Spid-X : a portable gamma camera for spectro identification and 2D spatial location of radioactive sources and dose measurement

3rd June 2024

LPSC Grenoble

Abel Vanel, on behalf of the Spid-X team :

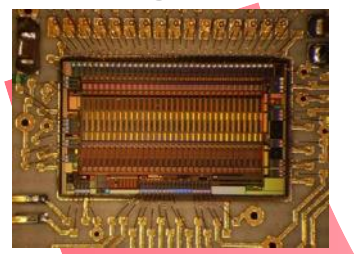
A. Vanel, R. Le Breton, O. Limousin, G. Daniel, D. Diquelou, J.-I. Hullo, V. Mogear, P. Serrano, G. Tauzin, M.-C. Vassal, V. Lepeltier, M. Potigon, M. Alvarez Gomez, D. Suplisson

1. Introduction

From Astrophysics to the Nuclear Industry

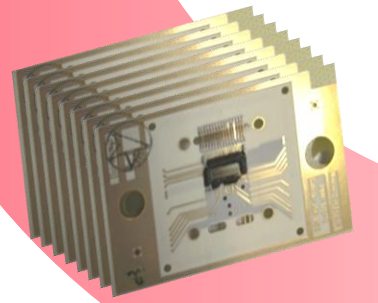
Caliste
Hybridization Technology

IDeF-X HD ASIC
32 analog channels

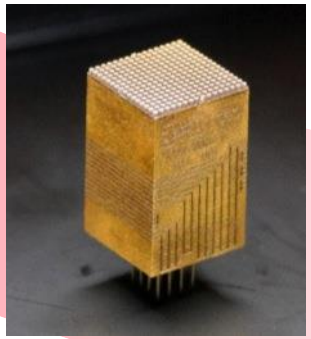


Mounting on PCB

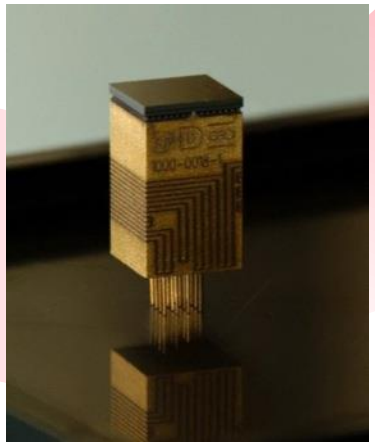
8 ASIC stack perpendicular to the detection surface



Top surface preparation

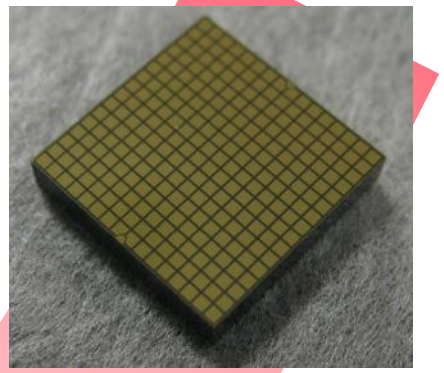


Electrical body
with a 16 x 16 pin grid array



Caliste camera

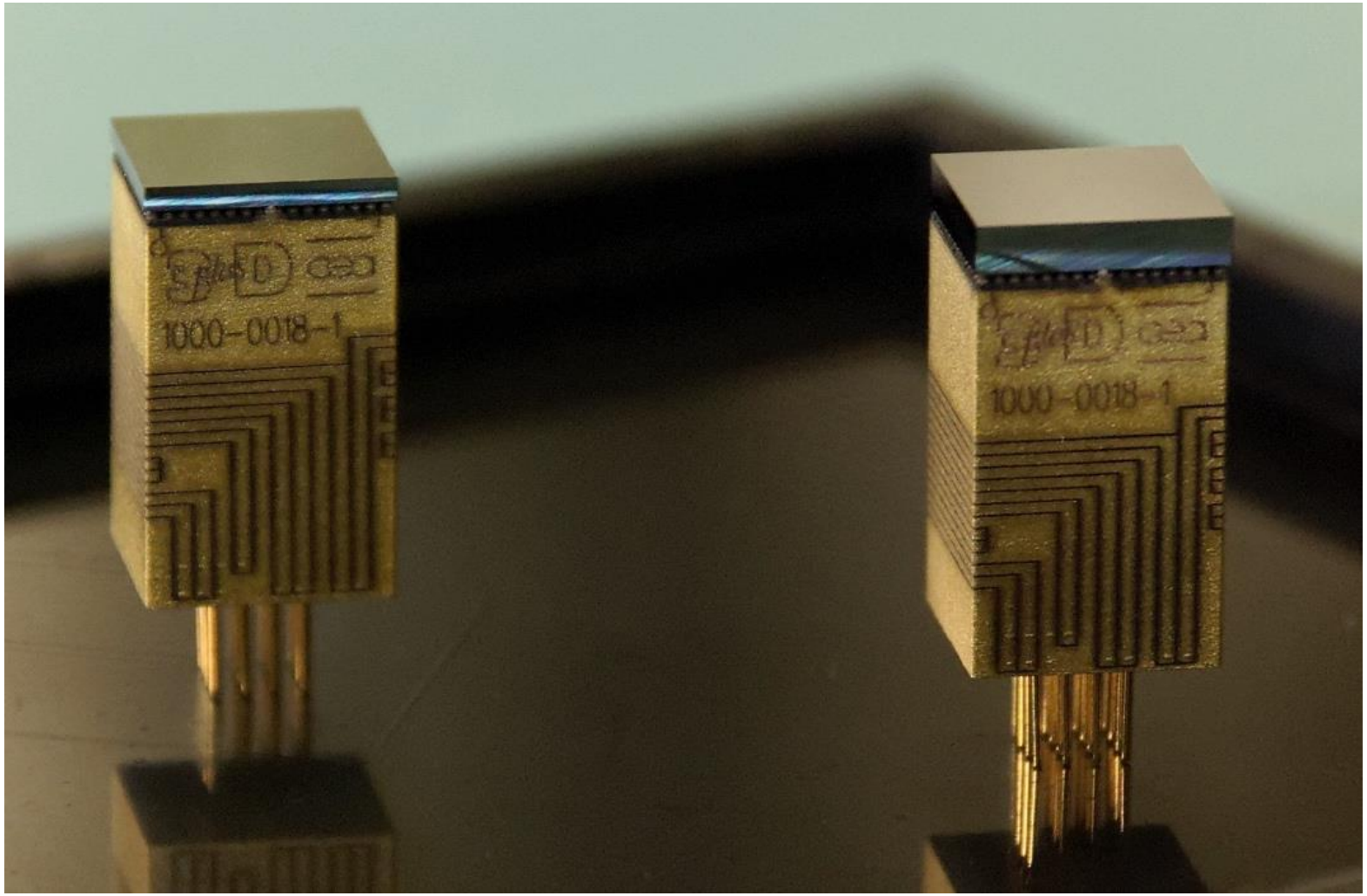
CdTe 256-pixel detector
(pixel pitch, thickness, Al Schottky)
+
(Pt entrance electrode)



Assets of CdTe :

- High Z and High density
- High resistivity
- Pretty low pair creation energy
- Easy to procure in Space grade

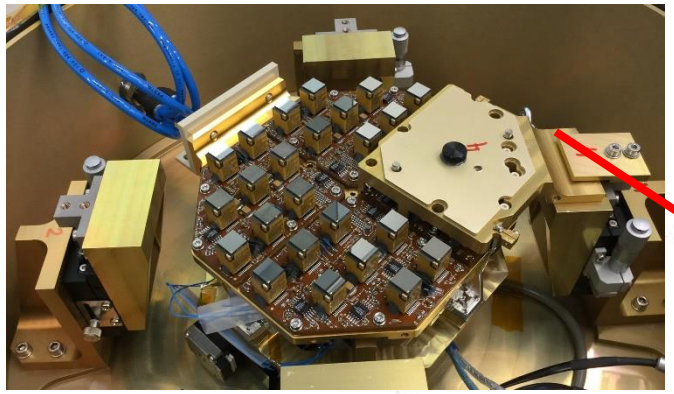
Fully assembled Caliste
(Two different CdTe thicknesses)



