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3D localization of radioactive sources by triangulation method using a single gamma camera

DE LA RECHERCHE À L'INDUSTRIE

28/06/2022

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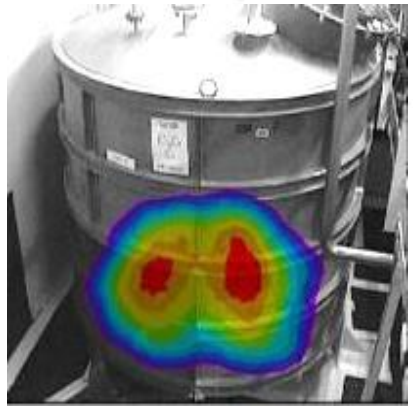
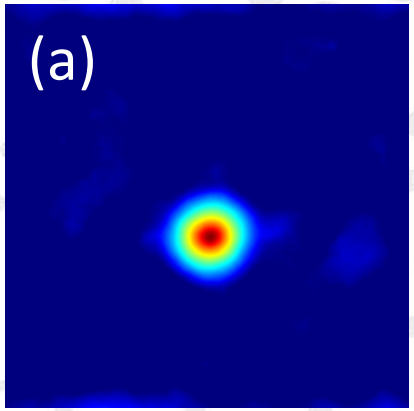
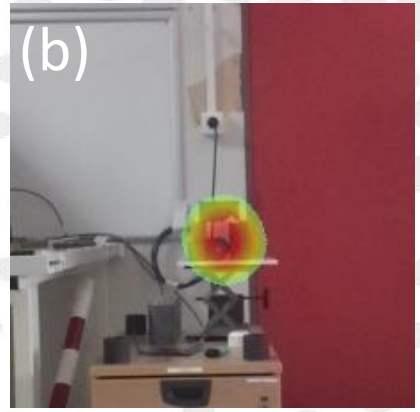
Introduction, context, purposes

- **Localization of radiological hot spots**
  1. Superimposing a gamma image on a visible image
  2. Respecting ALARA* principle
- **Applications:**
  1. Nuclear decommissioning
  2. Radiation protection
  3. Accidental situations
  4. Nuclear waste management applications







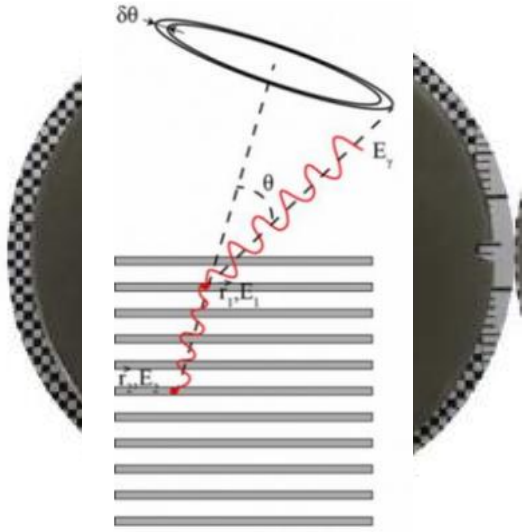
(a): Hot spot reconstruction using the coded-aperture method via Nanopix. (b): Superimposition of a gamma image on a visible image to locate the hot spot.

Gamma imagers pictures (a) CARTOGAM. (b) IPIX. (c) Nanopix.

* As Low As Reasonably Achievable

Introduction, context, purposes

- **Localization in our current compact imaging systems:**
  1. Stationary measurements;
  2. Two distinct **2D** localization techniques.
     - Coded-aperture;
     - Compton scattering.



Extracted from: http://www.univearths.fr/

- **Development of a new generation of gamma imager:**
  1. Moving system
  2. **3D** localization

Source to detector distance ??

Gamma camera **Nanopix**

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- Imaging techniques
- Imaging systems
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- Simulation validation
- Conclusions & outlooks

