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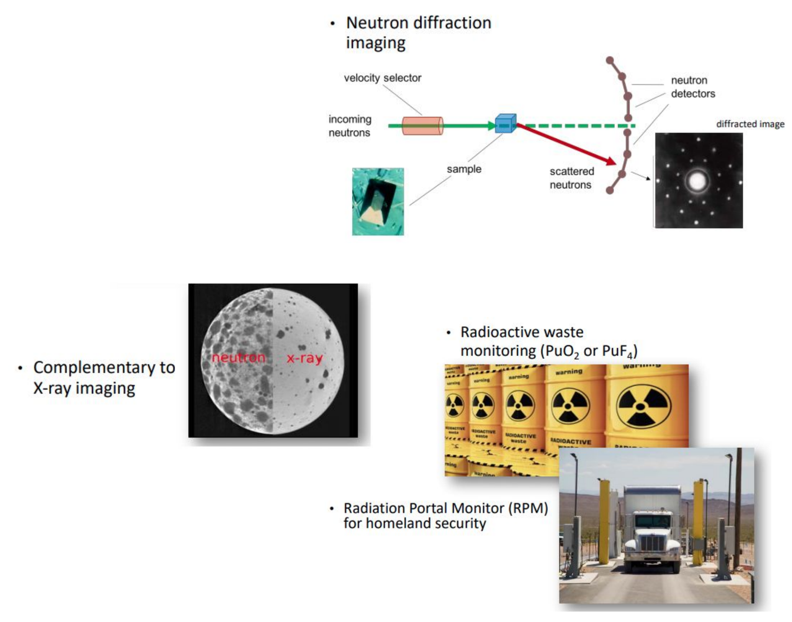
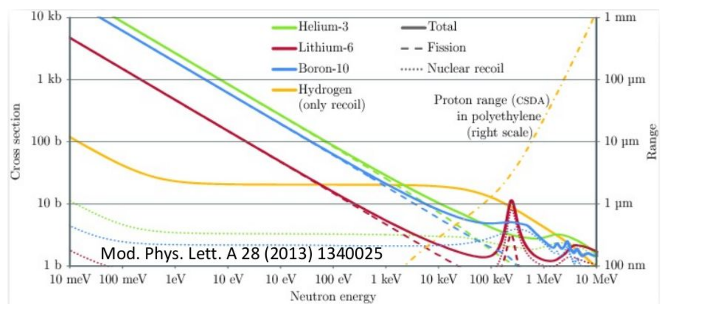
uRANIA: µ-RWELL and sRPC for neutron detection



Thermal neutron detection

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

Thermal neutron detection relies on the capture and conversion to ionizing particle. Due to the ^{3}He shortage a call for alternative solutions arises. By means of a thin layer of ^{10}**B** facing the gas gap (e.g. sputtered on a plain cathode) is possible to reveal thermal neutrons in a standard µ-RWELL detector reaching efficiency in the range of 5% for the simplest converter setup.

