume
Cover
70
Reference point
30
20
50
Source
Shadow bar

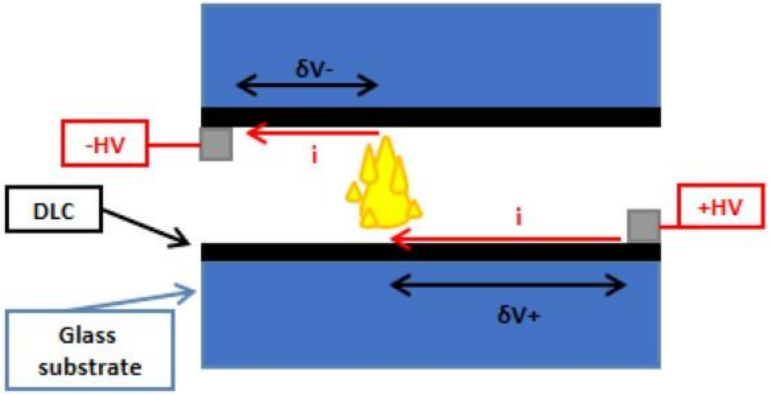

RD51

Spare slides

Bulk RPC vs surface RPC



$$\tau=\rho_V \varepsilon_0(\varepsilon_r+2d/g)$$



$$\tau=f(\rho S,p,\ldots)$$

The graphite layer is coated(O(1 MOhm/□) on the back of the resistive electrode with the aim to supply the HV.
The voltage drop across the bulk electrode is **δV+ ⊕ δV-, does not depend on the incidence position.** The two contributions are equal.

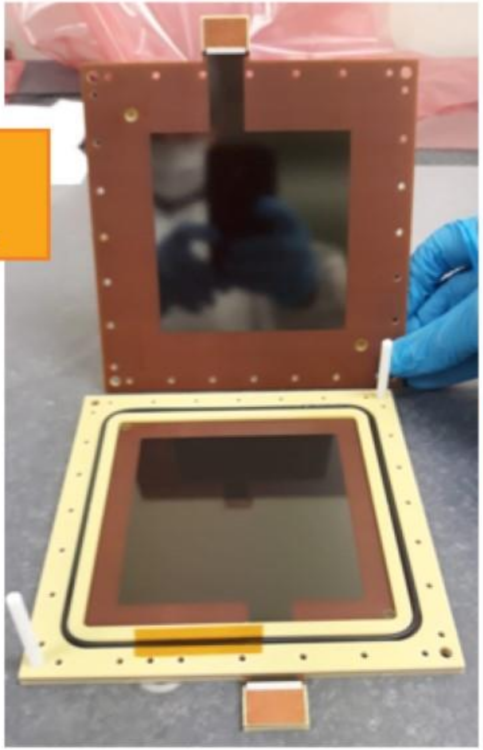
The **voltage drop on the DLC surface, δV+ ⊕ δV-,** depends on the **distance between the event and the ground connection .** The two contributions can be very different, while their sum is roughly constant.

sRPC – evolution from the first prototype

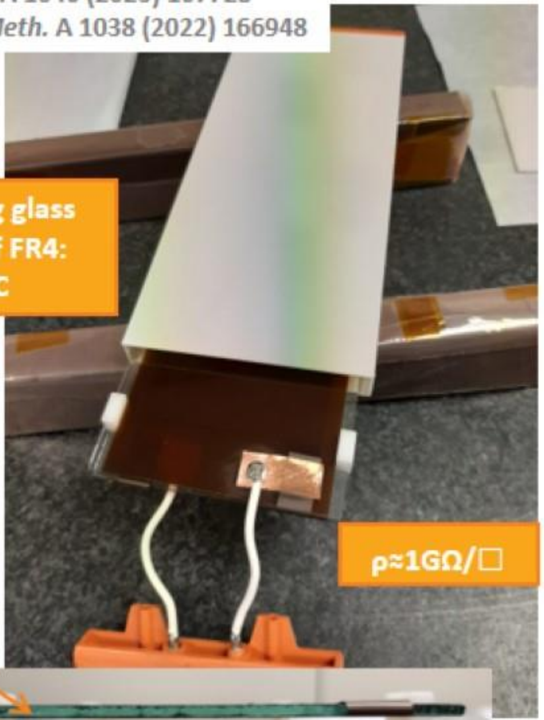
G. Bencivenni et al., *The surface Resistive Plate Counter: An RPC based on resistive MPGD technology, Nucl. Instrum. Meth.* A 1046 (2023) 167728
G. Bencivenni et al., *The surface Resistive Plate Counter: An new RPC based on resistive MPGD technology, Nucl. Instrum. Meth.* A 1038 (2022) 166948


