Alphabeast : a CMOS based Detector for Neutron Dosimetry

On behalf of the DeSIs team

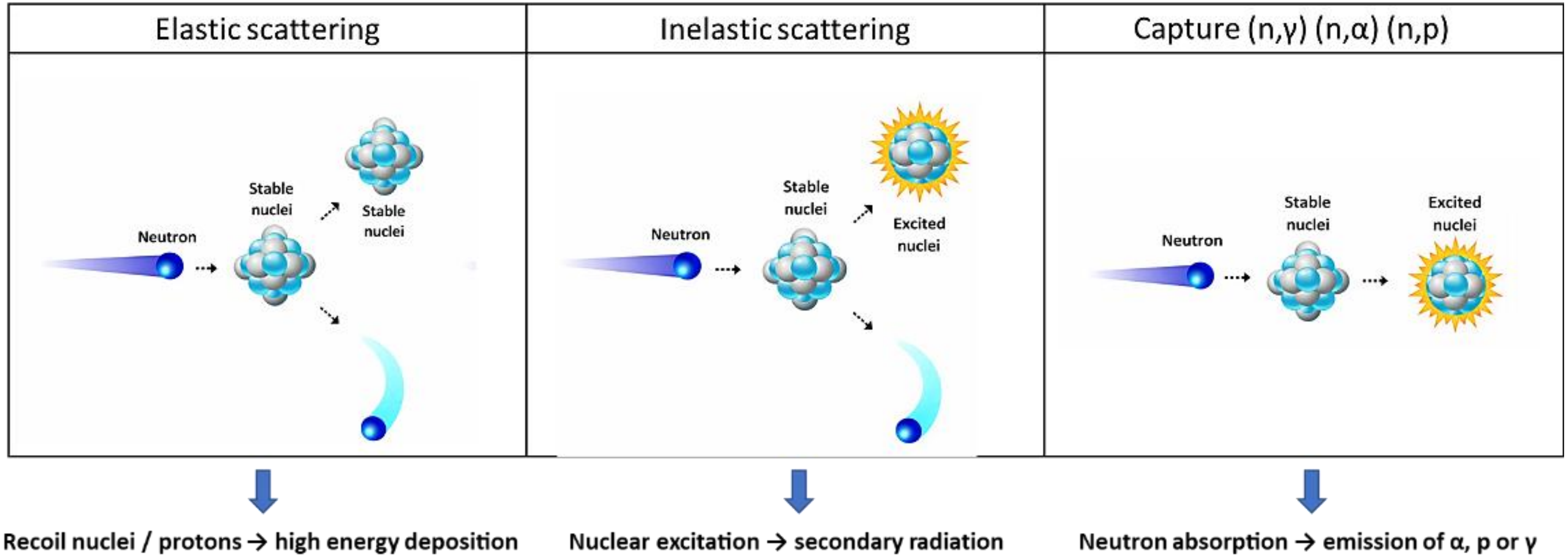
Djokhar BETELGUERIEV
(djokhar.betelgueriev@iphc.cnrs.fr)

Institut Plurisdisiplinaire Hubert Curien, CNRS, Strasbourg, France

AlphaBeast sensor: purpose and operating principle

Motivation: Why Detecting Neutrons Matters

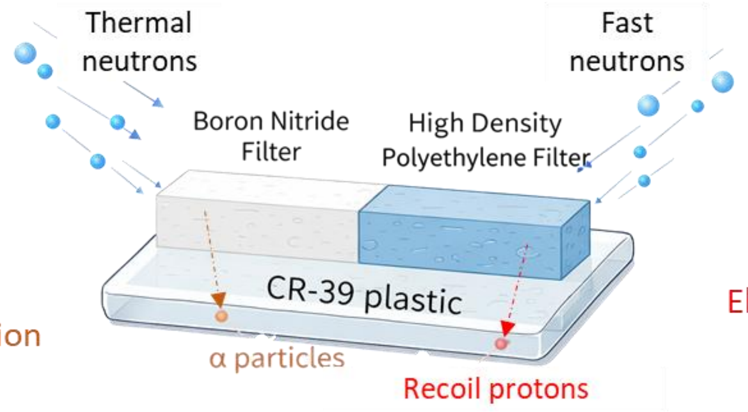
Neutrons are indirectly ionizing radiation:
they generate charged secondary particles with high LET through nuclear interactions.



Neutron dosimetry relies on detecting the secondary particles produced by these interactions.

Current Standard : CR-39 Passive Detectors

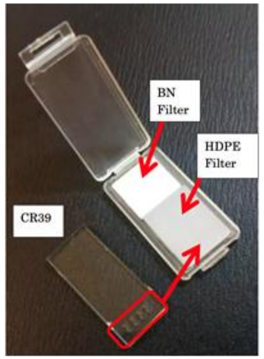
Composite CR-39 neutron detector

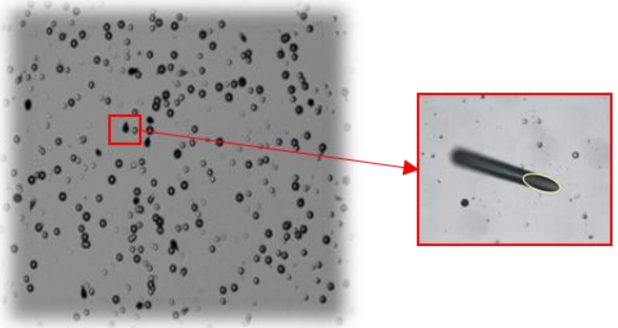


10B(n,α)7Li

neutron capture -> alpha emission

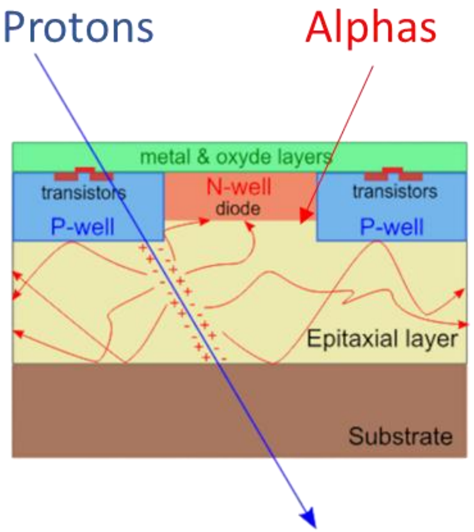
Elastic scattering on hydrogen → recoil protons

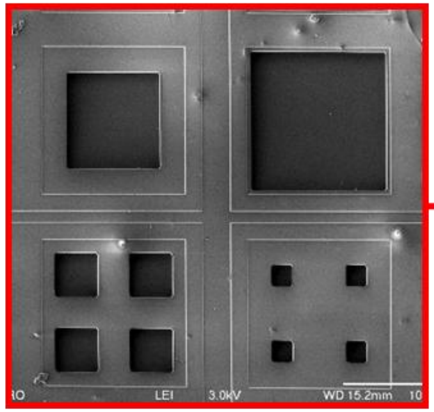


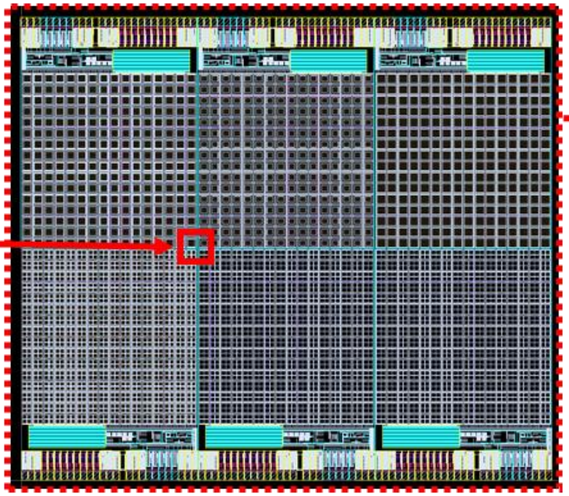


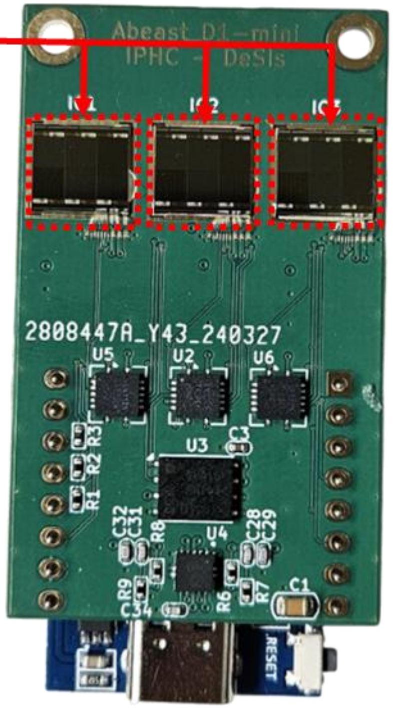
- Single use
- No real-time
- Time consuming

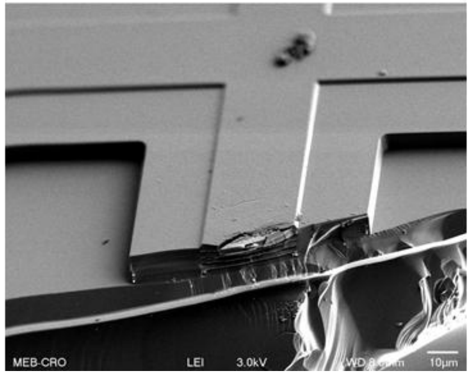
Alphabeast : CMOS Technology

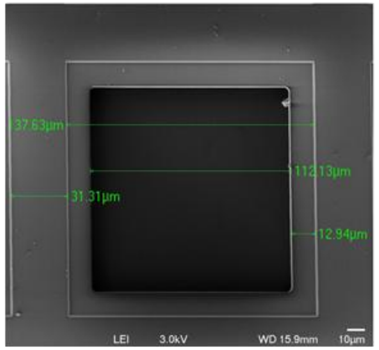












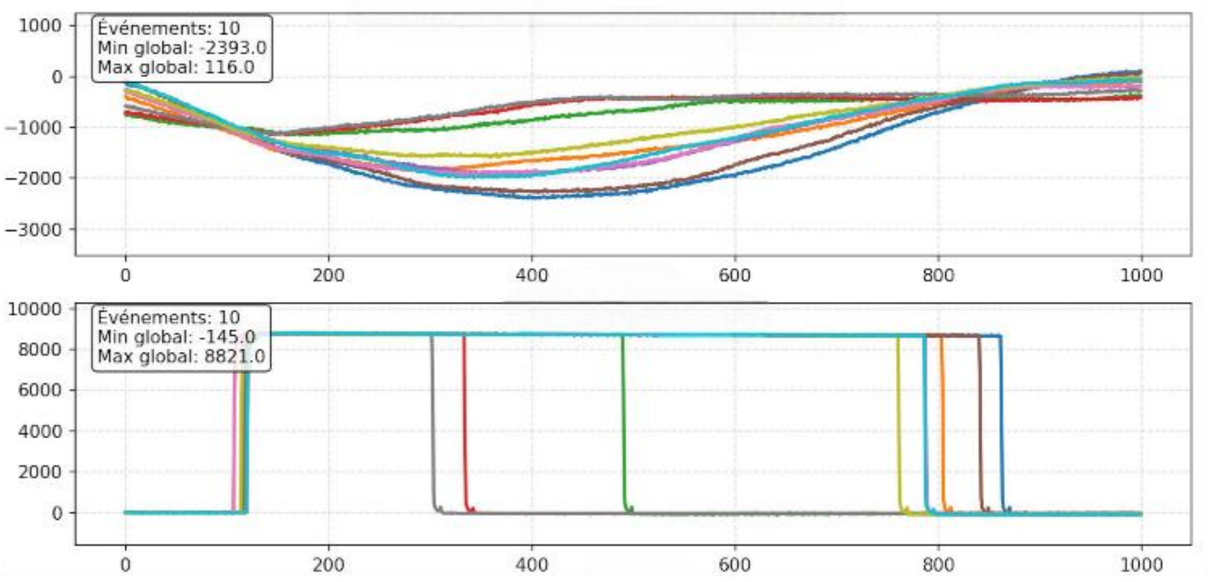
- **The silicon oxide layer acts as a surface filter**, reducing leakage and surface noise.
- The **size of the collection well is optimized to balance signal and noise**

Mono-abeast sensor (analog signal)

Analog Output

(10 hits, threshold : 235 ⇔1000 ADC ⇔336keV)

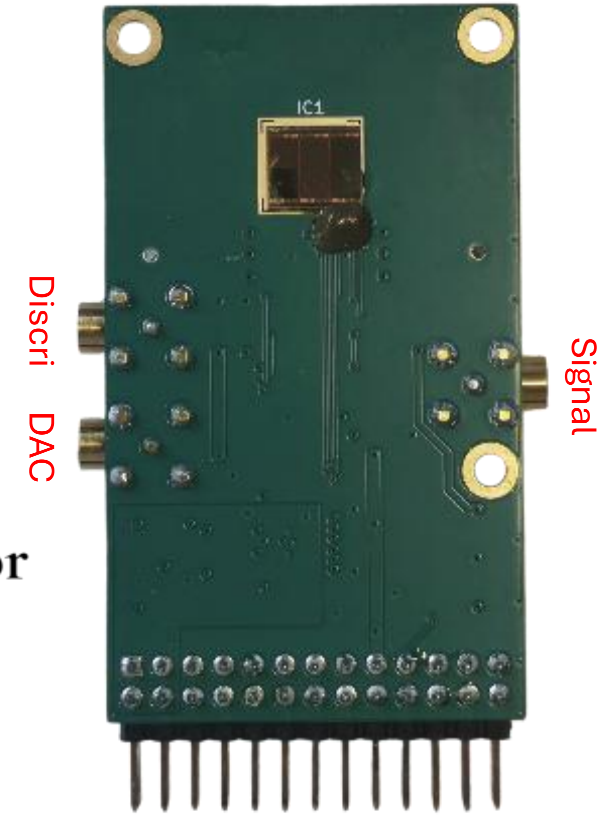
ADC values



Signal

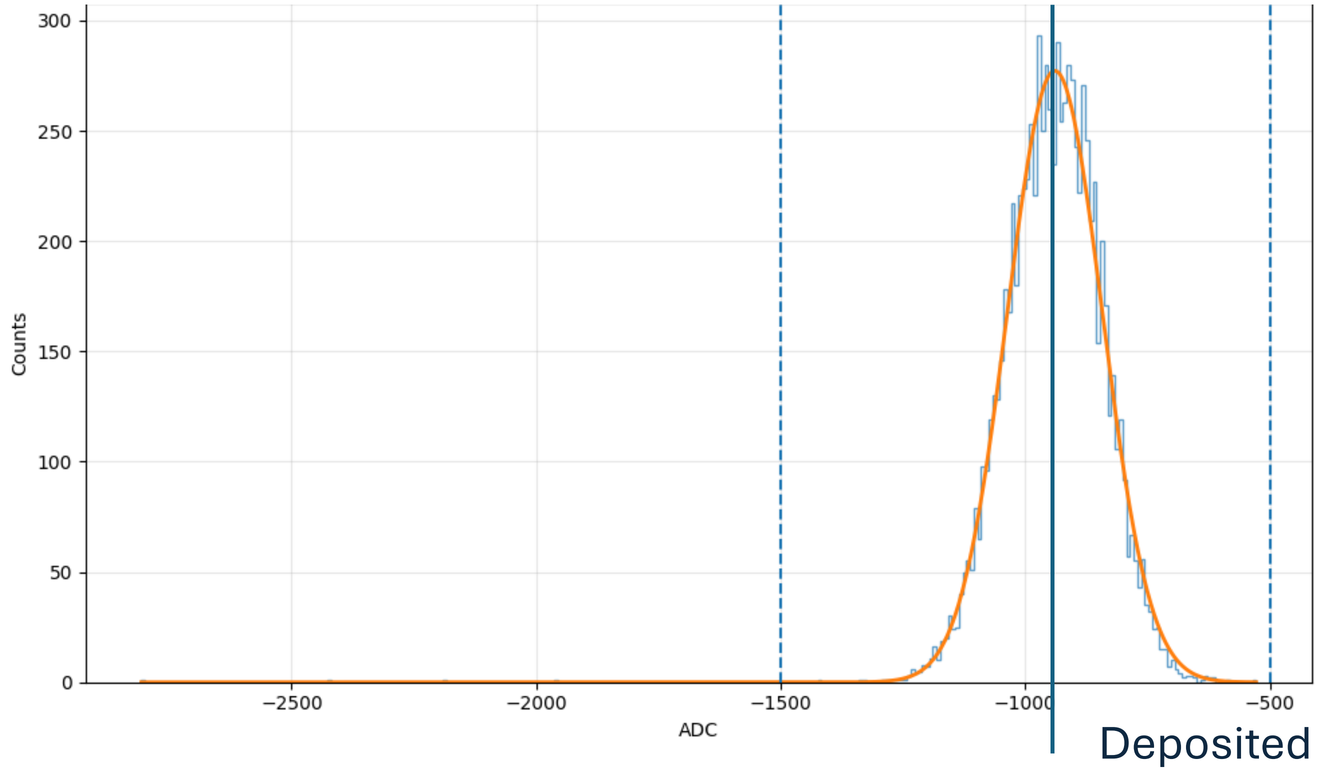
Discriminator Step

Samples (1 step = 312,5 ps)



