LCIM – *Laboratoire Capteurs et Instrumentation pour la Mesure*

Development of a gamma imager for 3D mapping of radioactivity for applications in nuclear industry

PHENIICS FEST 2026

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Supervisors: Guillaume AMOYAL
Maugan MICHEL

1. Context and objectives

Nuclear decommissioning

01 Planning

02 Radiological characterization

03 Decontamination

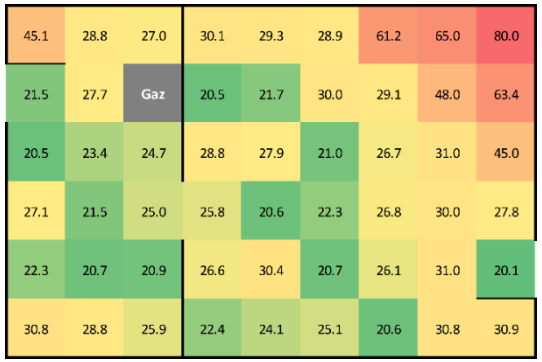
04 Dismantling

05 Preparation for reuse

06 Final survey

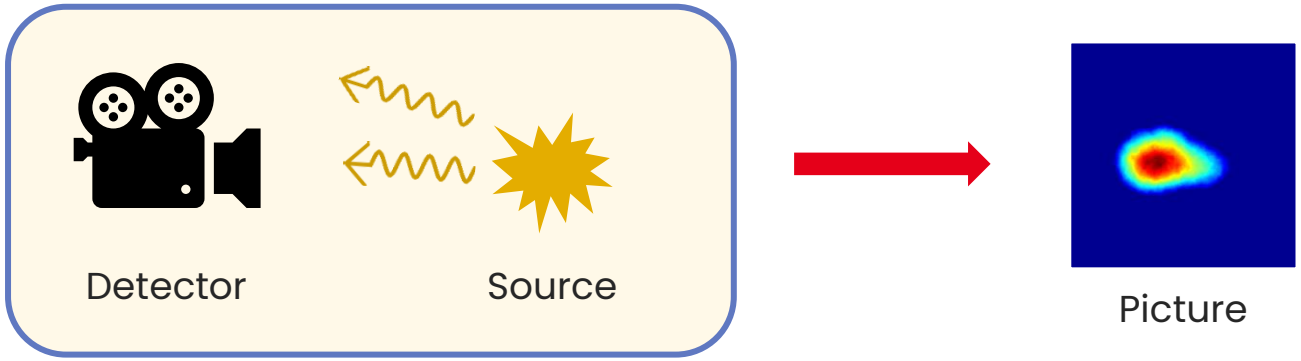
Detection of **radioactive hotspots** through radiation imaging

© A. Macario-Barros



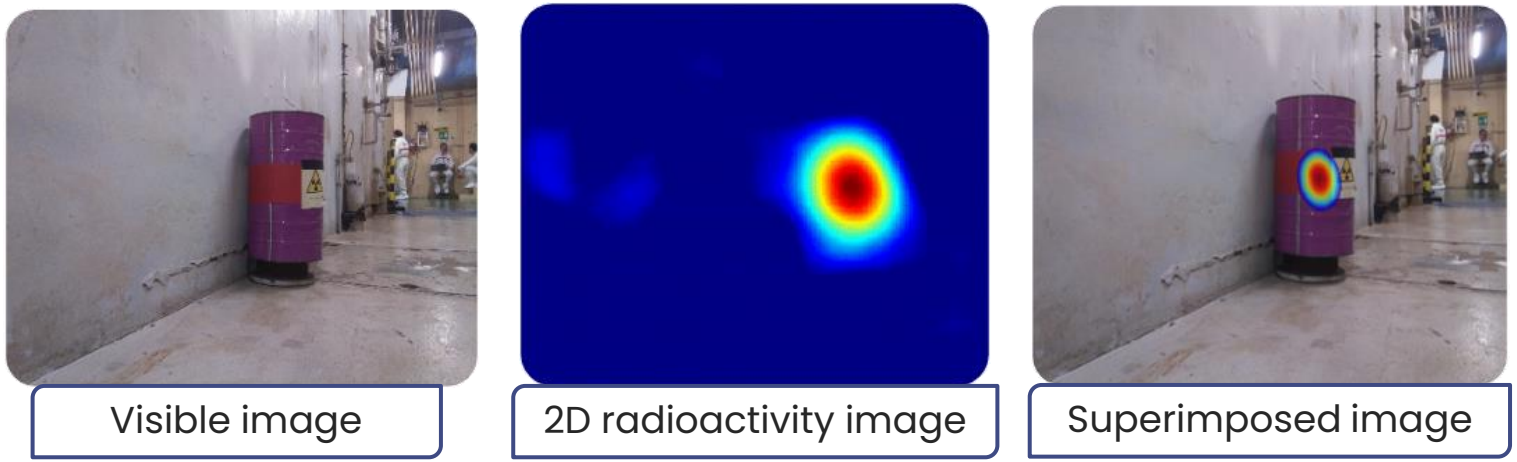
Ionizing radiation imaging

"To see radioactivity"



Several **advantages** in presence of unknown situations:

- **Visual localization** of radioactive hotspots
- **Quantitative information** (dose/activity)
- **Remote** measurements
  ALARA principle
  (*As Low As Reasonably Achievable*)



Visible image | 2D radioactivity image | Superimposed image

No information about depth!