~1.5 cm

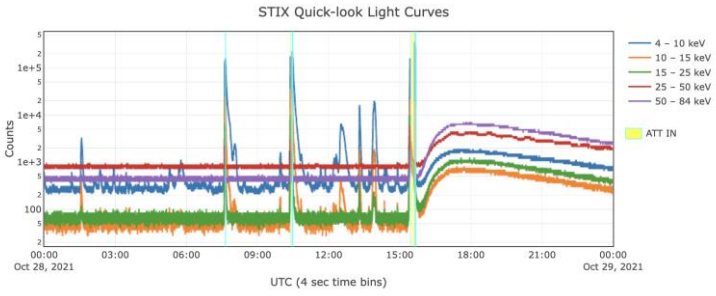
Hard X-ray imaging Spectrometer STIX : Caliste-SO onboard Solar Orbiter
STIX has been operational almost continuously since 2021 (launch in 02/2020)

STIX investigates solar flares by providing diagnostics of the hottest (>8 MK) flare plasmas and flare-accelerated electron above (>10 keV).



DEM
Detector Electronics Module

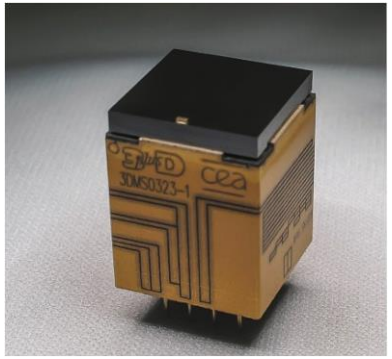
Energy range	4-150 keV
Angular resolution	7” to 180” (INTEGRAL was 10 arcmin)
Spectral resolution	~1 keV @ 6 keV
Time resolution	down to 0.1 s
FOV	2ºx2º



From Astrophysics to the Nuclear Industry: the ALB3DO laboratory

- **Severe nuclear accident:** analysis
- **Nuclear safety and facility:** monitoring
- **Nuclear power plants :** Dismantling and decommissioning
- **Operational radiation:** protection
- **Nuclear waste:** management

ALB3DO Astro to Industry = cea irfu + 3plusD a HEICO company



Caliste-O: industrial grade

+

Need for a versatile and mobile device for nuclear applications:

- Spectrometry → Identification
- Imaging → Localisation
- Dosimetry → Dose rate

=

Spid-X !

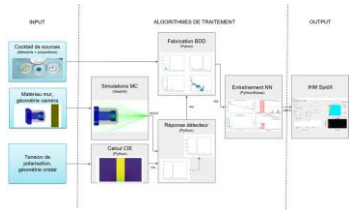
2. The Spid-X gamma camera

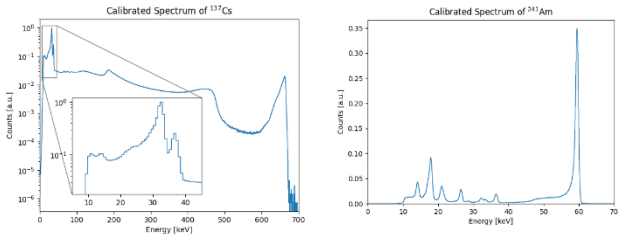
In a nutshell

Spid-X in a nutshell

Spectrometry

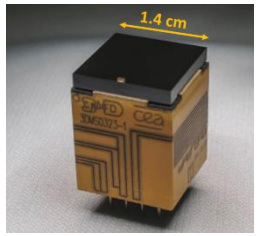
Artificial Intelligence
Automatic Identification



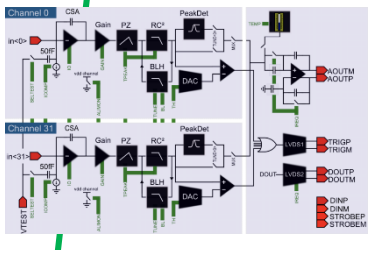


Hardware

3D PLUS Technology
Caliste-O



ASIC Idef-X



- Photon by photon counting
- Data saving (FITS)

Dedicated ‘HMI’ software

Dosimetry :

- At the level of Spid-X
- Distance (on-going)
- Intrinsic sources activity (on-going)

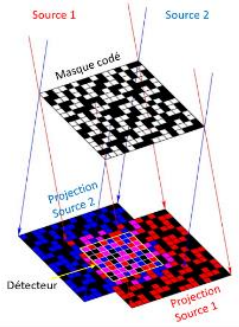
Other functionalities

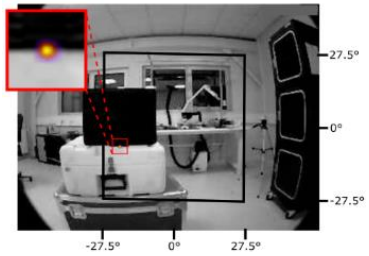
- Autonomous (batteries)
- Portable (~3kg)
- Wi-Fi

Localisation / Imaging

Point and extended sources

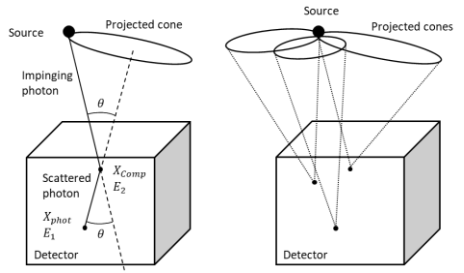
Coded mask (E < 250 keV)

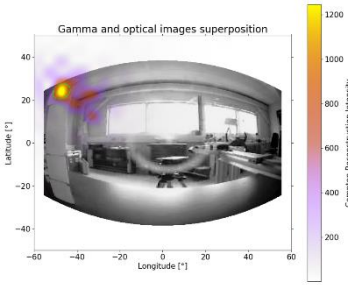




+ Artificial Intelligence

Compton (E > 250 keV)





