Thick DSSSDs for γ-ray astronomy in the MeV range

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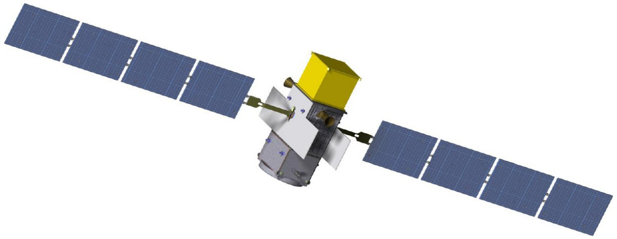
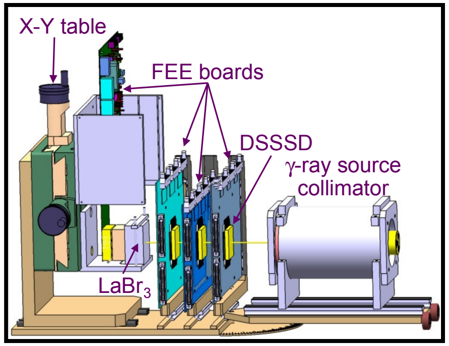


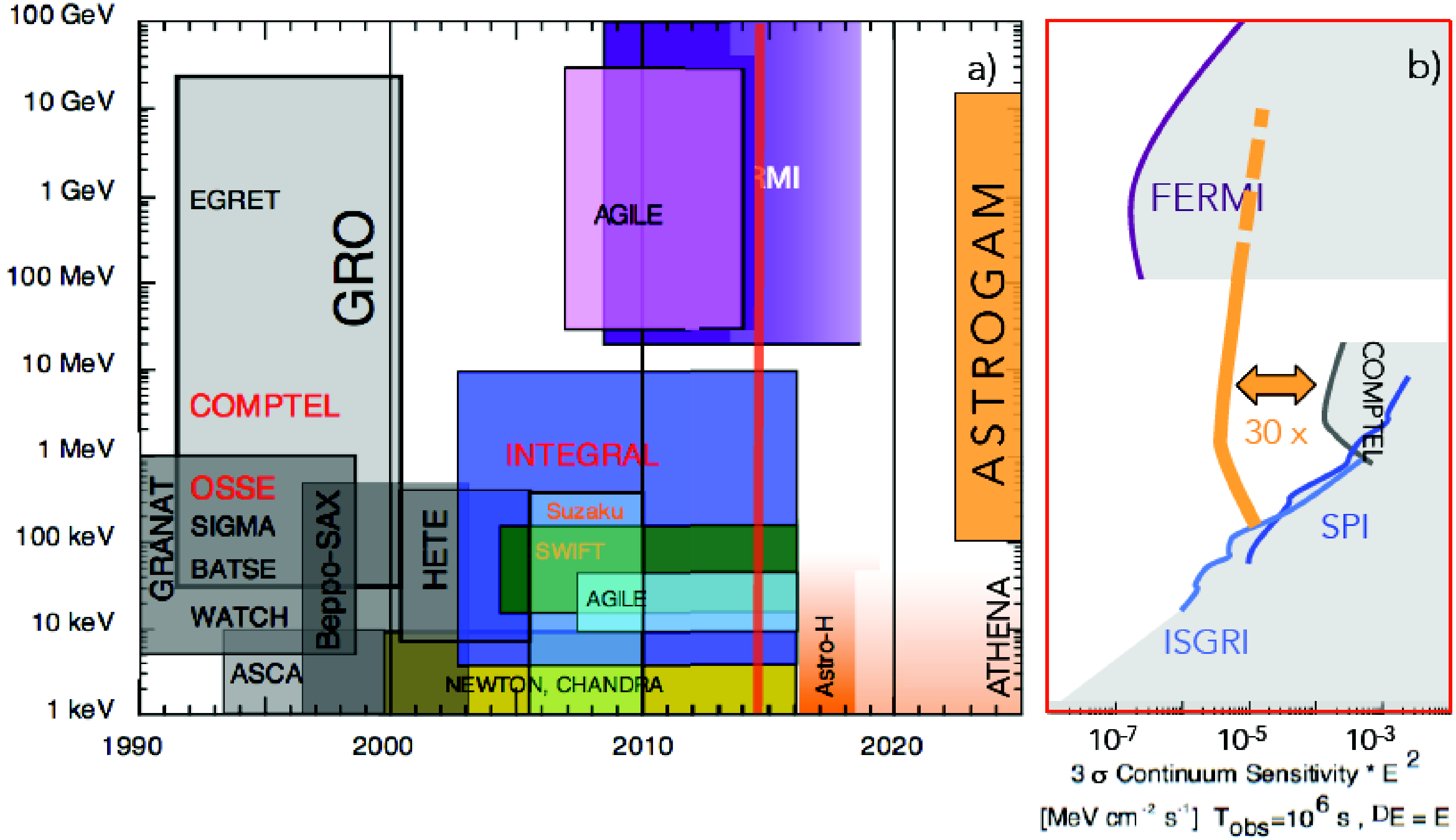


GASPARD – HYDE – TRACE workshop, 2016, January 23rd – 24th

Gamma-ray astronomy & ESA's 'Cosmic Vision'

ASTROGAM

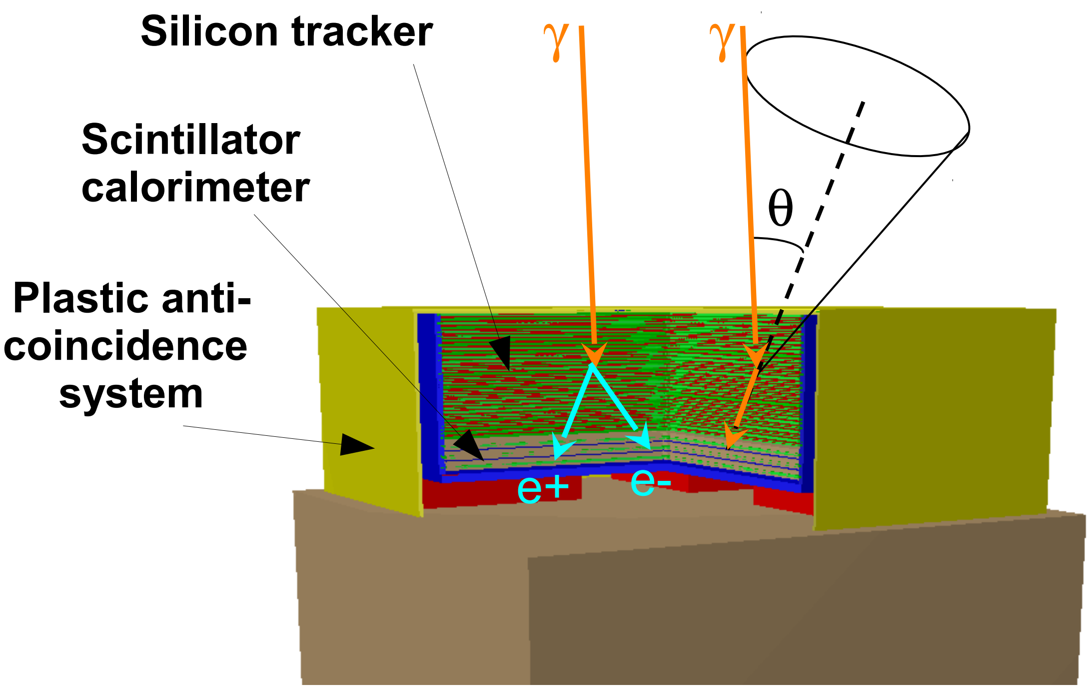
Proposal in response of ESA's call (2014, 2015) for a fourth Medium-size mission (program “Cosmic Vision 2010 – 2025”)