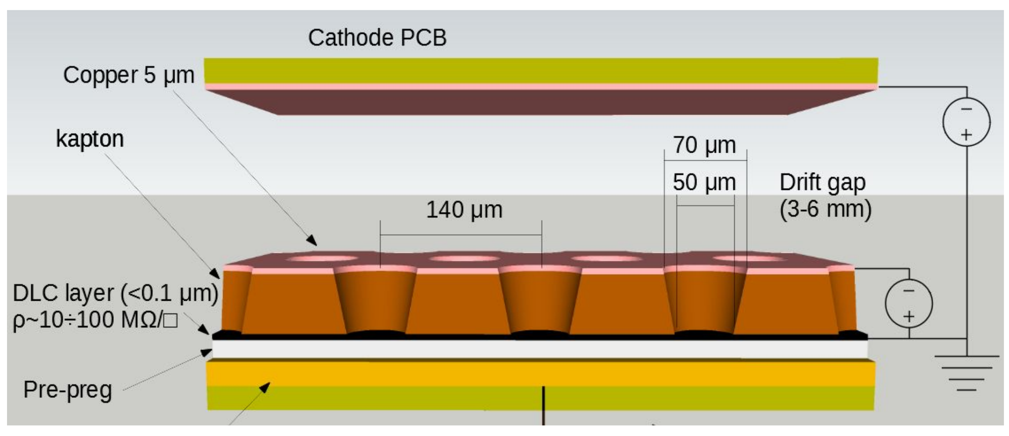


The goal of the **uRANIA-V** (**µ-RWELL A**dvanced **N**eutron **I**maging **A**pparatus) project is the development of an innovative **thermal neutron detector** based on **micro-Resistive WELL (µ-RWELL) technology** and **sRPC technology**. A thin layer of ^{10}**B$_4$C** on the cathode surface allows the **thermal neutron conversion** into ^{7}Li and α ions to be easily detected in the active volume of the device. These charged particles ionize in the gas volume and the gaseous detectors measure the signals. Results from tests performed with different converter layouts show that a thermal neutron (25 meV) **detection efficiency between 5÷10%** can be achieved with a single detection layer. A detailed comparison between the **experimental data** and the **full simulation** of the neutron physics and the detector behaviour has been performed. Future applications of these technologies range from the neutron diffraction imaging to radioactive waste monitor or radiation portal monitor for homeland security.

The µ-RWELL detector... …with a planar converter

See M. Poli Lener talk for more on µRWELL

The **µ-RWELL** is a **resistive** Micro Pattern Gaseous Detector (**MPGD**): compact, spark protected and with a single amplification stage[1]. Key points of the technology are the scalability as well as the mechanical flexibility that allows to adapt the design to different geometries and applications. **The cathode, sputtered with ^{10}B$_4$C, is used as a neutron converter:** the charged ions produced ionize the gas in the drift gap. Applying a suitable voltage between the **top Cu-layer and the DLC** the WELL acts as a **multiplication channel for the ionization** produced in the conversion/drift gas gap.



...with a grooved converter

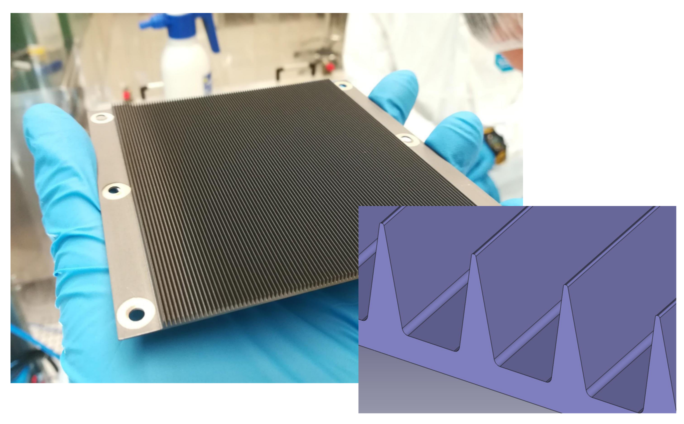
The idea behind this converter was to increase the coated surface with a folding structure with a slope of 10°, a variable width (0.25÷1mm) and 2.5 µm ^{10}B thickness

PROS:

- Easy mechanical upgrade

CONS:

- Ionization extraction for denser schemes



...plus a mesh converter

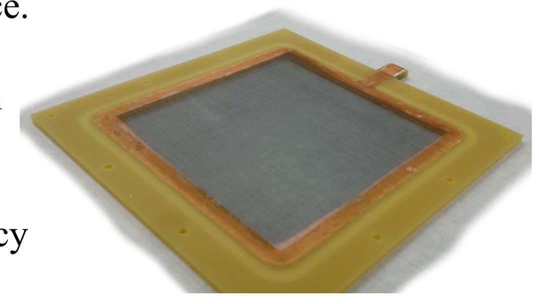
This converter exploits a ^{10}B coated metallic mesh inserted in the gas gap between the standard planar (^{10}B coated) cathode and the PCB-RWELL. The optical transparency, affecting the number of electrons passing through the mesh, is a crucial parameter to be optimized without reducing too much the boron coated surface.

