Study of small scale position-sensitive scintillator detector for gamma-ray spectroscopy

Zhulieta Toneva

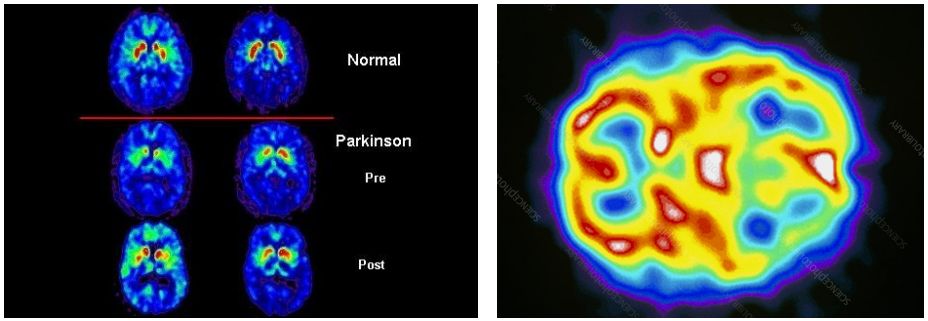
Sofia University "St. Kliment Ohridski"
Sofia, Bulgaria

11 July 2019

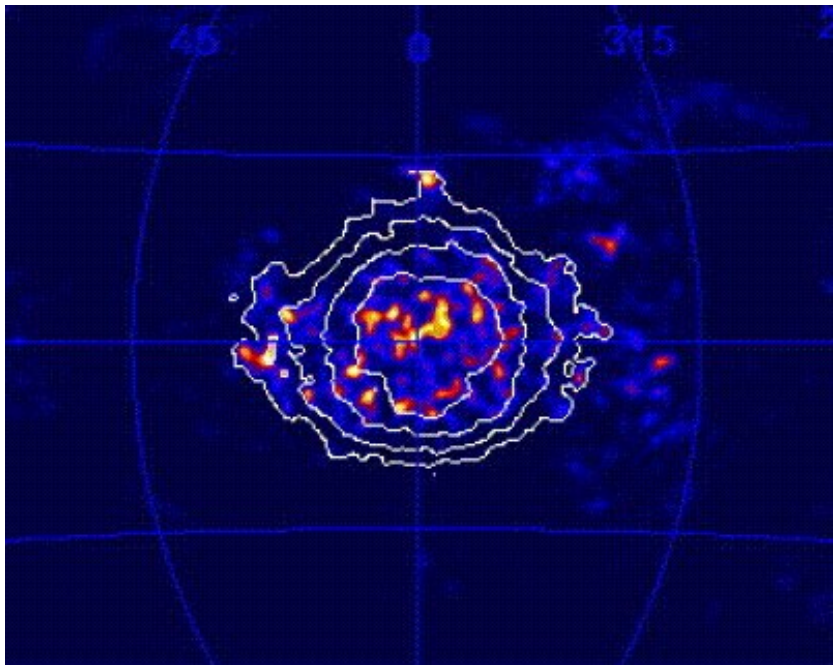
Outline

γ-ray spectroscopy and imaging

- Particle physics
- Nuclear physics
- **Medical physics**



PET brain scan & SPECT brain during migraine
Credit: Dept. of Nuclear Medicine, Charing Cross Hospital / Science Photo Library

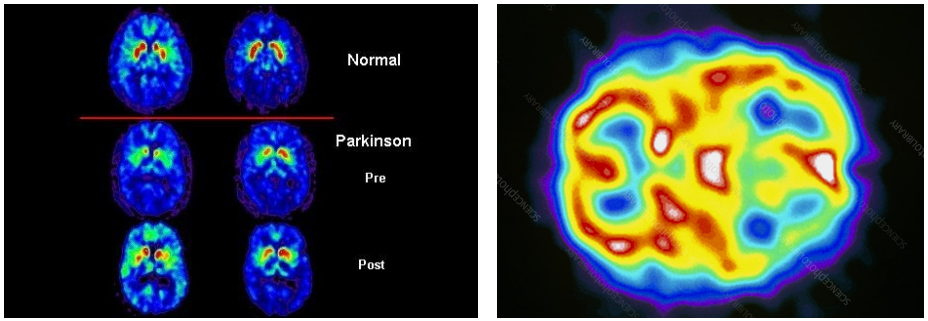


SPI image of 511 keV emission of centre of our Galaxy
Credit: J. Kndlseder (CESR) & SPI team

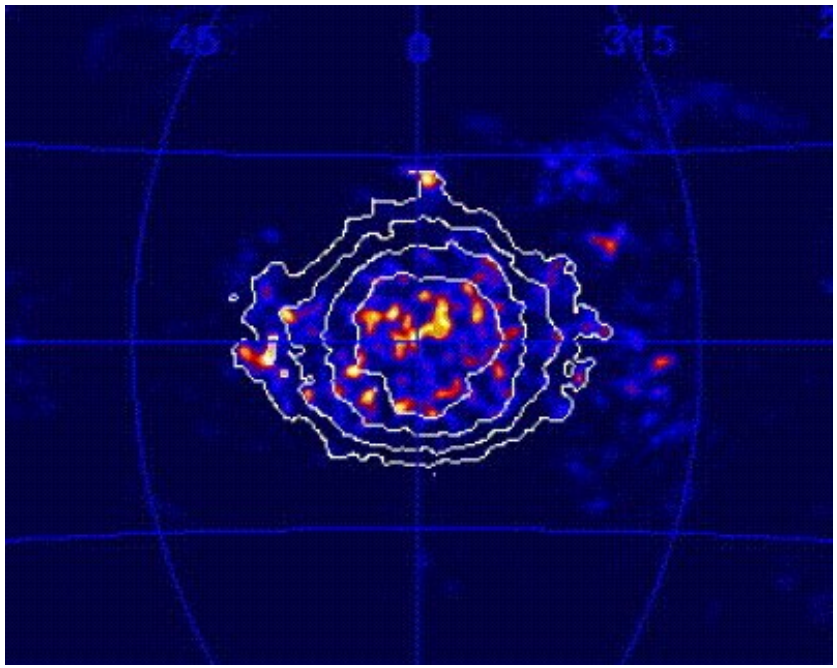
- **Astronomy**

γ-ray spectroscopy and imaging

- Particle physics
- Nuclear physics
- **Medical physics**



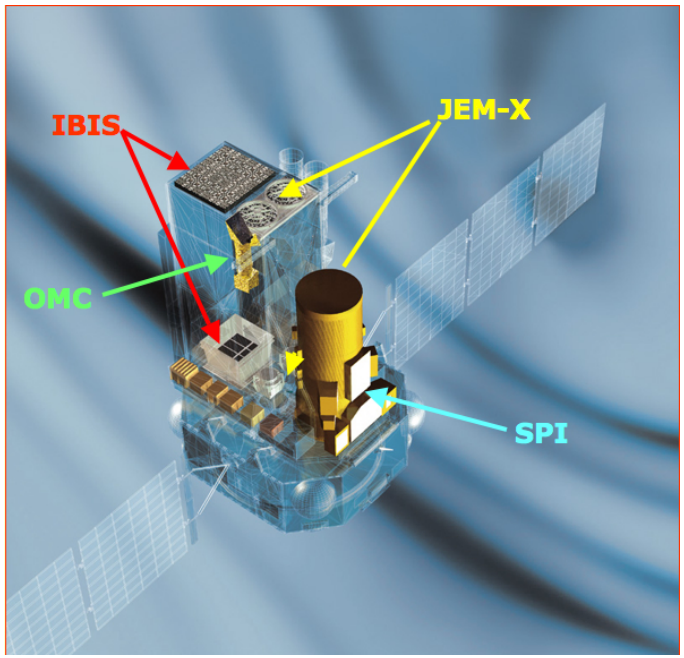
PET brain scan & SPECT brain during migraine
Credit: Dept. of Nuclear Medicine, Charing Cross Hospital / Science Photo Library