3D imaging

Pictures from: Euratom project CLEANDEM (grant agreement n° 945335)

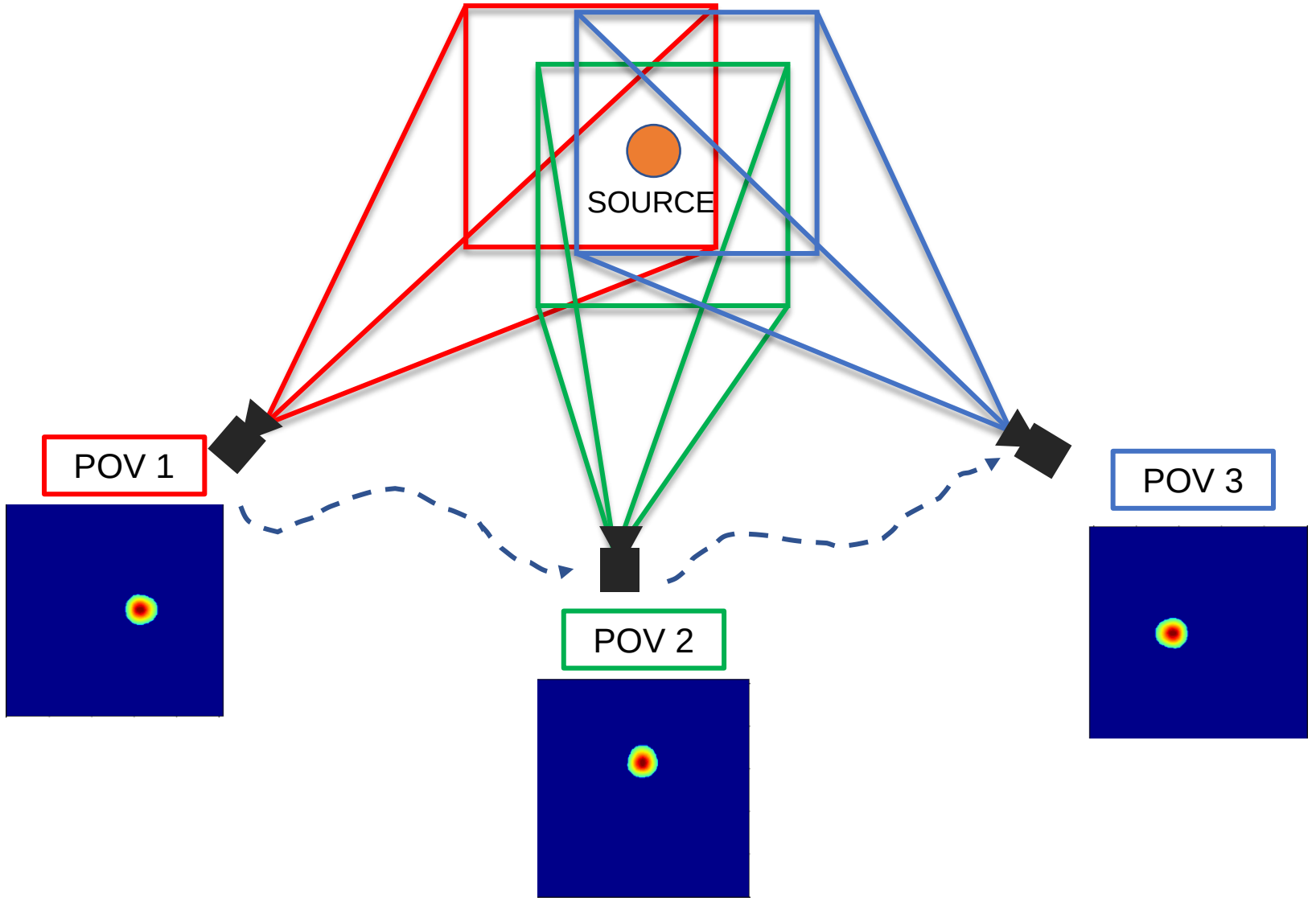
2. 3D gamma imaging method

Method's overview

- Recording of **2D gamma** images
- Move the detector to a different position
- Acquisition of **images from different points of view** (POV)
- **3D image reprojection**
- Triangulation
- Estimation of the source position

Need to know the detector's position at each POV!

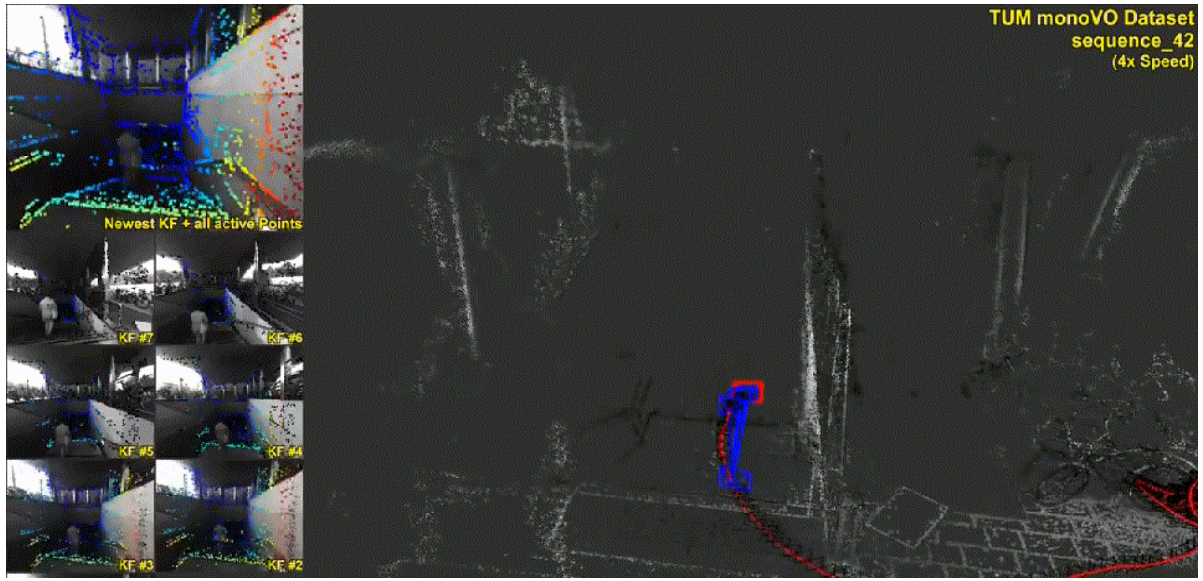
No prior information about the environment