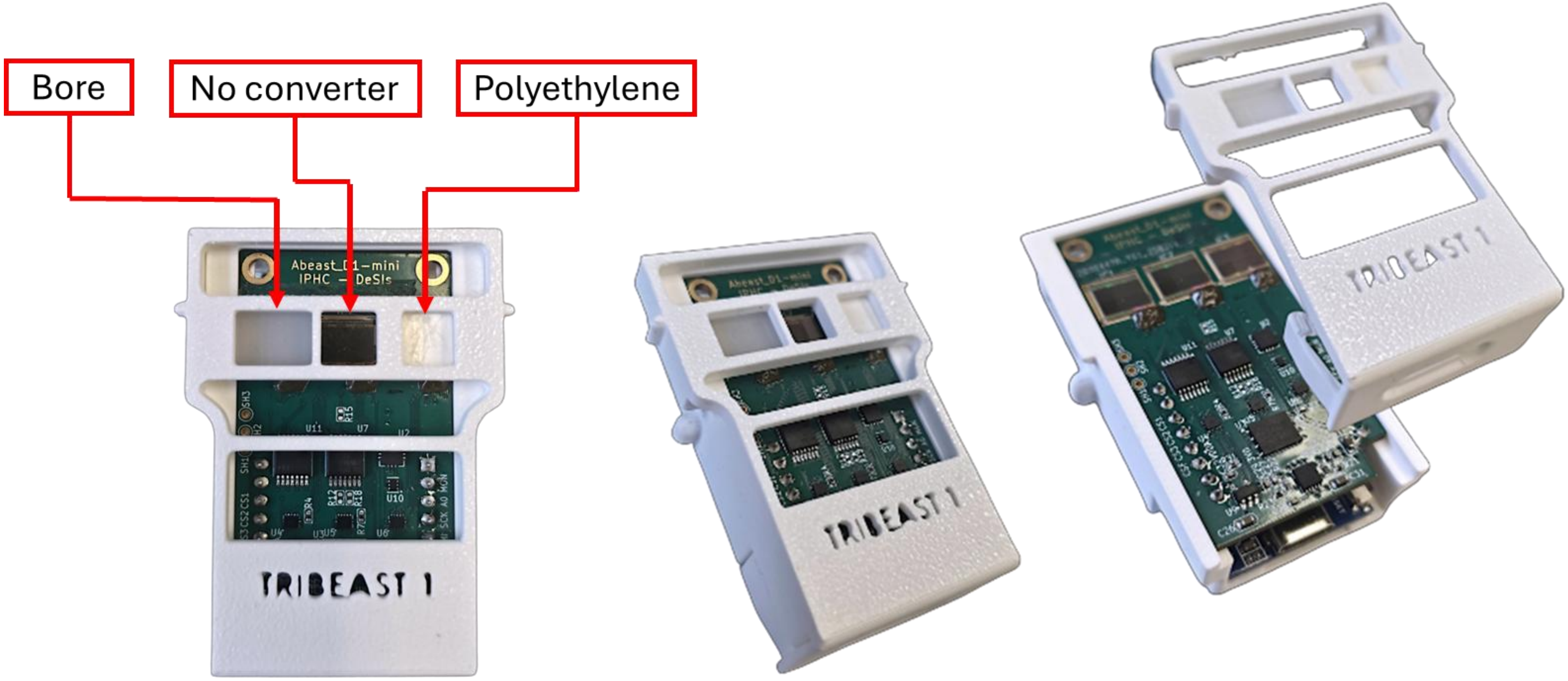
Mono-abeast sensor (analog signal)

Analog min Amplitude distribution

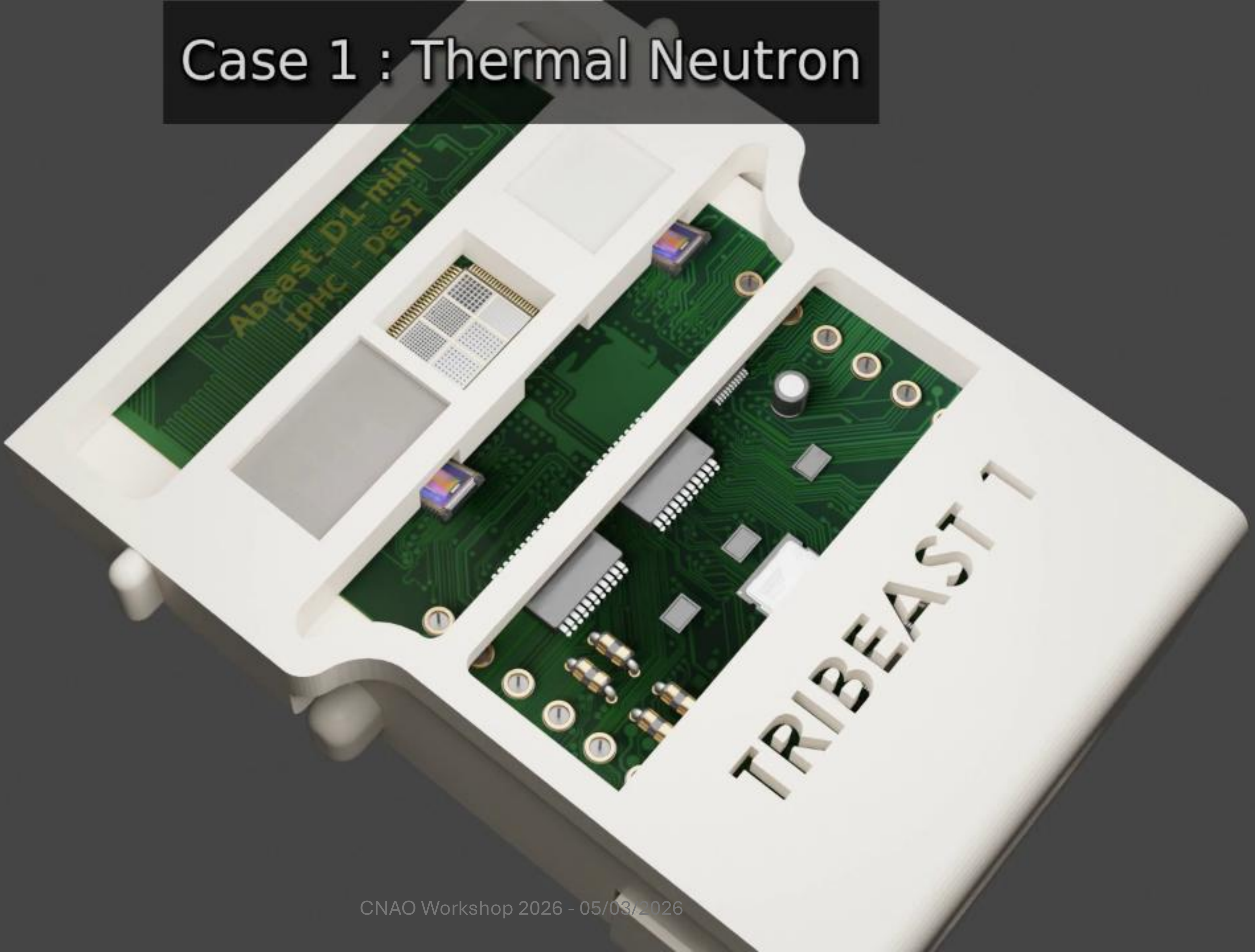


Deposited energy

Tri-beast sensor (neutron couting)