PROS:

- 3 conversion cathode, up/dw mesh

CONS:

- Mesh electrical transparency
- Additional assembly steps

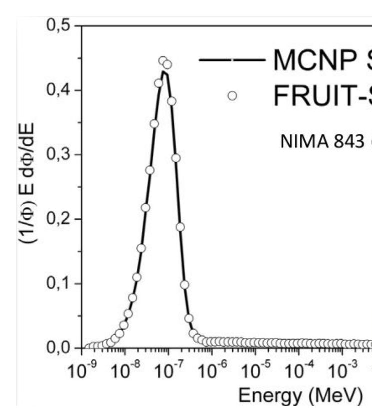


The sRPC detector with planar converters

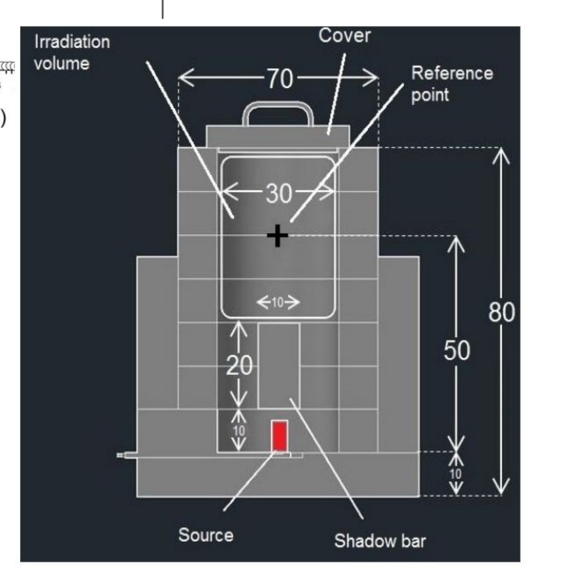
See M. Giovannetti talk for more on sRPC

The revolutionary approach proposed in this contribution is to realize an RPC based on easily modulated **surface resistivity electrodes** manufactured with industrial DLC sputtering techniques on flexible or semi-rigid supports[2]. This is a completely different concept from the one used in traditional RPCs characterized by volume resistivity. The electrodes of the sRPC consist of a 2 mm thick standard float glass sheet on which a suitably patterned Apical® foil sputtered with DLC has been glued. The range of DLC surface resistivity explored at the moment is 1÷24 GΩ/□. Detectors have been operated with the C2H2F4/iso-C4H10/SF6 = 93.5/5/1.5 gas mixture. Three layout are tested to convert the neutron using a **sputtered with ^{10}B$_4$C** layer on the cathode and/or on the anode.

ENEA-HOTNES facility



The HOTNES facility[3] is a **calibrated ^{241}Am-Be thermal neutron source** placed in a cylindrical cavity delimited by polyethylene walls. A shadow bar prevents fast neutrons from directly reaching the samples. The design of the bar and the walls is such that the thermal neutron fluency is **nearly uniform** (**758±16 cm^{-2}s^{-1}** @ reference plane). The energy distribution of the neutron generated by HOTNES is well known: **a 100 meV peak with a 290 meV FWHM**, thus higher than **25 meV** (thermal neutrons reference). Since the neutron cross section depends mainly on their energy, **an efficiency larger by a factor of two** is expected with thermal neutrons w.r.t. the one evaluated at HOTNES.



Simulations

Crucial tool for the design of the ^{10}B converters is the simulation of the **neutron physics** (GEANT4) and the **detector response** (mainly GARFIELD++) to:

- Extract detection efficiency from current measurements
- Drive the design of the different converters
- HOTNES energy distribution and angular divergence considered in the simulation
- Gas mixture ionizing energy ≈ 31.5 eV
- Particles range in gas < 6mm ⇒ 10^4 e$^-$I$^+$ from ionization

For the **grooved cathode** the ionization of the conversion products depends strongly on the site of their production: the ones in the peak have a larger mean ionization than the ones from the slope or the bottom of the spacing.