First homemade prototypes

Refined work from CERN PCB workshop



sRPC using glass instead of FR4: gsRPC

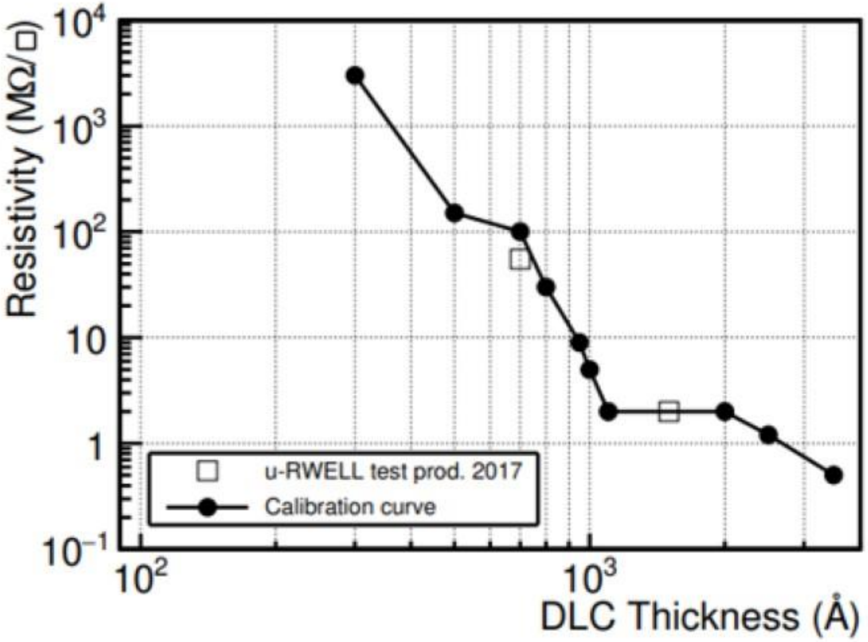


ρ≈1GΩ/□

2mm gas gap

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 diamond as well as 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 (Ar, N_2, C_2H_2) used in the process
- The production of DLC Apical® foils for detectors (μ-RWELL, MicroMegas, sRPC) has been done by the Be-Sputter Co., Ltd. in Japan (size ~1.2x0.6 m²)
- A DLC machine, co-funded by CERN and INFN, is going to enter in operation at the CERN MPT- Workshop (size ~2x0.6 m²)

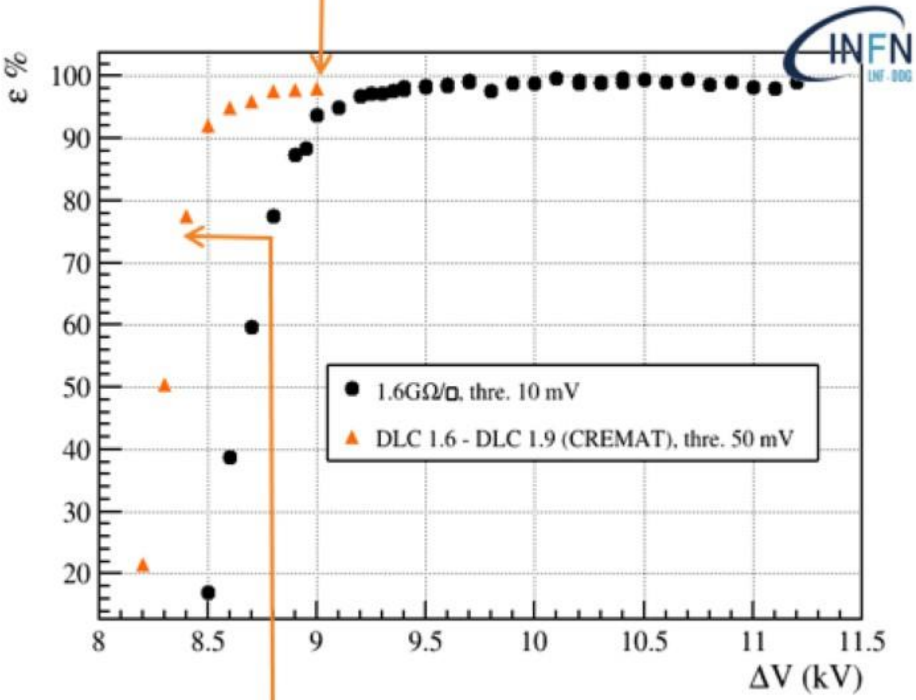


The Cathode Puzzle (II)