Simultaneous Localization And Mapping

SLAM (*Simultaneous Localization And Mapping*) problem

*"**Mathematical problem** that seeks to determine a **robot's trajectory** while **simultaneously creating a map** of the environment"* [1]



Engel *et.al.* (2016)

[1] A. M. Barros, "Modular device for automated and reliable mapping of indoor installations".

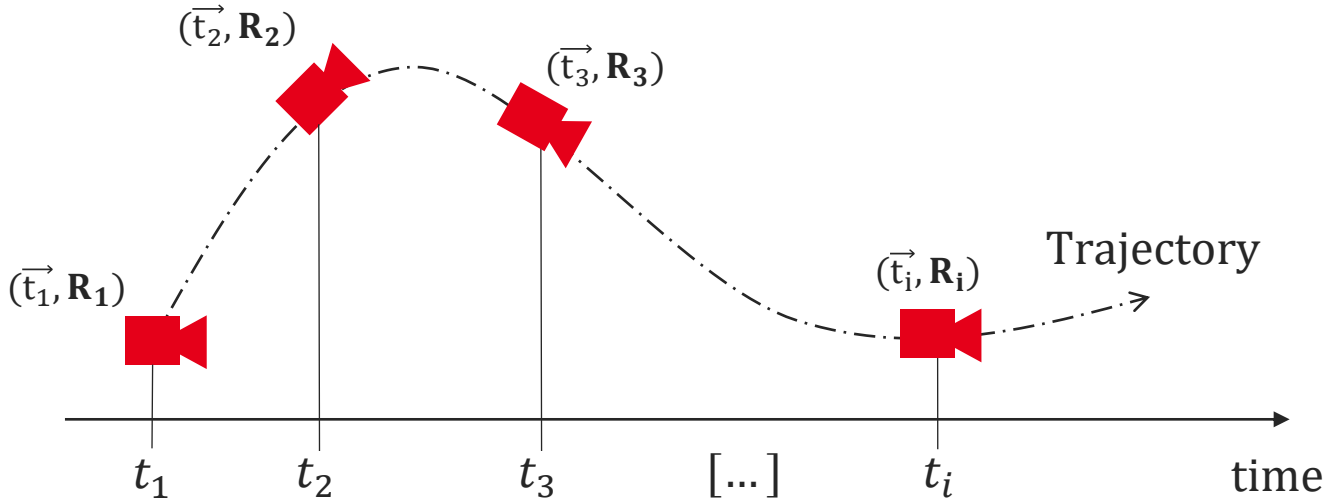
SLAM working principle

Sensor (LiDAR, visual camera, radar, IMU unit …)

Input data (depth values, color images, acceleration values …)

SLAM algorithm

Trajectory & point cloud estimation



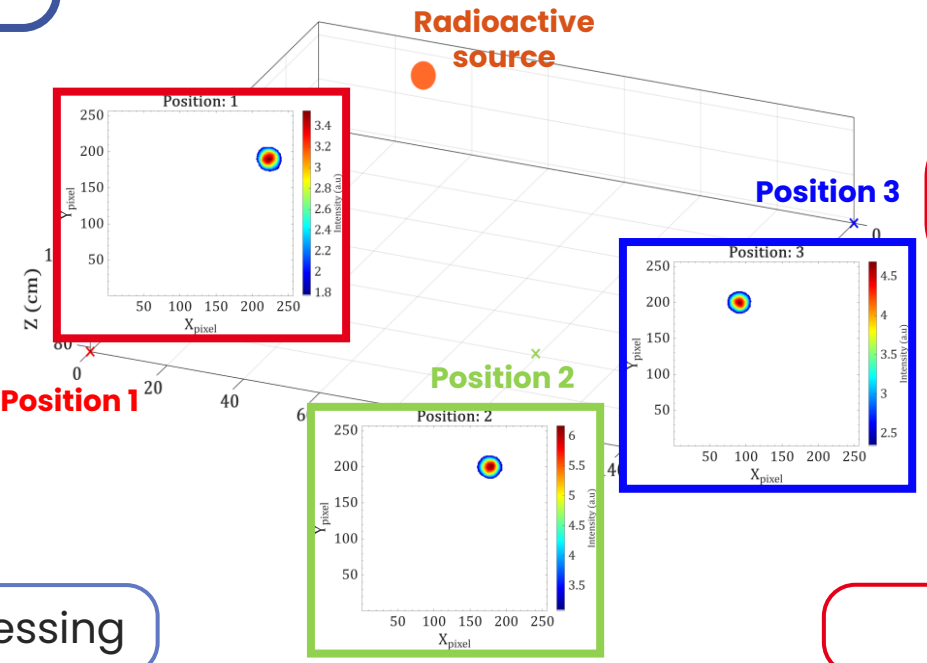
$\vec{t} = [x, y, z]_{3\times1}$
$\mathbf{R} = [R_x, R_y, R_z]_{3\times3}$

