A Single-pixel Gamma Imaging System

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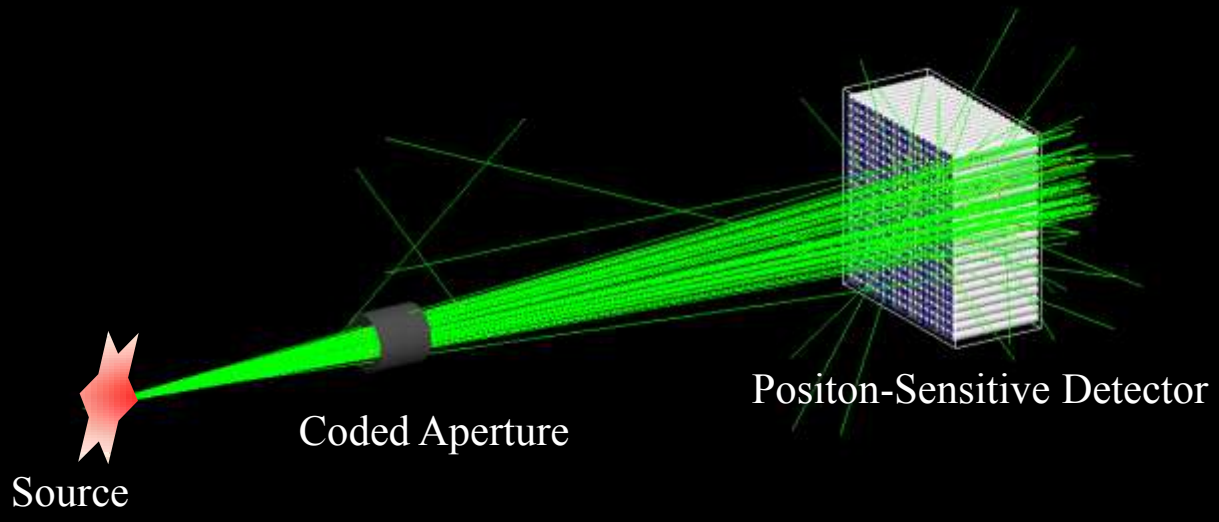
The Gamma-ray Imaging



Why Coded Aperture?

Higher SNR,
Satisfactory Spatial Resolution

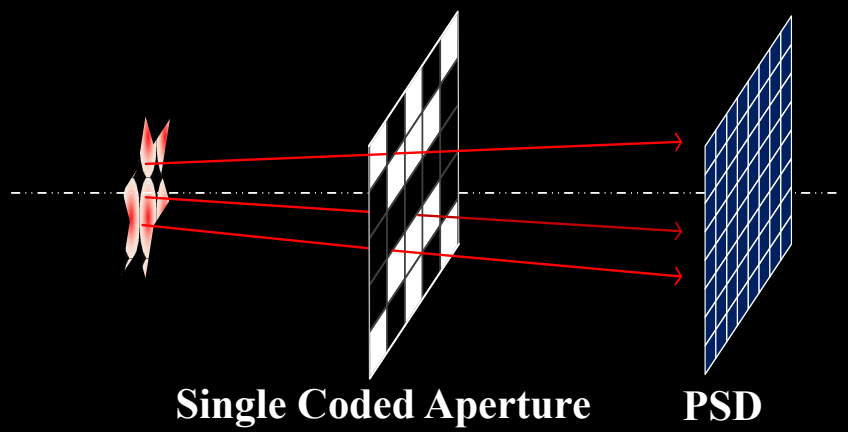
Widely Used In:

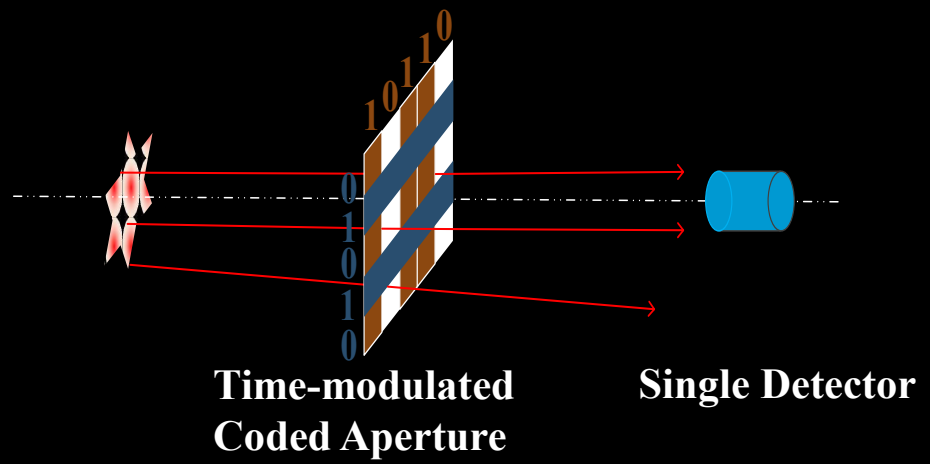
X-ray/Gamma-ray Astronomy
Nuclear Medicine
Nuclear Security
Nuclear Industry
…

Two steps of coded-aperture gamma-ray imaging:

1. *the coded aperture imparts a spatial modulation onto gamma rays, resulting in a coded image;*
2. *The source distribution can be recovered from the coded image.*

From Multi-Pixel to Time-modulated Aperture





poor energy resolution
or poor spatial resolution
or too costly
…

excellent energy resolution
good spatial resolution
cost-efficient
…

The Single-Pixel Gamma Imaging System

Before each measurement, we changed the aperture pattern according to a pseudo-random number sequence.

Coded Aperture:

two groups of orthogonal bars
made of square steel rods
self-supporting geometry

Detector:

3 inch BGO crystal
Hamamatsu PMT R1307
shielded by 5-cm-thick lead bricks
Φ5cm entrance window

Source Reconstruction Method

Compressed Sensing (CS) theory: *a sparse signal can be recovered with high confidence from a small set of linear, non-adaptive measurements.*

Underdetermined equations?

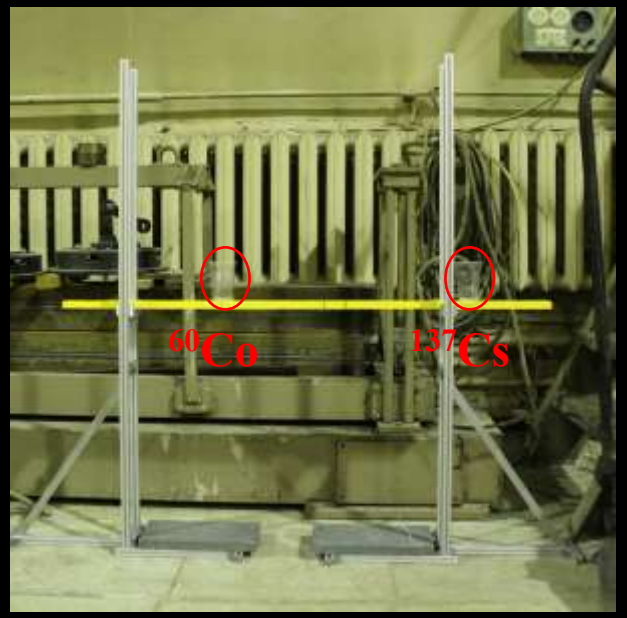
$$\begin{cases} a_{11}f_1 + a_{12}f_2 + \ldots + a_{1N}f_N = g_1 \\ a_{21}f_1 + a_{22}f_2 + \ldots + a_{2N}f_N = g_2 \\ \ldots \\ a_{M1}f_1 + a_{M2}f_2 + \ldots + a_{MN}f_N = g_M \end{cases}$$

$\boldsymbol{f}$— *the unknown source distribution*
$\boldsymbol{g}$— *detector's response*

Seek a sparse solution in space Φ:

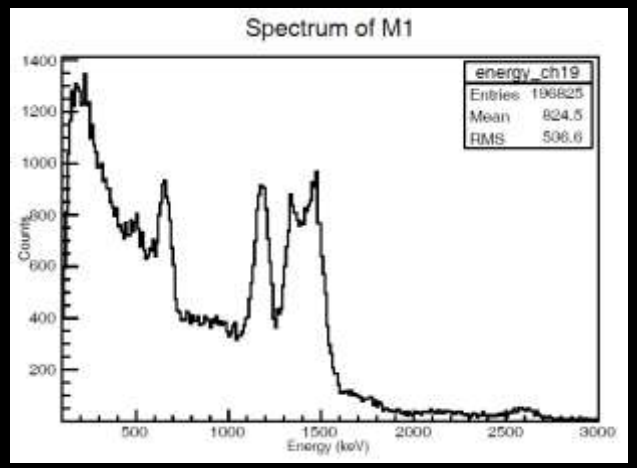
$$\textit{Minimize } ||\boldsymbol{x}||_1,$$
$$\textit{subject to } ||\boldsymbol{A\Phi x - g}||_2 < \eta \textit{ and } f = \boldsymbol{\Phi x} \geq \boldsymbol{0}$$