+ Artificial Intelligence

Spid-X principle diagram

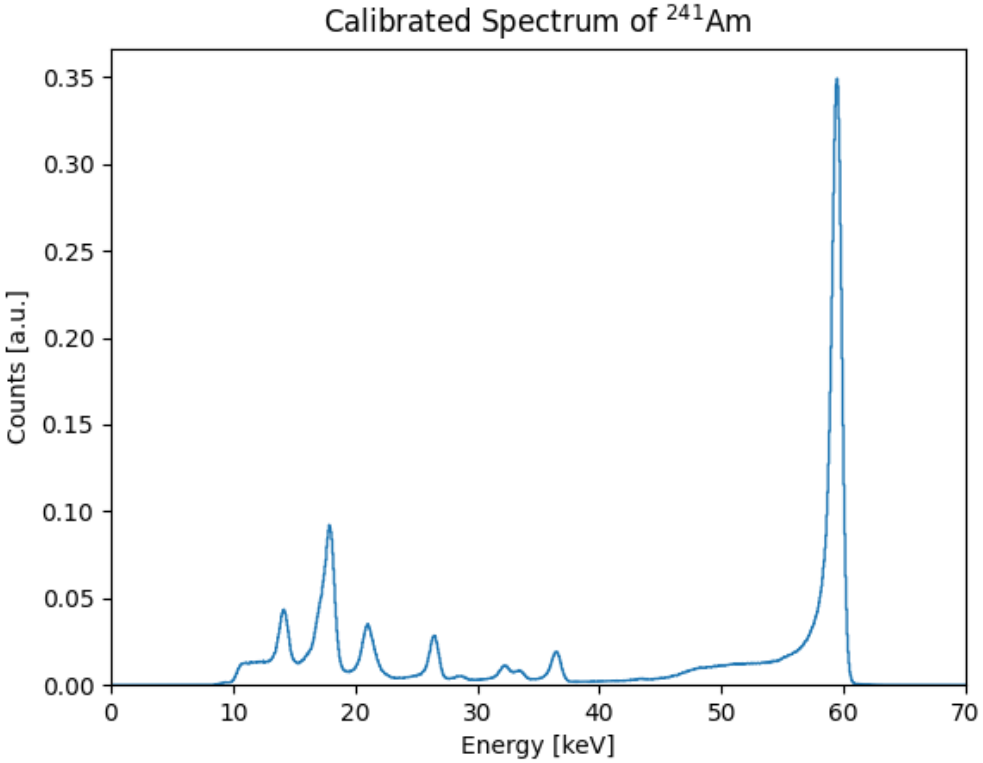
Spid-X DEM-2

3. Laboratory performances

Highlights

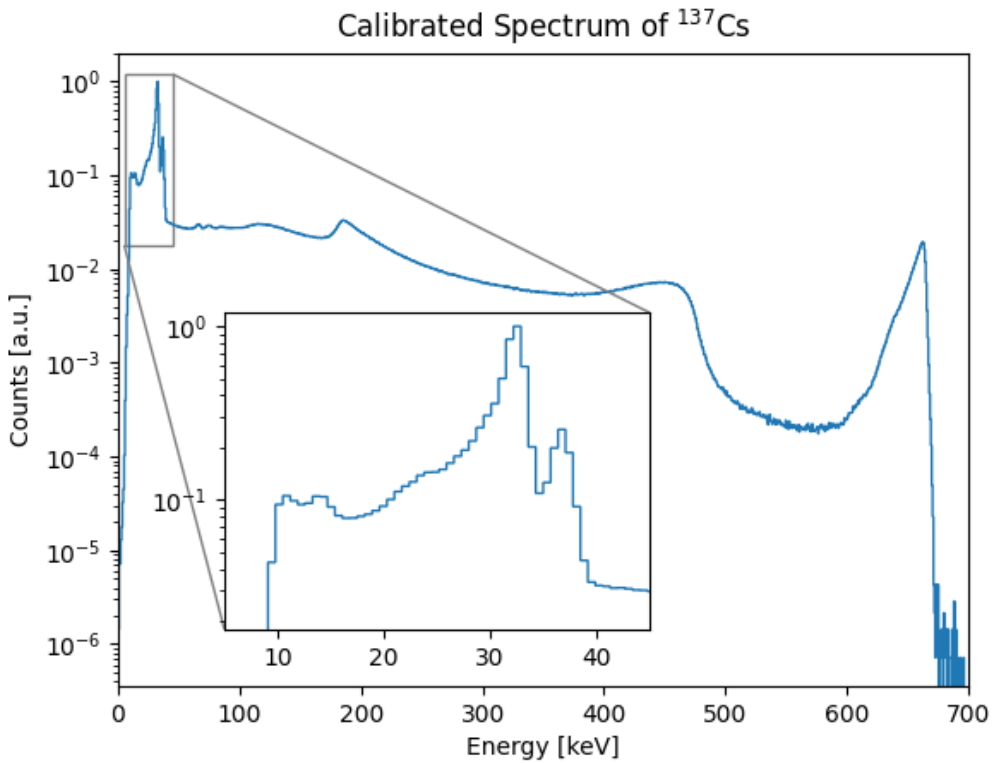
Spectrometry

Calibrated spectra - 256 pixels – Single events



Resolution at 60 keV:

- FWHM : (949 ± 3) eV (1.6%)
- Right side : (895 ± 1) eV (1.5%)
- Best Pixel FWHM : (750 ± 30) eV (1.3%)



Resolution at 662 keV:

- FWHM : (10.2 ± 0.5) keV (1.5%)
- Right side : (4.6 ± 0.1) keV (0.69%)

Automatic identification

Sensitivity tests, in less than 1 min, on axis, and without obstacle :

- **^{241}Am, 407 kBq :**
  - 1 m (1.5 nSv/h)
- **^{137}Cs source, 3.39 MBq :**
  - 1.75 m (83 nSv/h).

Localisation of multiple source in the same scene

In this example : identification in less than 1 min for the two sources, localisation of both in 27 minutes

4. First in-situ measurements

Results and associated performances

Two in-situ locations

01

DOSIMETRY CALIBRATION FACILITY

- 12/2022
- Spid-X DEM-1 V2
- ^{241}Am, ^{60}Co and ^{137}Cs sources available
- First in-situ tests:
  - Background measurement
  - Dosimetry Calibration
  - Automatic spectro-identification
  - Imaging
  - Time resolution and moving source

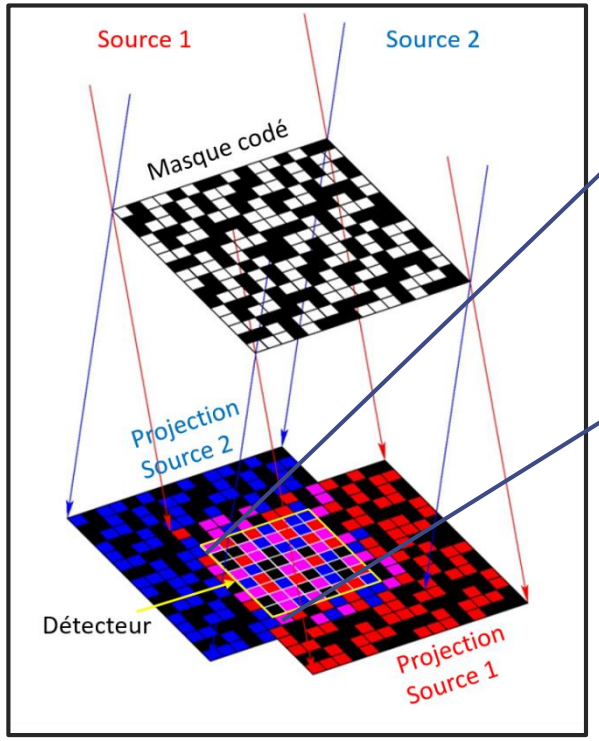
02

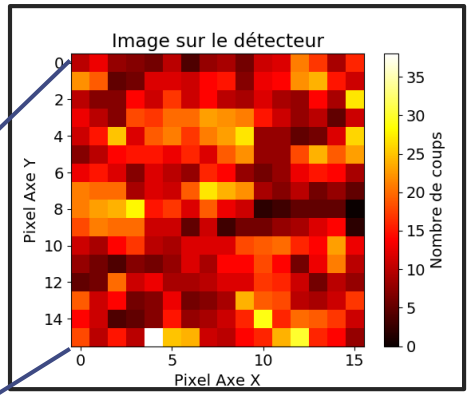
NUCLEAR WASTE MANAGEMENT FACILITY

- 04/2023
- Spid-X DEM-1 V3
- Nuclear waste barrel analysis
- ^{152}Eu and ^{241}Am sources avalaible
- Stress tests in unknown conditions:
  - Imaging
  - Identification

Backgrounds :
~10 times higher (in dosimetry) than in our lab.

Coded mask imaging





Observation $\boldsymbol{Y}$

Coded mask $\boldsymbol{M}$

ε: unknown noise

Position(s) of the source(s) → $\boldsymbol{X}$

Problem to solve

$$\boldsymbol{Y} = \boldsymbol{M}.\boldsymbol{X} + \boldsymbol{\varepsilon}$$

- Classical MLEM method: point source(s) OK
- Artificial Intelligence : for multiple and extended sources