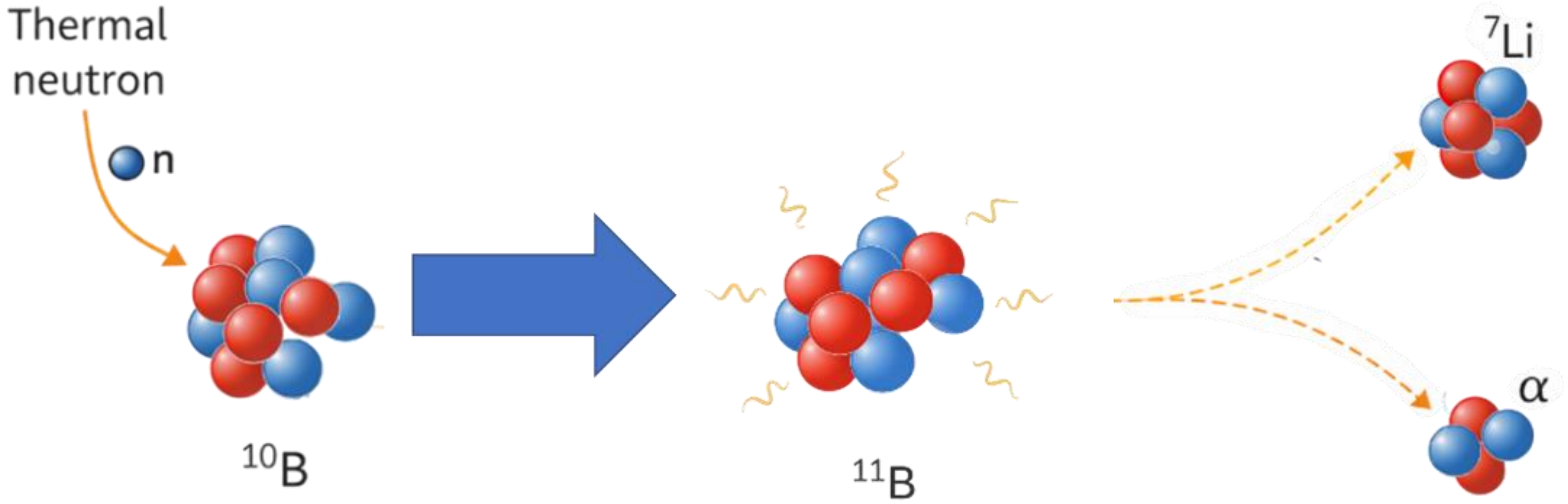


Case 1 : Thermal Neutron

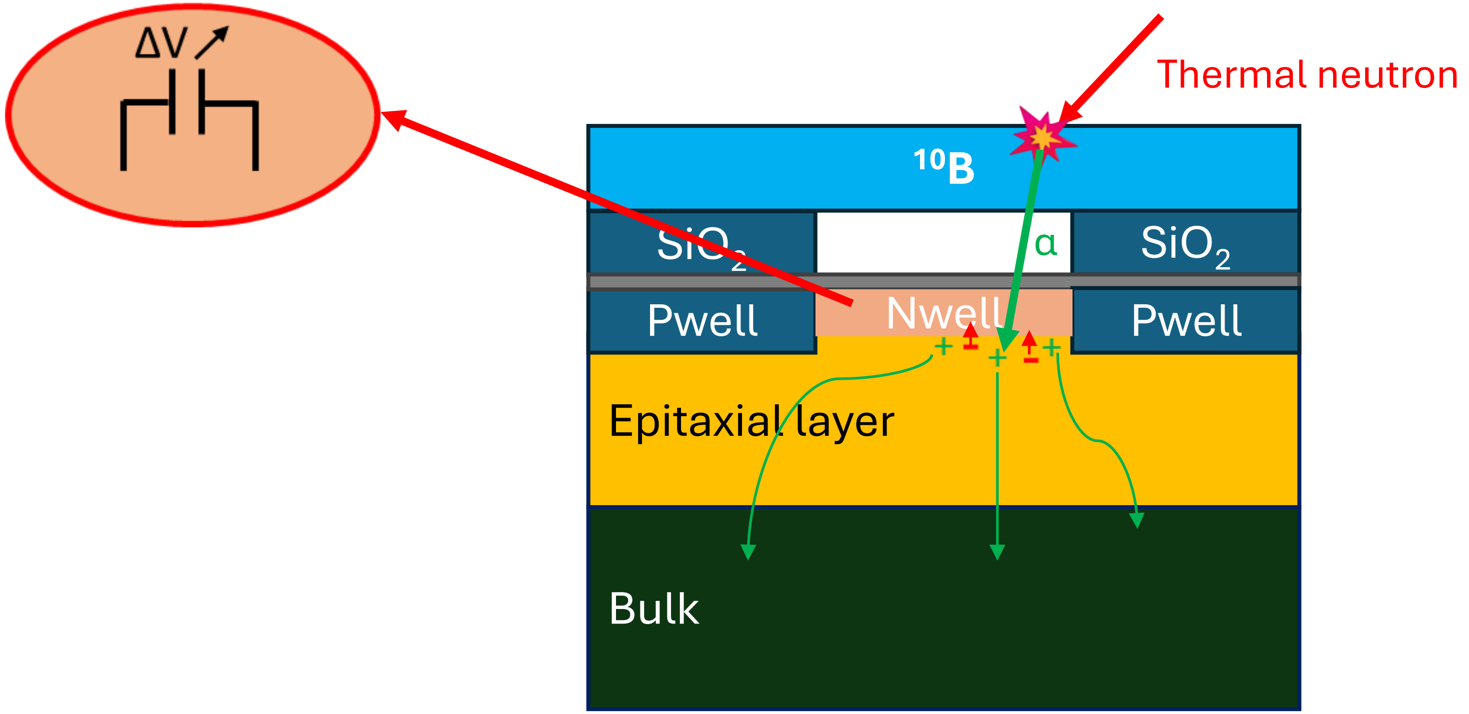


Bore 10 Layer

$^{10}B(n,\alpha)^{7}Li$

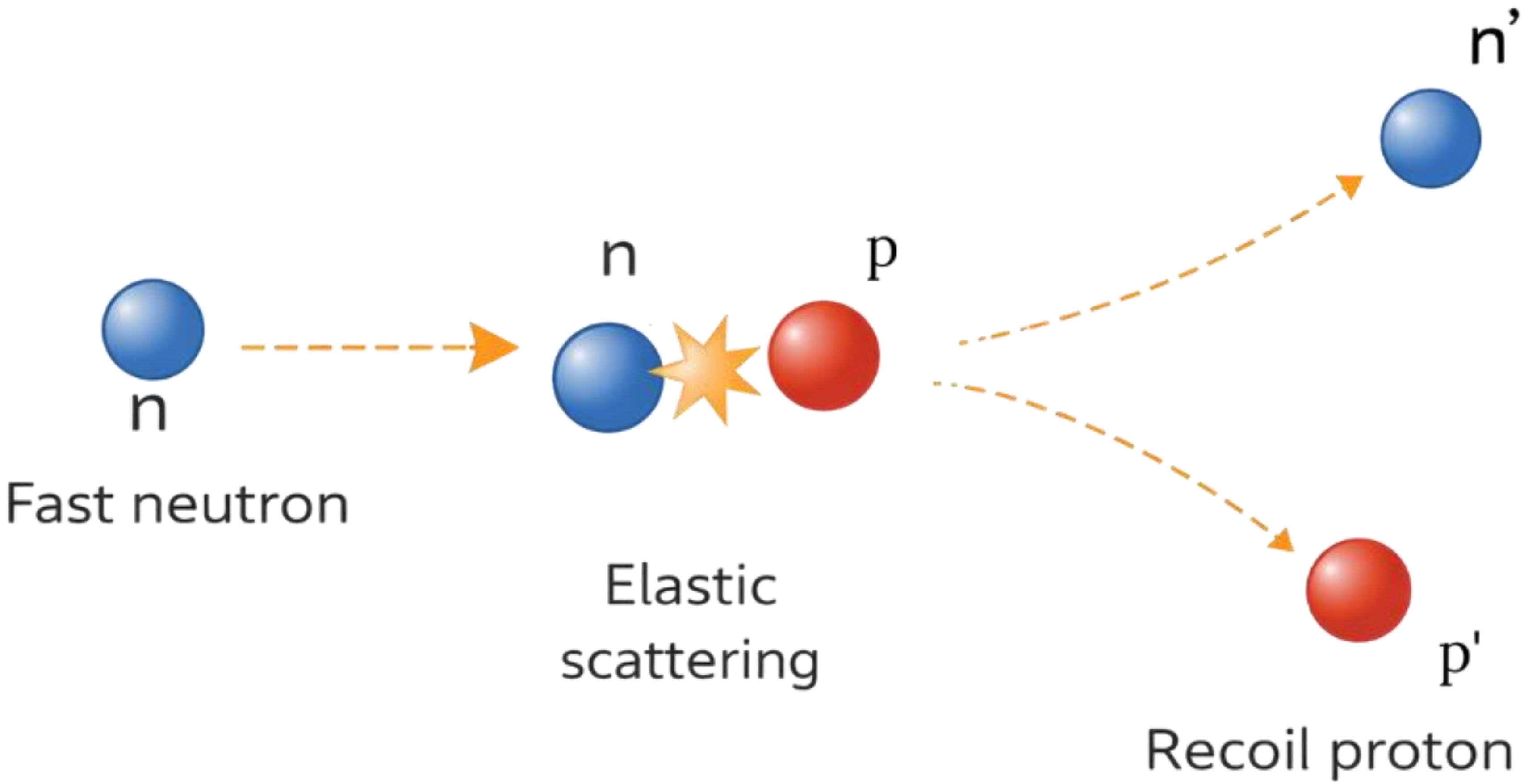


Alphabeast : Thermal Neutron Conversion via Boron Capture

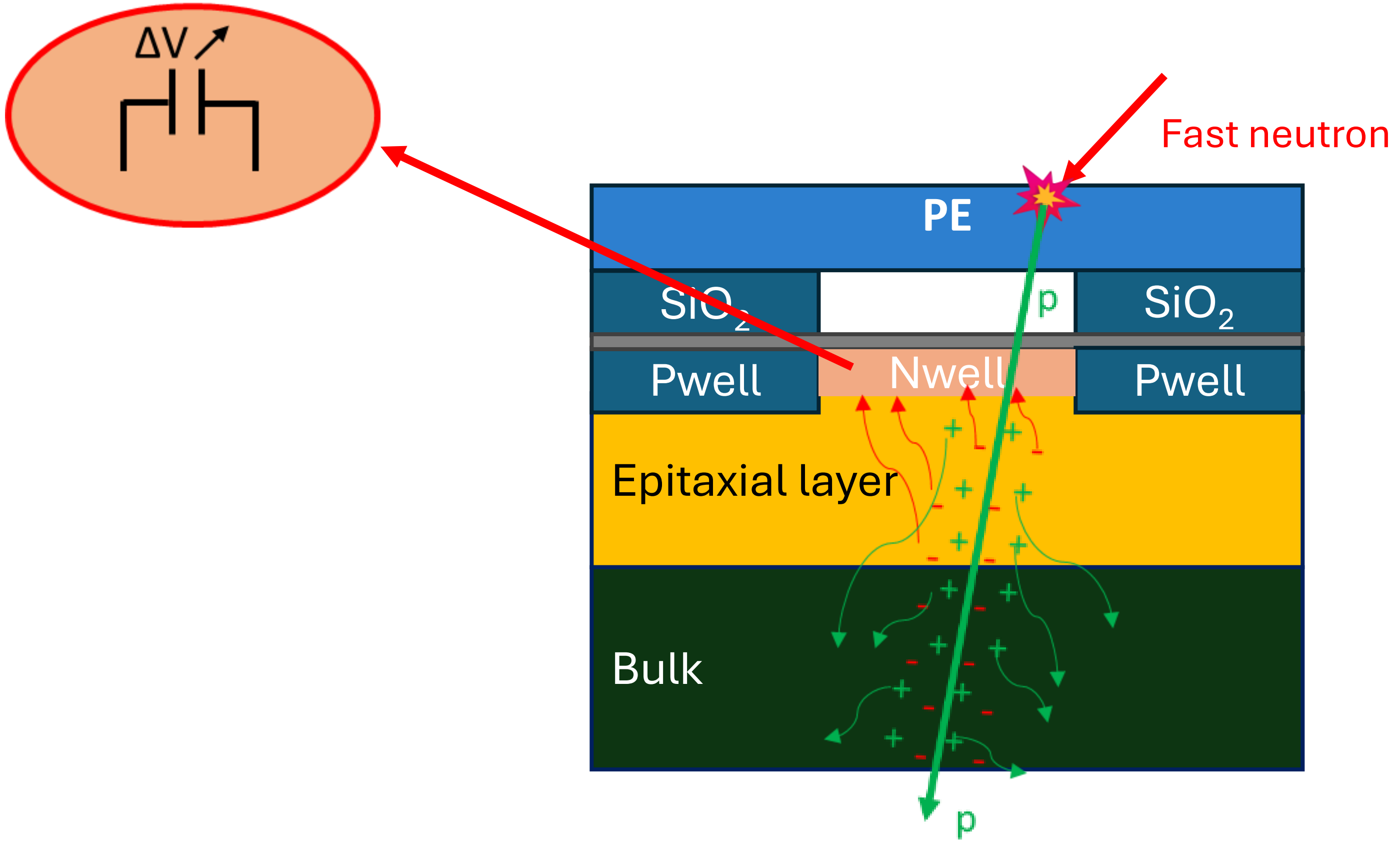


Case 2 : Fast Neutron

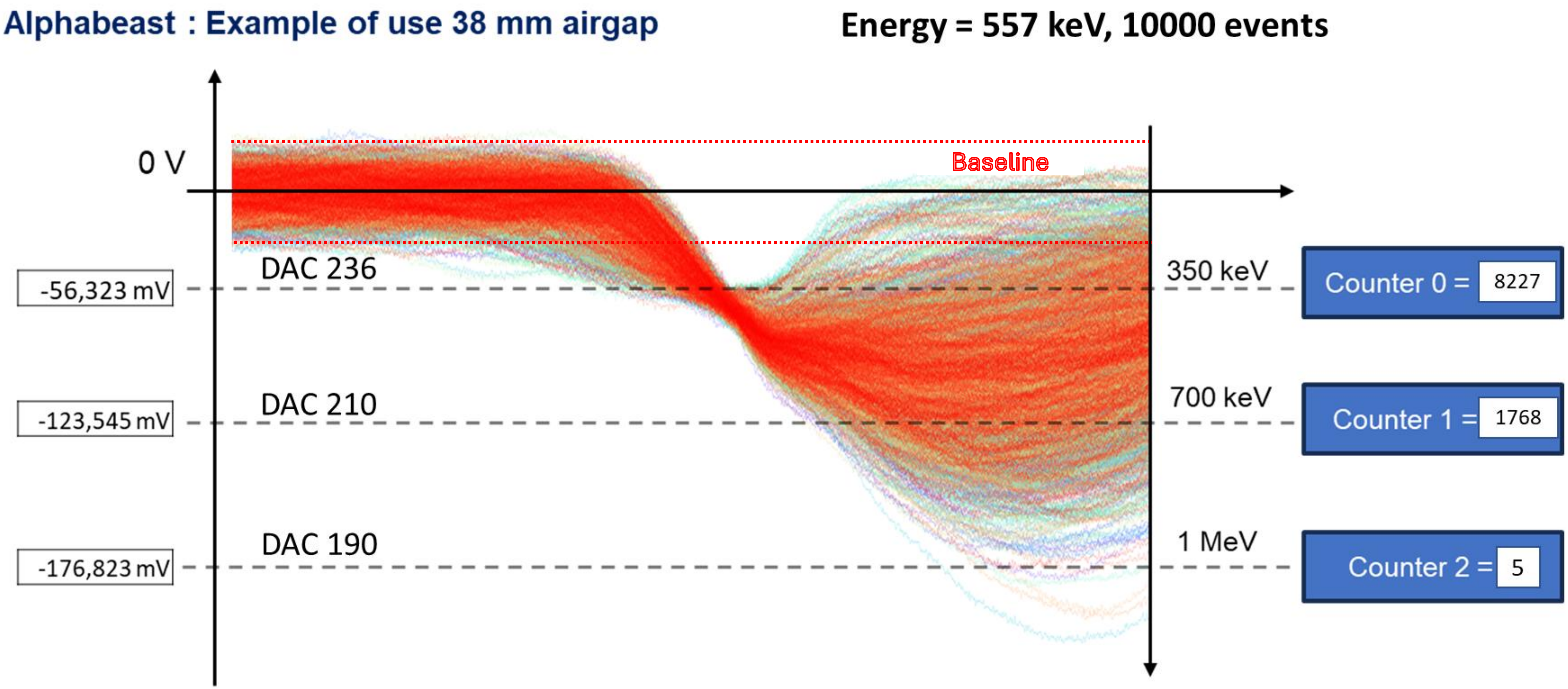

Abeast_D1-mini
IPHC - DeSI
Polyethylene Layer


n’
n
p
n
Fast neutron
Elastic
scattering
p'
Recoil proton

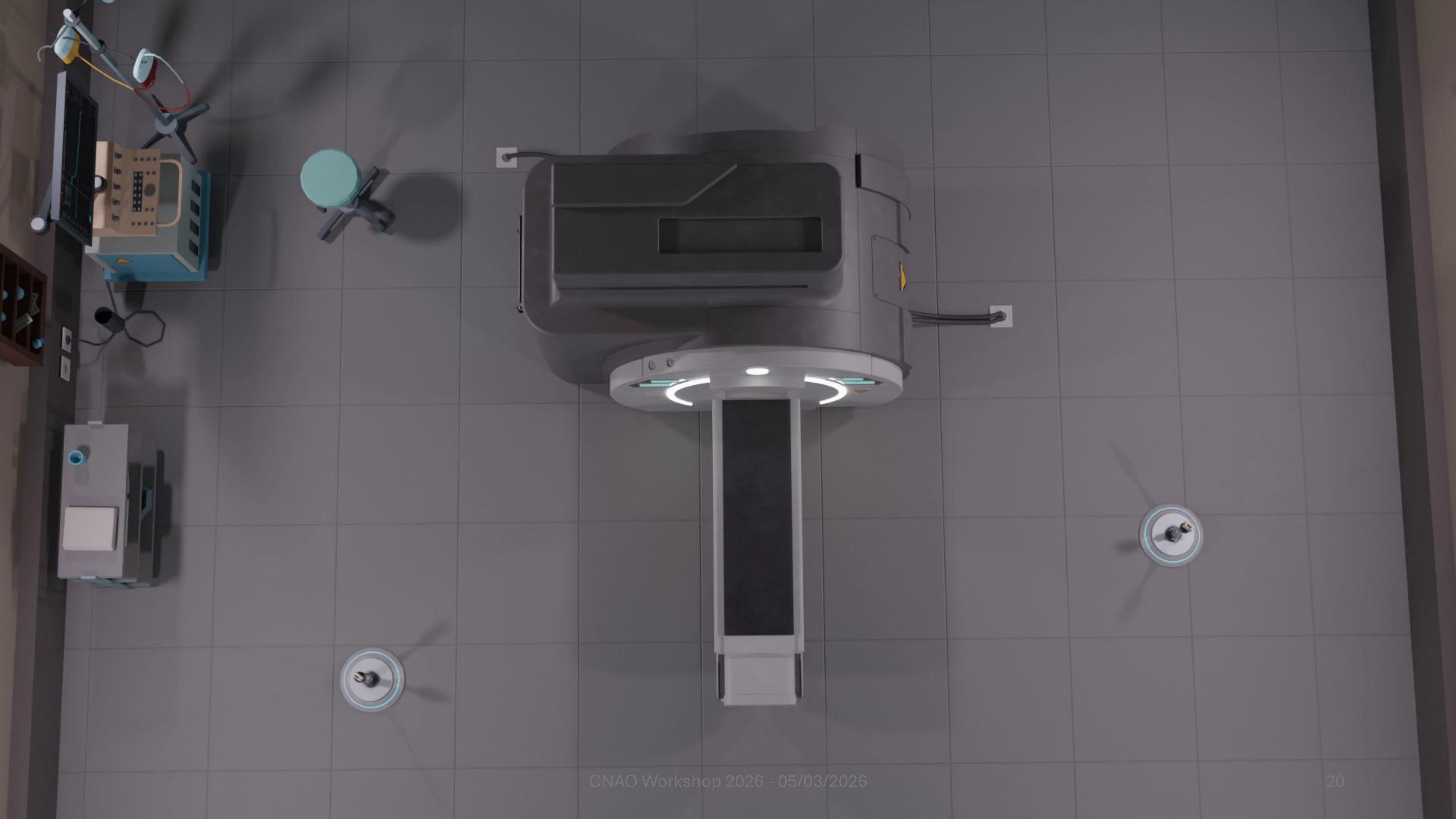
Alphabeast : Fast Neutron Conversion via Proton Recoil



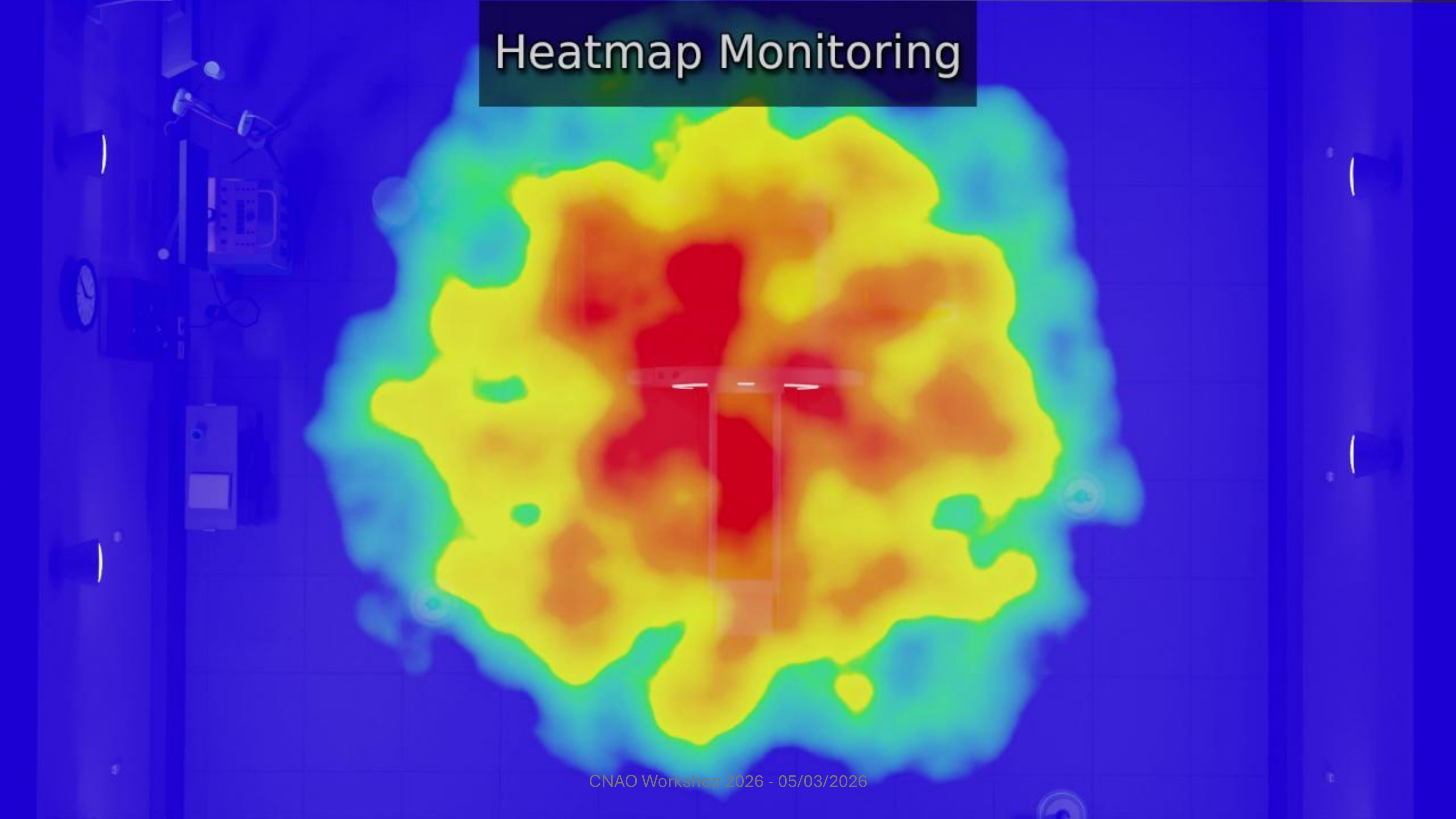
Tri-beast sensor : internal thresholds (neutron counting)