Prepare a new γ-ray space telescope operating in the MeV range (100 keV – 10 GeV)

- **Nucleosynthesis** (γ-ray radioactivities)
- Low-energy cosmic-ray physics
- High-energy solar physics
- ...
- Active Galactic Nuclei
- Physics of neutron stars and stellar black holes

Instrument and performances



- **Tracker** - Double sided Silicon strip detectors (DSSSDs) for fine 3-D position resolution
- **Calorimeter** - High-Z material for an efficient absorption of the scattered photon → CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background → plastic scintillator

Angular resolution (on-axis, FWHM)

- 1 deg @ 2 MeV → 4x better than COMPTEL

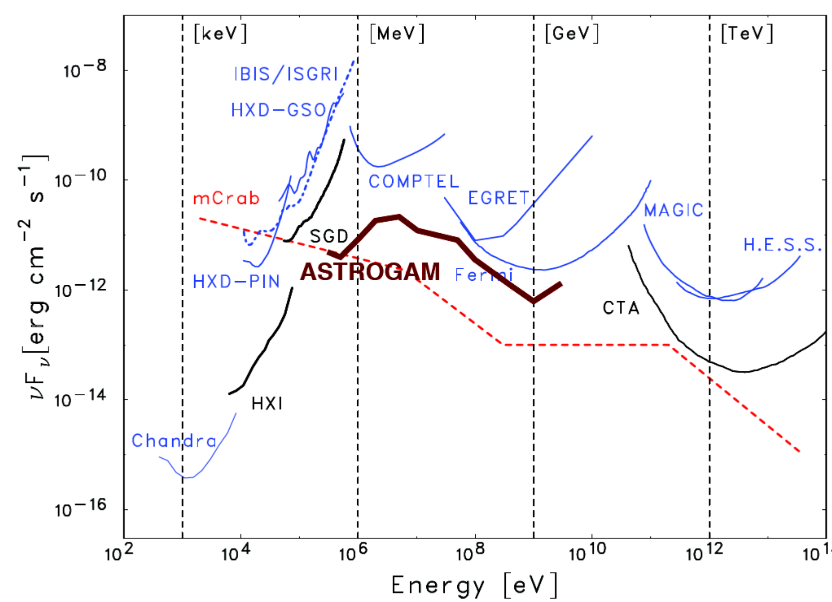
Spectral resolution (1-sigma)

- 10 keV @ 1 MeV
- 30 keV @ 5 MeV

3x better than COMPTEL

Sensitivity

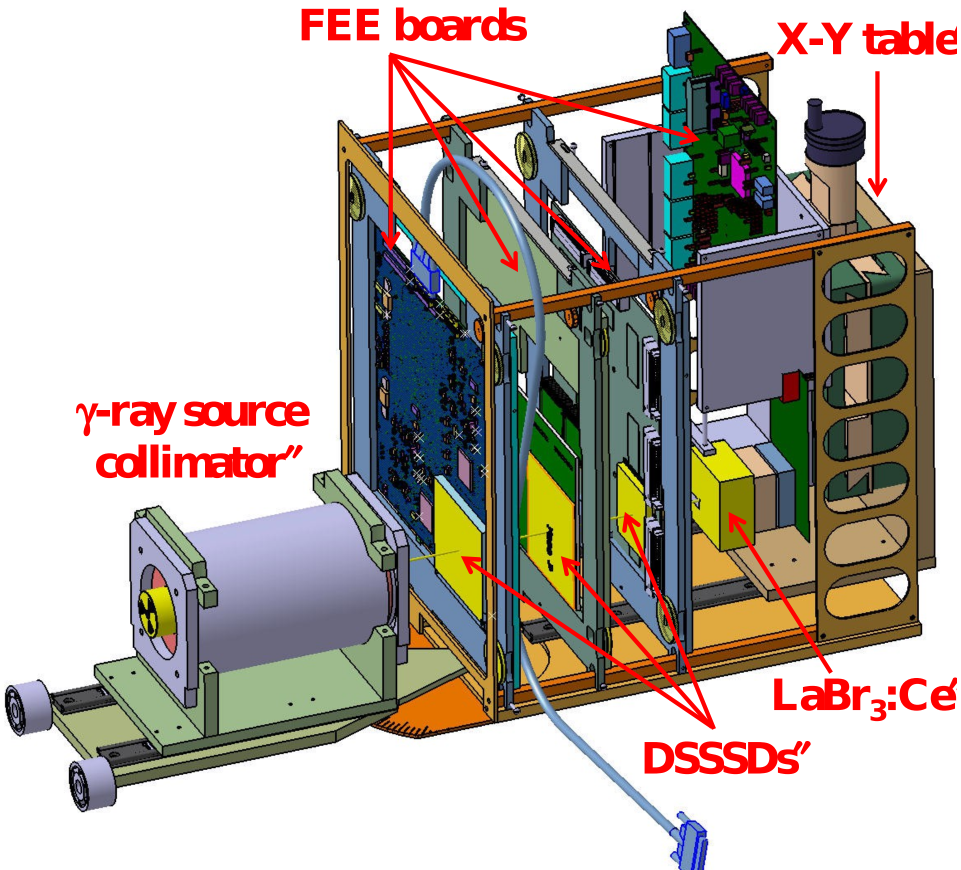
- Continuum (3σ, ΔE=E) → >10x COMPTEL
- Line (3σ) → >10x better than SPI/INTEGRAL



COCOTE, a COmpact COmpton TElescope

P2IO funding (40 k€) for 2012 – 2014
DEFI Instrumentation aux limites (17 k€) for 2014 – 2015

- Build a small-scale prototype aiming at the definition and characterization of building blocks in view of a later use for spatial application
- Development of a dedicated read-out electronics based on ASICs solutions



