uRANIA
a μRwell Advanced Neutron Identification Apparatus

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on behalf of the uRANIA collaboration

International Conference
on Technology and Instrumentation in Particle Physics

May 24-28, 2021

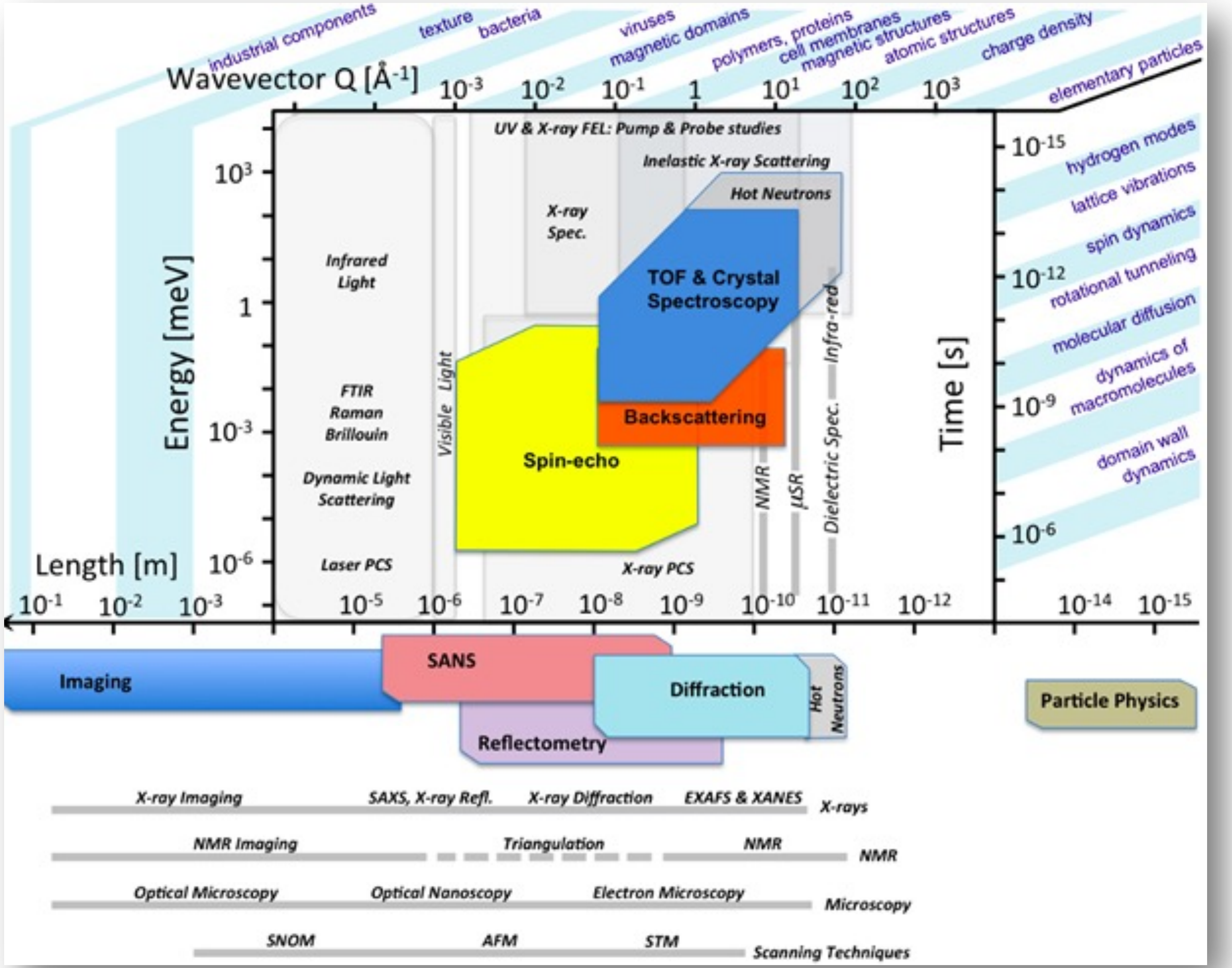
Outline

- Neutron Detection
- micro-RWELL Technology
- The uRANIA Project
- Development of a Simulation Toolkit
- Proof of Concept
- Ongoing and Future Studies
- Technology Transfer to Industries

Reasons to go for Neutrons

- PROBING STRUCTURE AND MOTION
- HIGH PENETRATION
- A PRECISE TOOL
- HIGH SENSITIVITY AND SELECTIVITY
- A UNIQUE PROBE FOR MAGNETISM
- A PROBE OF FUNDAMENTAL PROPERTIES

ESS Technical Design Report S. Peggs (ESS, Lund)(ed.), 2013

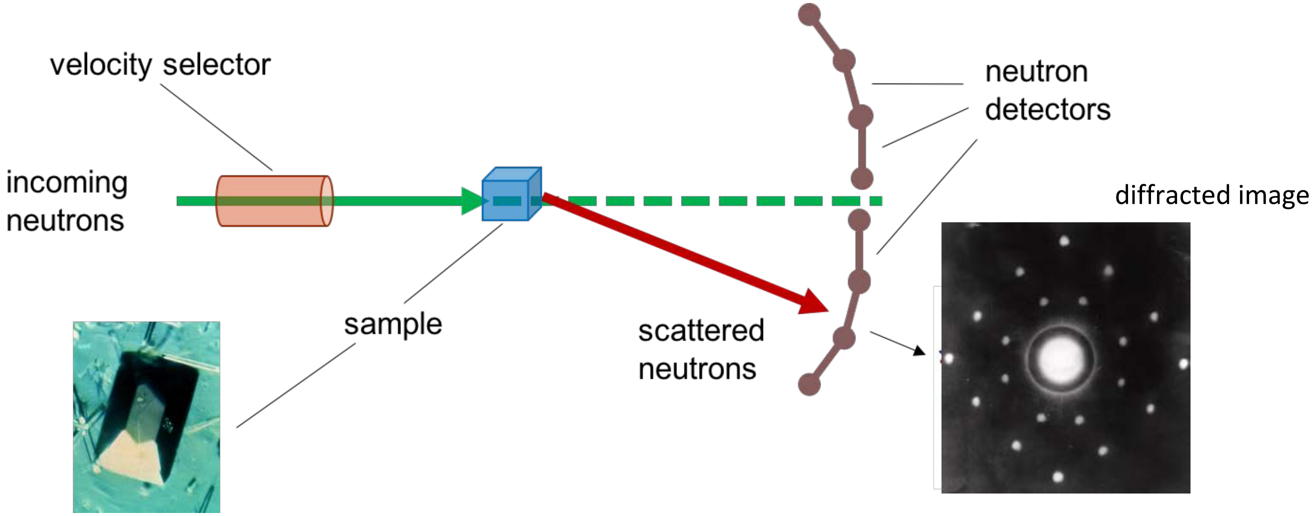


Few Applications relevant for our project

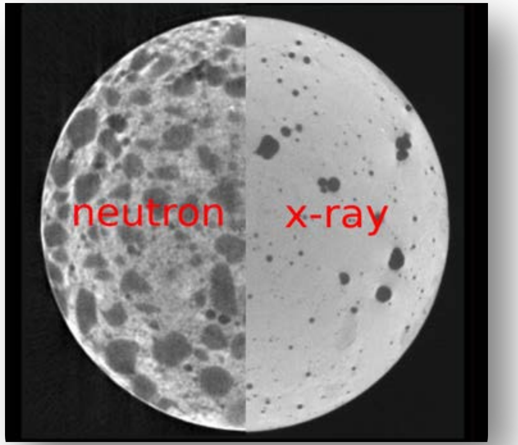
- Radioactive waste monitoring (PuO_2 or PuF_4)