Hybrid layout: float glass cathode – DLC anode

- Detector shows high stability (efficiency plateau larger than 2kV)
- Float glass cathodes don't show of photon-feedback or field emission effects
- Not a solution for high-rate because limited by the relatively high resistivity of the float glass

Onset of **DLC-DLC** layout instabilities

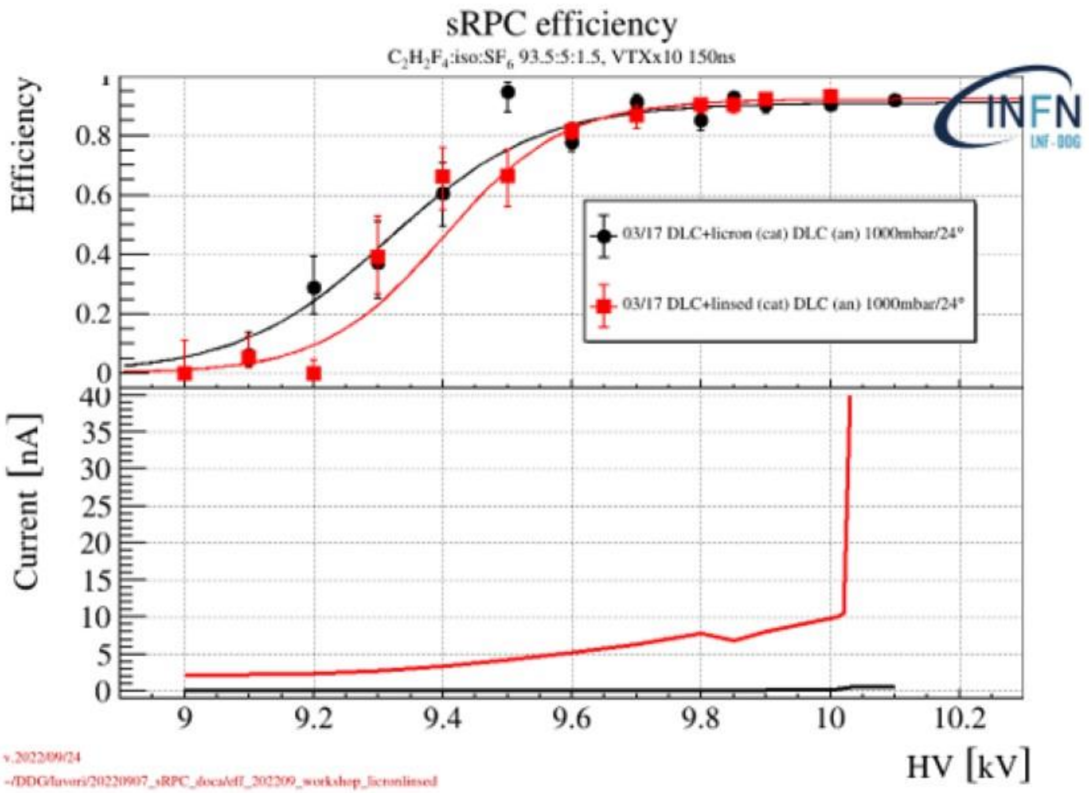


CREMAT 110 FEE lowering the operating point for **DLC-DLC** layout by **500V**

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**



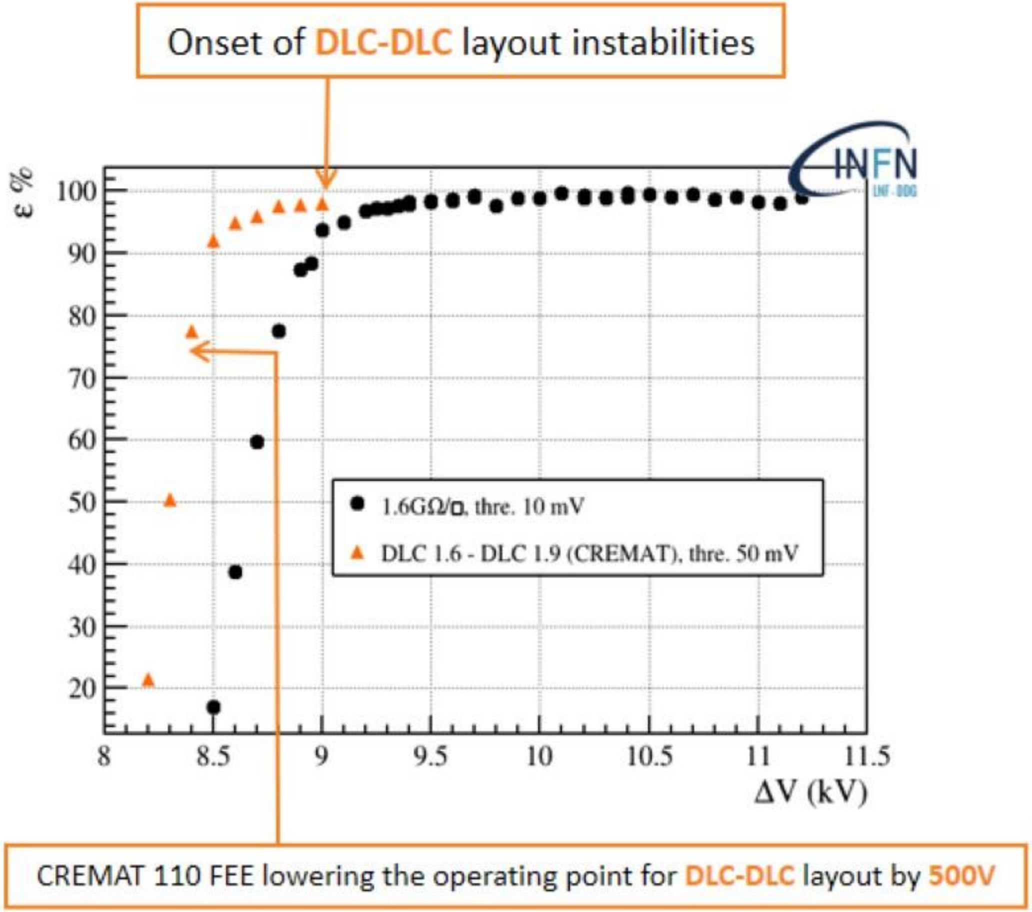
The Cathode Puzzle – II

Symmetrical layout: DLC cathode – DLC anode

