Measure to protect: Instrumentation for modern radiation protection

On behalf of the DeSIs team

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

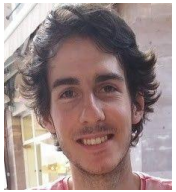
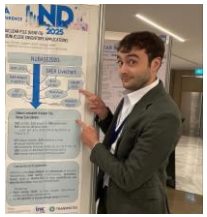
Journées R&T CNRS/IN2P3 – 09/12/2025

Our Team

- **Permanent researchers**
  - Nicolas ARBOR (PR)
  - Alexandre BIGOT (MCF)
  - Christian FINCK (50%)
  - Daniel HUSSON (MCF)
  - Abdel-Mjid NOURREDDINE (PR)
  - Marie VANSTALLE (Team leader - MCF)
- **Permanent engineers/technicians**
  - Séverine CHEFSON (AI)
  - Stéphane HIGUERET (Technical manager – IR)
  - Thê-Duc LÊ (AI)
  - Djokhar Betelgueriev (IR-CDD)
- **PhD students**
  - Jonathan COLLIN, ATER – Dir. A. Nourreddine – 2022-2025
  - Lucia Garcia-Garcia, CNRS – Dir. N. Arbor – 2024-2027
  - Giovanna Rezende, CNRS-CNES – Dir. M. Vanstalle – 2024-2027



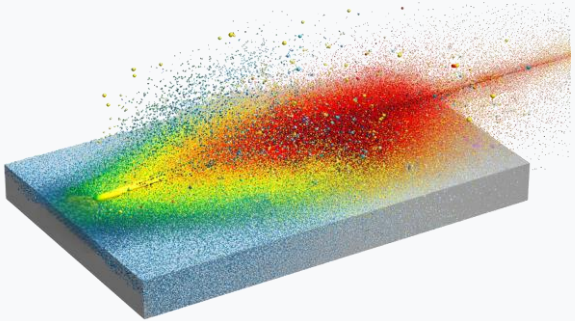


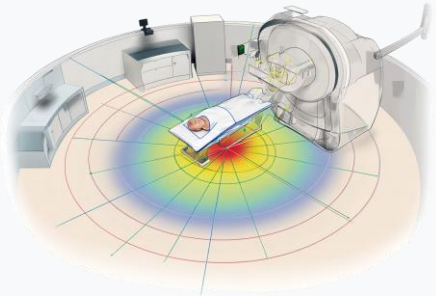



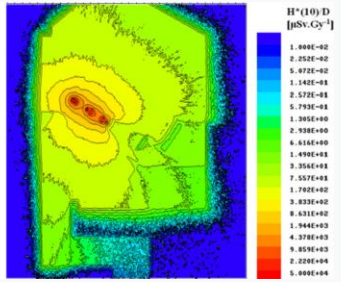


DeSIs – Dosimetry, Simulation & Instrumentation

Hadrontherapy & Space radiation	**Dosimetry**	**Radioactivity**
Measure and model secondary particles produced by heavy ions.	Accurately measure the dose in treatment systems.	Detect and map contaminations and activations







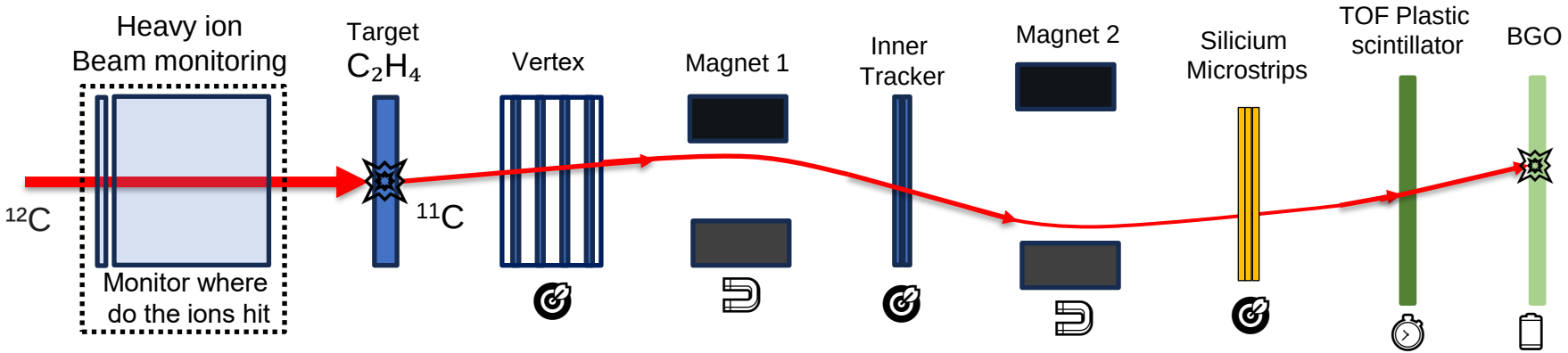
J. Farah, Phys. Med. Biol. **59** (2014)

Partnerships and collaborations

Hospitals (radiotherapy, radiobiology) • **Heavy ion facilities** (HIT, CNAO, GANIL, GSI...) • **Academic laboratories** • Nuclear industry & instrumentation

Measurement and modeling of secondary particles produced by heavy ions

FOOT: FragmentatiOn Of Target experiment



Measure the track before and after bending, enabling precise reconstruction of the particle's trajectory

