Machine Learning Workshop
IN2P3/IRFU

Extended sources reconstructions by means of Coded mask aperture systems and Deep learning algorithm

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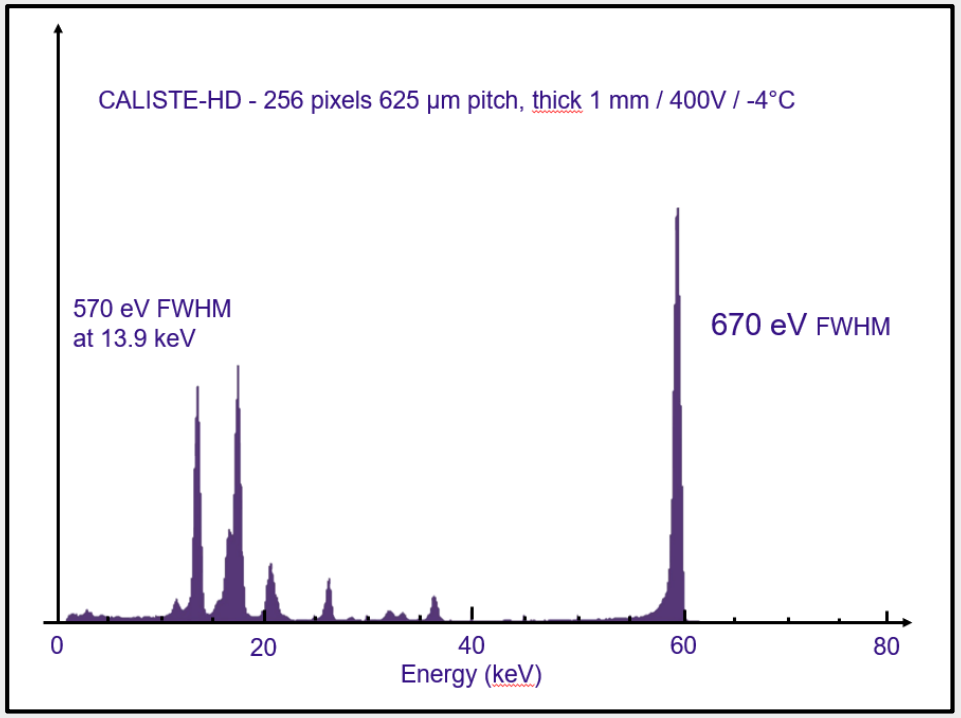
CALISTE DETECTOR

CdTe semi-conductor crystal

Miniature pixelated spectro-imager

Works at **nearly room temperature**: high performance at -15°C
Low power consumption: 200 mW

First developments for **astrophysical** application
→ STIX: Spectrometer Telescope Imaging X-rays
Observation of Bremstrahlung from accelerated electrons near the Sun



^{241}Am Spectrum

Different versions of Caliste: Caliste-SO, Caliste-HD, Caliste-O…

From space applications to **industrial** applications:
→ Medical application: breast tumor cells detection
→ **Nuclear safety application**

Caliste Family

CALISTE HD

Pixelated detector 16 x 16 pixels
- 625 µm pixel pitch
- 1 mm thickness
- Surface: 1 cm²
- Other versions available

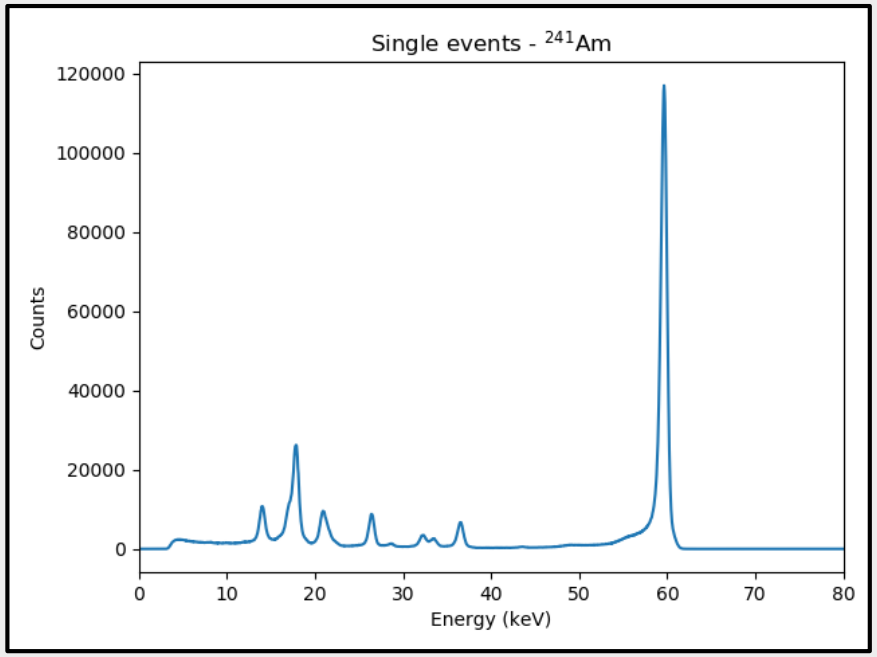
High **energy range**: from 2 keV to 1 MeV

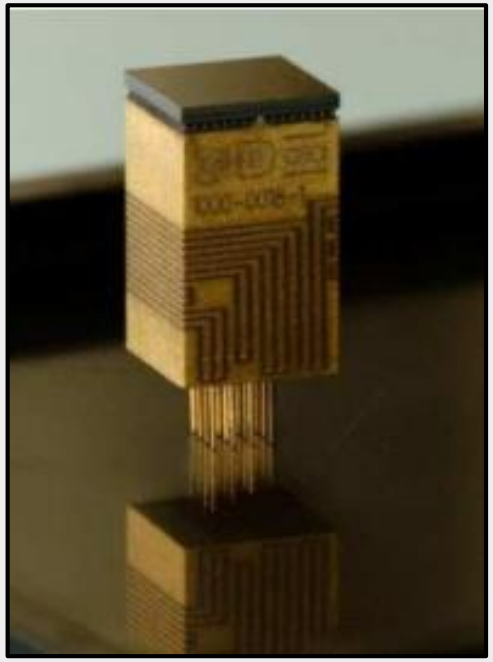
High energy resolution
- 670 eV FWHM at 60 keV (1,1 %)
- 4,1 keV FWHM at 662 keV (0,62 %)