Automatic identification and Coded mask imaging

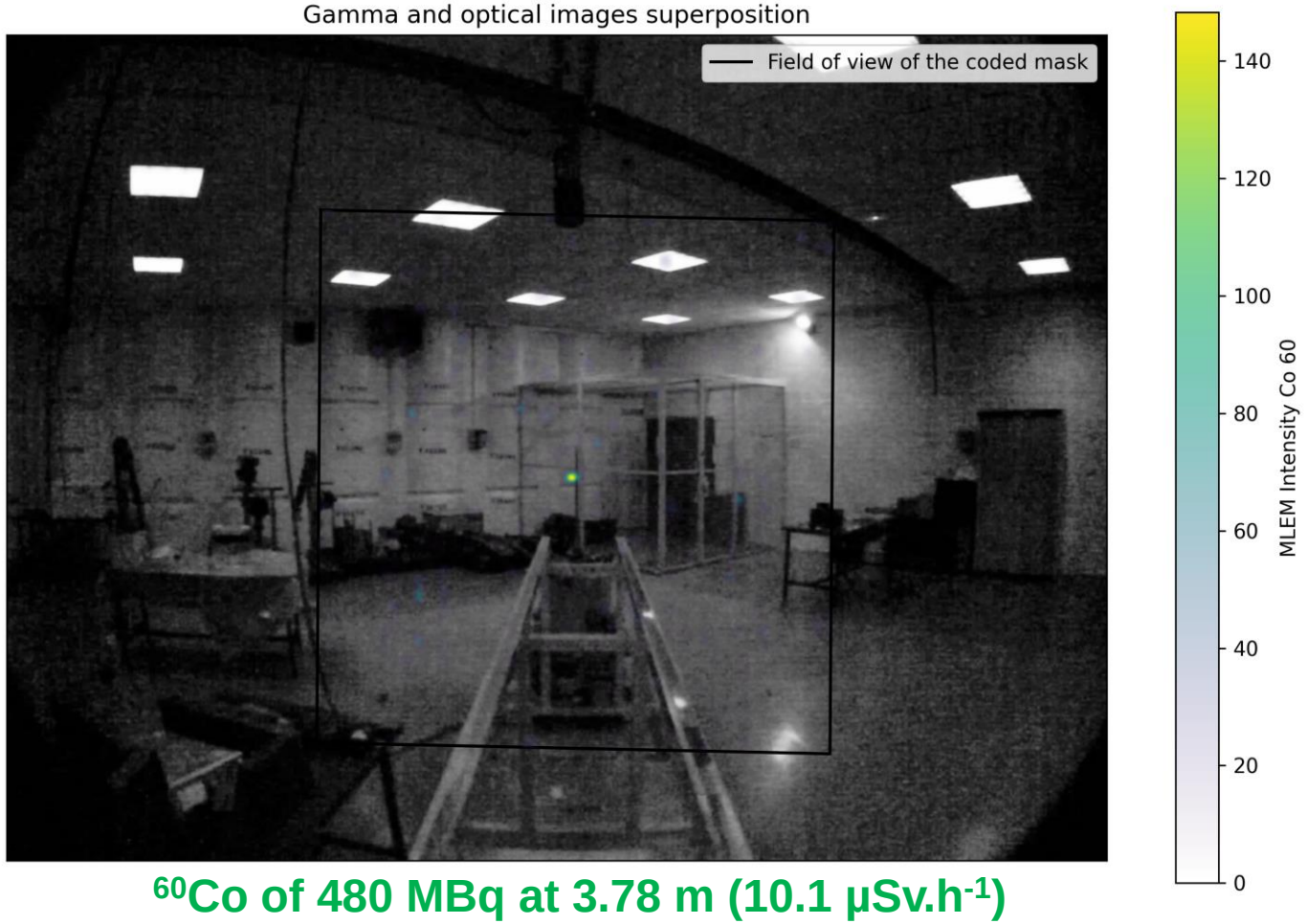
Sources available :
- **^{60}Co:** 0.48 GBq and 46.19 GBq
- **^{137}Cs:** 1.48 GBq and 1.46 GBq
- **$^{(241)}$AmBe:** 49.82 GBq

Coded mask imaging:
- **FoV:** 55°
- **Accurate (1°)** in all studied cases, with 1 or 2 sources in the coded mask field FoV

Identification :
- No absorber between the source(s) and Spid-X.
- **Accurate** in all simple cases, with 1 or 2 sources in the room

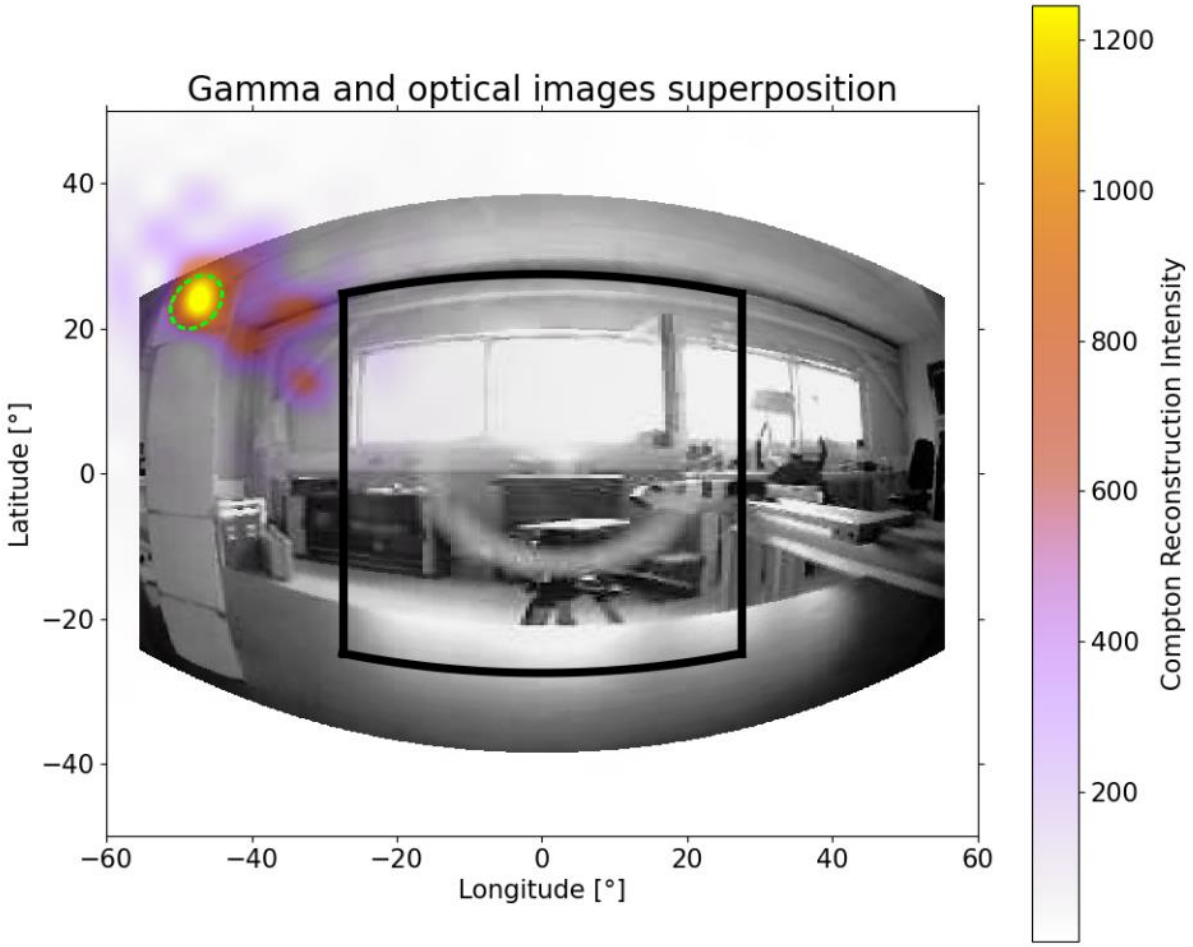
Acquisition **Maximum Likelihood Expectation Maximization**