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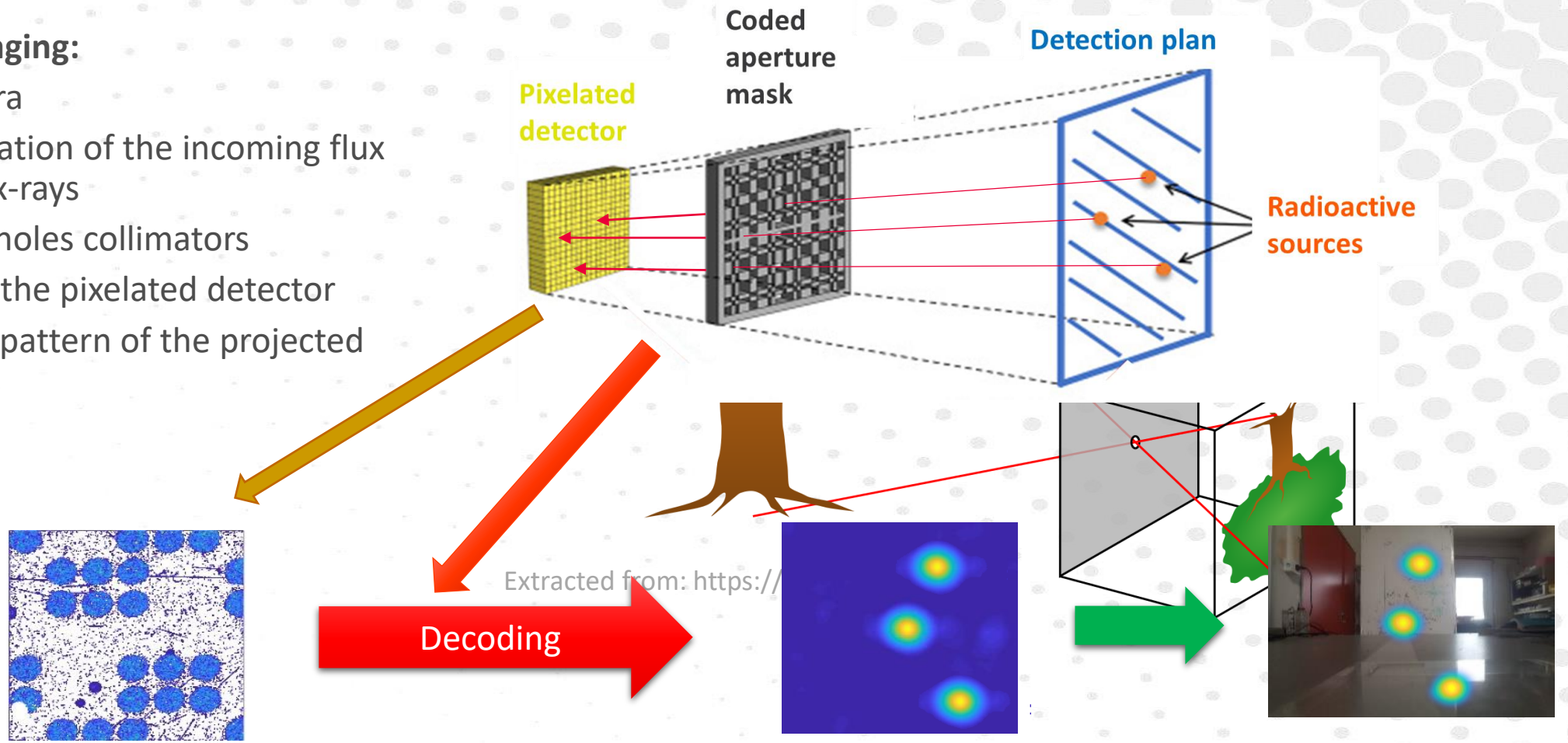
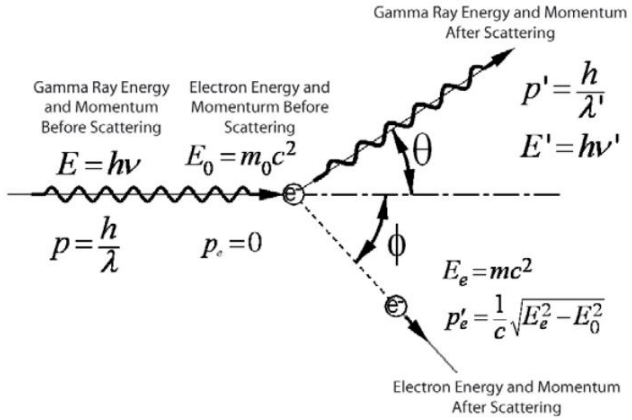
Imaging techniques

- **Coded-aperture imaging:**
  1. Pinhole camera
  2. Spatial modulation of the incoming flux of γ-rays and x-rays
  3. Masks: multi-holes collimators
  4. Projection on the pixelated detector
  5. Decoding the pattern of the projected shadow

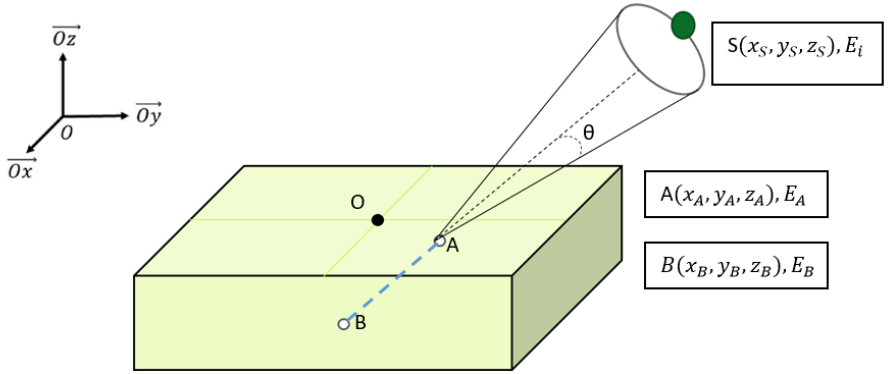


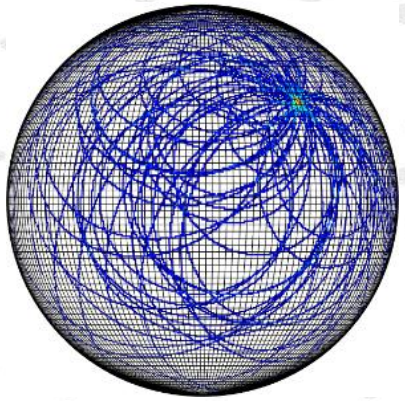
- **Compton imaging:**
  1. Compton scattering
  2. Information preserved: energy and direction of the γ-ray.
  3. Calculation of scattering angle
  4. Intersection of cones



$$\cos(\theta) = 1 + \frac{m_e c^2}{E_i} - \frac{m_e c^2}{E_a}$$

Compton scattering diagram showing the interaction between the incident photon and electron initially at rest to the scattered photon and electron given kinetic energy [1]





[1] J. Parks, "The Compton Effect-- Compton Scattering and Gamma Ray Spectroscopy," 2009.

