DE LA RECHERCHE À L'INDUSTRIE

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ARTIFICIAL INTELLIGENCE APPLIED TO THE SPECTRO-IDENTIFICATION OF RADIONUCLIDES IN COMPLEX RADIOLOGICAL ENVIRONMENTS

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CALISTE DETECTOR

- **CdTe** semi-conductor crystal
- **Miniature pixelated spectro-imager**
- First developments for **astrophysical** application
- Works at **nearly room temperature**: high performance at -15°C
- **Low power consumption**: 200 mW
- From space applications to **industrial** applications:
  → Medical application: breast tumor cells detection
  → **Nuclear safety application**

Caliste Family

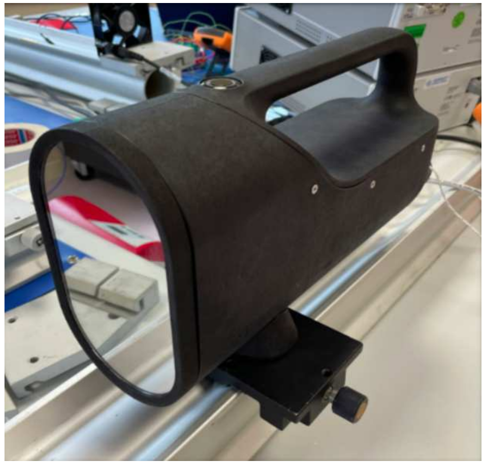
CALISTE O

- **Pixelated** detector 16 x 16 pixels
  - 800 μm pixel pitch
  - 2 mm Crystal thickness
  - Surface: 2 cm^2
  - Other versions available

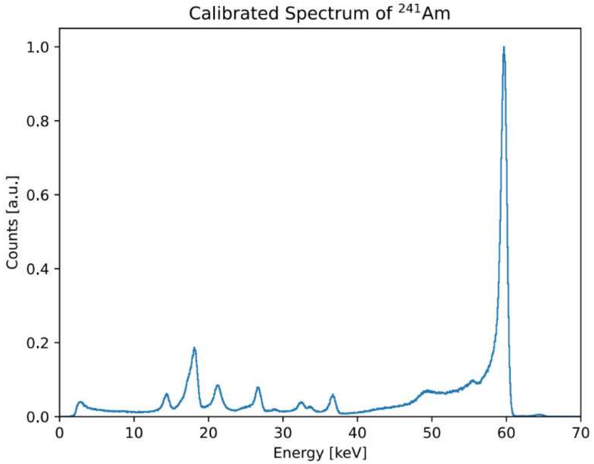
- High **energy range**: from 2 keV to 1 MeV

- **High energy resolution**
  - 3.05 keV FWHM at 122 keV (2,5 %)
  - 9.93 keV FWHM at 662 keV (1,5 %)

- **Capable of**
  - **Spectroscopy: Radioactive sources identification**
  - Imaging: Coded mask and Compton localisation



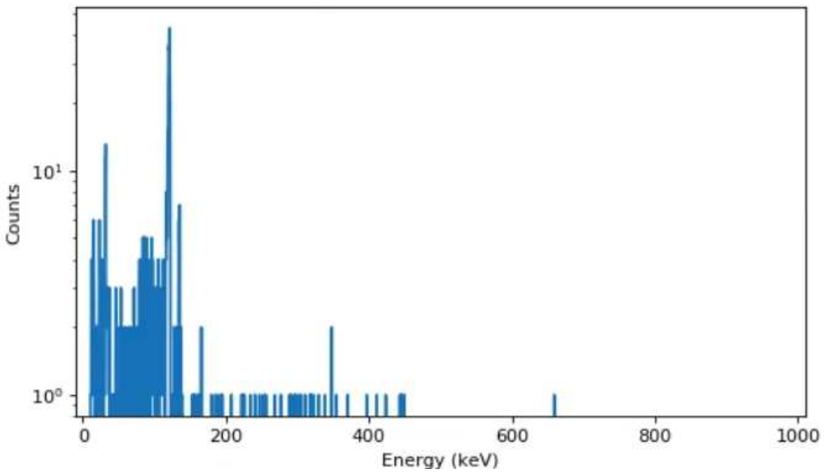
Spid-X Camera



^{241}Am Spectrum

OUR AI TOOL: REAL TIME SPECTRAL IDENTIFICATION

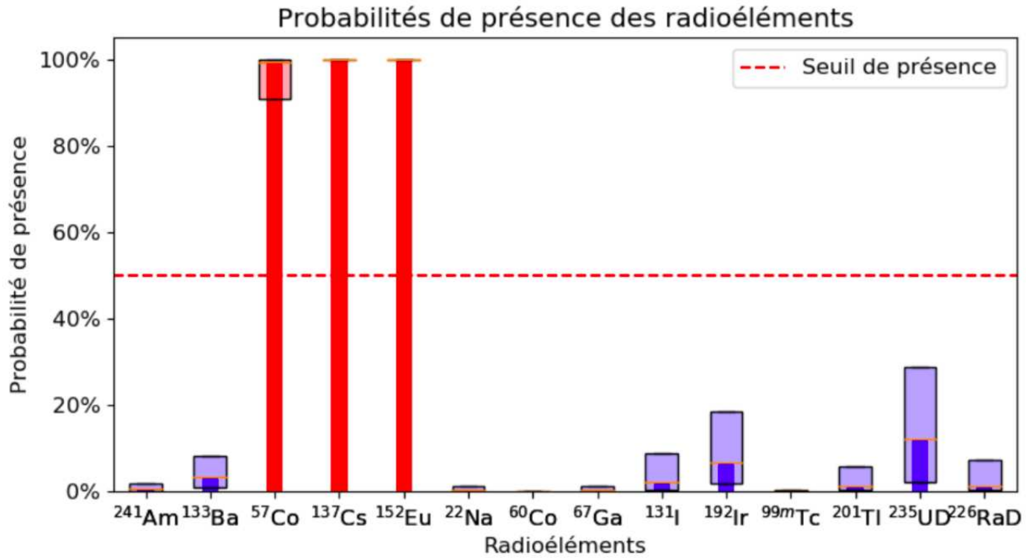
Measured spectrum example



Spec ID AI model

- Which radioelements? → Classification
- In which proportions? → Regression
- With uncertainties?