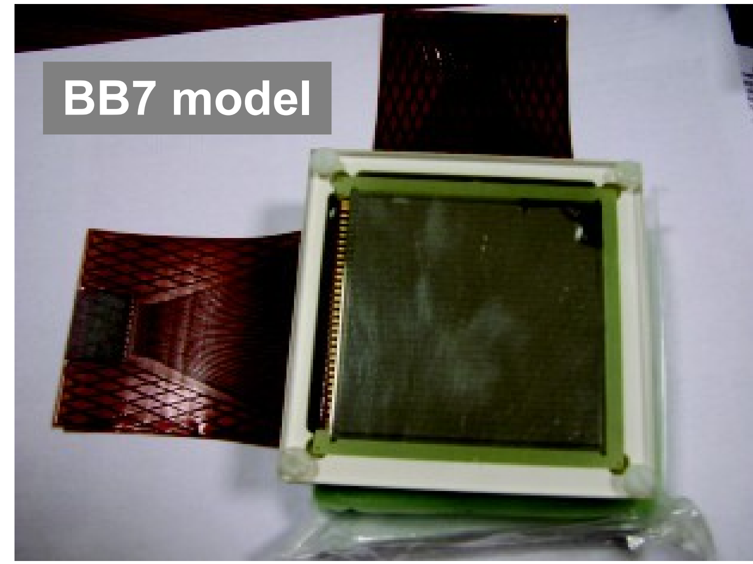
- **2 to 3 DSSSDs**
  - BB7 model (IPNO)
  - MUSETT-like (APC)
- **1 LaBr3:Ce** coupled to a multi-anode PMT for (x,y,z) localization

Which DSSSD and electronic?

Which DSSSD?

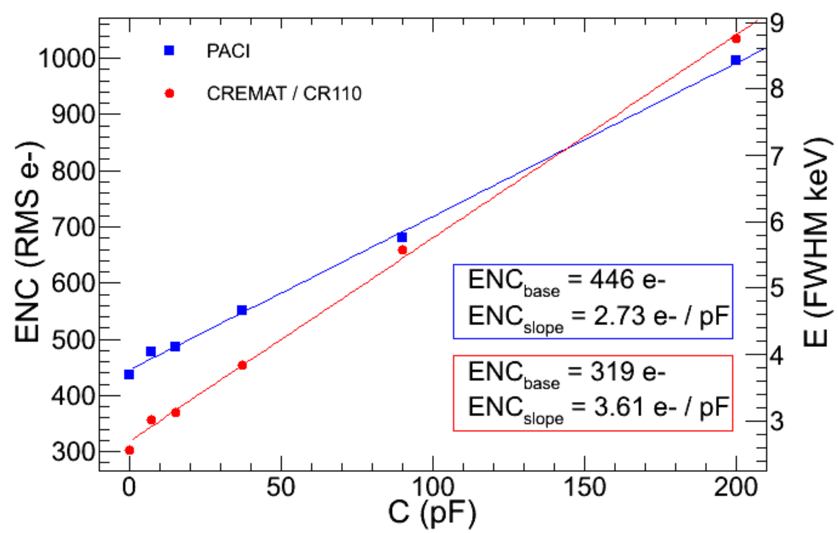
- As thick DSSSD as possible to maximize γ-ray interaction probability (no electrons tracked)
- Use Micron Semiconductor Ltd. BB7 model
  - 64 x 64 mm^2
  - 32 + 32 strips
  - 1.5 mm thick

  → **borrowed from GHT collaboration**



Which electronic?

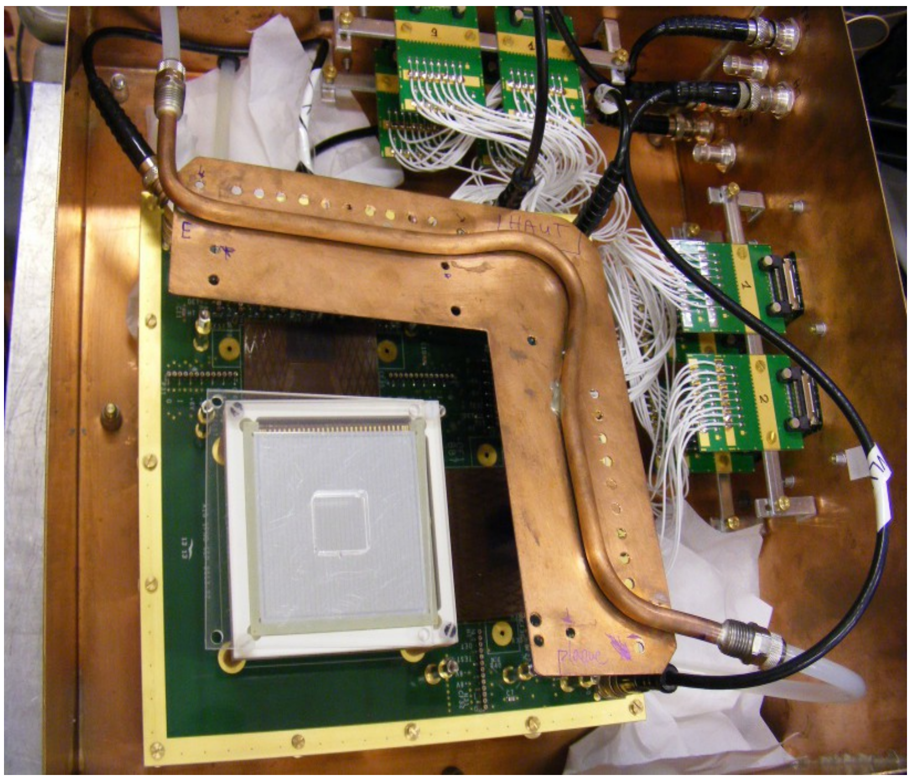
- Need to measure low energy deposits (40 keV – ~1 MeV) with low energy threshold (~10 keV)
- High gain / low noise electronics
- Modified home made PACI with higher gain



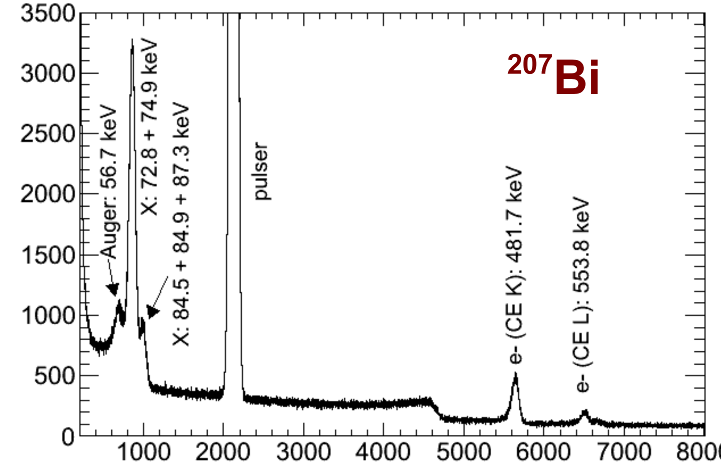
ENC = Equivalent Noise Charge

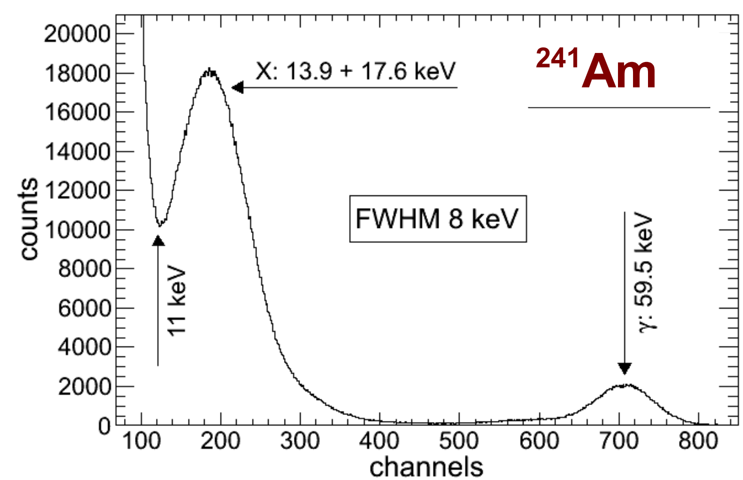
Results at room temperature

Test bench with PACI and cooling system
+ standard LED + amplifier (N568B)