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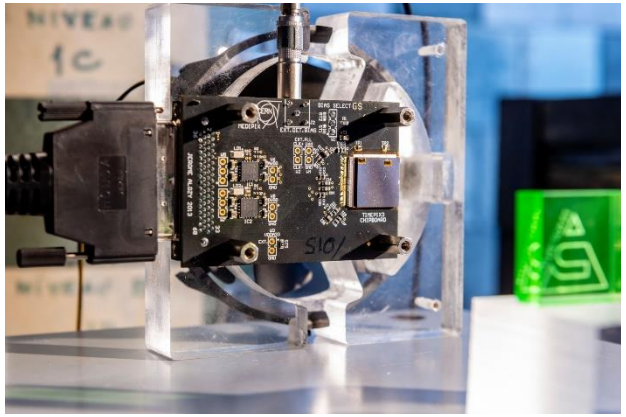
- **The operating gamma imagers:**

Gamma Imager	Imaging technique	Detector
Nanopix	Coded aperture masks	Timepix + 1 mm CdTe
Compton imager	Compton imaging	Timepix3 + 1 mm CdTe

Timepix3 © CERN

Nanopix © CEA List



Compton imager prototype © CEA List

Parameter	Timepix 3
Pixel arrangement	256 x 256
Pixel size 55 x 55 µm	55 x 55 µm
Technology	130 nm CSMO
Acquisition modes	1. Time (ToA) and Charge (ToT) 2. Time (ToA) 3. Event Counting and iToT
Readout type	Data Driven Frames

X-Ray Beam, IEEE Trans. Nucl. Sci. 64 (2017).

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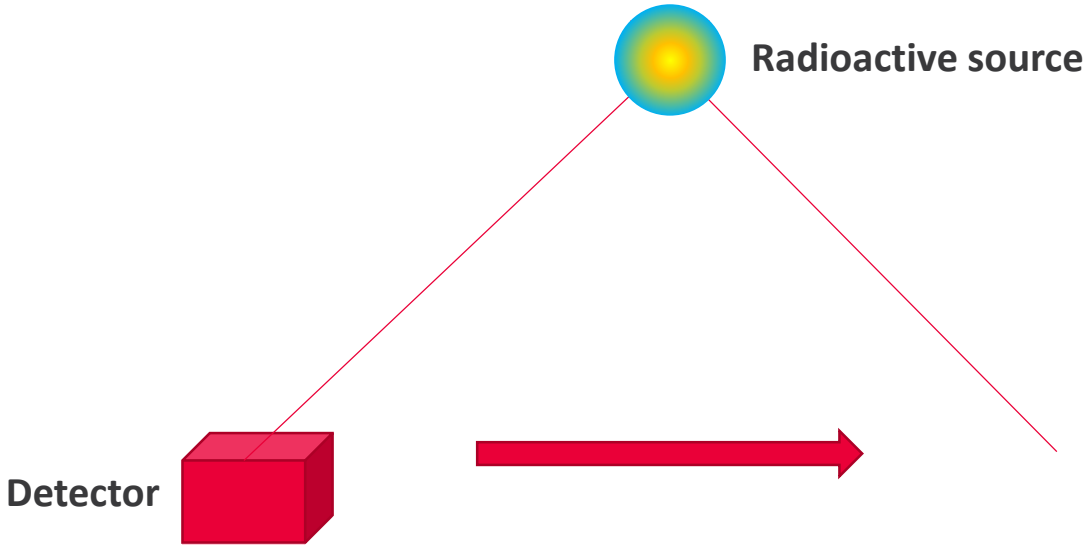
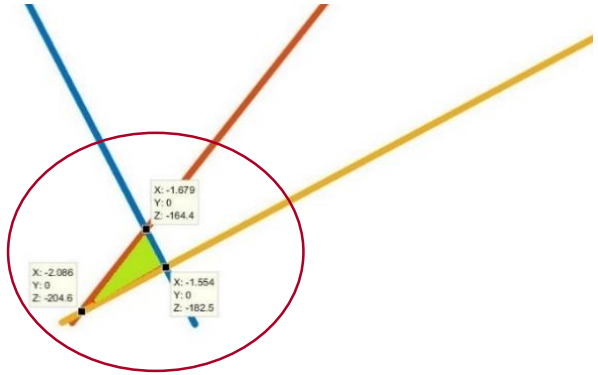
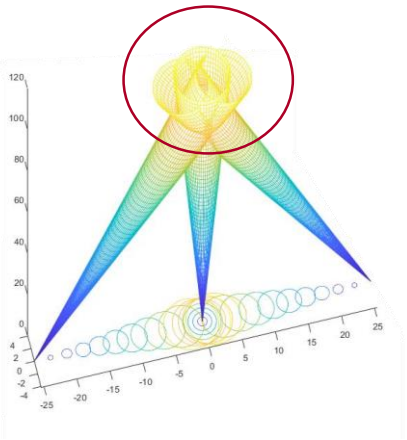
3D imaging: triangulation method

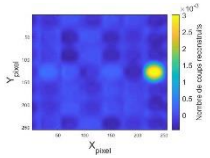
- **Triangulation method using a single detector**
  1. Moving the detector to different positions
  2. Recording the coordinates of each position of detector
  3. Performing several gamma images
  4. Calculating the director vectors
  5. Defining and characterizing the region of uncertainty