SPI image of 511 keV emission of centre of our Galaxy
Credit: J. Kndlseder (CESR) & SPI team

- **Astronomy**
- Project NDeGRA "Novel Detectors for Gamma-Ray Astronomy"

γ-ray spectroscopy & imaging in Astromony (8 keV - 8 MeV)



Integral
Credit: ESA

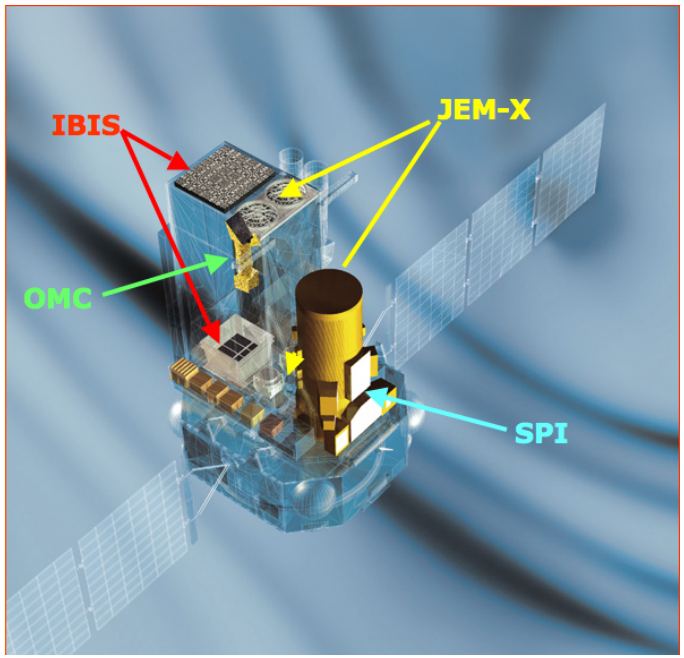
SPI Spectrometer on Integral

- Energy range: 8 keV - 8 MeV
- Energy resolution:
  2.2 keV FWHM @ 1.33 MeV
- 19 Ge detectors
  (Operating T of 85 K)

IBIS Imager on board the Integral Satellite

- Energy range: 15 keV - 10 MeV
- Energy resolution:
  8% @ 100 keV & 10% @ 1 MeV

γ-ray spectroscopy & imaging in Astromony (8 keV - 8 MeV)



Integral
Credit: ESA

SPI Spectrometer on Integral

- Energy range: 8 keV - 8 MeV
- Energy resolution:
  2.2 keV FWHM @ 1.33 MeV
- 19 Ge detectors
  (Operating T of 85 K)

IBIS Imager on board the Integral Satellite

- Energy range: 15 keV - 10 MeV
- Energy resolution:
  8% @ 100 keV & 10% @ 1 MeV

- SPI + IBIS weight:
  over 2 tones
- Complex sysmes
- Difficult to improve

- Long development time
- High risk for mission execution
- Expensive

Different approach

- Small and light
- Easy to build
- Easy to improve
- Cheap (to launch)
- Repeatedly reproduced

Different approach

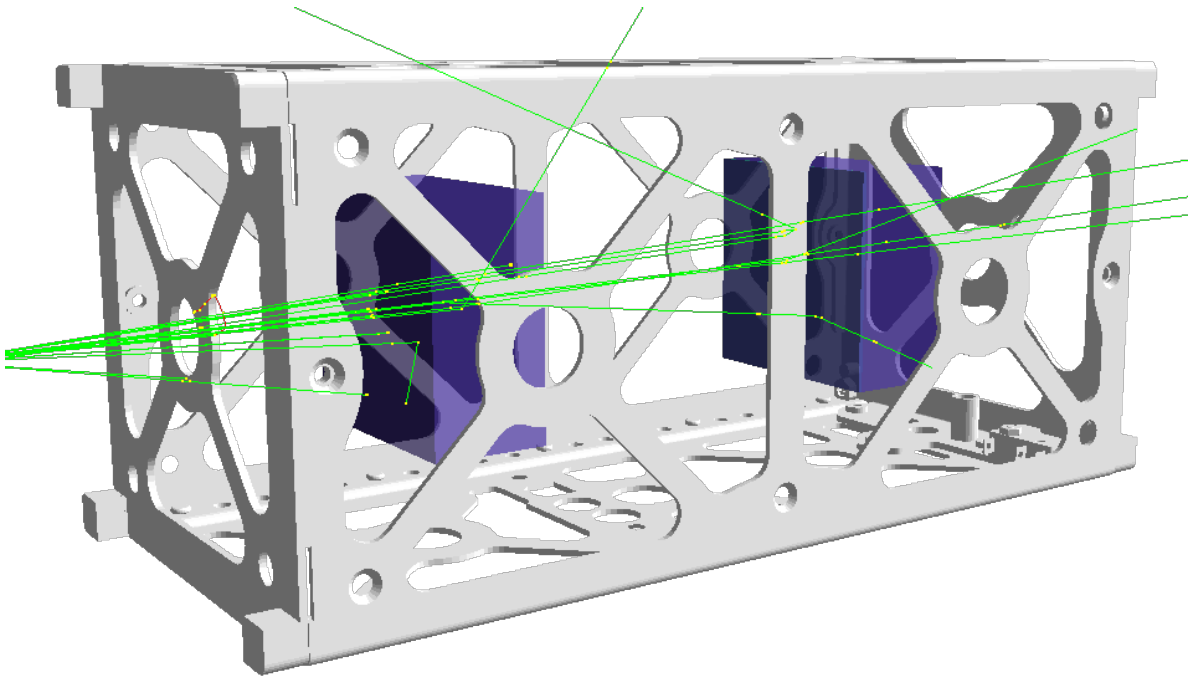
- Small and light
- Easy to build
- Easy to improve
- Cheap (to launch)
- Repeatedly reproduced