- Detector shows instability at higher 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 achieved

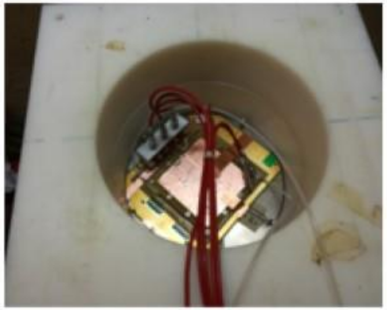
Hybrid layout: float glass cathode – DLC anode

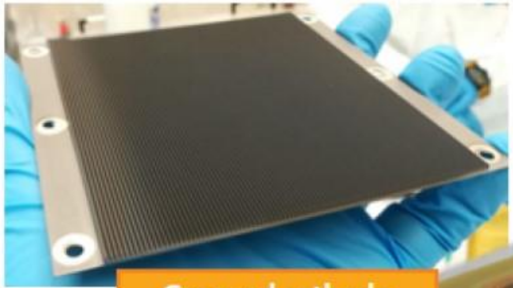
- Detector shows high stability (efficiency plateau larger than 2kV)
- Float glass cathodes don't suffer of photon-feedback or field emission effects
- Not a solution for high-rate because limited by the relatively high resistivity of the float glass



uRANIA → thermal neutron detection w/ μ-RWELL

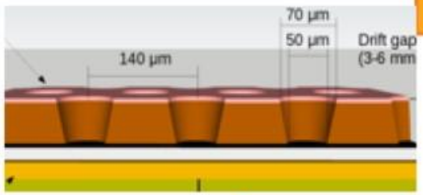
u	micro
R	esistive
A	dvanced
N	eutron
I	maging
A	pparatus





