uRANIA:

a micro-Resistive WELL for neutron detection

I. Balossino[A,B], G. Bencivenni[C], G. Cibinetto[A], G. Felici[C], I. Garzia[A], M. Gatta[C], M. Giovannetti[C,D], L. Lavezzi[E], G. Mezzadri[A], G. Morello[C], E. Paoletti[C], G. Papalino[C], M. Poli Lener[C], M. Scodeggio[A]

[A] INFN-Ferrara, Italy
[B] Institute of High Energy Physics, Chinese Academy of Sciences, PRC
[C] INFN-LNF Laboratori Nazionali di Frascati, Italy
[D] University of Rome "Tor Vergata", Italy
[E] INFN Torino, Italy

uRANIA-V

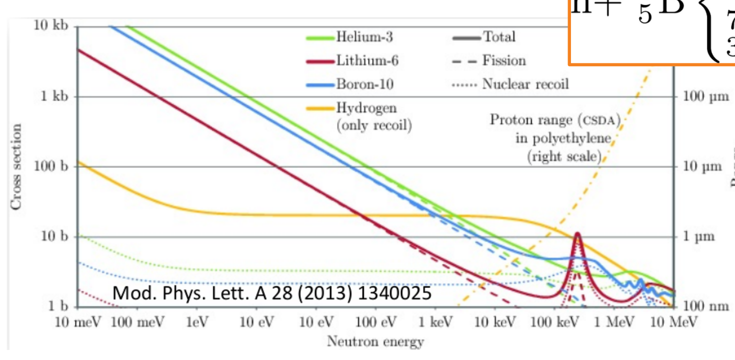
The goal of the **uRANIA-V** (**µ-R**WELL **A**dvanced **N**eutron **I**maging **A**pparatus) project is the development of an innovative **thermal neutron detector** based on **micro-Resistive WELL (µ-RWELL) technology**. The µ-RWELL is a reliable, cost effective, easily scalable, resistive MPGD. A thin layer of $^{10}B_4C$ 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. Results from tests performed with different converter layouts show that a thermal neutron (25meV) **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.