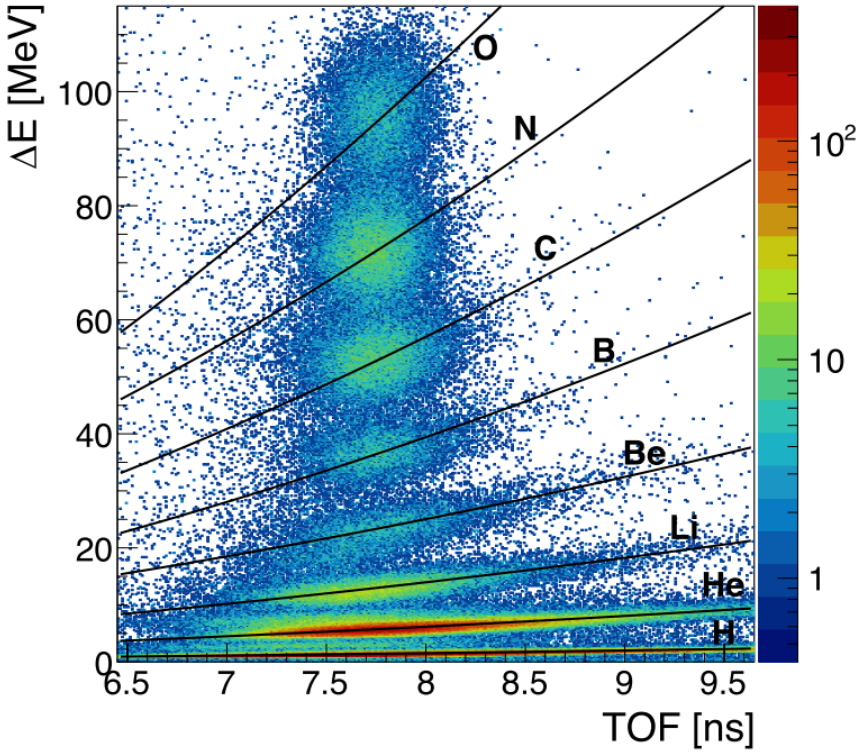
Bends the fragment trajectory according to its momentum-to-charge

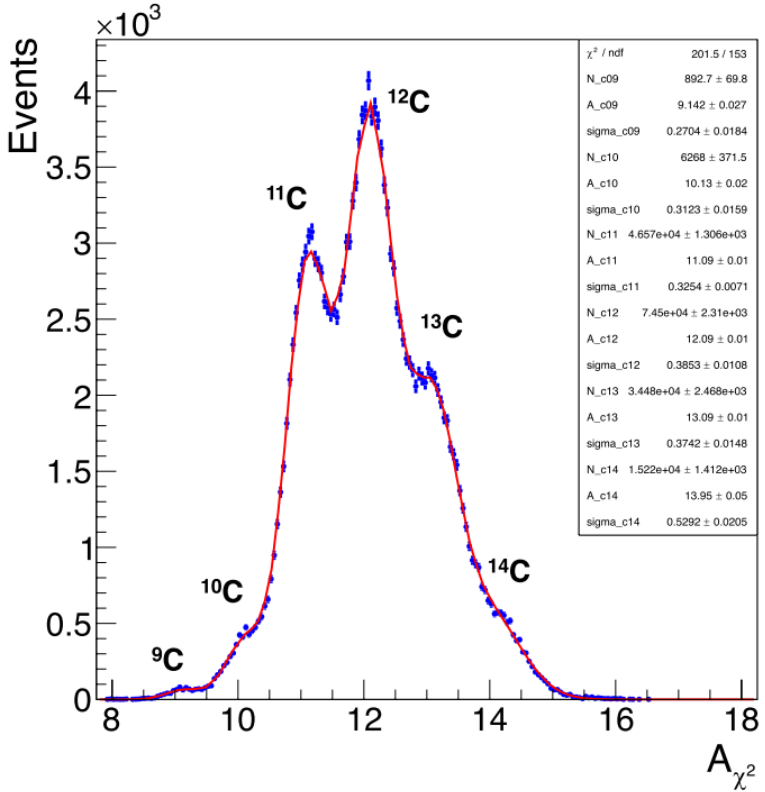
Measure the time-of-flight of the fragment and the deposited energy

Track + p/Z + ΔE → Element & isotope identification
→ Measure the differential production cross sections of nuclear fragments produced by ion–matter interactions

Measurement and modeling of secondary particles produced by heavy ions

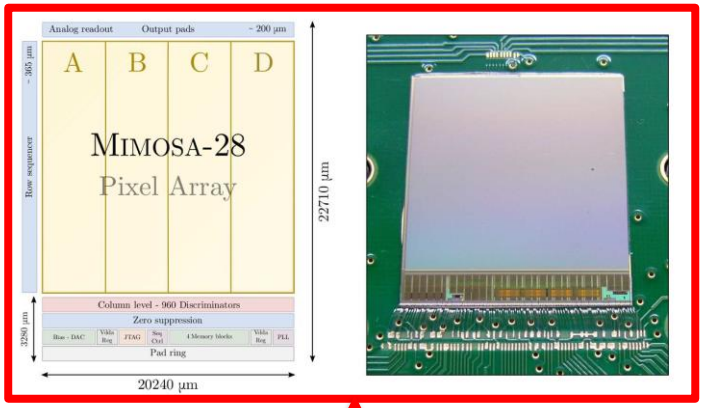
FOOT: the FragmentatiOn Of Target experiment