- Imaging & spectroscopy
- Energy range: 50 keV - 2 MeV

Different approach

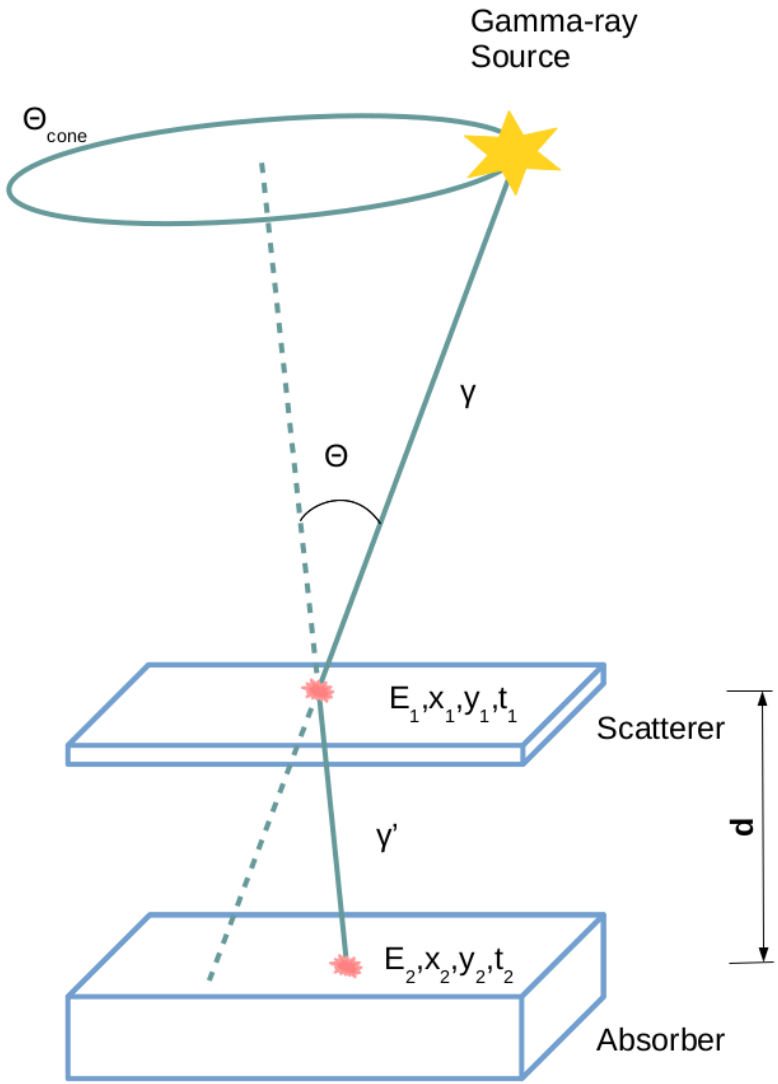
- Small and light
- Easy to build
- Easy to improve
- Cheap (to launch)
- Repeatedly reproduced

- Imaging & spectroscopy
- Energy range: 50 keV - 2 MeV
- Nanosatellite:
  up to 3 CubeSat units
  (each 10 x 10 x 10 cm^3)



How we can do that?

Compton telescope



$$cos\Theta = 1 - m_e c^2 (\frac{1}{E_2} - \frac{1}{E_1 + E_2})$$

$$d = (x_1, y_1) - (x_2, y_2)$$

$$Source(x, y) = (d, \Theta)$$

- Fast γ-γ coincidences

Materials

- Scintillator: **$CeBr_3$**
  - Good Energy resolution
    $< 5\%$ 662 keV
  - Fast scintillator
    < 1 ns time resolution

    (as $LaBr_3Ce$)
  - No internal radiation
  - High light output

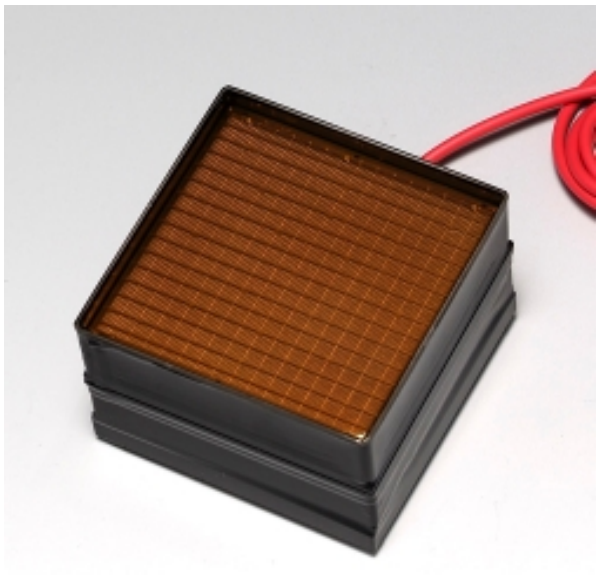
Credit: SCIONIX

Materials

- Scintillator: **$CeBr_3$**
  - Good Energy resolution
    $< 5\%$ 662 keV
  - Fast scintillator
    < 1 ns time resolution

    (as $LaBr_3Ce$)
  - No internal radiation
  - High light output

Credit: SCIONIX



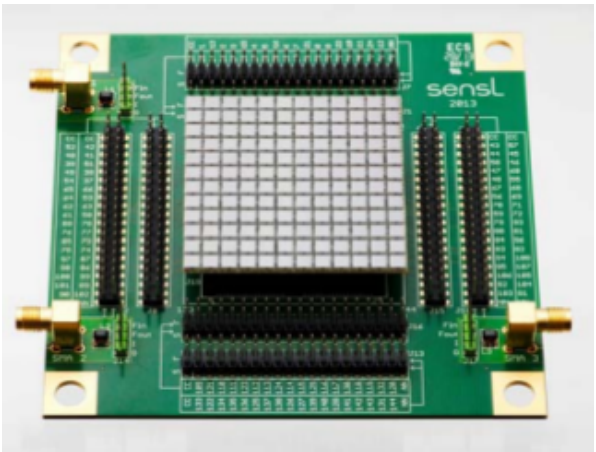
Credit: HAMAMATSU

- Light sensor: **MAPMT**
  - High-voltage operation
  - High Gain apx. 10^6

Materials

- Scintillator: **$CeBr_3$**
  - Good Energy resolution
    $< 5\%$ 662 keV
  - Fast scintillator
    < 1 ns time resolution
    (as $LaBr_3Ce$)
  - No internal radiation

