DE LA RECHERCHE À L'INDUSTRIE

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ORIGAMIX, A CDTE-BASED SPECTRO-IMAGER DEVELOPMENT FOR NUCLEAR APPLICATIONS

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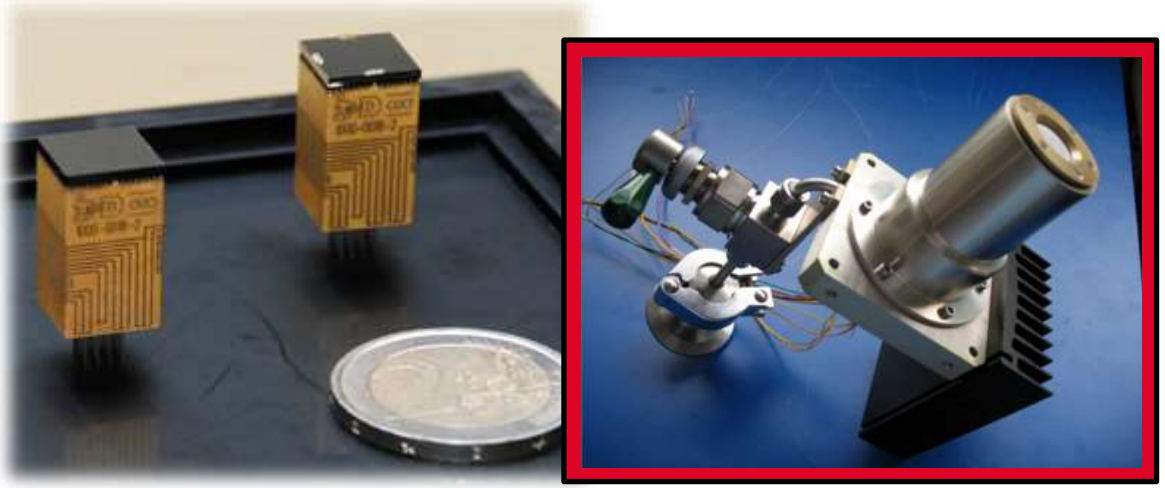


Sébastien Dubos, on behalf of the ORIGAMIX consortium

(1) : CEA, IRFU, Astrophysics Division
(2) : CEA, LIST, Sensors and Electronic Architectures

PREAMBLE

Our team

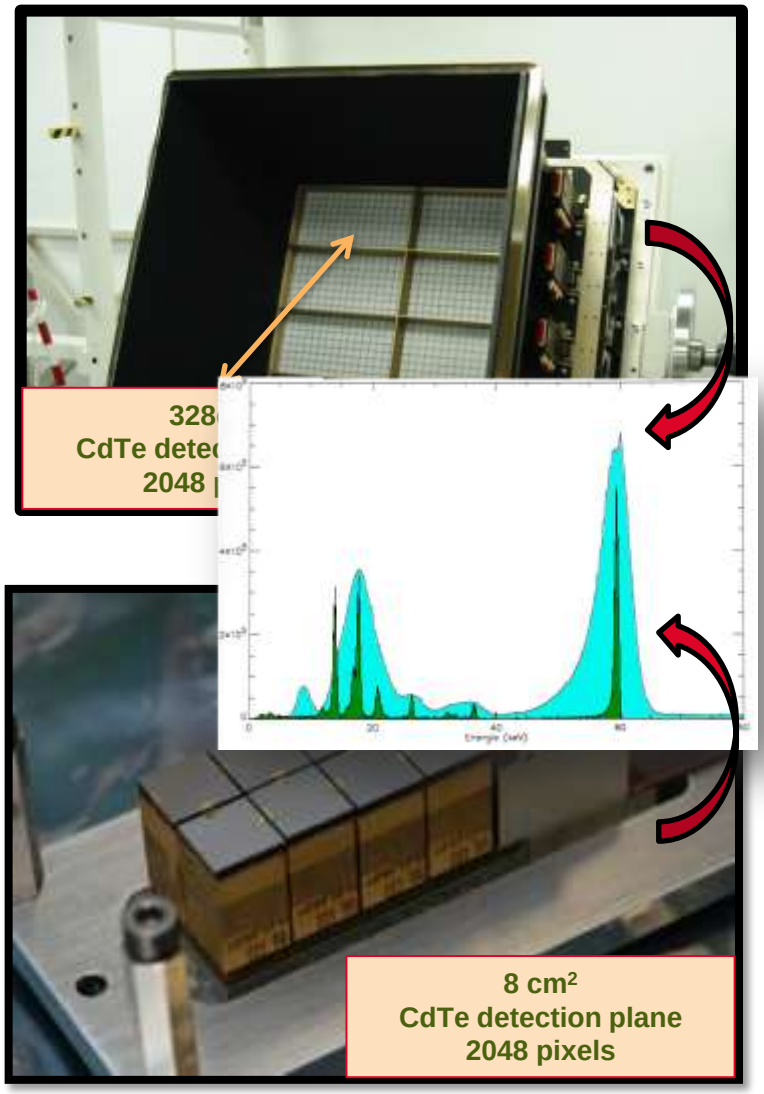
- Part of CEA-IRFU / Astrophysics Division
- Instrumental developments for space applications
- Domains: hard X-rays & gamma-rays
- Technologies: CdTe-based spectro-imagers
- Realization: Integral (14 years of operation in Space)

Innovative approach

- Close collaboration with microelectronics division
- Homemade & customs front-end electronics
- Smaller is better: modular systems
- 3D packaging for low noise, large detection area
- All steps of integration under our control

10 years R&D for Space apps

- Now:
  - CALISTE spectro-imagers
  - MACSI detection plane (2012), ready to fly



ORIGAMIX project: nuclear applications

TALK OUTLINE

Context / Motivations

ORIGAMIX project

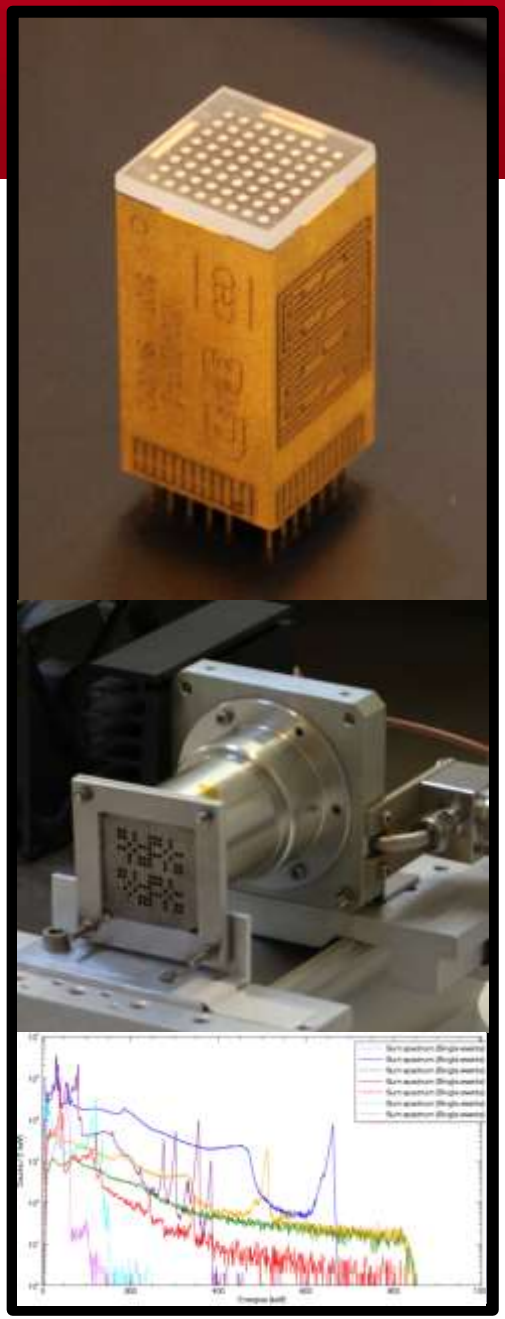
- Gamma imaging for post-accidental applications
- ORIGAMIX consortium
- Caliste HD assembly and key advantages
- First prototype

Spectroscopic performances

- Energy calibration, linearity
- Energy response < 800 keV
- Charge-sharing
- Energy response up to 1.4 MeV