TRIBEAST 1

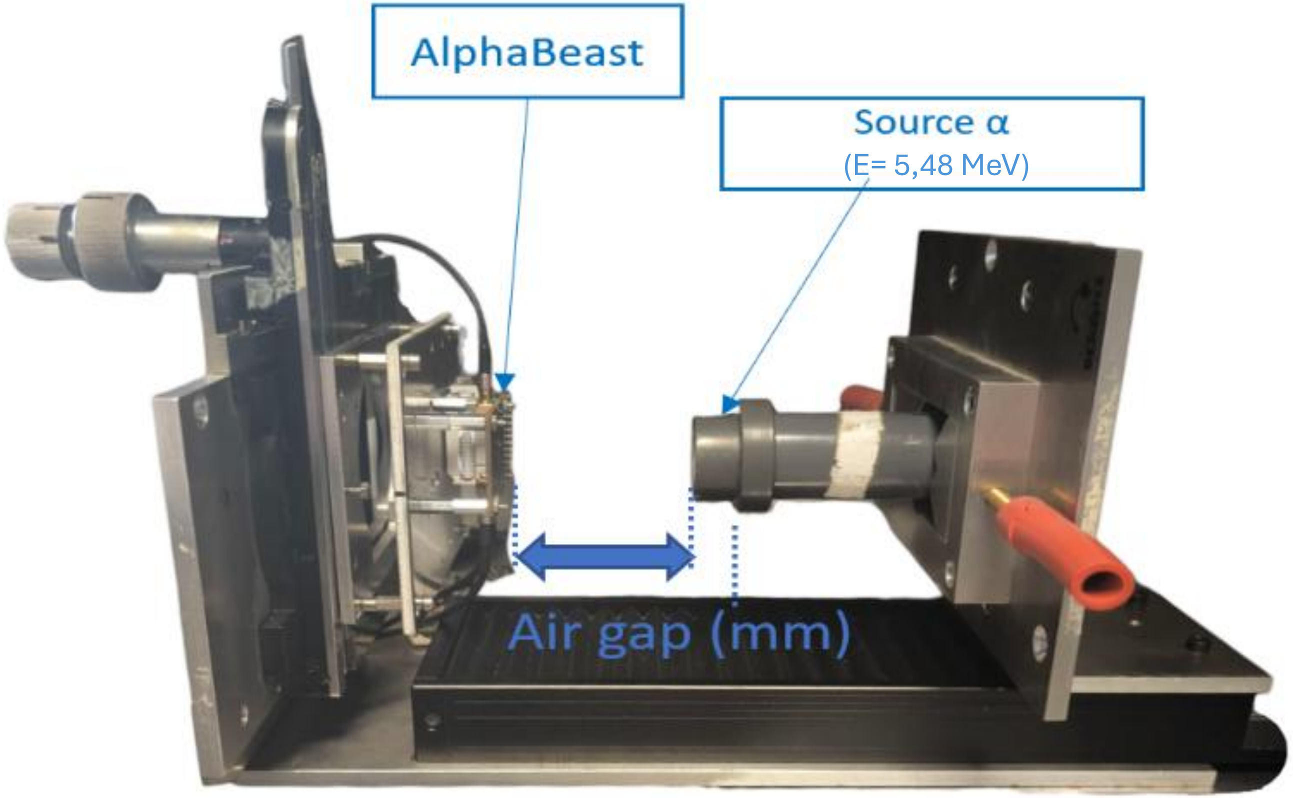


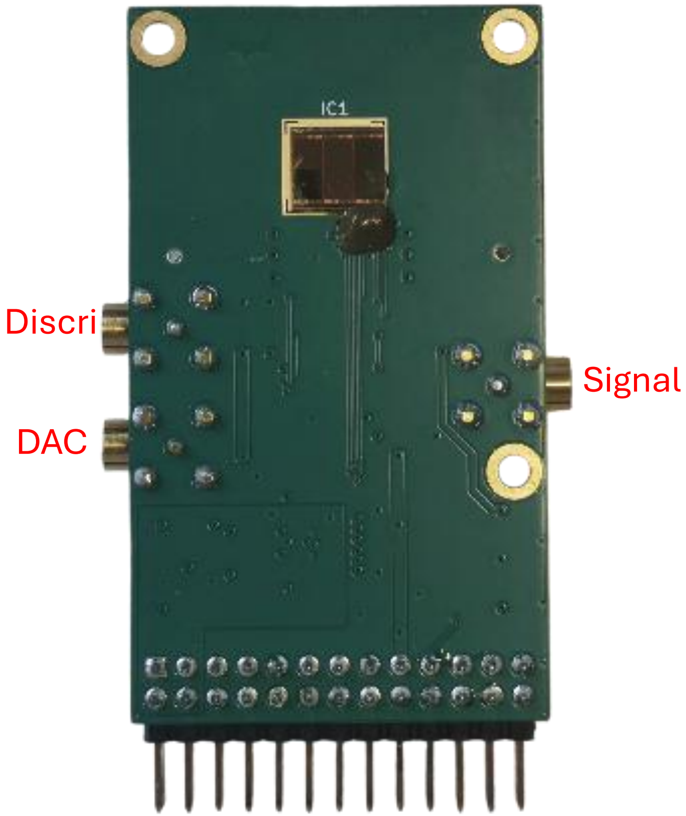
Heatmap Monitoring



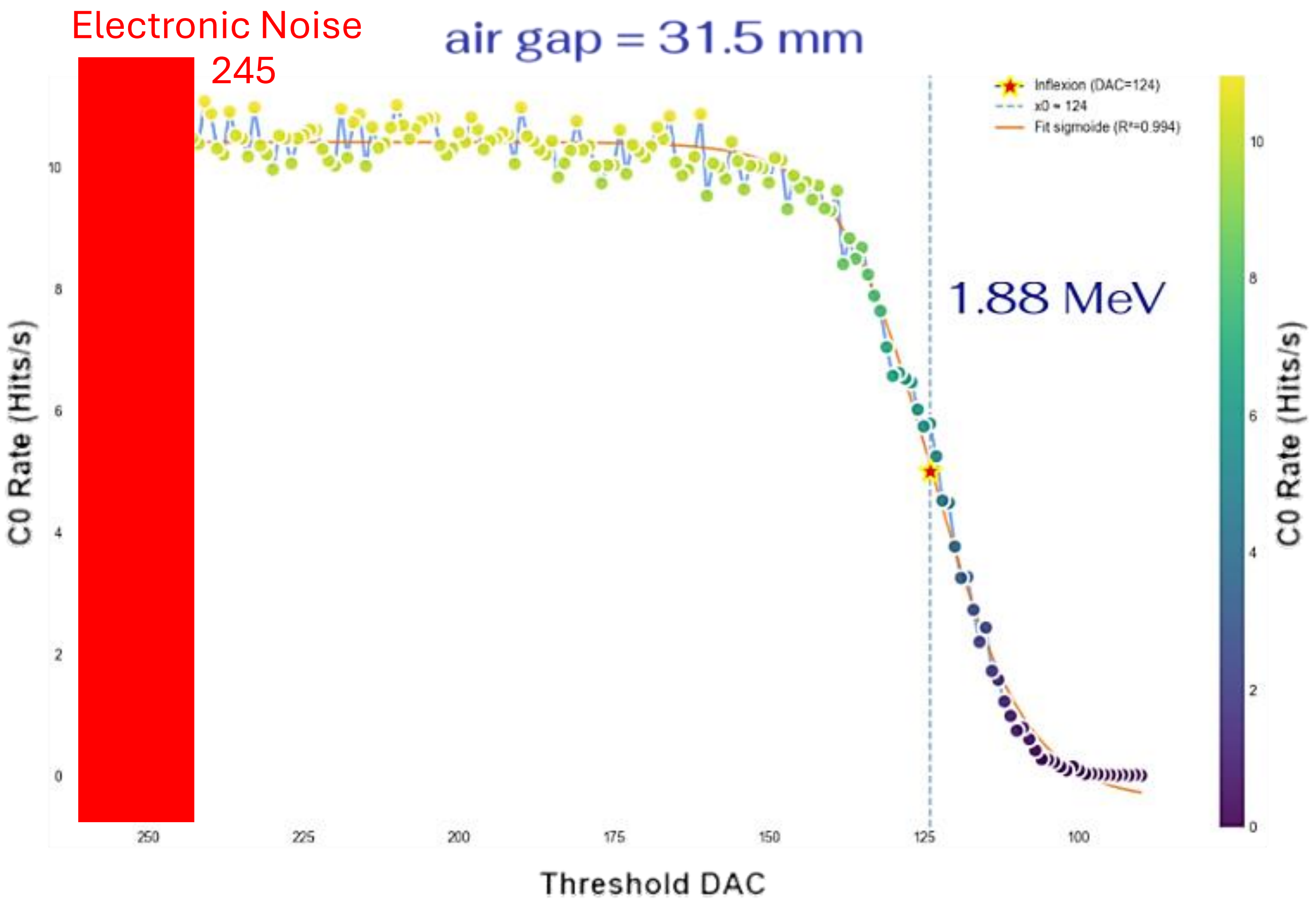
Laboratory tests

^{241}Am source

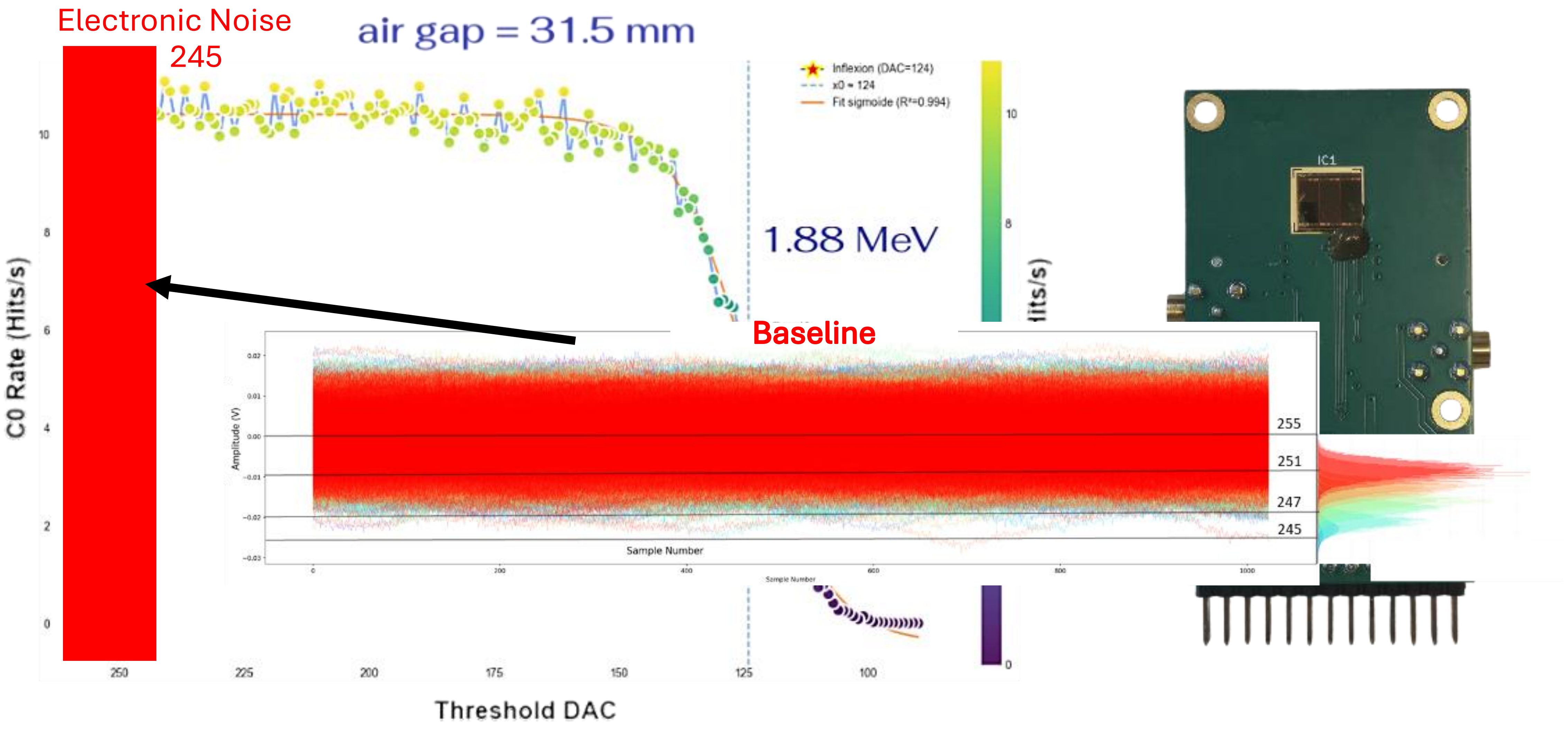




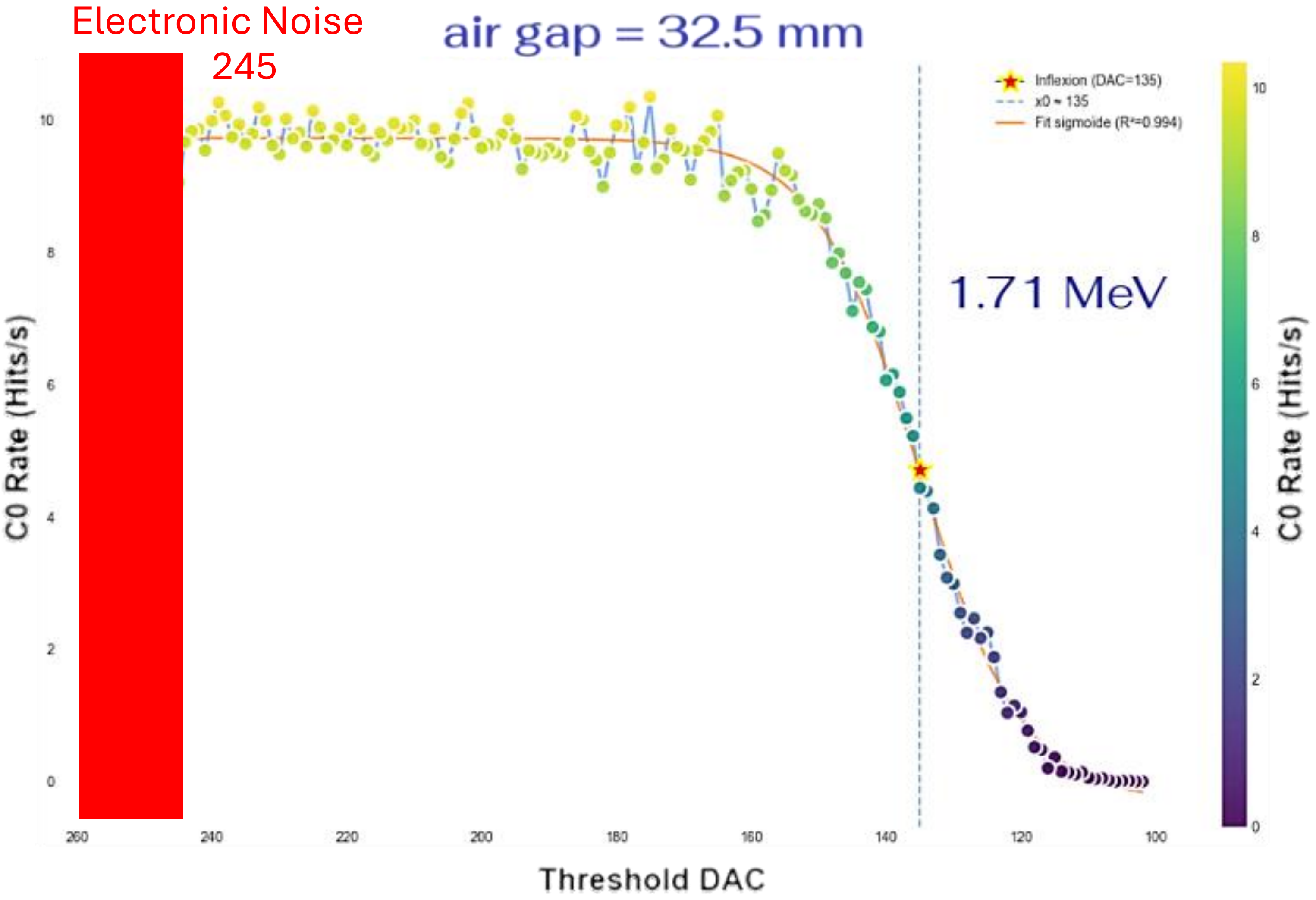
^{241}Am source



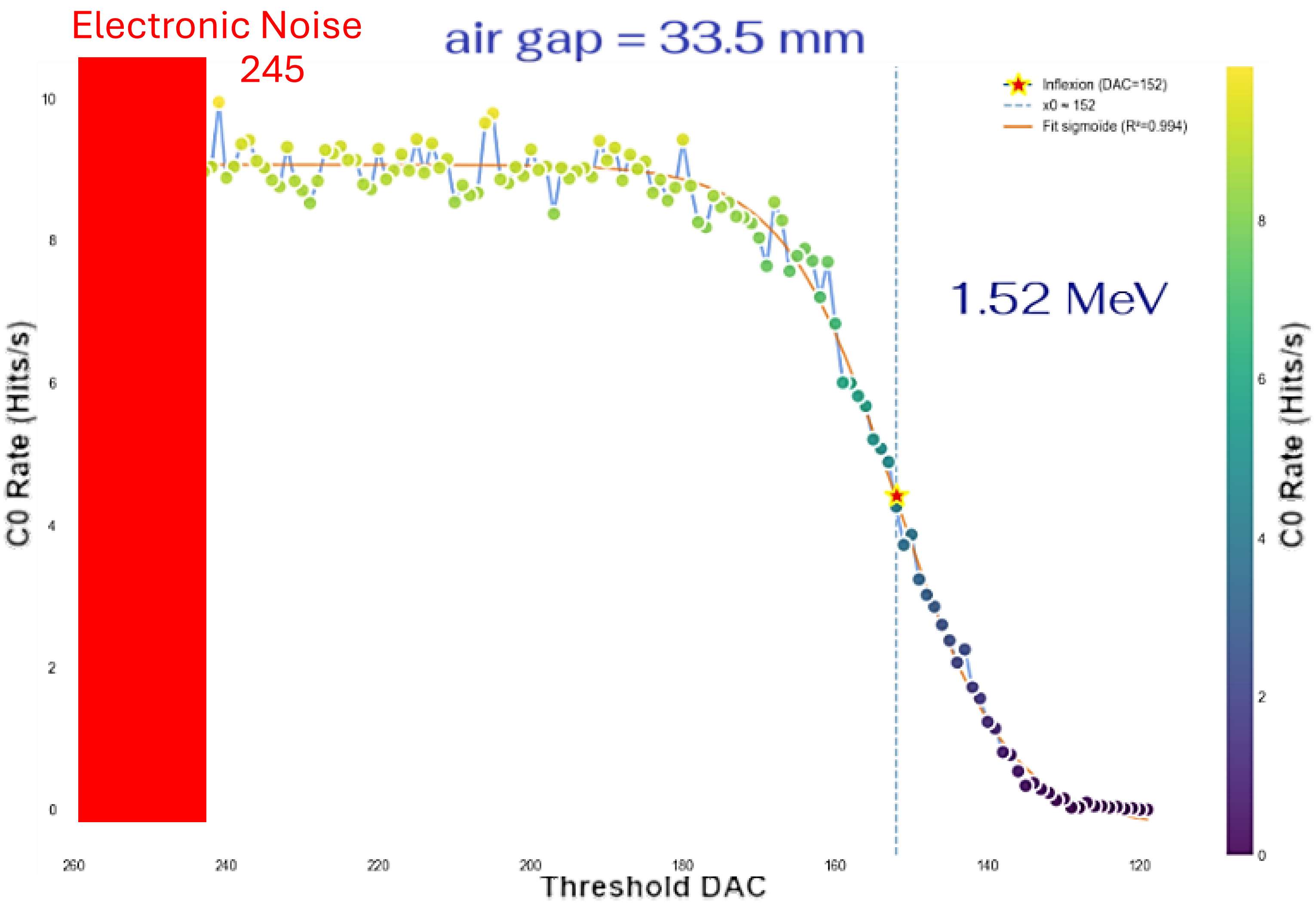
^{241}Am source



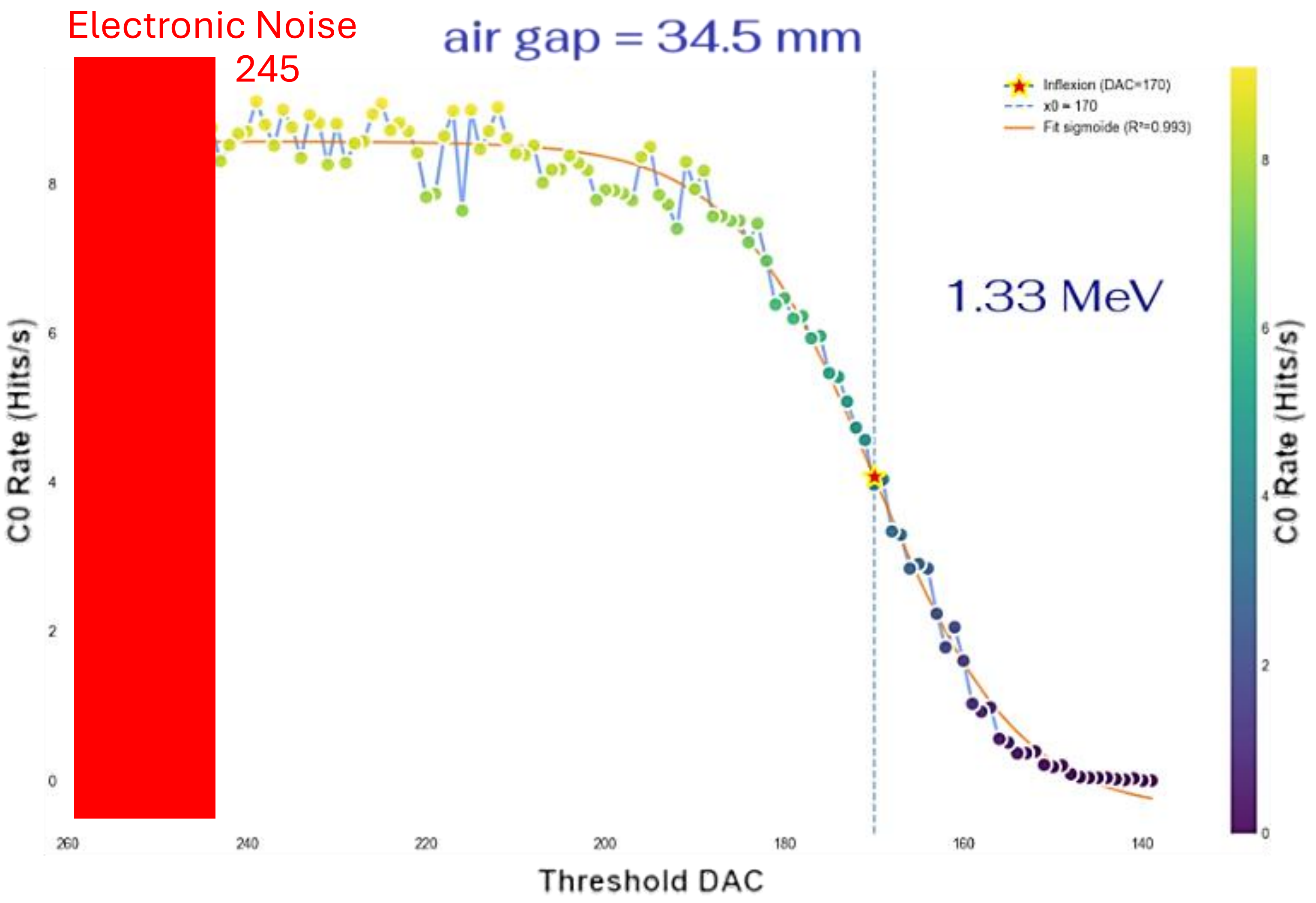
^{241}Am source

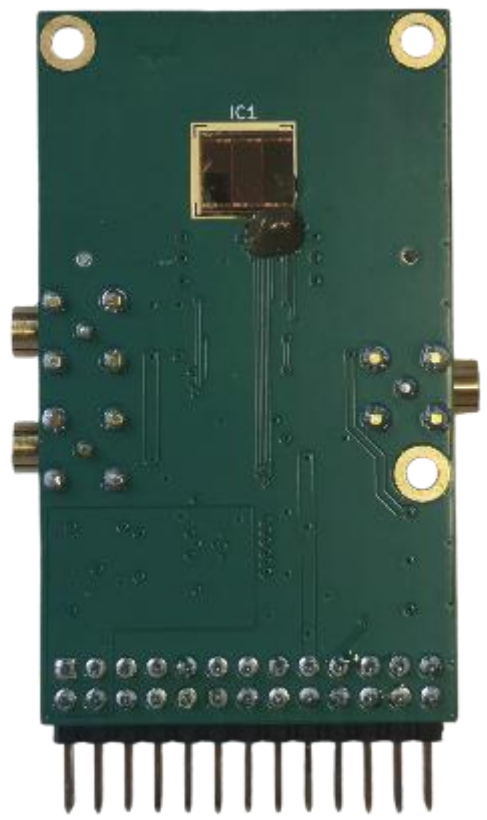


^{241}Am source

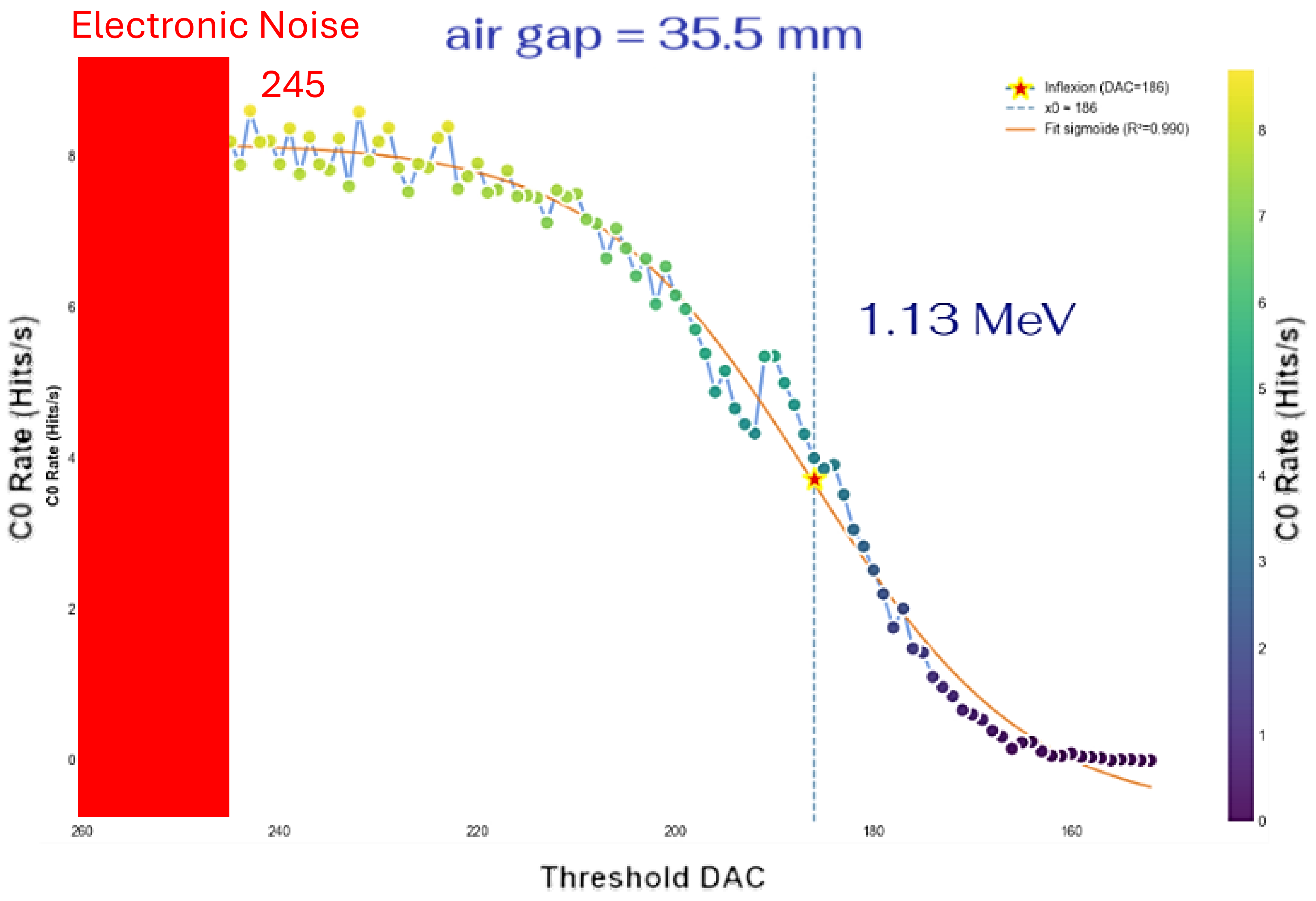


^{241}Am source

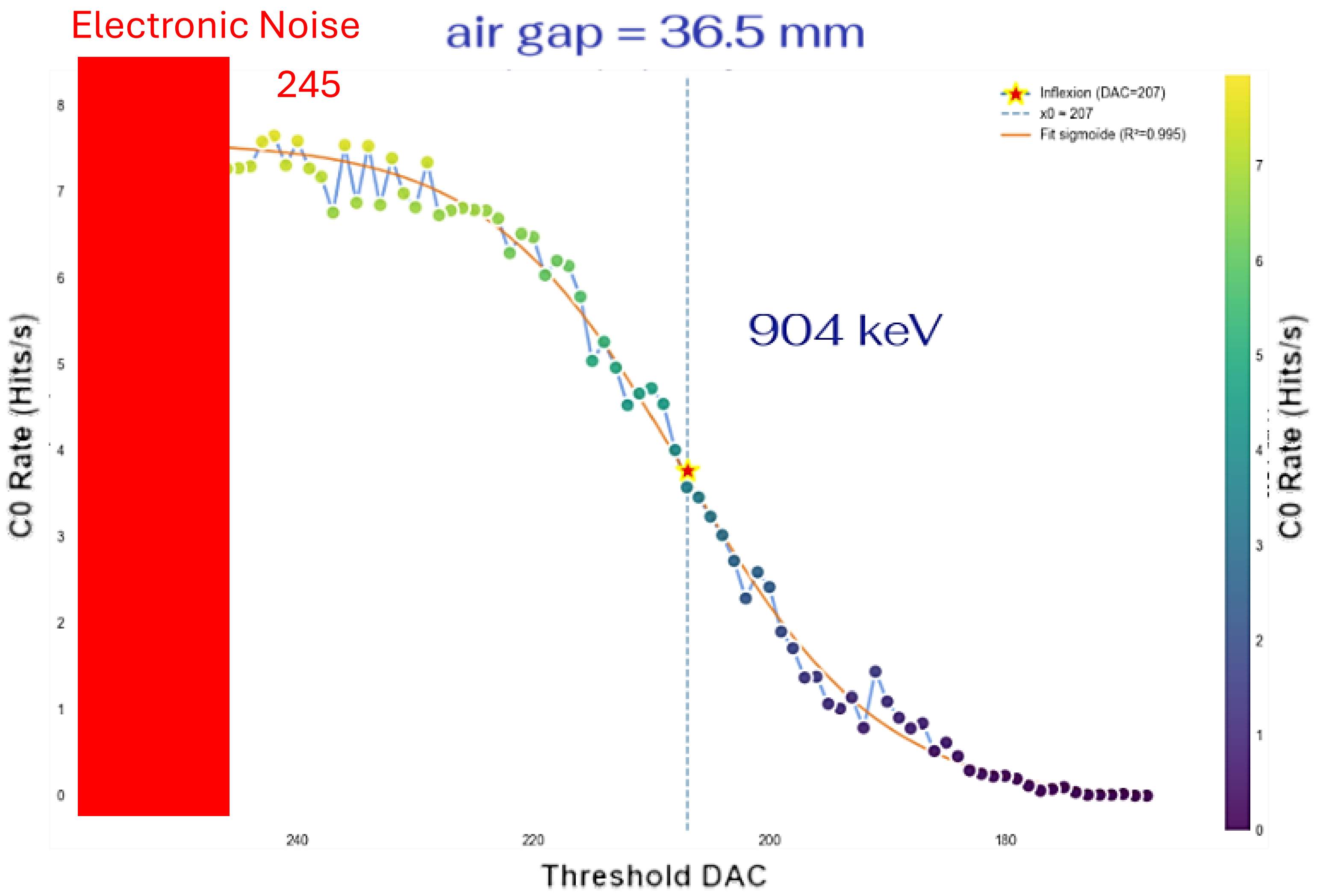




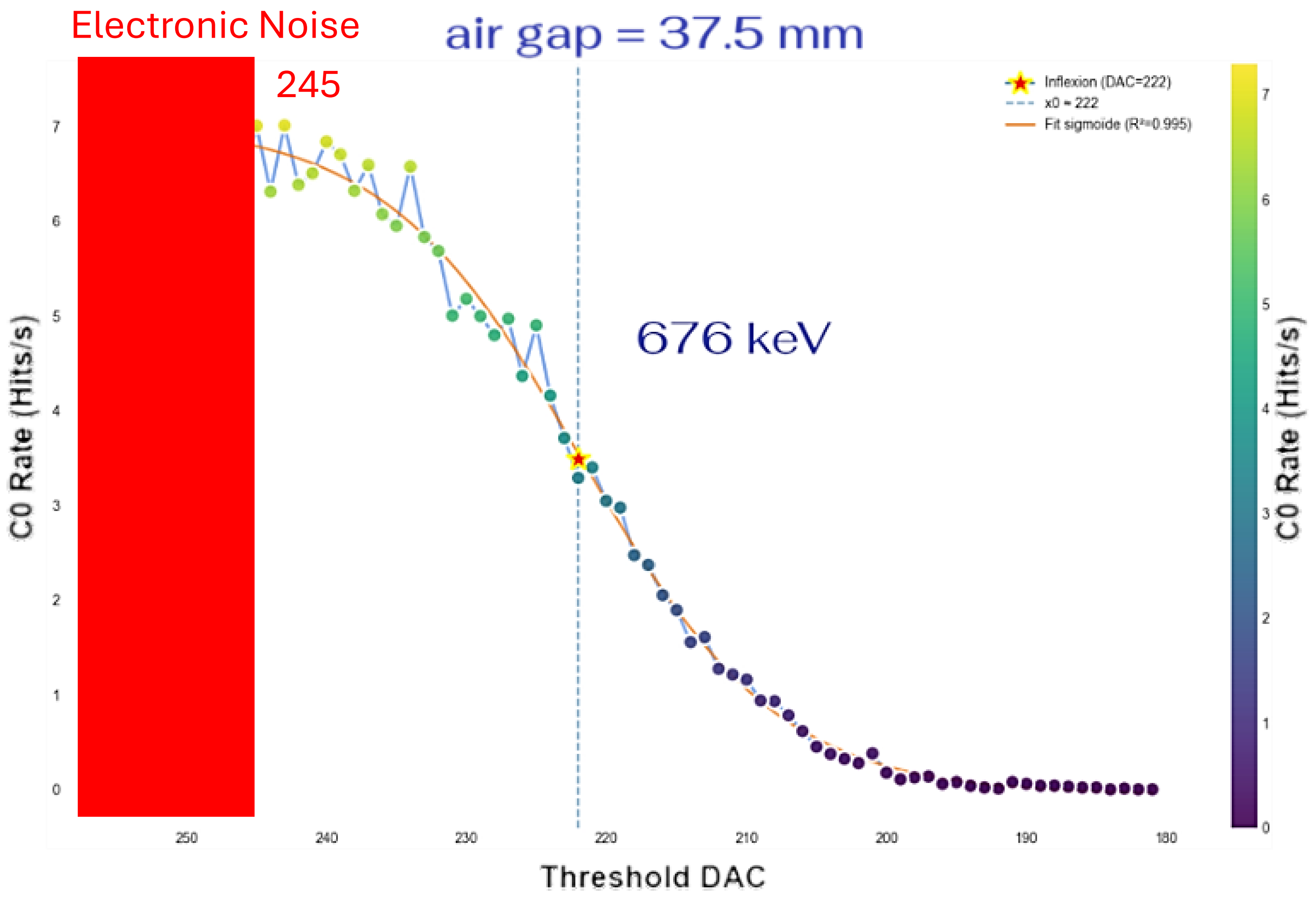
^{241}Am source