Spectroscopy: Radioactive sources identification

Imaging: Compton localisation

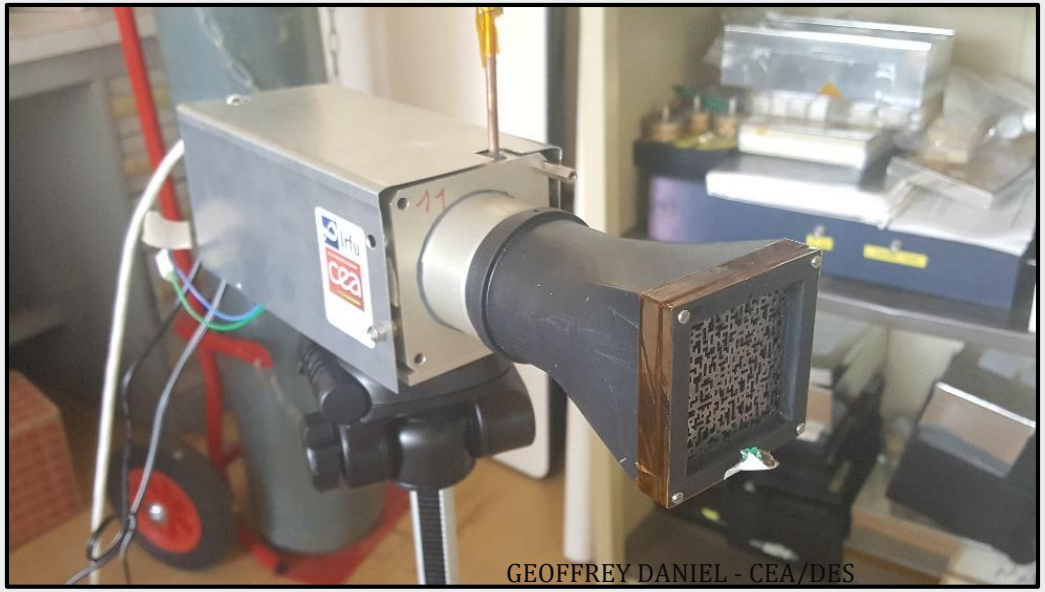
Coded Mask Aperture Imaging



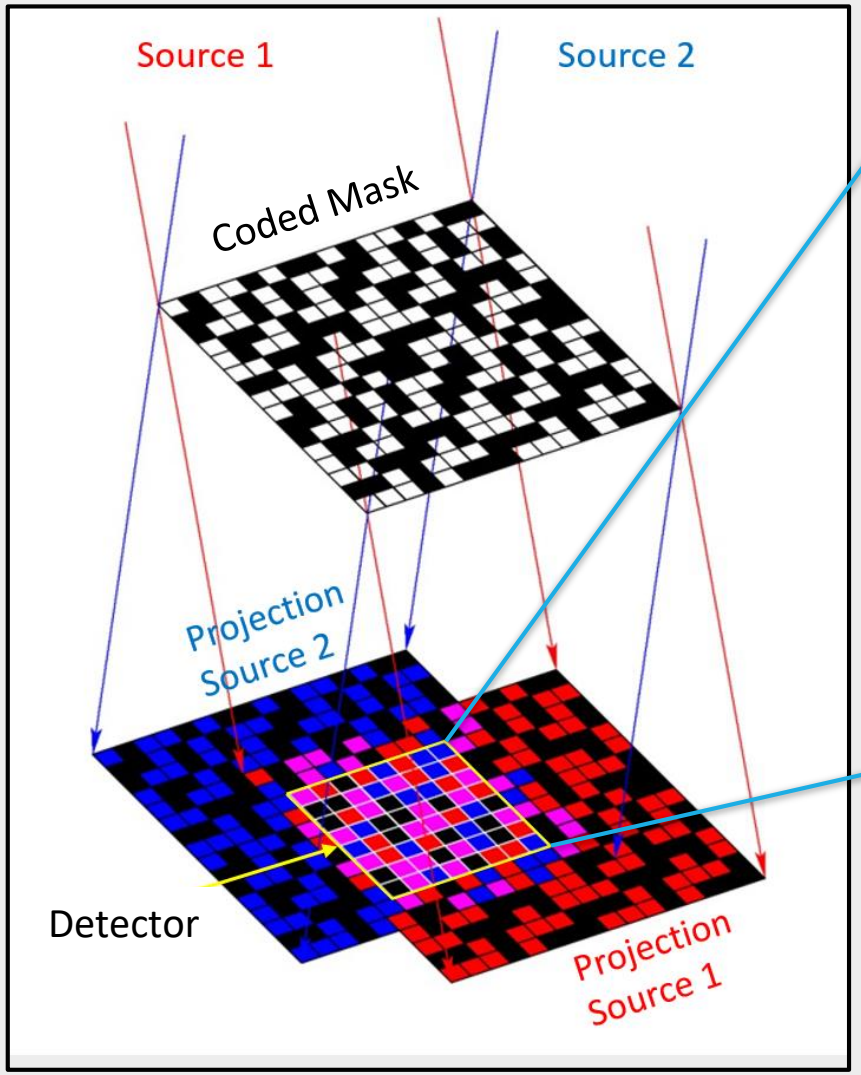


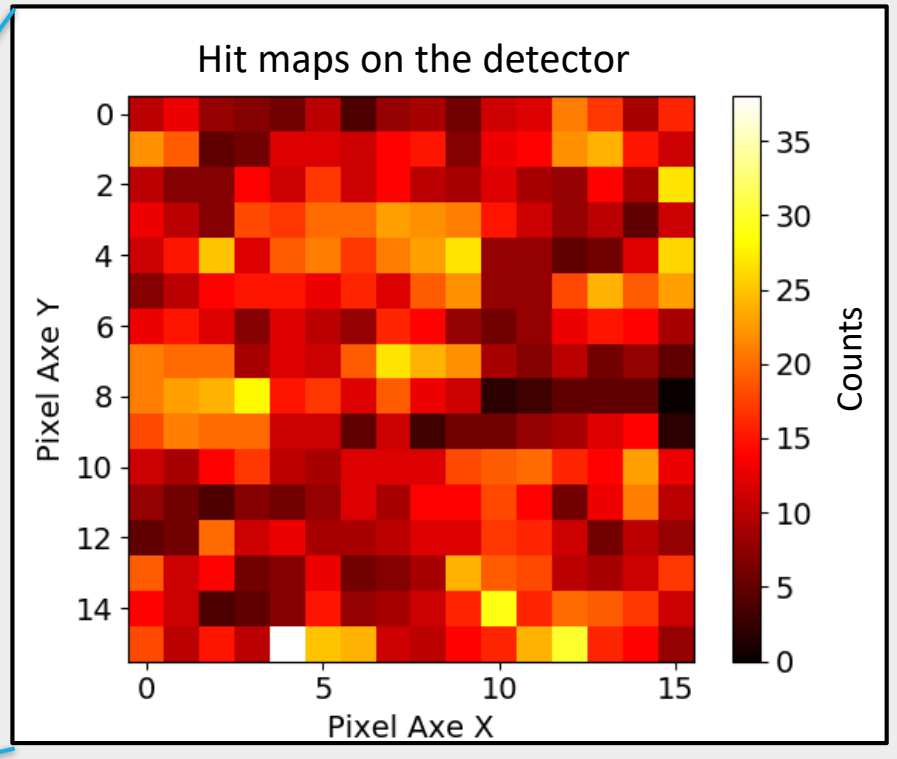
Caliste-HD (CEA Irfu)