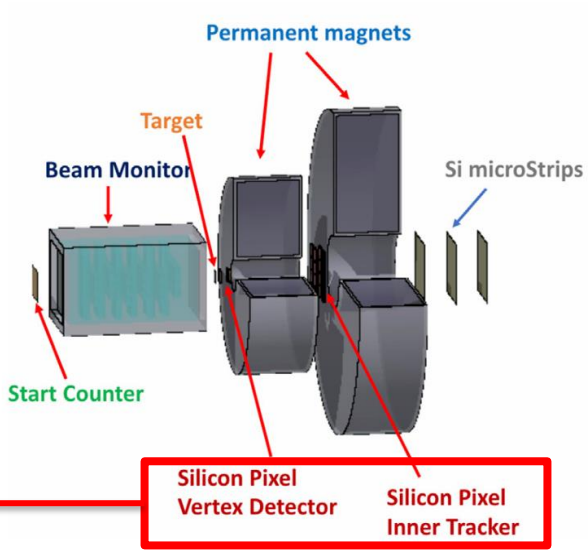


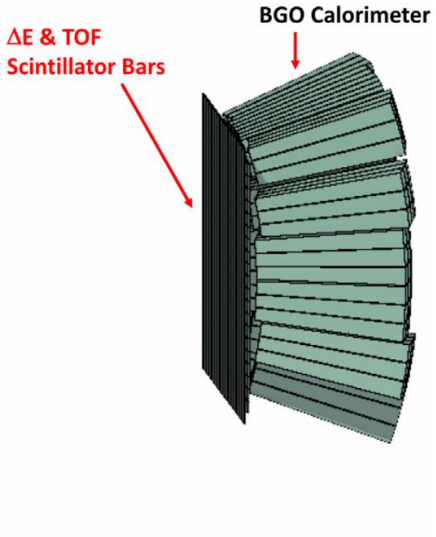


Measurement and modeling of secondary particles produced by heavy ions

MIMOSA (Monolithic Active Pixel Sensor)

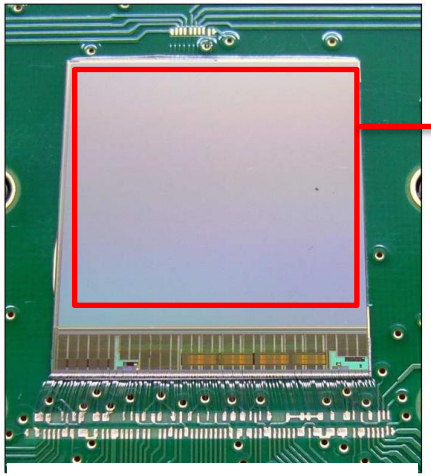


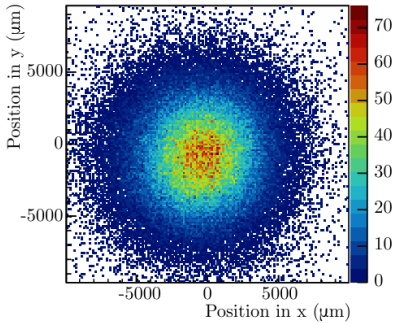


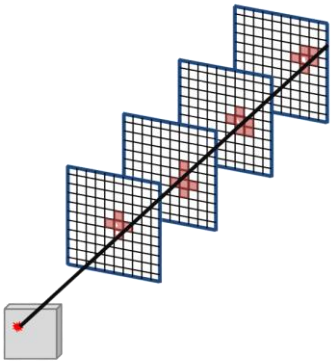


Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

MIMOSA (Monolithic Active Pixel Sensor)

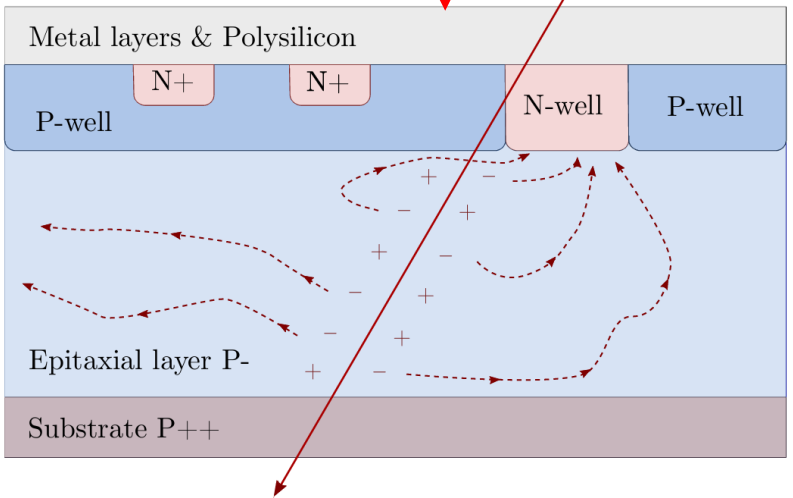






MIMOSA surface :

Spatial resolution : 4 µm



Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

- **Off-target dose**

Unwanted neutron dose delivered outside the treatment field.

- **Risk of secondary cancers**

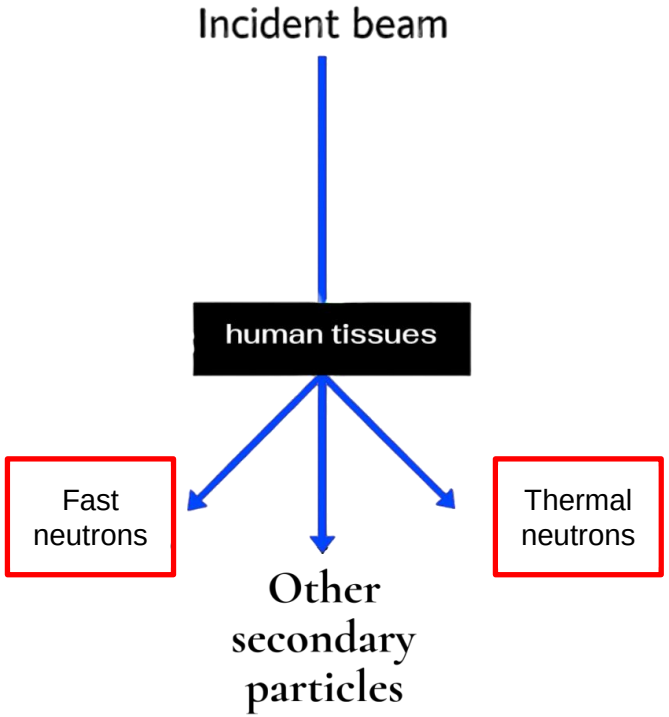
Neutron exposure can increase the probability of long-term radiation-induced malignancies.