Credit: SCIONIX

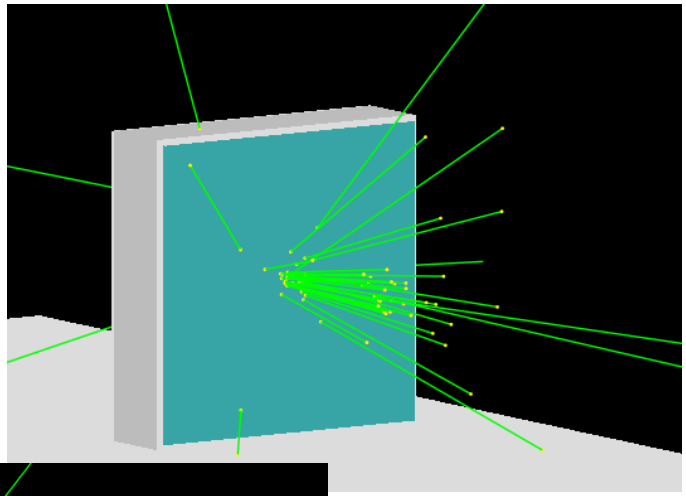


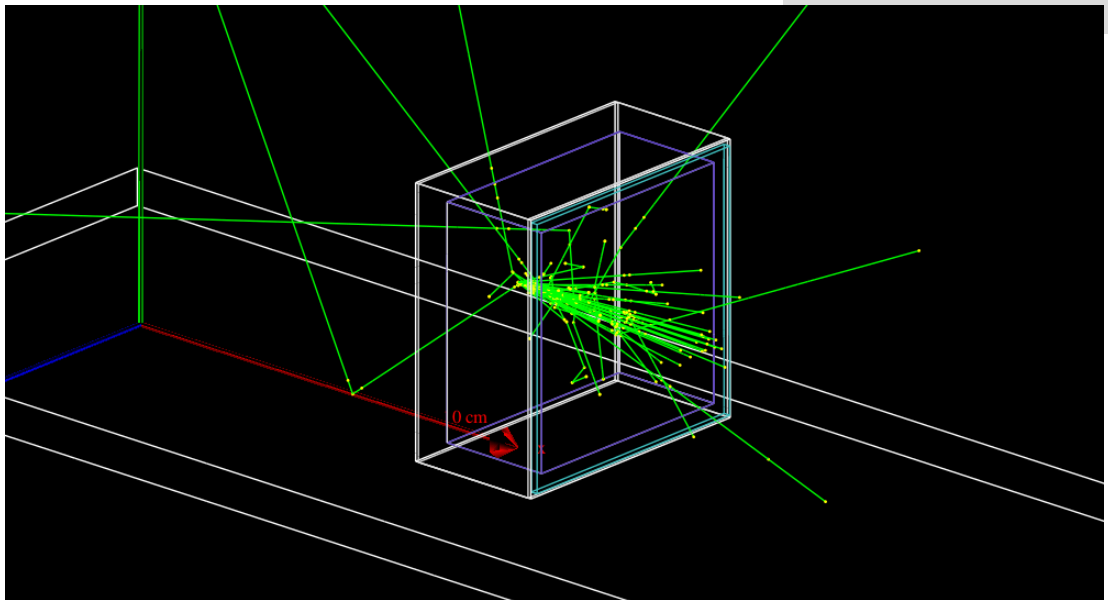
Credit: SENSL

- Light sensor: **SiPM**
  - Low-voltage operation ✓
  - High Gain apx. 10^6

Geant4 simulations

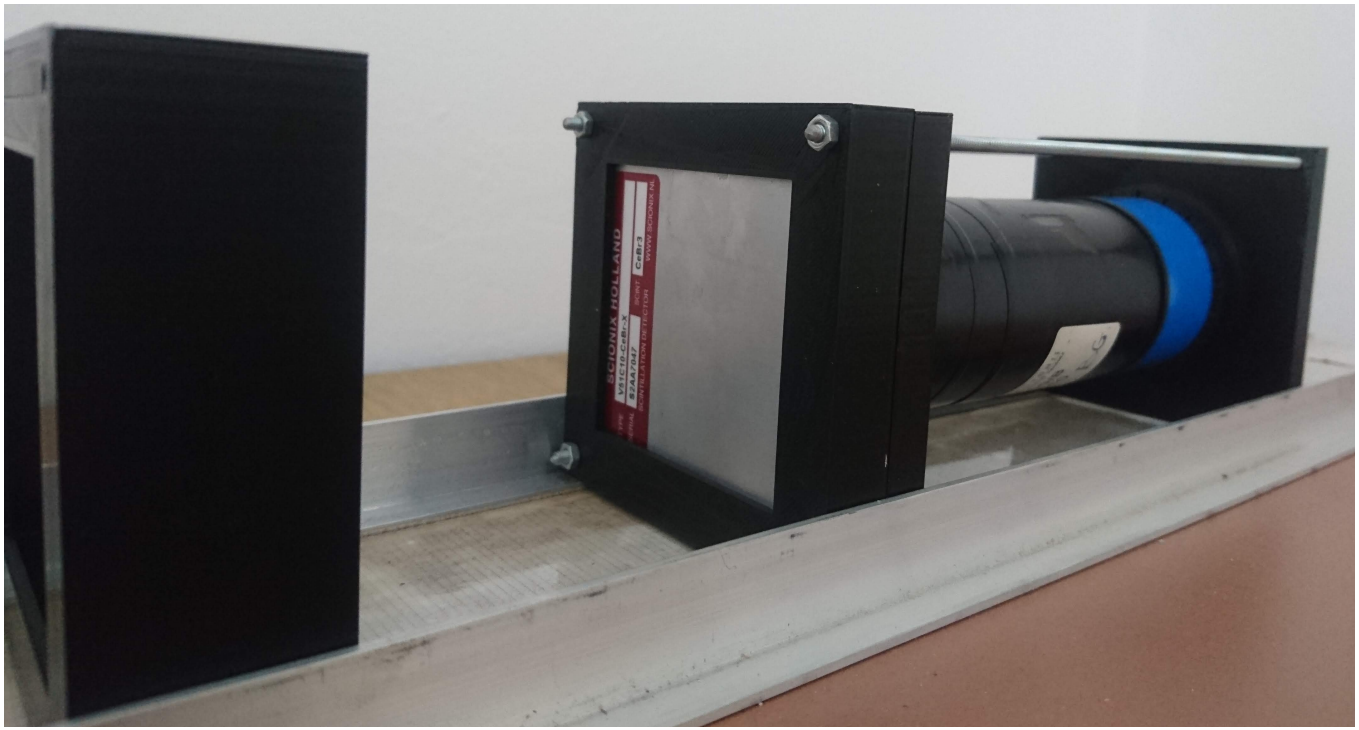
- Geometry - G4GDMLParser class (generated GDML file directly from CAD file)
- Beam - G4GeneralParticleSource (GPS) class (macro file)