WIX-HD Camera
Mass: 1 kg



CODED MASK APERTURE IMAGING





Observation $\boldsymbol{Y}$

Coded mask $\boldsymbol{M}$

ε: unknown noise

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

Problem to solve

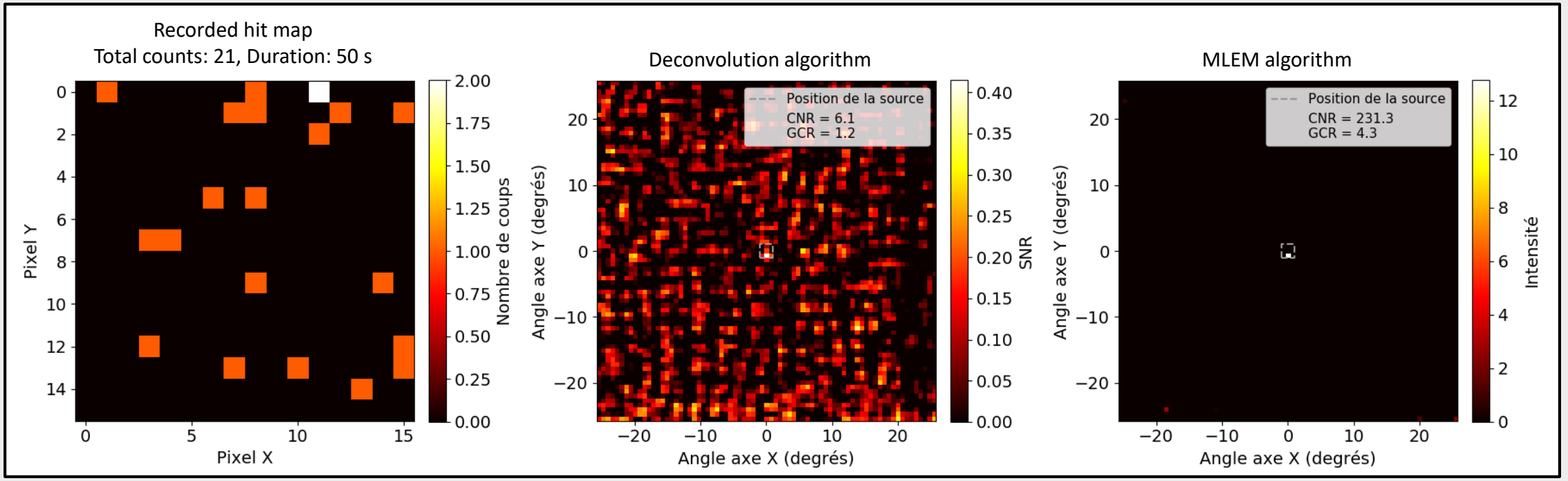
$$\boldsymbol{Y} = \boldsymbol{M}.\boldsymbol{X} + \boldsymbol{\varepsilon}$$

CLASSICAL ALGORITHMS

Two main algorithms:

- Deconvolution algorithm → Correlations between the mask and the recorded hit map
- MLEM (Maximum Likelihood Expectation Maximization) → Iterative algorithm, maximization of the likelihood $p(Y|X)$ to observe the data Y, given the position of the sources X

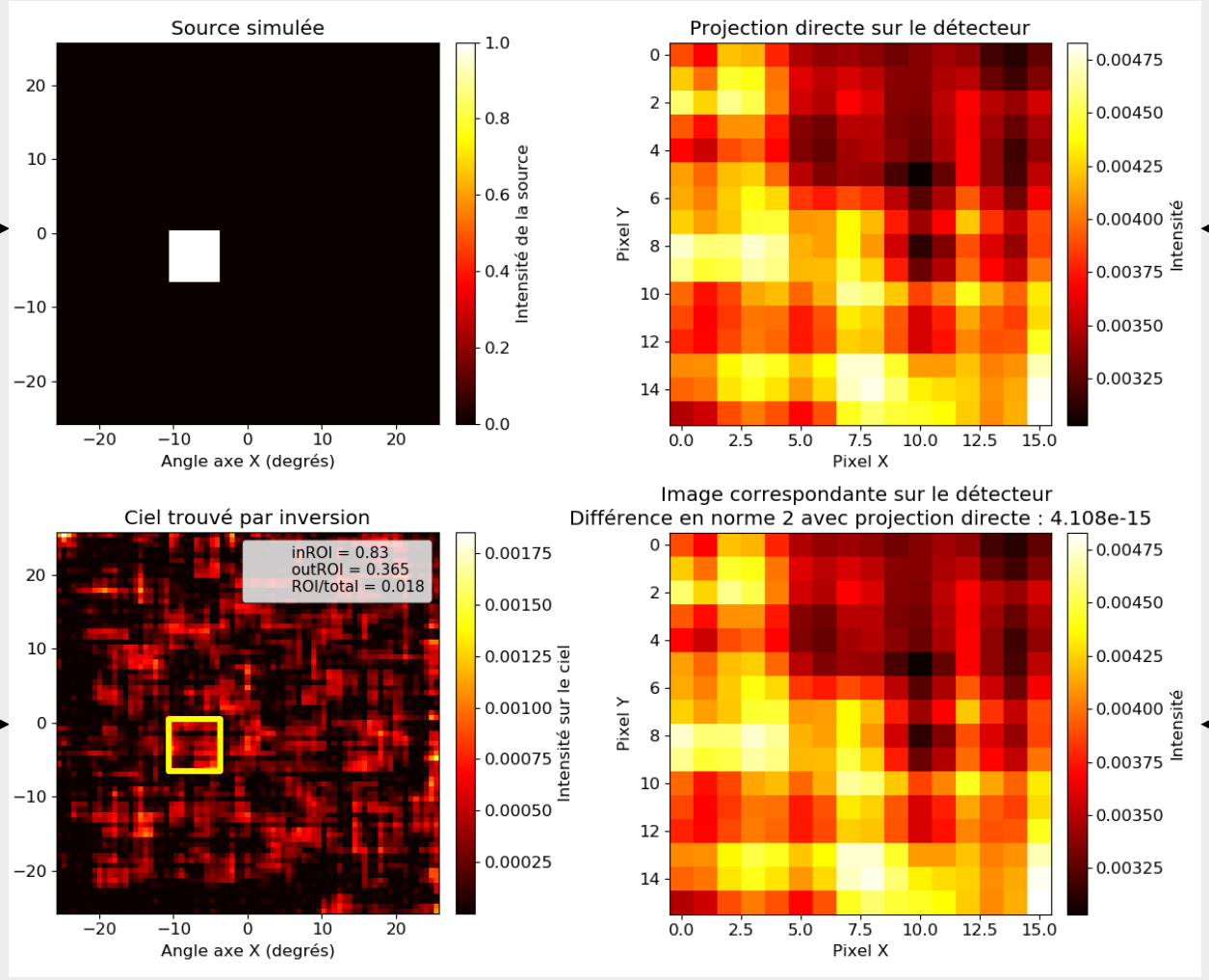
Tests on real data



EXTENDED SOURCES

Deconvolution problem is non injective

Simulation X



Projection of X on the detector, no noise

$$Y = M.X\ (\varepsilon = 0)$$

Estimation of X :

$$\hat{X} = \underset{X/\ \min(X)\geq 0}{\operatorname{argmin}} \|Y - M.X\|_2^2$$