Perspectives & conclusion

- Imagery
- Next steps



CONTEXT / MOTIVATIONS

Nuclear accidents: consequences

Three Mile Island: 1979

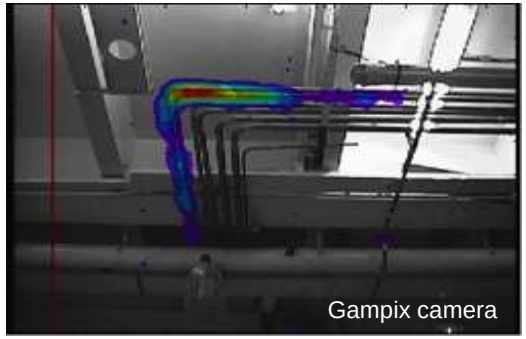
Tchernobyl: 1986

Fukushima: 2011

- Huge impacts on human health, environment and society… for dozens of years
- In most cases: need of human intervention ➔ appropriate equipment for intervention in accidental situations

Major risks

- Presence of hot spots strongly irradiating
- No information on their location and nature

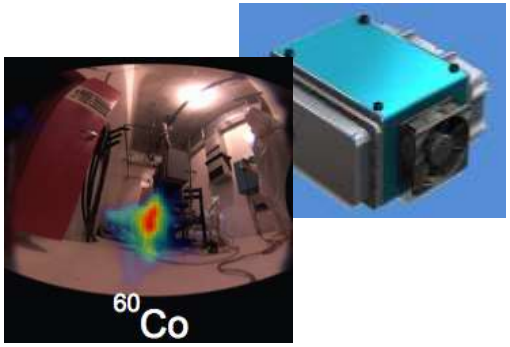


<u>Mitigation:</u> gamma imaging
➔Image AND Spectrometric information
➔Simple, modular and easy-to-deploy tools

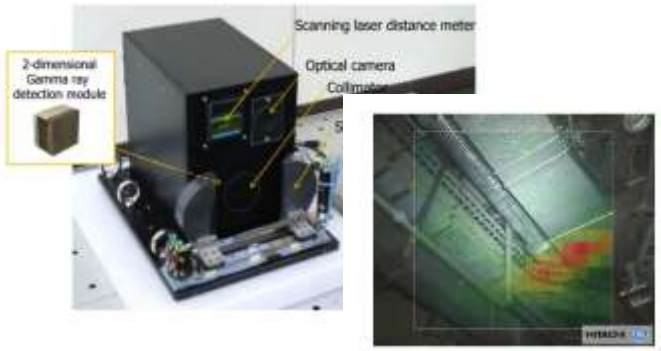
GAMMA IMAGING FOR POST-ACCIDENTAL APPLICATIONS

Already a strong international interest for this application, with various technologies

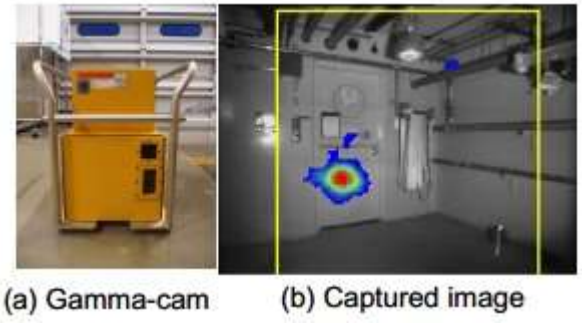
Toshiba



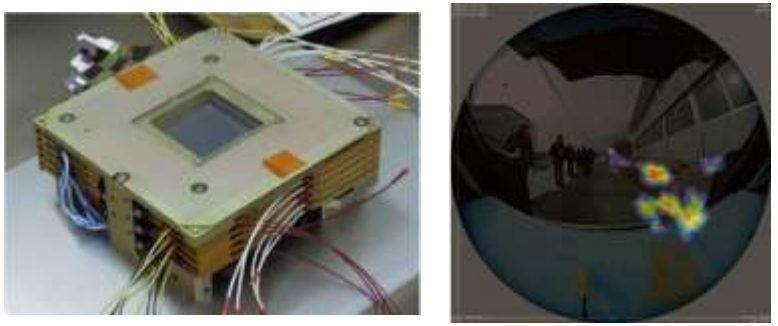
H3D (Polaris-H)



Hitachi



T. Takahashi *et al.*, Proceedings of the IEEE RTSD, 2012



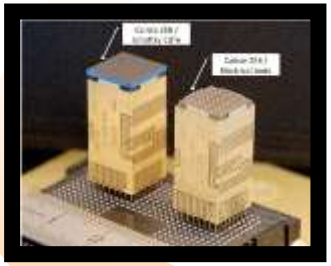
K. Ohno *et al.*, Proceedings of the IEEE RTSD, 2011

GAMMA IMAGING FOR POST-ACCIDENTAL APPLICATIONS

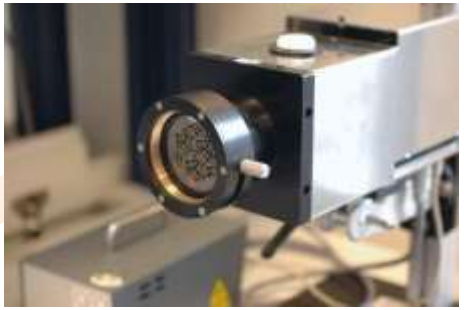
Instrumentation expertise in CEA

CEA DTEC – Marcoule

CEA LIST – Saclay



CEA IRFU – Saclay



CEA LETI – Grenoble

From sensor to system & applications

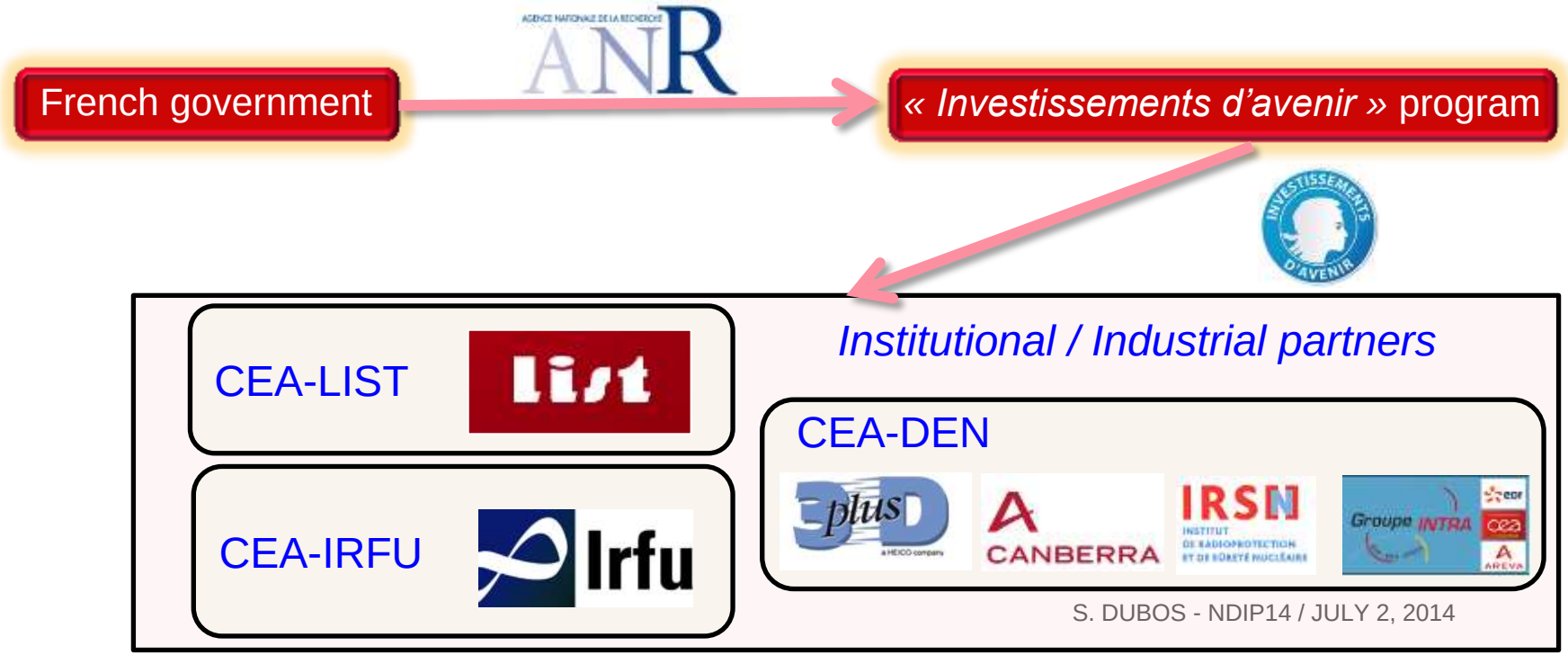
➔ **Cooperation**

THE ORIGAMIX PROJECT

ORIGAMIX Project

- Association between different labs. to design a new generation of gamma camera with combined imaging and fine spectroscopic capabilities
- Use of CALISTE technology in a small and portable device
- Associated with several institutional and industrial partners