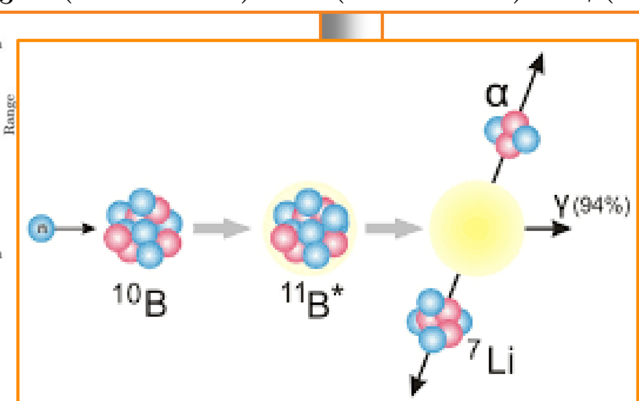
Thermal neutron detection

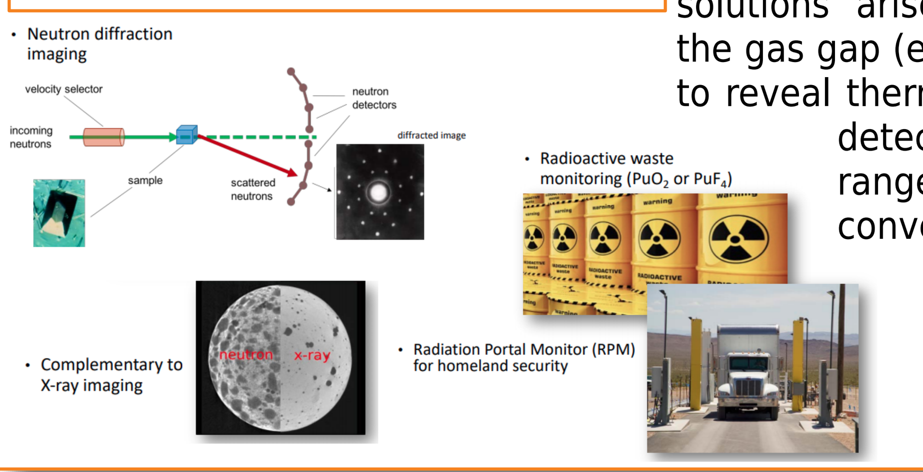
WHY

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

$$n + {}^{10}_{5}B \rightarrow \begin{cases} {}^7_3Li(1.02MeV) + \alpha(1.78MeV) & 6\% \\ {}^7_3Li(0.84MeV) + \alpha(1.47MeV) + \gamma(0.48MeV) & 94\% \end{cases}$$



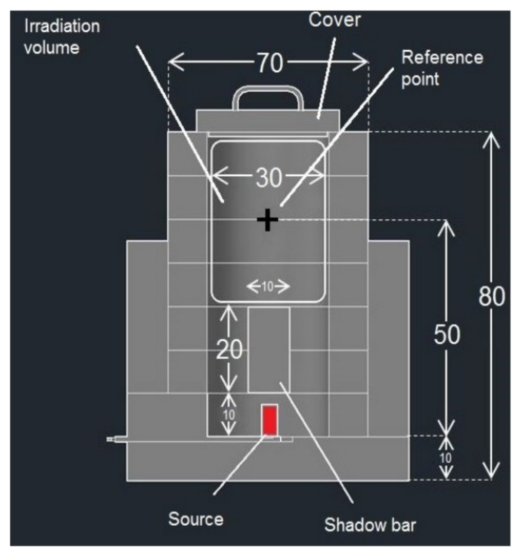




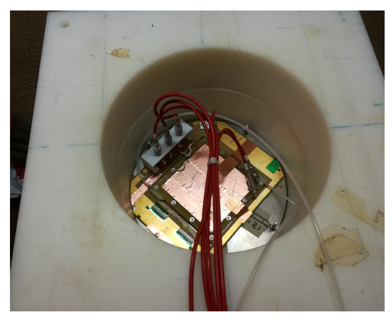
Thermal neutron detection relies on the capture and conversion to ionizing particle. Due to the ^{3}He shortage a call for alternative solutions arises. By means of a thin layer of ^{10}**B** facing the gas gap (e.g. sputtered on a plain cathode) is possible to reveal thermal neutrons in a standard µ-RWELL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

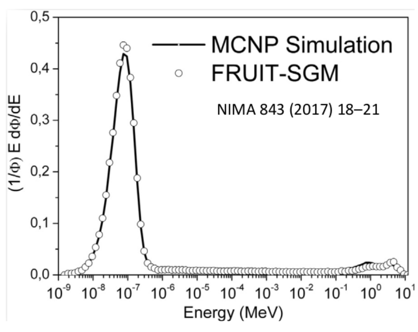
The ENEA-HOTNES facility

The HOTNES facility[2] 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±16cm^{-2}s^{-1}** @ reference plane). The energy distribution of the neutron generated by HOTNES is well known: **a 100 meV peak with a 290meV FWHM**, thus higher than **25meV** (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.



Experimental measurements and simulations show that a fraction of 17.7% of the neutrons are absorbed by the mechanical structure of our detectors.