"Pose" (position & rotation)

3D gamma imaging and SLAM coupling

Radiological measurement

Acquisition of multiple gamma images from different points of view



Spatial localization

Acquisition of a video of the surrounding scene

2D gamma imaging processing

SLAM algorithm

3D hotspot back-projection

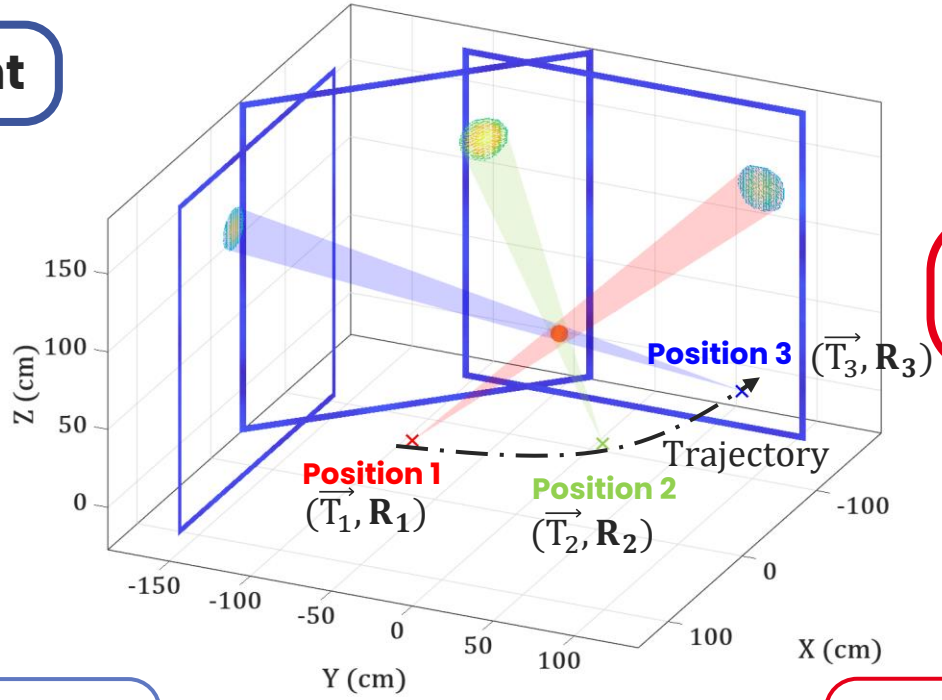
$$\vec{t} = [x, y, z]_{3\times1}$$
$$\mathbf{R} = [R_x, R_y, R_z]_{3\times3}$$

Detector's **pose**

3D gamma imaging and SLAM coupling

Radiological measurement

Acquisition of multiple gamma images from different points of view



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$$\vec{t} = [x, y, z]_{3\times1}$$
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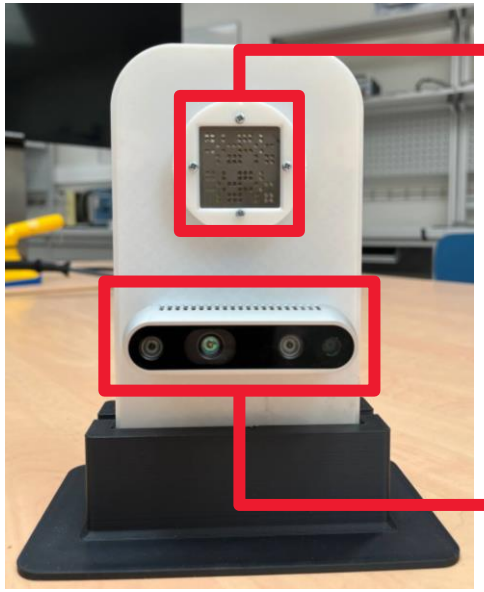
Detector's **pose**

3. Development of a prototype

Prototype design

MultImodal RAdioactivity imageR for 3D mapping (MIRAR3D)



Picture from: https://kt.cern/technologies/timepix3

Coded-aperture gamma imaging

- ❑ **Timepix3**-based hybrid pixel detector
  - 1 mm CdTe layer
  - 256 × 256 pixels (55 µm pixel pitch)
  - 1.56 ns time resolution
- ❑ 4 mm thick MURA rank-7 **coded mask** tungsten alloy

Simultaneous Localization And Mapping (SLAM)