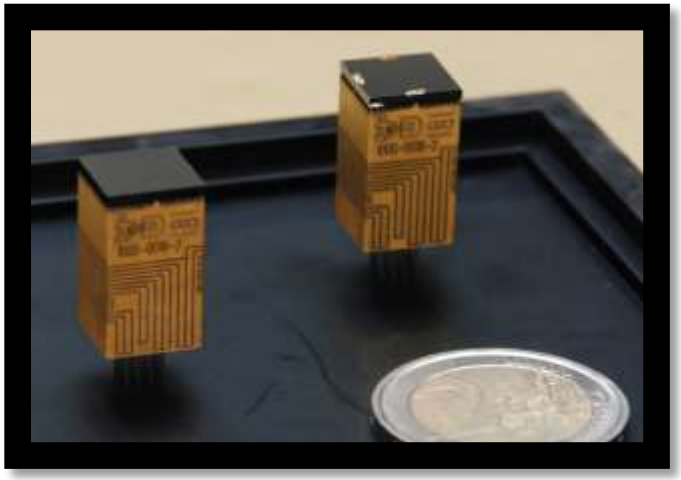
A multidisciplinary and complementary collaboration

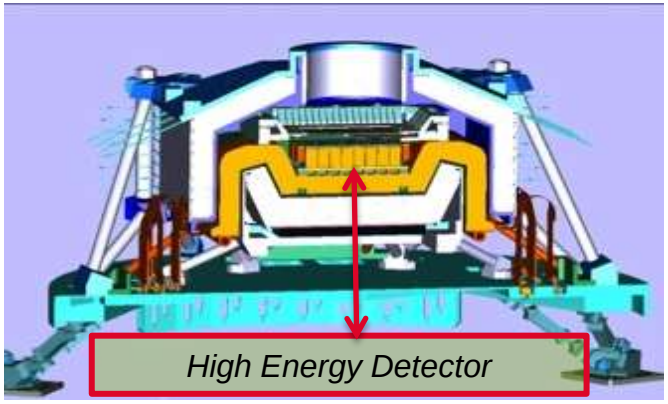


WHY CALISTE?

CALISTE key advantages

- Space qualification: low power, radhard, high count rate, high redundancy
- Pixelated detectors, self-triggered
- Time-resolved imaging & spectrometry
- Low threshold: 1.3 keV
- 2 - 250 keV, up to 1 MeV
- Very low noise (FWHM @ 60 keV : 0.7 keV / 1.1 %)
- Modular, aboutable on its 4 sides
- Polarimetry capabilities *(see Antier et al., NDIP 14)*





Astrophysics… and beyond

- Initialy developped by CEA-IRFU for HE astrophysics
- Focal plane for high-energy astrophysics
- Ex.: INTEGRAL, SIMBOL-X

- Also:
  - Solar Physics ➔ SOLAR-ORBITER
  - Nuclear Physics ➔ ORIGAMIX

IDEF-X HD ASIC MAIN PROPERTIES

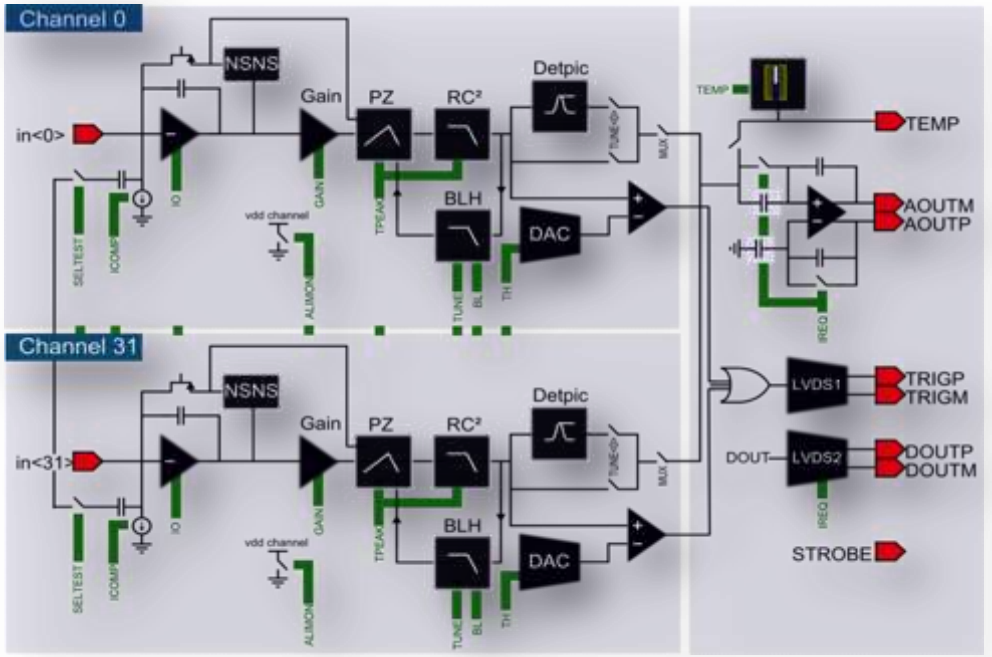
Full custom ASIC developed at CEA

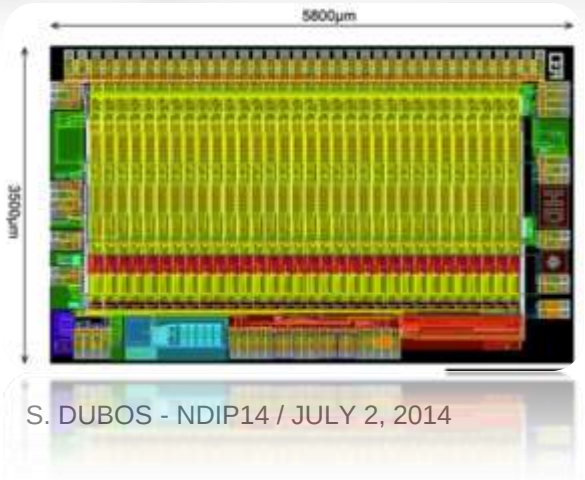
- **CMOS AMS 0.35µm**
- 1D ASIC ; Area: 5.8 x 2.5 mm²

- **32 spectroscopic channels**
- **Individual tunable threshold**
- **Tunable shaper**
- **4 tunable gains values:**
  ➔select the appropriate energy-range

- Fully-programmable

- **Low power: 800 µW/channel**
- **Radiation hard**

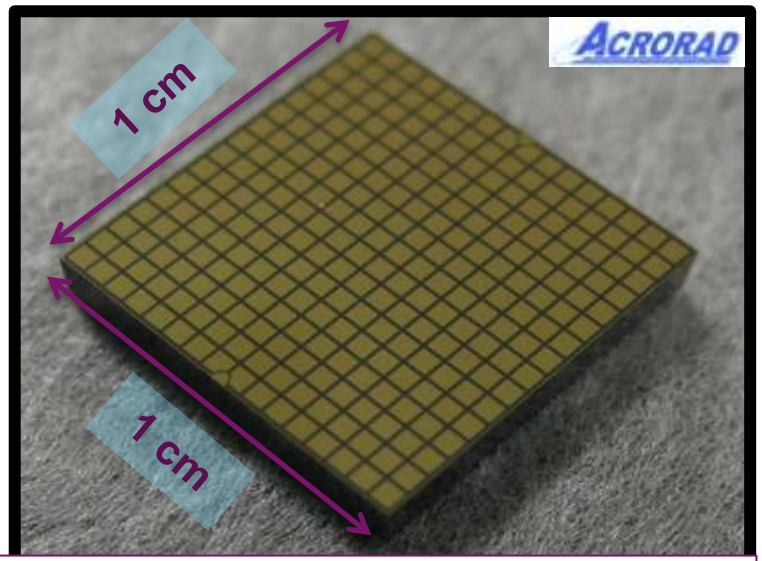




Low noise 33 el. rms floor

➔Low capacitance / low current detectors (1 pF / 1 pA)
➔Excellent spectroscopic performances

CALISTE HD: HYBRIDIZATION



- 1 cm² CdTe
- 256 pixels (16 × 16)
- 625 µm pitch
- 1mm thick for hard X-Ray domain is fine

Top surface preparation

3plus

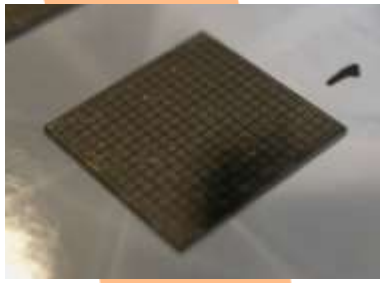
CdTe 256-pixel detector

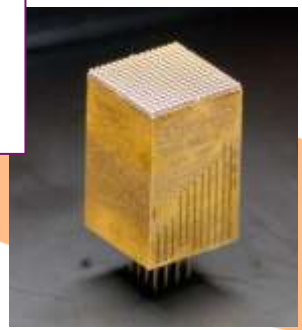
(625 µm pitch, 1 or 2 mm thick, Al Schottky)