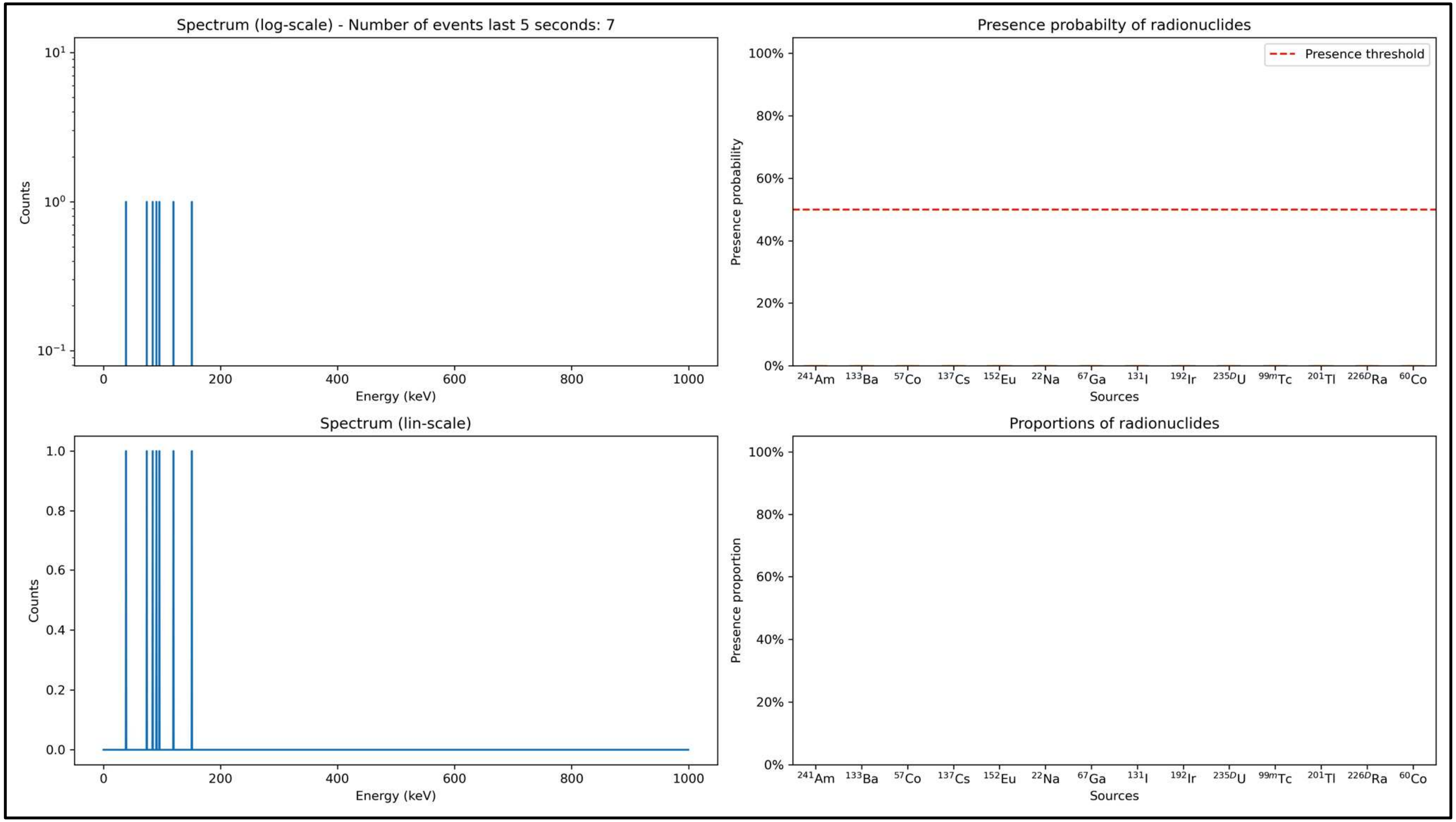
→ **Convolutional Bayesian Neural Network**



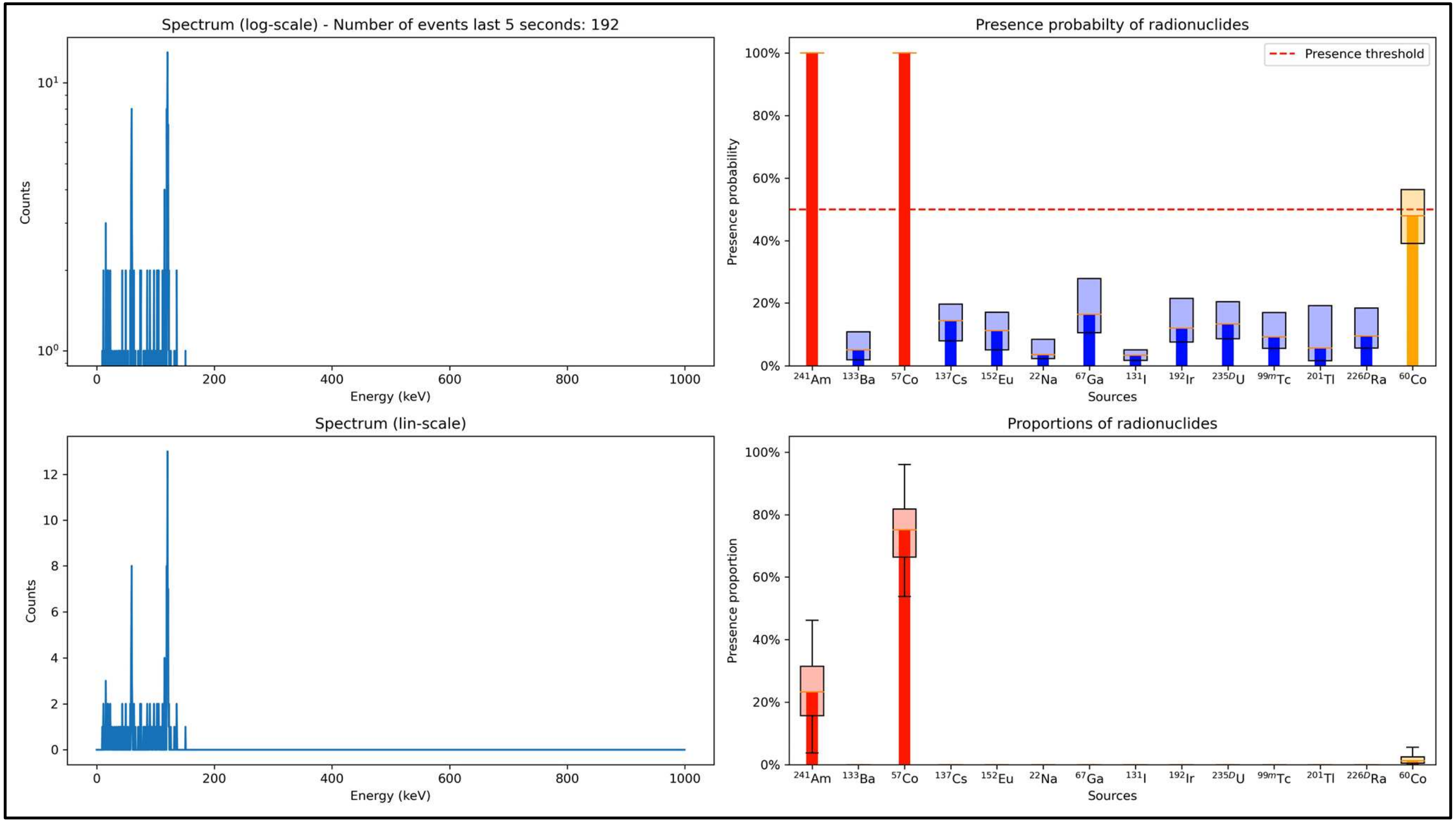
Use of **synthetic** data (MC) to train model:

