Instrumental issues for detection at nucleosynthesis energy range

R&D on a Compton telescope equipped with Si-DSSDs

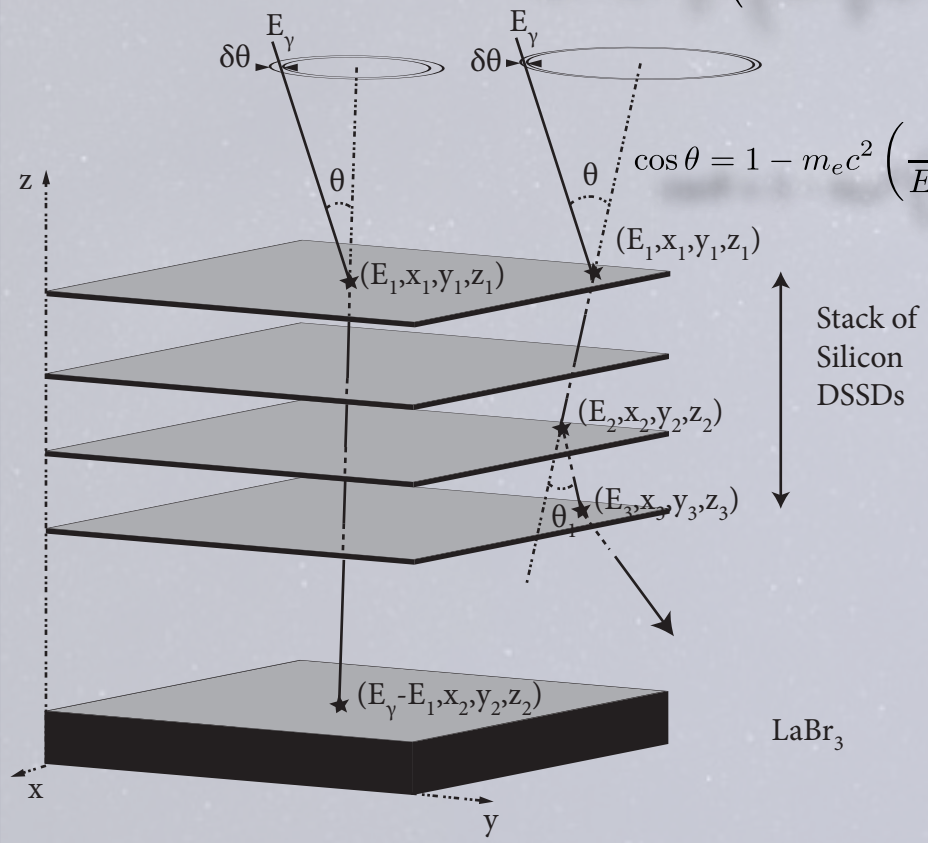
Philippe Laurent & Youri Dolgorouky

Compton Telescope

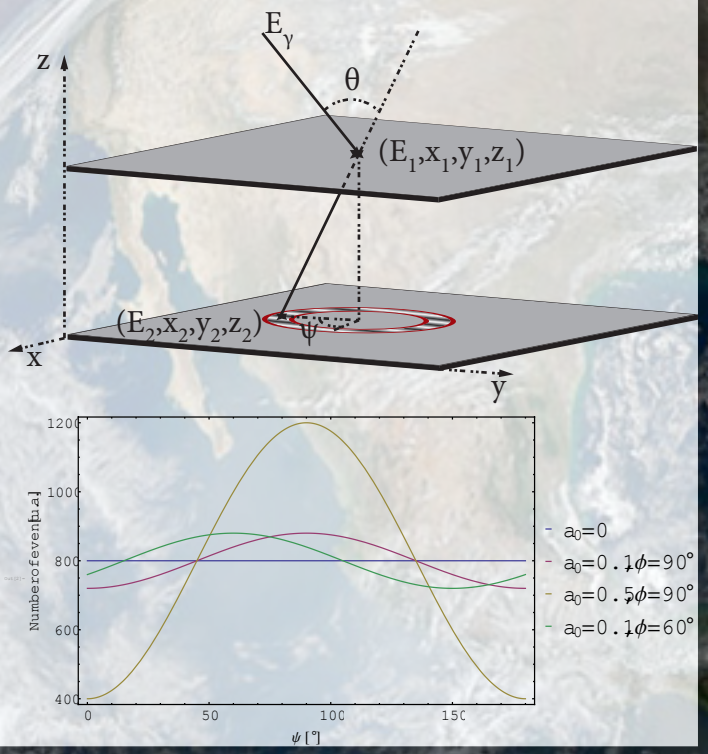
Energy and direction reconstruction of the cosmological sources