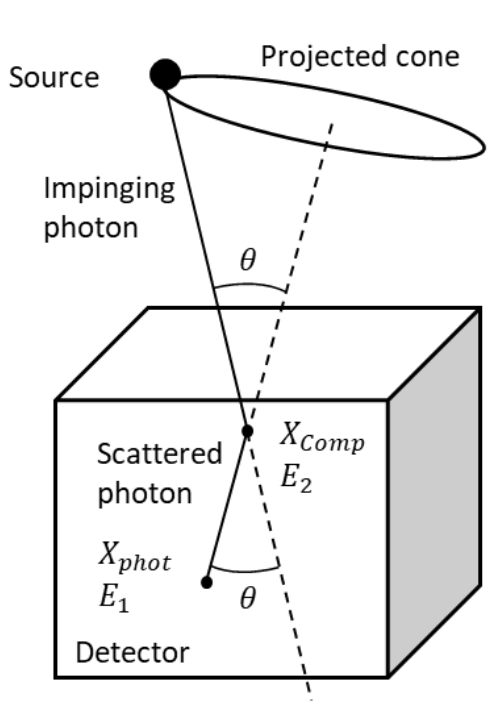
10 minutes – No MLEM threshold

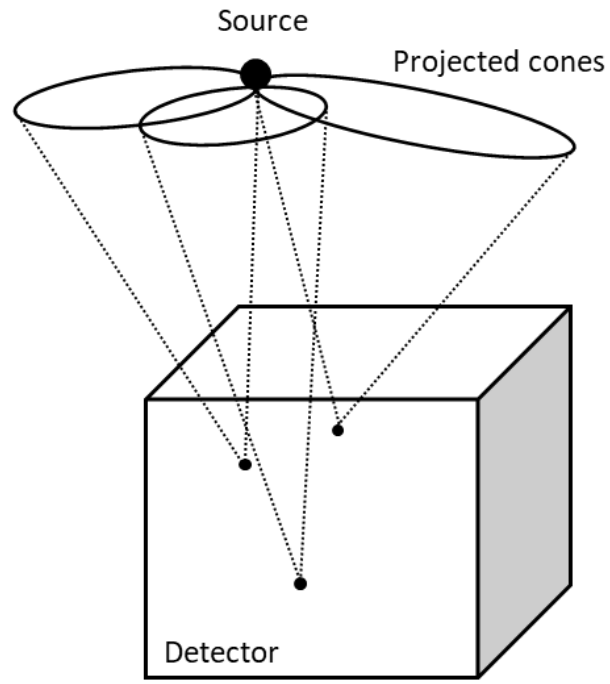


^{60}Co of 480 MBq at 3.78 m (10.1 µSv.h^{-1})

Compton Imaging







Compton Imaging

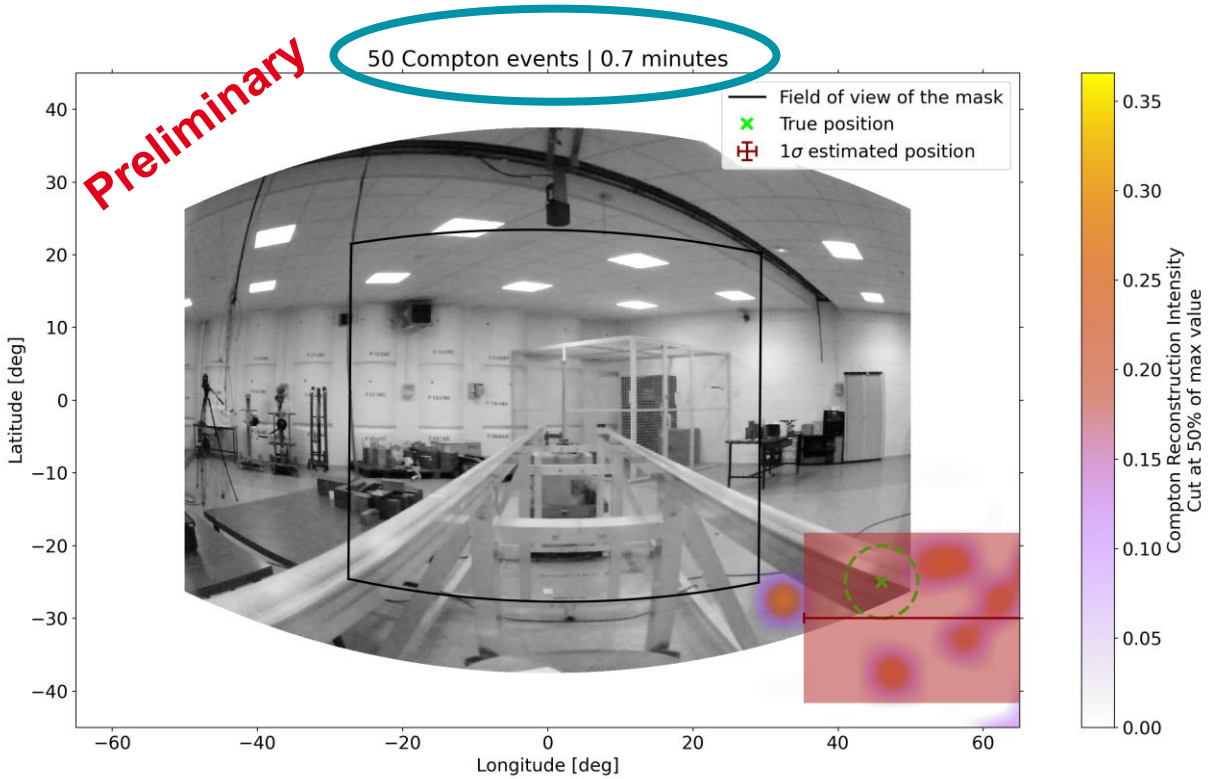
180° FoV available

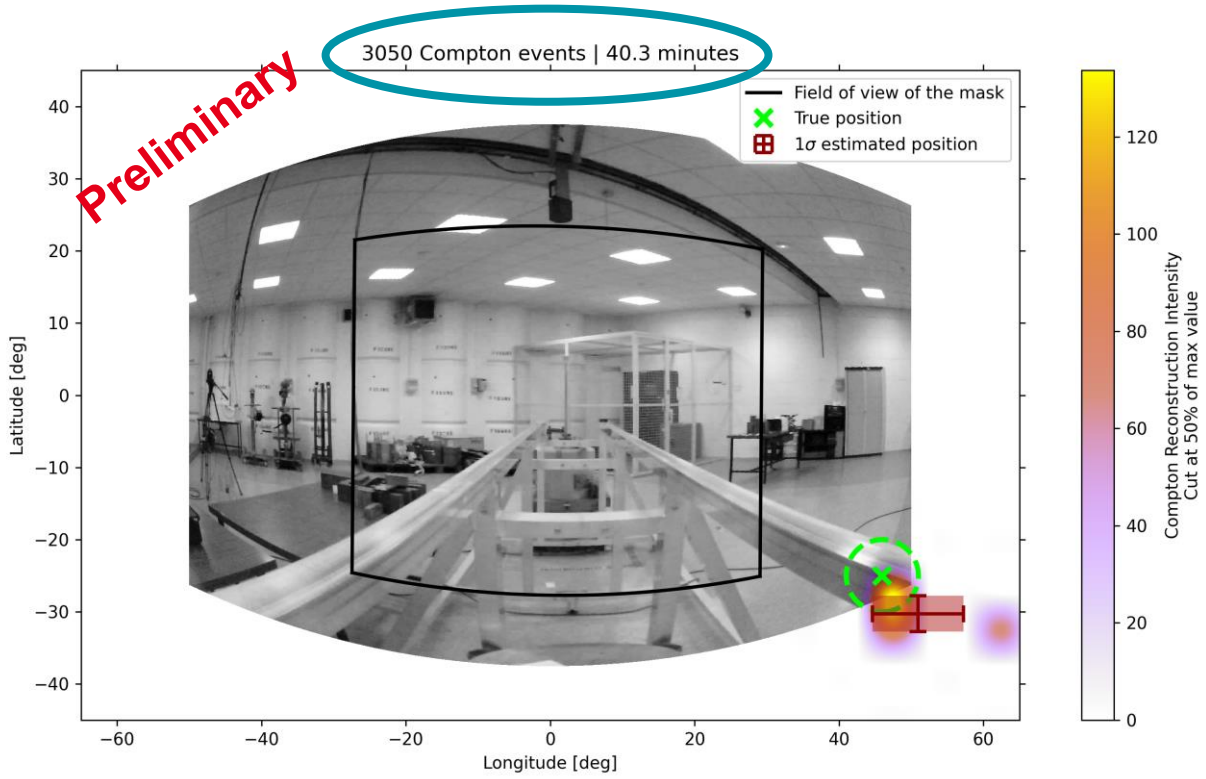
01

Optical Camera FoV : 70° V x 100° H

^{137}Cs of 1.48 GBq at 2.20 m (23.7 µSv.h^{-1})