Projection of $\hat{X}$

$$\hat{Y} = M.\hat{X}$$

$$\frac{\|Y - \hat{Y}\|_2}{\|Y\|_2} = 4{,}1.10^{-15}$$

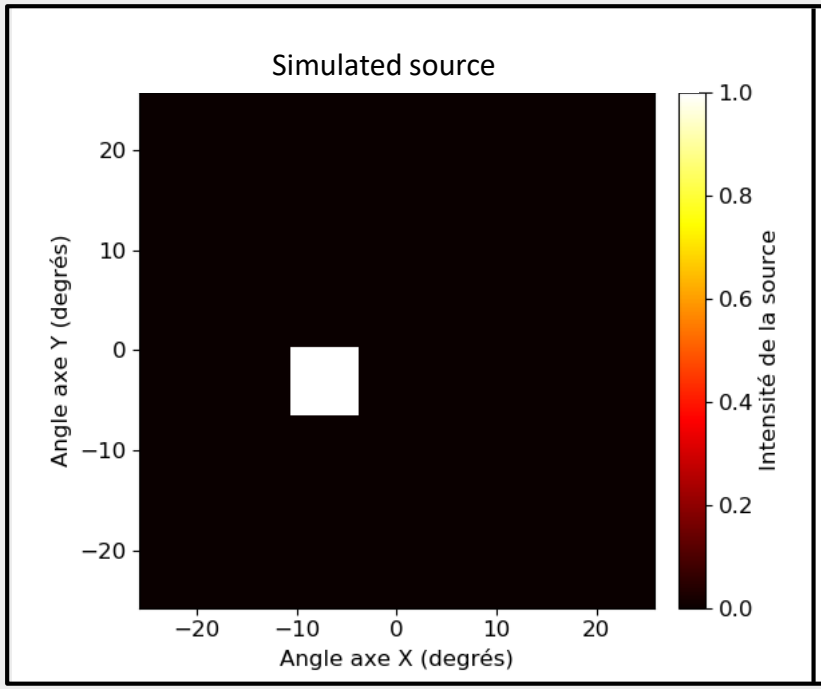
EXTENDED SOURCES

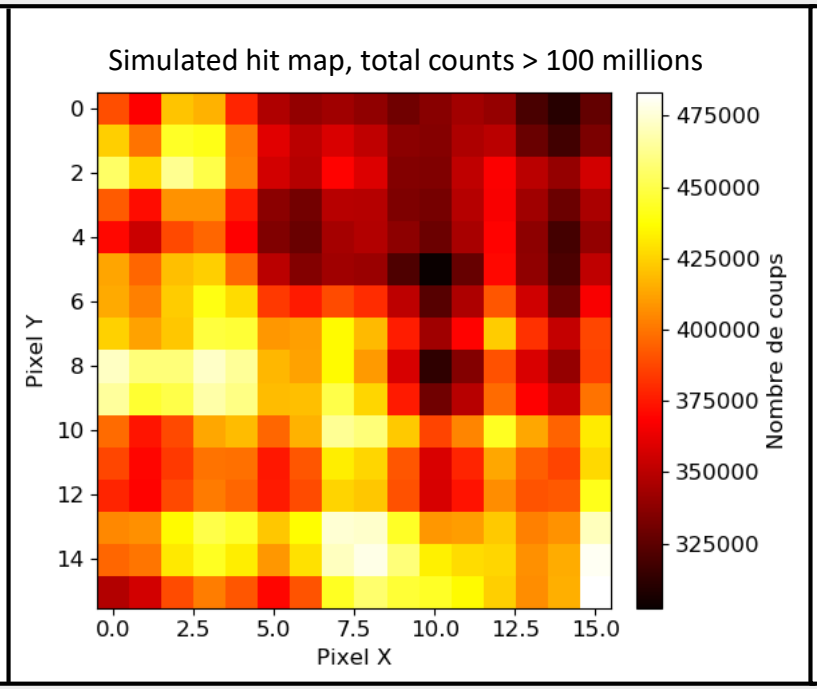
Limitations on extended sources

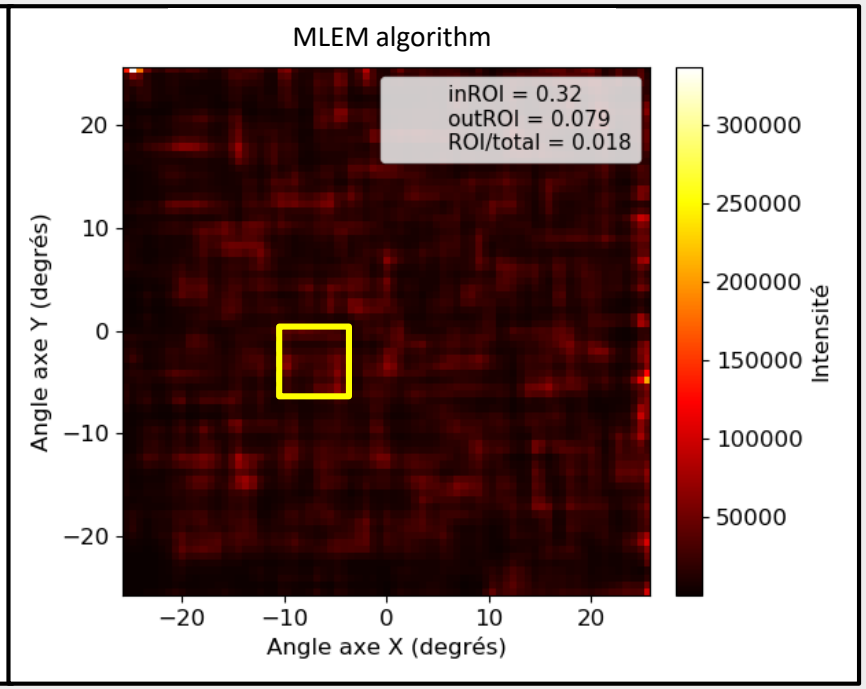
Classical algorithms are unable to reconstruct extended sources