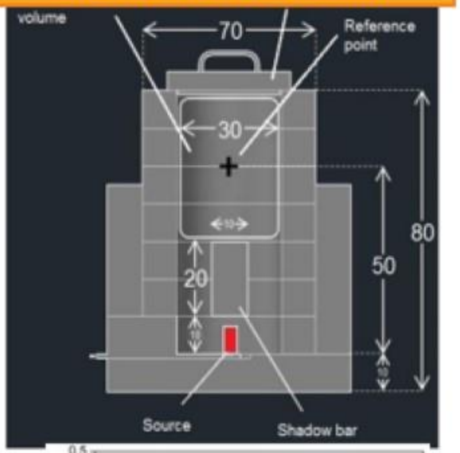
Grooved cathode

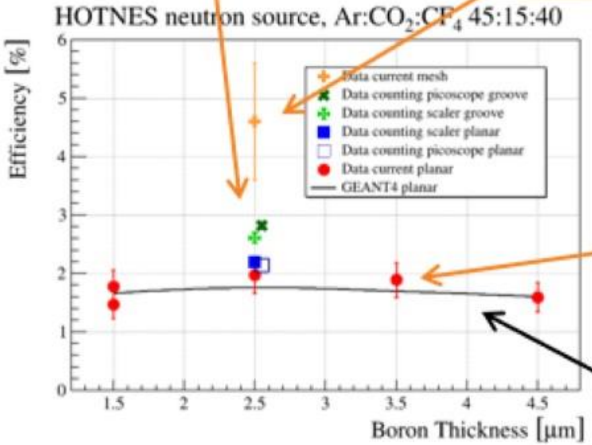
Mesh converter



μ-RWELL

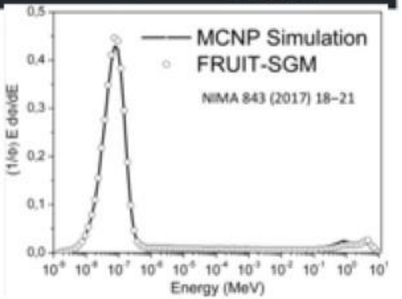
ENEA HOTNES Test facility





Planar Cathode

GEANT4



HOmogeneous **T**hermal **NE**utron **S**ource

- ^{241}Am-B source, polyethylene moderator
- Fully caracterized thermal neutron energy spectrum and fluence

uRANIA → thermal neutron detection w/ μ-RWELL

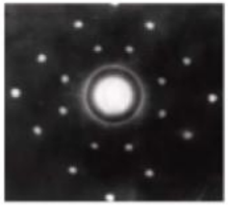
u	micro
R	esistive
A	dvanced
N	eutron
I	maging
A	pparatus

WHY

- Probing heavy structure in motion
- High penetration power
- High sensitivity and selectivity
- Unique probe
- for magnetism
- for fundamental properties
- Radioactive waste monitoring
- Radiation Portal Monitor (homeland security)
- Neutron diffraction imaging

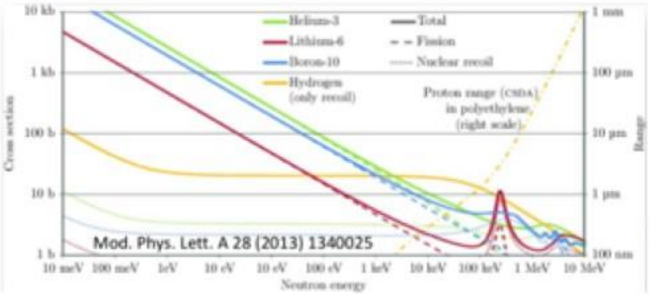
HOW

- High energy: Hadron Calorimeter
- Measure energy deposited in form of hadronic shower
- Moderate energy: np-Scattering
- Scattering with protons from H-materials
- Low Energy: Exo-energetic Nuclear Processes
- Use converter medium with large capture cross-section



$$n + {}^{10}_{5}\mathrm{B} \begin{cases} {}^{7}_{3}Li(1.02MeV) + \alpha(1.78MeV) & 6\% \\ {}^{7}_{3}Li(0.84MeV) + \alpha(1.47MeV) + \gamma(0.48MeV) & 94\% \end{cases}$$

Goal – Detection of thermal neutrons (E_k ~ 25meV):
${}^{10}B_4C$ deposition on μ-RWELL cathode, conversion to ionizing Particle ($\alpha/{}^7Li$ back to back → mutually esclusive events).
Not negligible $\alpha/{}^7Li$ cross-section with ${}^{10}B_4C$ → thickness optimization.



Cross section for common conversion materials