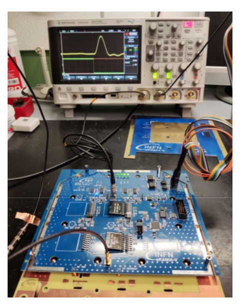
Counting mode measurement

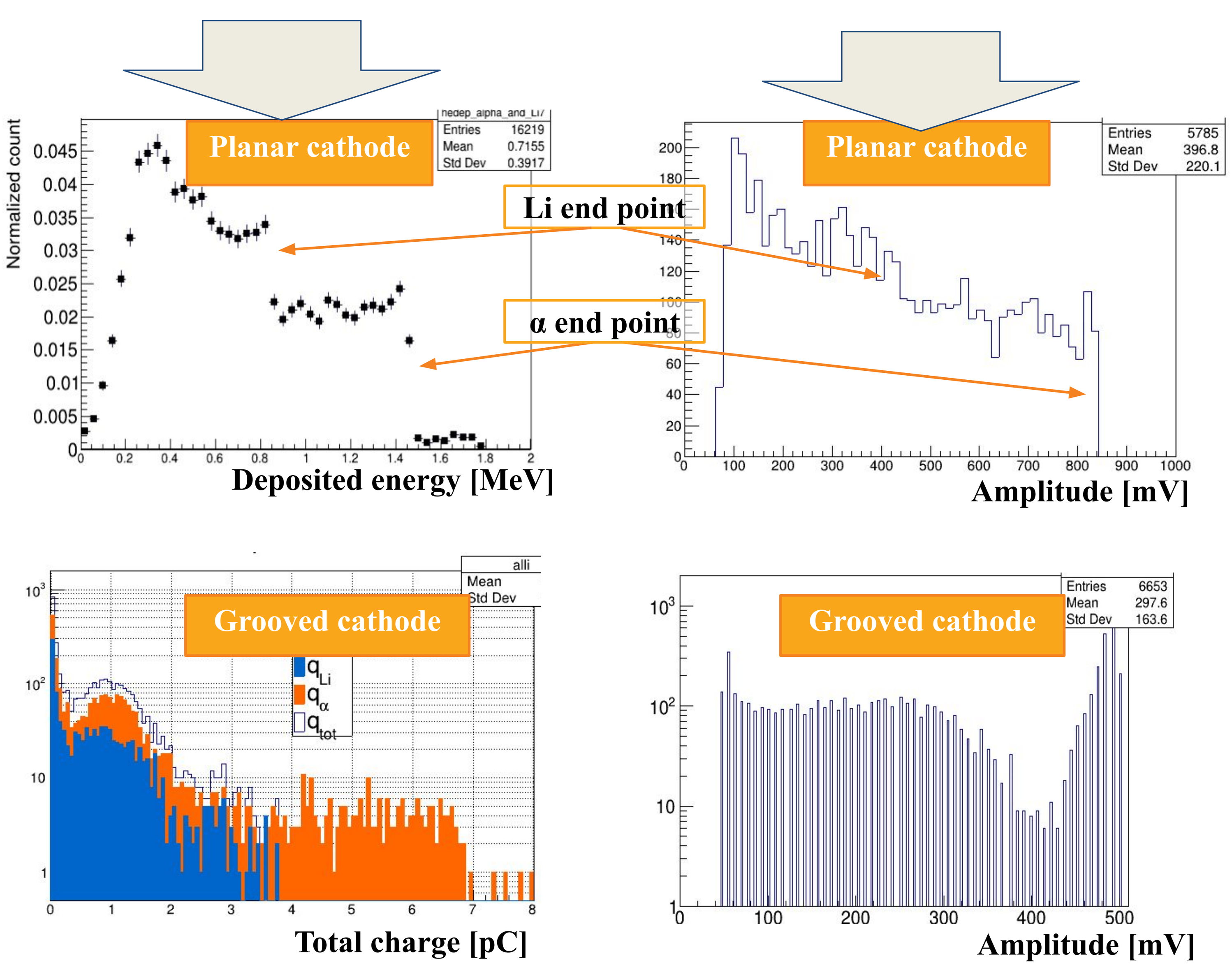
Custom FEE based on CREMAT amplifier (CR-110 & CR-200)

- Gain ≈ 2mV/fC – Shaping 1µs
- Q_{IN} saturation ≈ 4pC
- Input Noise ≈ 1.5fC
- FWHM = 2.4 x Shaping Time

The FEE is connected to a single pad readout of the detector. The FEE is equipped with both analog and digital output, and an on-board scaler.

The analog readout is use to acquire the waveform and to measure the amplitude spectrum using a Picoscope.