- **Activation and radiation protection**

Neutrons can activate surrounding materials, creating residual radioactivity that must be monitored for safety.

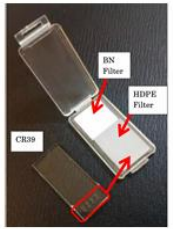
- **Difficult to quantify**

Neutrons have no electric charge, so they cannot be directly detected, making their measurement and modelling challenging.



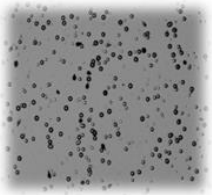
Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

Solid Nuclear Track Detector (CR-39)



Chemical treatment

Detector reading

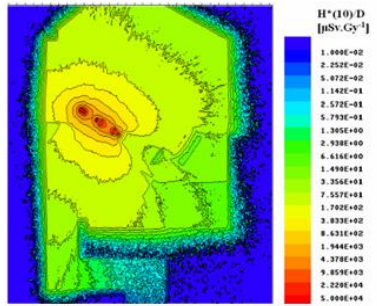


Tracks analysis

- ✗ Single use
- ✗ No real-time
- ✗ Time consuming

- Goal is to develop a 4D neutron monitoring system:
  - ⟶ sensor network (3D - space)
  - ⟶ real-time monitoring (1D - time)

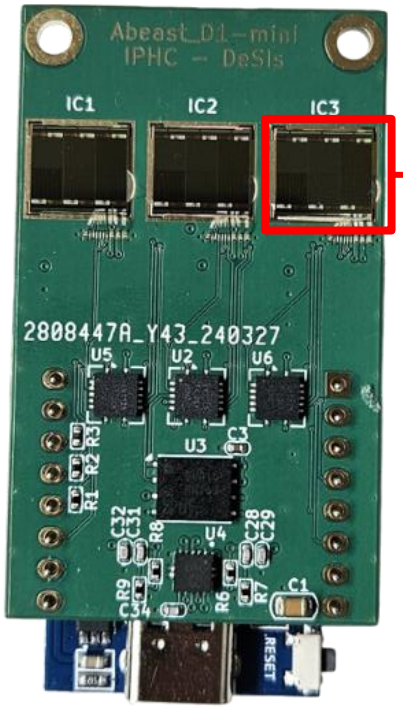
- Coupling with Monte Carlo neutron fields calculations

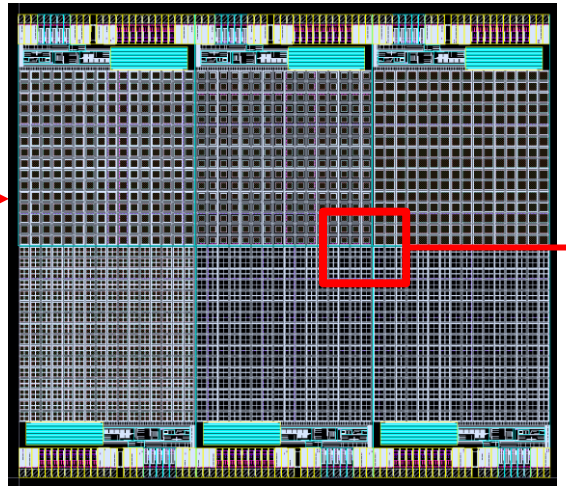


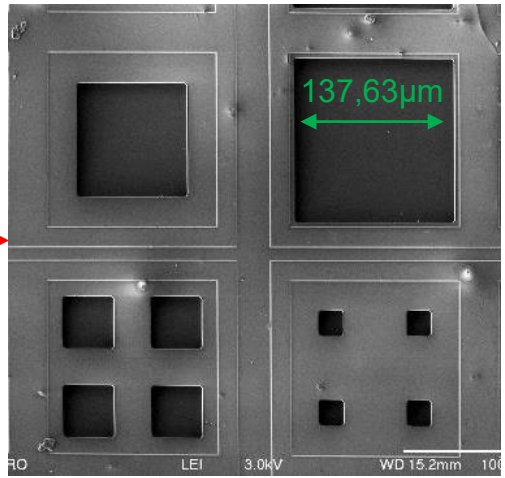
J. Farah, Phys. Med. Biol. **59** (2014)

Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

Alphabeast



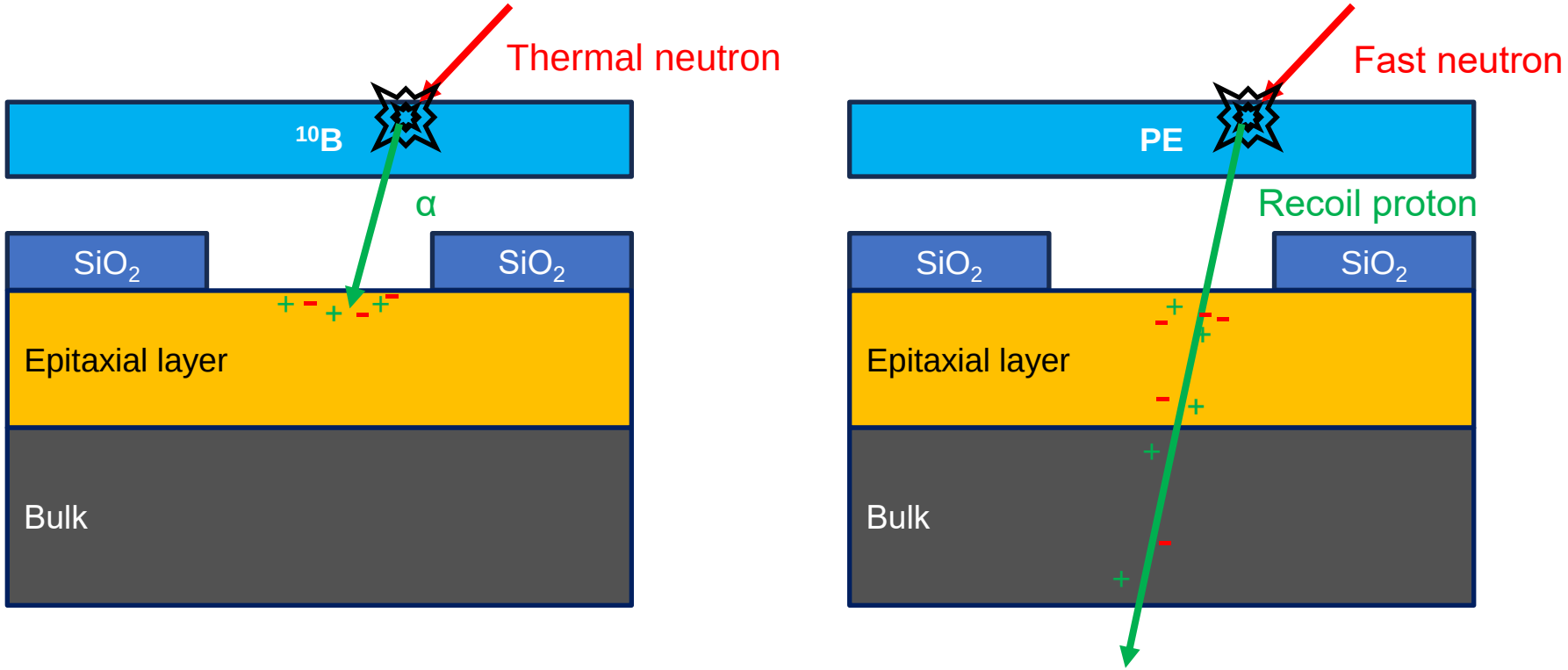




- **The silicon oxide layer acts as a surface filter**, reducing leakage and surface noise.
- The **size of the collection well is optimized to balance signal and noise**

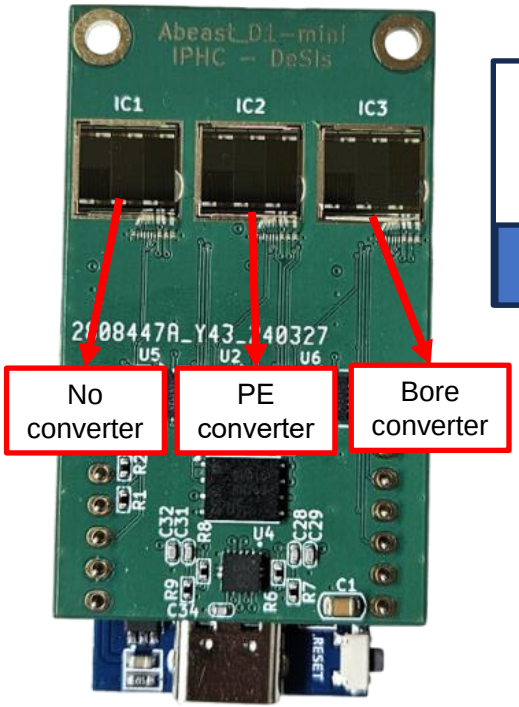
Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

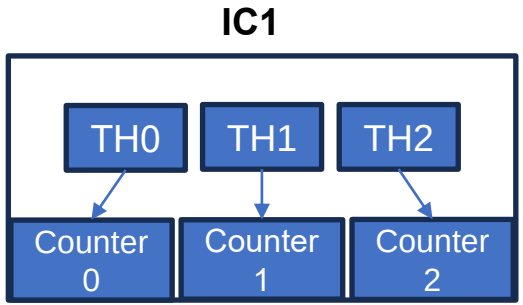
Alphabeast : Thermal neutron & Fast neutron detection **collab C4PI Techno XFAB 0.35**

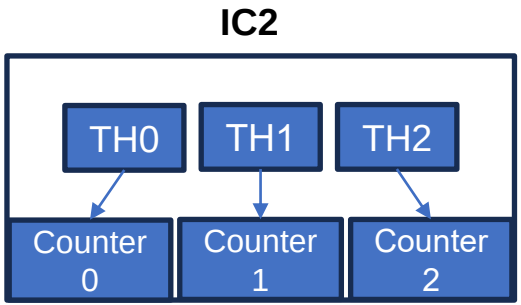


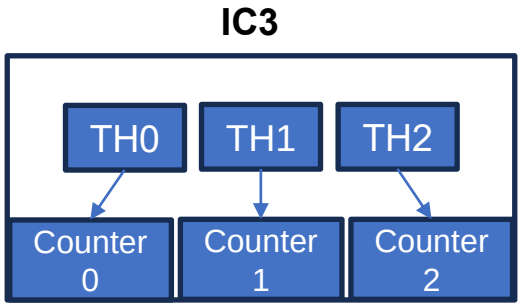
Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