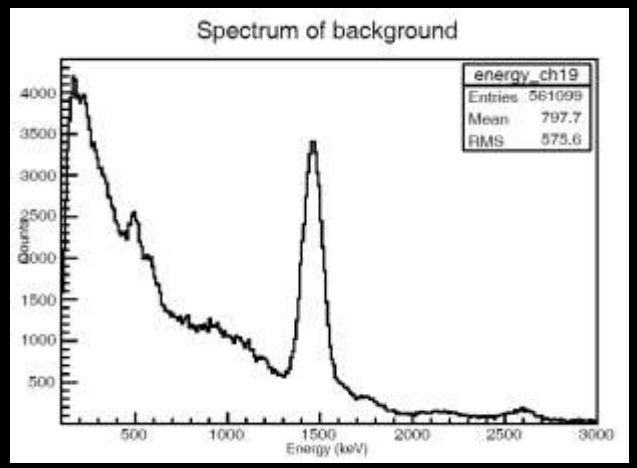
Test I: ^{137}Cs and ^{60}Co

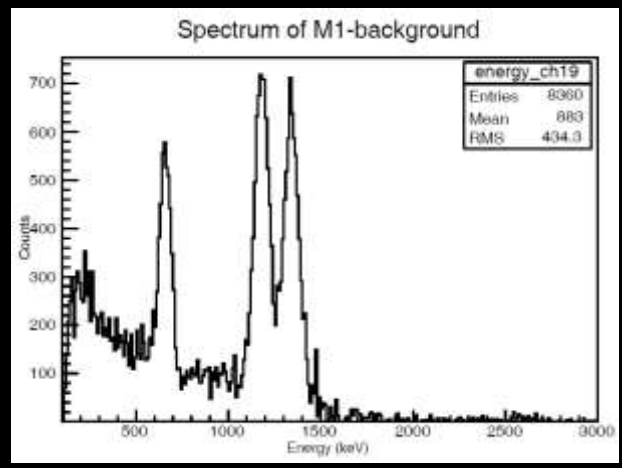


Gamma-ray Sources: ^{60}Co (1173, 1332 keV) and ^{137}Cs (662 keV)
Activity: **^{60}Co** ~70 kBq, **^{137}Cs** ~100 kBq
Location: ~240 cm to the detector, 60 cm separation distance