- Radiation Portal Monitor (RPM) for homeland security

- Neutron diffraction imaging

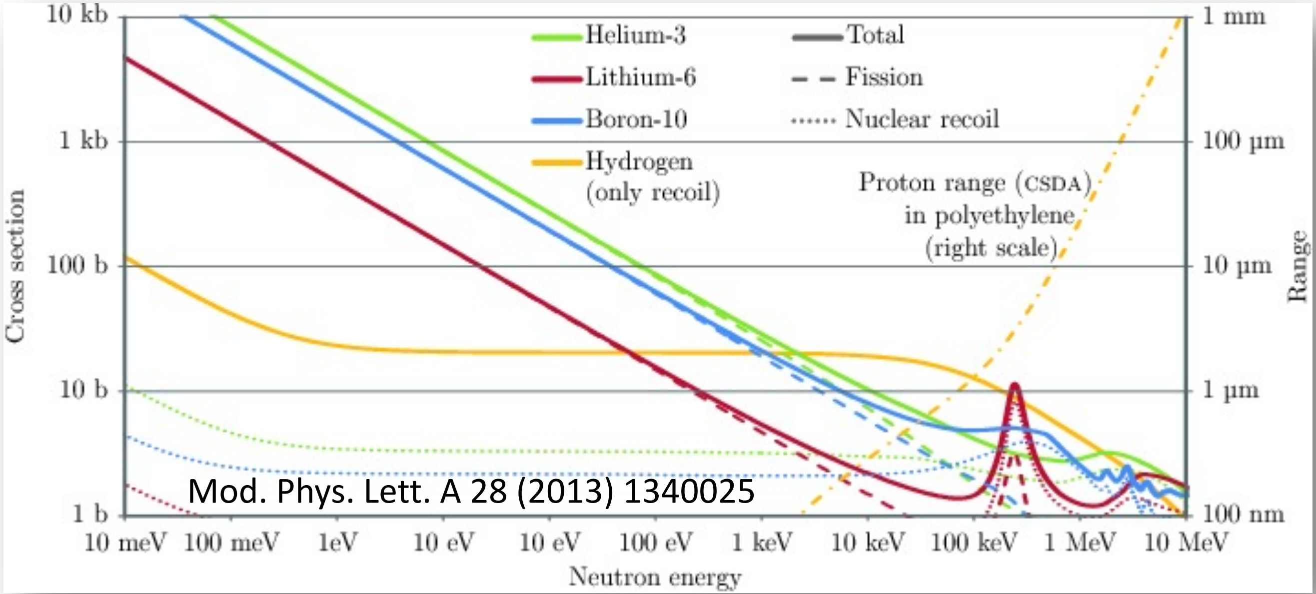


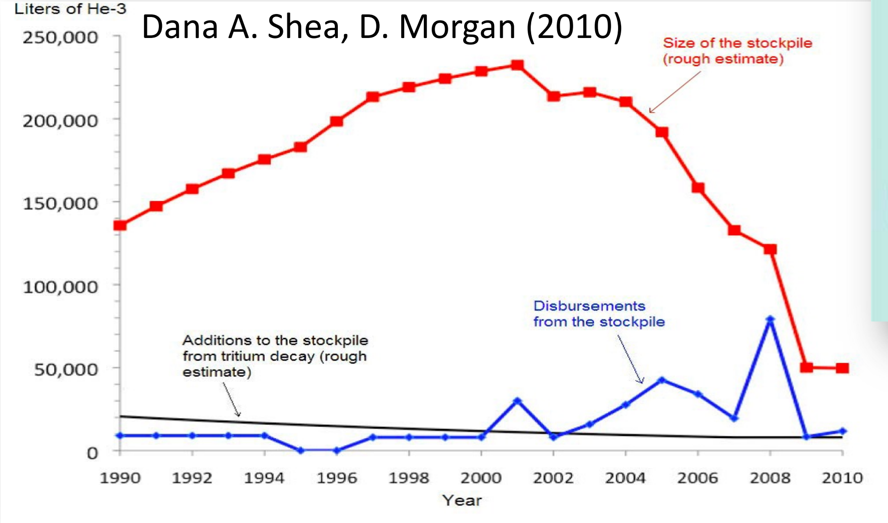
- Complementary to X-ray imaging

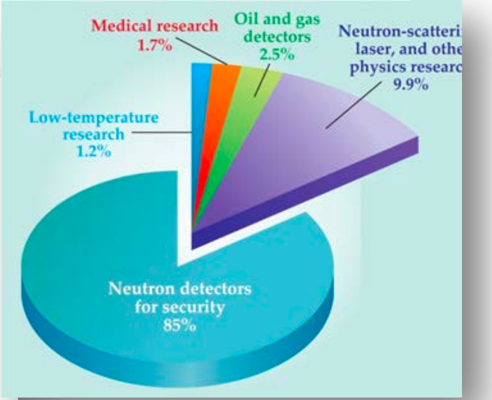


- High energy: Hadron Calorimeter
  - measure energy deposited in form of hadronic shower
- Moderate energy: np-Scattering
  - scattering with protons from material containing appreciable amounts of hydrogen
- Low energy: Exoergic Nuclear Processes
  - Use converter medium with large capture cross-section