Spectral resolution (p-side)



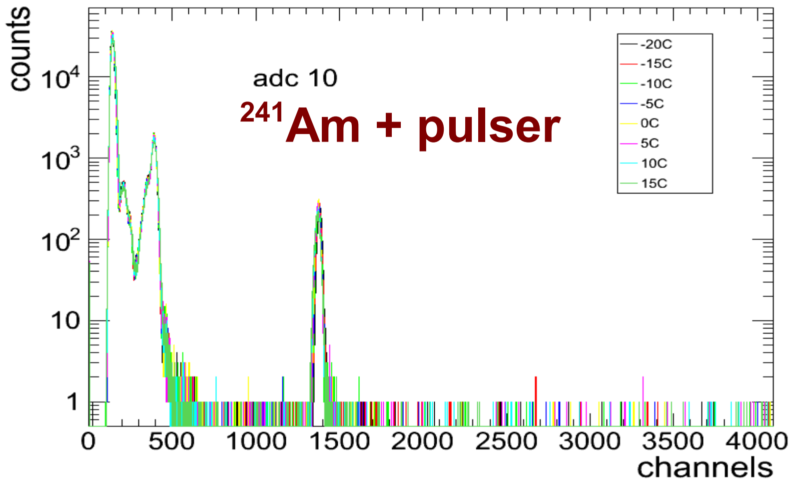


- ^{207}Bi: FWHM ≈ 11 keV (p-side)
- ^{241}Am: FWHM ≈ 8 keV / 13 keV (p-side / n-side)