+

(Pt entrance electrode)

ACRORAD

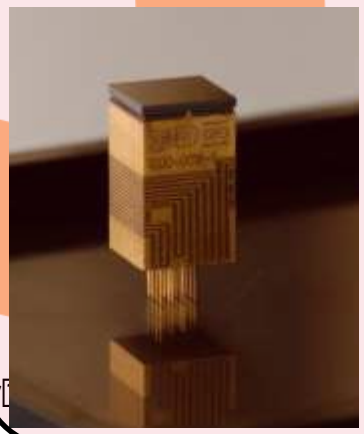




Electrical body

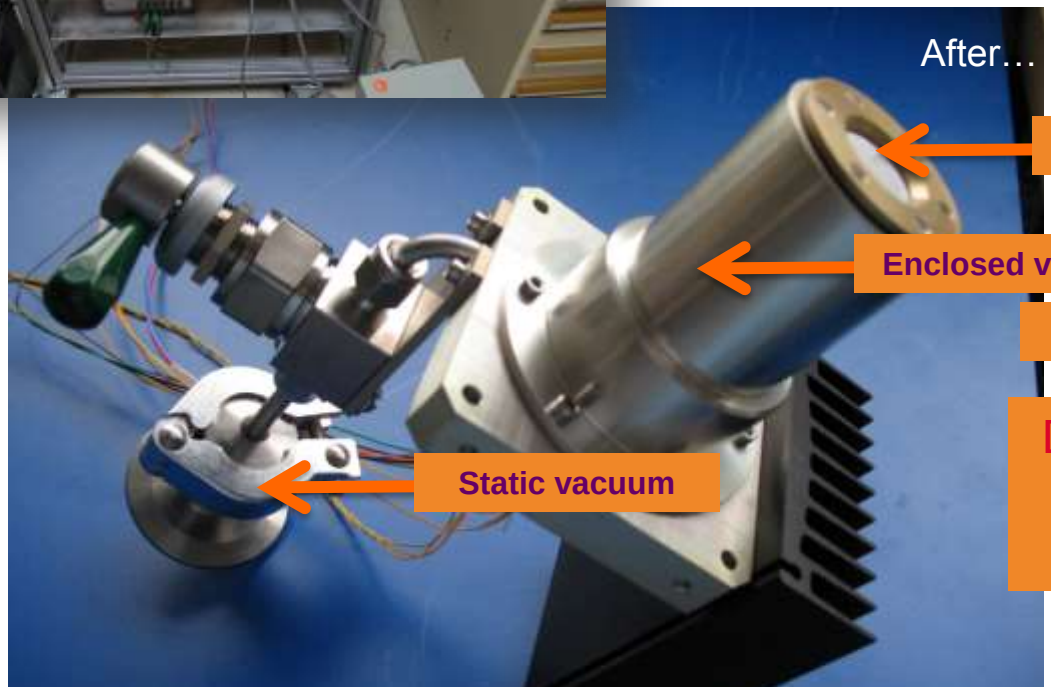
with a 4 x 4 pin grid array

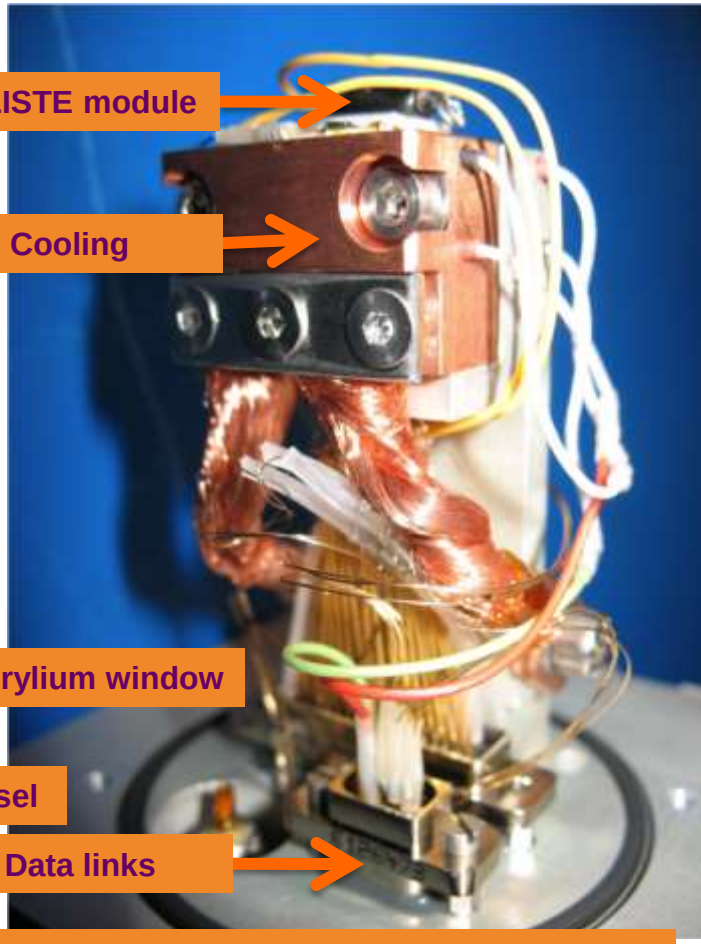
Caliste-HD camera



FIRST PROTOTYPE

Size matters…



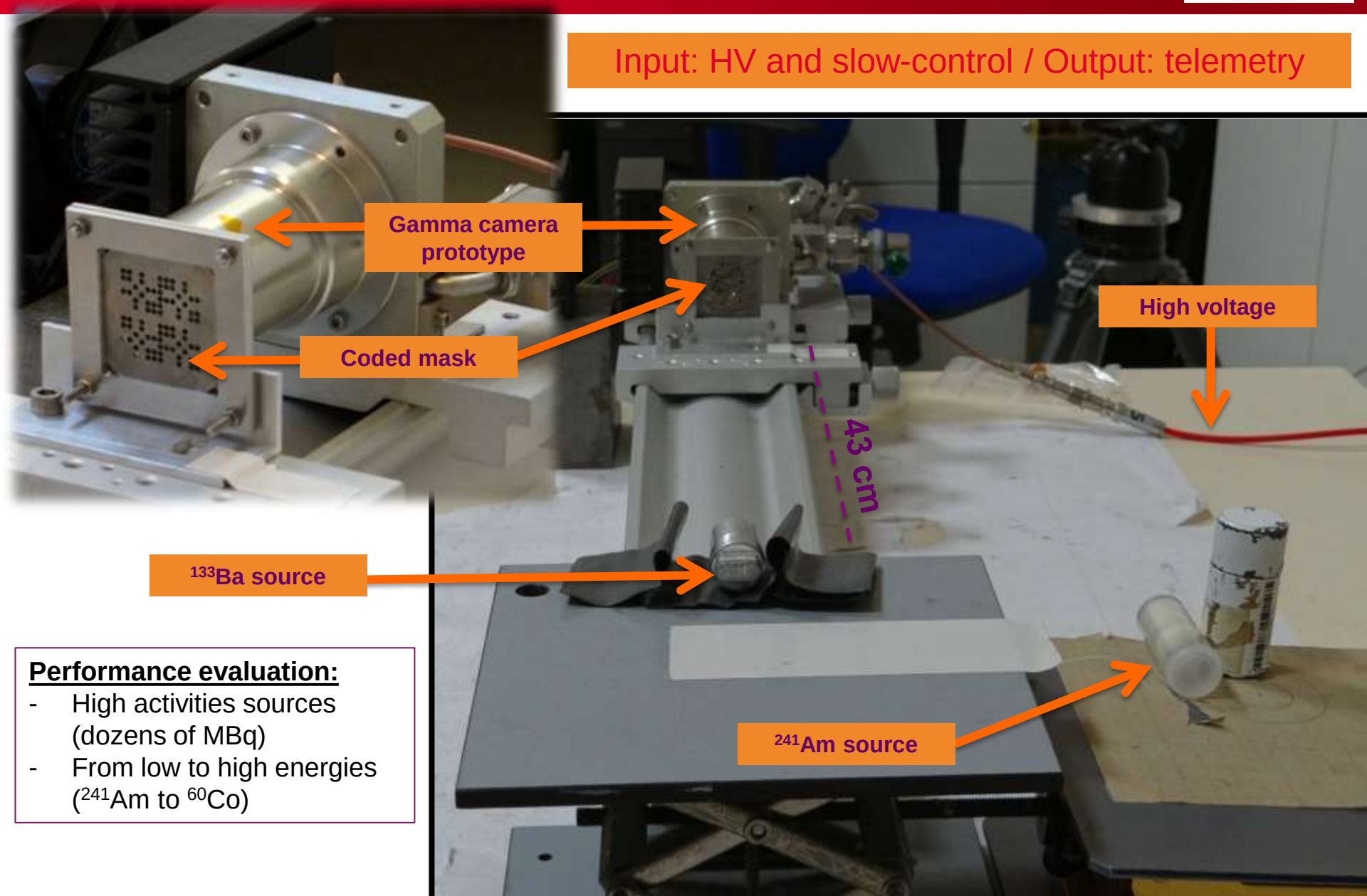


Detector, electronics and cooling system included in a portable device

FROM CALISTE TO ORIGAMIX

TEST BENCH

Input: HV and slow-control / Output: telemetry



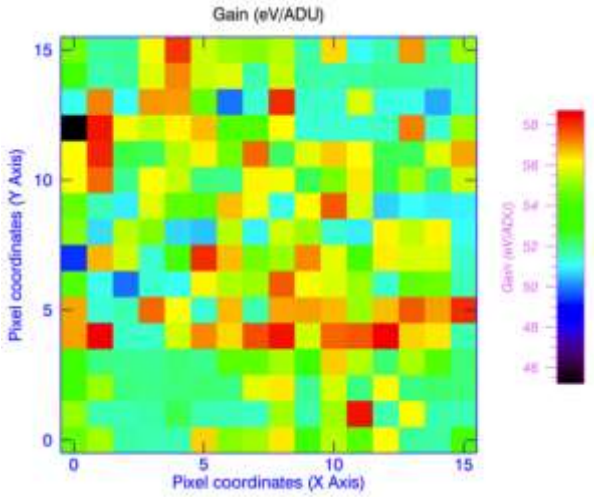
Performance evaluation:

- High activities sources (dozens of MBq)
- From low to high energies (^{241}Am to ^{60}Co)

ENERGY CALIBRATION - LINEARITY

Energy calibration