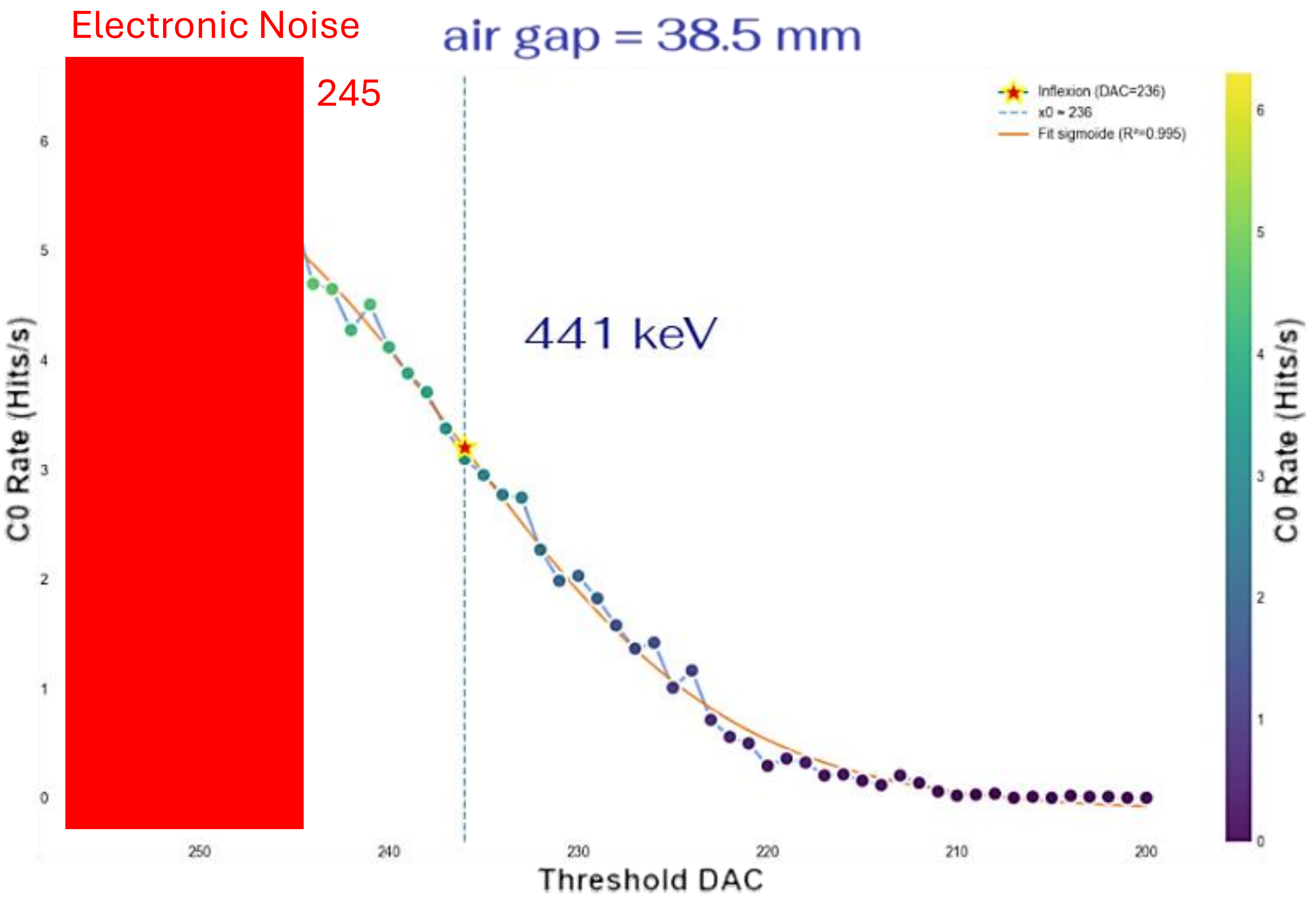
^{241}Am source



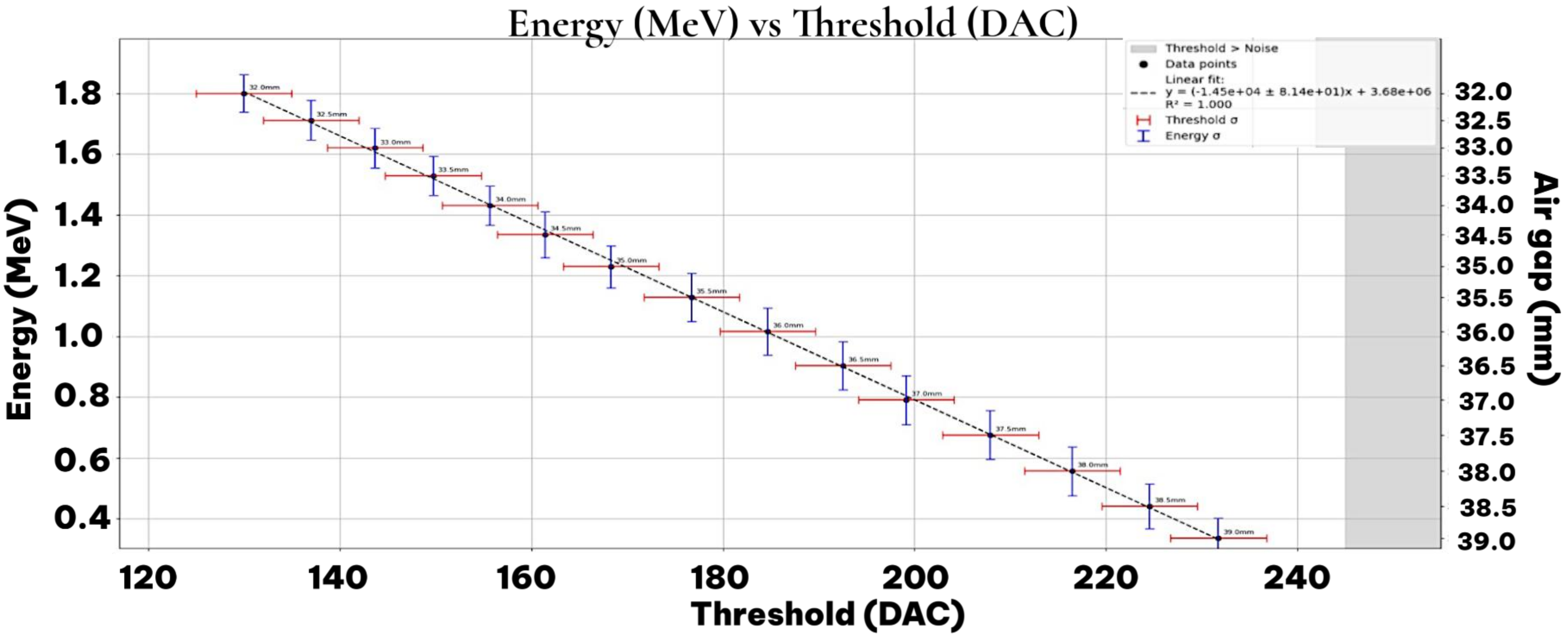
^{241}Am source



^{241}Am source

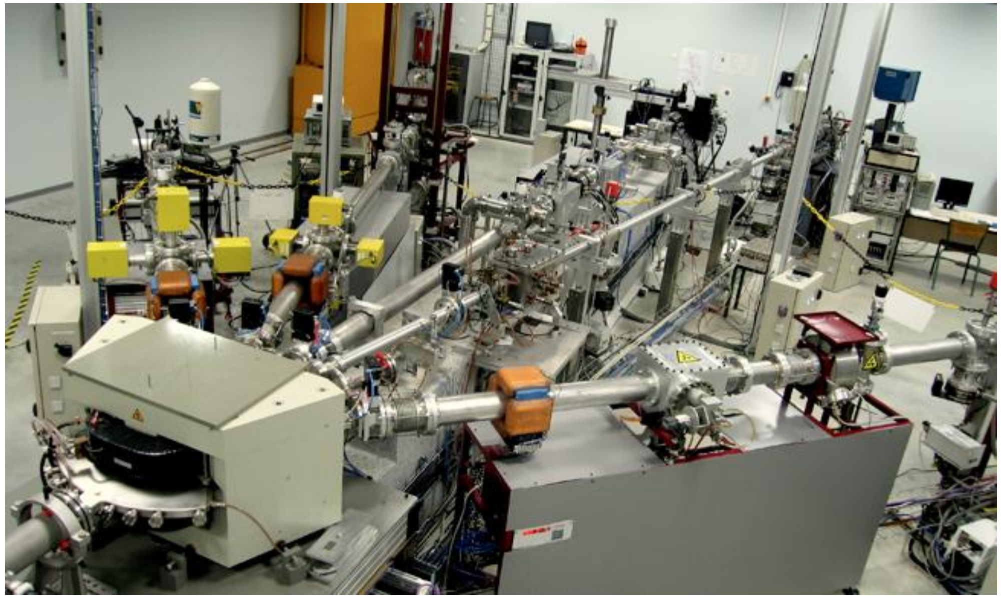


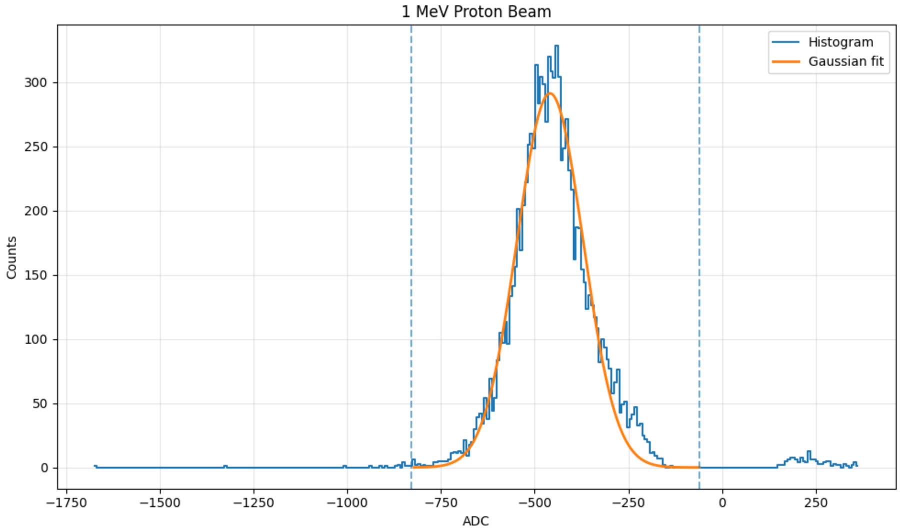
^{241}Am source



AIFIRA facility (Bordeaux-France)

- Micro-beam (< 1 μm) facility with alpha and proton up to 3 MeV
- Scanning of the sensor to test the homogeneity of the response
- Detection efficiency calculations





Detection efficiency:

Fast neutrons (10 MeV)	Thermal neutrons
$\varepsilon_{fast} \approx 3 \times 10^{-5}$ hit/(n.s^{-1}.cm^{-2})	$\varepsilon_{th} \approx 4 \times 10^{-4}$ hit/(n.s^{-1}.cm^{-2})

Experiments