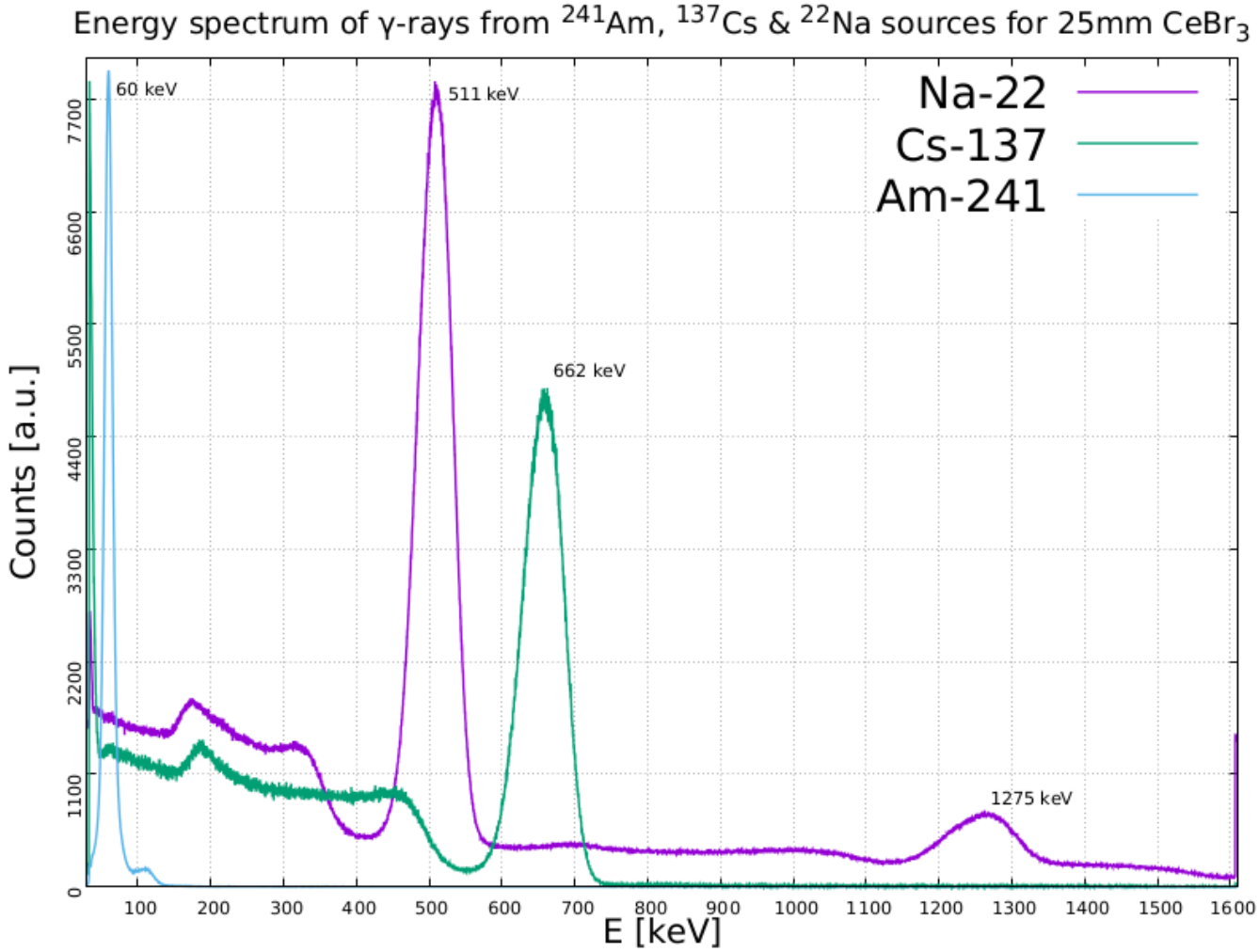


Experimental setup for $CeBr_3$ energy resolution estimations

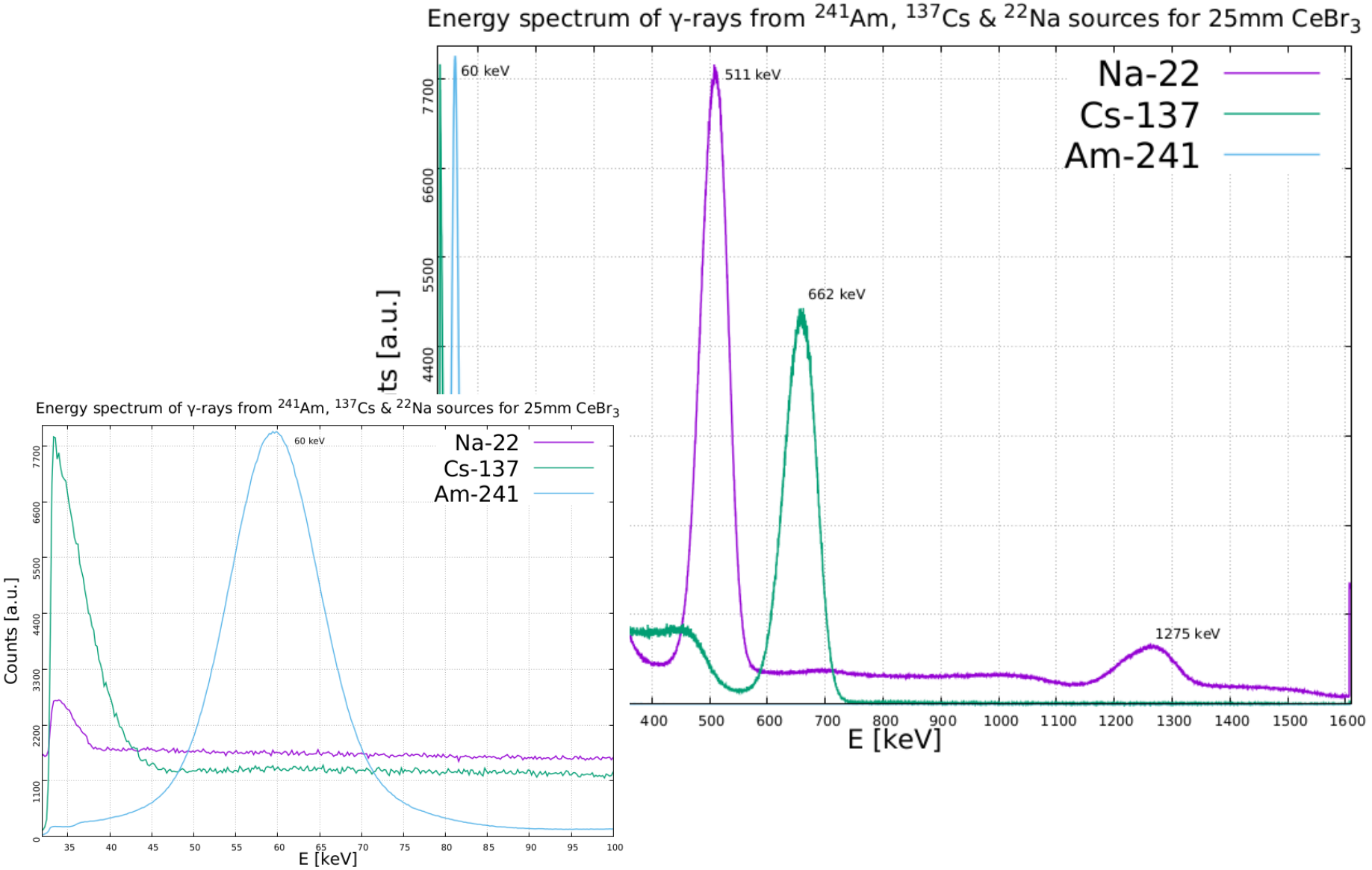
- $CeBr_3$ - thickness 25 & 10 mm
  - 51 x 51 mm^2
- PMT - XP20D0B, Photonis
  - 51 mm, round tube
- HV - N1470, CAEN (operating HV -1000 V)
- ^{137}Cs, ^{22}Na & ^{241}Am