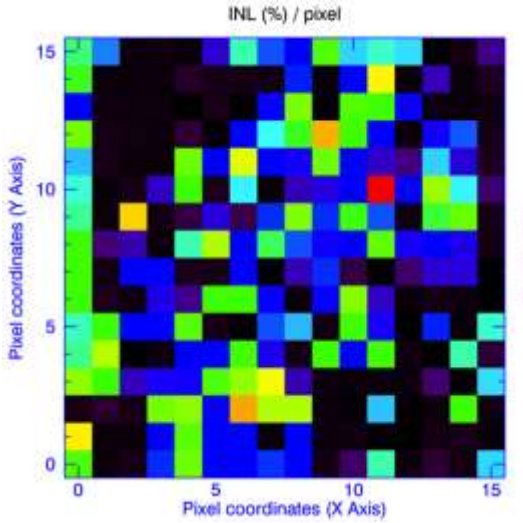
- Output in channels (ADU)
- Calibration for each pixel, independently
- 5 peaks, from 4 different sources
- 30 keV – 661 keV

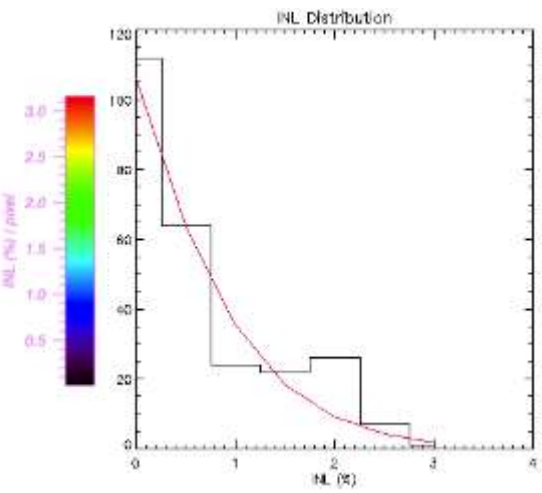


Gain – Linearity

- Gain : 51.47 eV/ADU

- INL max over 5 peaks:
  - Mean: 0.81%
  - <1% for 176/256 pixels (70%)
  - <2% for 220/256 pixels (87%)





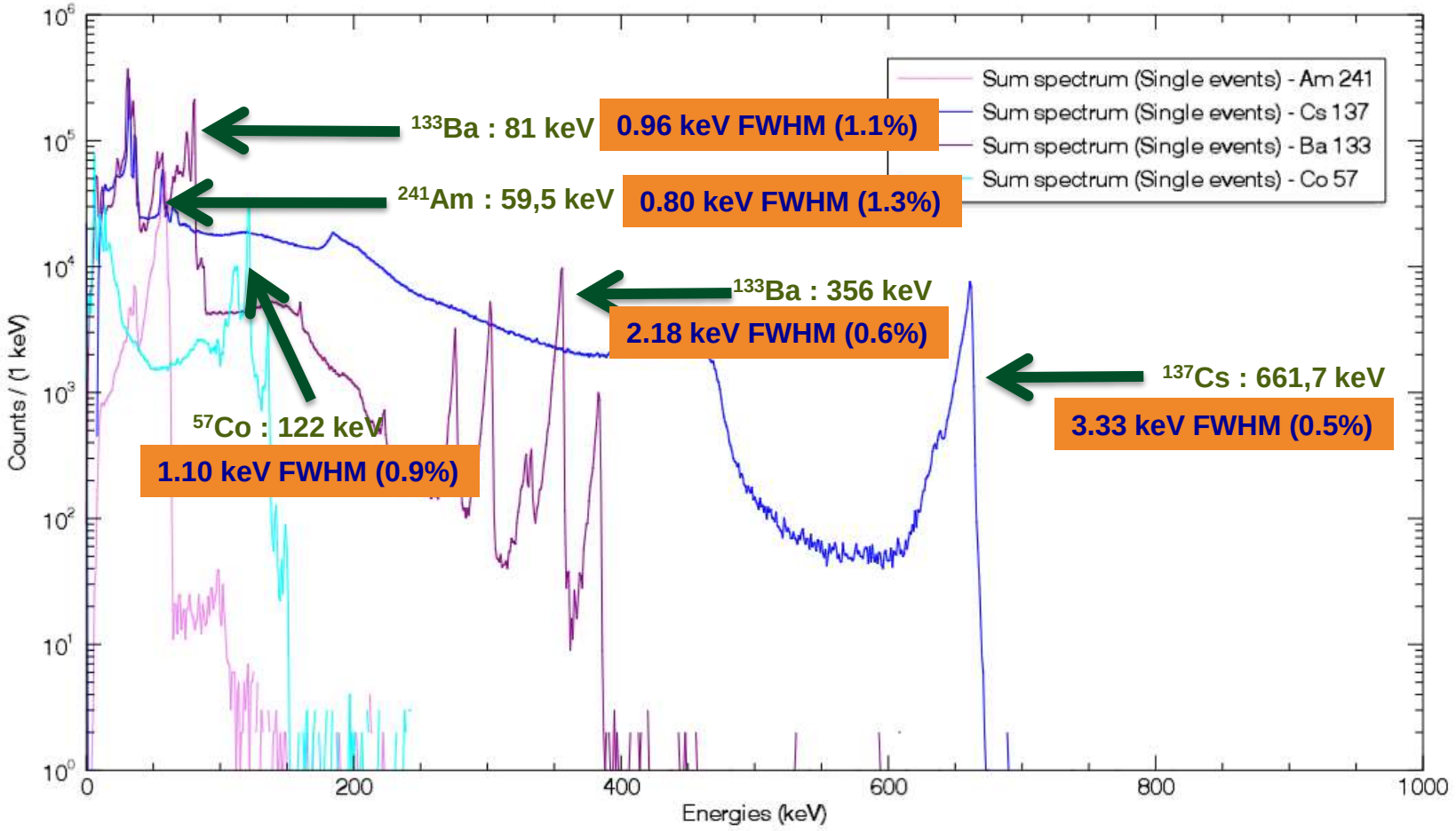
- Fine energy calibration + linearity

➔High spectroscopic performances

ENERGY RESPONSE < 800 KEV

Sum spectrum, for various sources

- Single events only (only 1 triggered pixel per frame)
- Best energy resolutions, but less efficiency
- Detection efficiency < 50% after 143 keV, Compton effect predominant