Alphabeast



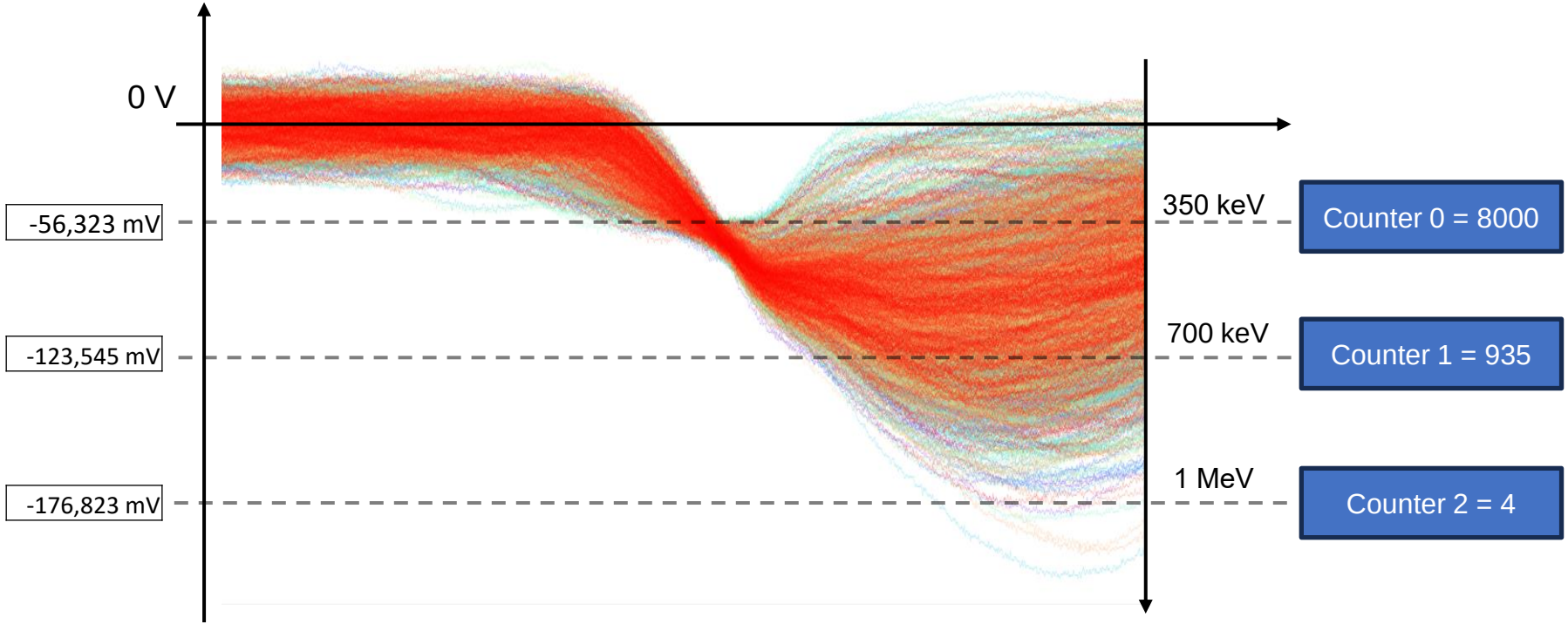






Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

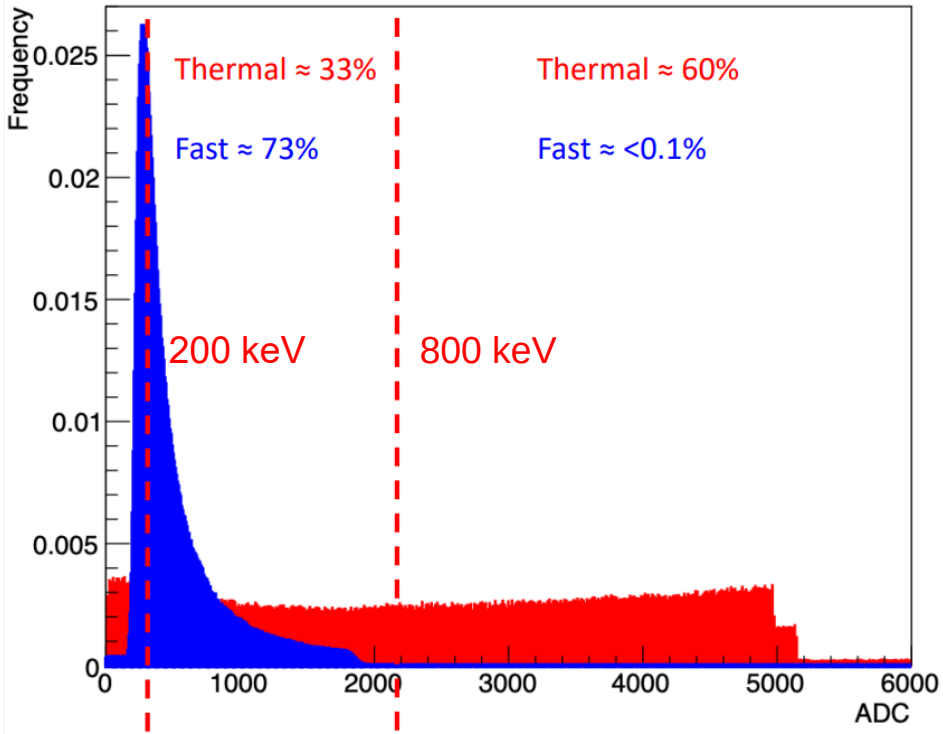
Alphabeast : Example of use 38 mm airgap



Measure and map charged particles and secondary neutrons with high spatial and temporal precision.