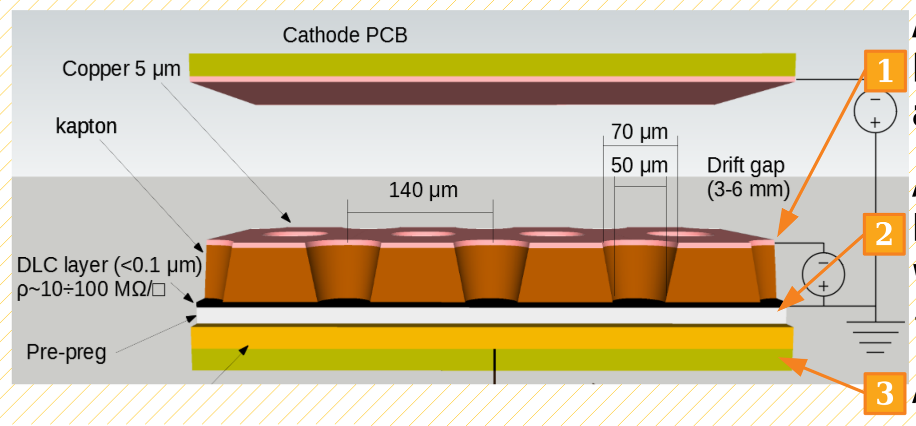


The µ-RWELL detector...

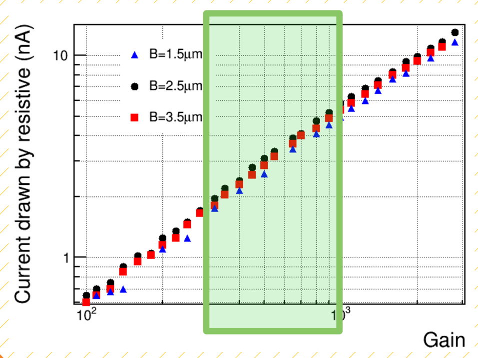
...with a planar converter

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 $^{10}B_4C$, 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.

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

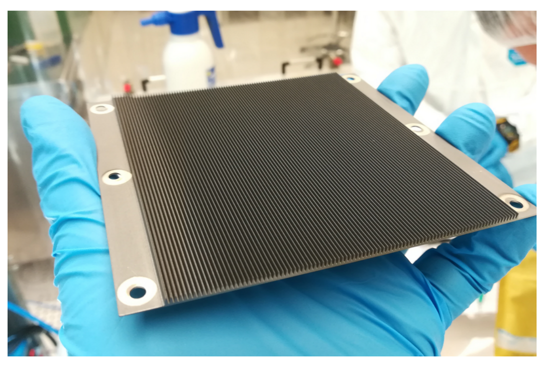


1. A **WELL** patterned kapton foil acting as **amplification stage**
2. A **resistive DLC layer Diamond-Like-Carbon** w/ surface resistivity ~ 50÷100 MΩ/□
3. A standard readout PCB

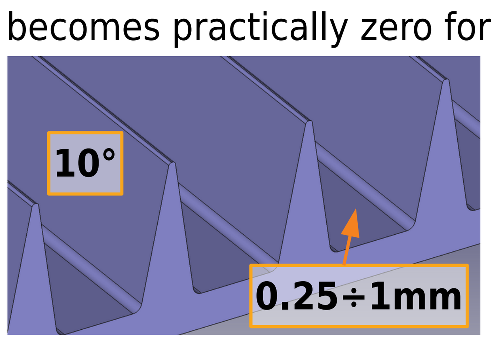


The working point is decided measuring the current drawn by the detector as a function of the gain. The detector shows a linear behavior at low gain, but at higher values some saturation occurs due to the high charge involved in the process. For these studies t has been decided to focus on the region **Gain = [300,1000]**.

...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. The width is a crucial parameter. For a very packed geometry the ^{10}B surface increases but the mean path of the conversion ions produced in the bottom of the groove gets smaller. Moreover it gets difficult to extract their ionization electrons because there the drift field is not uniform and becomes practically zero for denser schemes.