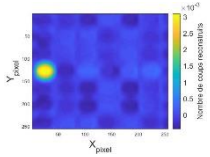


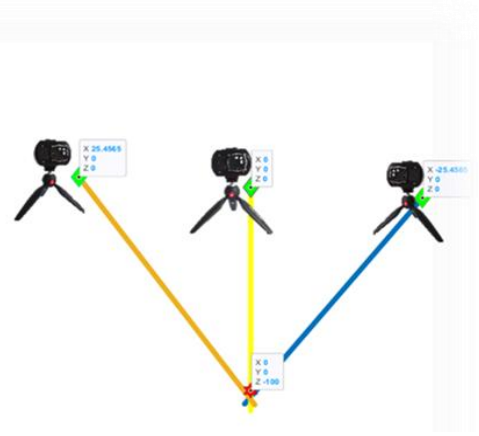


1^{st} position (x_1,y_1,z_1)



2^{nd} position (x_2,y_2,z_2)





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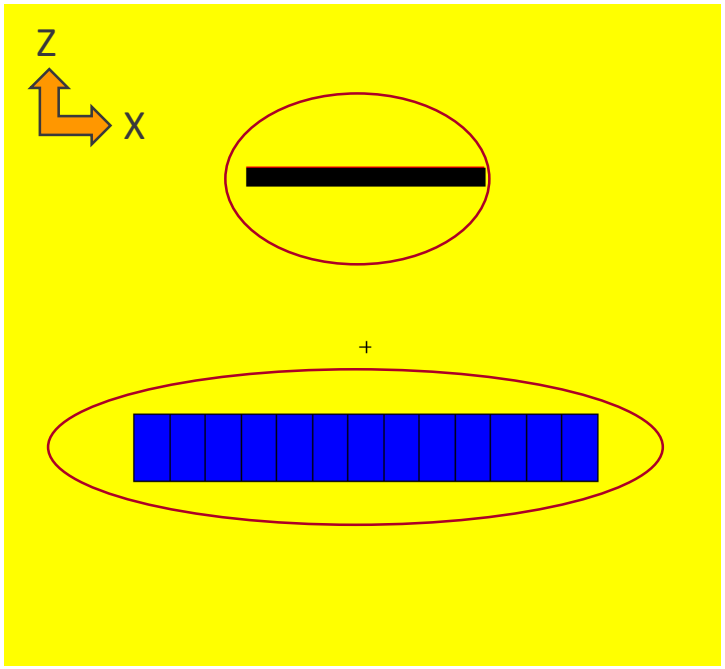
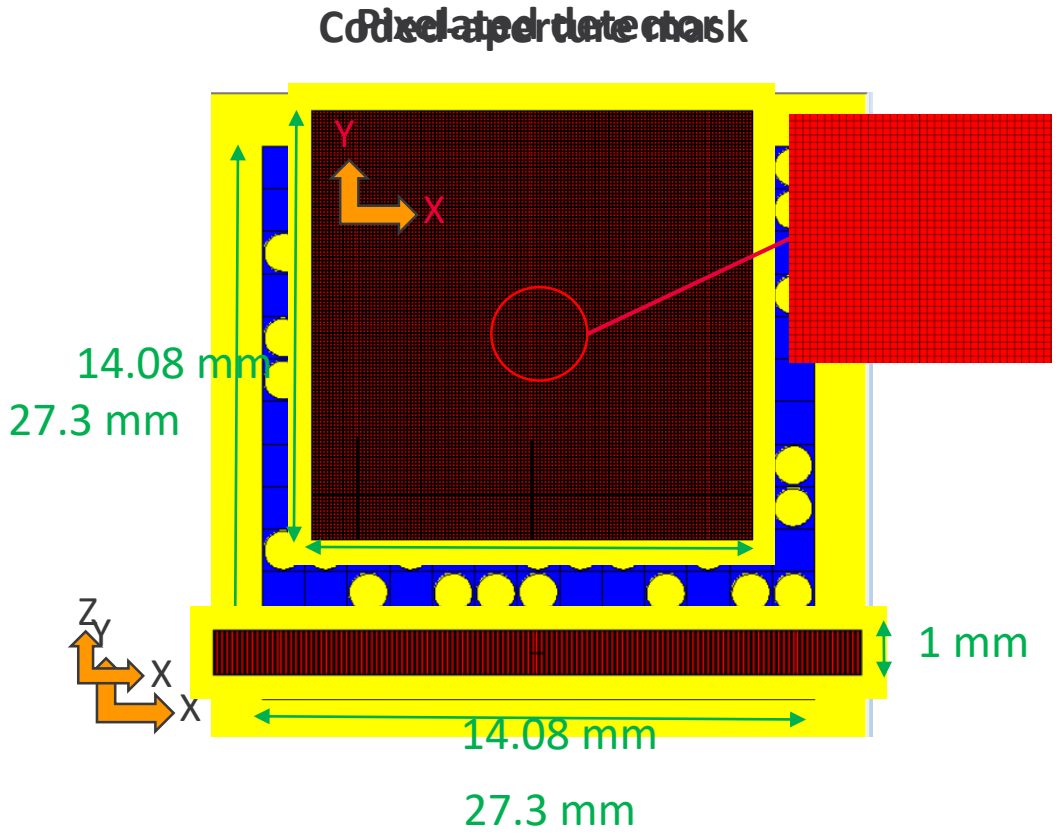
Simulation validation