Neutron Detection in a Nutshell





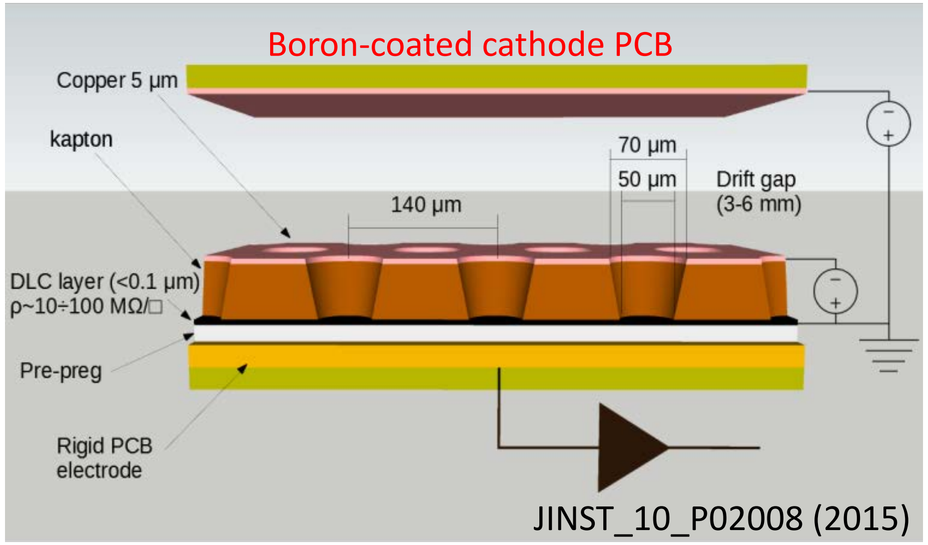


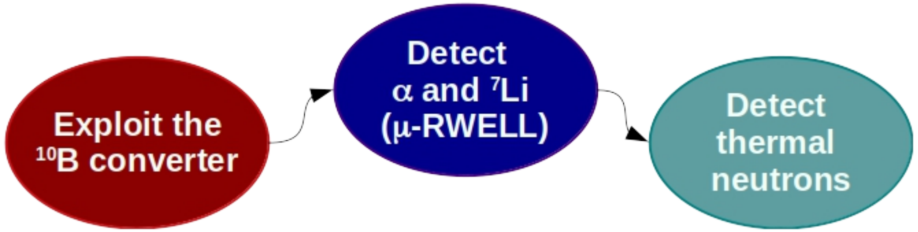
Helium-3 shortage calls for alternatives https://phase1.attract-eu.com/showroom/project/u-rwell-advanced-neutron-imaging-apparatus-urania/

funded by ATTRACT

u-RWELL Advanced Neutron Imaging Apparatus (uRANIA)

- Development of an innovative neutron detector based on micro-Resistive WELL technology: a compact, spark-protected, single-amplification stage MPGD



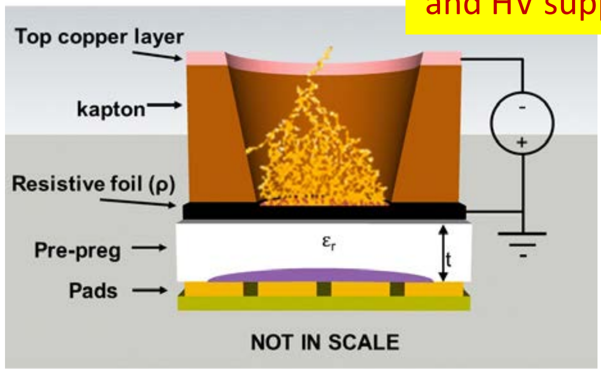


Applications in grain mapping of structural and functional materials, characterization of protein crystals at spallation sources

Applications to homeland security → RPM portals

μ-Resistive Well Detector

easy assembly and HV supply



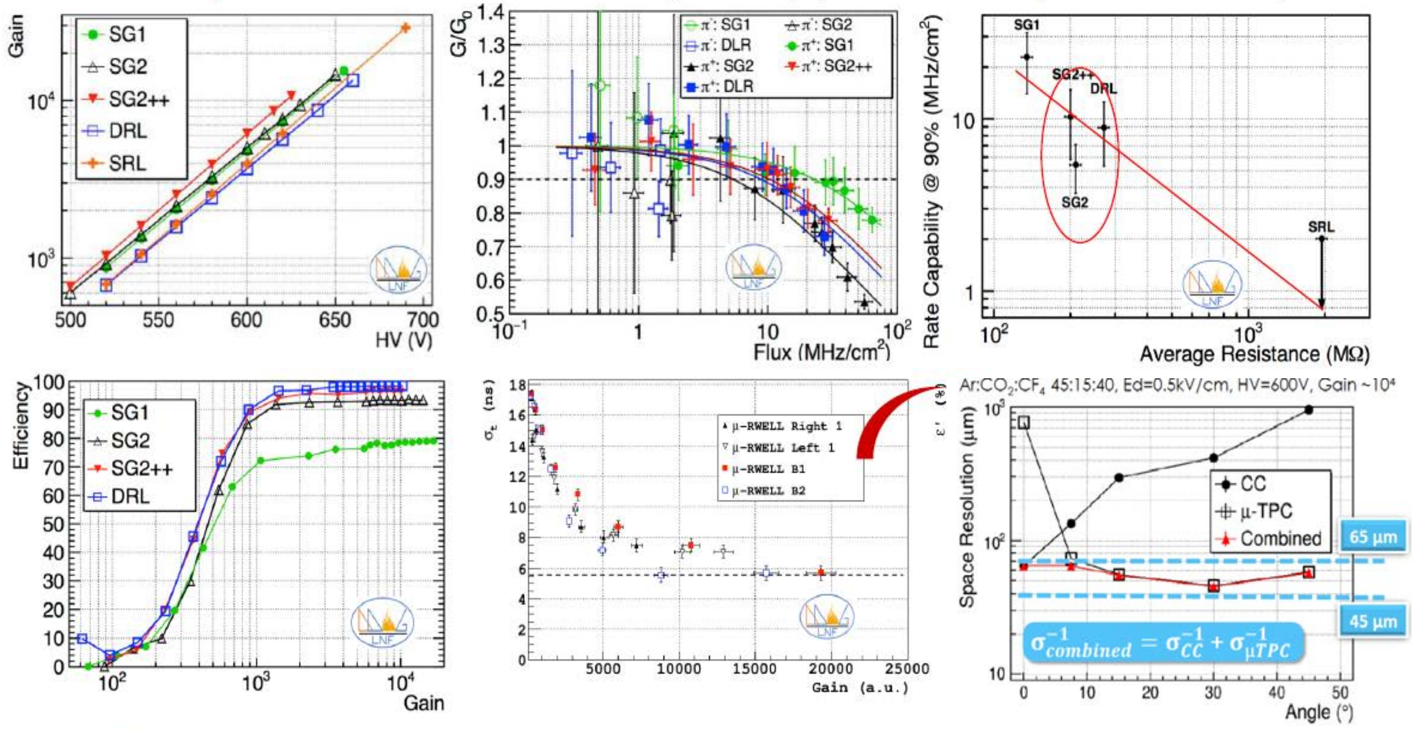
The "WELL", suitably polarized applying HV between top and DLC, acts as a multiplication channel for the ionization produced in the gas

JINST **14** P05014 (2019)

- Single amplification stage resistive MPGD composed of
    - μ-RWELL_PCB
    - drift/cathode PCB defining the gas gap
- μ-RWELL_PCB
    - ampl.-stage
    - res.-layer
    - r/out PCB (with suitable segmentation)
- Large area & flexible geometry
- Comes in two flavors: low rate and high rate