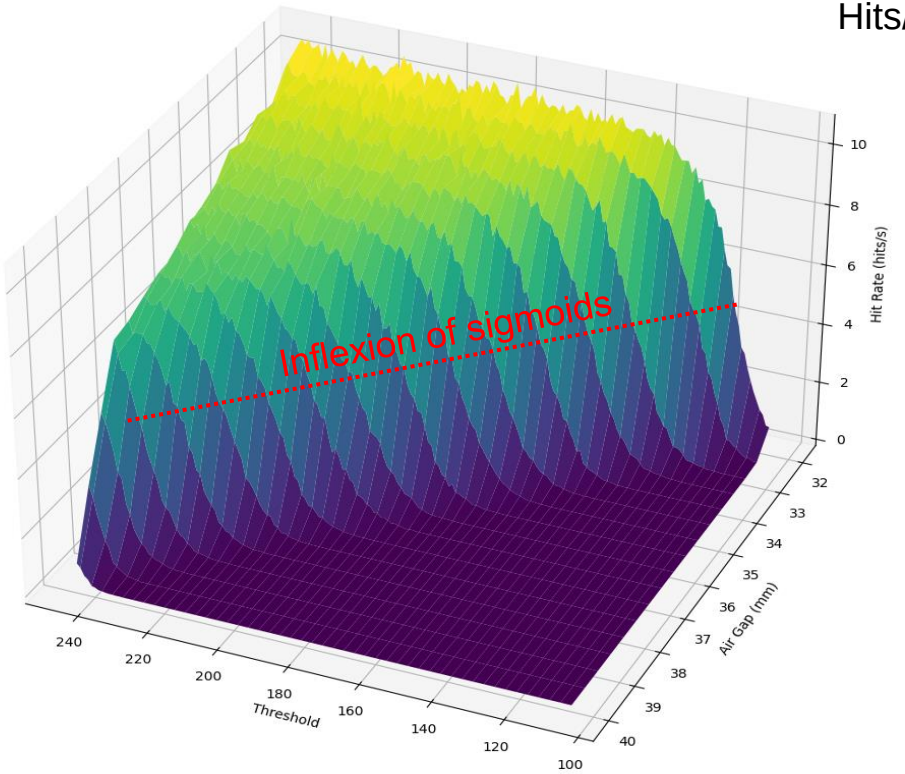
Alphabeast

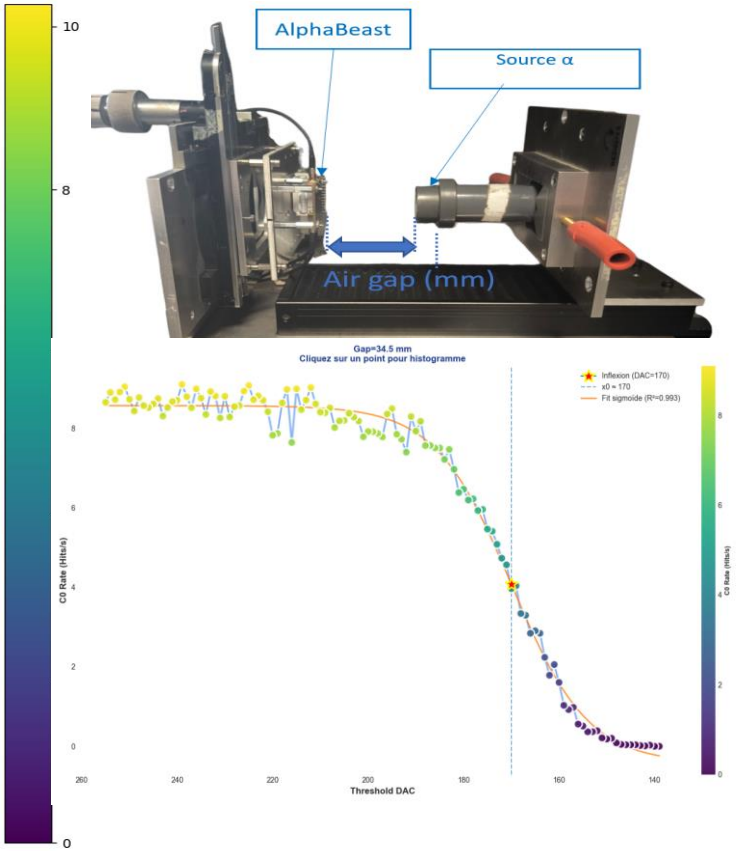
- 3 internal thresholds to be set for autonomous counting