- Sources we do not have in lab
- Voluntary decalibration → operational conditions
- Mixture creation

OUR AI TOOL: REAL TIME SPECTRAL IDENTIFICATION



OUR AI TOOL: REAL TIME SPECTRAL IDENTIFICATION



PERFORMANCE

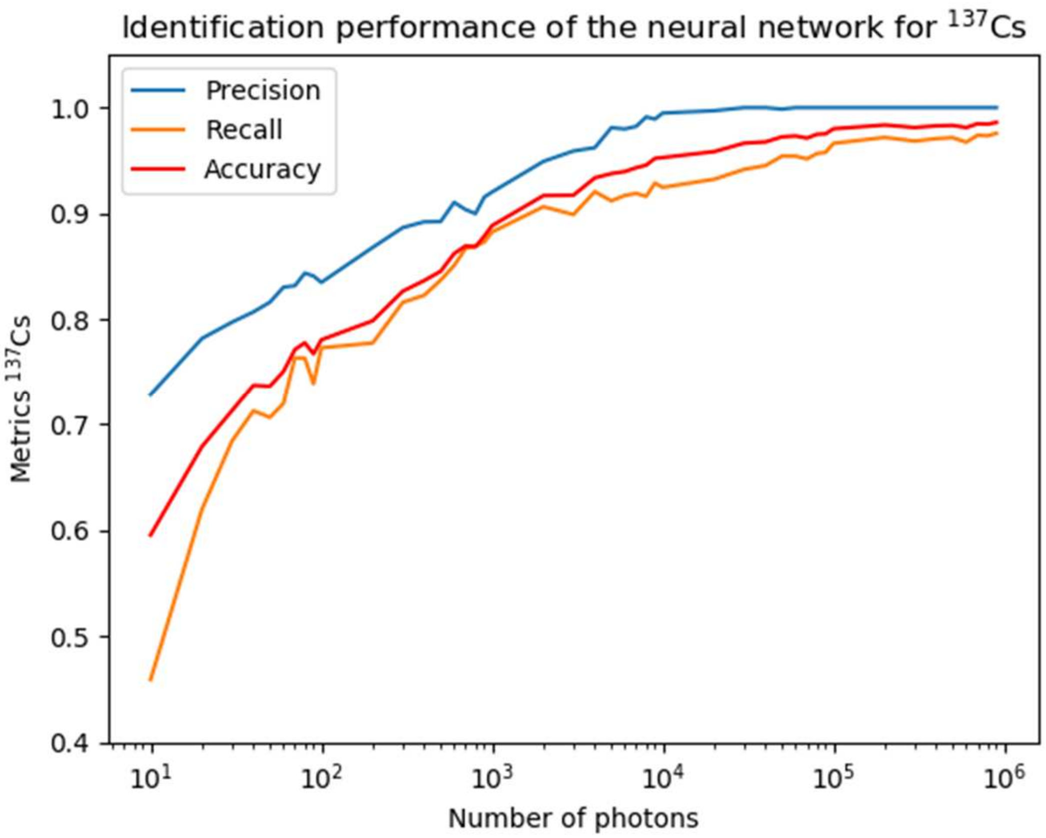
Precision: False positive influence
Recall: False negative influence
Accuracy: Right identification rate

Accuracy:

- > 80 % with more than 200 photons
- > 90 % with at least 1000 photons
- > 95 % with at least some thousands of photons

- Similar performance for other radionuclides: ^{241}Am, ^{133}Ba, ^{57}Co, ^{152}Eu, ^{22}Na