Gain up to ~ 10^4

Rate capability (@ G = 5000) ~ 5-10 MHz/cm^2



Efficiency ~ 98%

σ_t ~ 5-6 ns

Space resolution in u-TPC-mode

Neutron capture through Boron coating

$$n + {}^{10}B \rightarrow {}^{11}B^* \rightarrow \alpha + {}^{7}Li$$

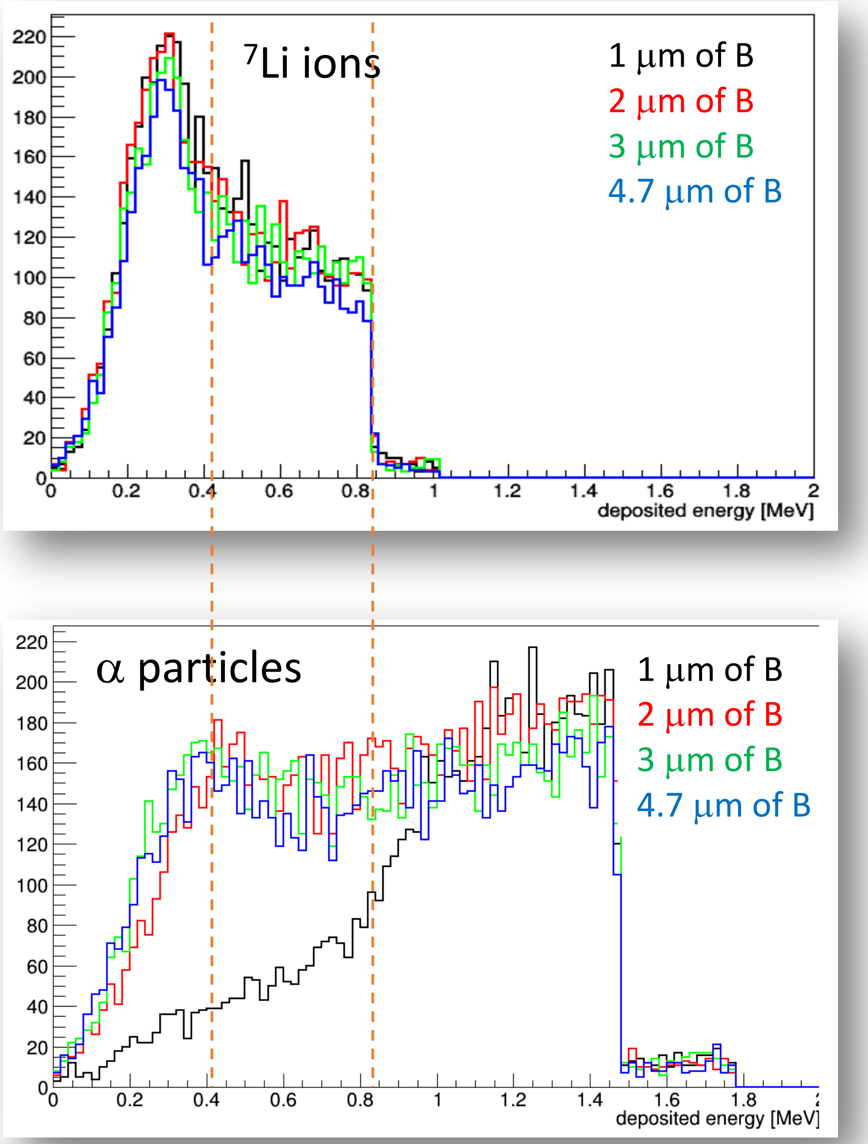
- chemically stable
- not too expensive
- adherence to substrate
- low impurity level uniform sputtering thickness on large surface

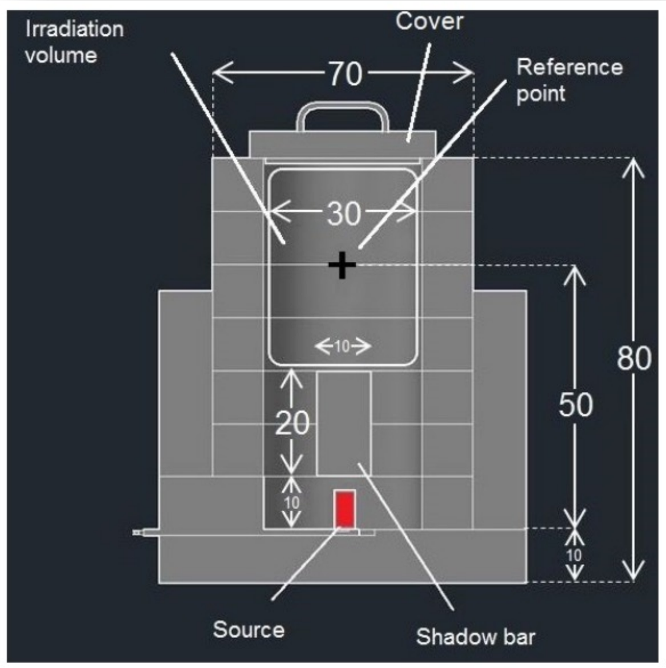
- B_4C enriched with 97% of ^{10}B sputtered on a copper surface at the ESS Coating Workshop in Linköping (Sweden) with direct current magnetron sputtering technology
- About 94% of the time the recoiling ^{7}Li ion is produced in an excited state and de-excites in flight, emitting a 477 keV γ ray
- α particle and a ^{7}Li ion are produced back-to-back, only one enters the gas volume and produces detectable signal

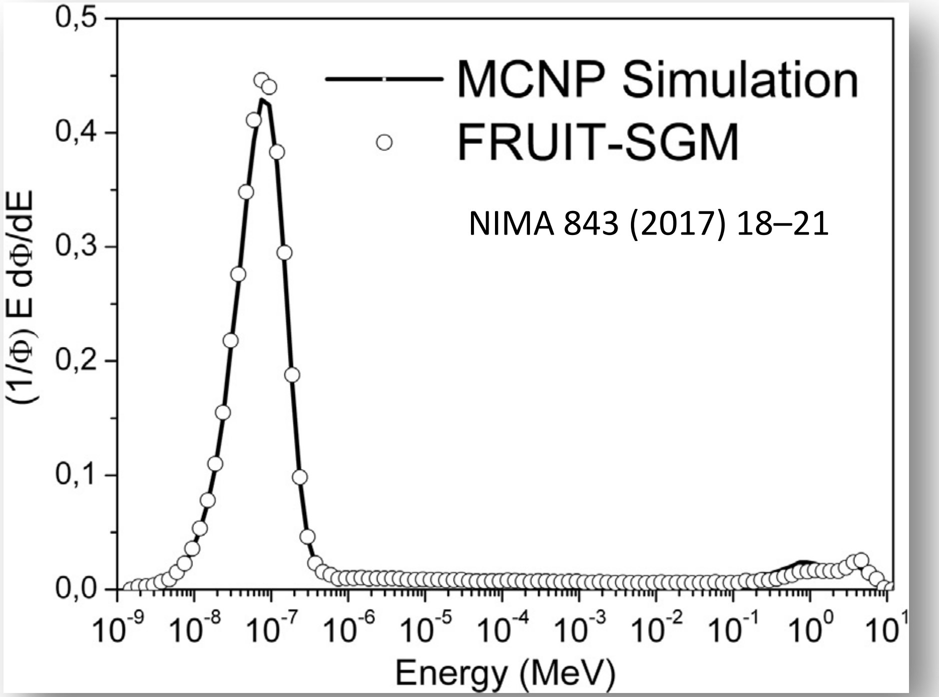
Neutron Converter Simulation

- Simulation is used to optimize the detector and to extract the detection efficiency from the current measurement
- Gas mixture ionizing energy ~ 31.5 eV
- Particles range < 6 mm of gas
    - all the energy released in the gas
    - ~10^4 number of primaries
- Neutron source energy distribution and divergence considered in the simulation