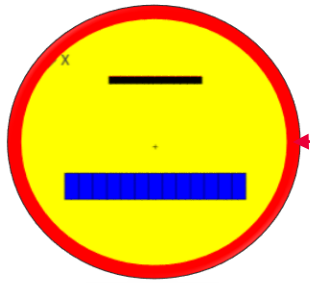
- **Gamma imaging simulation**

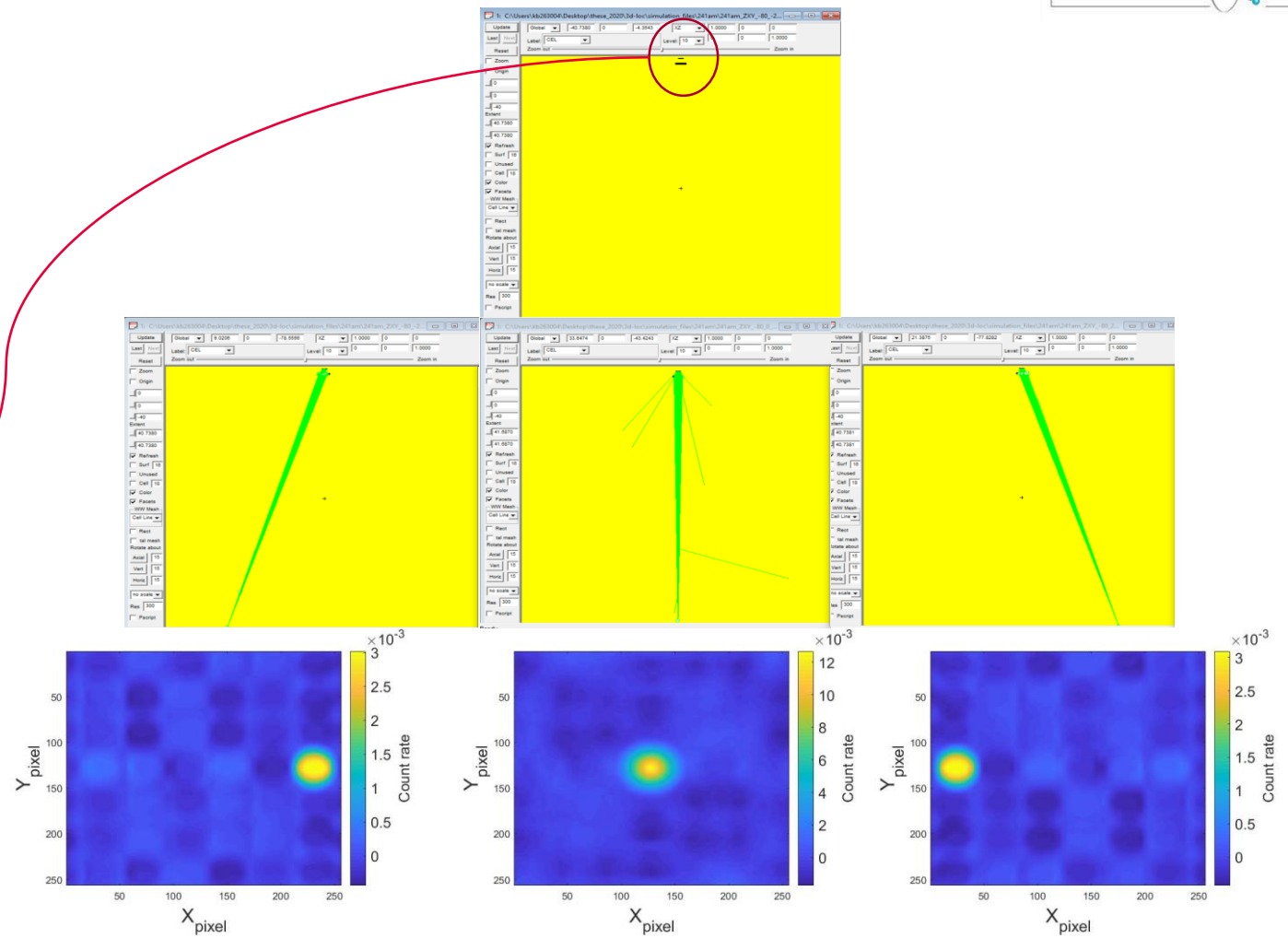




Simulation validation

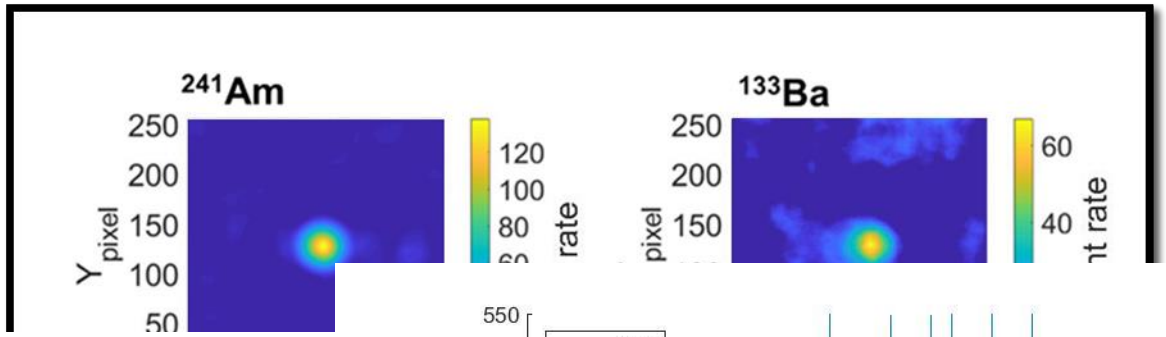
- **Gamma imaging simulation**
  1. Moving vertically the source from 60 cm to 500 cm
  2. Moving horizontally the source: left, center, right
  3. Varying the displacement step