^{137}Cs and ^{60}Co: Energy Spectrum





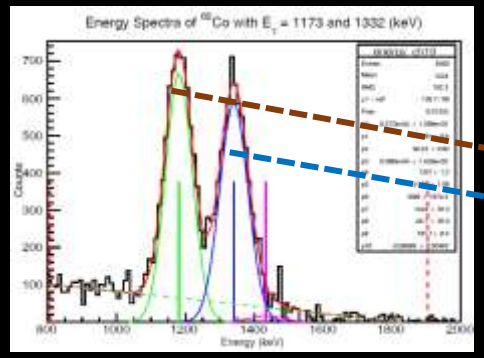


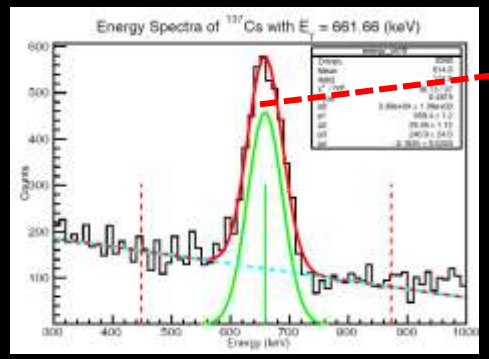
Measurement No. 1

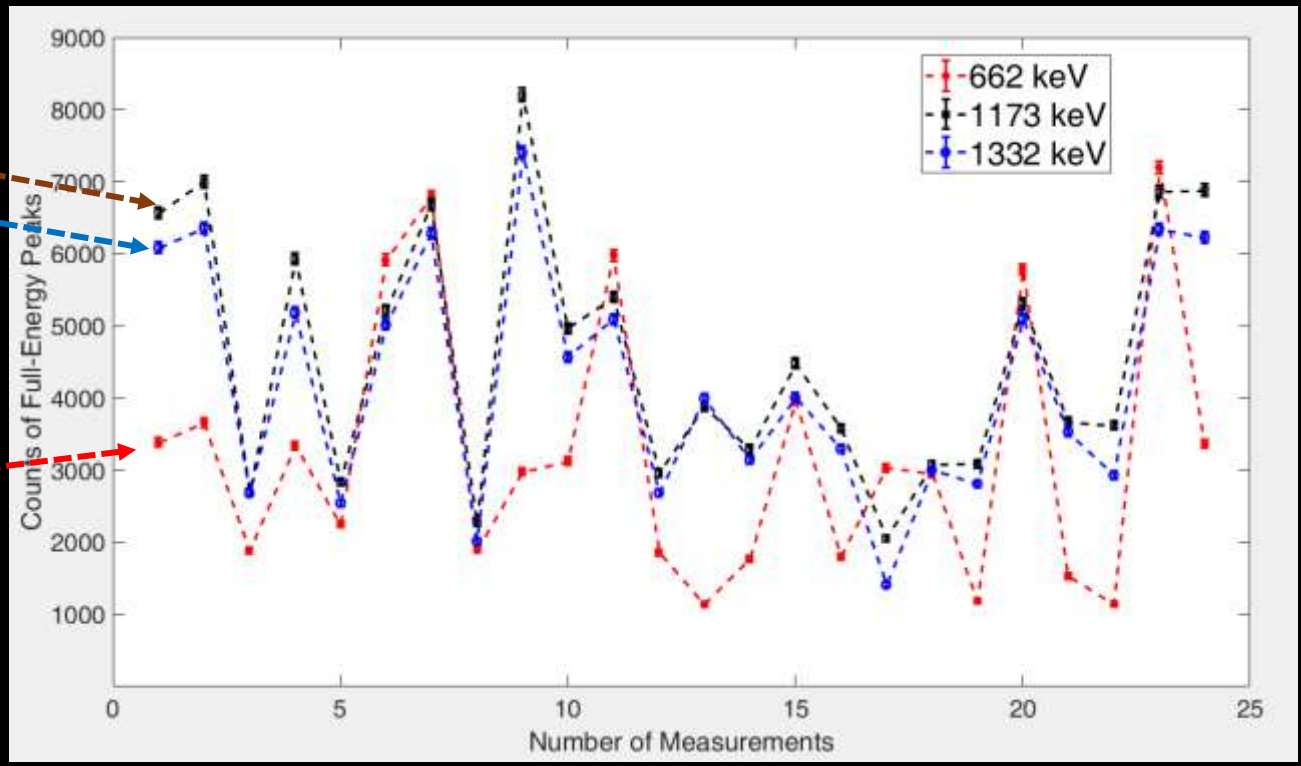
Background
(Shield the entrance window)