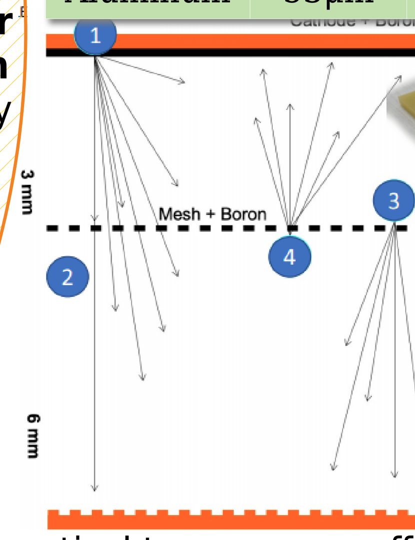
PROS:
- Easy mechanical upgrade

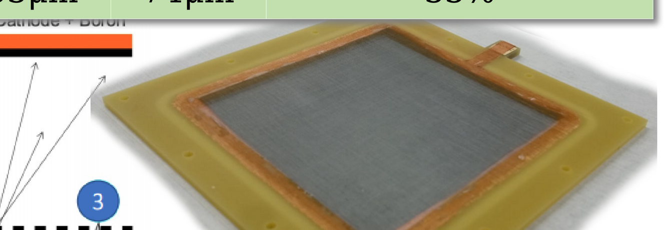
CONS:
- Ionization extraction for denser schemes

...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.

Material	Wire ⌀	Pitch	Optical trasparency
Copper	56µm	190µm	60%
Aluminum	53µm	74µm	33%





PROS:
- 3 conversion surfaces: cathode, up/dw mesh

CONS:
- Mesh electrical transparency
- Additional assembly steps

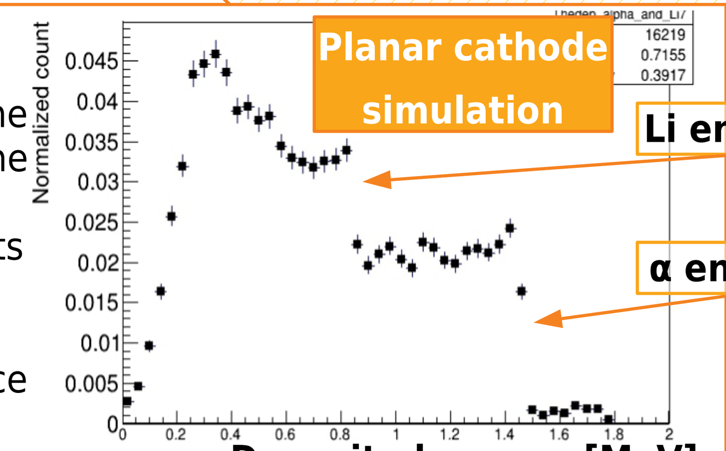
The optical trasparency, affecting the number of electrons passing through the mesh, is a crucial parameter to be optimized without reducing too much the boron coated surface.