Test on real data of mixtures with **random decalibration**



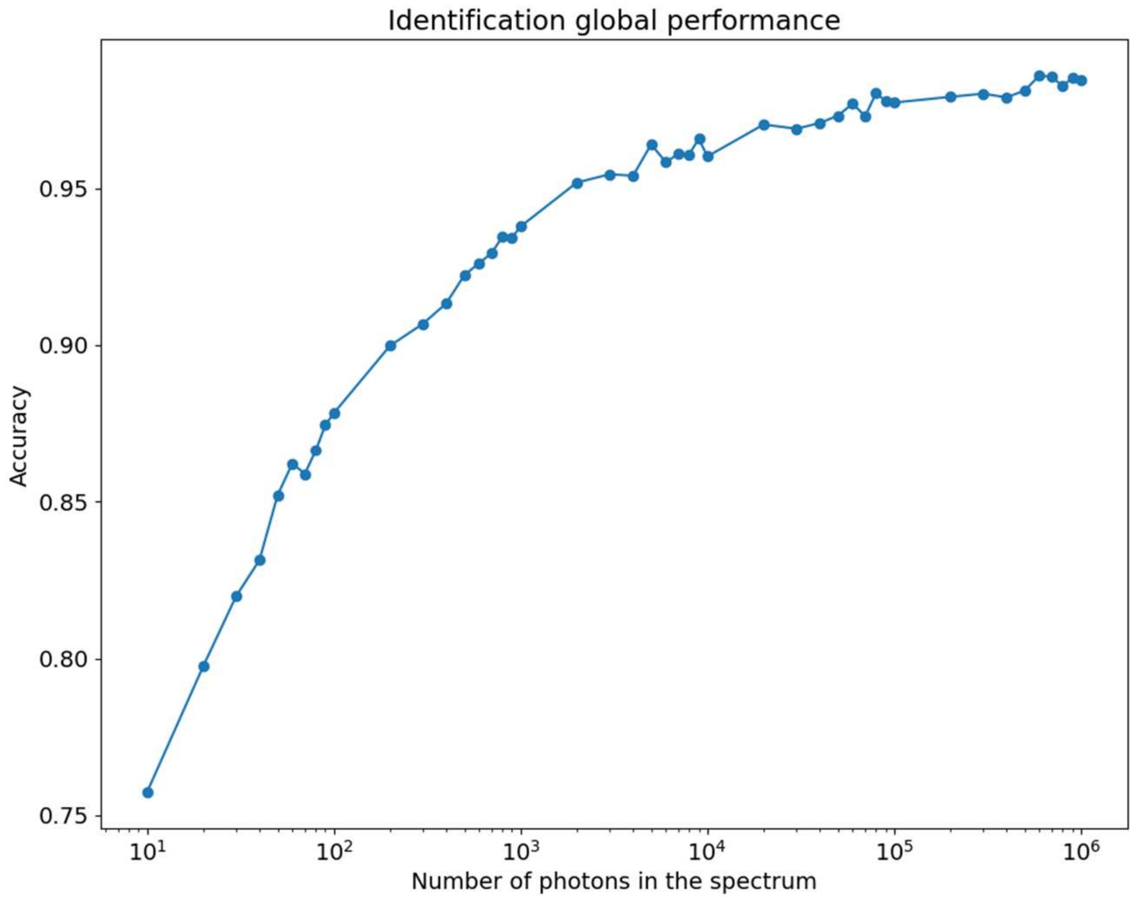
PERFORMANCE

Accuracy: Right identification rate

Accuracy:
- > 90 % with at least 200 photons
- > 95 % with at least 2000 photons

- Global performance for all radionuclides

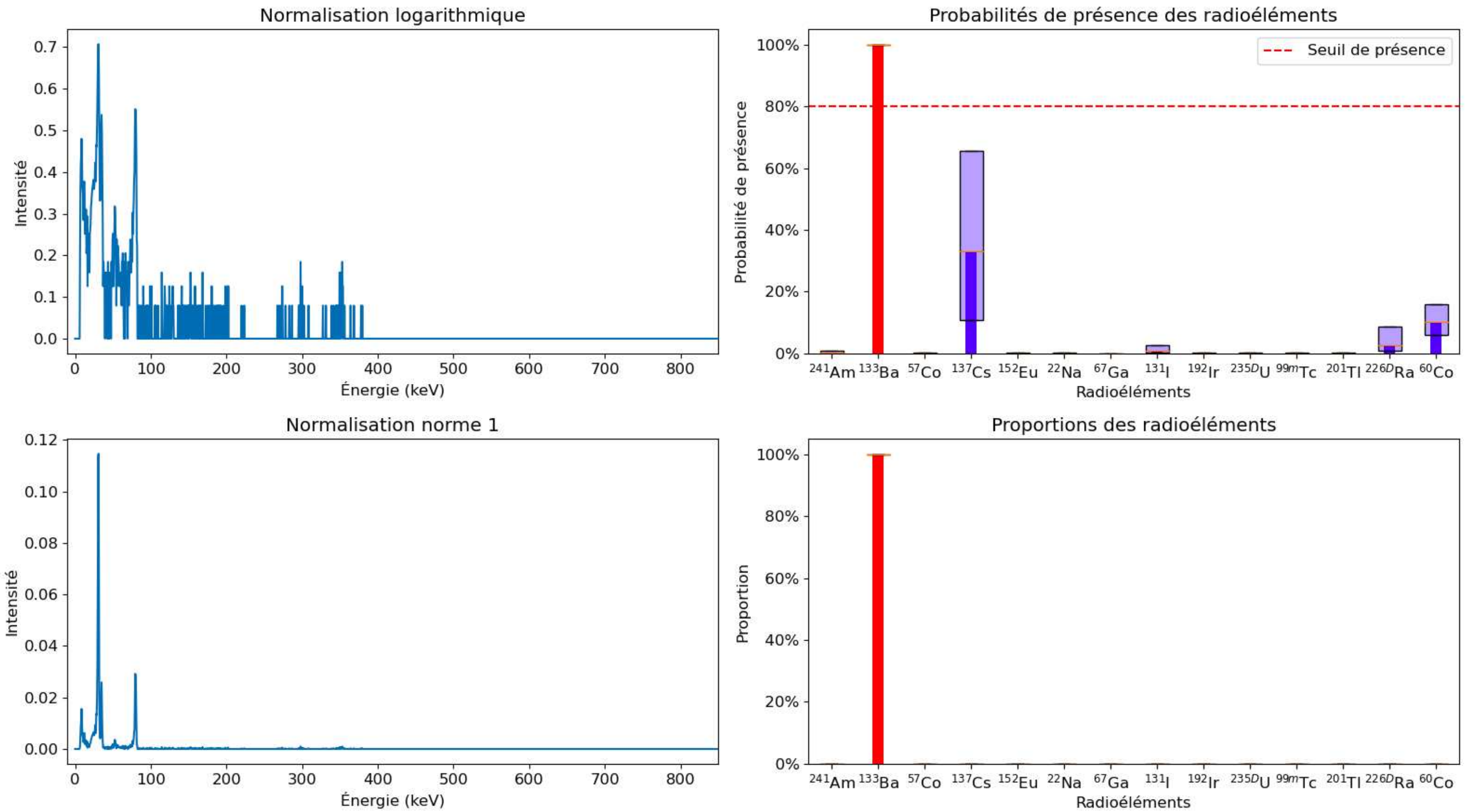
Test on real data of mixtures with **random decalibration**