Energy release for different Boron thickness



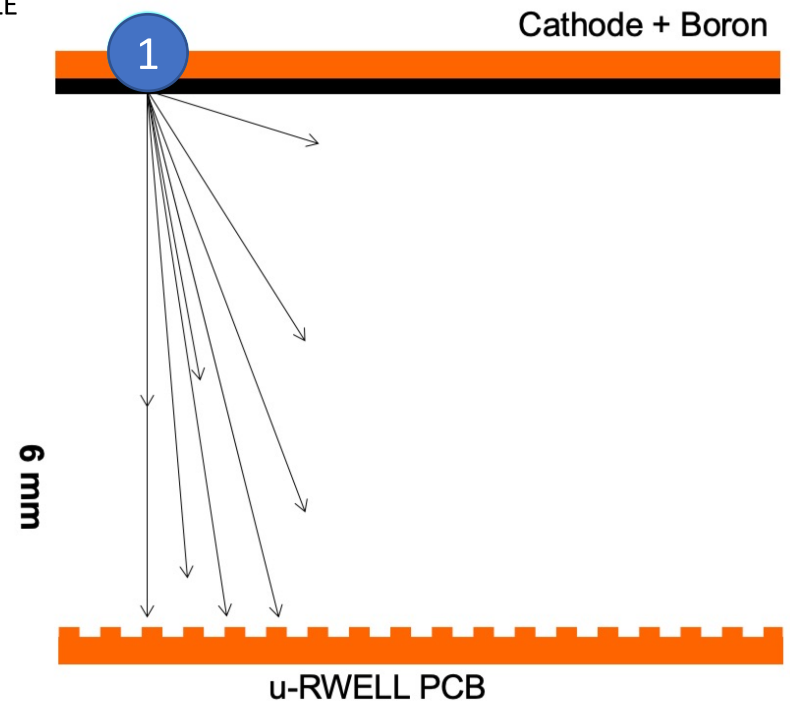




Source test facility: Hotnes (ENEA)

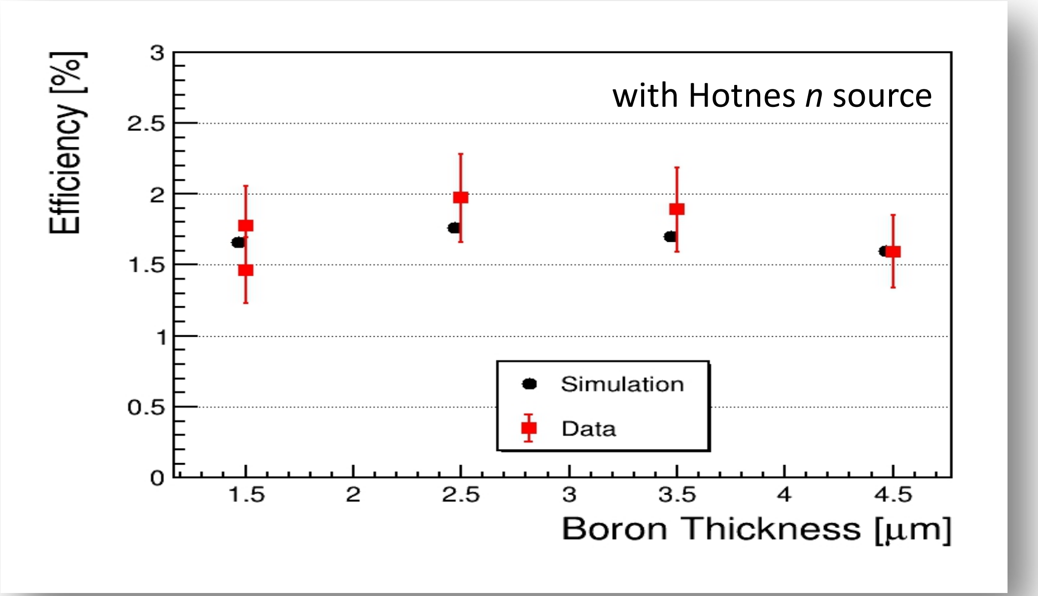
- Detector characterization done @ ENEA (Frascati, Italy)
- HOmogeneous Thermal NEutron Source (HOTNES) – ^{241}Am-B source
- Thermal fluence rate about 750 cm^{-2} s^{-1}
- Shadow bar to stop photons
- Energy spectrum peaks at 100 meV (FWHM ~290 meV)

Proof of concept with planar cathode



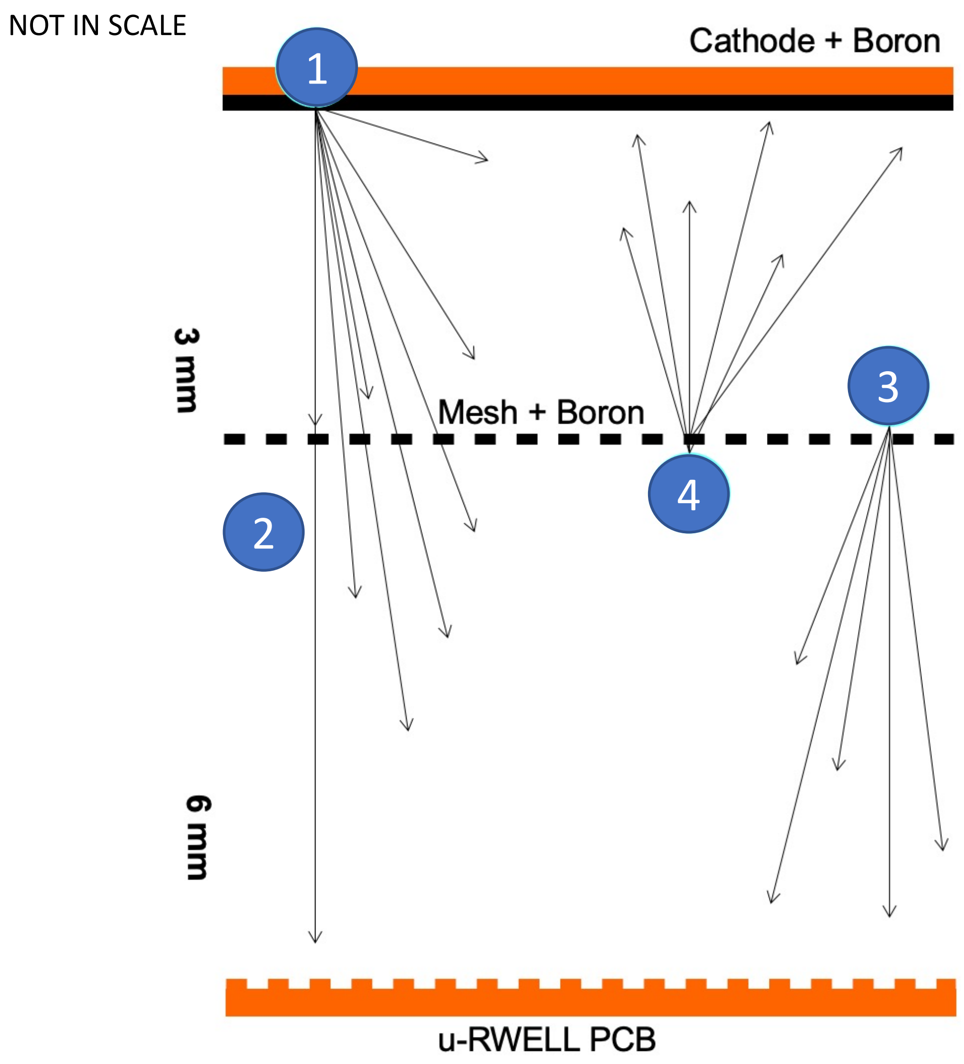
$$i = \Phi * \varepsilon * N_{ION} * G * S$$