General methodology

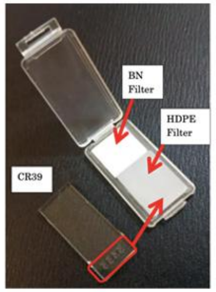
- We have tested the Alphabeast sensors in different environments
- Our main goal is to evaluate the reliability of the measurements by comparing data from :

  - **mono-beast** (ADC distributions -> countings for fast/thermal neutrons)

  - **tri-beast** (countings for fast/thermal neutrons)

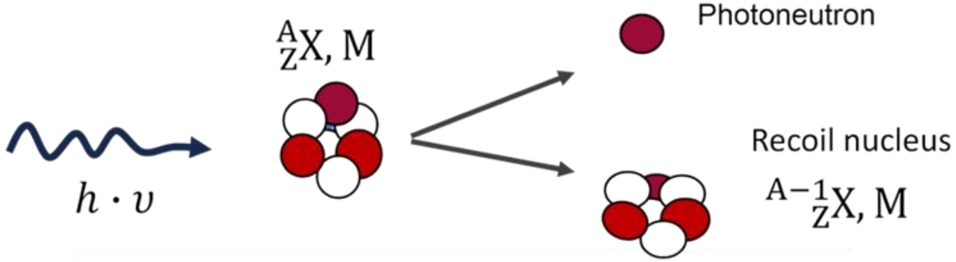
  - **CR-39** (countings for fast/thermal neutrons)

  - **Monte-Carlo simulations** (neutrons fluences)

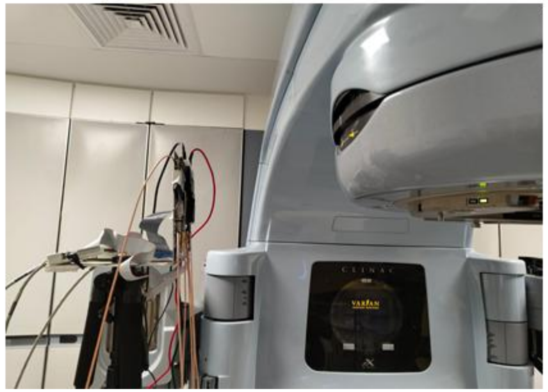


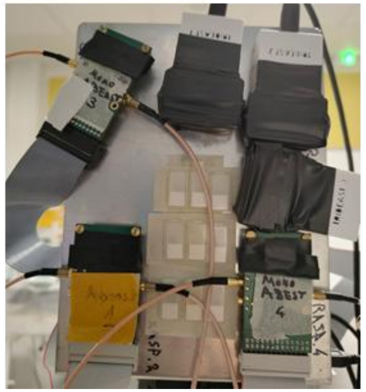
Neutron Monitoring in a Clinical Radiotherapy Environment