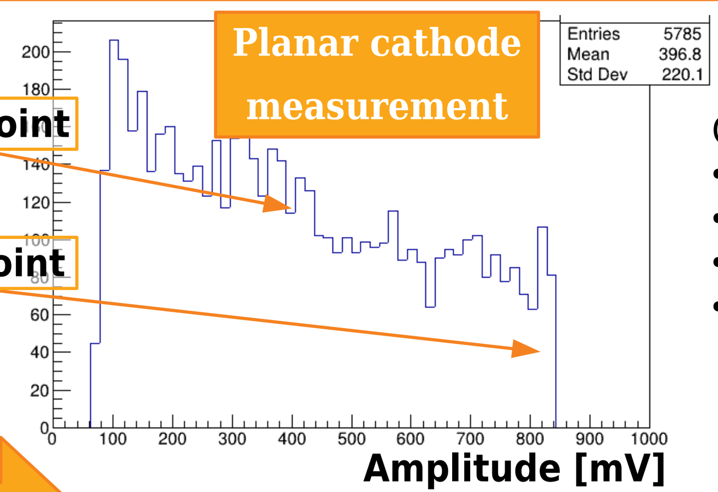
Simulations

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

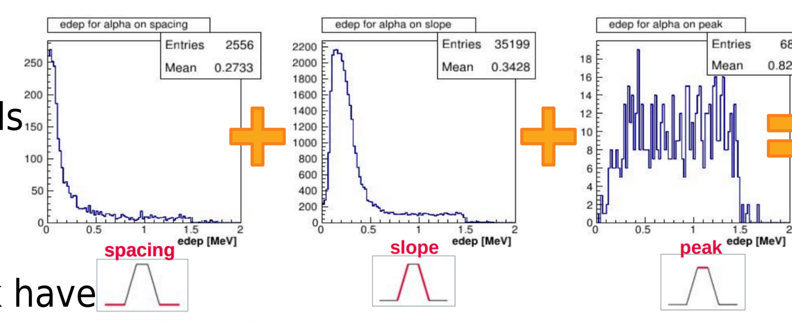
- HOTNES energy distribution and angular divergence considered in the simulation
- Gas mixture ionizing energy ≈ 31.5 eV
- Particles range in gas < 6mm ⇒ 10^4 e$^-$I$^+$ from ionization

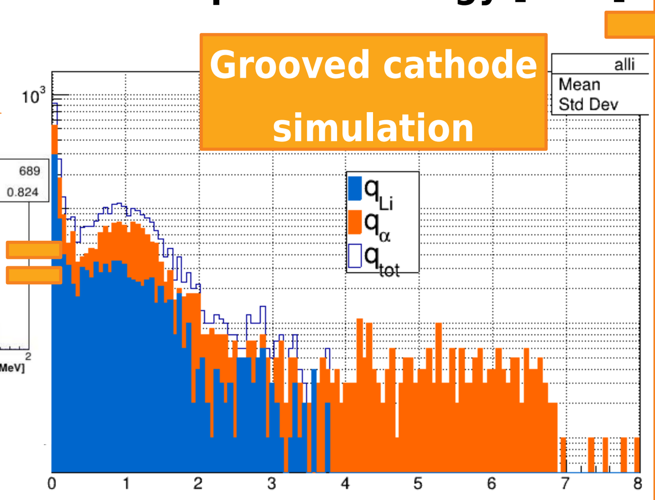


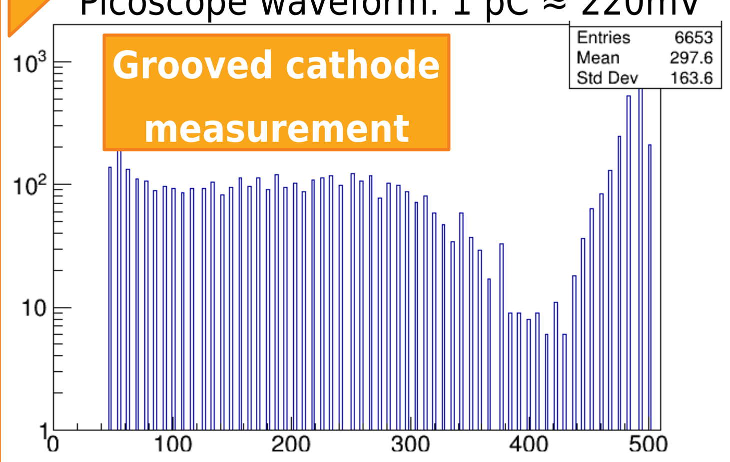


Picoscope waveform: 1 pC ≈ 220mV

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.