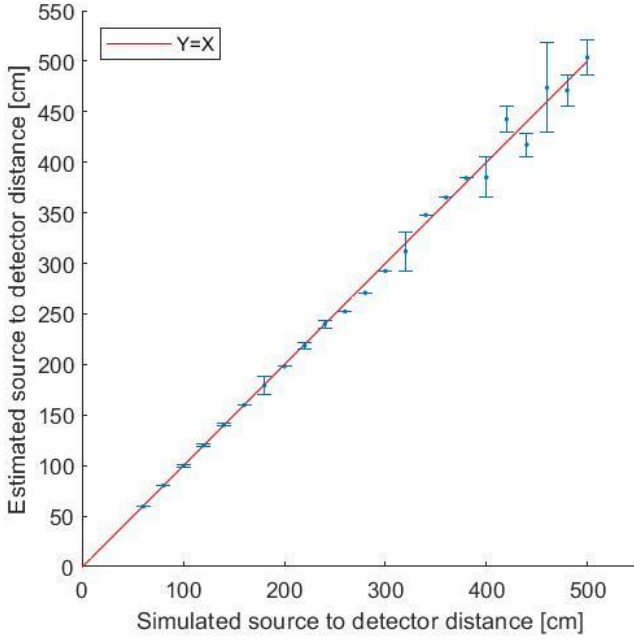




Simulation validation

- **Gamma imaging simulation: results**
  - Increase in uncertainties:
  - ➢ Degradation of the angular resolution due to the increase in energy



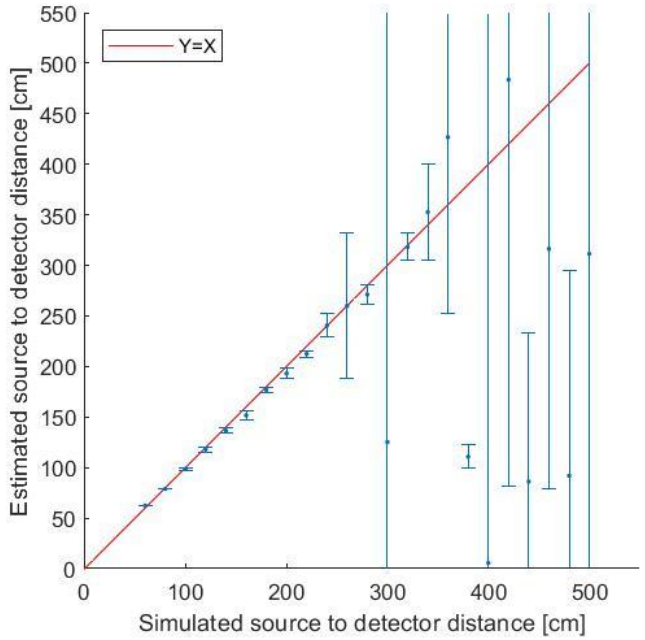


^{241}Am (59,6 keV)

- Decrease the displacement step to 25 cm
- Decrease the dose rate (20 times lower)
  - Increase in uncertainties:
  - ➢ Degradation of the angular resolution due to low count rate and the displacement step.

^{133}Ba

([81, 276, 302 ,356, 383] keV)