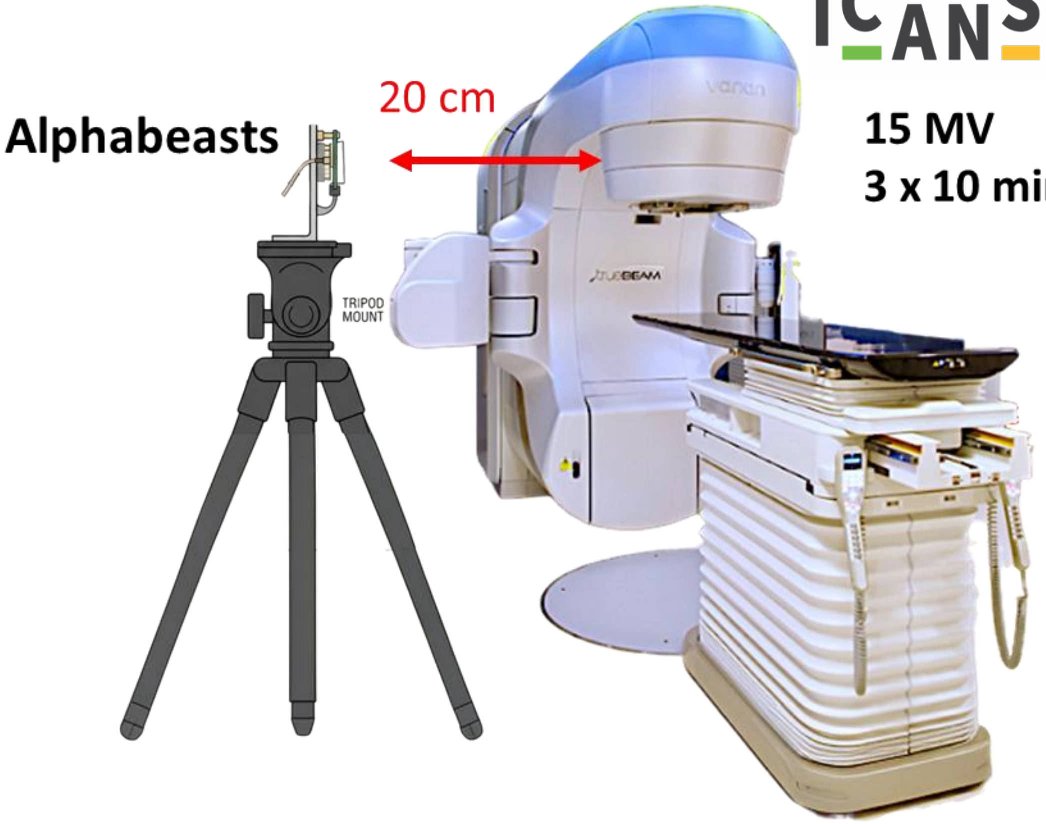
Photo-nuclear reaction



$$ {}^{A}_{Z}X + \gamma \rightarrow {}^{A-1}_{Z} X + n $$

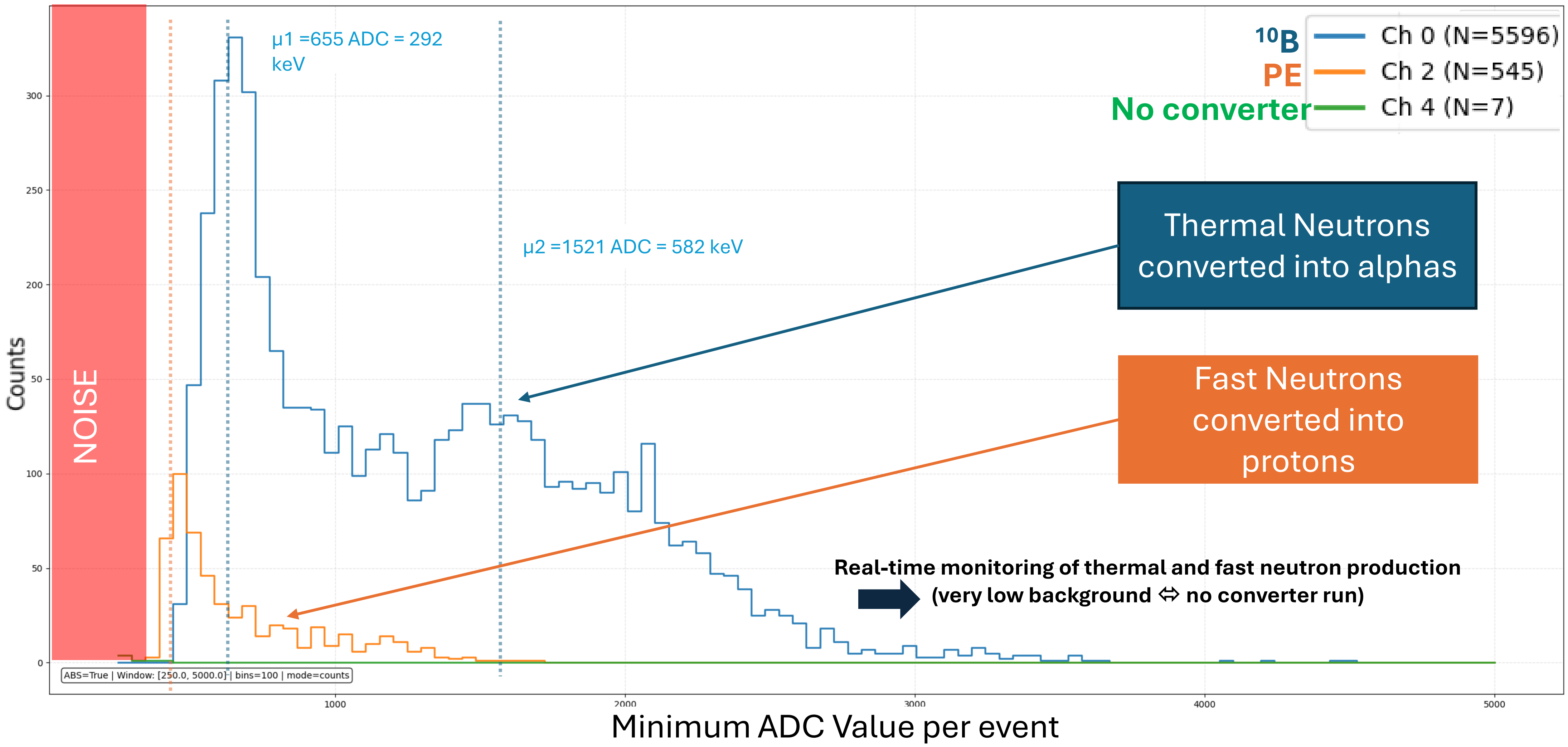






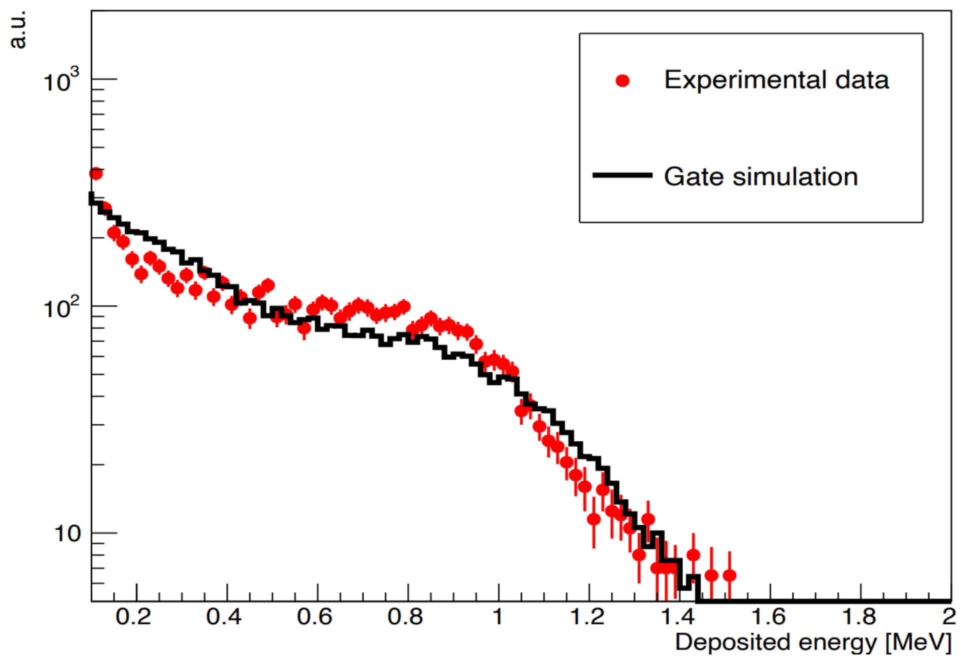
15 MV
3 x 10 min

Neutron Energy Deposition Histograms in a Clinical Radiotherapy Environment

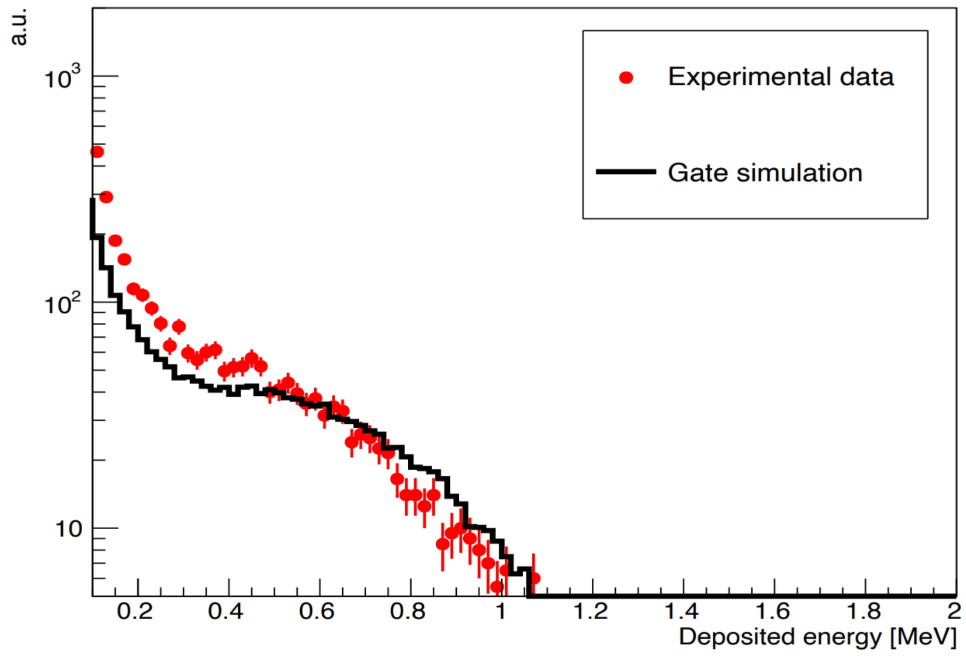


Neutron Monitoring in a Clinical Radiotherapy Environment

15 MV run with ^{10}B converter



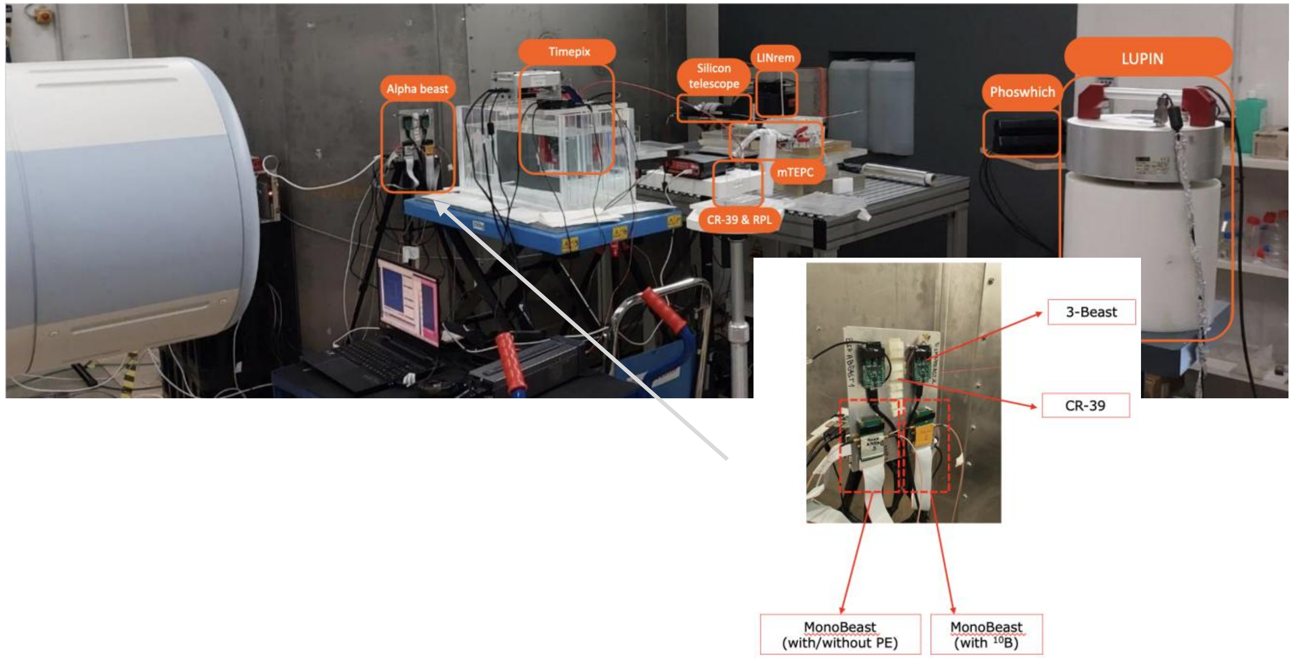
15 MV run with PE converter

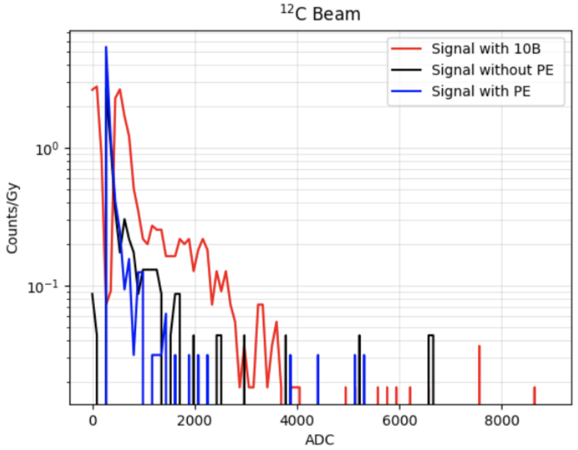


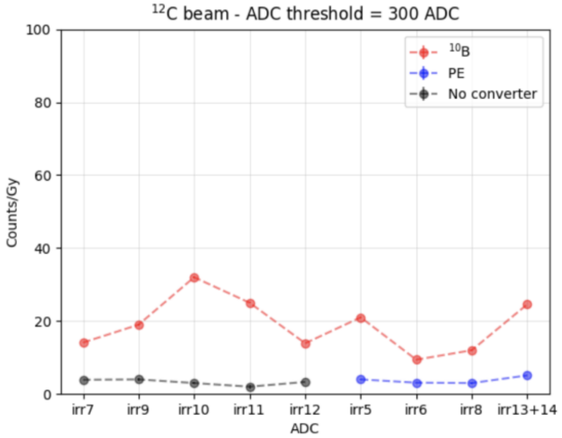
➡ **Good agreement between calculated deposited energy and signal distribution for both thermal and fast neutrons**

Neutron Monitoring in a hadrontherapy room

- Experiment at HIT in 11/2025 with EURADOS WG9 members
- Inter-comparison of 8 neutron detectors (C and O beams)



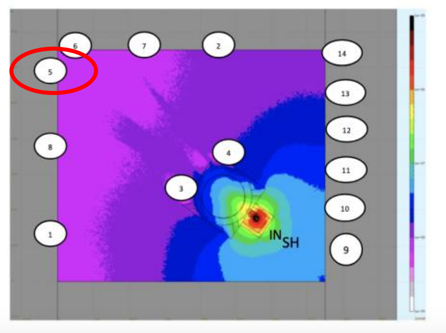


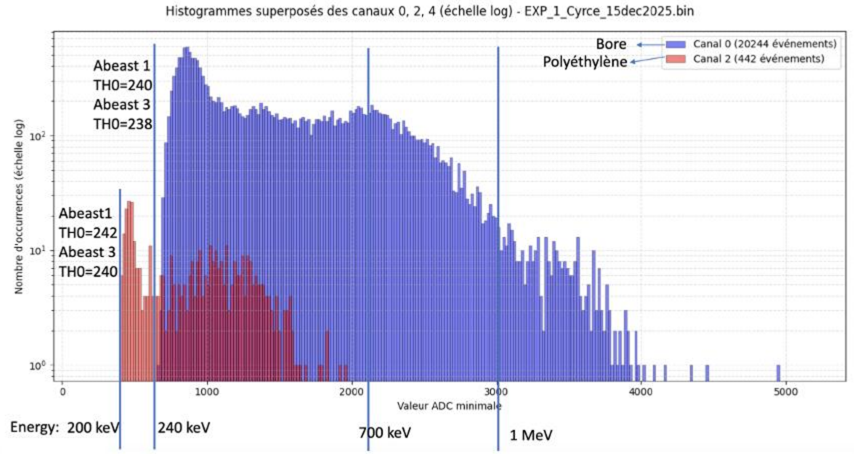


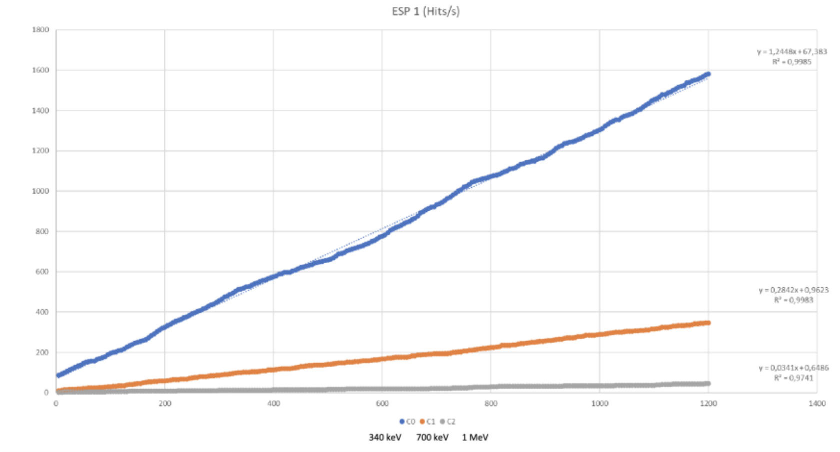
➡ **Real-time monitoring of thermal neutron production for different irradiation conditions**
Inability to measure the fast neutrons component (contamination of secondary protons)

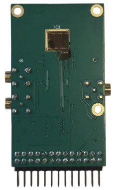
Neutron Monitoring in a cyclotron casemate

- Experiment at CYRCé cyclotron (IPHC)
- Neutron fluence monitoring for activation calculations







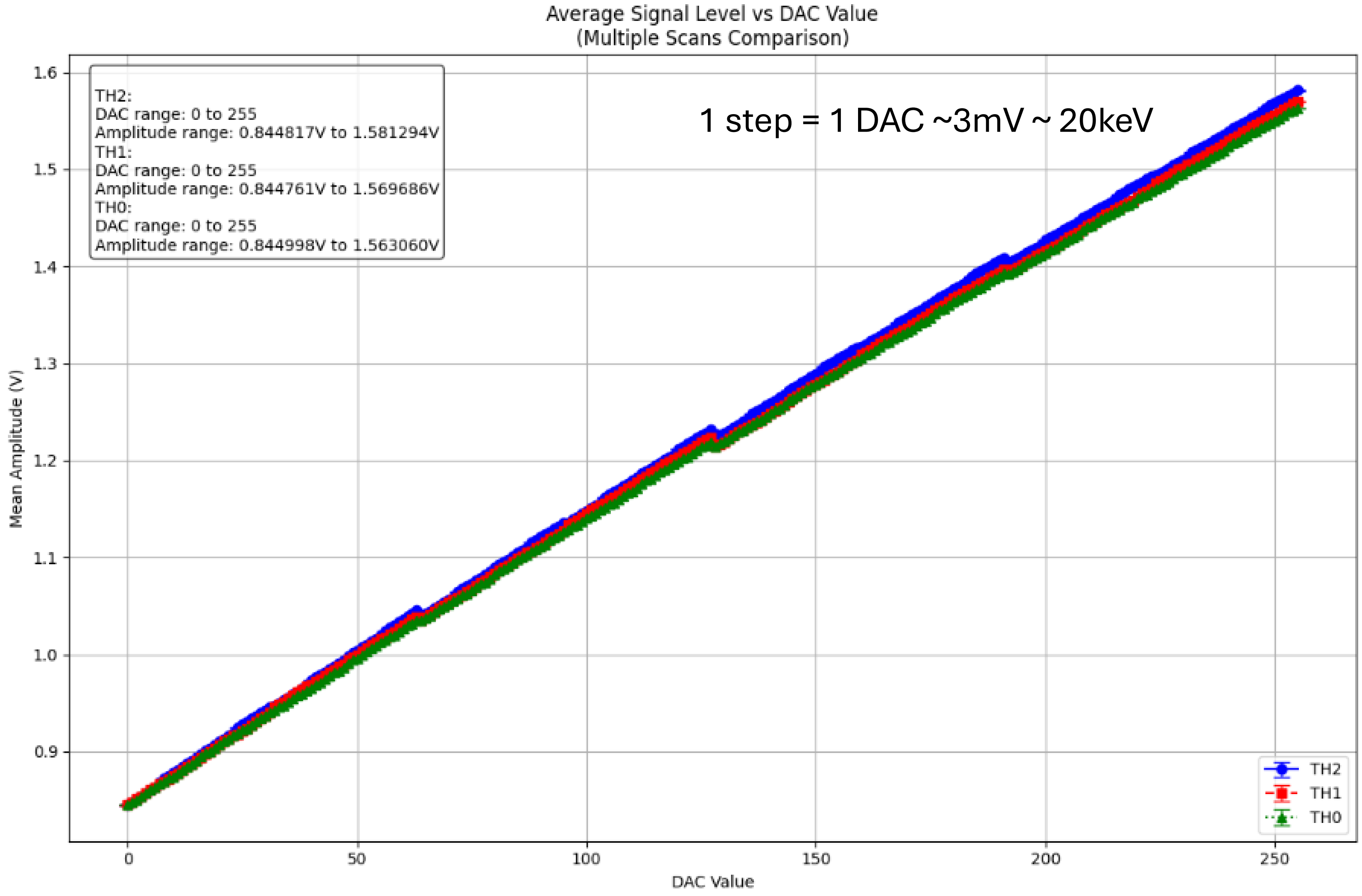


Real-time monitoring of thermal neutron production during cyclotron operation
Unexpected secondary protons contaminations (on-going MC calculations)

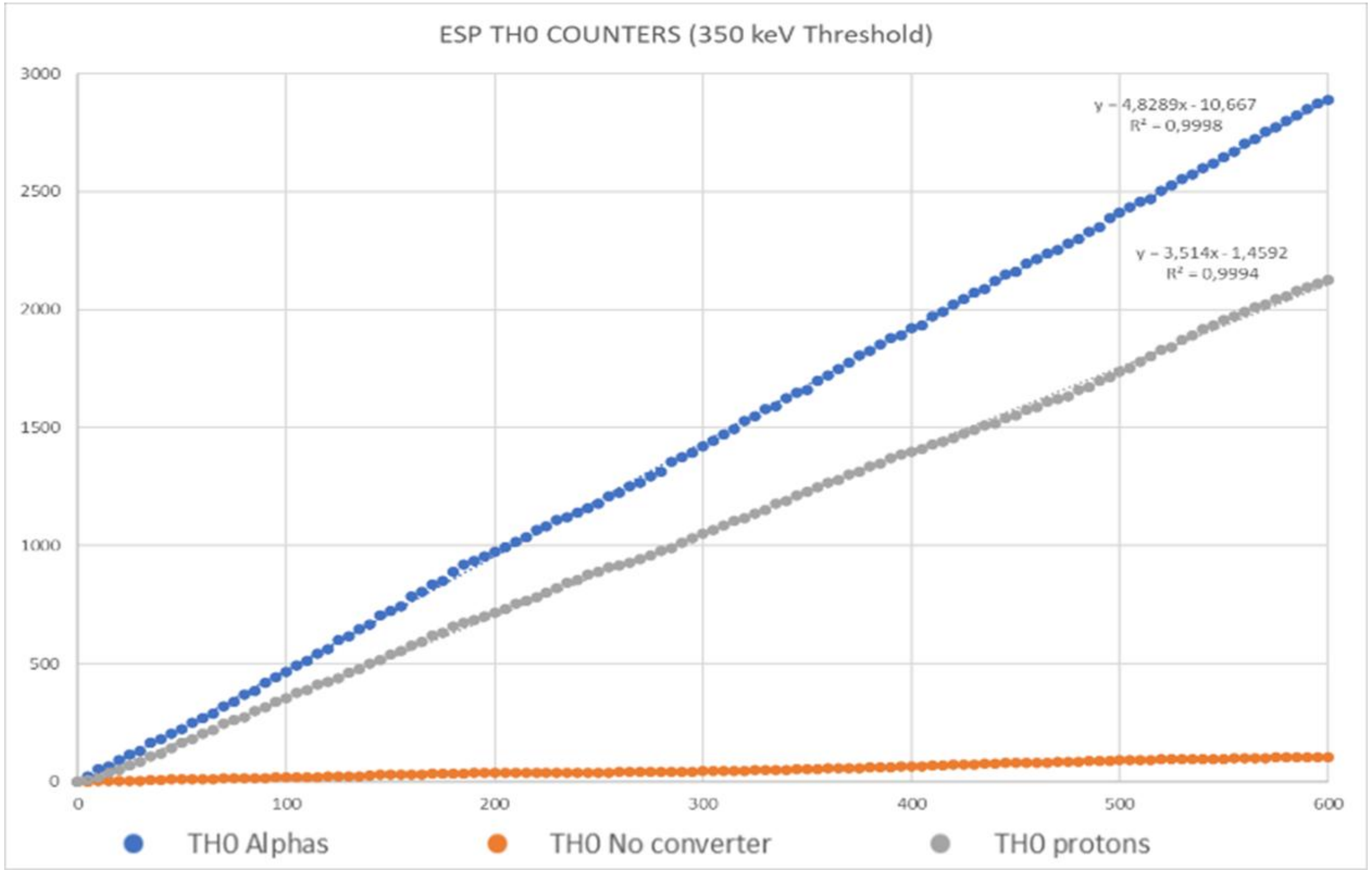
Merci

Thank you for your attention

Annexes

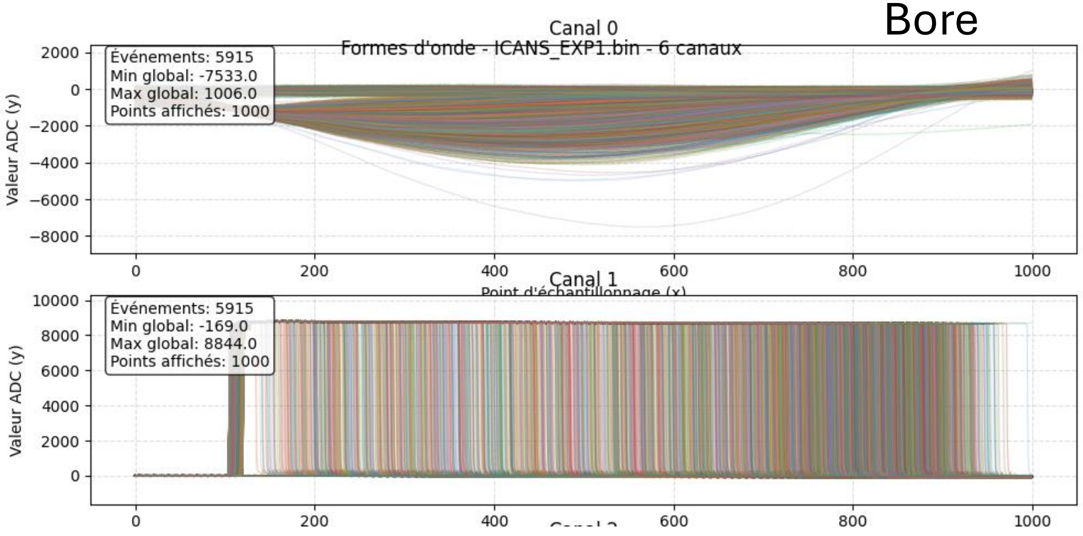

Average Signal Level vs DAC Value
(Multiple Scans Comparison)
TH2:
DAC range: 0 to 255
Amplitude range: 0.844817V to 1.581294V
TH1:
DAC range: 0 to 255
Amplitude range: 0.844761V to 1.569686V
TH0:
DAC range: 0 to 255
Amplitude range: 0.844998V to 1.563060V
1 step = 1 DAC ~3mV ~ 20keV
Mean Amplitude (V)
DAC Value
TH2
TH1
TH0

