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New 3D coded aperture collimator for X/gamma-ray wide-field imaging

Yaroslav Susaiev, Vincent Schoepff, Olivier Limousin

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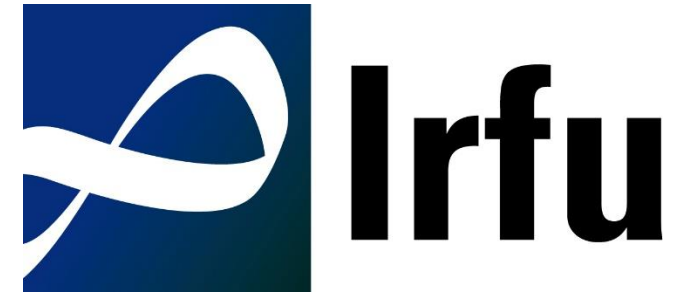
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Talk #07-193

New 3D coded aperture collimator for X/gamma-ray wide-field imaging

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Presented by

Yaroslav Susaiev

yaroslav.susaiev@cea.fr

Supervised by

Vincent Schoepff, CEA List

Olivier Limousin, CEA Irfu



1. Introduction to X/gamma-ray imaging
2. X/gamma-ray imaging with coded masks
3. First 3D coded mask prototype
4. Conclusions and perspectives



Fragment of semicolumn Ionic capital. Rome, Palatine Hill, lower peristyle of Domus Augustana.