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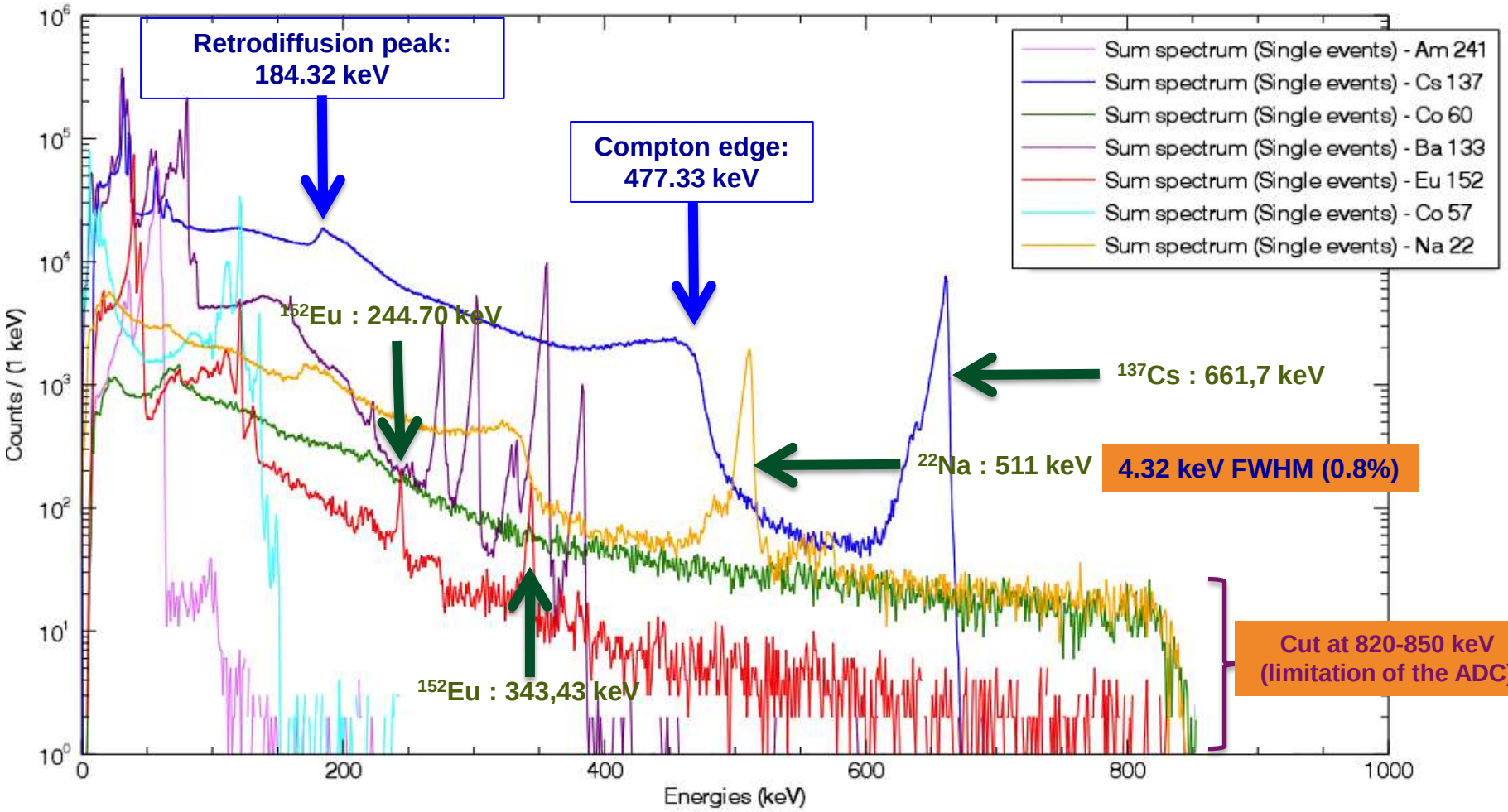
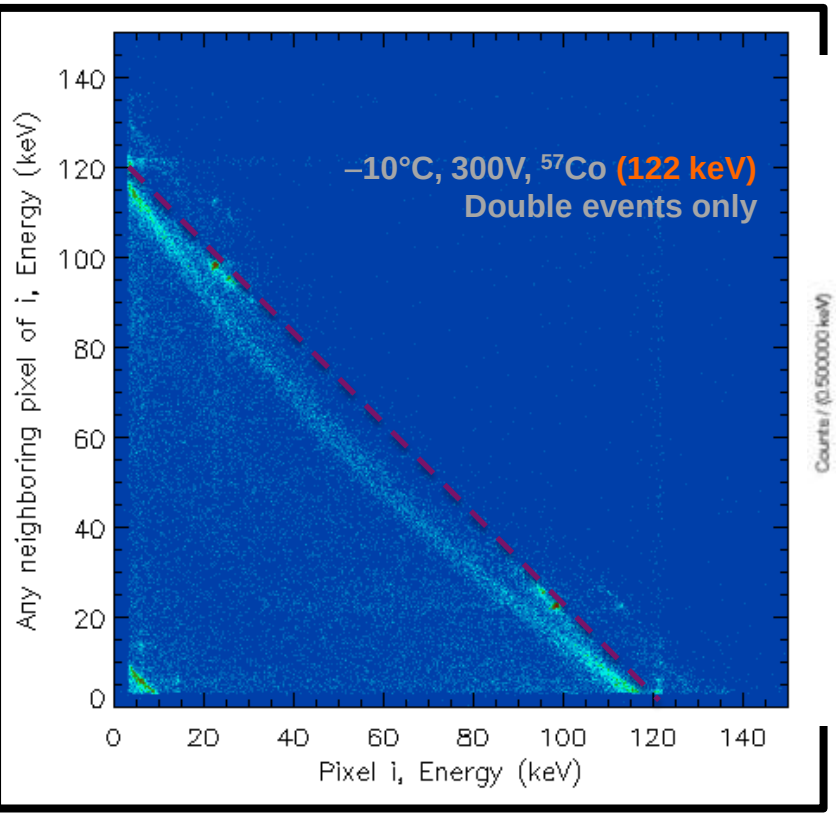
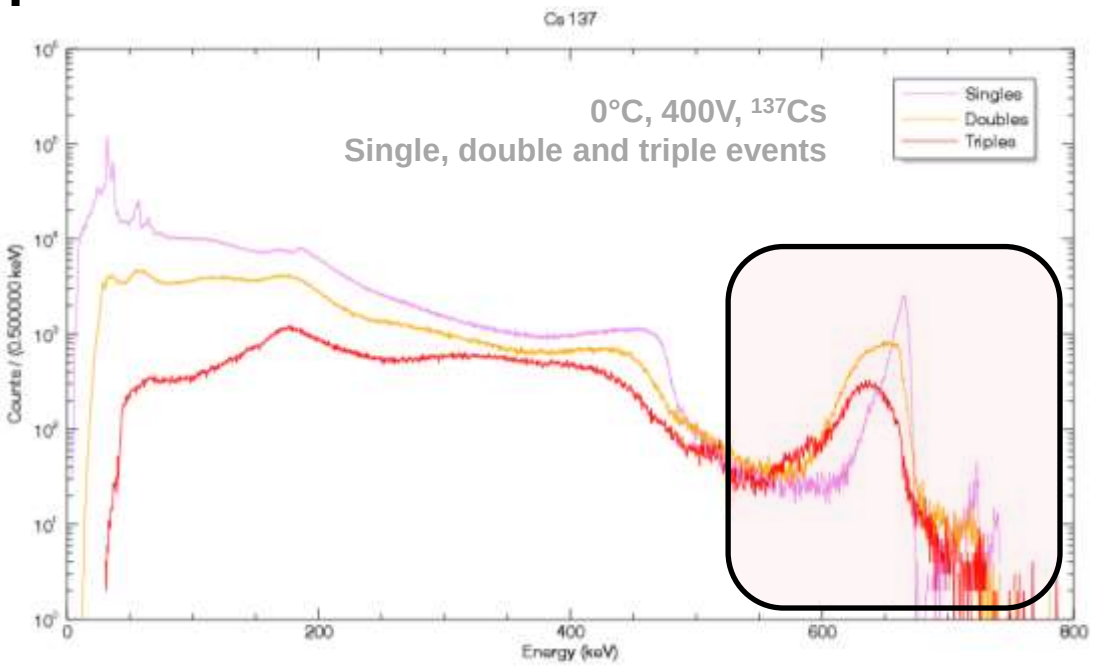