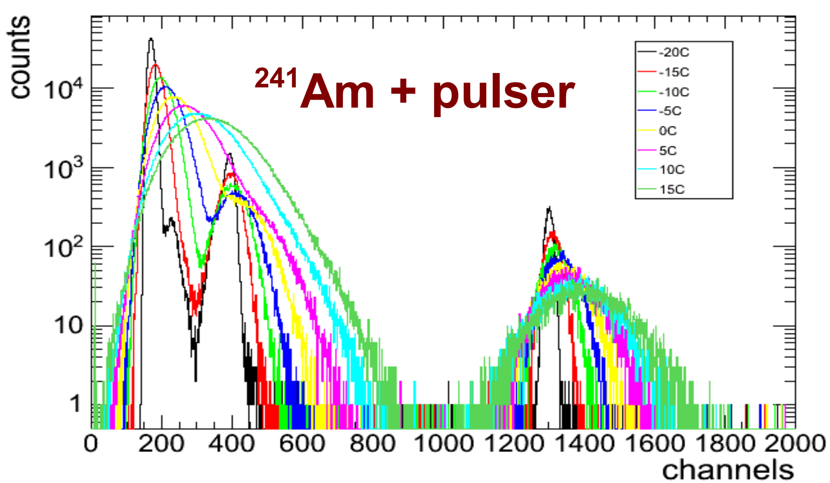
Effect of temperature

Tests performed in IPNO climatic chamber

Good strip

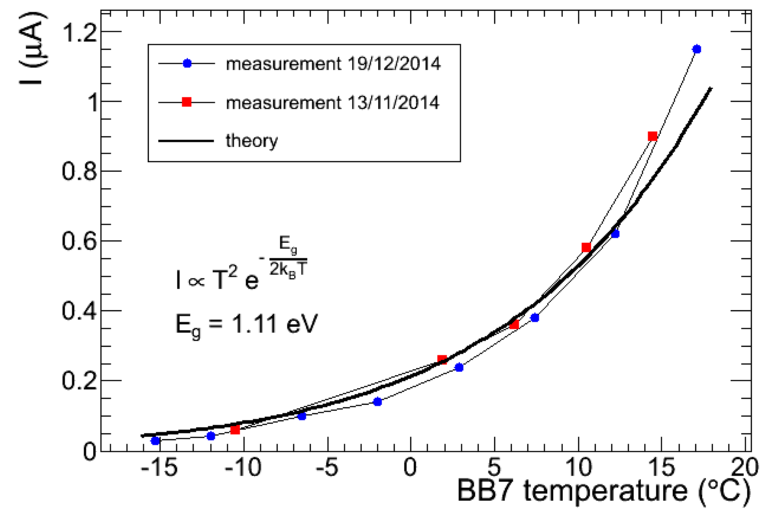


Bad strip



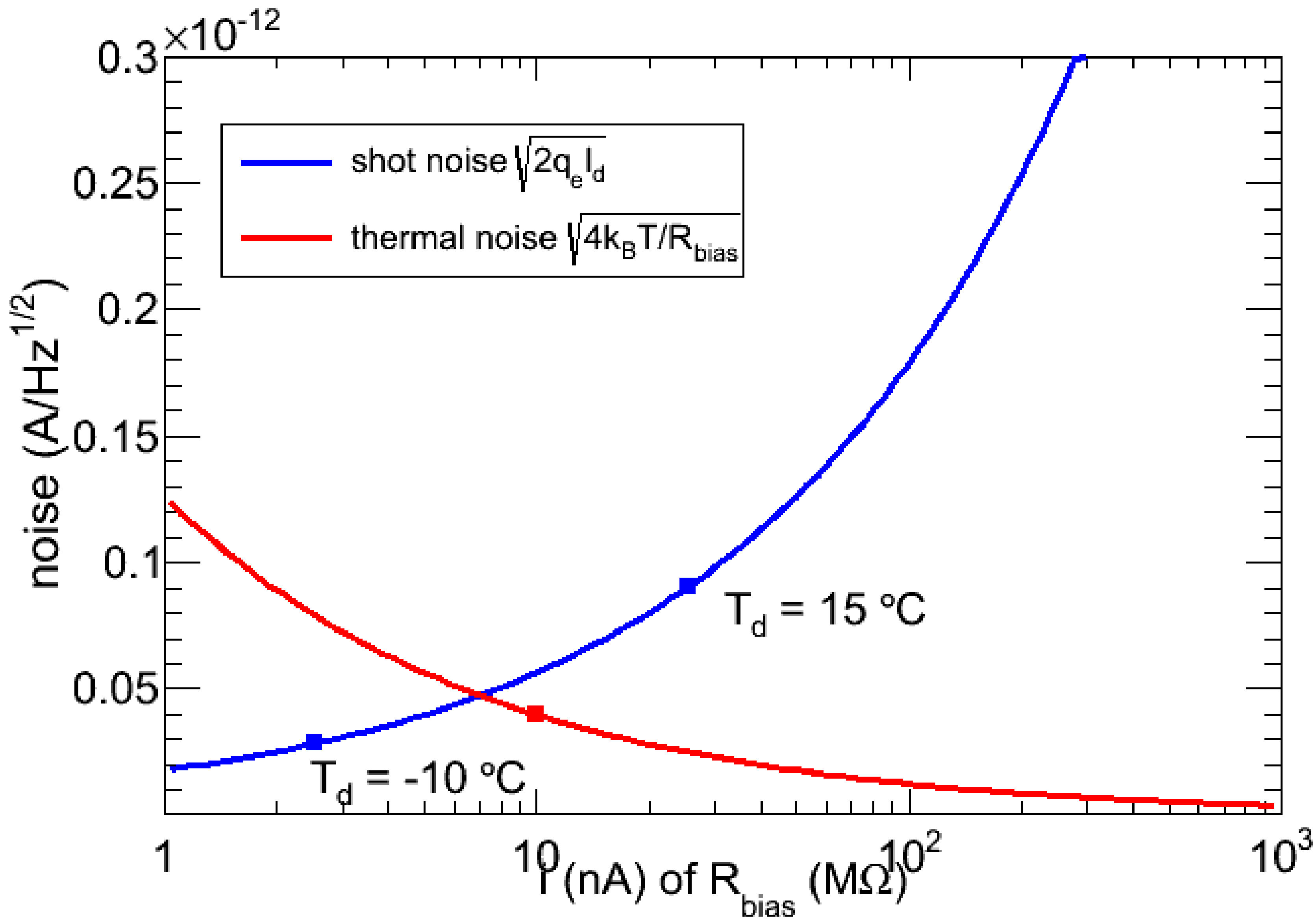
Strip known to have a large contribution to the leakage current according to Micron.

I = f(T)



- Energy resolution depends on temperature for strips with high leakage current.
- No energy resolution dependance for regular strips (!)

Noise contributions



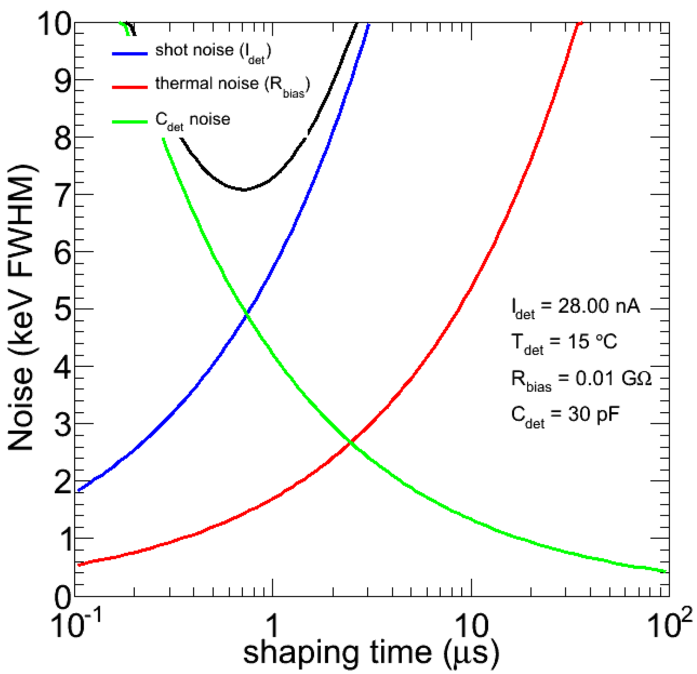
- Resolution should depend on temperature
- Electronic noise dominated by other effect

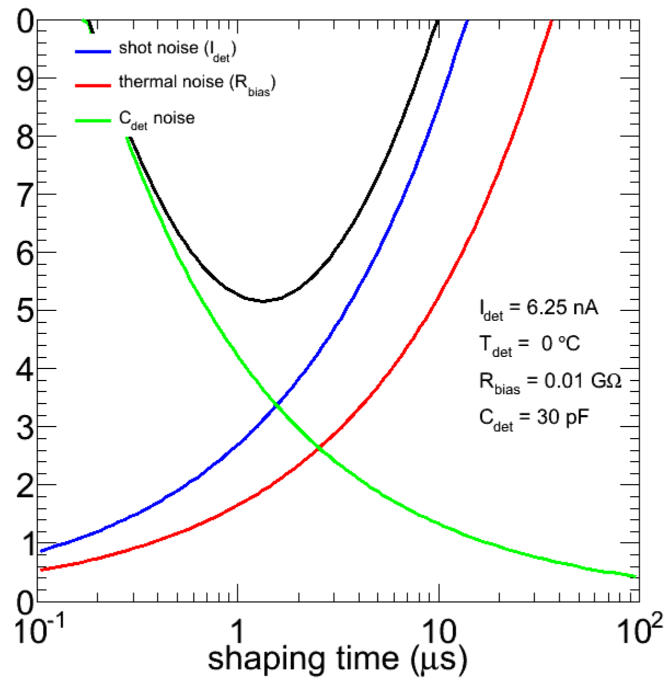
Noise and energy resolution (PACI)

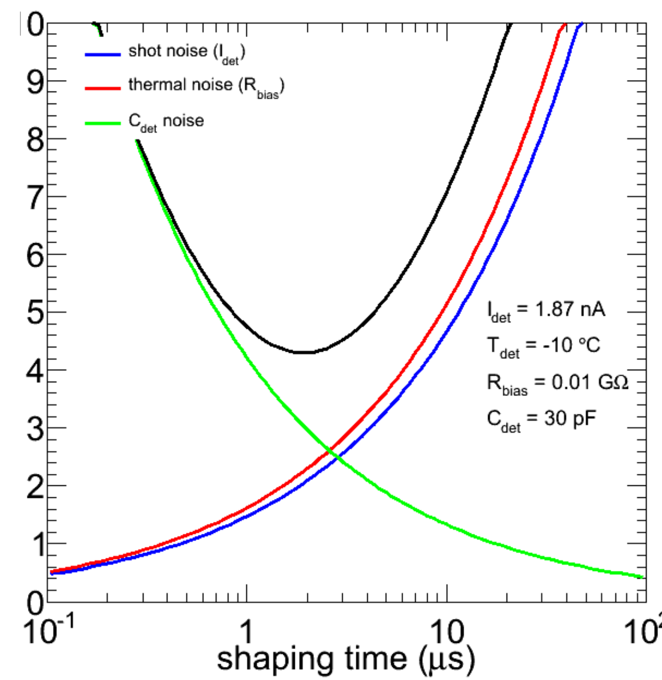
Based on Bloser et al. (2003)

$$ENC^2 = (ENC_{base} + ENC_{slope} \times C_{tot})^2/\tau + 2A\tau\left[\frac{I_{leak}}{q} + \frac{kT}{q^2 R_{bias}}\right]$$