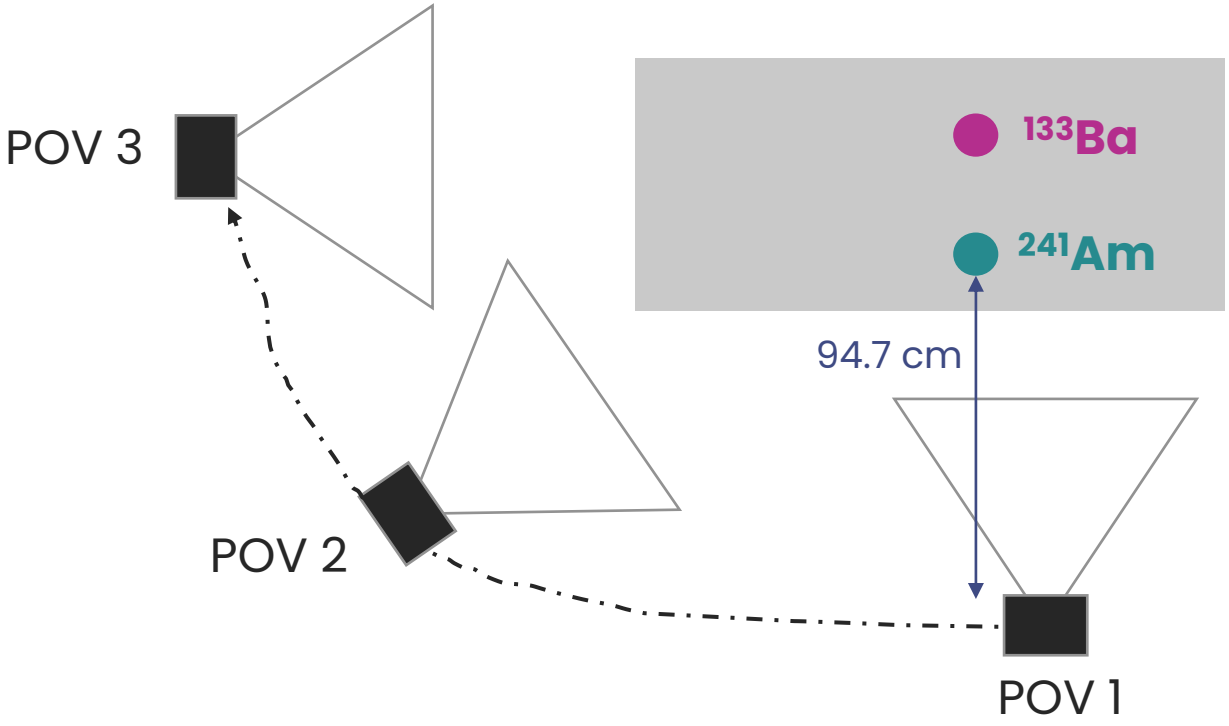
- ❑ Intel ® RealSense™ **RGB-D** (color and depth) **camera**
  - Evaluation of the imager's poses (position and rotation) at each measurement point
  - 3D sparse **point cloud** of the environment

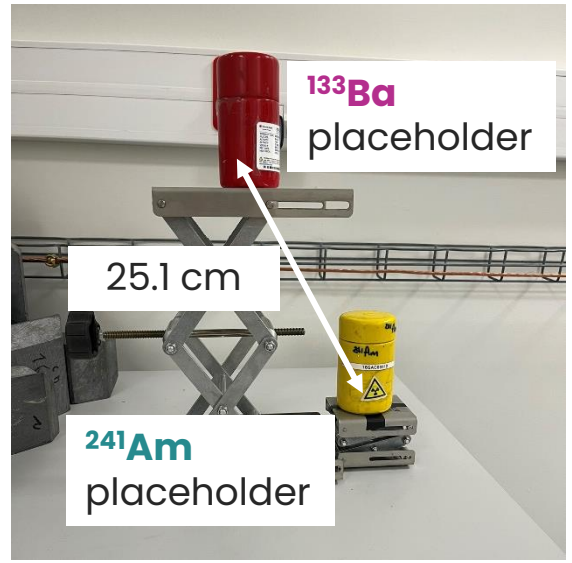
Dimensions: (18 cm × 10 cm × 2.8 cm)
Weight = 325 g

4. Experimental validation

Experimental set-up

- Measurement of ^{241}Am (25.9 MBq) and ^{133}Ba (39.5 MBq) point-like sources
- **Three POVs** measured
- **25.1 cm distance** between sources