Energy Spectrum
of the incident gammas

^{137}Cs and ^{60}Co: Full-Energy Peak Areas





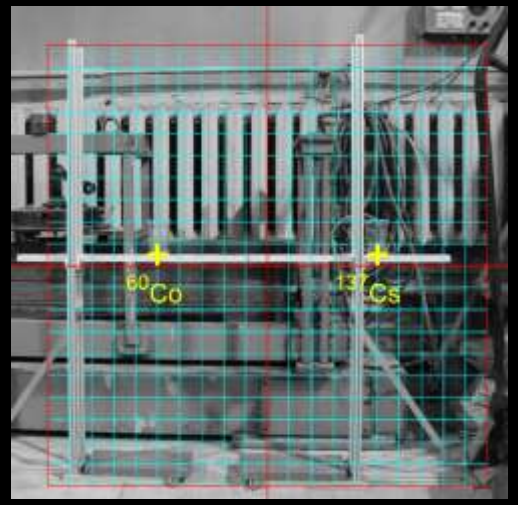


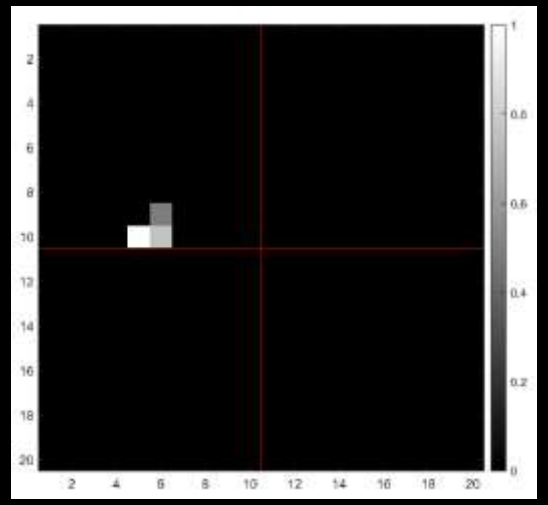
24 Measurements, each lasted 2 hours

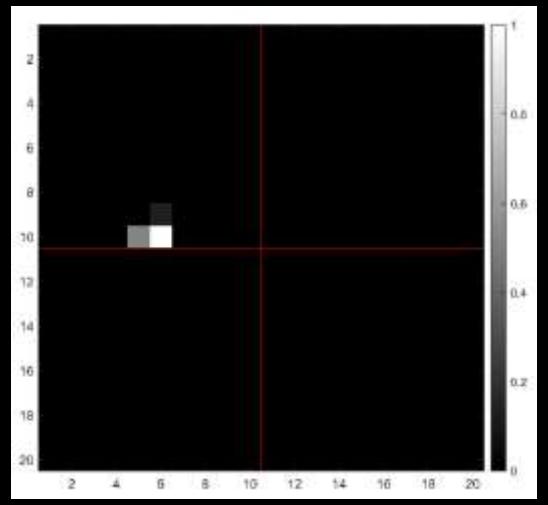
^{137}Cs and ^{60}Co: Source Reconstructions