A = 1.3







(I_{det} , T_{det}) from BB7 measurements — C_{det} includes strip + Kapton

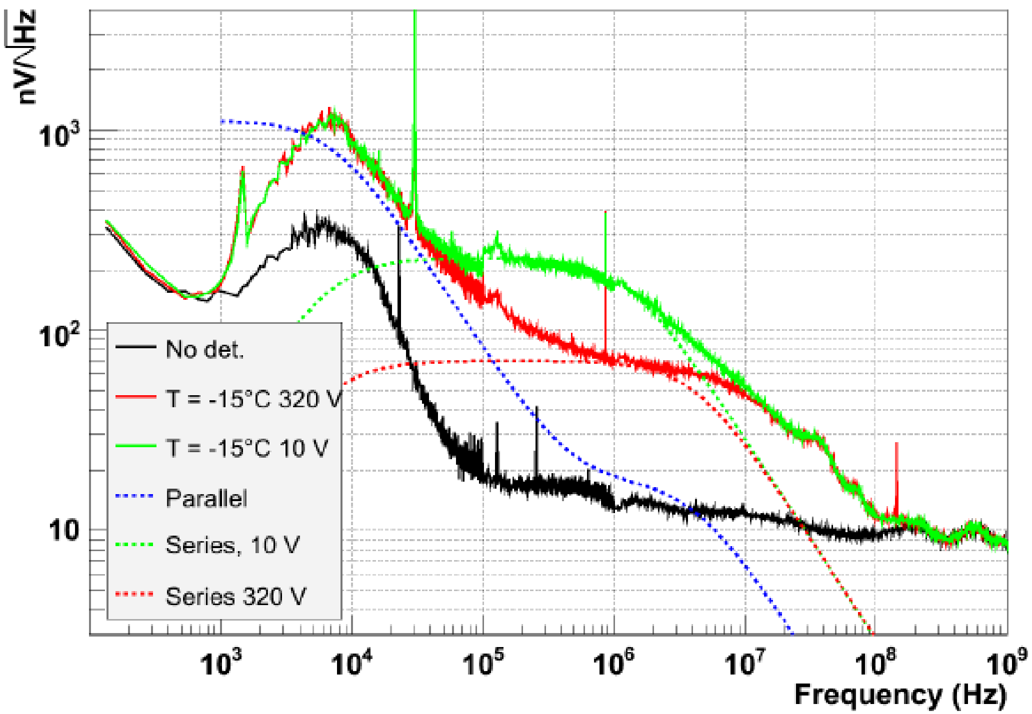
Comments:

- Shaping time of 1 μs not always optimum but is a good compromise
- With decreasing leakage current (temperature):
  - “Shot noise / thermal noise” ratio decreases and eventually gets < 1
  - Optimal shaping time increases

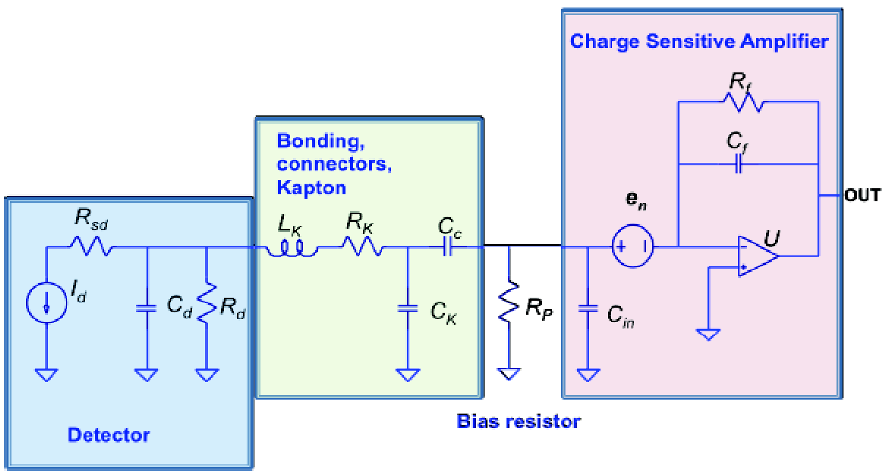
Noise spectral density measurement

- Investigation of possible unaccounted source of noise using a spectrum analyzer

Measurements



One-strip model



Simulation with LT-spice and Cadence

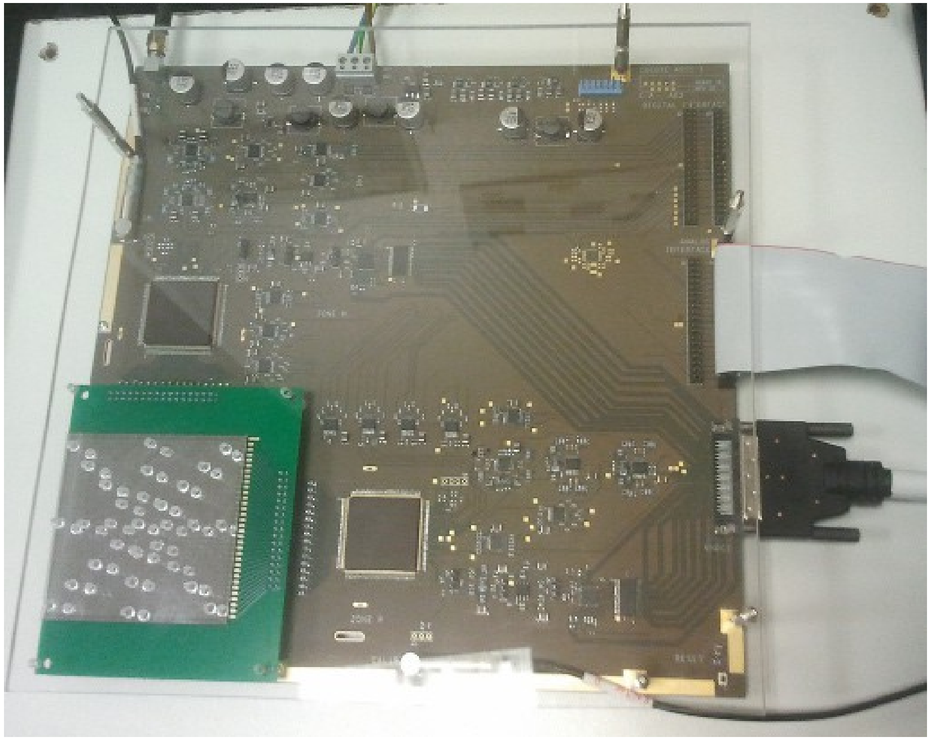
- Simulation reproduce qualitatively the noise spectral measurements
- However, energy resolution calculated is smaller than measured

