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# uRANIA-V: resistive gaseous devices for thermal neutron detection

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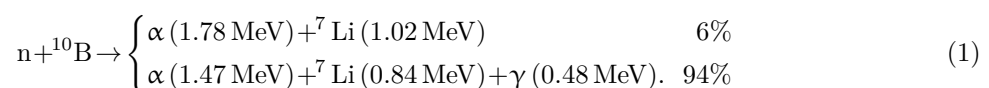
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**Abstract.** The uRANIA-V project foster the development of new technologies for thermal neutron detection with gaseous detectors. The first is the micro-Resistive WELL ( $\mu$ -RWELL), a compact resistive Micro-Pattern-Gaseous Detector (MPGD) born for HEP applications. The second proposed technology is the surface-Resistive Plate Counter (sRPC). This detector is a novel type of RPC which principle of operation is based on surface resistivity. For both detectors different  $^{10}\text{B}_4\text{C}$  converter have been exploited to detect thermal neutrons, achieving in both case overall efficiencies ranging between 5 and 10%.

## 1 The uRANIA-V project

The uRANIA-V project aims at the development of innovative neutron detectors, based on micro-Resistive WELL ( $\mu$ -RWELL, [1]) and Surface Resistive Plate Counter (sRPC) [2] detectors. For many years neutron detectors have exploited the high cross-section of neutrons with  $^3\text{He}$ . Nevertheless in the latest years its cost increased due a shortage of this element, involving as a consequence a large impact on the neutron detector production.  $^{10}\text{B}$  is a suitable candidate as a converter for neutrons, with the expected reactions:



This element can be actually deposited by means of magnetron sputtering machines [3] on several surfaces of the detector, thus obtaining a converter embedded in the active volume of the detector. At least one of the two charged particles is emitted towards the gas gap. All the measurement reported here have been carried out at the ENEA-Frascati HOTNES facility, with a  $^{241}\text{Am-B}$  source (a polyurethane pit ensures an almost uniform particle fluence ( $750 \text{ Hz/cm}^2$ ) at a distance of 20 cm) [4].



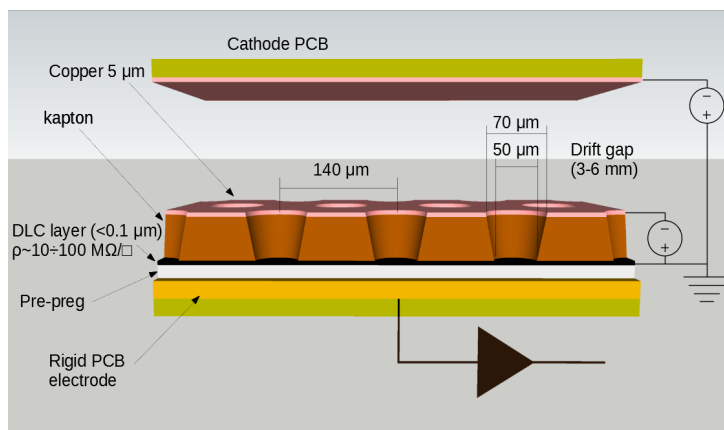


Figure 1: Crosssection of the  $\mu$ -RWELL.

## 2 The $\mu$ -RWELL technology

The  $\mu$ -RWELL is a resistive Micro-Pattern Gaseous Detector (MPGD) consisting of two printed circuit boards (PCBs): a cathode PCB, which defines the drift gap, and the  $\mu$ -RWELL\_PCB, which integrates both the electron amplification and the readout stage (Fig. 1).

The core element is a 50  $\mu\text{m}$ -thick polyimide (Apical<sup>®</sup>) foil, copper-clad on the top side and coated on the bottom side with a Diamond-Like Carbon (DLC) layer [5]. This foil is coupled to a standard PCB readout board through a 50  $\mu\text{m}$  thick pre-preg layer. The DLC film, typically 10  $\div$  100 nm thick, is deposited to obtain the required surface resistivity (50  $\div$  100  $\text{M}\Omega/\square$ ), providing both spark suppression and current evacuation.

The amplification structure is realized by chemically etching the top copper surface of the polyimide foil, producing a GEM-like matrix of truncated conical wells with a diameter of 70 (50)  $\mu\text{m}$  at the top (bottom) and a pitch of 140  $\mu\text{m}$ . Applying a suitable high voltage between the copper layer and the resistive DLC layer establishes the electric field inside the wells, which initiates charge multiplication. The induced signals are capacitively coupled to the strips or pads of the underlying readout board [6]. The introduction of the resistive layer enables stable operation at gas gains up to  $10^4$  with a single amplification stage, while inherently limiting the maximum rate capability due to the finite surface resistivity [7].