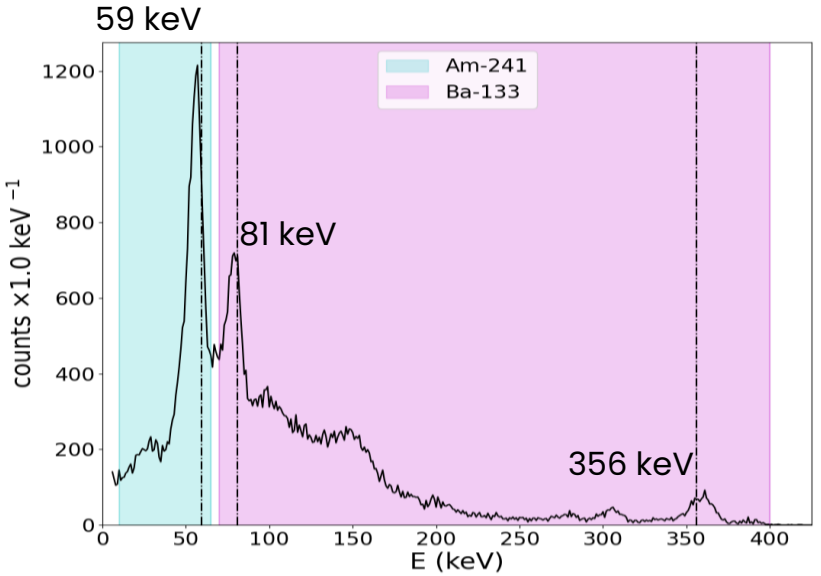


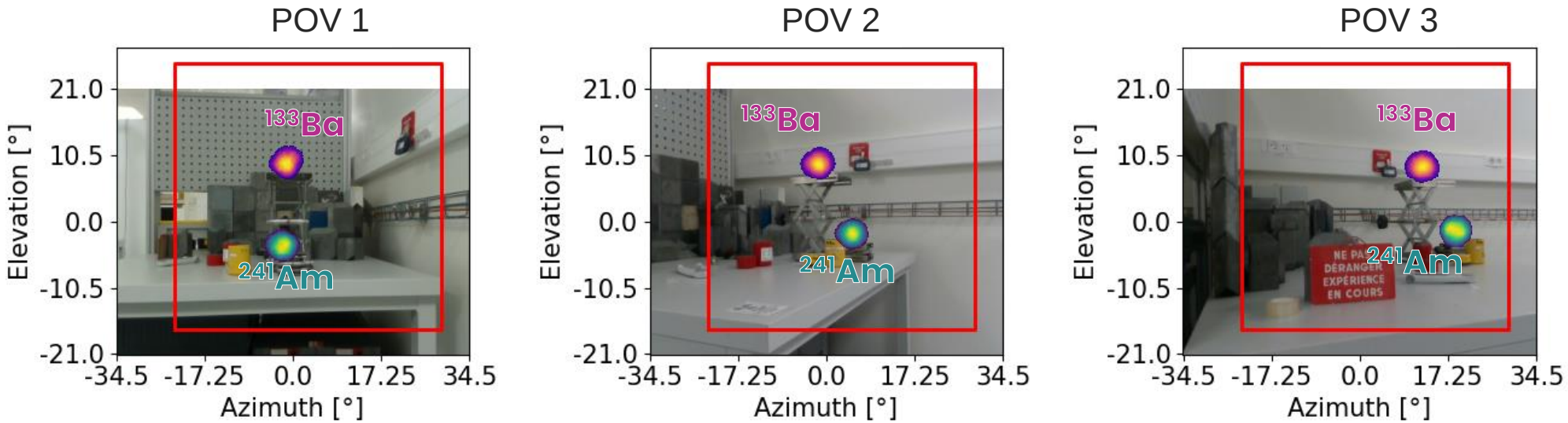
Sources separation

“spectro-imaging”:
Separation of the two radionuclides by selecting their energy emission in the energy spectrum.

^{241}Am
E_γ=59 keV

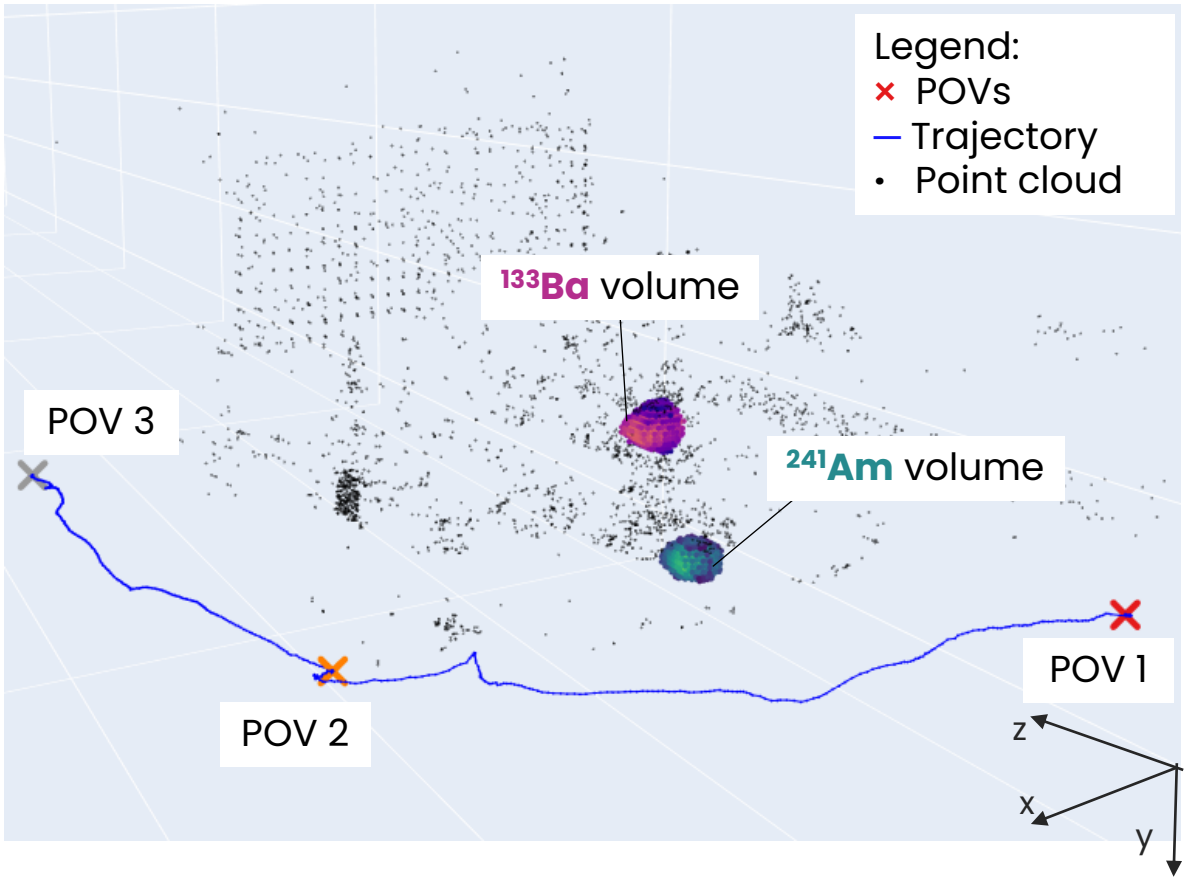
^{133}Ba
$E_{\gamma,1}$= 81 keV
$E_{\gamma,2}$= 356 keV