G. Brulin, B. Genolini, J.-J. Dormard et al., IEEE NSS/MIC (2016)

ASIC based readout

- Identification of low-noise, high-gain and small power consumption ASICs
  → IDEAS company (specialized in spatial and medical detection)

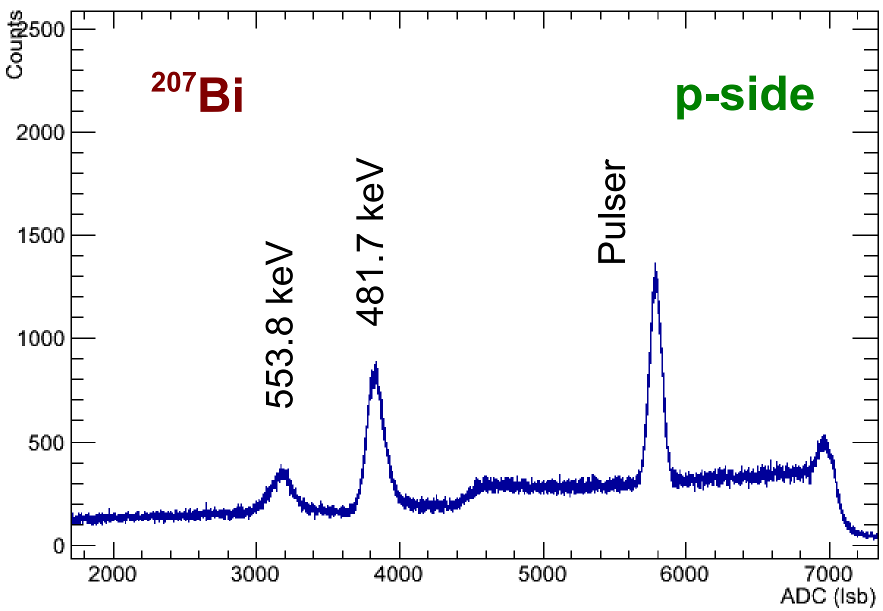
- Choice of the VA32TA7 model
  (32 channels, bipolar)
  - Pre-amplifier
  - Fast shaper
  - Slow shaper + sample/hold
  - Multiplexed analogue readout
  - Trigger generation
  - Single Event Upset (SEU) protection
  - 10-bit Wilkinson ADC



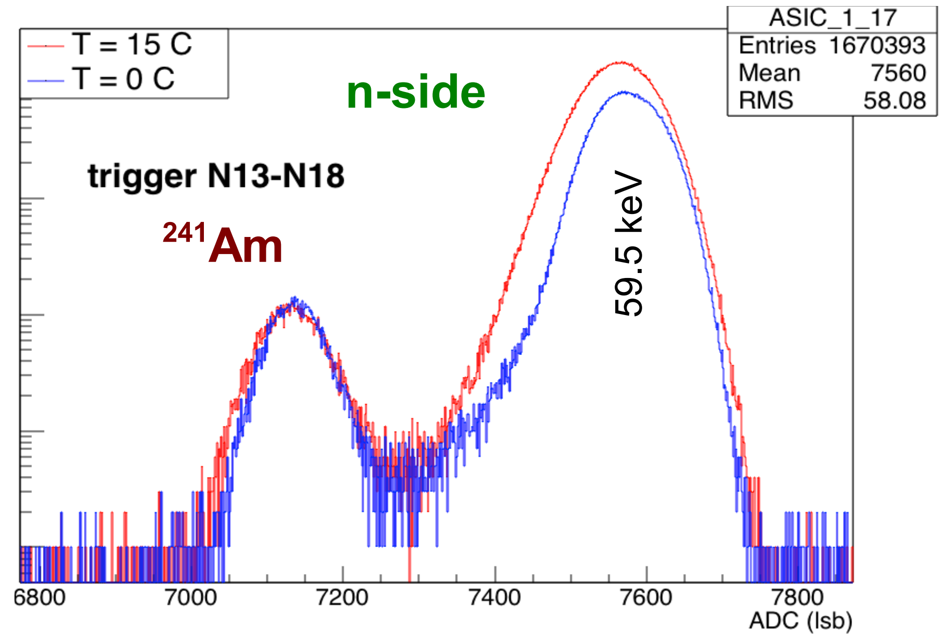
- FEE board
  - 1 BB7 AC-coupled to ASICs
  - 2 VA32TA7 ASICs
  - 2 external ADC (14 bits, 80 MS/s)
  - Interface to FPGA (ML605, Xilinx)

Results

- Qualification phase where non linearity, dynamic range, calibration for both ASICs were studied
- Measurements with radioactive sources