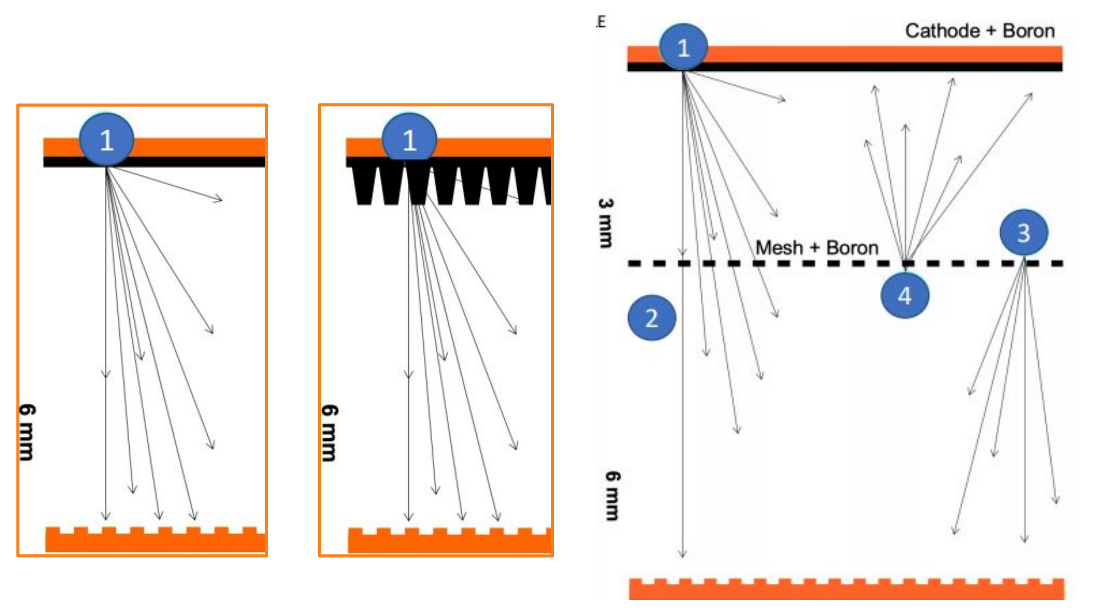


Current mode measurement

The current flowing through the resistive layer of the µ-RWELL is proportional to the number of electrons released in the gas and the detector gain. In the equations i is the current, Φ the neutron flux, ε the neutron conversion efficiency, N the average number of ionization electrons, G the detector gain and S the detector surface. With a 50pA sensitivity current meter it was possible to extract the conversion efficiency, the only unknown parameter.

For the planar and grooved cathodes the only current contribution came from the coated cathode.

The mesh setup has four different contributions and the mesh transparency has to be taken into account.



(1) $i = \Phi \cdot \varepsilon \cdot N \cdot G \cdot S$

(1) $i_1 = \Phi \times \varepsilon_1 \times N_1 \times G \times S \times T_{elec}$

(2) $i_2 = \Phi \times \varepsilon_2 \times N_2 \times G \times S$

(3) $i_3 = \Phi \times \varepsilon_3 \times N_3 \times G \times S$

(4) $i_4 = \Phi \times \varepsilon_4 \times N_4 \times G \times S \times T_{elec}$

Summary and results

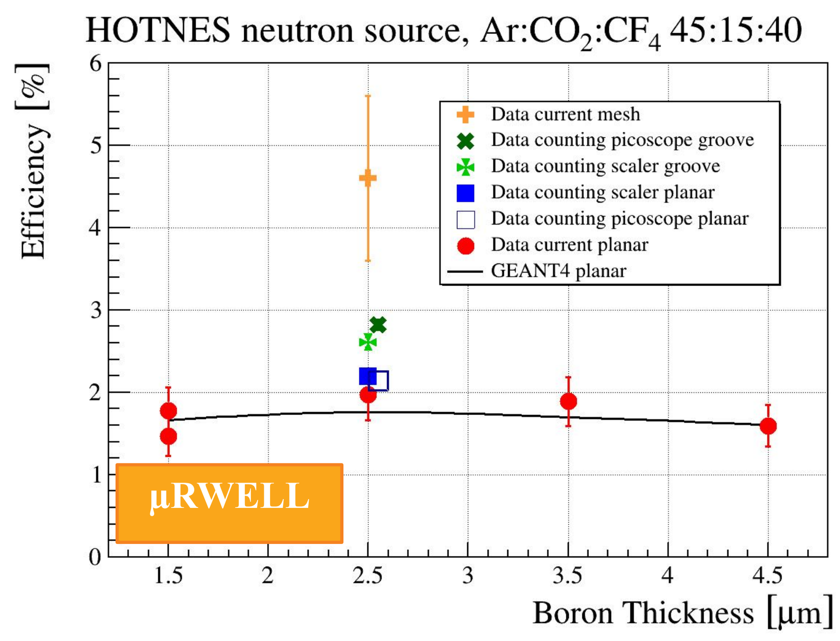
A **single layer of ^{10}B** on the cathode of µRWELL and sRPC exhibits an **efficiency of 2.19±0.05%** in current mode and in counting mode. The thickness optimization shows an efficiency maximum at **2.5 µm of ^{10}B**.