Stochastic Origin Ensemble with Resolution Recovery





Plots : cut at 50% of the maximum reconstructed value, for both methods

Optical images : optical distortions not taken into account yet (in progress)

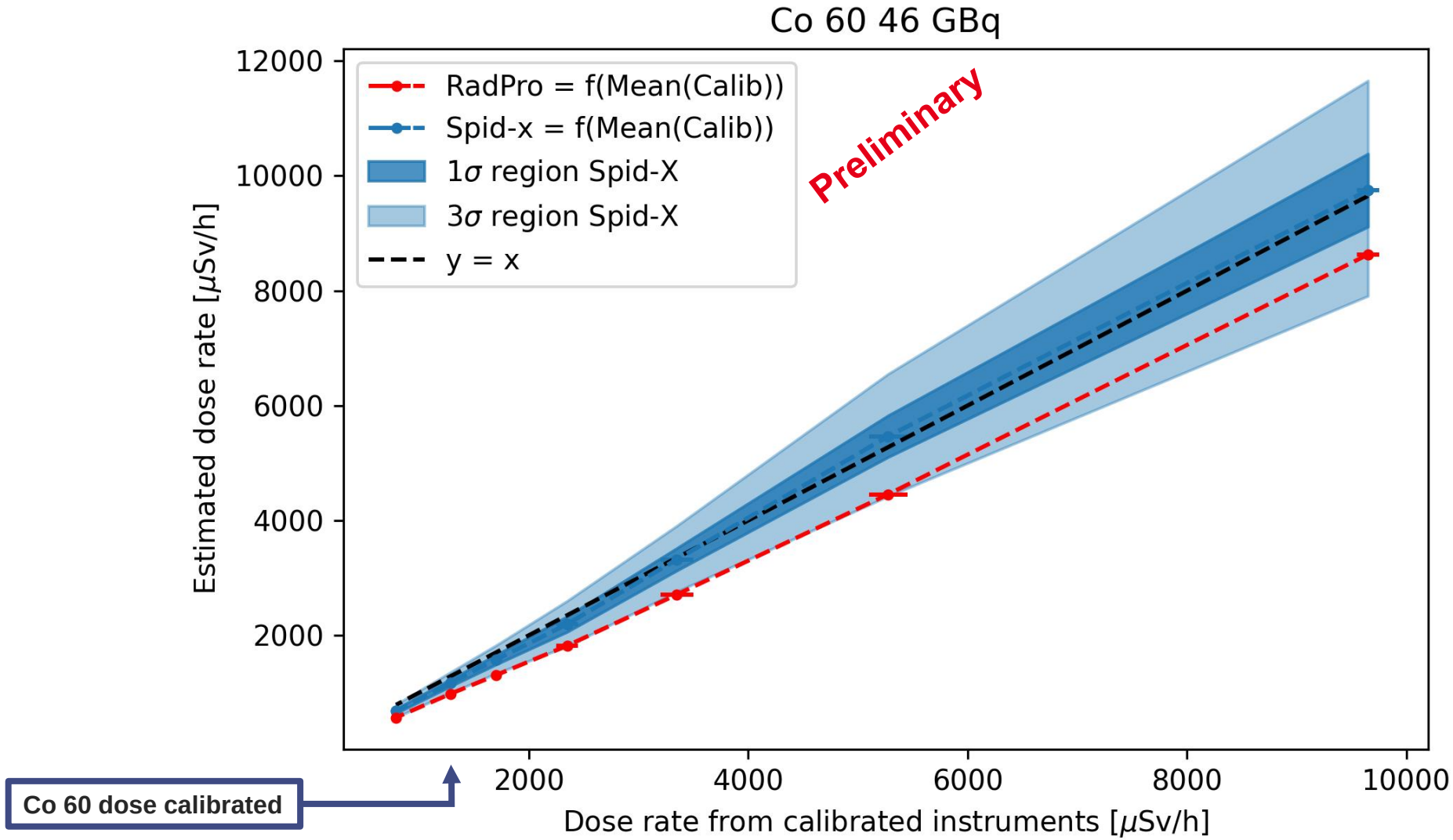
More about Compton imaging algorithms :

Compton imaging reconstruction methods: A comparative performance study of direct back-projection, SOE, a new Bayesian algorithm and a new Compton inversion method applied to real data with Caliste, G. Daniel et al, Eur. Phys. J. Web Conf., 225 (2020)

Dosimetry
At the level of Spid-X

Work in progress

01



RadPro: http://www.radprocalculator.com/Gamma.aspx

Waste barrel single-blind experiment

Questions to answer :

- How many sources?
- Which isotopes?
- Positions in the waste barrel?
- How long is:
  - The identification ?
  - The imaging ?

Identification :

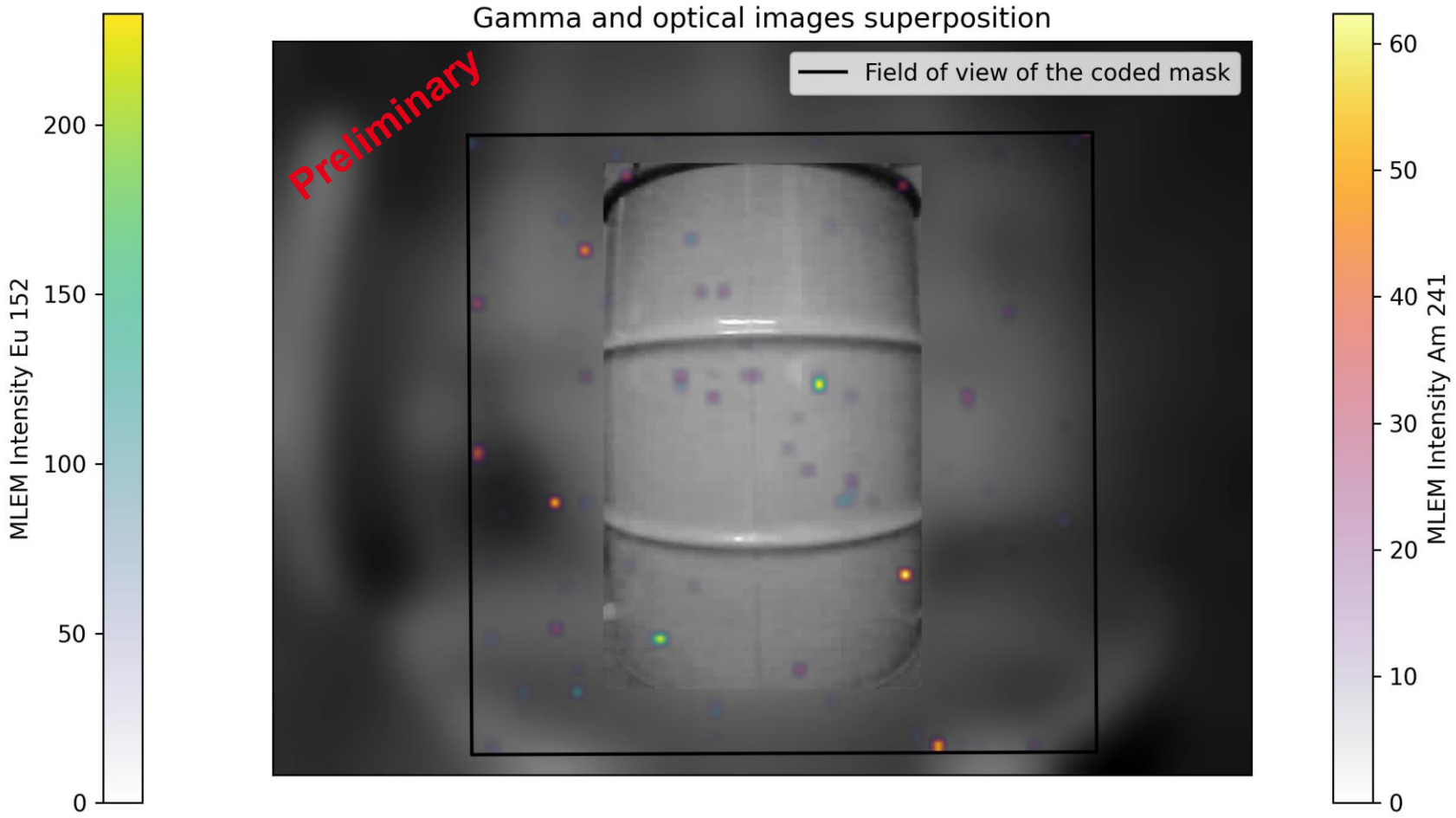
- **^{152}Eu:** few tens of secondes
- **^{241}Am:** about 1 minute