FWHM ≈ 13 keV

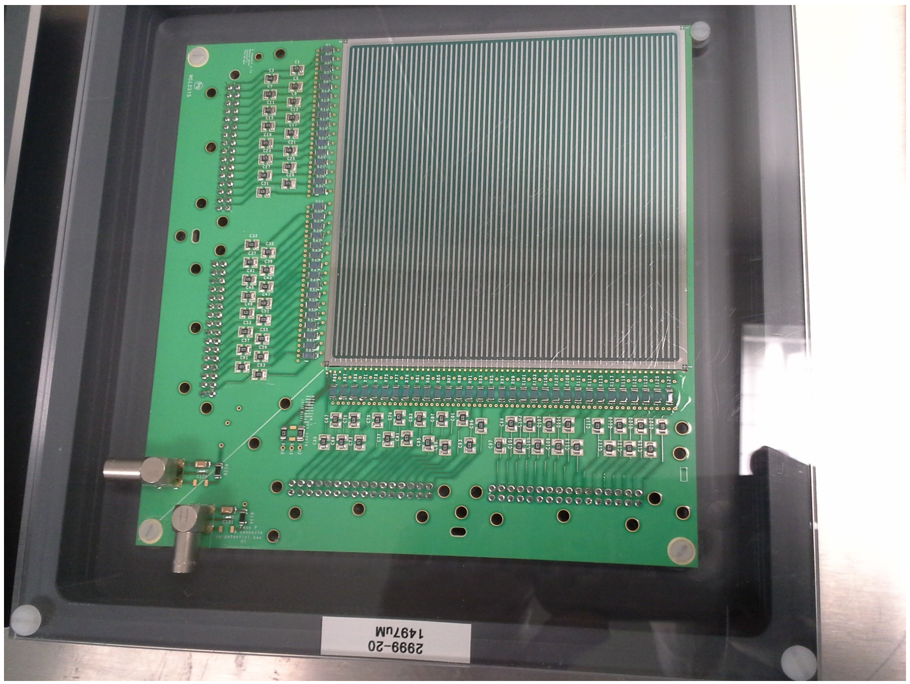


FWHM ≈ 10 keV

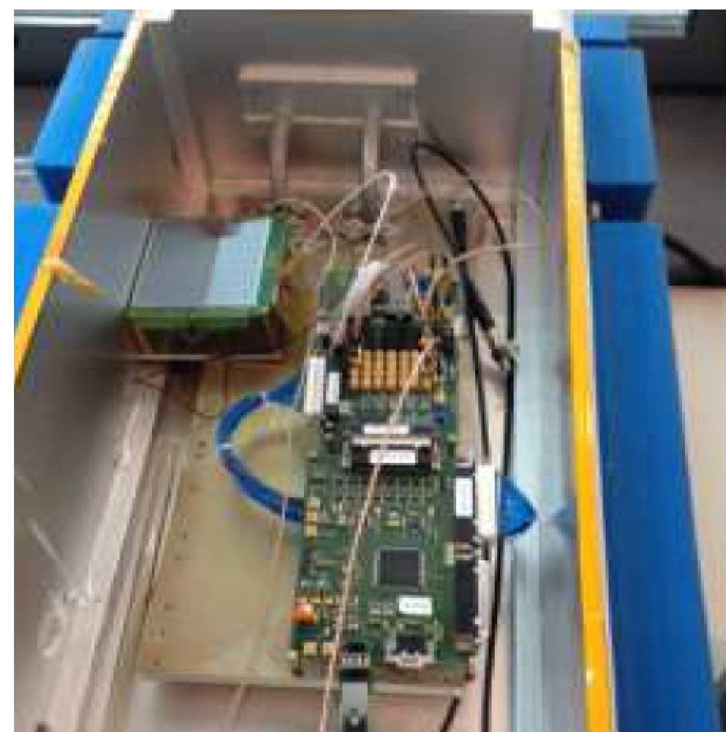
- VA32TA7 ASIC provides the level of integration needed for compact applications
- Spectral resolution slightly worst than with PACI at the moment

Large thick DSSSDs

APC/AIM R&T program through grants of the french spatial agency (CNES)



MUSETT-like
- 10 x 10 cm^2
- 64 + 64 strips
- 1.5 mm thick
- Strip width 600 μm
- 5 nA / strip @ 0°

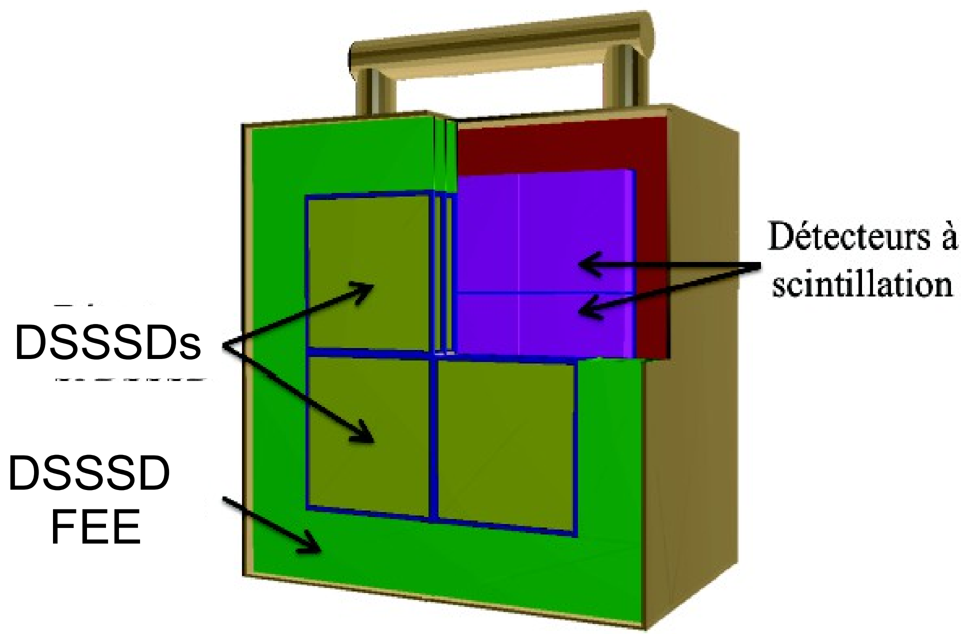


- Readout based on the IDeF-X ASIC
- DSSSD DC-coupled to ASIC

Credits: P. Laurent & W. Bertoli

ComptonCAM

Development of an **ultra-sensitive portable gamma camera** for the localization and characterization of radioactive decommissioning waste

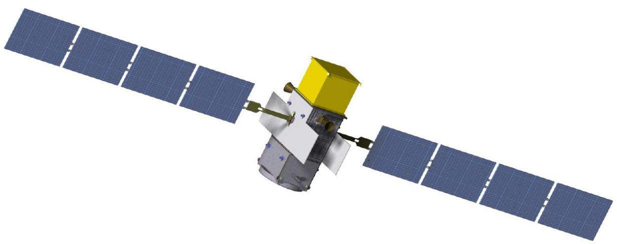


- The dismantling of nuclear installations requires the identification and location of radioactive contamination in potentially large areas
- Nuclear plants produce radio-isotopes emitting in the γ-ray band
- Identification must be performed using a gamma camera allowing the inlay of an image in gamma rays in a visible image
- High sensitivity needed to localize quickly very low activity radioactive wastes

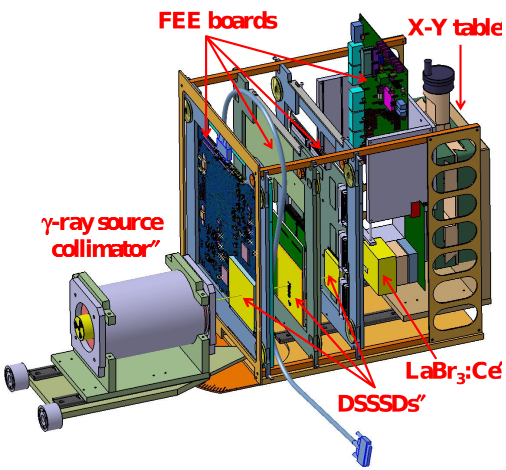
Project in response of ANDRA's call
"Optimization of the management of decommissioning radioactive waste"

CSNSM IPN ORSAY THEORIS systel électronique

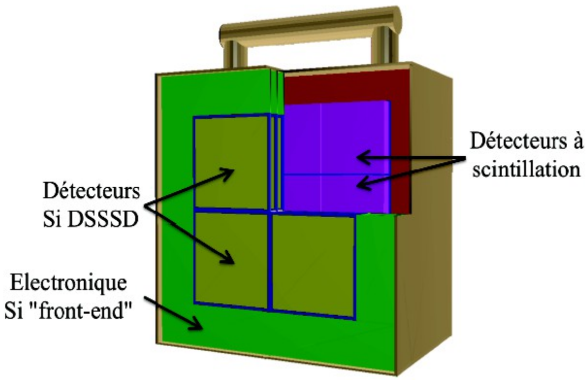
Summary



Next generation of γ-ray telescope in the MeV range will rely heavily on DSSSD technology



Large and thick DSSSDs with a dedicated electronic show good performances for spatial application



Same technology can be used in the nuclear industry for the characterization and localization of radioactive decommissioning waste