### 2.1 The converter geometries

Originally developed for high-energy physics applications, this detector technology can be readily adapted to neutron detection by introducing a converter within the active volume. In the present case, a thin layer of  $^{10}\text{B}_4\text{C}$  was employed: the interaction of thermal neutrons with the converter material generates heavy charged particles (either  $\alpha$  or  $^7\text{Li}$ ) that are released into the detector's active volume. Small scale prototypes (active area  $10 \times 10 \text{ cm}^2$ ) and different  $^{10}\text{B}_4\text{C}$  coated cathode structures have been realized and tested at the HOTNES facility of the ENEA Frascati, fig. 2. Meshes sputtered with  $^{10}\text{B}_4\text{C}$  have been moreover introduced in the device active volume and tested at the same facility. The results obtained from tests conducted at HOTNES with different configurations of  $^{10}\text{B}_4\text{C}$  converters, demonstrate the possibility of achieving a detection efficiency for thermal neutrons (25meV) between 4% and 8%, fig. 3, using a single detection layer.

## 3 The sRPC detector

A new detector, the sRPC, has been recently introduced in the context of HEP applications. It represents a simpler and more cost-effective solution compared to  $\mu$ -RWELL. The sRPC, fig. 4, is a new RPC based on electrodes with surface resistivity, a principle of operation that differs from traditional RPCs [10, 11, 12], which employ electrodes characterized by volumetric resistivity. The sRPC electrodes leverage the established industrial technology of DLC sputtering on thin polyimide sheets (50 $\mu\text{m}$ ), already used in the production of  $\mu$ -RWELL.

The Cremat-based FEE, sec. 4, allowed us to read both anodic and cathodic signals, reducing/eliminating sources of uncorrelated noise and making the operation of the detector much more

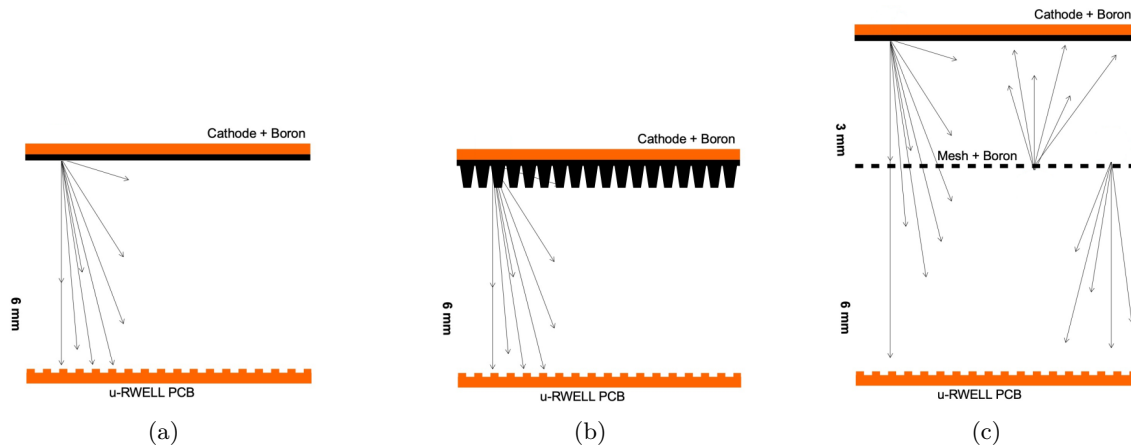


Figure 2: Sketches of the converter geometries: (a) a single planar converter on the cathode, (b) a single groove converter on the cathode, (c) three conversion surfaces, one on the cathode and a mesh with a deposition on both sides. A similar study has been performed with MWPC with planar and V-shaped cathodes [8].