Even in the case of high counting statistics and without any noise

Need for regularization or other algorithms







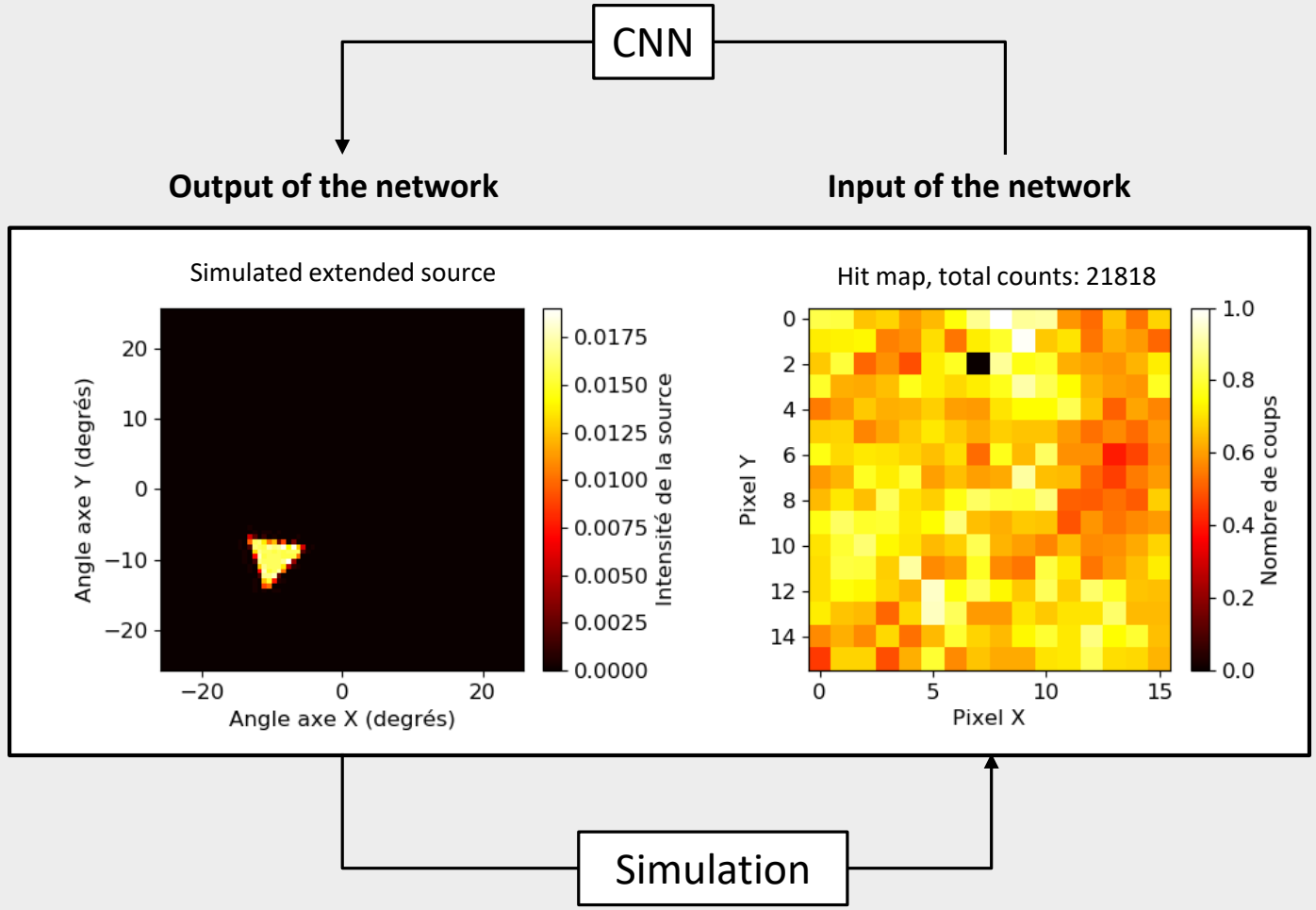
DEEP LEARNING APPROACH

Deep Learning

New for this topic: two studies in 2019 and 2020 on simulated point sources

Online learning

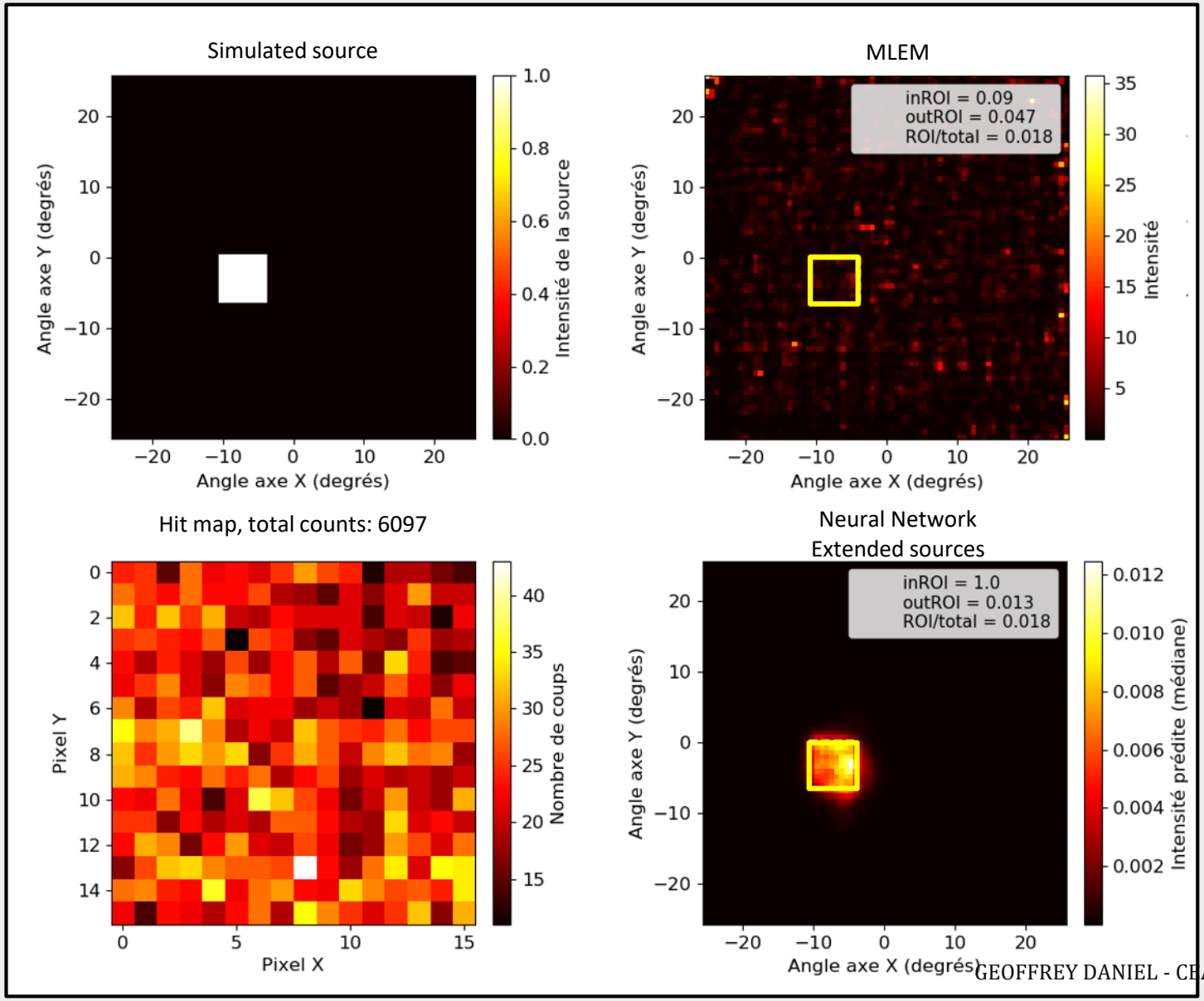
- From simulations
- Creation of 1000 examples and learning for one epoch (iteratively)
  - 900 training examples
  - 100 validation examples
- Learning more that 200 million examples