Sources localization

3D spectro-imaging result



Source's volume barycenter

^{241}Am	^{133}Ba
$x = (-3.9 \pm 2.3)$ cm	$x = (-4.2 \pm 2.5)$ cm
$y = (16.3 \pm 2.1)$ cm	$y = (-7.1 \pm 2.3)$ cm
$z = (91.5 \pm 2.8)$ cm	$z = (105.3 \pm 3.0)$ cm

Estimated distance between sources

$d_{est} = 27.2 \pm 3.4$ cm $d_{real} = 25.1 \pm 0.5$ cm

Absolute error on the distance:
$\epsilon_{abs} = 2.1$ cm

3D gamma spectro-imaging validated!

5. Conclusion

Conclusions and perspectives

Conclusions:

1. Development and validation of a 3D gamma imaging method
2. Development of a dedicated prototype
3. Experimental validation in laboratory conditions

Perspectives:

1. Tests on spatially extended sources
2. Correction of angular resolution degradation effects
3. System integration

Looking for field tests!

Thank you for your attention!

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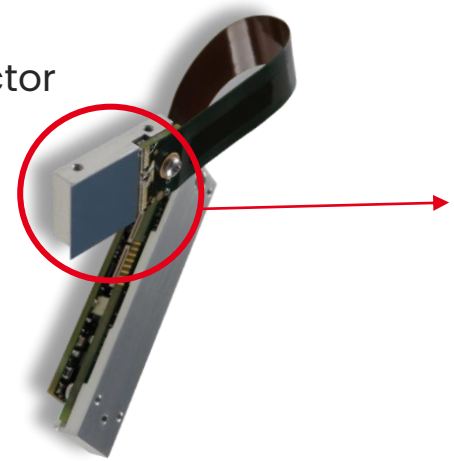
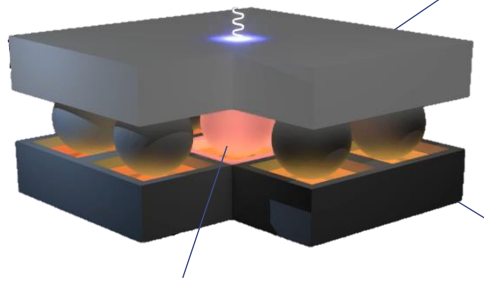
Hybrid pixel detector calibration

Detector's working principle

MiniPIX TPX3
Hybrid pixel detector based on CERN Timepix3 ASIC



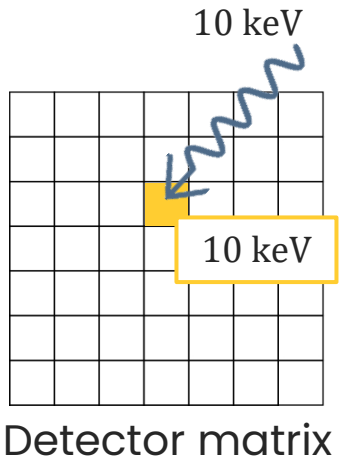


Timepix3 ASIC
- 256×256 pixels
- $55\mu m$ pixel pitch

Localized energy deposition:

- The deposited charge is confined to the pixel of first interaction

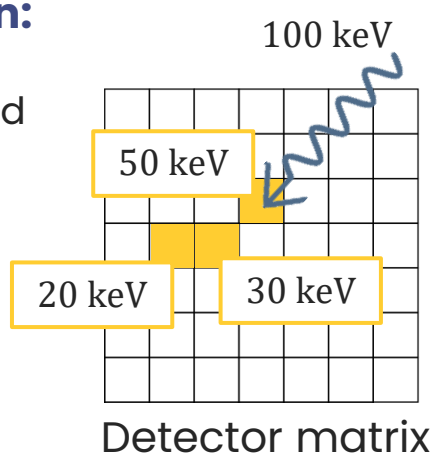
→ Most probable for $E_\gamma < 100$ keV (photoelectric absorption)



Broadened energy deposition:

- The deposited charge is shared among multiple pixels

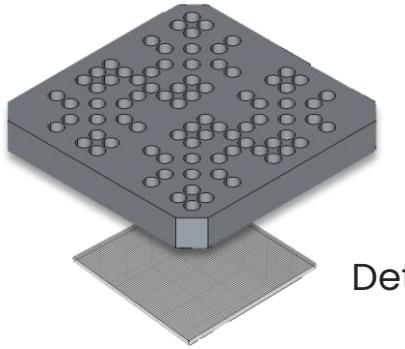
→ Most probable for $E_\gamma > 100$ keV (Compton scattering)