ISSUES ON COMPLEX ENVIRONMENTS

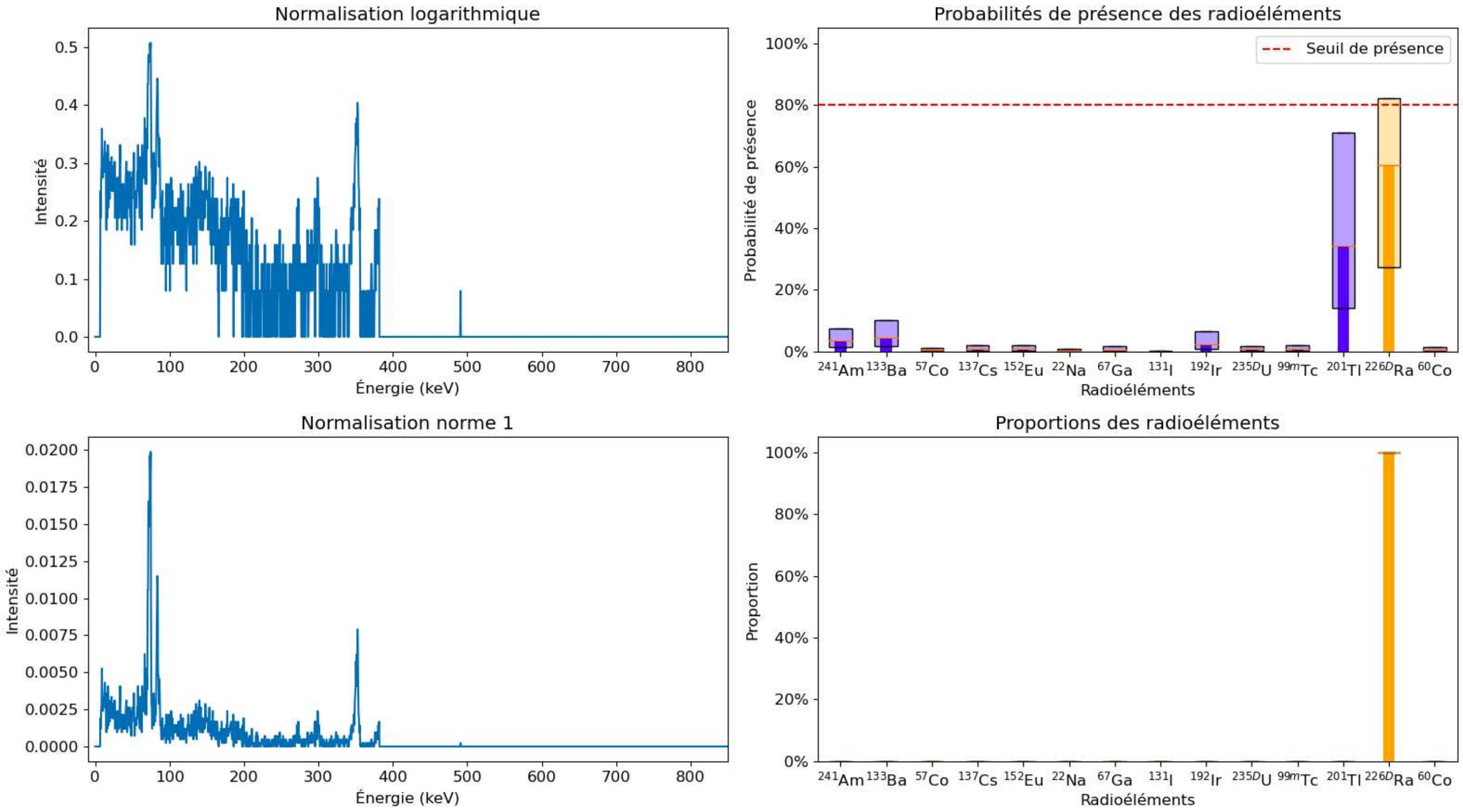
SPECTRAL ID ISSUE IN COMPLEX RADIOLOGICAL ENVIRONMENTS

Identification result from a Ba source in controlled environment



SPECTRAL ID ISSUE IN COMPLEX RADIOLOGICAL ENVIRONMENTS

Identification result from a Ba source behind 6mm of Pb



ISSUE AND CORRECTION PROPOSITION

➢ Loss of accuracy in complex environments
→ Absorbing/scattering materials
→ Train the model on those cases

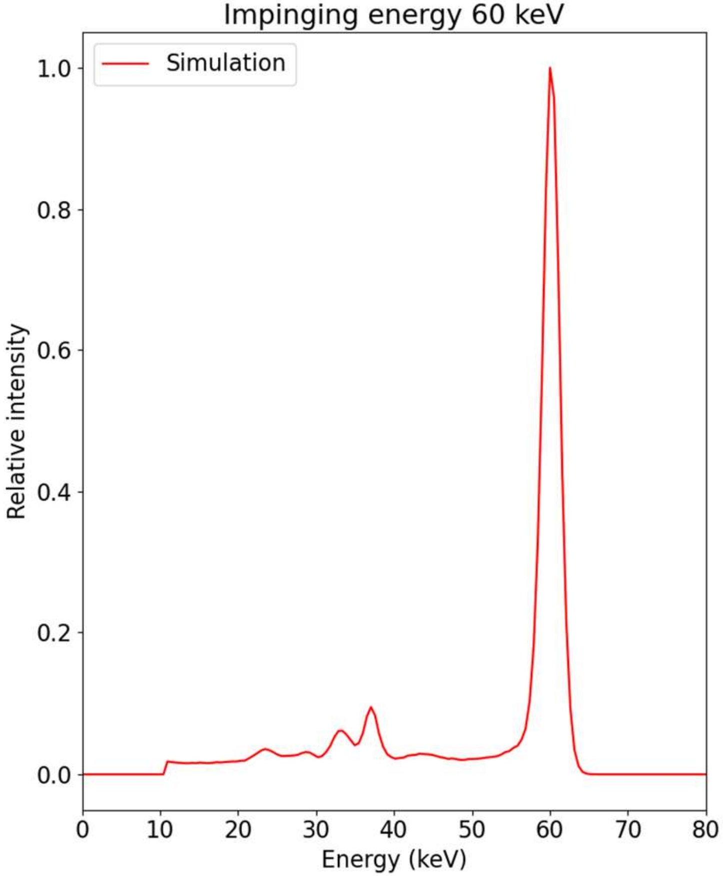
➢ Need of data
→ Monte Carlo issue
→ Time generation