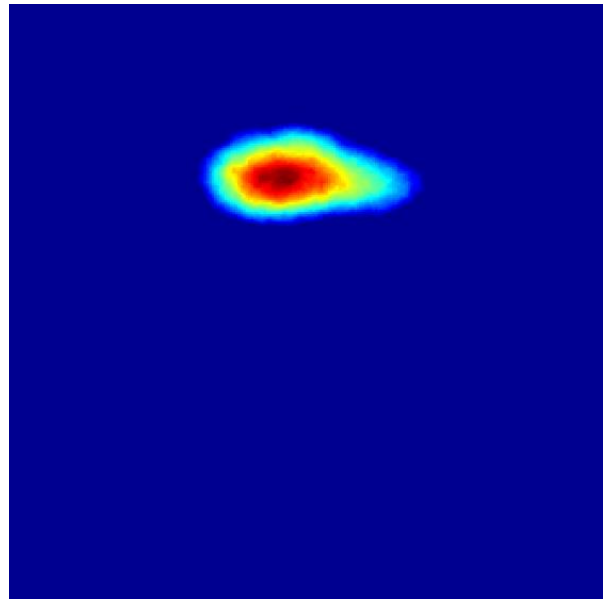
1 Introduction ● to X/gamma-ray imaging

Visualization of the radioactivity

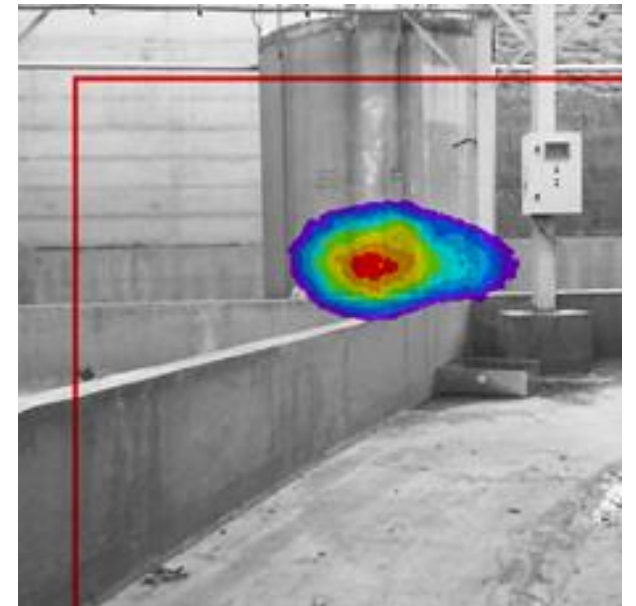
Visible image



Radioactivity image

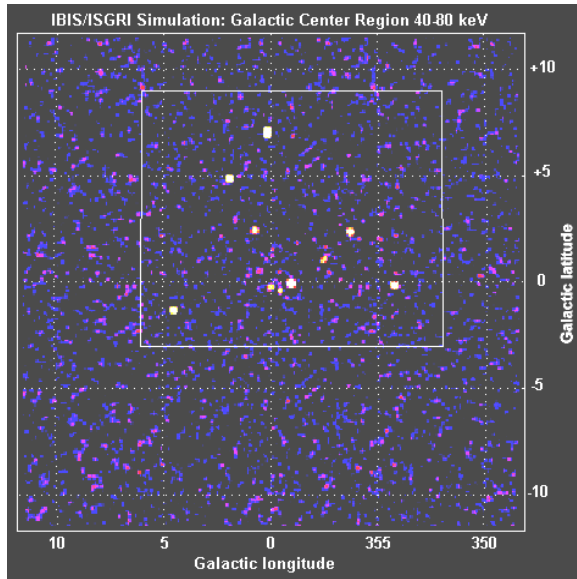


Superimposed image



dose rate, intensity, position in 2D

High-energy astrophysics



Credit: CEA Irfu

Dismantling activities



Credit: S. Le-Couster/CEA

Operational radiation protection

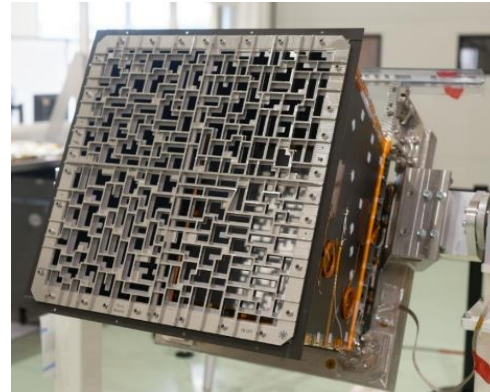


Credit: Regis Duvignau/Reuters

Nuclear security



Credit: Nuclear Engineering International



Credit: CNES/APC/CEA

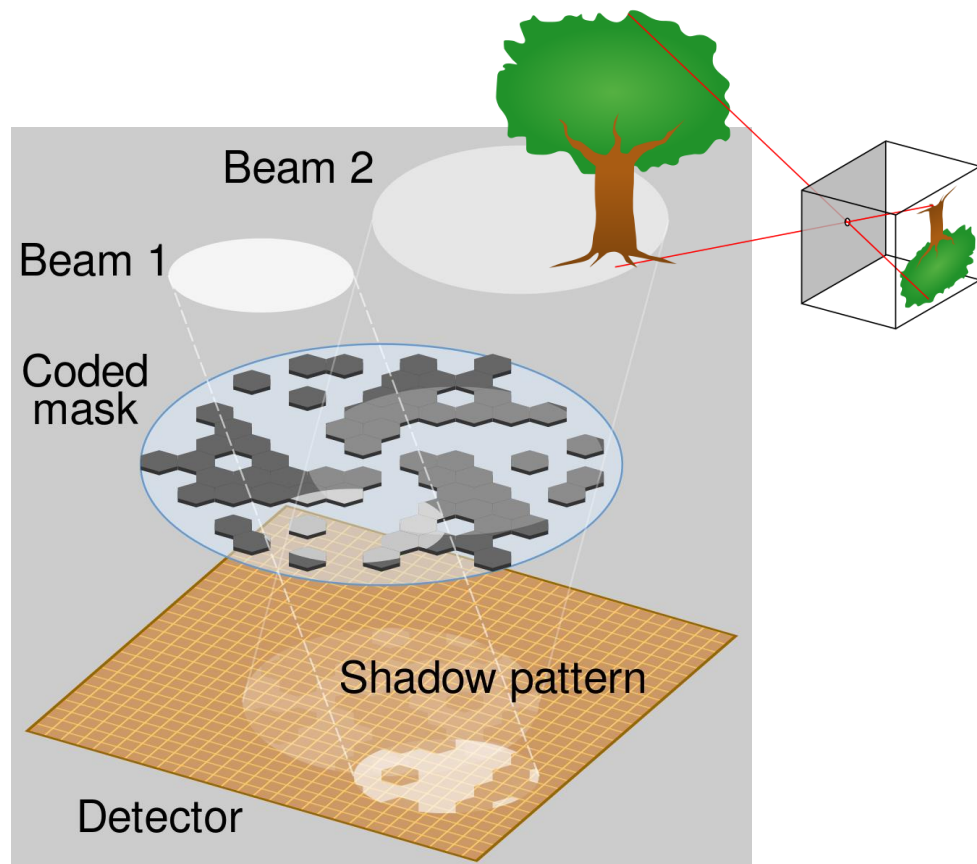


Credit: CEA List

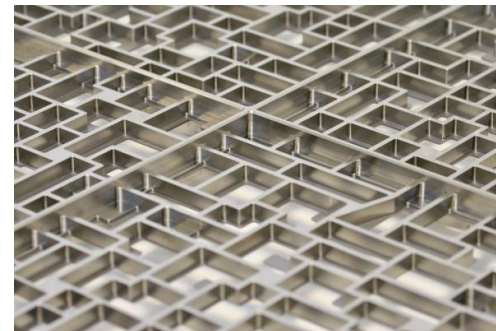
Parameter	Astrophysical applications	Nuclear applications
Energy range	4 keV–20 MeV	60 keV–1.3 MeV
Camera size	>9 m, >100 kg	<15 cm, <2 kg
Structure of the signal	Stable or transient	Usually stable
Signal to noise ratio	Weak signal, strong background	Strong signal, strong background

We address the two investigated applications

2 X/gamma-ray imaging with coded masks



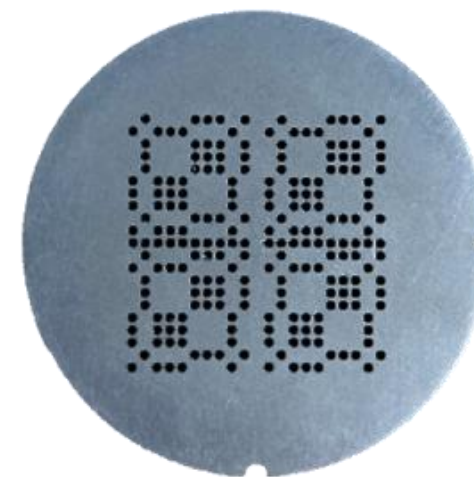
*"HURA hexagonal coded aperture mask principle",
by Cmglee, licensed under CC BY-SA 3.0*



*"Detail of the flight model of the
ECLAIRs instrument's coded mask".
Credit: SVOM@APC*

**Random array
coded masks**

**MURA coded
masks**



*"MURA rank 11 coded mask".
Credit: CEA List*



Credit: Mirion Technologies, Inc.



Credit: NUVIA media library



Credit: CEA List



Credit: 3D PLUS

Parameter	iPIX	NuVISION	Nanopix	SpidX
Camera size	18.9 cm × 9 cm × 9 cm	10 cm × 10 cm × 24 cm	7 cm × 3 cm × 5 cm	32 cm × 16.6 cm × 10.9 cm
Coded mask dimension	1.5 cm	1.5 cm	1.5 cm	4.5 cm
Detection area	1.4 cm ²	4.0 cm ²	1.4 cm ²	1.4 cm ²
Field of view	48.8° × 48.8°	45° × 45°	48.8° × 48.8°	55° × 55°
Angular resolution	2.5° (150 arcmin)	3.5° (210 arcmin)	2.5° (150 arcmin)	1° (60 arcmin)

New generation of 3D coded masks

180° × 180° field of view, sub-degree angular resolution

3 ● First 3D coded mask prototype

Parameters

Geometry

Coded pattern

Dimensions

Thickness (hole width)

Open fraction

First 3D coded mask prototype

Hemisphere

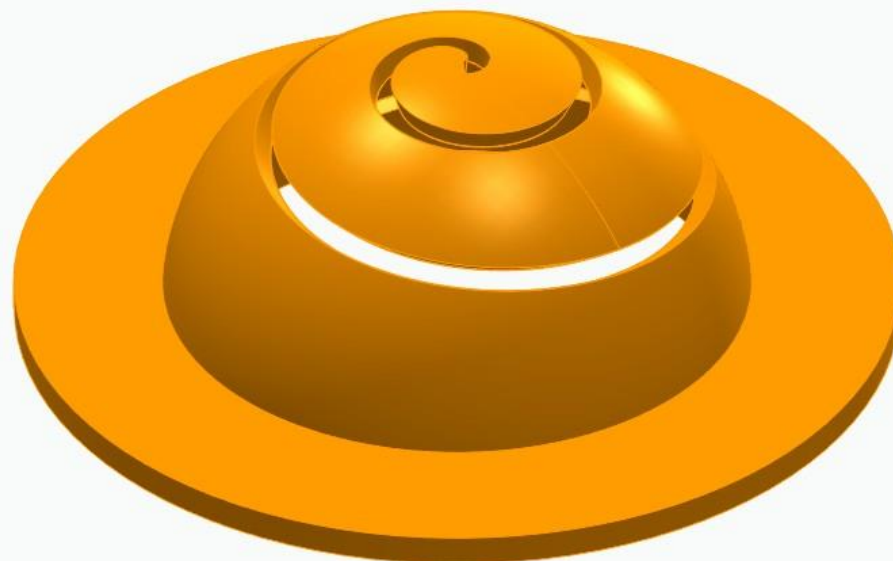
One-arm Archimedean spiral

ø18.75 mm (ø28 mm with shielding)