Detector energy resolution

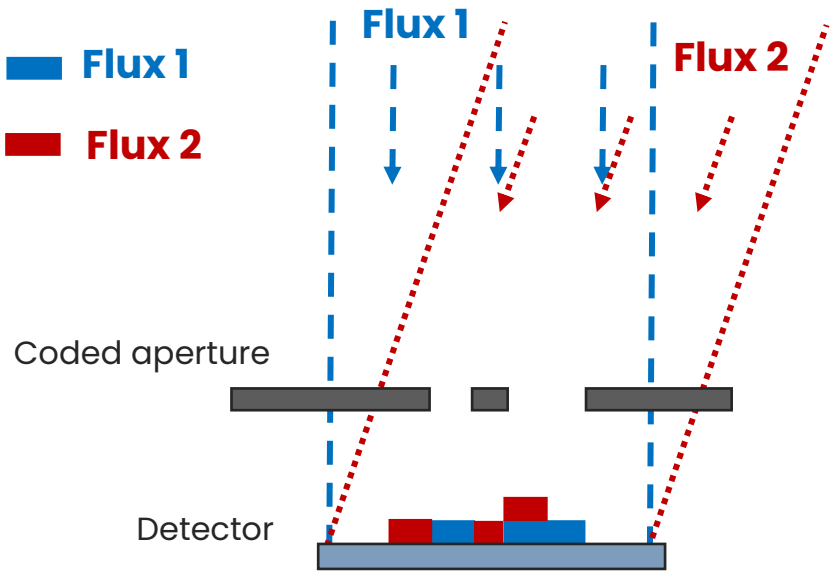
Energy (keV)	$\Delta E/E$ (%)		
	Set 1	Set 2	Reference
59.5	9.3	7.3	7.6
80.99	15.6	10.4	14.6
661.7	4.4	3.7	3.9
1332.5	4.6	2.8	4.5

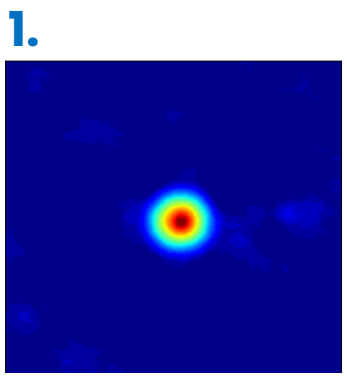
Coded-aperture imaging

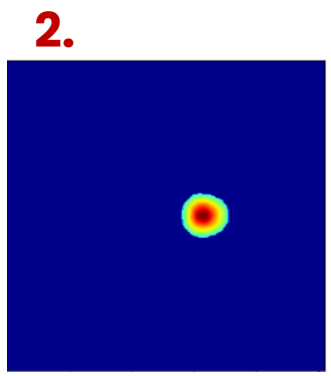


Mask
- Opaque elements (**high Z** material)
- Transparent elements (holes)

Detector
- Sensitive to ionizing radiation
- Sensitive to the **position of interaction** (**pixelized**)







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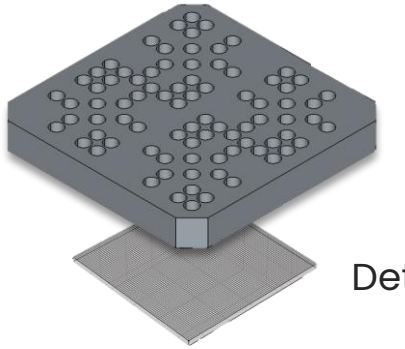

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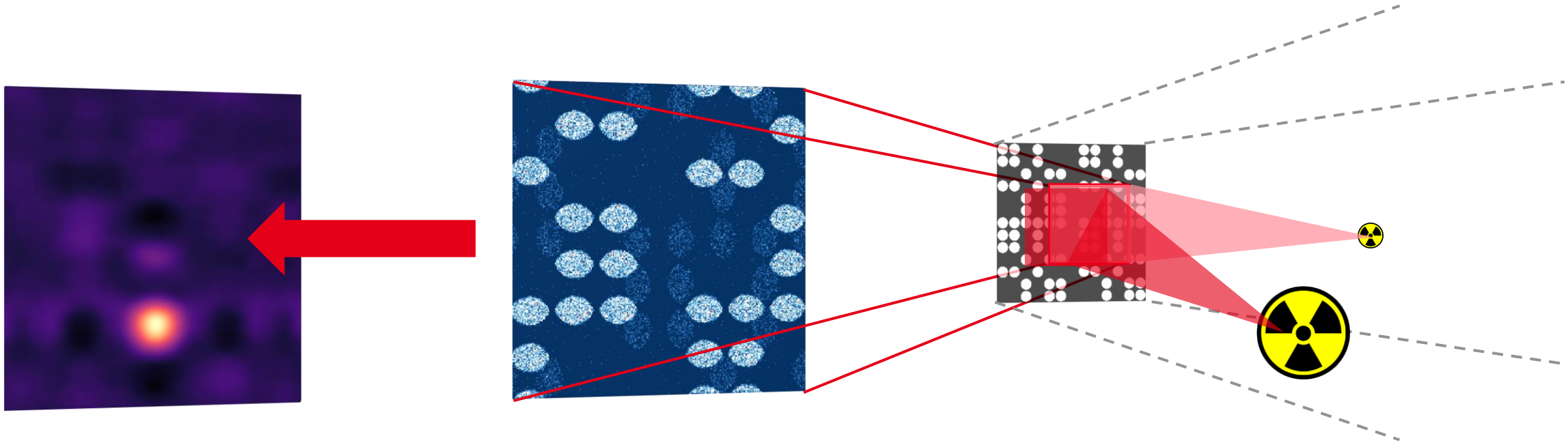

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