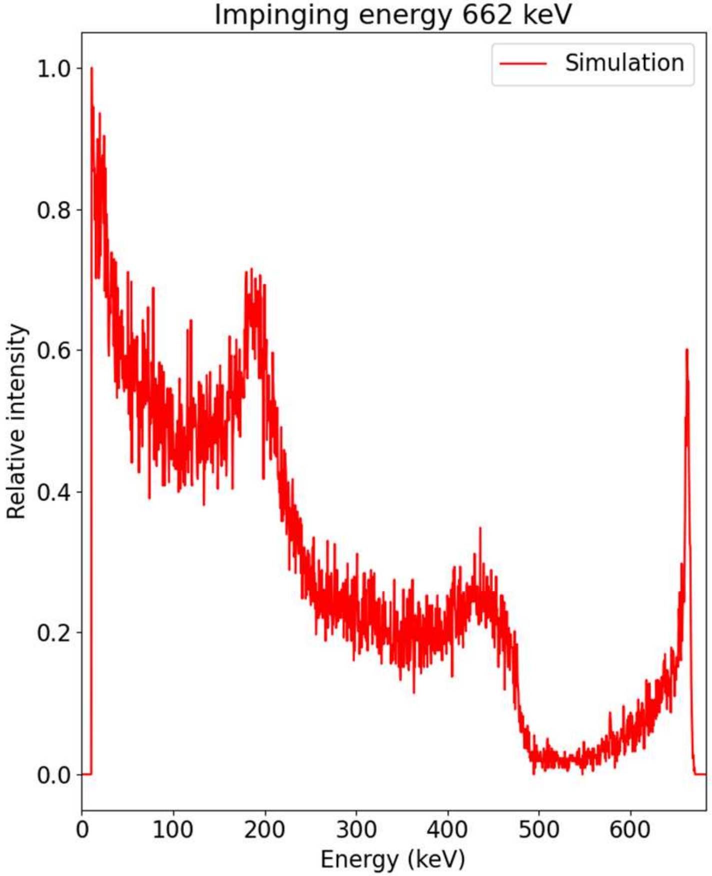
➢ Artificial data generation bypassing Monte Carlo
→ Deep Learning model to interpolate different scenarios

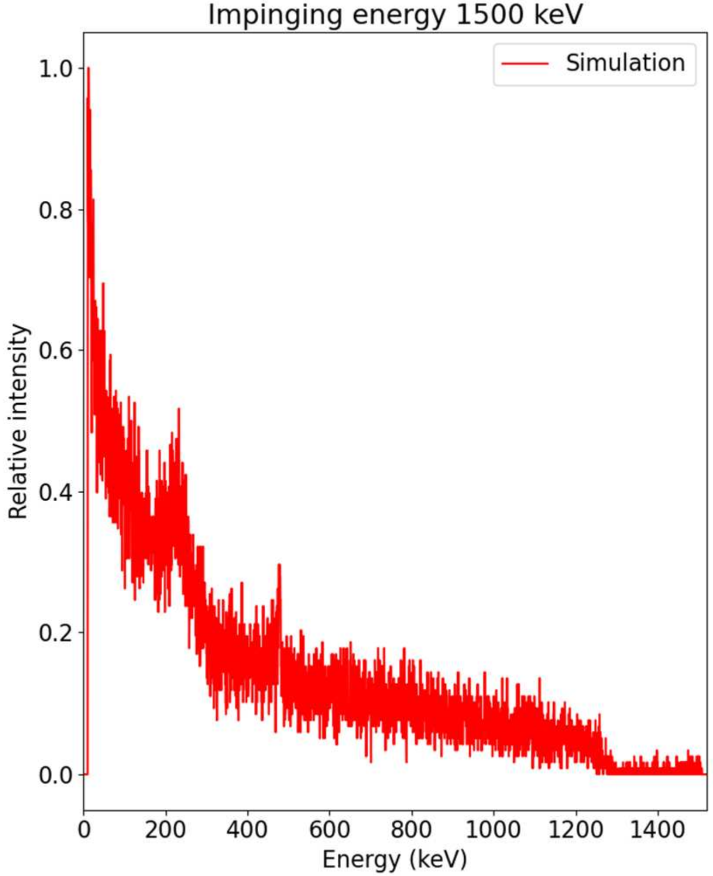
➢ How?
→ **Physical modelization + Mono energetic detector response**