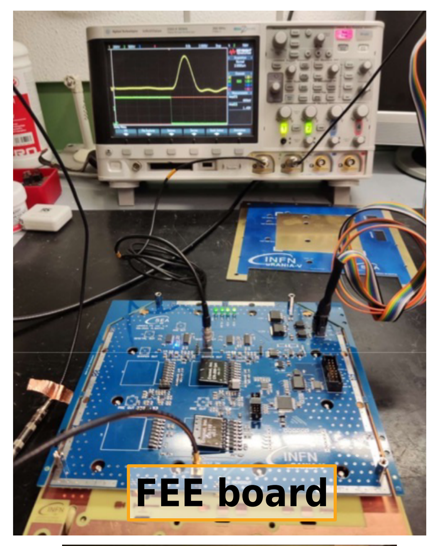


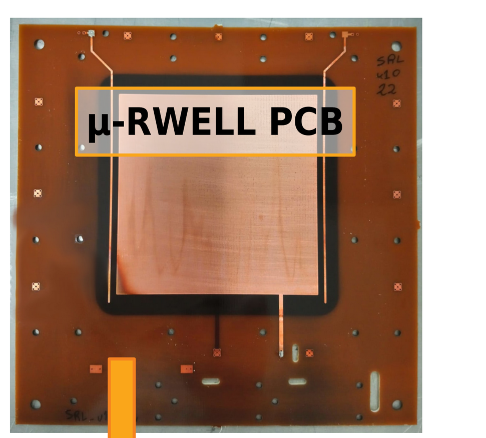
Counting mode measurement

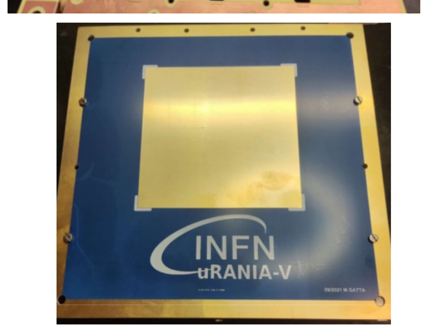
Custom FEE based on CREMAT amplifier (CR-110 & CR-200)

- 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.





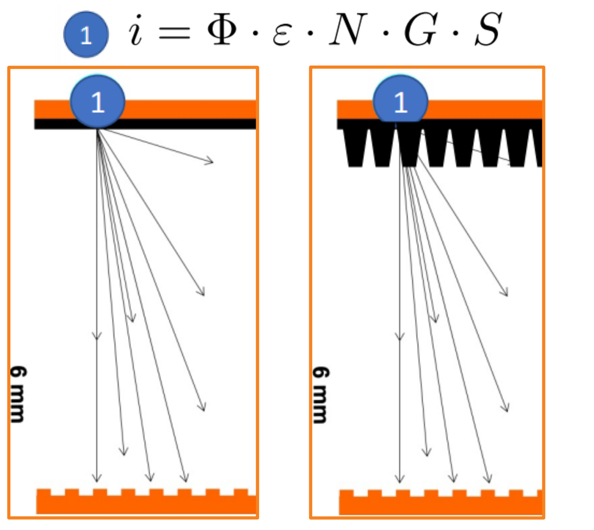


Current mode measurement

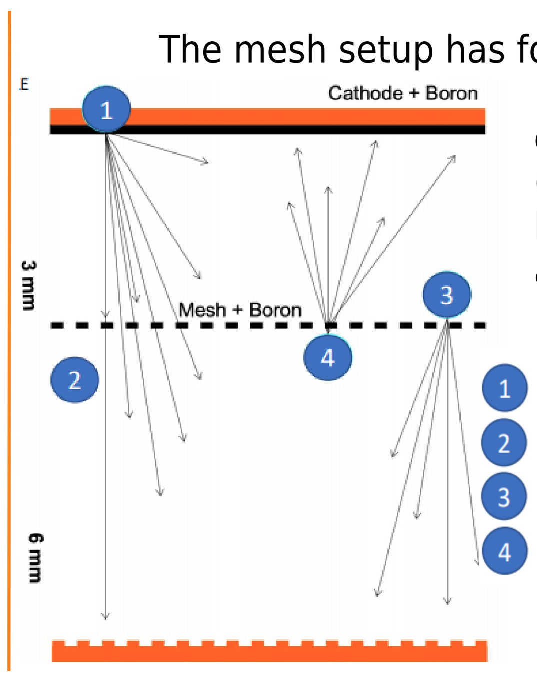
The current flowing through the resistive layer of the µ-RWELL is proportional to the number of electrons released in the gas and the detector gain. In the equations ***i*** is the current, **Φ** the neutron flux, **ε** the neutron conversion efficiency, ***N*** the average number of ionization electrons,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