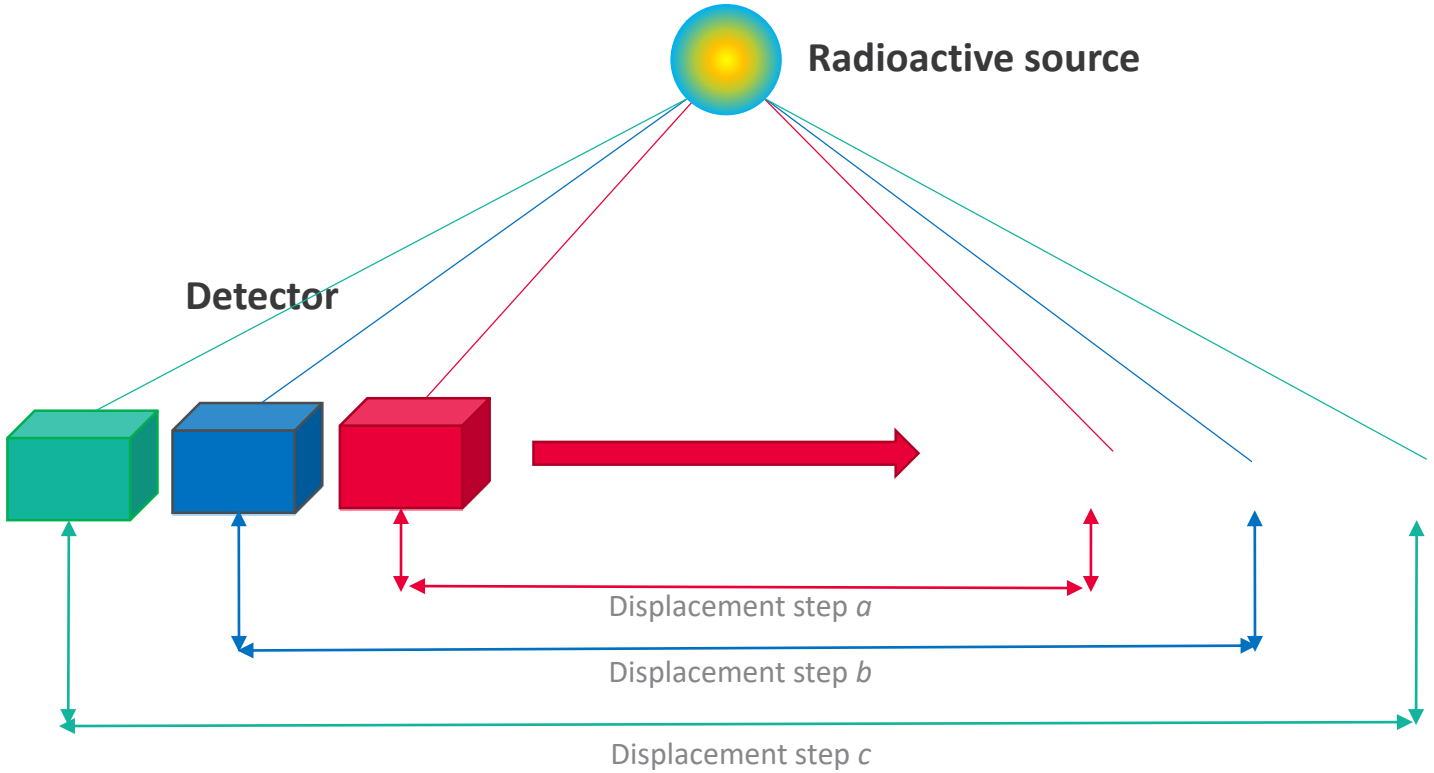


^{137}Cs (662 keV)

Coverage factor **K = 2**

Simulation validation

- **Gamma imaging simulation: results**
  1. Studying the impact of displacement step: FOV* ; triangulation calculations

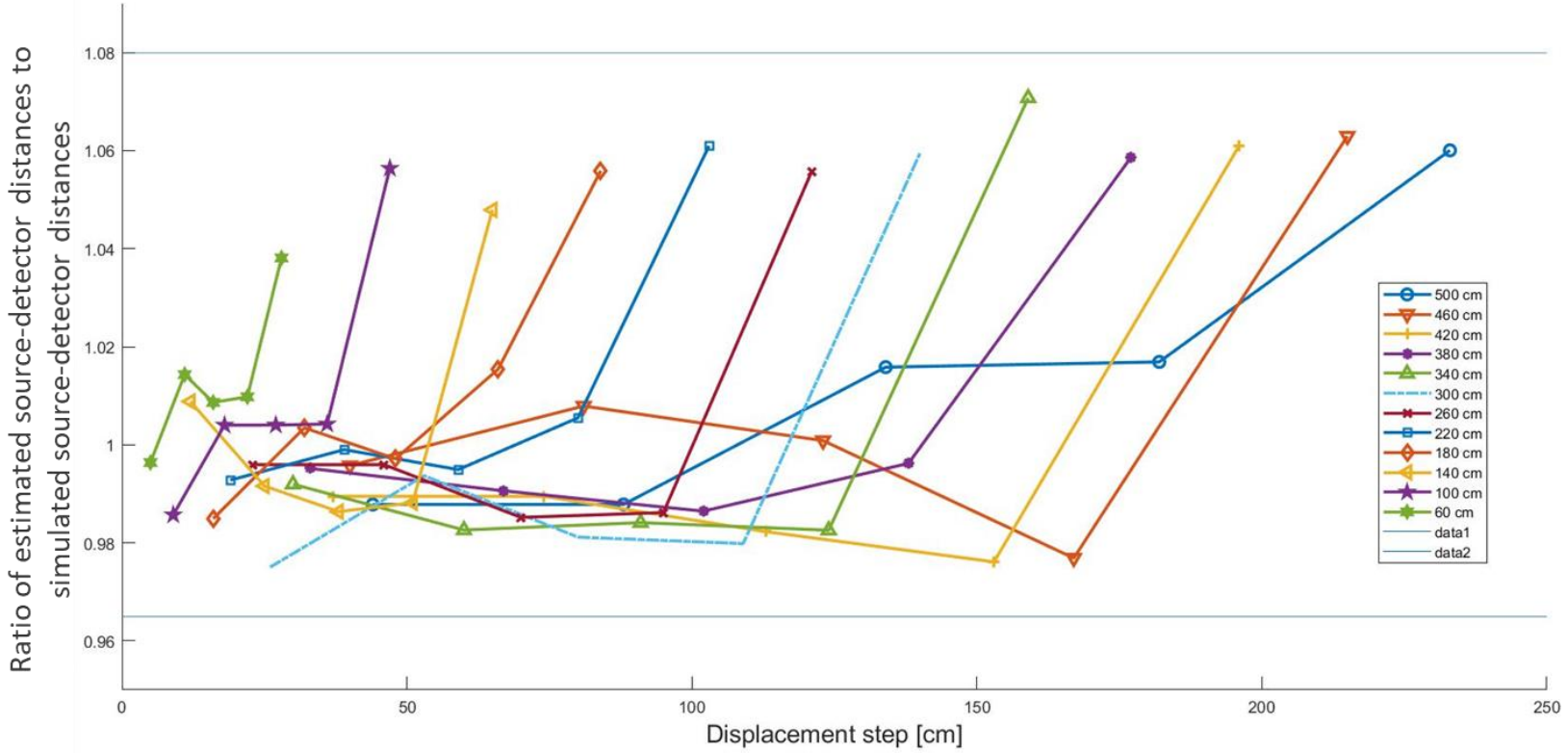


* Field Of View

Simulation validation

- **Gamma imaging simulation: results**
  - Studying the impact of displacement step: FOV* ; triangulation calculations