$CeBr_3$ energy resolution



$CeBr_3$ energy resolution

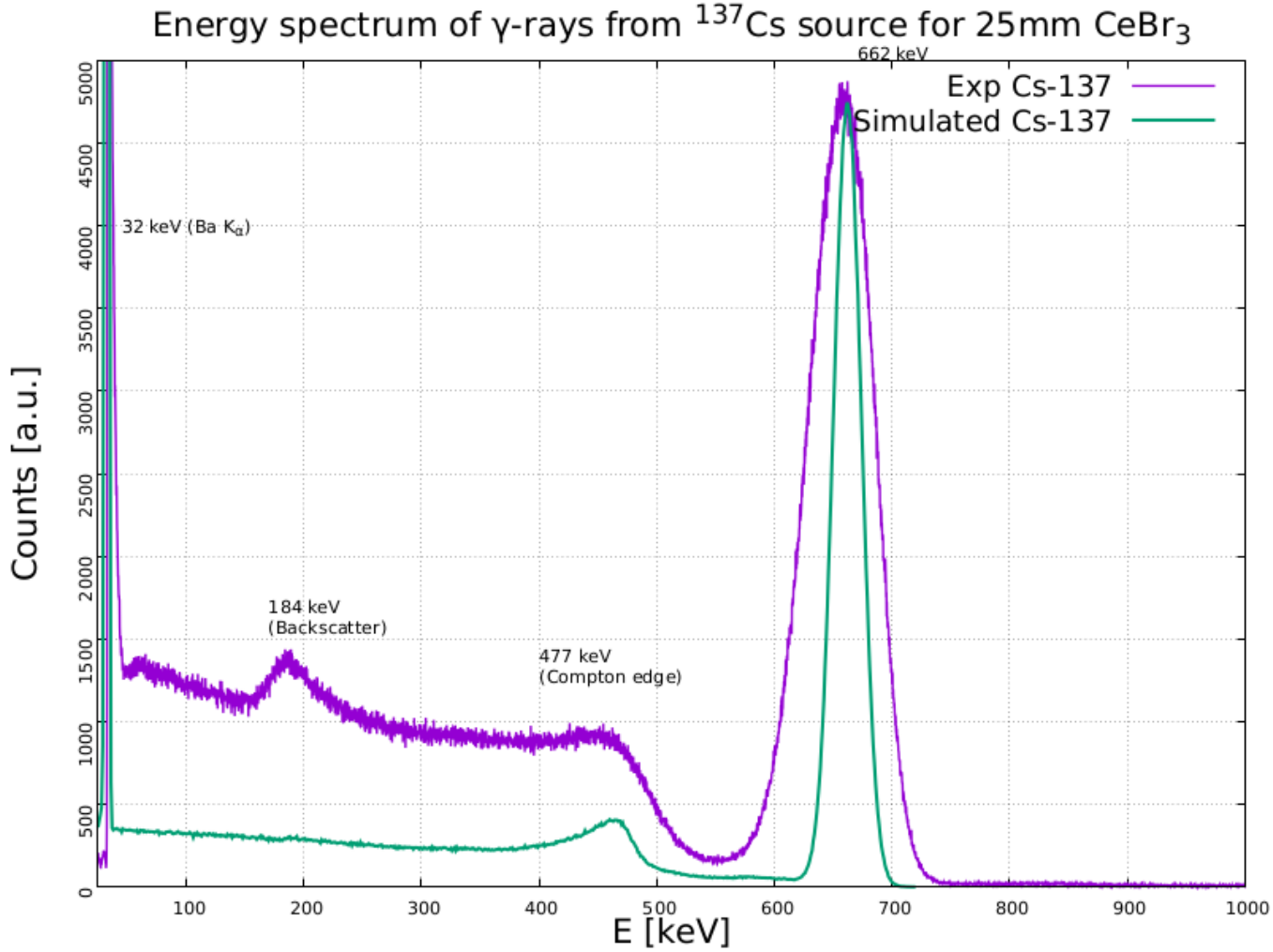


$CeBr_3$ energy resolution

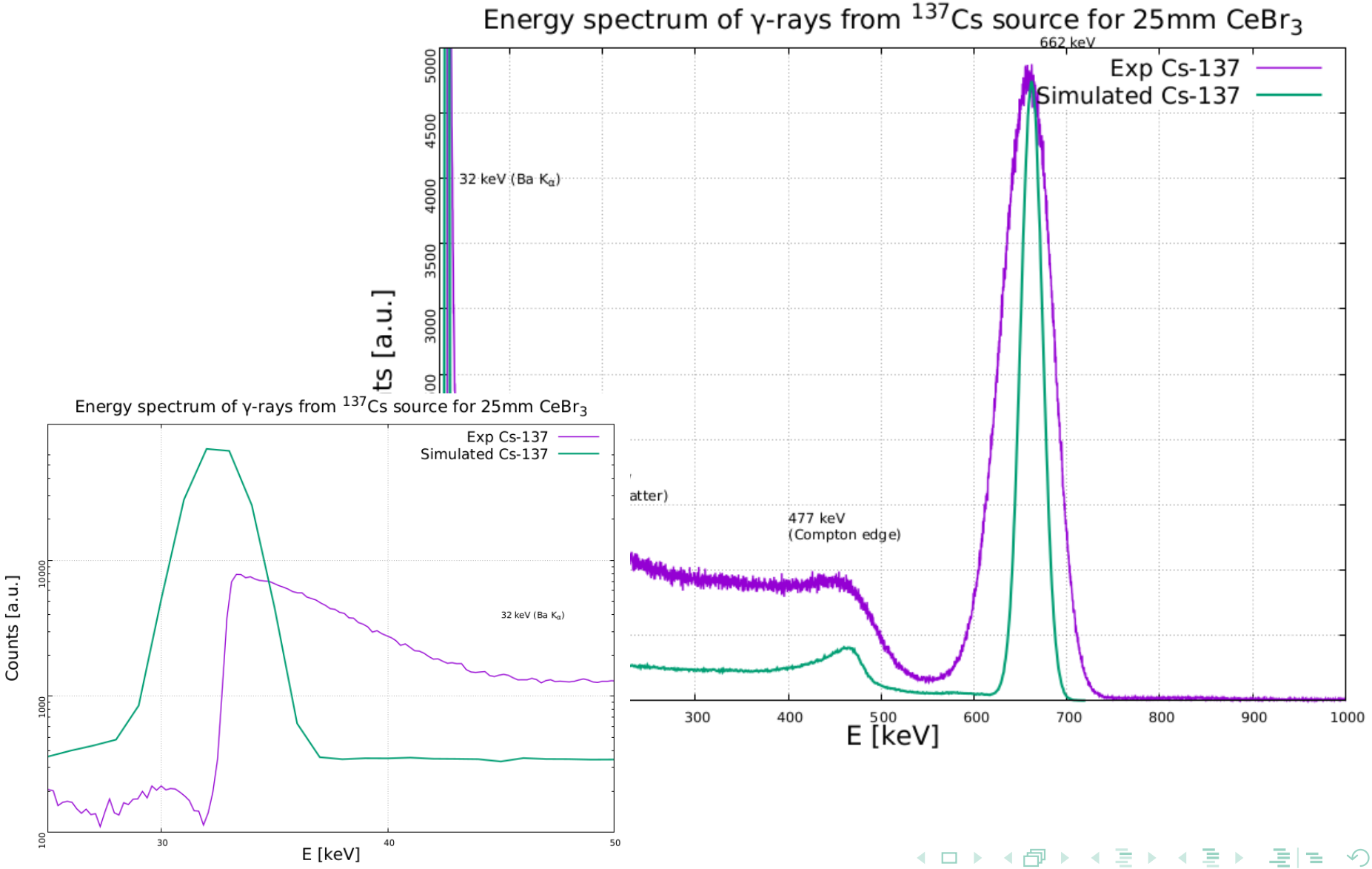
- $CeBr_3$ - thickness 25 mm
  - 18% @ 60 keV ^{241}Am
  - 8.7% @ 511 keV ^{22}Na
  - 9.0% @ 662 keV ^{137}Cs (vs. 4%)
  - 8.1% @ 1274 keV ^{22}Na
- $CeBr_3$ - thickness 10 mm
  - 30% @ 60 keV ^{241}Am
  - 9.8% @ 511 keV ^{22}Na
  - 9.4% @ 662 keV ^{137}Cs (vs. 4%)
  - 7.2% @ 1274 keV ^{22}Na