0.75 mm

10.2 %

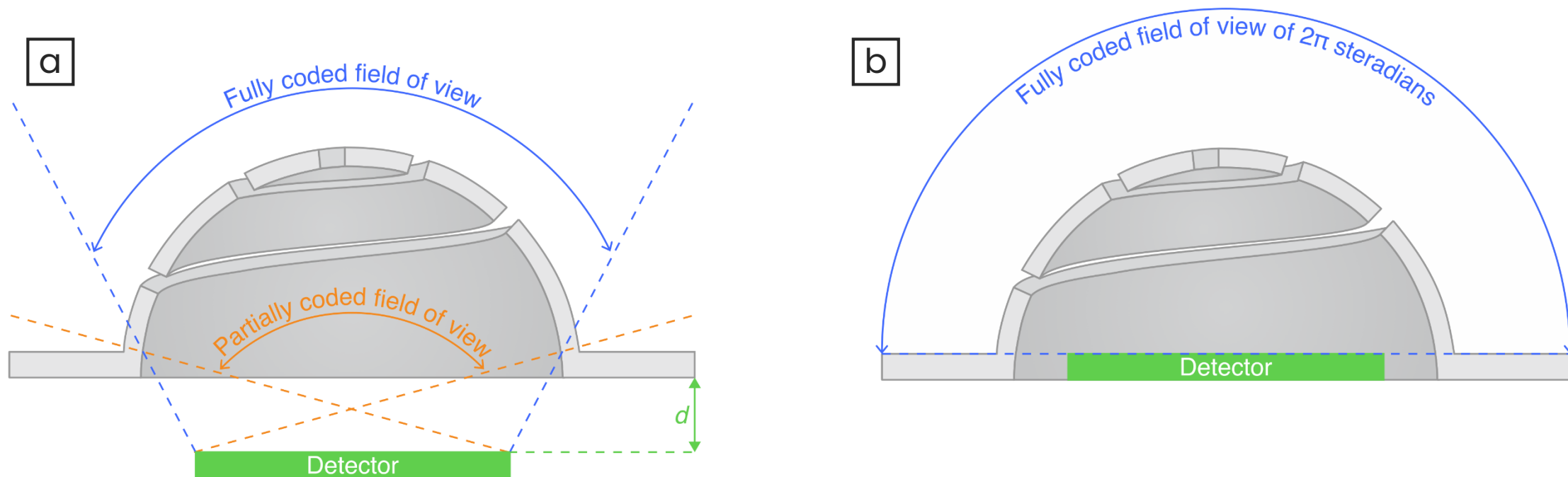
Stainless steel 3D printing



Tantalum machining



Fully coded field of view and partially coded field of view of 3D coded mask imager

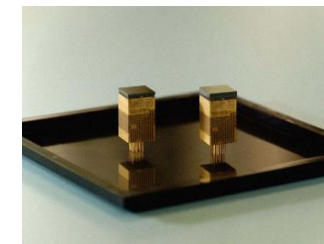


- a. Real configuration: there is a distance $d \neq 0$ between the mask and the detector
- b. Ideal configuration: mask is placed on the top of the detector $d=0$

Our 3D coded mask imagers



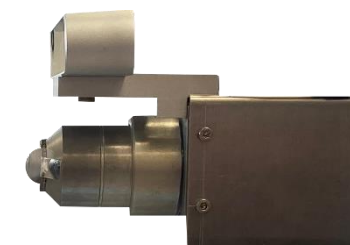
Credit: CERN



Credit: CEA Irfu

Parameters

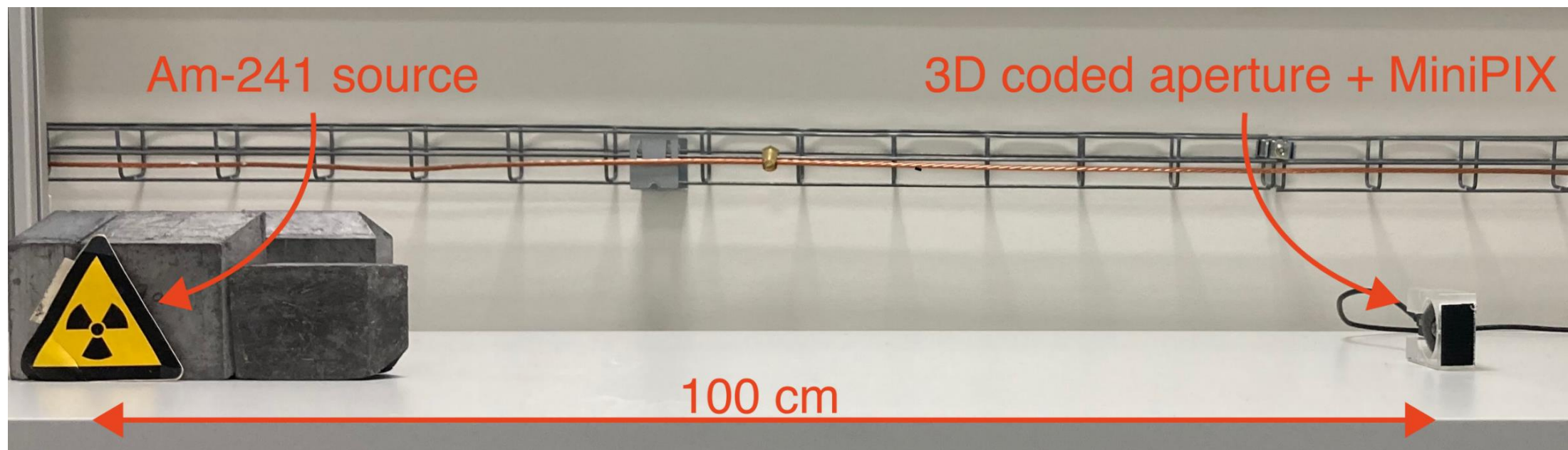
	Timepix3	Caliste-HD
Dimensions	14 mm × 14 mm × 1 mm	10 mm × 10 mm × 1 mm
Pixel resolution	256 × 256	16 × 16
Pixel dimensions	625 μm × 625 μm	55 μm × 55 μm