DEEP LEARNING RESULTS: TESTS ON SIMULATION

Extended sources
Simulation

Computation time:
MLEM: 3,5 s (100 iterations)
CNN: 0,035 s



DEEP LEARNING RESULTS

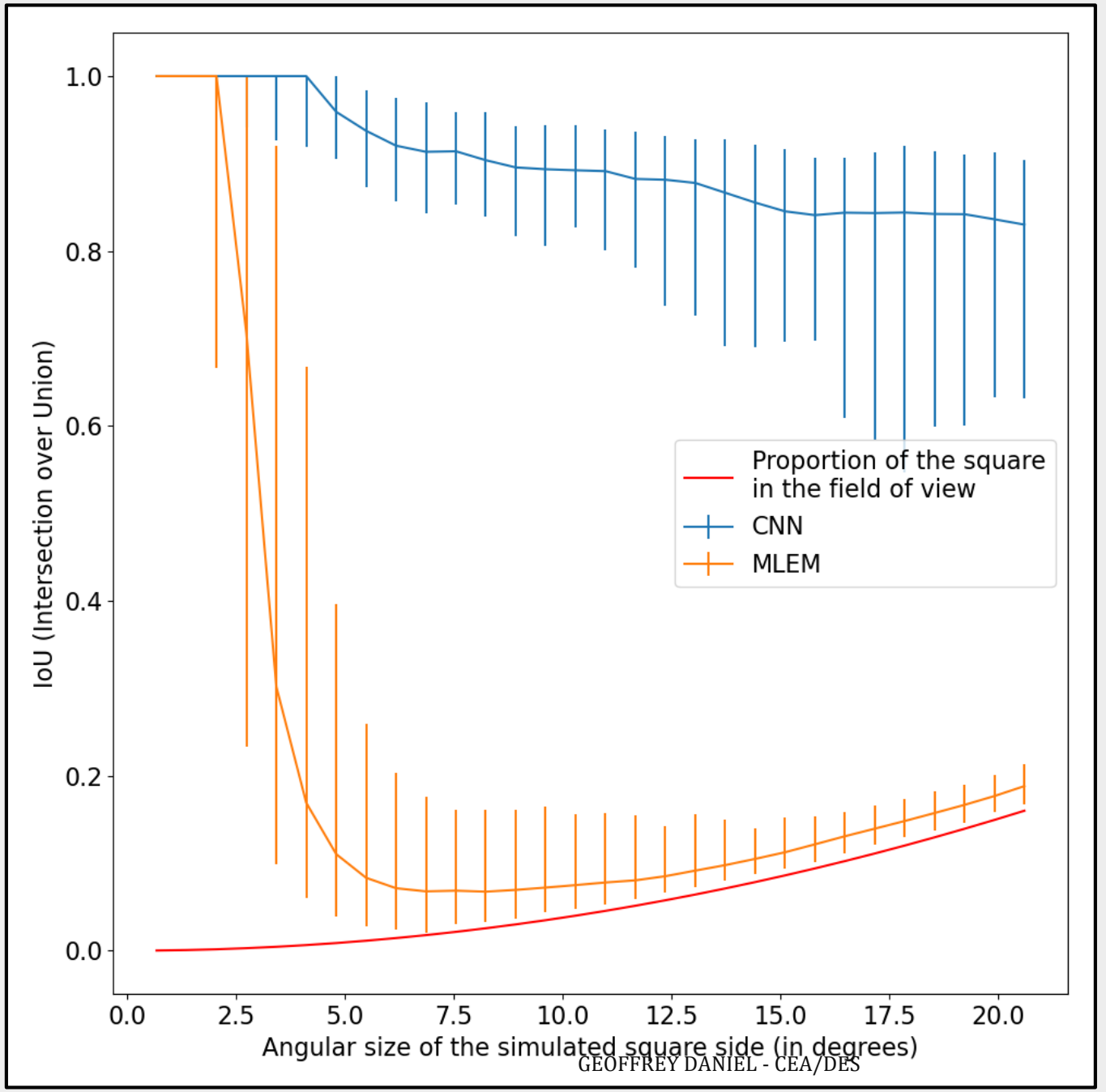
Performances on extended sources reconstruction

Simulations of square sources, different sizes

- 10 millions of photons
- No noise
- No disabled pixels
- 1000 examples for each size

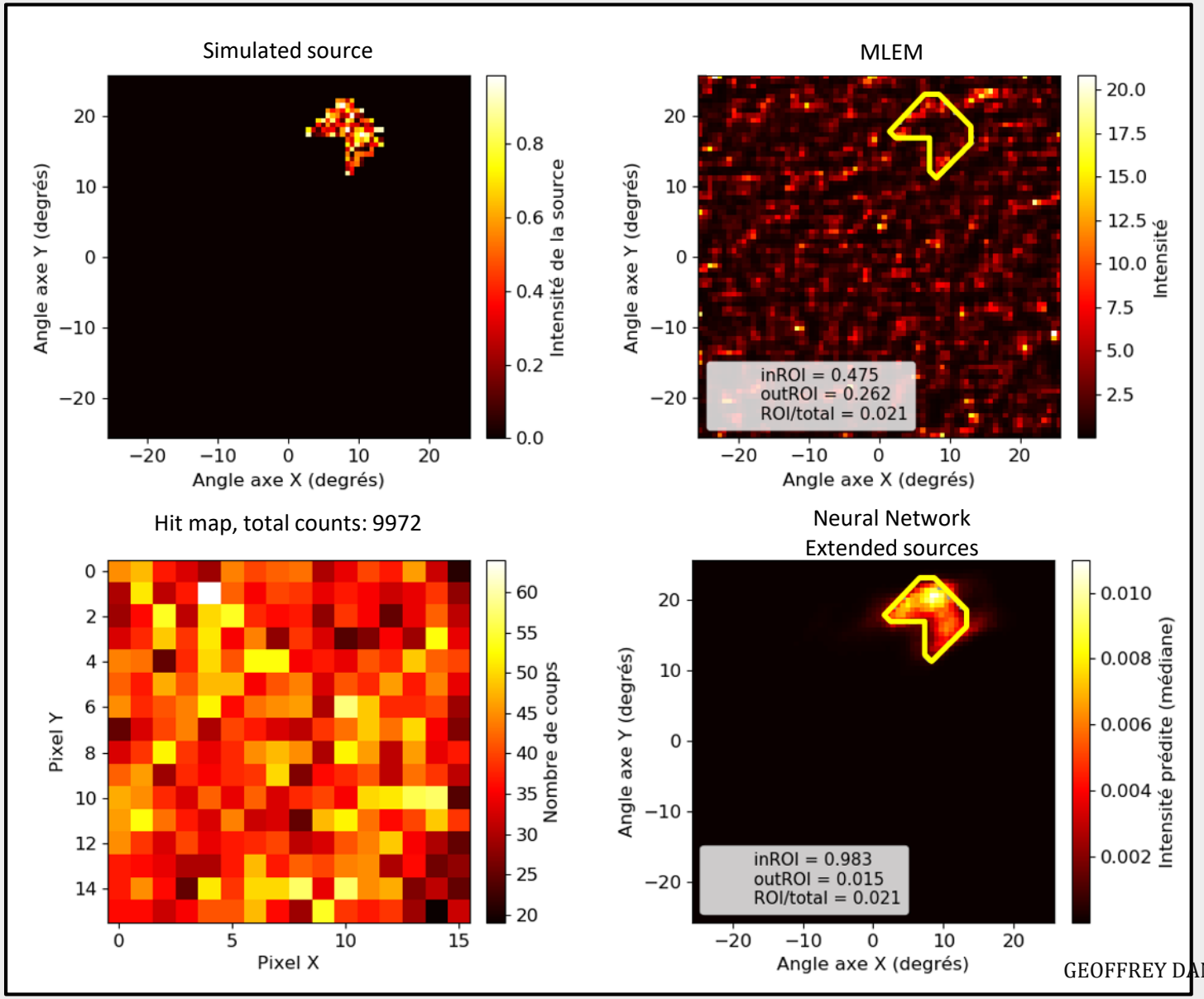
Metric: Intersection over Union (IoU)