MONO ENERGETIC DETECTOR RESPONSE

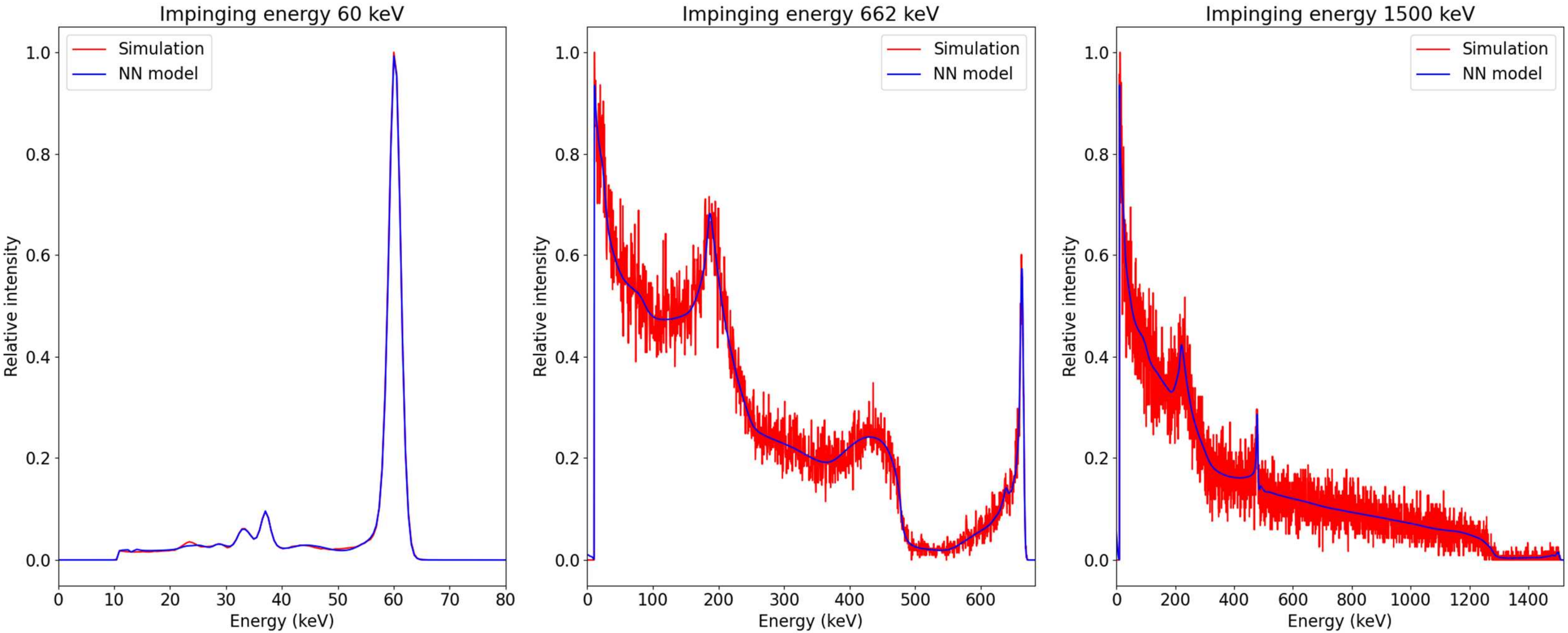
RESPONSE MATRIX INTERPOLATION - MONO ENERGETIC MC SIMULATION



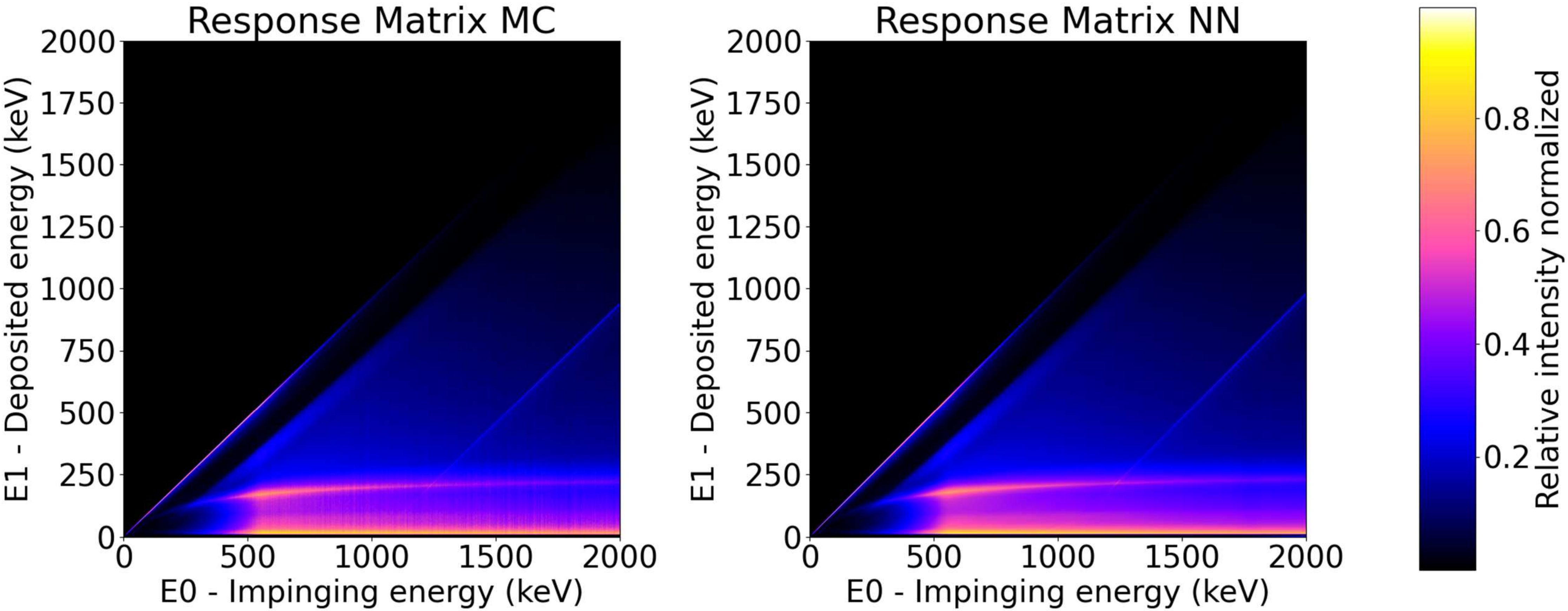




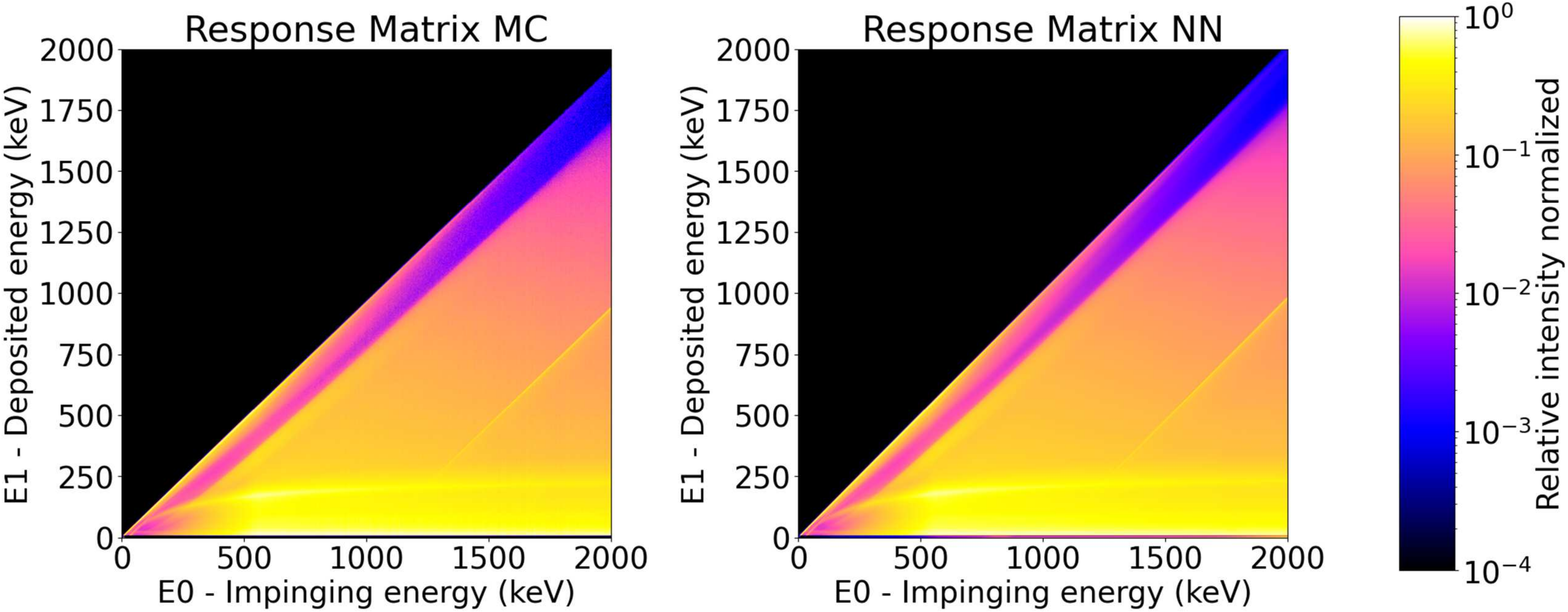
RESPONSE MATRIX INTERPOLATION - MONO ENERGETIC RESULTS



RESPONSE MATRIX INTERPOLATION



RESPONSE MATRIX INTERPOLATION - LOG



PHYSICAL MODELIZATION

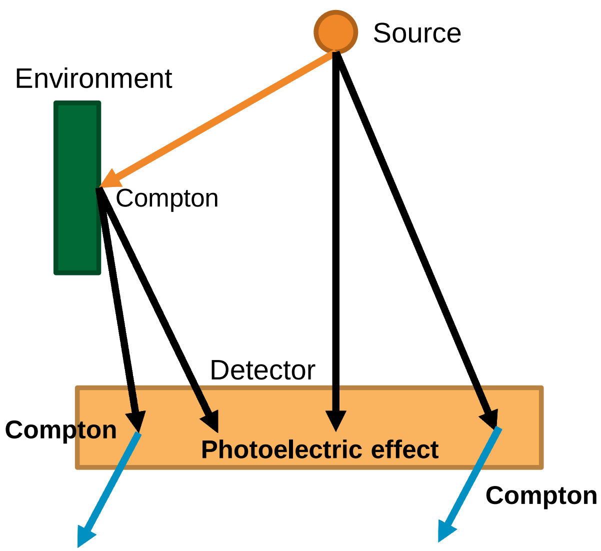
PHYSICAL MODELIZATION

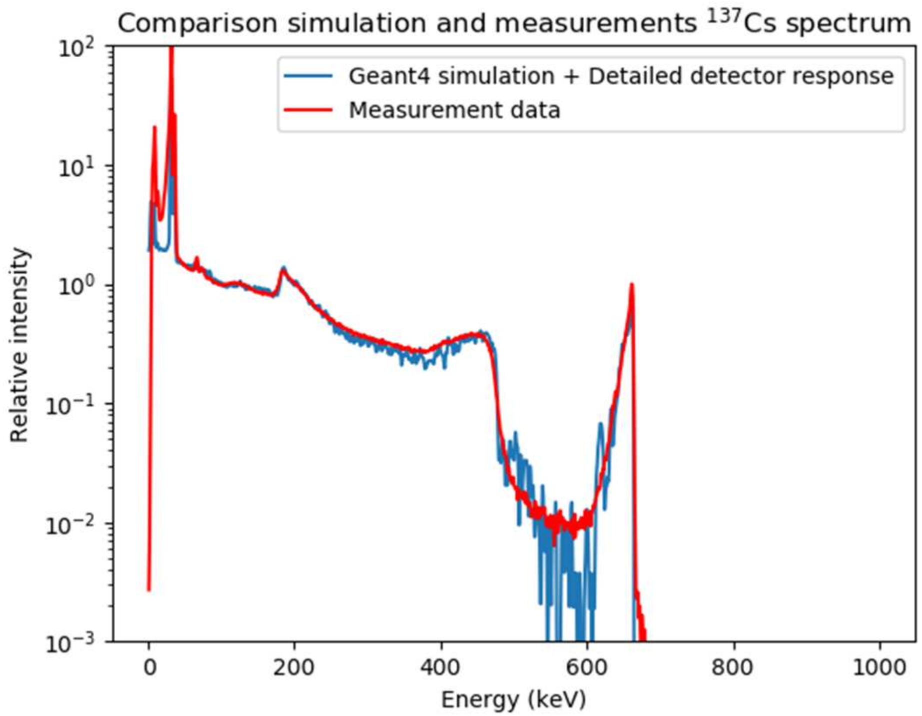
Detailed Geant4 model

- Photoelectric absorption
- Compton diffusion
- Modelisation of direct environment: multiple Compton scattering

Development of an analytical Physics based model

- Fast and less detailed
- Sufficiently representative for Neural Networks identification





CONCLUSION AND OUTLOOKS

So far:

- High accuracy on Spectral ID based on deep learning algorithms trained on synthetic data
- Study on complex environments issues
- Interpolated response matrix

Next steps:

- Evaluate response matrix performance
- Gather physical modelling
- New spectral ID model trained on artificial complex environment data

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[1] *Artificial gamma ray spectra simulation using Generative Adversarial Networks (GANs) and Supervised Generative Networks (SGNs),* Felipe M.F. de Oliveira, G. Daniel, O. Limousin, NIM-A, (2023)

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[5] *The Spid-X gamma camera: A miniature gamma ray integral field spectrometer for nuclear industry applications,* R. Le Breton et al., NIM-A, (2023)