- i = current (C s^{-1})
- Φ = neutron flux (758 cm^{-2} s^{-1})
- ε = efficiency = #α seen/#neutrons → from simulation
- N_{ION} = # ele from ionization = primaries & secondaries = E_{DEP}/E_{ION}
- G = gain
- S = surface 10 x 10 cm^2



Efficiency for thermal neutrons (25 meV) about twice the values of the Hotnes setup due to the source energy distribution

Boron-coated mesh



Adding a boron-coated mesh to increase the efficiency

material	wire diameter [um]	pitch [um]	opt. transparency
Copper	56	190	60%
Aluminum	53	74	33%

Different contributions studied independently with simulation and source test

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. $i_4 = \Phi \times \varepsilon_4 \times N_4 \times G \times S \times T_{elec}$

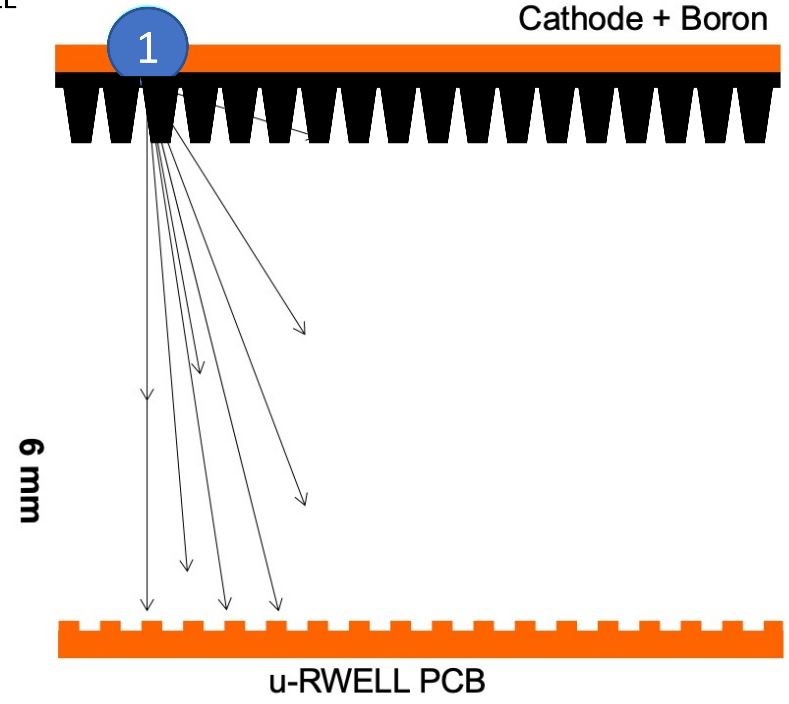
Preliminary results show

- about a factor 2 efficiency increase
- negligible dependance on the Boron thickness
- importance of optical transparency tuning

Grooved cathode

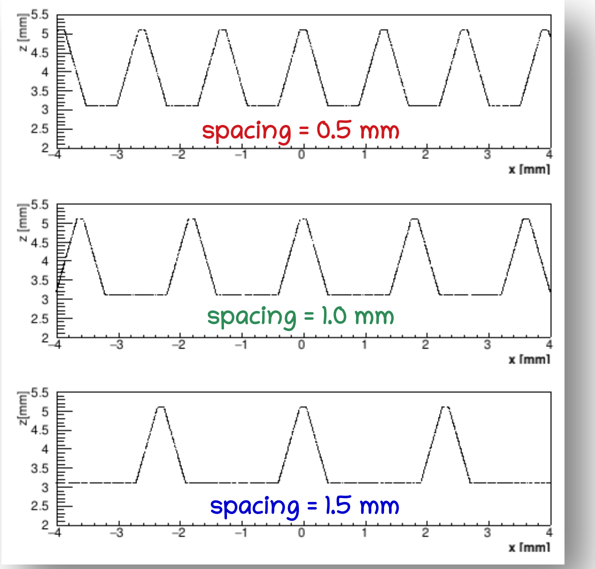
Grooved cathode can also increase the efficiency

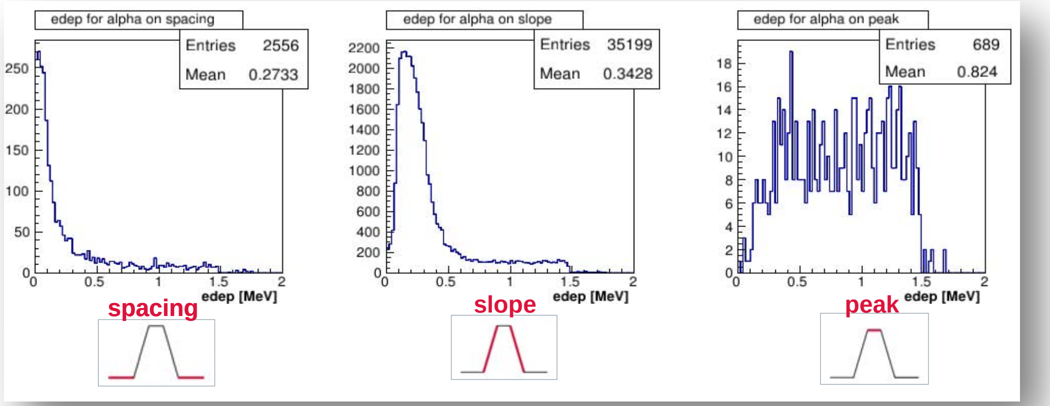
NOT IN SCALE



Different geometries under study

For each layout, the energy deposit has been considered on the spacings, slopes and peaks





A factor ~2 of increase in the efficiency can be achieved

Counting mode electronics

- Readout large fraction of the chamber with one channel
- Developed for large area application where position information is less relevant (RPM, RWM)
- Two readout under testing
  - CAEN A1422-based
    - gain ~0.2 mV/fC
    - noise ~20 mV
    - signal duration ~5 um
  - CREMAT CR110-based
    - gain ~0.5 mV/fC
    - noise ~20 mV
    - signal duration ~5 um