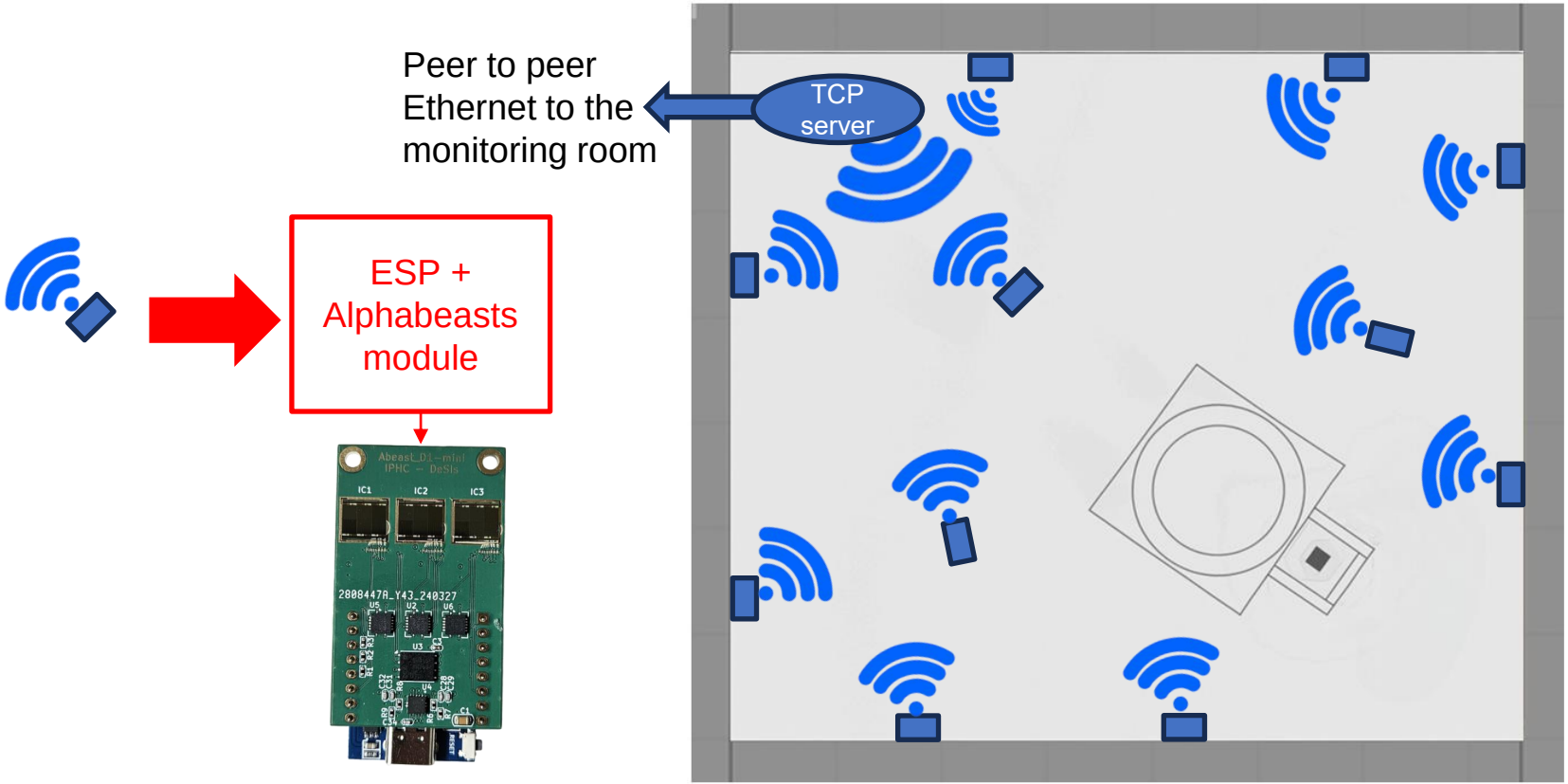
$\varepsilon_{th} \approx 4x10^{-4}$ hit/(n.s^{-1}.cm^{-2})
$\varepsilon_{fast} \approx 4x10^{-5}$ hit/(n.s^{-1}.cm^{-2})

Measure and map charged particles and secondary neutrons with high spatial and temporal precision.





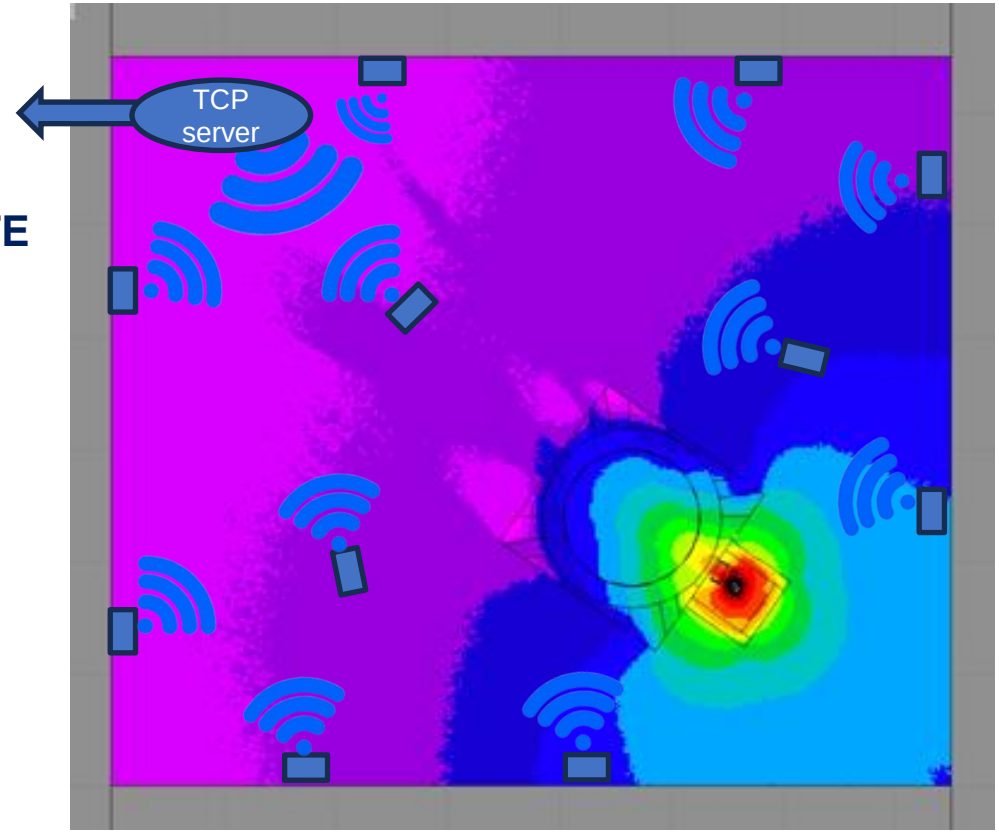
Perspectives and next developments



Perspectives and next developments

Real time 4D neutron heatmap monitoring (x, y, dose proxy, time)

Direct comparison with GEANT4/GATE



Merci

Thank you for your attention