Coded mask imaging :

- **Not enough data, let's wait**

Acquisition

5 minutes – No MLEM threshold



Sources available : 4 ^{152}Eu, 10 MBq each and 4 ^{241}Am, 3.6 MBq each

Waste barrel single-blind experiment

Questions to answer :

- How many sources?
- Which isotopes?
- Positions in the waste barrel?
- How long is:
  - The identification ?
  - The imaging ?

Identification :

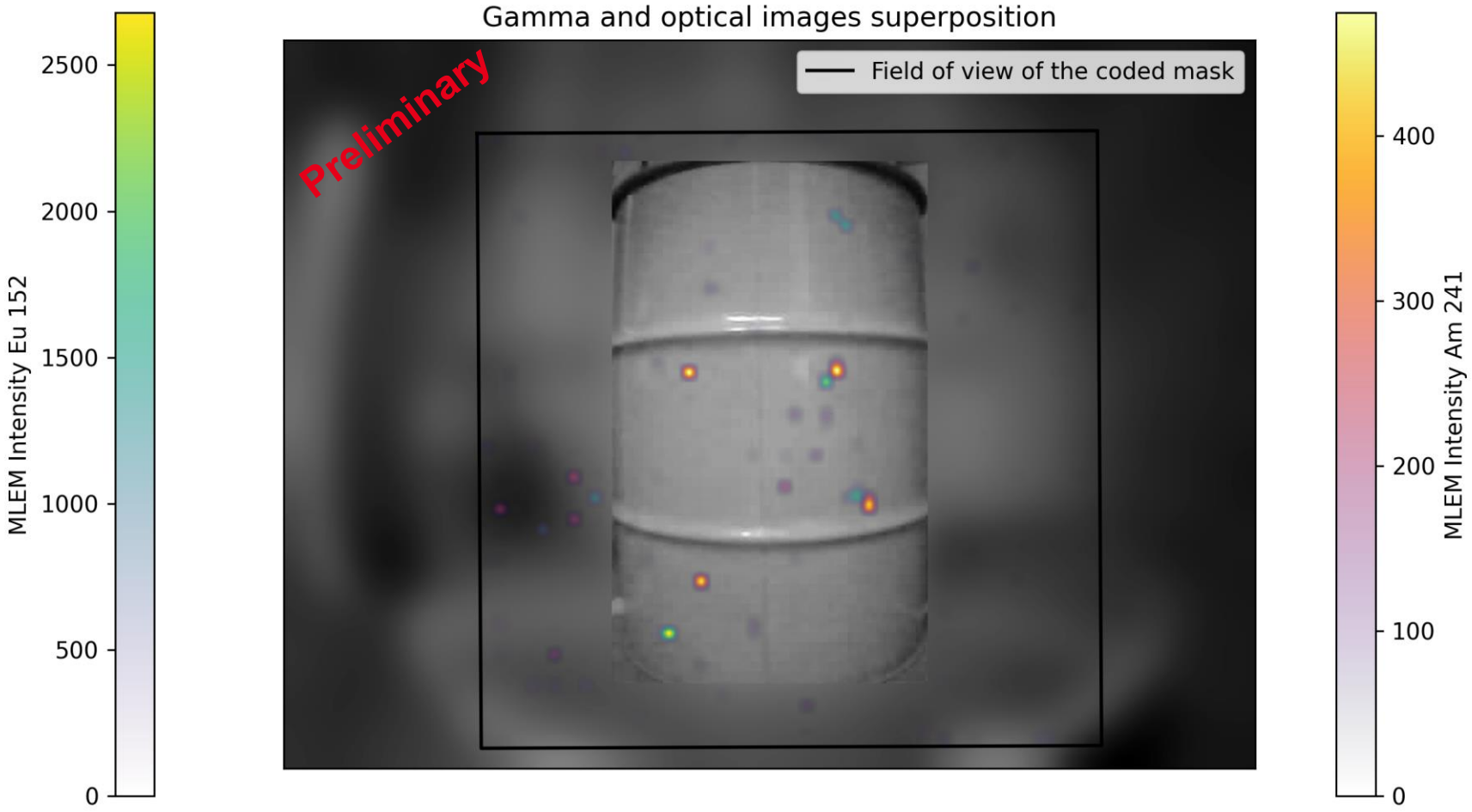
- **^{152}Eu:** few tens of secondes
- **^{241}Am:** about 1 minute

Coded mask imaging :

- **Positions stable, ghosts are desapearing. Let's confirm the result.**

Acquisition

50 minutes – No MLEM threshold



Sources available : 4 ^{152}Eu, 10 MBq each and 4 ^{241}Am, 3.6 MBq each

Waste barrel single-blind experiment

Questions to answer :

- How many sources?
- Which isotopes?
- Positions in the waste barrel?
- How long is:
  - The identification ?
  - The imaging ?

Identification :

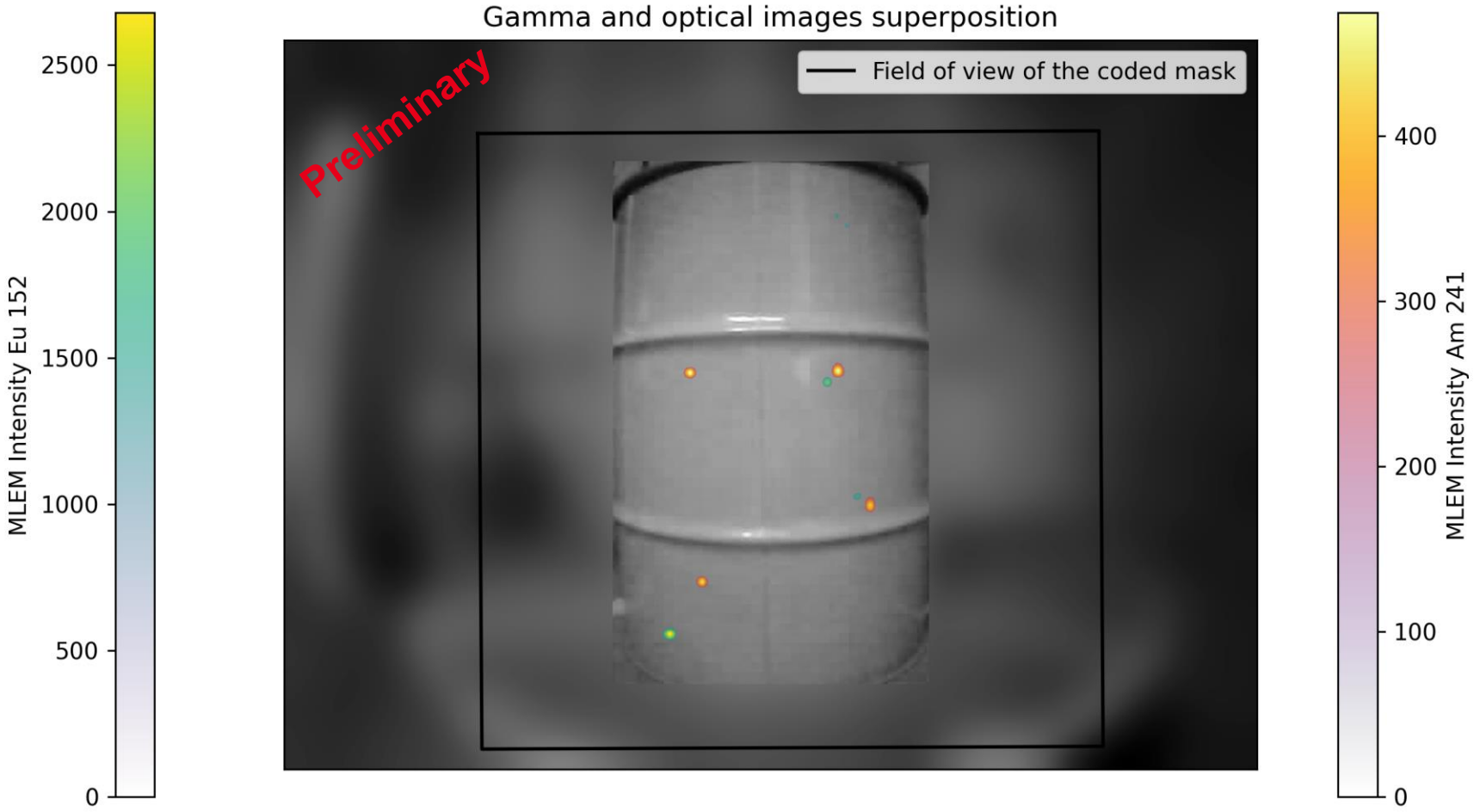
- **^{152}Eu:** few tens of secondes
- **^{241}Am:** about 1 minute