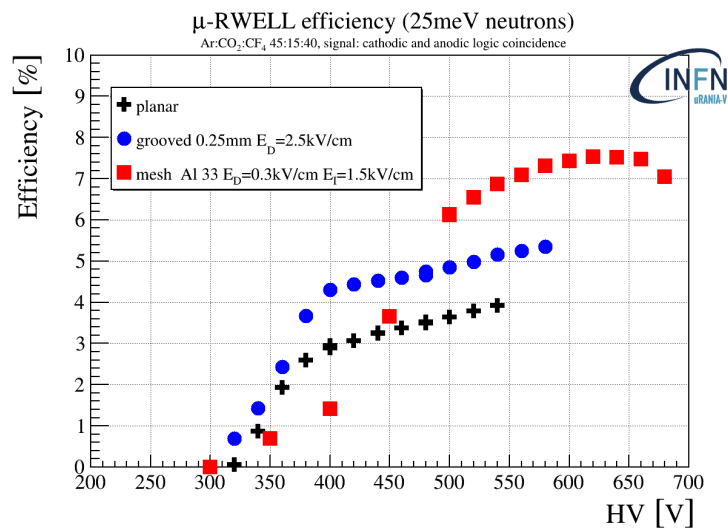


Figure 3: Efficiency obtained with the three different layouts of  $\mu$ -RWELL, for 25 meV neutrons: (black) the planar cathode; (blue) the grooved cathode; (red) the planar cathode plus the metallic mesh. The  $^{10}\text{B}_4\text{C}$  thickness is  $2.5\ \mu\text{m}$  for every converter.

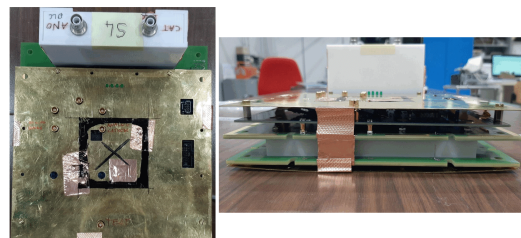
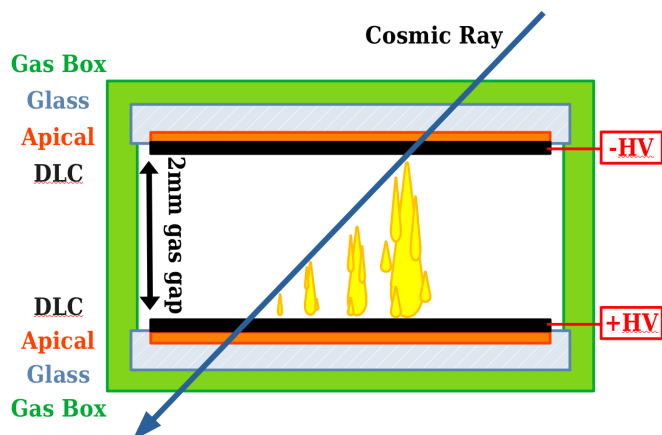


Figure 4: Sketch of a DLC-electrodes sRPC. The standard gas mixture used is  $C_2H_2F_4:iC_4H_{10}:SF_6$  93.5:5:1.5.

Figure 5: The detector with electronics viewed from above (left); the detector with electronics viewed from the side (right)

stable and noise-free, fig. 5. The sRPC technology can be used for the detection of thermal neutrons by replacing the DLC sputtered electrodes with  $^{10}B_4C$  ones. Three different layouts of electrodes coated with  $^{10}B_4C$  have been tested, Fig. 6:

1. Boron coated cathode – DLC coated anode
2. DLC coated cathode – Boron coated anode
3. Boron coated cathode - Boron coated anode

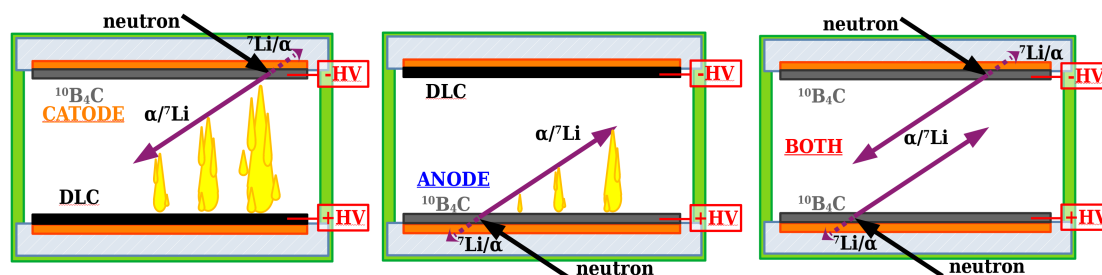


Figure 6: Sketch of the three sRPC layouts considered for thermal neutron detection.

With these layouts it was achieved a detection efficiency of 4%, 2%, and 6%, respectively (Fig. 7).