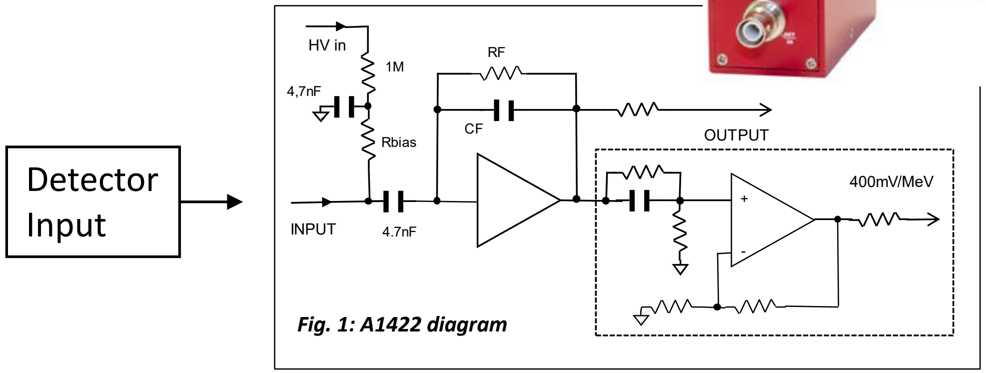
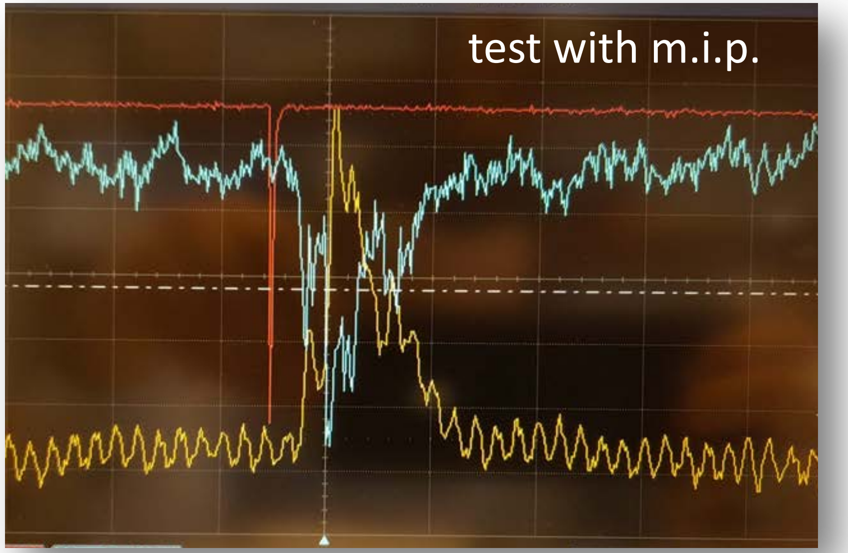