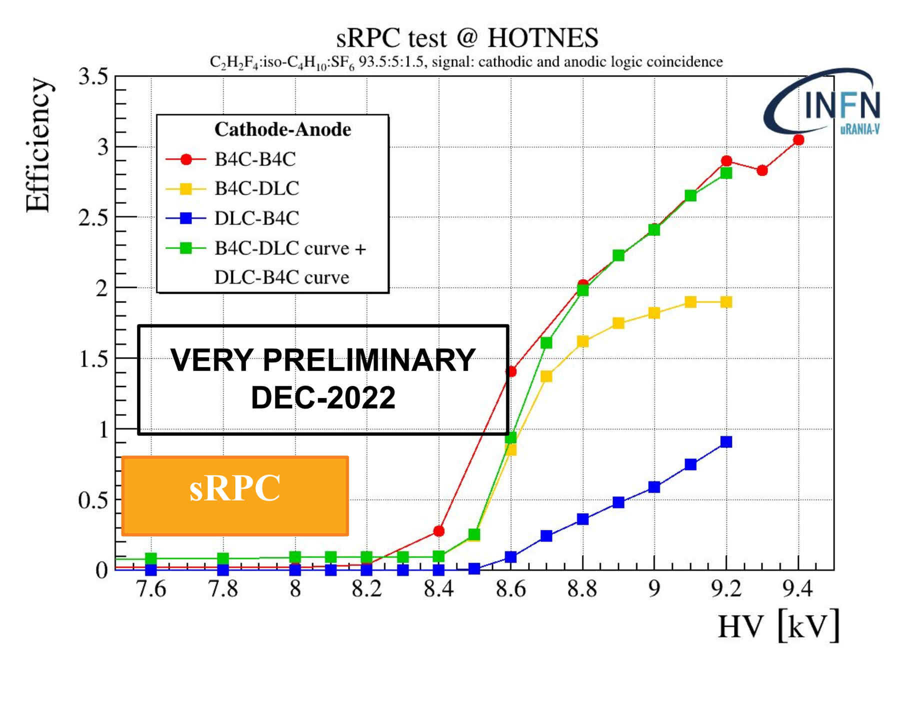
The configuration with the higher value of efficiency is reported for a µRWELL with a planar coated **cathode** + coated **mesh** configuration. Here the efficiency reaches **4.6±1.0%** but the mechanical assembly is more complex.

An improvement of the single stage conversion for µRWELL technology is reported with the **grooved** cathode where an efficiency of **2.61±0.06%** is measured.

Three configurations are studied with **sRPC** technology to investigate the conversion together with the amplification if the ^{10}**B** thickness is placed on the cathode and/or the cathode. The results are preliminary but consistent. The efficiency achieved with this technology is very **promising** thanks to the **goodness** of the results, the **ease** of the manufacturing and the production **cost**.

The neutron capture cross section depends on the neutron energy. As shown by GEANT4 simulations, with respect to the HOTNES spectrum, the detection efficiency for the thermal neutron (25 meV) **increases by a factor of two**, thus corresponding to a thermal neutron efficiency ranging from 5 to 10%.





Publications

[1] G. Bencivenni et al., *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*, 2015 *JINST* **10** P02008

[2] G. Bencivenni et al., The surface Resistive Plate Counter: An RPC based on resistive MPGD technology, 2023 NIM A 1046 167728

[3] A. Sperduti et al., *Results of the first user program on the Homogeneous Thermal Neutron Source (ENEA/INFN)*, JINST_12_P12029 (2017)

The 7th International Conference on Micro Pattern Gaseous Detectors 2022, 11-16 December