CHARGE-SHARING



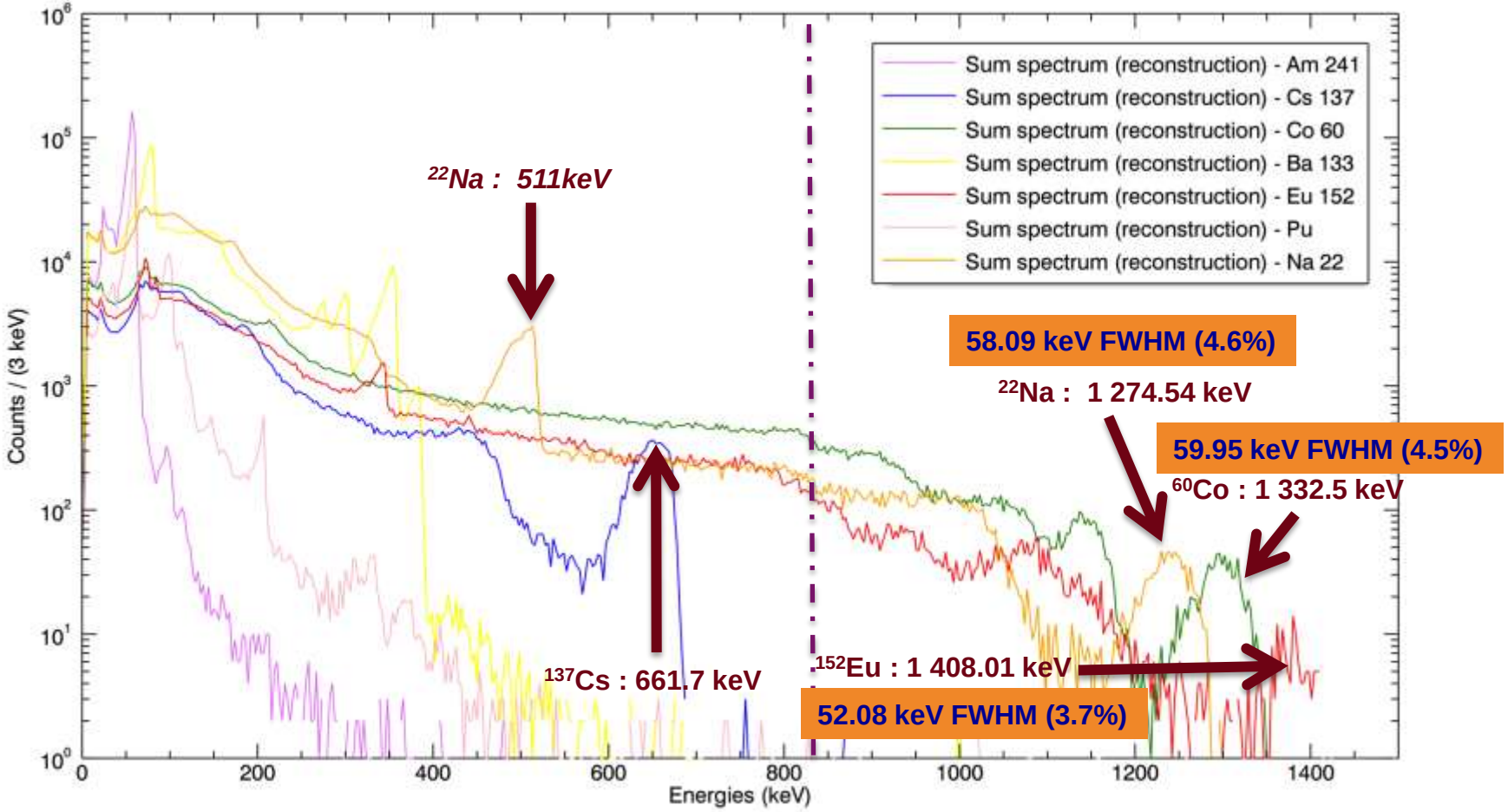


- **Charge-sharing:** ≈ 20 - 25 % (origin: energy deposition, fluorescence and diffusion)
  - ➔ Correlation graph
  - ➔ Loss in energy reconstruction (up to 10 %)
  - ➔ Loss of energy resolution
  - ➔ Becomes preponderant at high energies
  - ➔ Reconstruction: all events summarized (higher efficiency for high energies)

ENERGY RESPONSE > 800 KEV

Sum spectrum, for various sources

- All multiplicities summarized
- Photoelectric peaks measured up to 1.33 MeV (!)
- Very low efficiency, mainly Compton effect



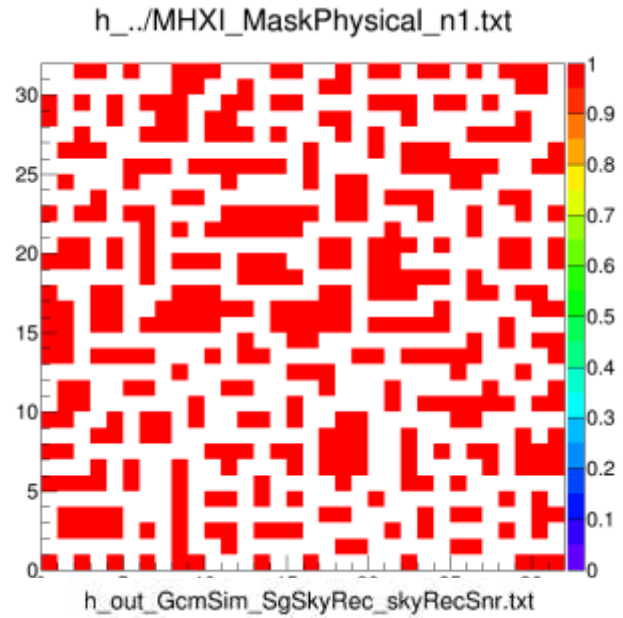
NEXT STEP: IMAGERY

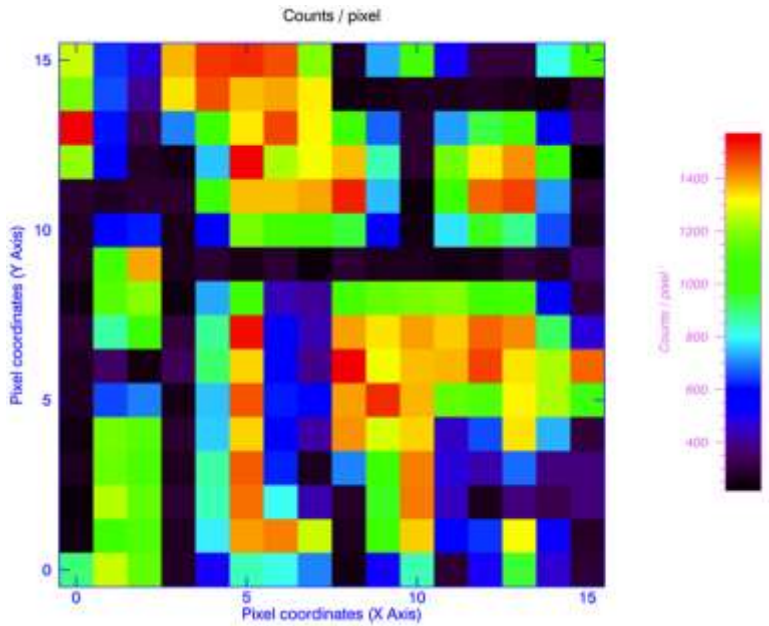
Goal

- Precise source localization
- Use of coded masks (spatial resolution)
- Energy selection:
  - Better signal/noise ratio
  - Source discrimination

Example: ^{241}Am source

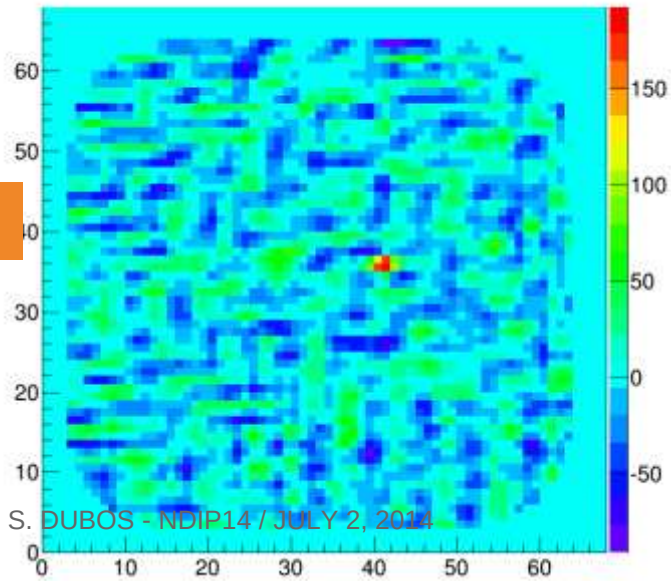
- 0.360 mm-thick tungsten mask
- 1 mm from the entrance window, source at 43 cm