Threshold-Based Counting of AlphaBeast (350 keV)

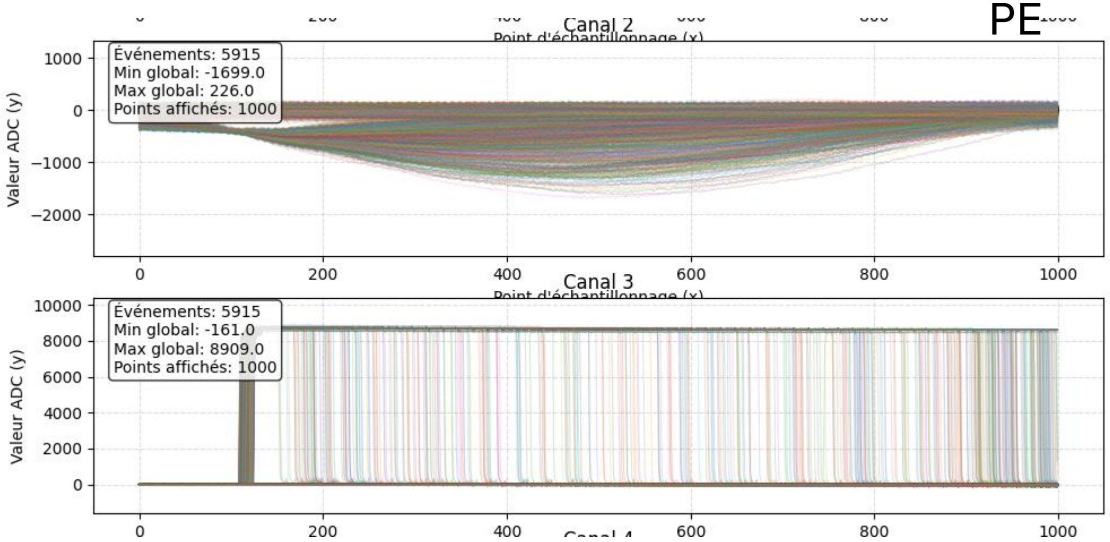


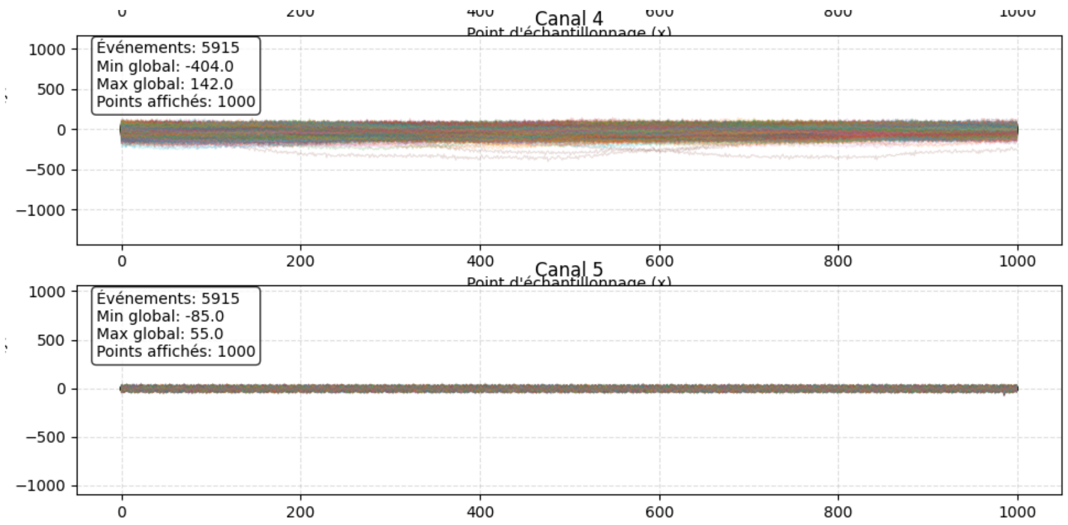
Analog Signals for Alphabeast

Bore



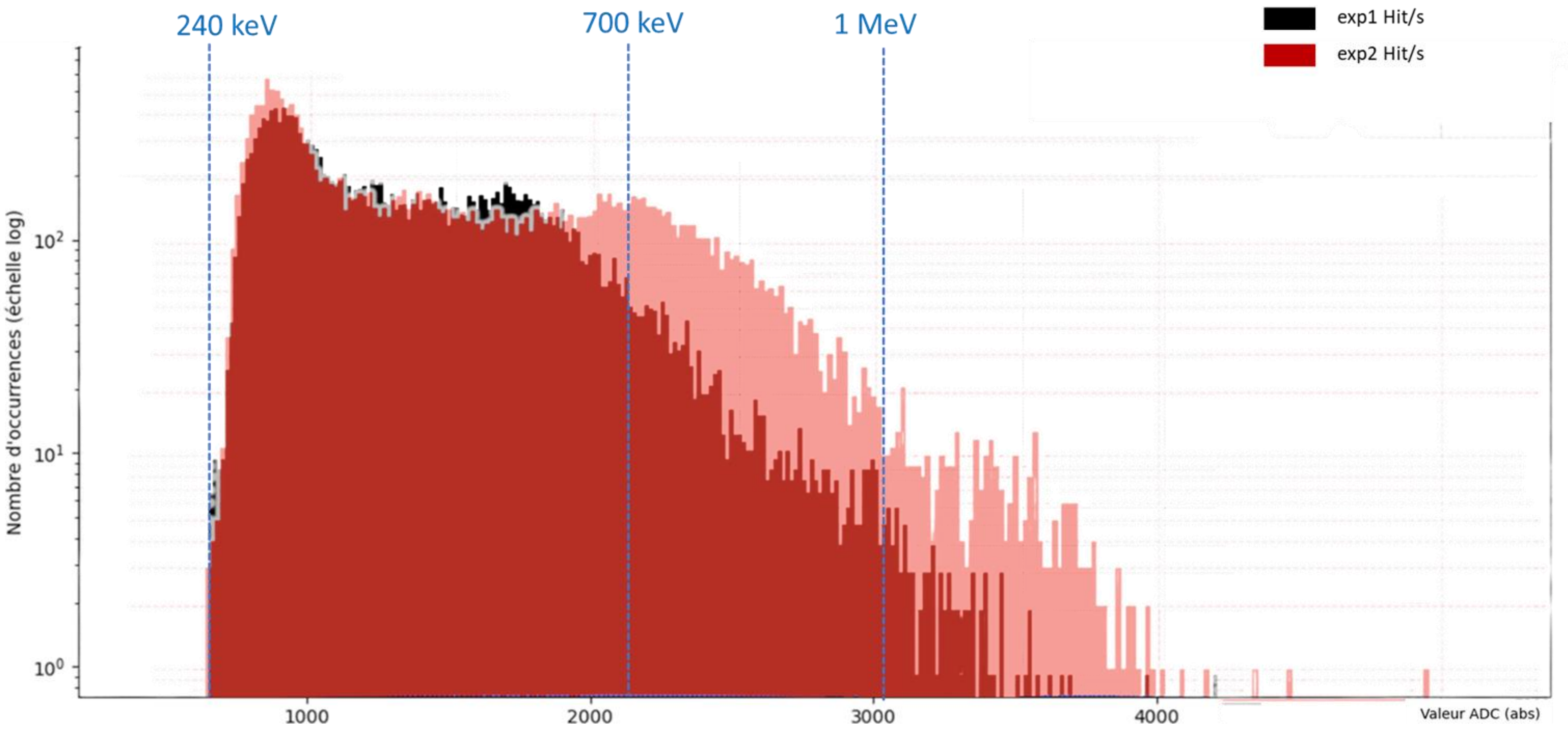
PE

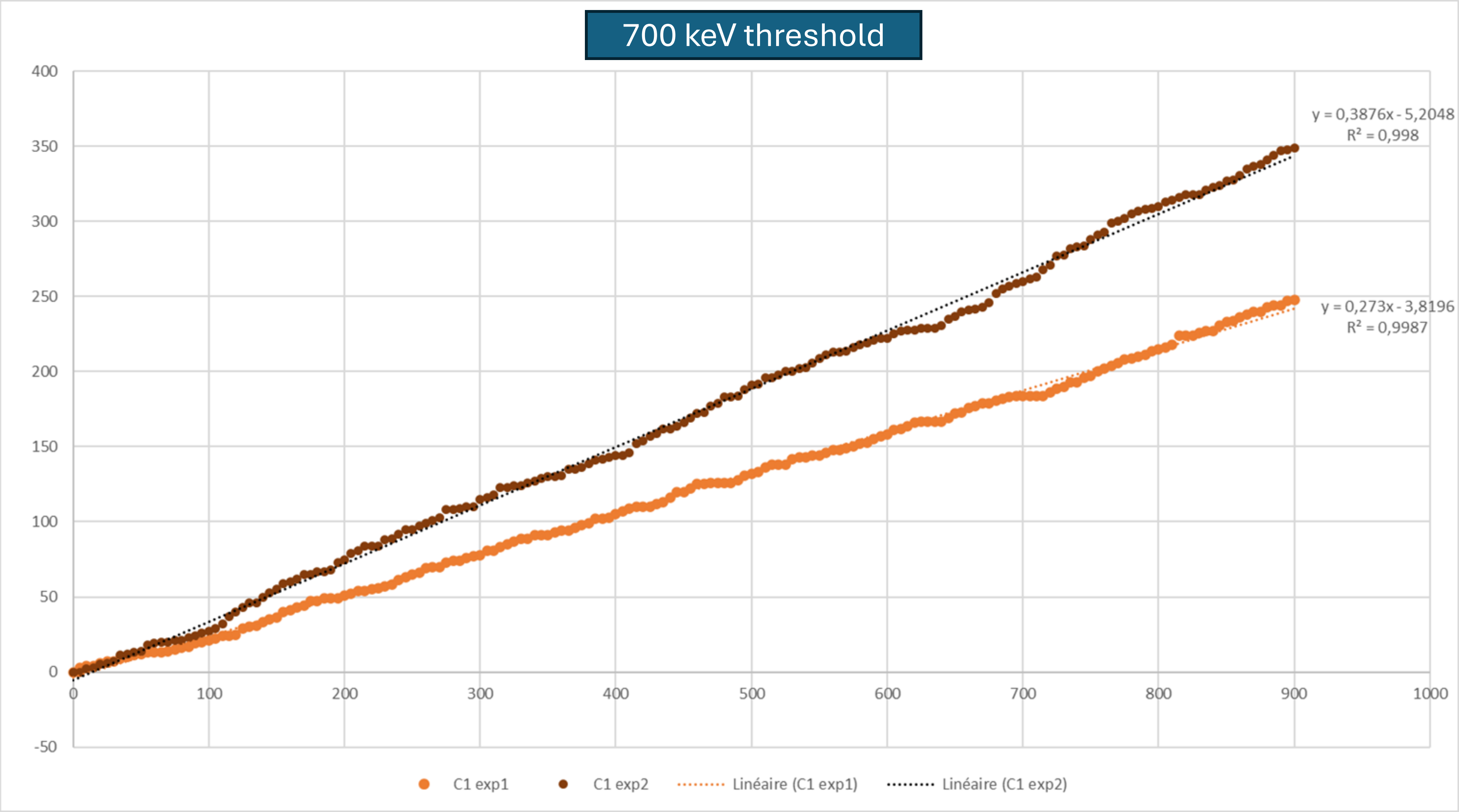


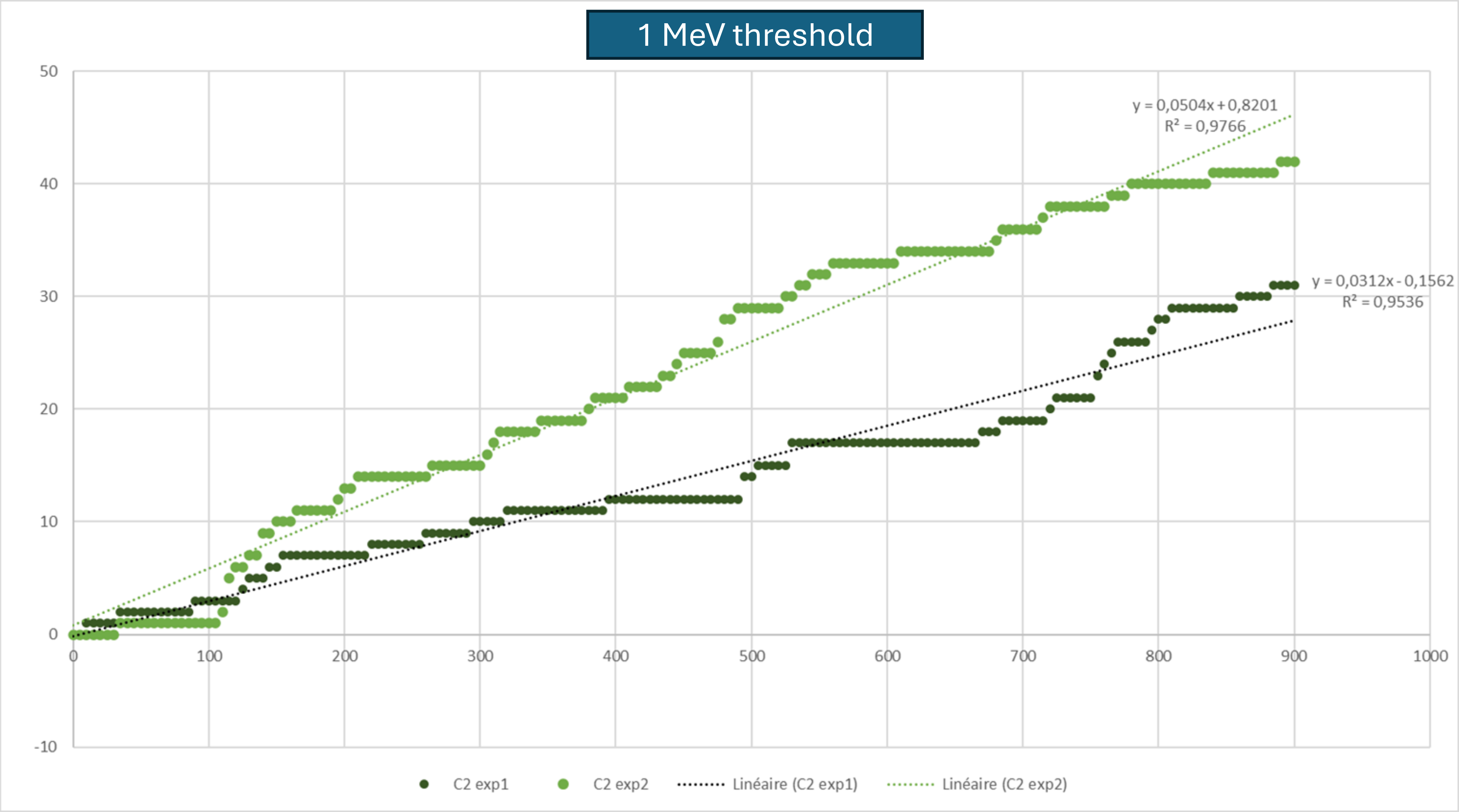


No converter

Counter & Analog




700 keV threshold
400
350
300
250
200
150
100
50
0
-50
0
100
200
300
400
500
600
700
800
900
1000
y = 0,3876x - 5,2048
R² = 0,998
y = 0,273x - 3,8196
R² = 0,9987
C1 exp1
C1 exp2
Linéaire (C1 exp1)
Linéaire (C1 exp2)



1 MeV threshold
y = 0,0504x + 0,8201
R² = 0,9766
y = 0,0312x - 0,1562
R² = 0,9536
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
700
800
900
1000
C2 exp1
C2 exp2
Linéaire (C2 exp1)
Linéaire (C2 exp2)