- NOTE: PMT is smaller than the size of $CeBr_3$

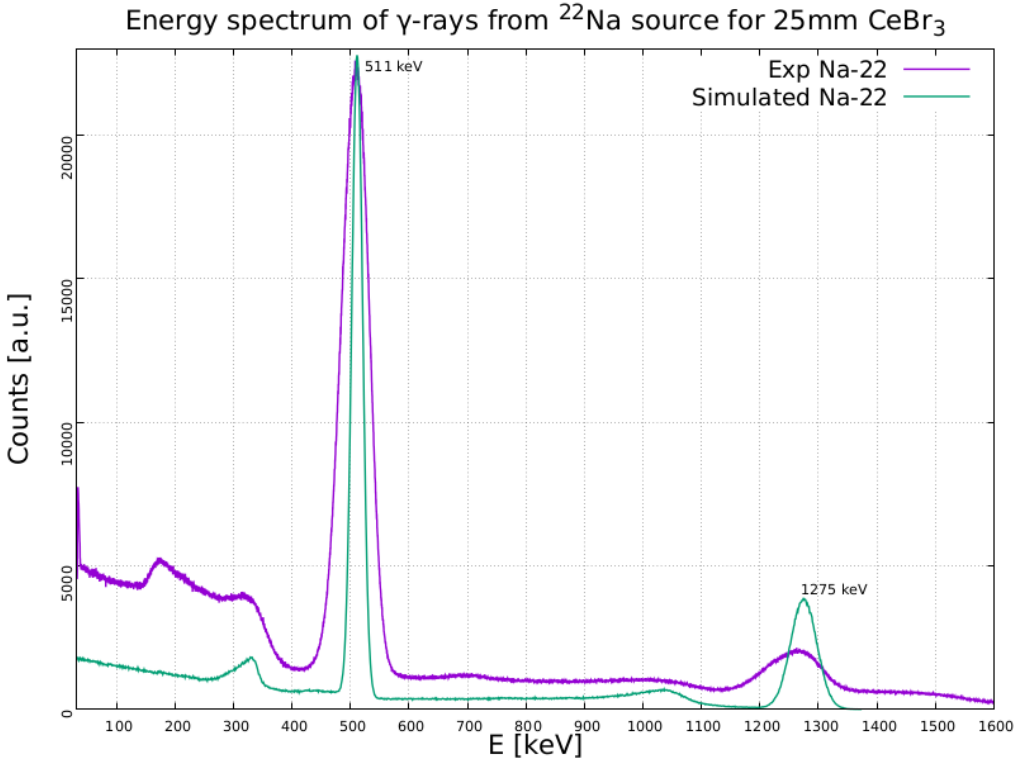
Comparison between the experimental and simulated spectrums for 25 mm thicker $CeBr_3$ with ^{137}Cs



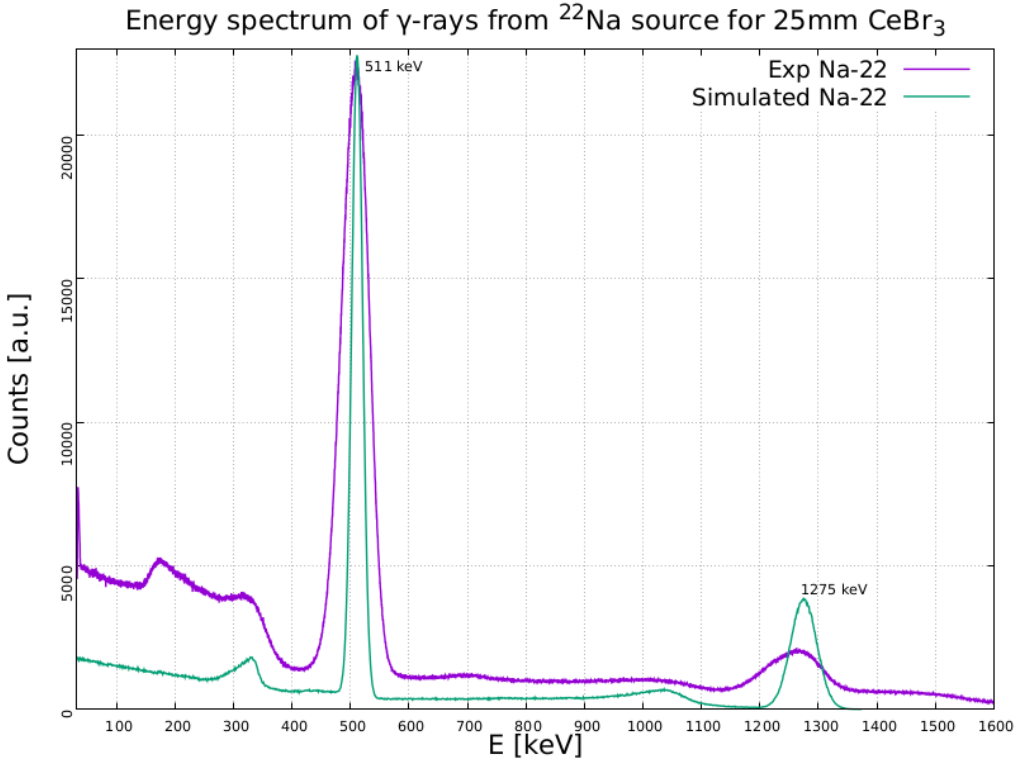
Comparison between the experimental and simulated spectrums for 25 mm thicker $CeBr_3$ with ^{137}Cs



Comparison between the experimental and simulated spectrums for 25 mm thicker $CeBr_3$ with ^{22}Na



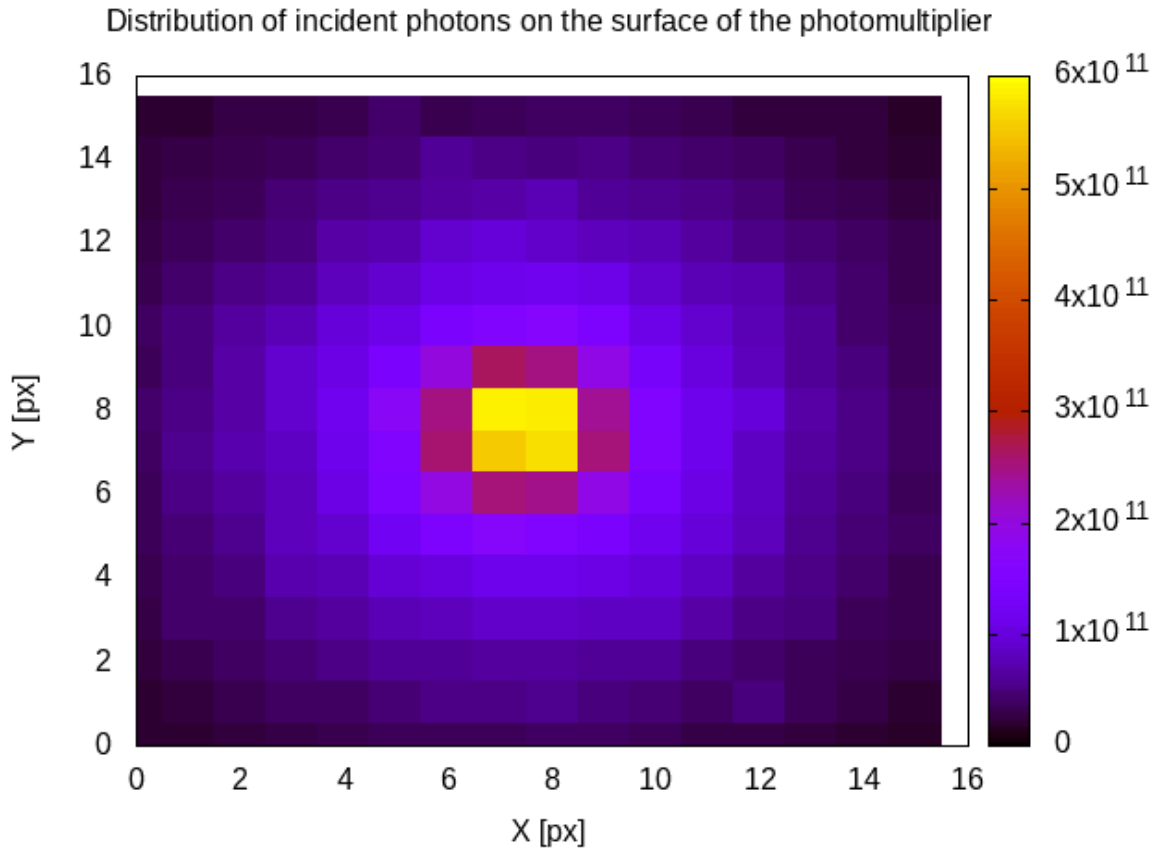
Comparison between the experimental and simulated spectrums for 25 mm thicker $CeBr_3$ with ^{22}Na