Parameter

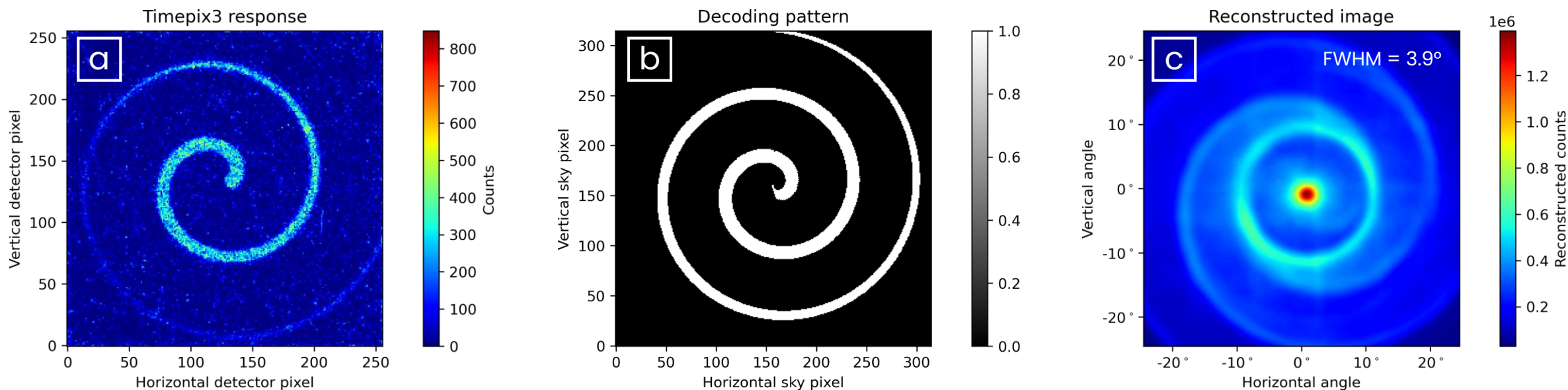
	Timepix3 imager	Caliste-HD imager
Geometrical field of view	154.3° × 154.3°	126.9° × 126.9°
Angular resolution	3.5°	2.8°
Mask-to-detector gap	3.56 mm	6.8 mm

Objective: localization of an Am-241 source placed in front of the Timepix3 imager



- Am-241 activity: 74 MBq
- Acquisition time: 50 minutes
- Source-to-detector distance: 1 m

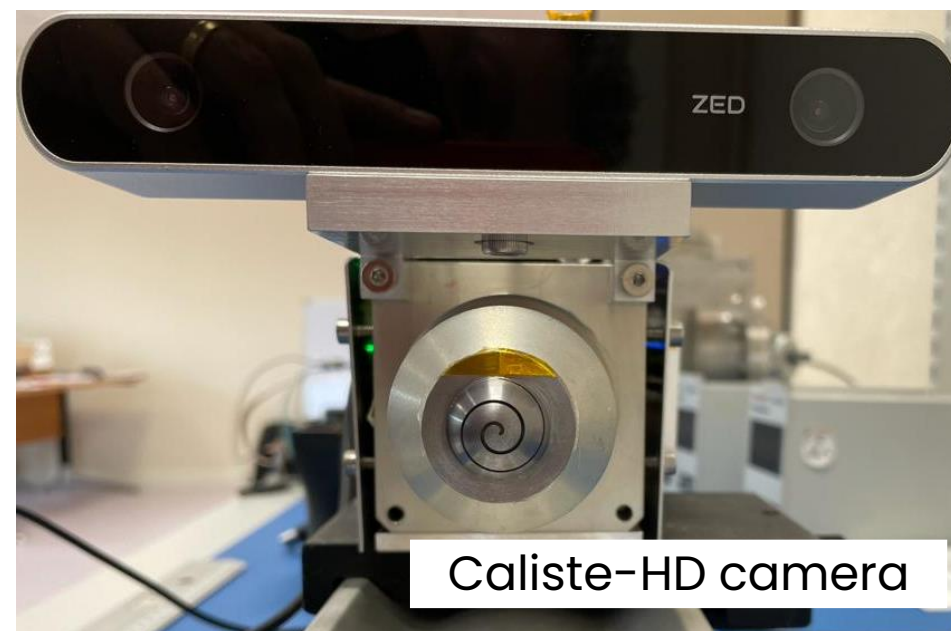
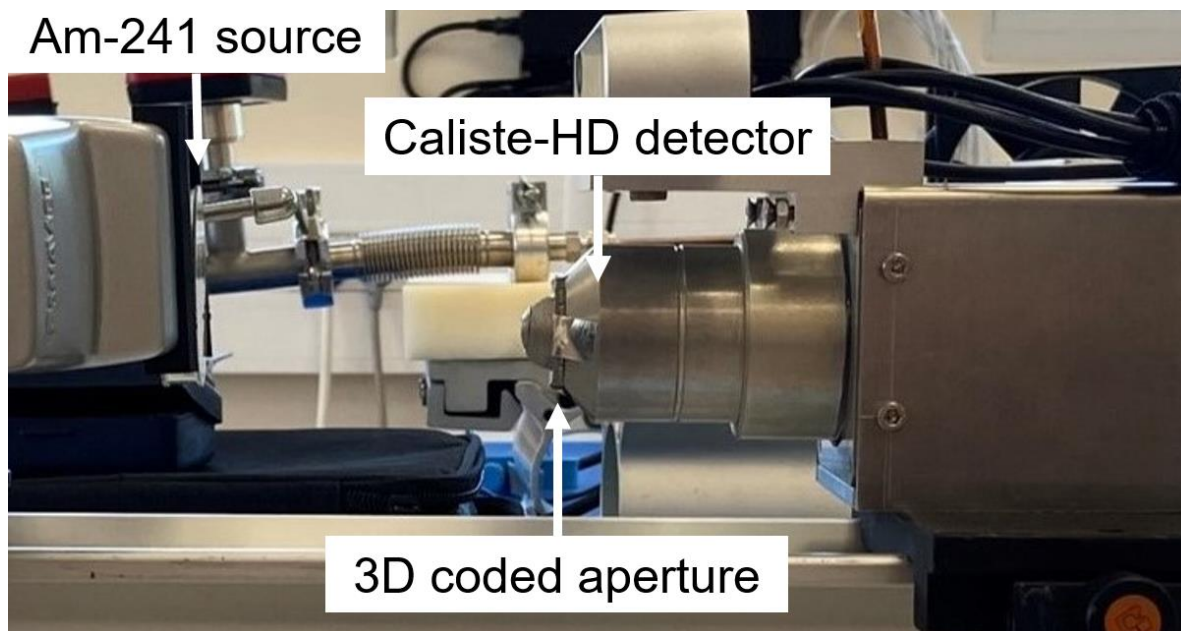
Am-241 (74 MBq) is localized at sky zenith