- Ratios ≈ 1
- Increase with displacement step
- ➢ Degradation of the angular resolution



Evolution of the ratios of estimated source-detector distances to simulated source-detector distances according to the displacement step values.

* Field Of View

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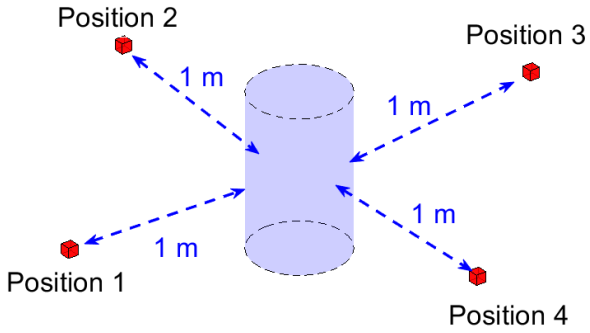
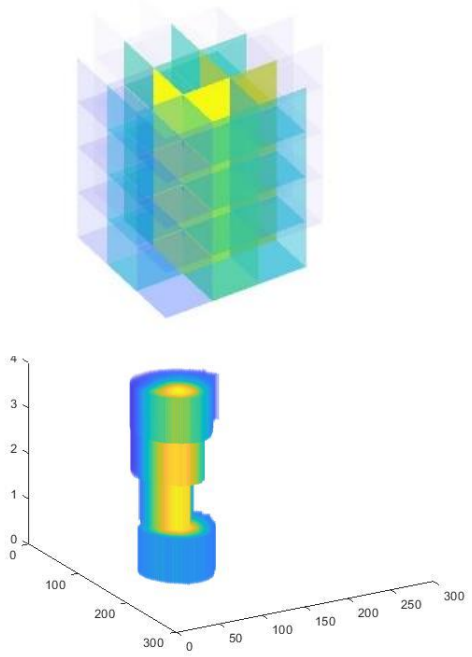
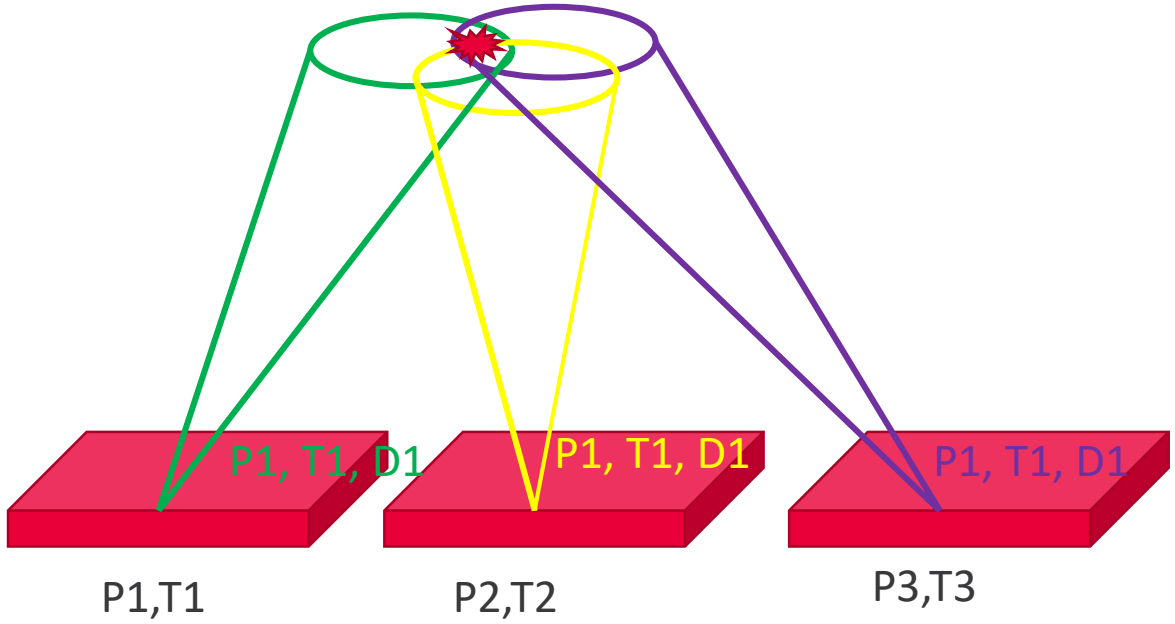
Conclusions and outlooks

- **3D localization using a single gamma imaging system based on a coded-aperture mask using triangulation method**
  - Localization estimated from 60 cm up to 500 cm.
  - Relative uncertainties < 10 % (K = 2).

- **A 3D system based on Compton imaging technique**
- **3D hot spot reconstruction**







Displacement of the detector (position, time, direction)

Thank you !

28/06/2022

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