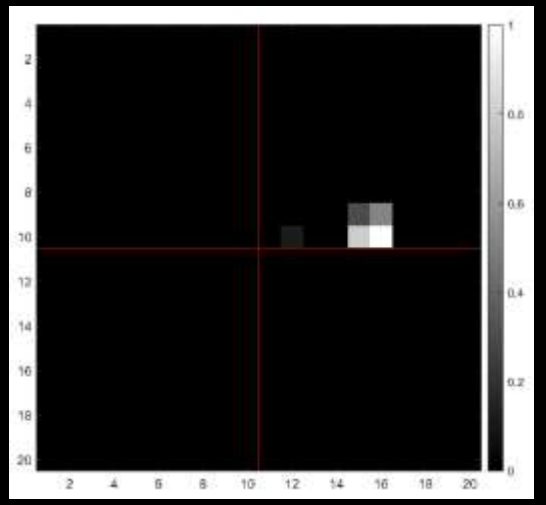
Photography

Recovered Sources









20×20 Pixels

^{60}Co: 1173 keV

^{60}Co: 1332 keV

^{137}Cs: 662 keV

Test II: ^{238}Pu-Be Neutron Source

Activity: 1.2×10^{10} Bq
Neutron: ~10^{6} n/s
Paraffin Moderator: 30cm×30cm×25cm

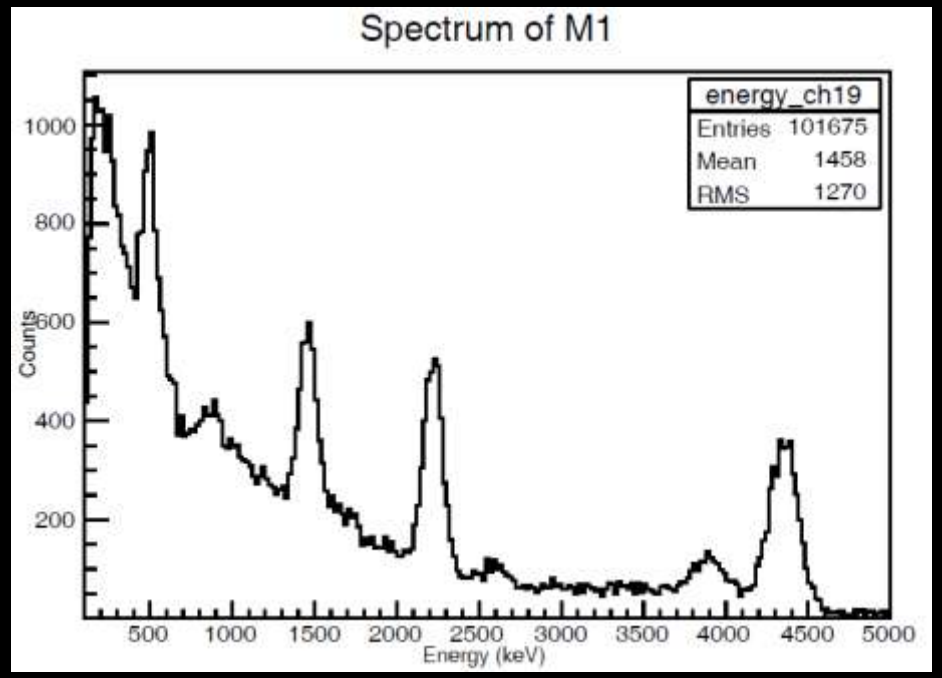
4.44 MeV gamma rays from:

$$^{4}_{2}\alpha + ^{9}_{4}\mathrm{Be} = ^{12}_{6}\mathrm{C}^{*} + ^{1}_{0}\mathrm{n}$$

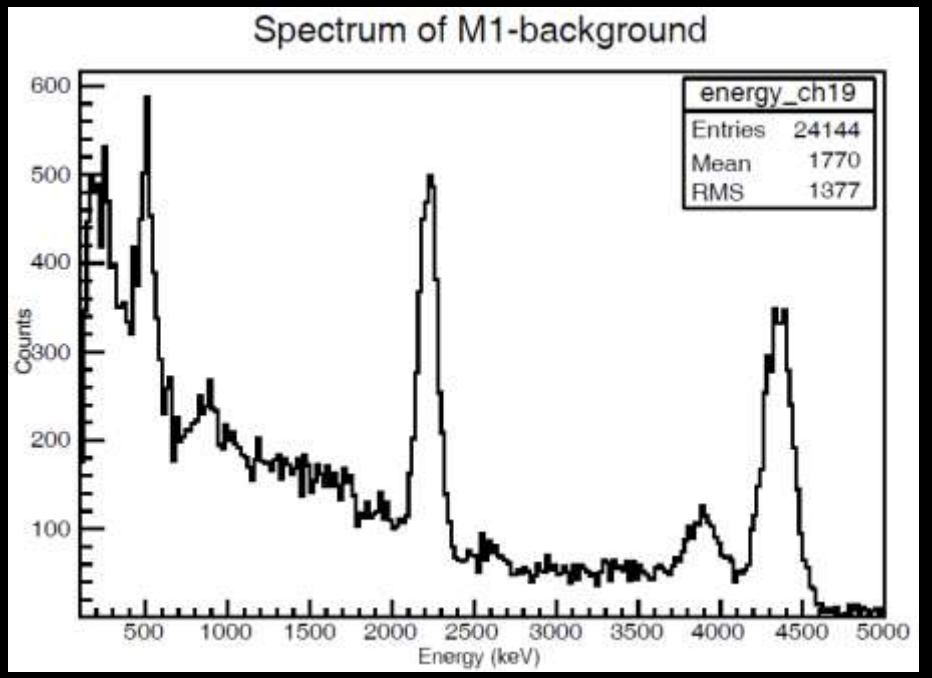
2.22 MeV gamma rays from:

$$^{1}_{0}\mathrm{n} + ^{1}_{1}\mathrm{H} = ^{2}_{1}\mathrm{H} + 2.22\,\mathrm{MeV}$$