- a. Raw image from Timepix3
- b. Decoding matrix corresponding to the position of the source
- c. Reconstructed image of the source obtained by the deconvolution algorithm

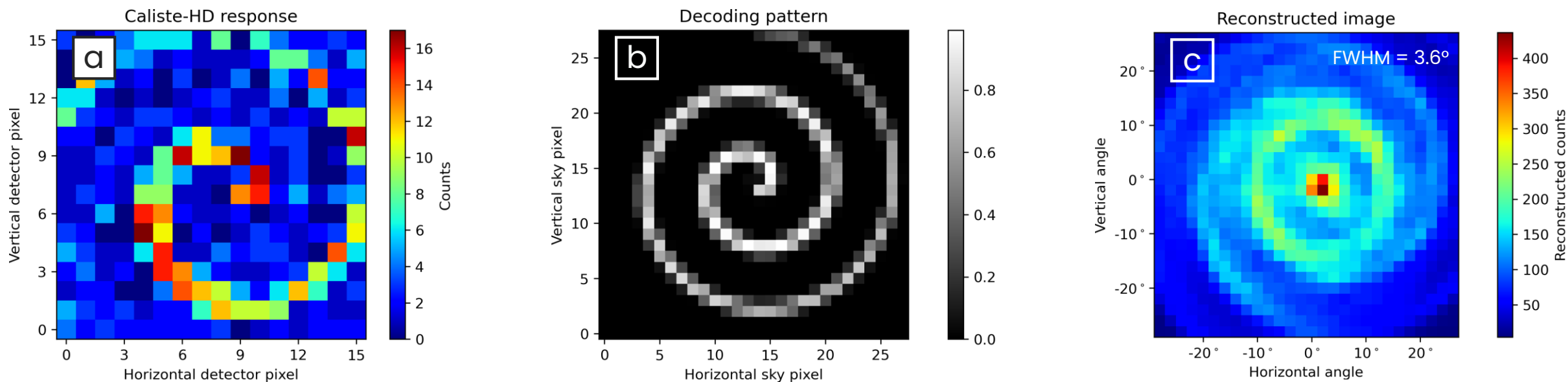
* The sky is discretized with 315×315 positions, with a resolution of 0.2° . Counts upper threshold = $1e+6$.

Objective: localization of an Am-241 source placed in front of the Caliste-HD imager



- Am-241 activity: 400 kBq
- Acquisition time: 1 hour
- Source-to-detector distance: 1 m

Am-241 (400 kBq) is localized at sky zenith

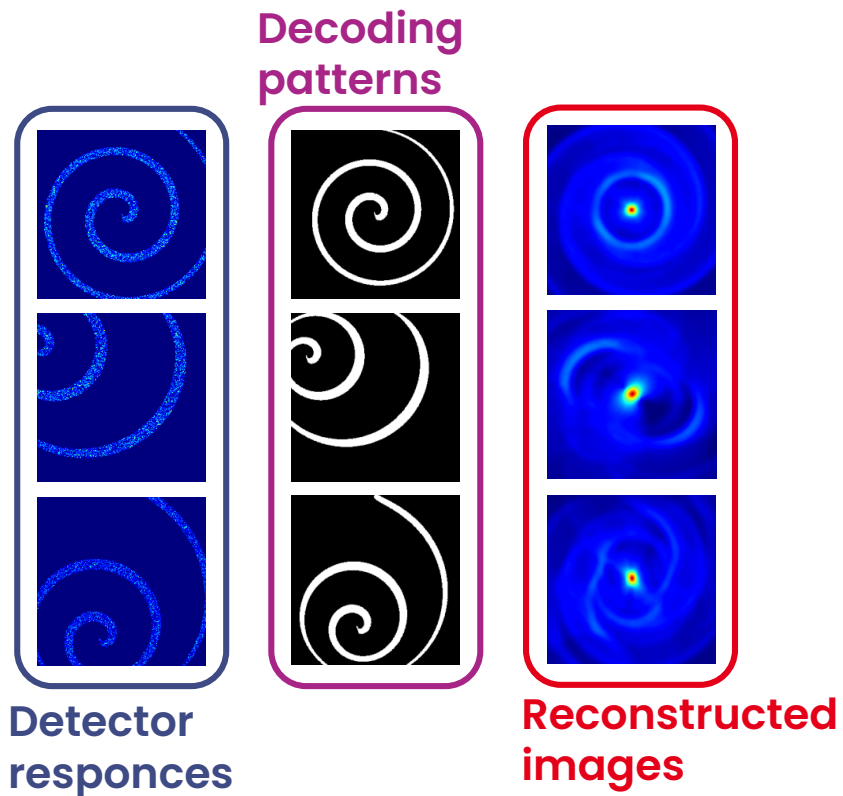


- a. Raw image from Caliste-HD
- b. Decoding matrix corresponding to the position of the source
- c. Reconstructed image of the source obtained by the deconvolution algorithm