### 3.1 The hybrid sRPC

With the aim of further simplifying the detector design, and in view of possible applications to homeland security requiring large-area coverage, a third hybrid layout was developed, featuring a Boron-coated cathode and a float-glass anode. In this configuration, the high voltage on the glass anode was supplied through a thin graphite layer, similarly to the GSC approach [12]. Two prototype configurations were investigated: (i) Boron-coated cathode with DLC-coated anode, and (ii) Boron-coated cathode with float-glass anode. The results are reported in Fig. 8. Both layouts demonstrated stable operation up to high voltages (corresponding to large gas gains). In particular, the Boron–float-glass configuration exhibited an operating plateau of approximately 1 kV. For thermal neutron detection, the operating range is sufficiently separated (about 200 V) from the onset of sensitivity to minimum ionizing particles (m.i.p.s)<sup>1</sup>. This separation is especially pronounced in the Boron–DLC layout. In the Boron–float-glass case, the high resistivity of the substrate and the

<sup>1</sup>A dedicated study comparing the  $\gamma$  response to the thermal neutron response is still pending and will be addressed in future work.

relatively intense neutron flux reduce the separation, although this limitation is not expected to compromise performance in radiation portal monitor (RPM) applications, where high-rate operation is not required.

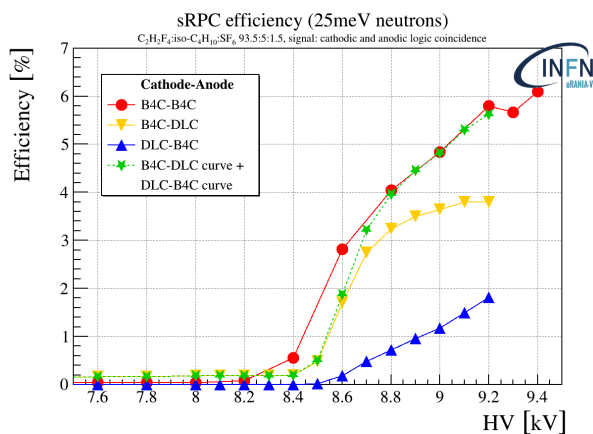


Figure 7: Detection efficiency of 25 meV neutrons obtained using the three different layouts.

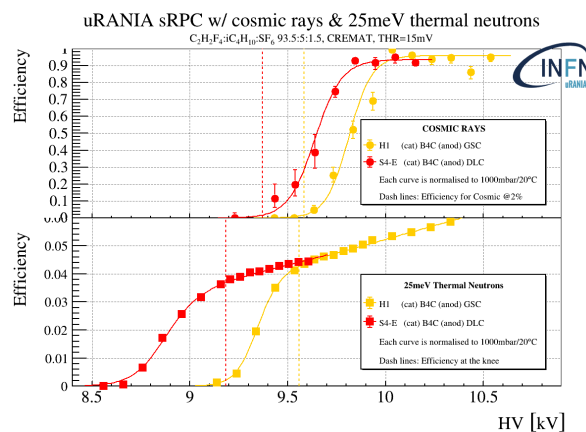


Figure 8: Comparison between efficiency with cosmic rays and thermal neutrons, for sRPC with  $^{10}\text{B}_4\text{C}$  cathode and (red) DLC anode and (yellow) float-glass anode.

#### 4 The Cremat-based FEE

For both proposed detectors, a single channel FEE was developed based on the CREMAT CR-110 CSA (Gain = 1.4 mV/fC [13]), followed by a shaping stage to reduce the signal fall time (thereby mitigating issues related to signal pile-up) and to increase the signal-to-noise ratio of the channel. The module used is the CR-200 with a 1  $\mu\text{s}$  (FWHM of about 2.4  $\mu\text{s}$  [14]).

The electronics allow reading of induced signals of both polarities: both the negative signals, induced on the pad of the  $\mu$ -RWELL, or on the anode of the sRPC and the positive signals induced on the top of the amplification stage of the  $\mu$ -RWELL, or on the cathode of the sRPC.

#### 5 Conclusions

Thermal neutron detectors based on resistive gaseous detectors and  $^{10}\text{B}_4\text{C}$  converters have been successfully developed and tested.

The  $\mu$ -RWELL represents a mature technology, well suited for large-scale production thanks to the use of standard industrial fabrication techniques [15]. For 25 meV thermal neutrons, with an appropriate converter, a single detector layer can achieve an efficiency in the range of 4  $\div$  8%. Prototypes with an active area of 20  $\times$  20  $\text{cm}^2$  are currently under construction at CERN, with tests foreseen in the near future.

The sRPC, still at an early R&D stage, has shown encouraging results, particularly in the hybrid configuration. Its simple design and intrinsic scalability are key advantages, enabling the straightforward realization of high-efficiency multilayer structures. These features make the sRPC an attractive option for applications requiring the monitoring of large areas, such as Radiation Portal Monitors in ports and airports.

In conclusion, both technologies are well suited for multilayer operation, where overall detection efficiencies of several tens of percent can be achieved.

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