Coded mask imaging :

- **Threshold on the MLEM result, 50 % of the maximum for each source**

Acquisition

50 minutes – MLEM threshold at 50 %



Sources available : 4 ^{152}Eu, 10 MBq each and 4 ^{241}Am, 3.6 MBq each

Waste barrel single-blind experiment

Questions to answer :

- How many sources?
- Which isotopes?
- Positions in the waste barrel?
- How long is:
  - The identification?
  - The imaging?

Identification :

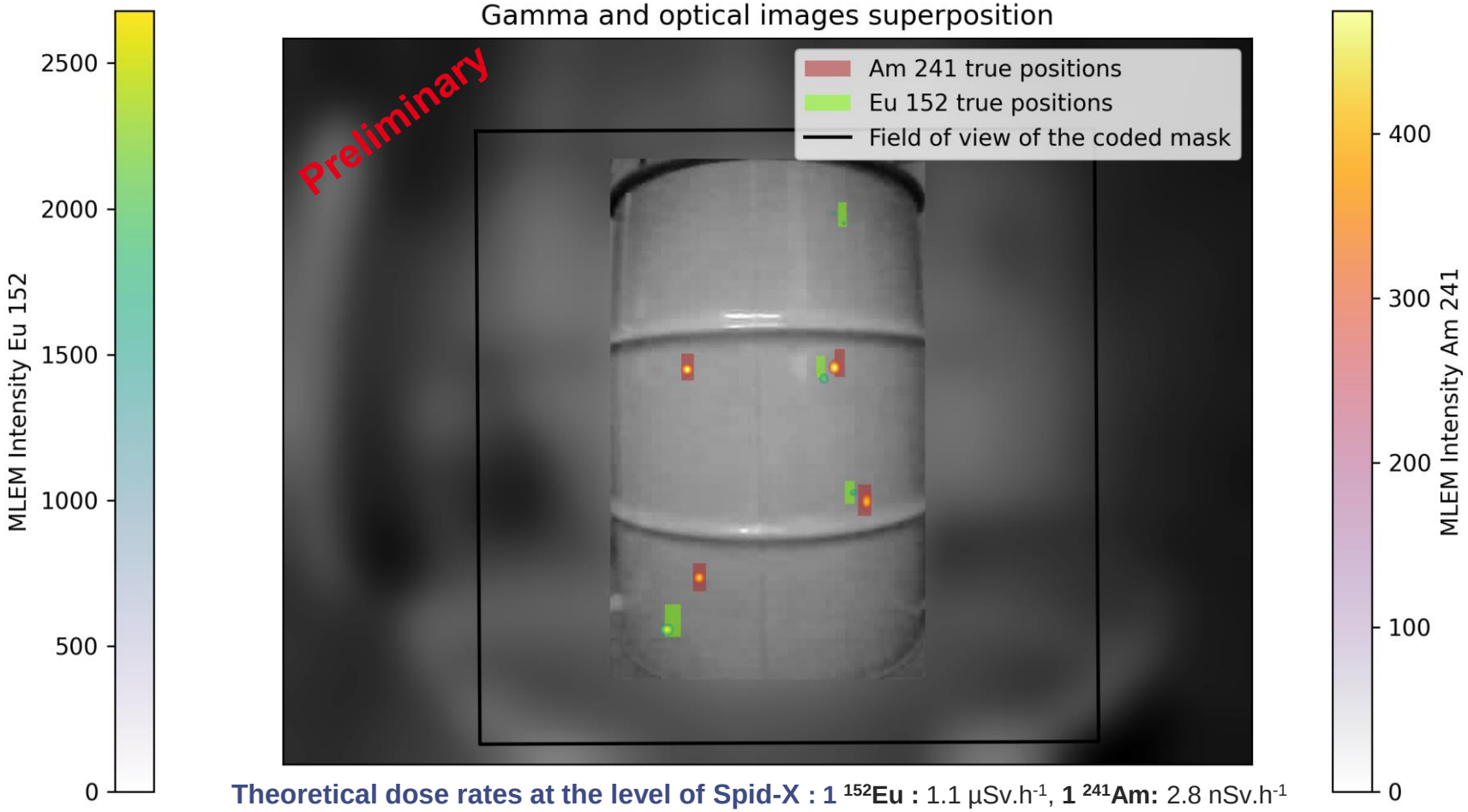
- **^{152}Eu:** few tens of secondes
- **^{241}Am:** about 1 minute

Coded mask imaging :

- **Positions and identification validated by our colleagues**
- **Reconstruction precision within 1° of the true positions**

Acquisition

50 minutes – MLEM threshold at 50 %



Theoretical dose rates at the level of Spid-X : 1 ^{152}Eu : 1.1 µSv.h^{-1}, **1 ^{241}Am:** 2.8 nSv.h^{-1}

Sources available : 4 ^{152}Eu, 10 MBq each and 4 ^{241}Am, 3.6 MBq each

5. Conclusion

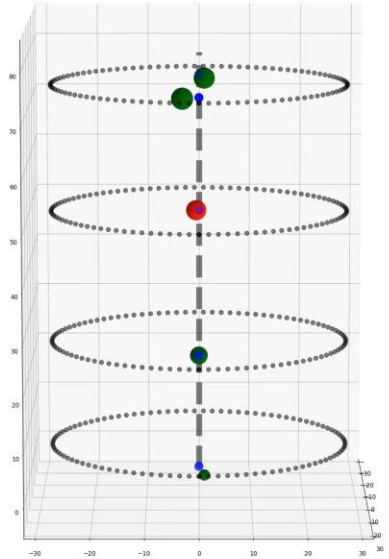
And outlooks

Conclusion and outlooks

Summary

Promising first in-situ results confirming spectro-identification, imaging and dosimetry capabilities of Spid-X in unknown environments:

- **Spectrometry:** correct identification of all source(s) in presence
- **Imaging:** coded mask localisation of up to 4 same sources (up to 2x4 total), with a precision of 1° with respect to the true positions
- **Dosimetry:** « simple » model with deatime correction for high dose rates already implemented and giving good results



Tomography of waste barrel

Ongoing and Outlooks

Spid-X DEM-2 (pre-industrial model) caracterised in laboratory

- All spectrometry, imaging and dosimetry specifications validated
- Schedule of water ingress and solid particule protection tests ongoing

Thank you for your attention!

On behalf of the Spid-X team

CEA SACLAY
91191 Gif-sur-Yvette Cedex
France
abel.vanel@cea.fr