* The sky is discretized with 28×28 positions, with a resolution of 1.8°

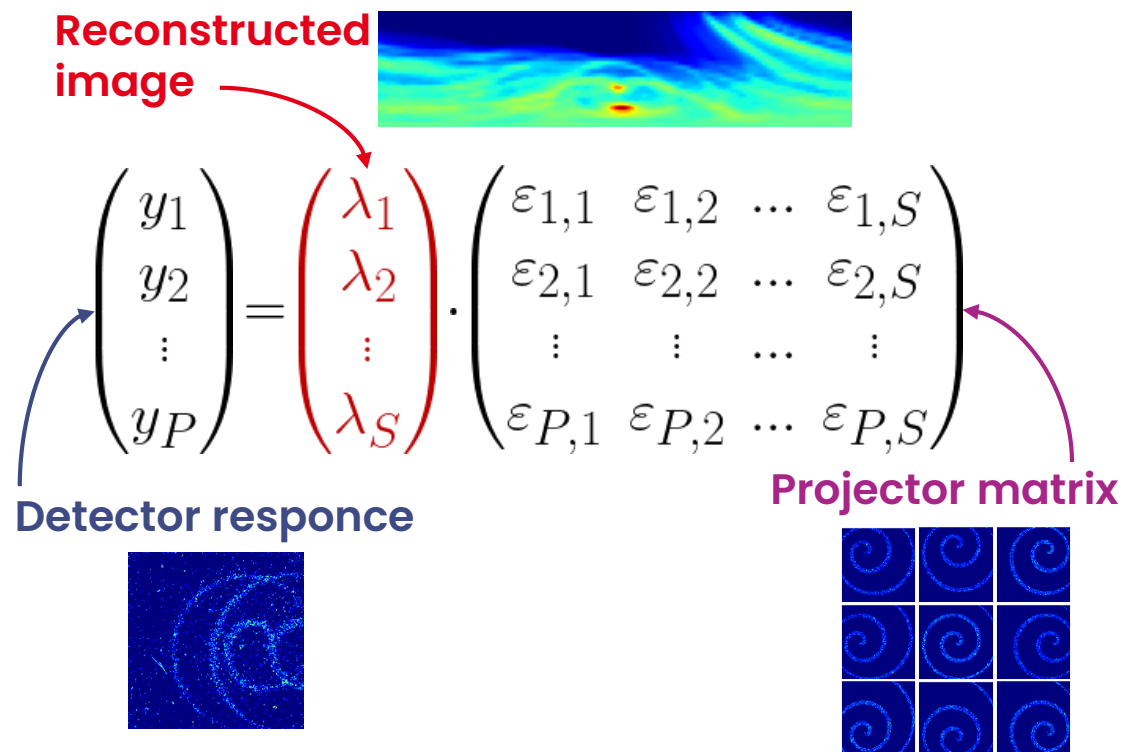
Source oriented deconvolution

Performs deconvolution and reconstructs the source with respect to its position in the sky

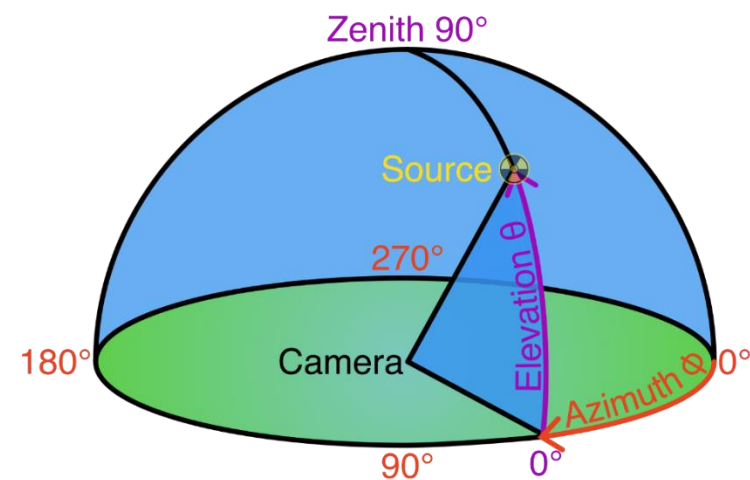
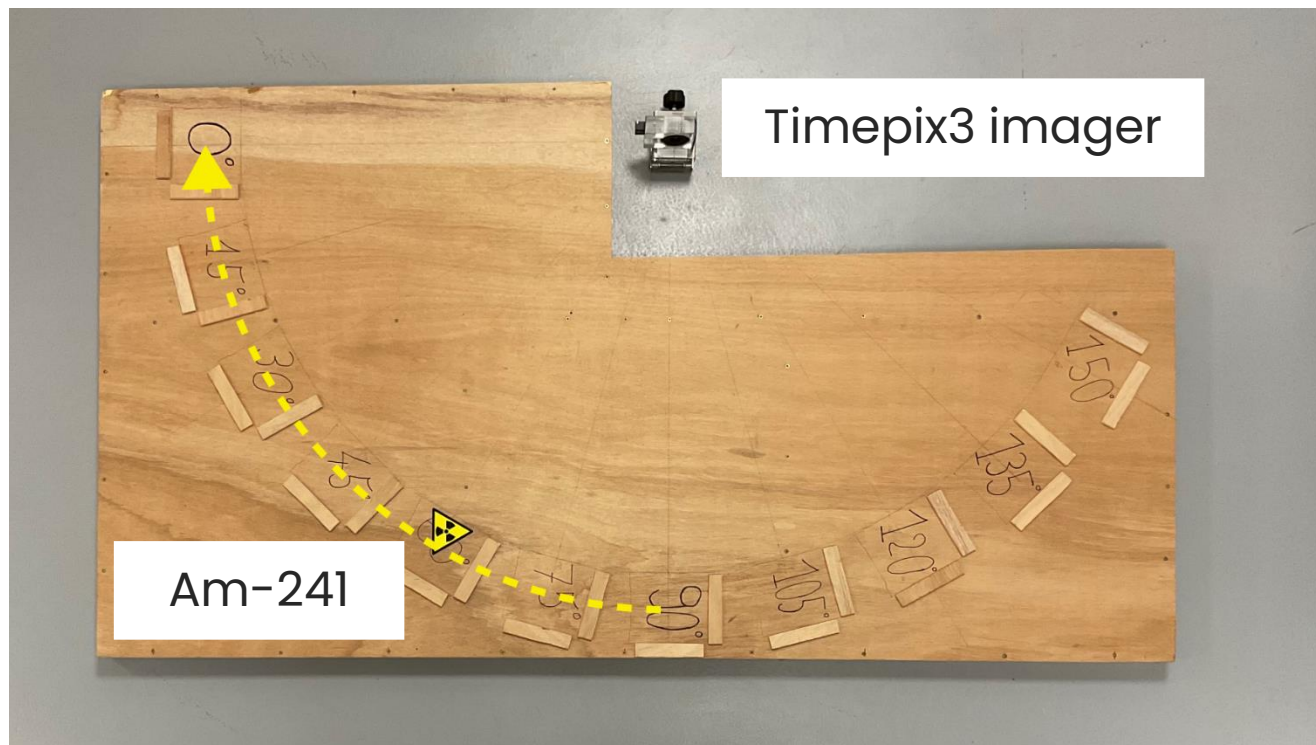