^{238}Pu-Be: Energy Spectrum

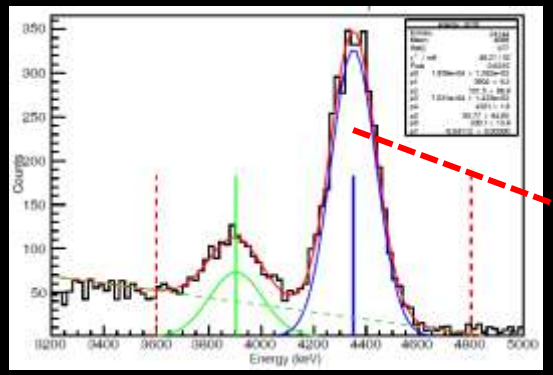


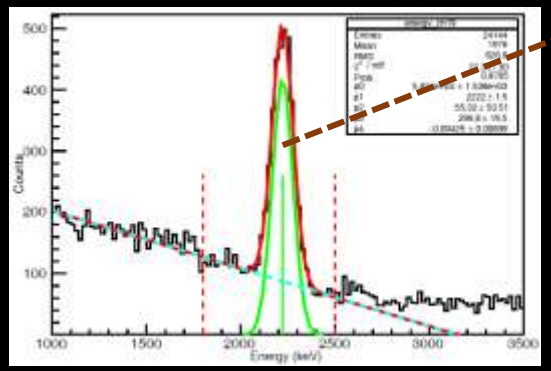
Before background subtraction

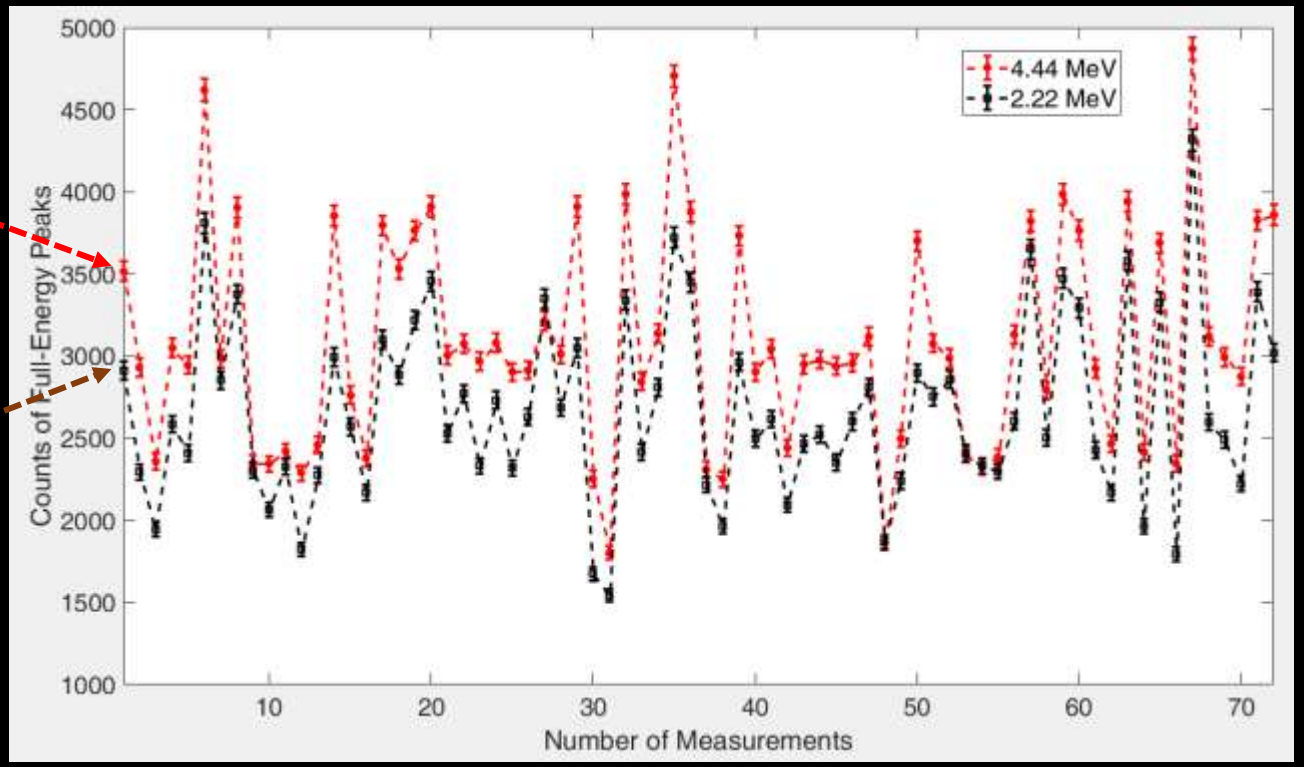


After background subtraction

^{238}Pu-Be: Full-Energy Peak Areas

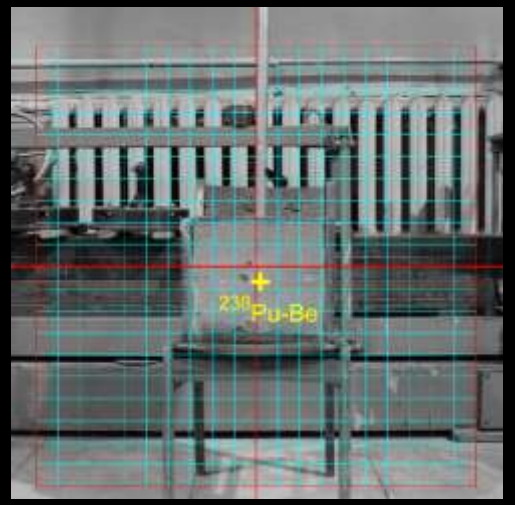


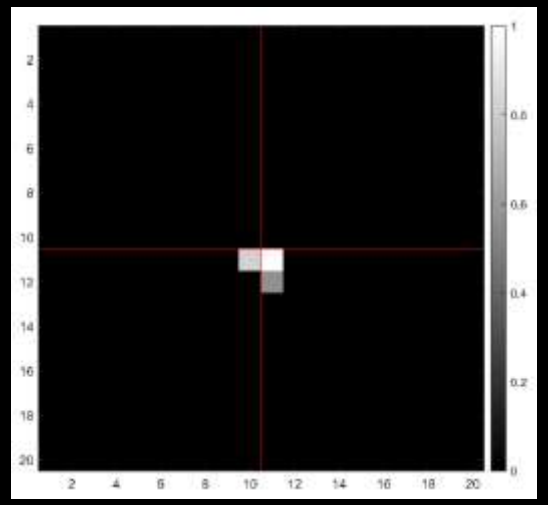


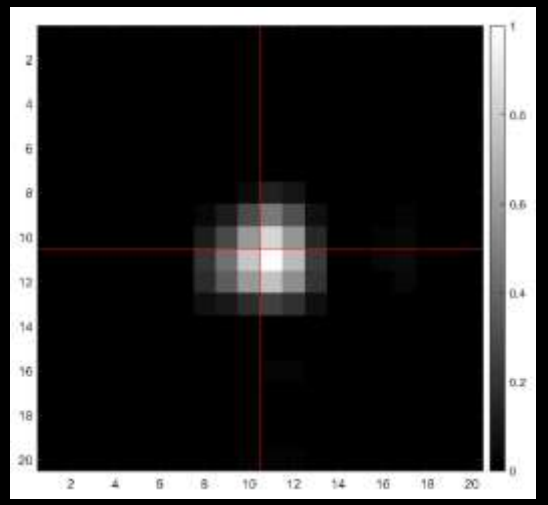


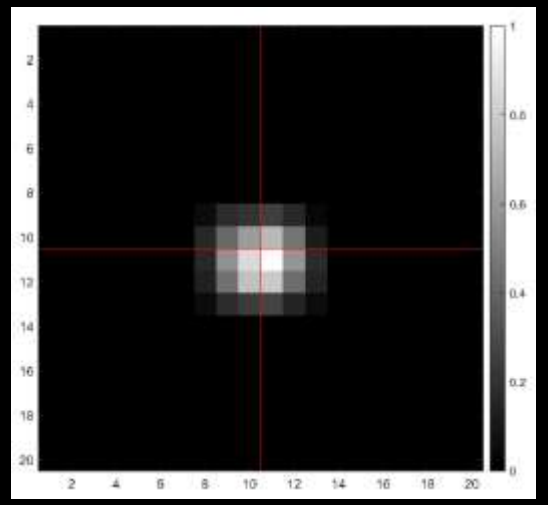
72 Measurements, each lasted 30 minutes

^{238}Pu-Be: Source Reconstructions









20×20 Pixels

Reconstruction:
4.44 MeV

Reconstruction:
2.22 MeV

Geant4 simulation:
2.22 MeV

Some Possible Improvements

Coded aperture from heavy material → Higher spatial resolution

Detector with higher energy resolution

Detector with higher efficiency → Shorter measurement time

Better shielding of the detector

Several detectors instead of only one → Less measurements

Thanks for Your Attention !