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

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

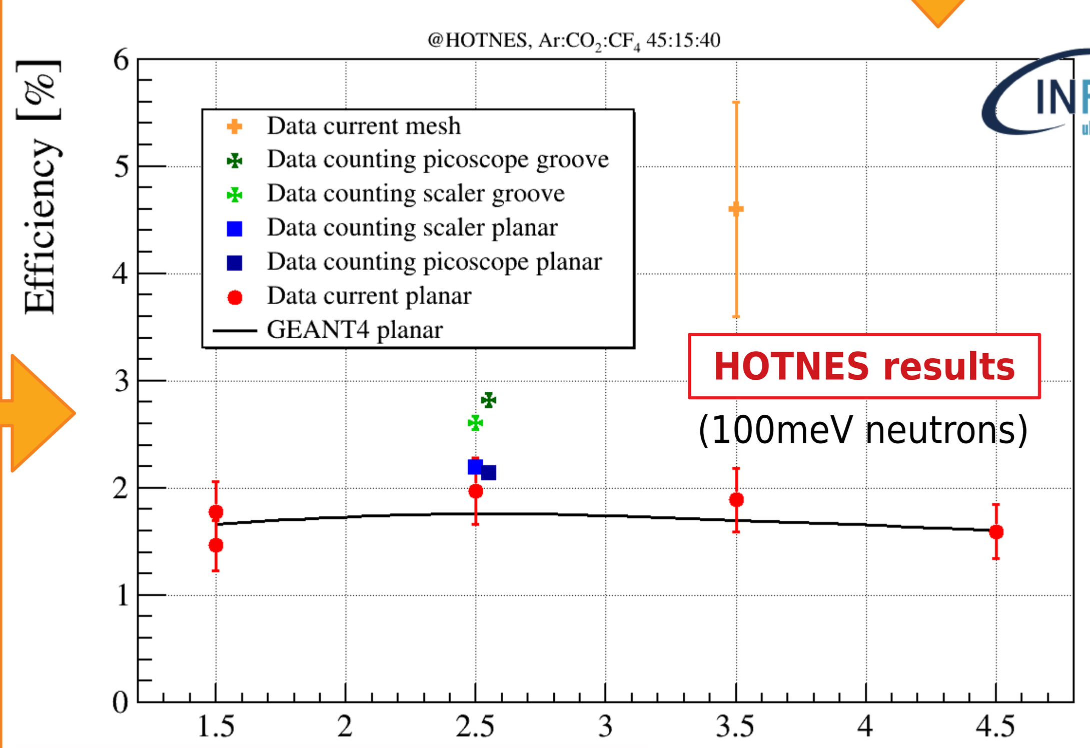


The mesh setup has four different contributions. For 1 and 4 the mesh electron trasparency (T_{elec}, from simulation) has to be taken into account.



$$i_1 = \Phi \times \varepsilon_1 \times N_1 \times G \times S \times T_{elec}$$
$$i_2 = \Phi \times \varepsilon_2 \times N_2 \times G \times S$$
$$i_3 = \Phi \times \varepsilon_3 \times N_3 \times G \times S$$
$$i_4 = \Phi \times \varepsilon_4 \times N_4 \times G \times S \times T_{elec}$$

Summary and results



- For the **planar cathode** a scan for different ^{10}B thickness has been performed in current mode, measuring an efficiency ≈ **1.5~2.0%**
- The planar coated **cathode +** coated **mesh** configuration in current mode exhibits an efficiency of **4.6±1.0%**
- The counting mode measurements for the **planar** and **grooved** cathode layouts show the following results:
  - Planar → **2.19±0.05%**
  - Grooved → **2.61±0.06%**

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 (25meV) **increases by a factor of two**, thus corresponding to a thermal neutron efficiency ranging from **5 to 10%**.

Pubblications
[1] G. Bencivenni et al., *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD*, 2015 *JINST* **10** P02008
[2] A. Sperduti et al., *Results of the first user program on the Homogeneous Thermal Neutron Source (ENEA/INFN)*, JINST_12_P12029 (2017)

15th Pisa Meeting on Advanced Detectors 22-28, 2022