Maximum Likelihood Expectation Maximization

Iteratively estimates the Poisson data to find the optimal reconstructed image



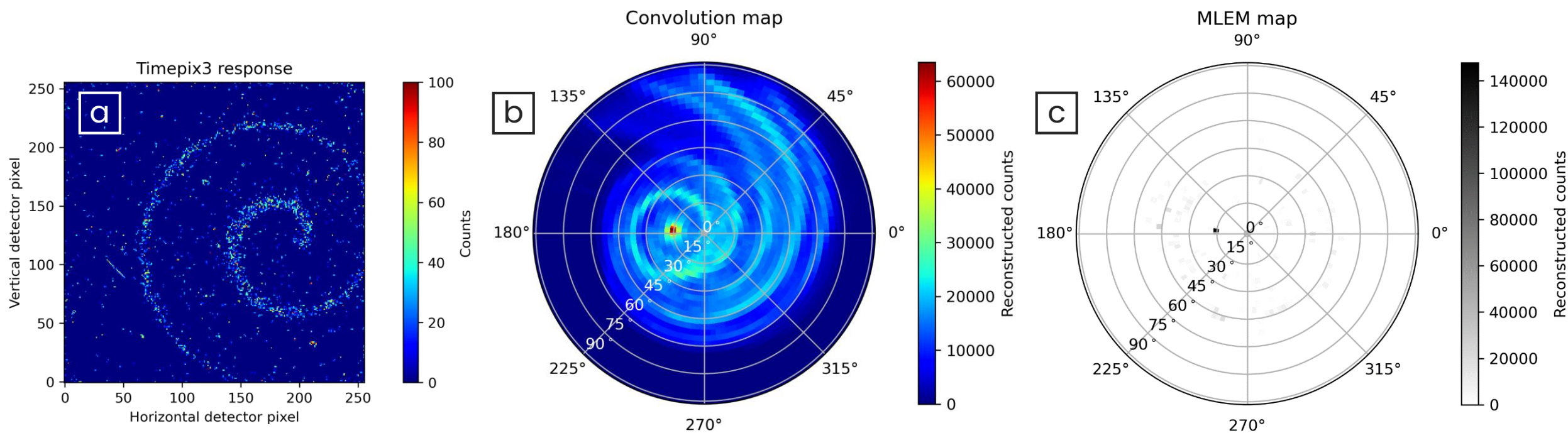
Objective: localization of an Am-241 source off-centered from the sky zenith



Horizontal coordinate system

- Am-241 activity: 74 MBq
- Acquisition time: 100 s (10 frames per second)
- Source-to-detector distance: 80 cm

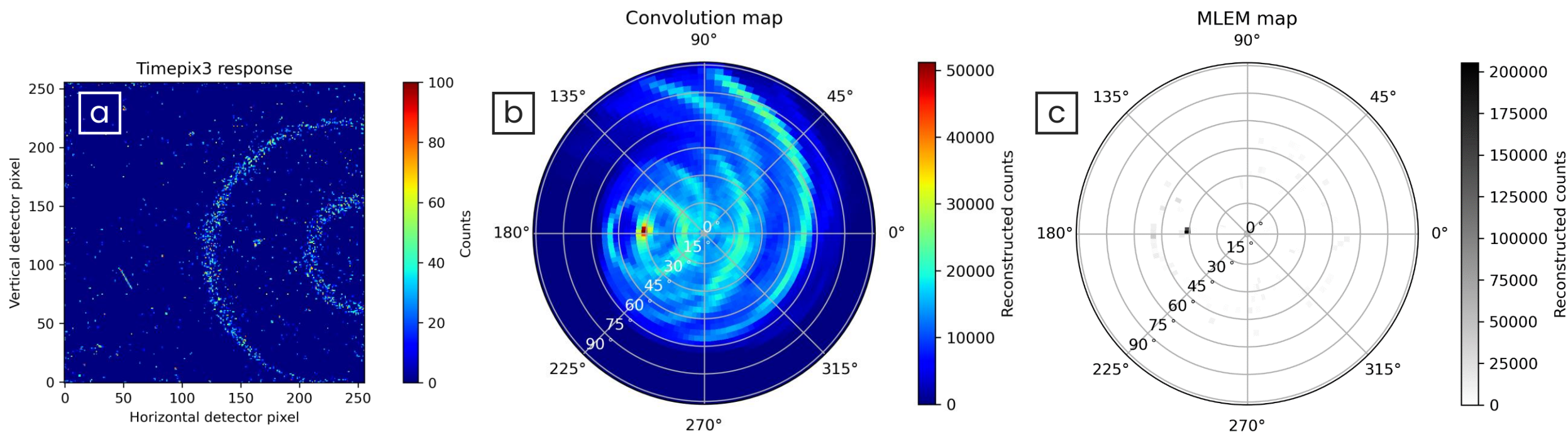
Am-241 (74 MBq) is localized at an elevation of 15°



- a. Raw image from Timepix3
- b. Reconstruction map obtained by the source oriented deconvolution
- c. Reconstruction map obtained by MLEM (100 iterations)

* The sky is discretized with 120×30 positions, with a resolution of 3° . Counts upper threshold = $1e+2$.

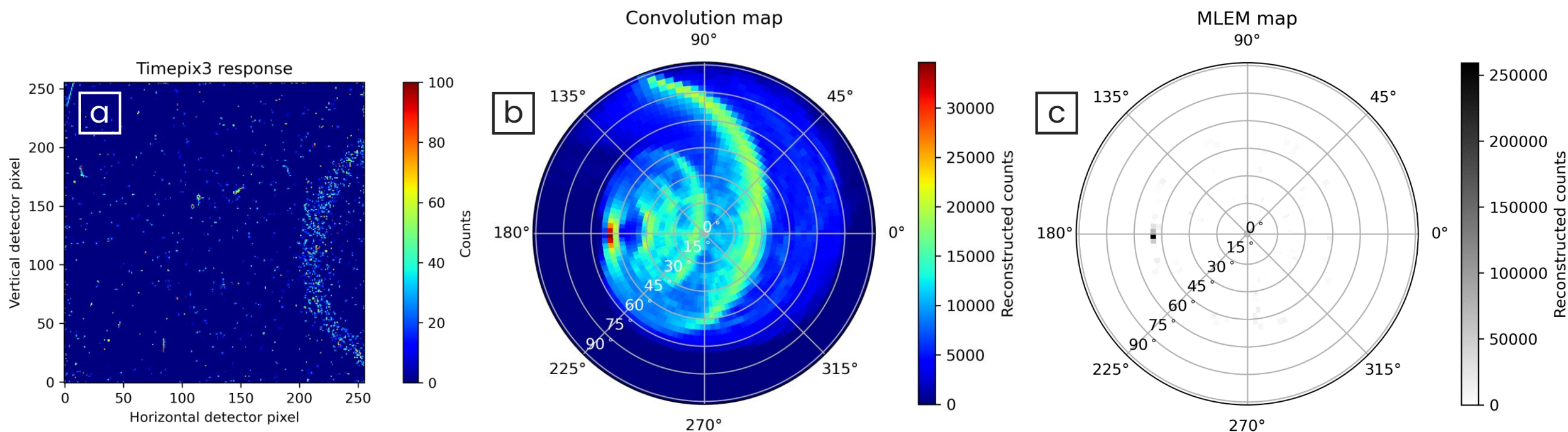
Am-241 (74 MBq) is localized at an elevation of 30°



- a. Raw image from Timepix3
- b. Reconstruction map obtained by the source oriented deconvolution
- c. Reconstruction map obtained by MLEM (100 iterations)

* The sky is discretized with 120×30 positions, with a resolution of 3°. Counts upper threshold = $1e+2$.