After deconvolution

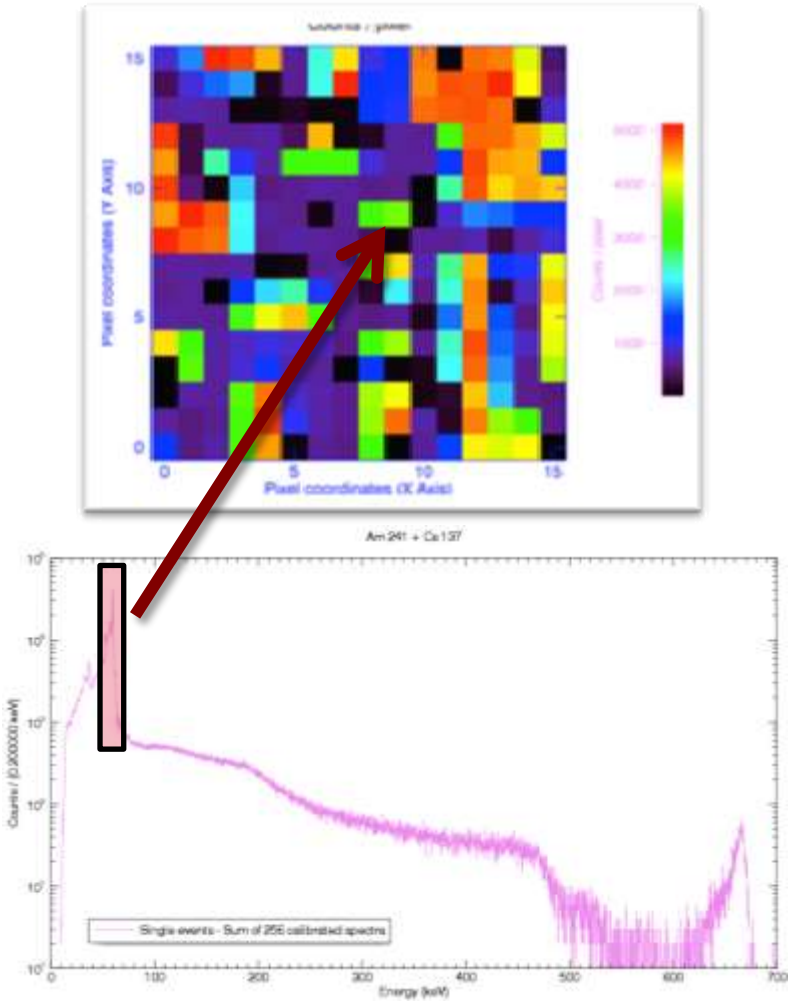
6° angular resolution



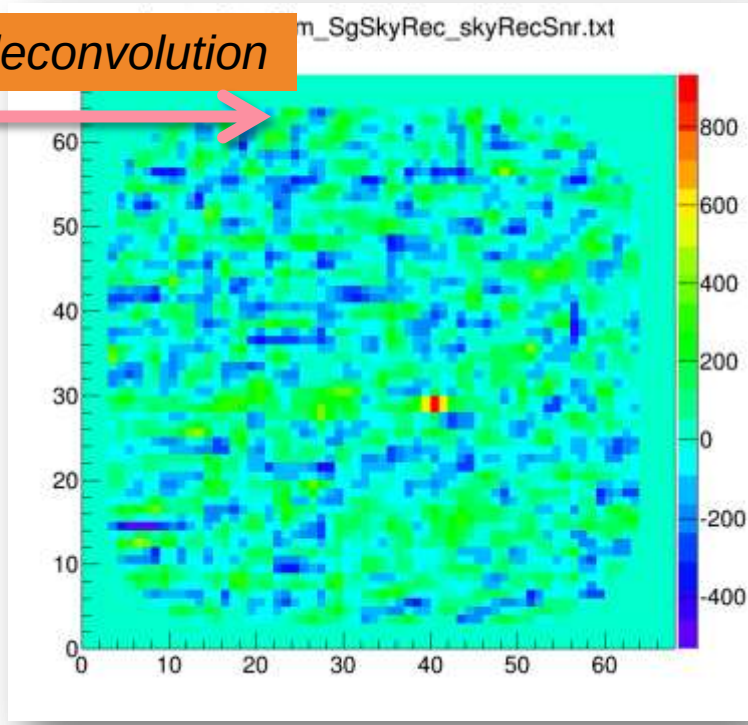
NEXT STEP: IMAGERY

Example: ^{241}Am + ^{137}Cs

- 2 sources in the field of view
- Selection: peak at 60 keV ± 3-sigma



After deconvolution



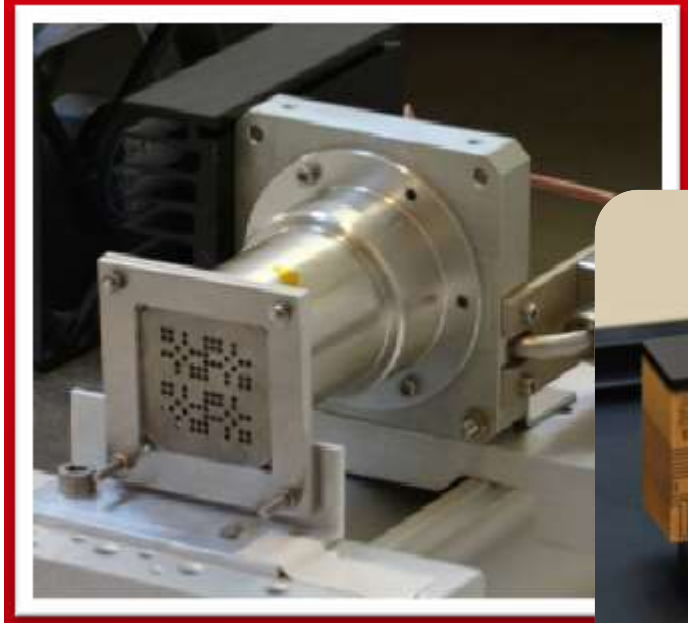
CONCLUSION / PERSPECTIVES

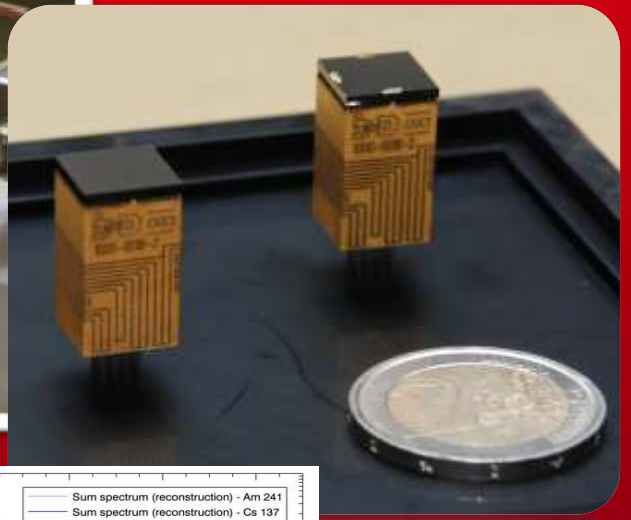
- ORIGAMIX is a new project dedicated to nuclear applications
- Integration of the CALISTE module in a gamma-imaging system
- First demonstrator already tested with various sources
- Excellent spectrometric performances, from low to high energies (up to 1.4 MeV)
- First tests with source localization.

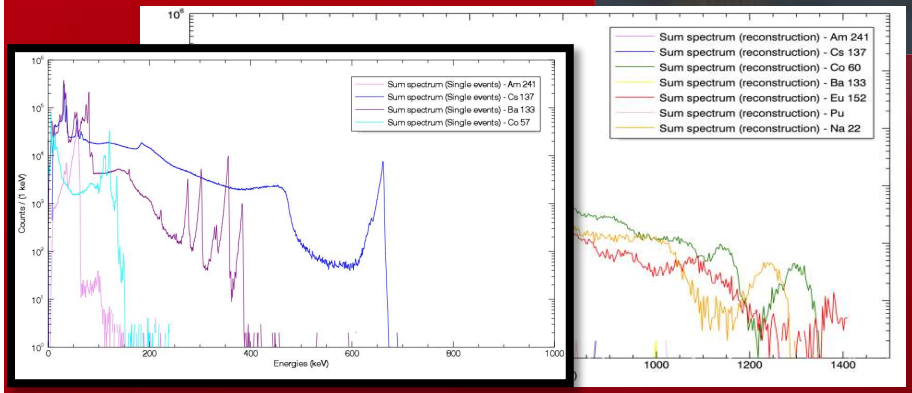
- Fine evaluation needed (sensitivity, time of exposure, optimum pattern for coded mask…)
- Data acquisition and processing, new geometries…

A lot of work to do, but already promising results!

THANK YOU FOR YOUR ATTENTION







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