Fig. 1: A1422 diagram

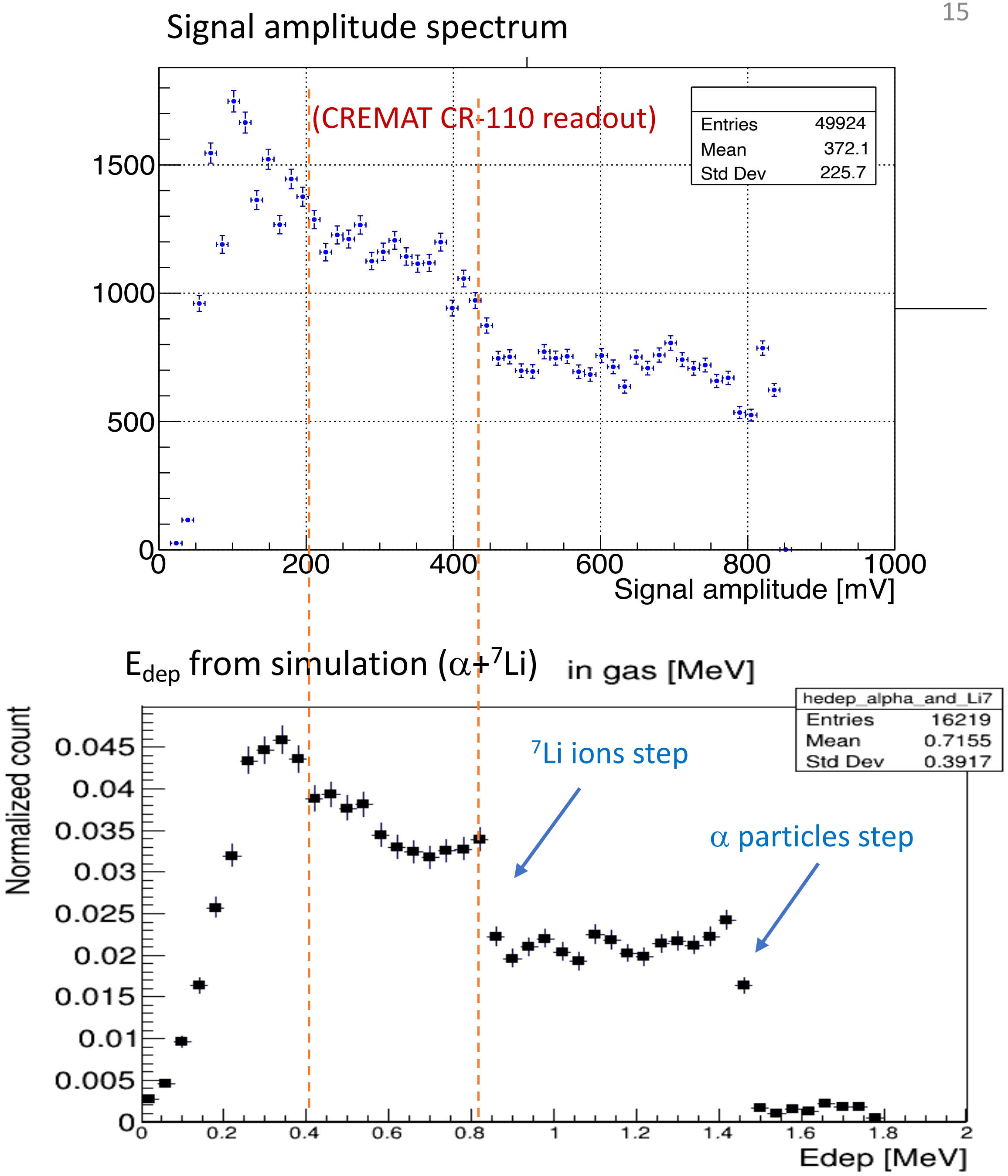


signal waveform acquired with a Picoscope for amplitude analysis

Anode signal
TOP signal
reference PMT

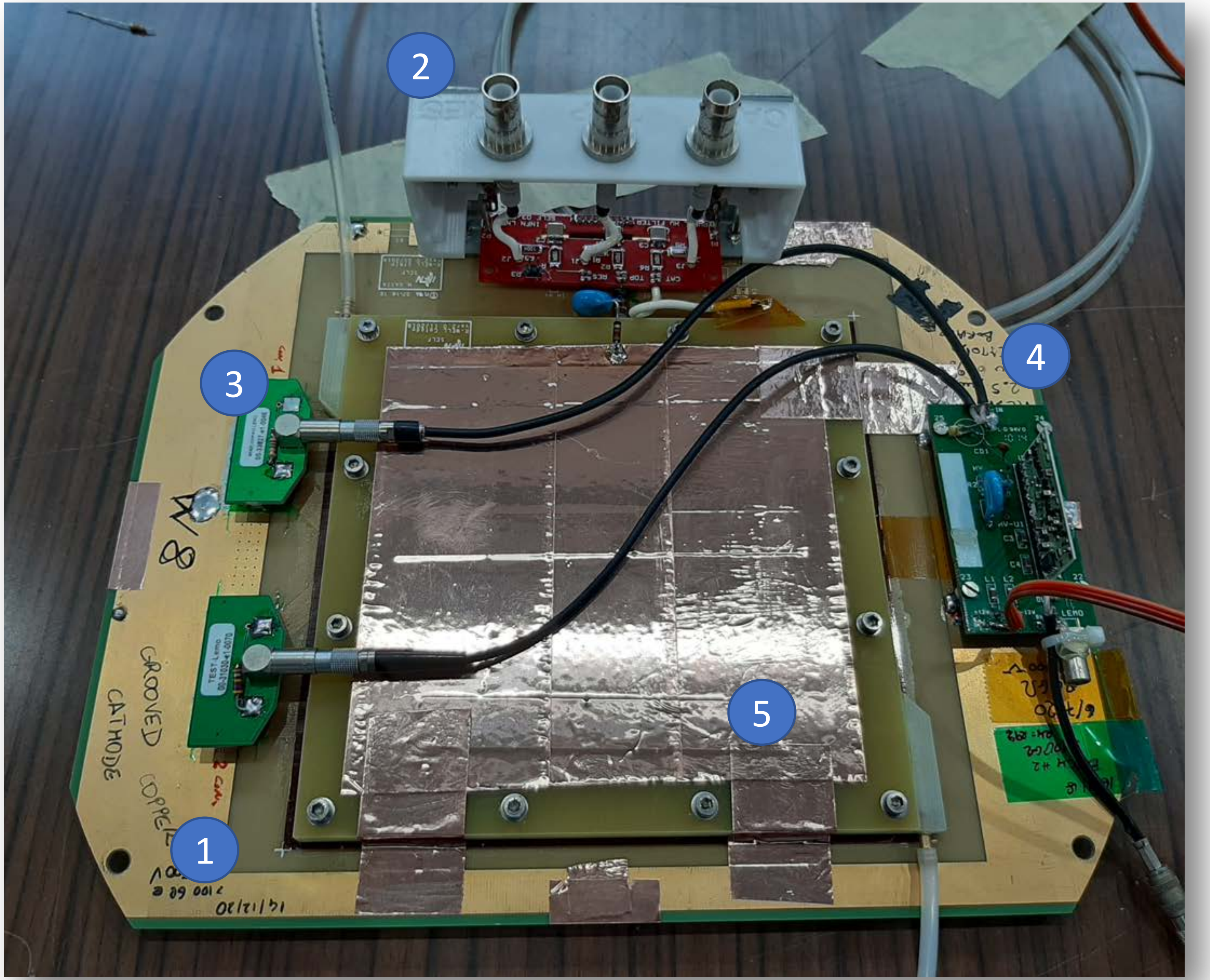
Counting mode electronics

- First validation done with Hontes source
- Signal amplitude from neutron conversion (top) is compared with simulation (bottom)
- Simulation reproduces the same features of the data down to the noise level



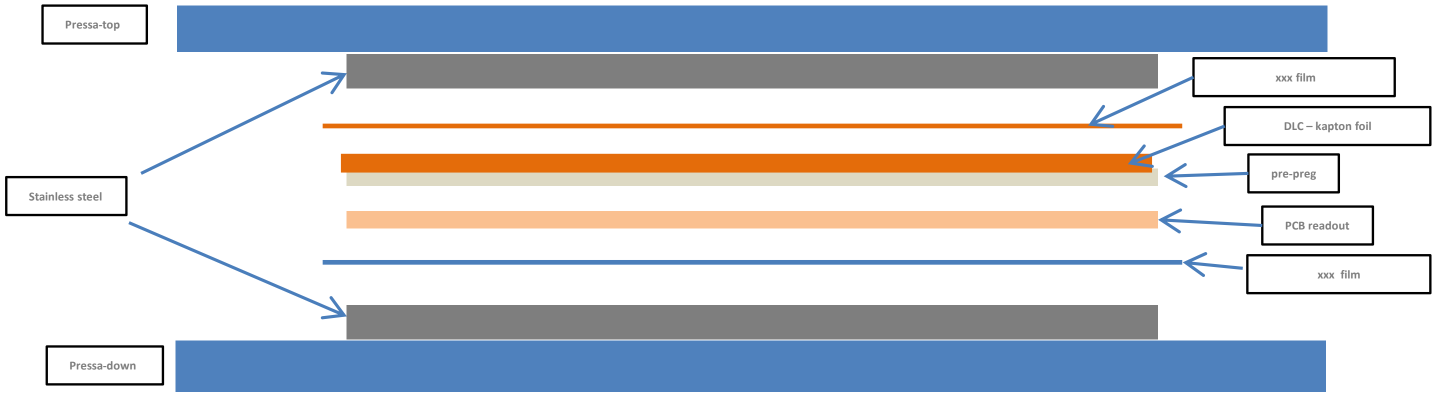
All in all

1. μRWELL_PCB
2. HV and filtering
3. Anode readout connectors
4. Counting mode electronics
5. External shielding

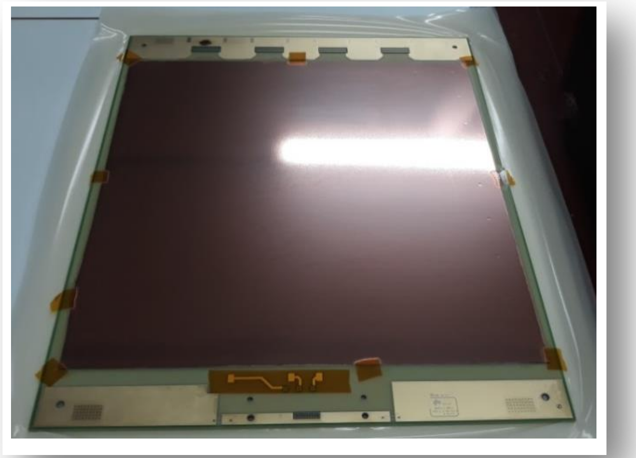


Technology transfer: μ-RWELL_PCB @ELTOS

- ELTOS performs the coupling of the DLC-foil with the readout PCB (only for low-rate layout)
- The max size of the μ-RWELL-PCB that can be produced by ELTOS is about 600x700 mm^2. Up to 8 PCBs of such a size can be manufactured at the same time
- The PI etching to be done @ CERN



33x33 cm^2 active area LR - RWELL



INFN and ELTOS participate to the AIDAinnova project for further TT
https://cordis.europa.eu/project/id/101004761

Summary and Conclusions

- The μ-RWELL technology, robust, easy to assemble and relatively cheap MPGD, can be a valuable alternative for neutron detection
- μ-RWELLs have been successfully tested for thermal neutron detection with a ^{10}B layer as converter
  - Source test data confirms simulation studies with good accuracy
- Efficiency improvement by means of grooved cathode, converting mesh and other detector layout
  - 10-20% efficiency achievable with a single detector for 25 meV neutrons
  - higher efficiency with multiblade or multi-stack configurations
- For neutron imaging applications standard MPGD electronics can exploit the high spatial resolution of the μ-RWELL detector
- For Radiation Portal Monitors counting electronics under development will reduce the costs
- Technology Transfer is ongoing
  - large area μ-RWELL_PCB can be produced by industries (except for the Kapton etching)