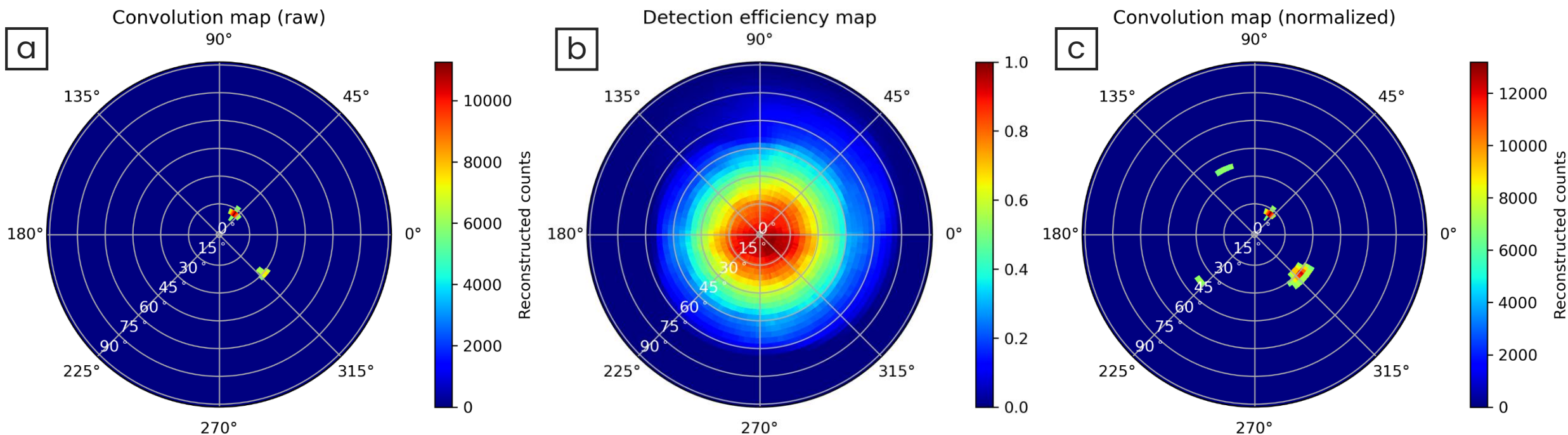
Am-241 (74 MBq) is localized at an elevation of 48°



- a. Raw image from Timepix3
- b. Reconstruction map obtained by the source oriented deconvolution
- c. Reconstruction map obtained by MLEM (100 iterations)

* The sky is discretized with 120×30 positions, with a resolution of 3°. Counts upper threshold = $1e+2$.

Two sources are localized with equal reconstructed intensities



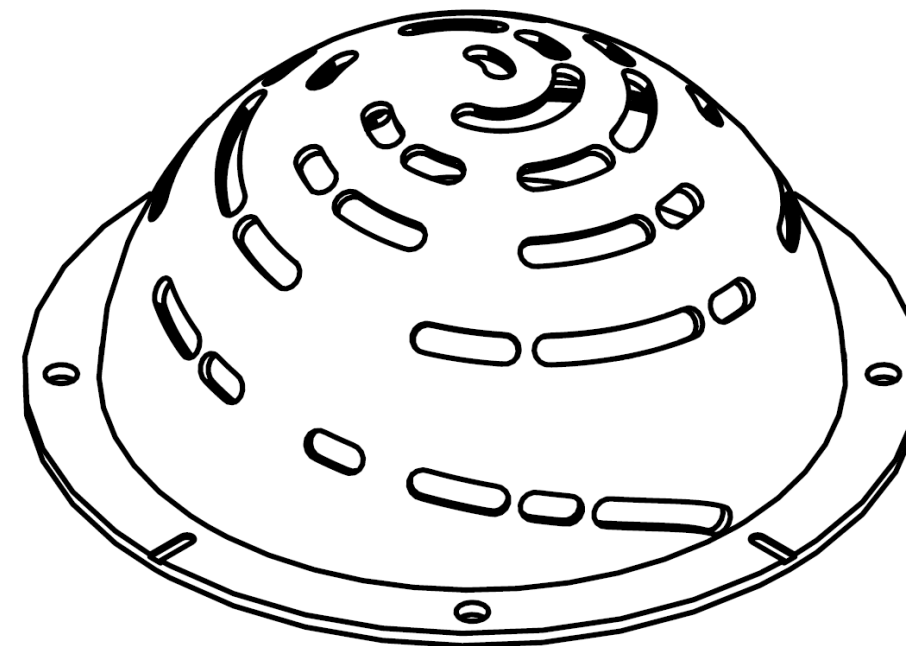
- a. Raw reconstruction map obtained by the source oriented deconvolution
- b. Detection efficiency map
- c. Normalized reconstruction map

* The sky is discretized with 120×30 positions, with a resolution of 3° . Reconstructed counts lower threshold = 50%.

4 ● Conclusions and perspectives

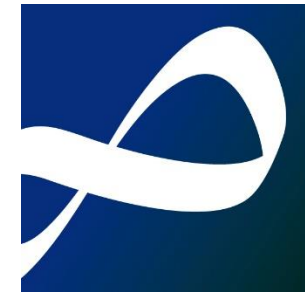
- ✓ The first 3D coded mask prototype is **manufactured** and **characterised**
- ✓ Prototype provides **larger field of view** than usual commercial solutions
- ✓ Standart **decoding algorithms** are **improved** to work with complex mask geometries
- ✓ The second 3D coded mask prototype is **designed** and has been recently **manufactured**

- **Hemispherical geometry**
- **Larger mask dimensions**
resulting in 2π sr field of view
- **Two-arm spiral pattern**
resulting in better sensitivity
- **Linear MURA pattern**
- **“Mask/anti-mask” feature**





list



Irfu

Thank you for your attention!

Yaroslav Susaiev
yaroslav.susaiev@cea.fr