$$\mathrm{IoU} = \frac{\mathrm{Area}(\mathrm{True} \cap \mathrm{Recons})}{\mathrm{Area}(\mathrm{True} \cup \mathrm{Recons})}$$



DEEP LEARNING RESULTS: TEST ON OTHER SHAPE

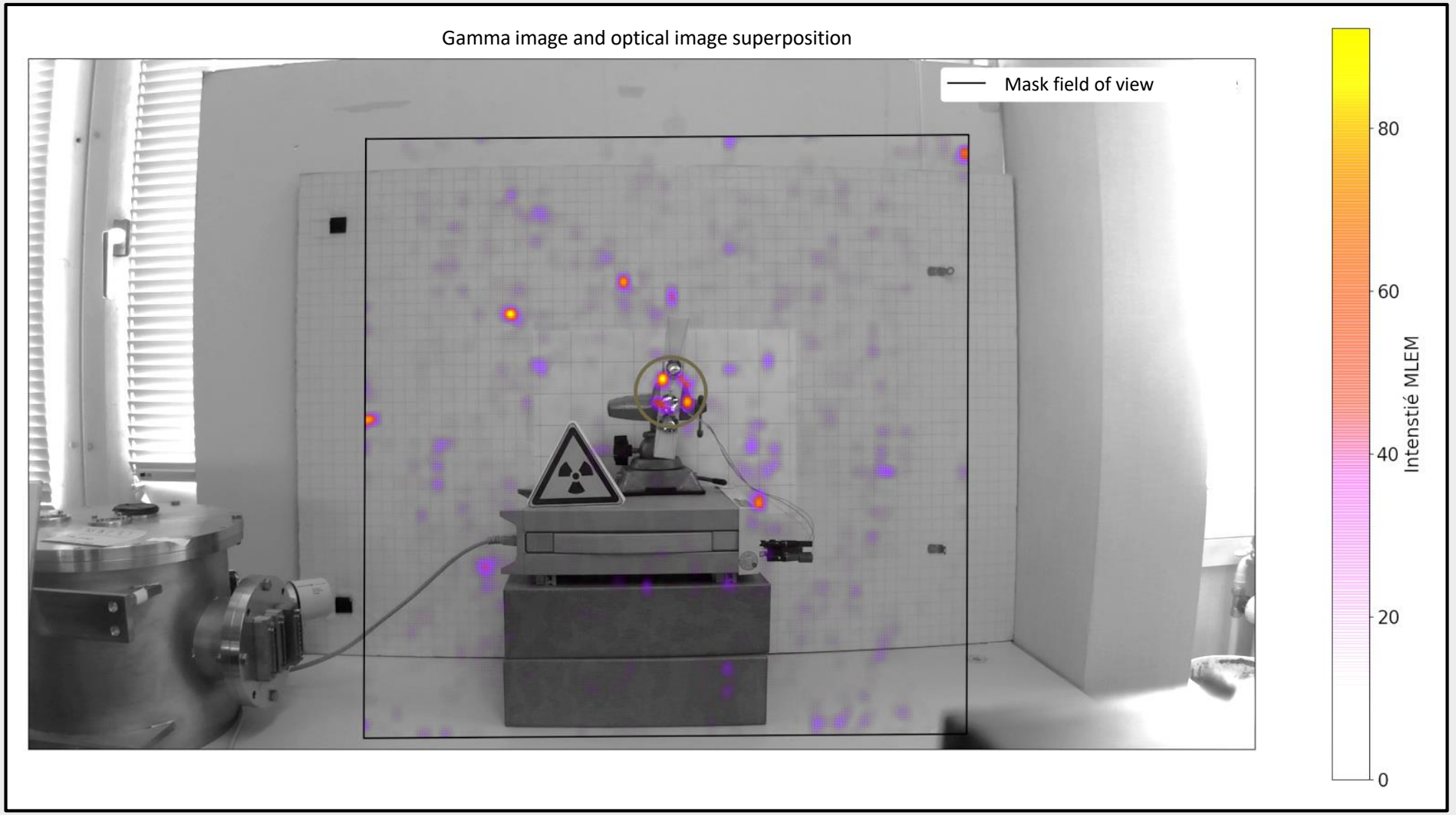
Extended sources
Simulation



DEEP LEARNING RESULTS: REAL DATA

Extended source
Real Data

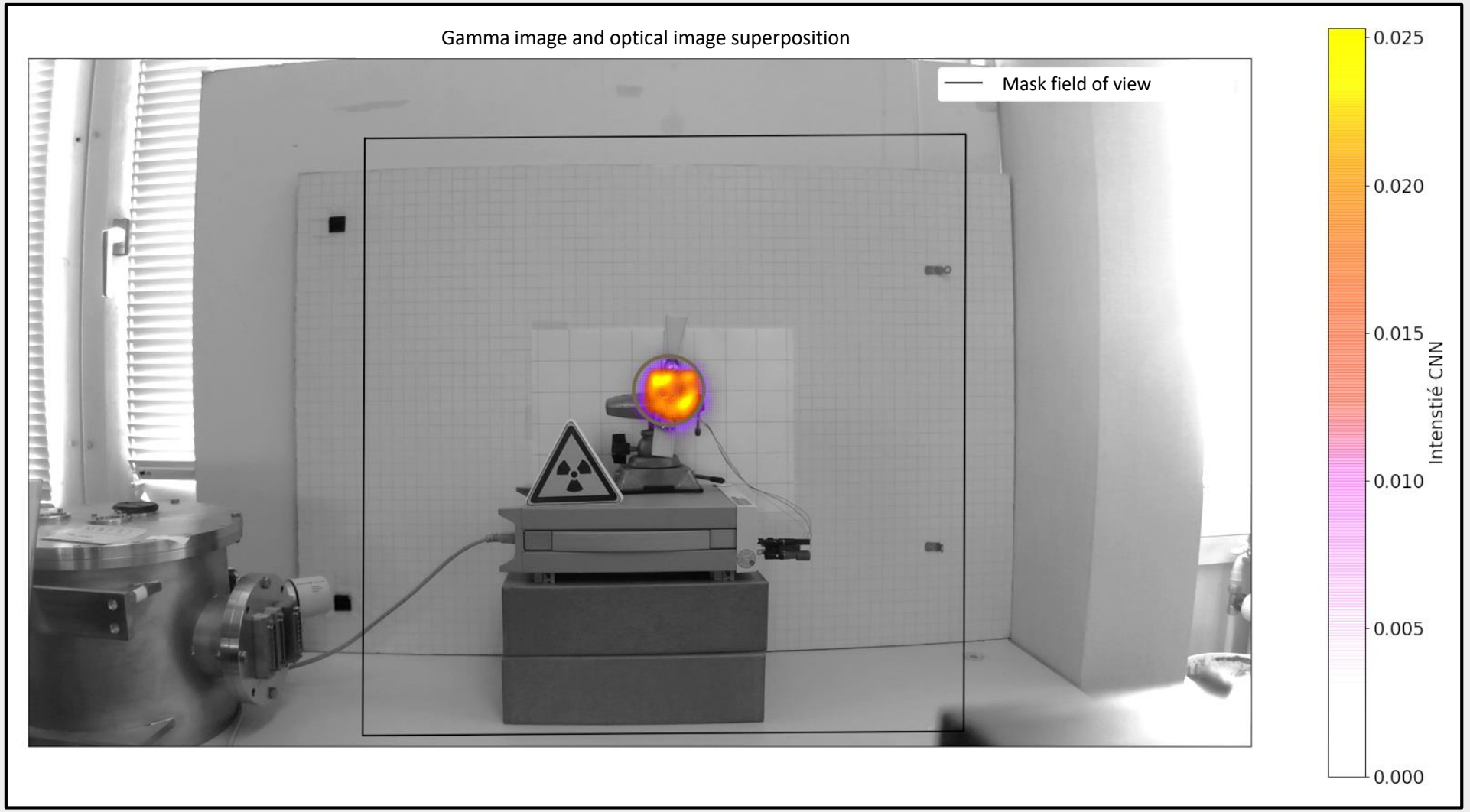
MLEM algorithm
Acquisition: 2 h 35 mn



DEEP LEARNING RESULTS: REAL DATA

Extended source
Real Data

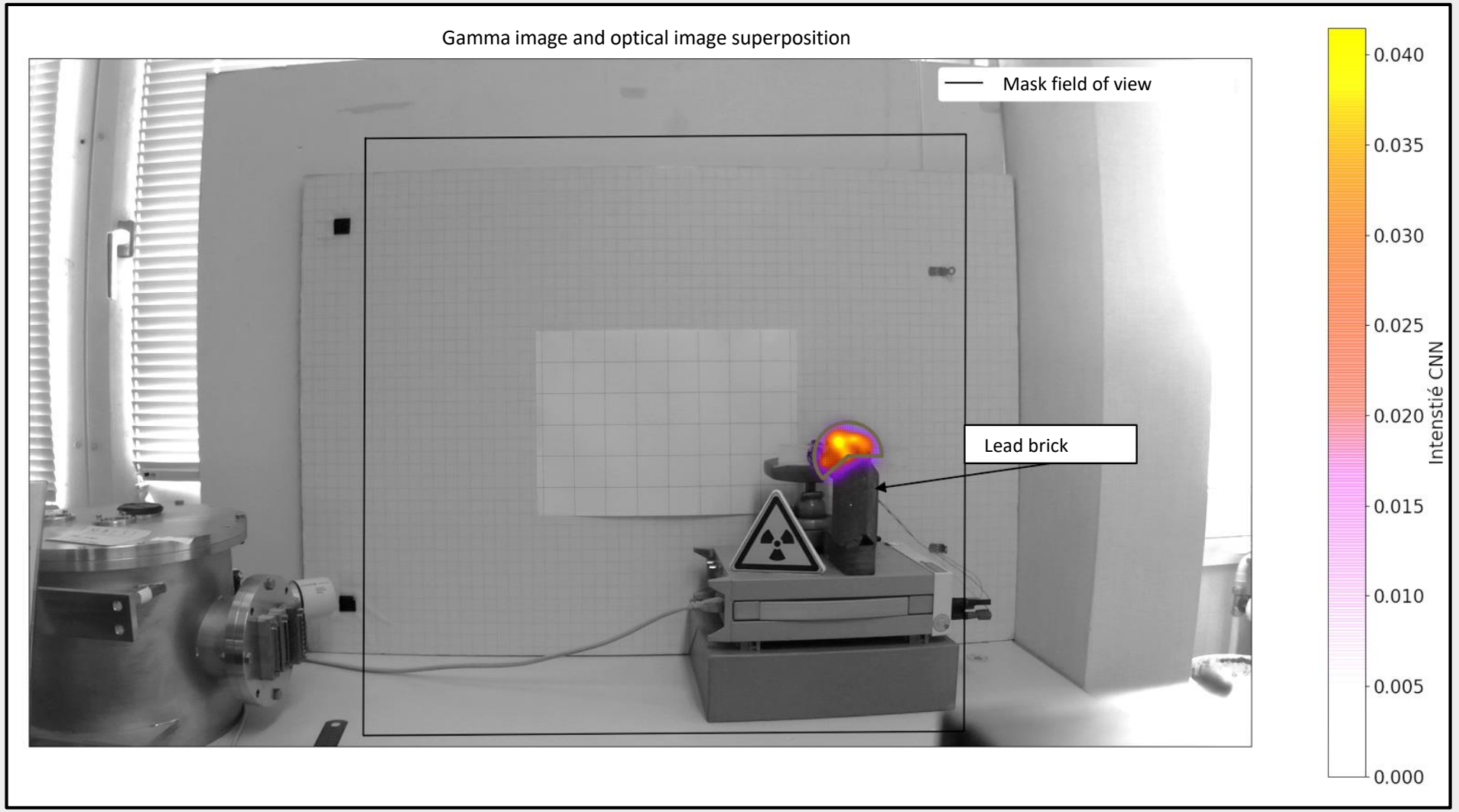
Neural Network
Acquisition: 2 h 35 mn



DEEP LEARNING RESULTS: REAL DATA

Extended source
Real Data

Neural Network
Acquisition: 1 h 30 mn



CONCLUSION

Neural Networks: Solution for the problem of **extended** sources reconstructions

→ Regularization through the data and the learning method

Interesting improvements of the **computation time** with Neural Network

Outlooks

- One neural network to process extended and point sources data
- Tests in operational conditions
- Applications in other fields: instrumentation for astrophysics, medical imaging…

Thank you for your attention!