- Experimental data
  - 18% @ 60 keV ^{241}Am
  - 8.7% @ 511 keV ^{22}Na
  - 9.0% @ 662 keV ^{137}Cs
  - 8.1% @ 1274 keV ^{22}Na
- Simulated data
  - 5.1% @ 60 keV ^{241}Am
  - 4.3% @ 511 keV ^{22}Na
  - 4.4% @ 662 keV ^{137}Cs
  - 3.9% @ 1274 keV ^{22}Na

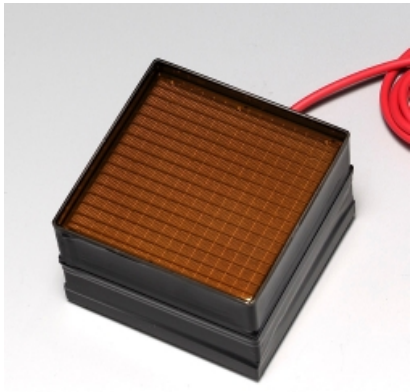
Preliminary results from simulations for the position resolution of 25 mm $CeBr_3$

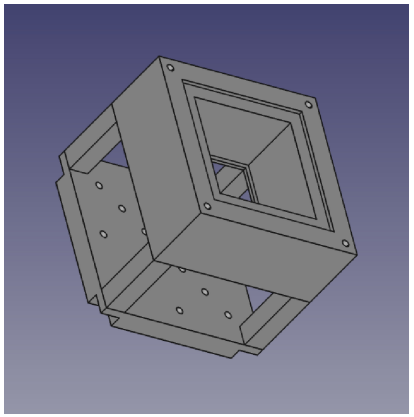
- One pixel = anode size
  2.8×2.8 mm^2
- Position resolution:
  < 5.3 mm (2σ)

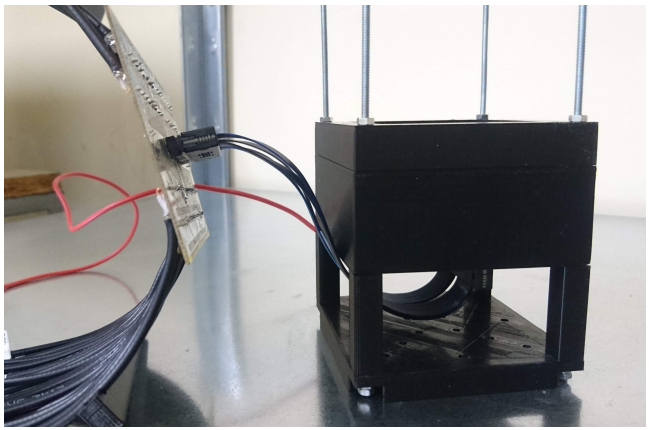


Almost ready for more precise measurements with MAPMT

- MAPMT - H9500, Hamamatsu
  - 16 x 16 anodes
  - anode size 2.8 x 2.8 mm^2
- HV N1470, CAEN







- Anode uniformity:
  one photoelectron calibration

Summary

- Thicker than 10 mm scintillator for scatterer or even a different concept?
- Promising preliminary results for the position resolution.
- Good results from simulations - input information for the specification of the readout electronics and a better understanding of the experimental setup.

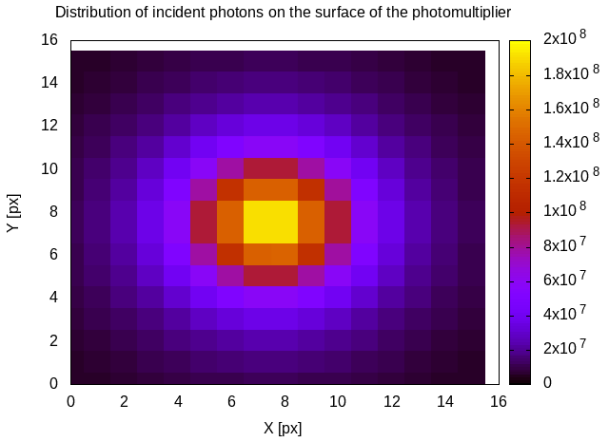
- Outlook
  - Investigating the potential issues $CeBr_3$ bad energy resolution.
  - Construct and build a new system for testing the individual channel response of the MAPMT.
  - Preparing the SiPM for operation and test.

This work is supported by DN18/17 NSF under NDeGRA project

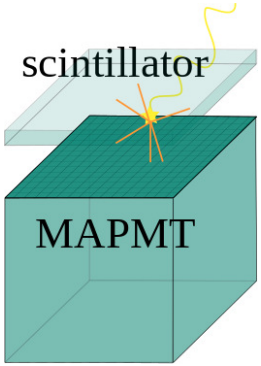
Thanks to my colleagues:
S. Ivanov, G. Georgiev, V. Kozhuharov and S. Lalkovski

Time for questions?

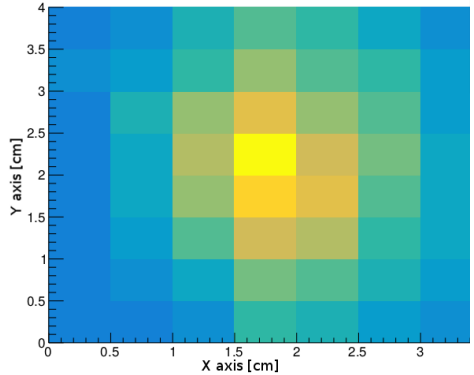
Proof of concept



- Geant4 simulations



- Monolithic plastic scintillator
- MAPMT
- $^{90}Sr/^{90}Y$
- Position resolution < 8 mm



Springer, in press, Chapter DOI.: 10.1007/978-3-030-22204-8_40