$$E_\gamma = E_1 + \frac{1}{2} \times \left(E_2 + \sqrt{E_2^2 + \frac{m_e c^2 E_2}{1 - \cos\theta_1}} \right)$$

$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_\gamma - E_1} - \frac{1}{E_\gamma} \right)$$



Polarization



Main constrains

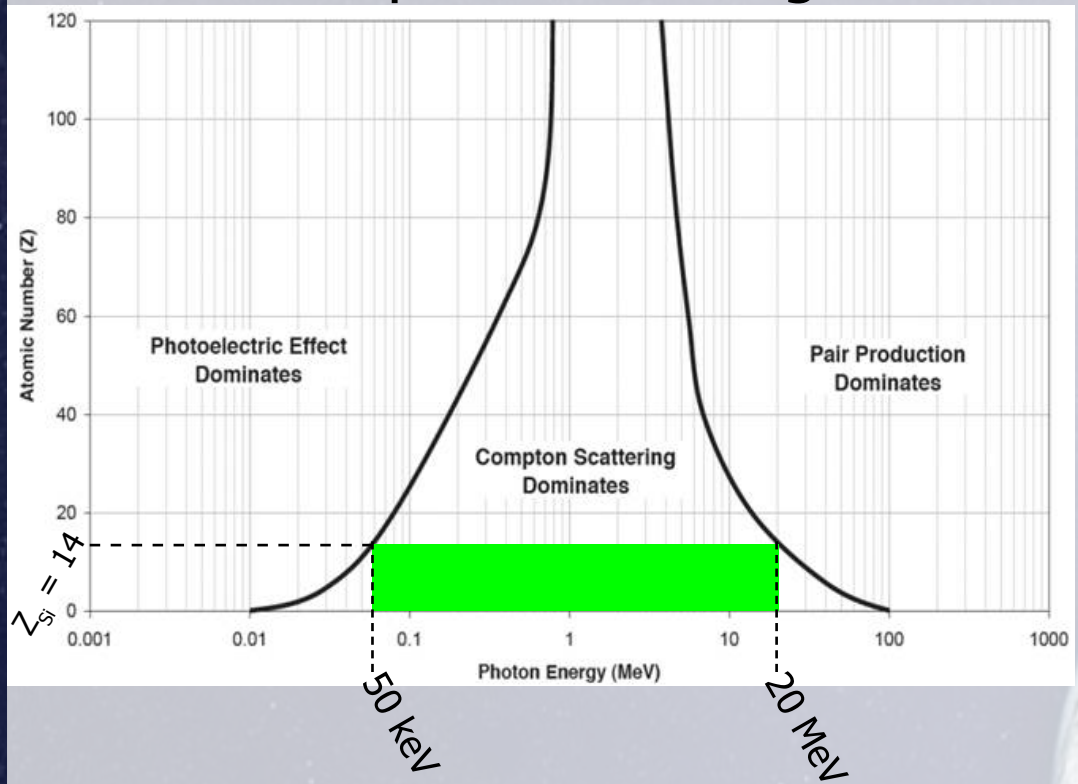
- Satellite :
  - **Mass budget**
    - **Electrical power** budget
      - **Technological Readiness Level**

- Environment :
  - **Radioactive background** at 1 MeV

- Compton telescope technic :
  - **Predominance of the Compton scattering** around the 1 MeV energy range

Silicon Double Sided Strip Detectors (Si-DSSD)

Compton Scattering



Stable element : low radioactivity

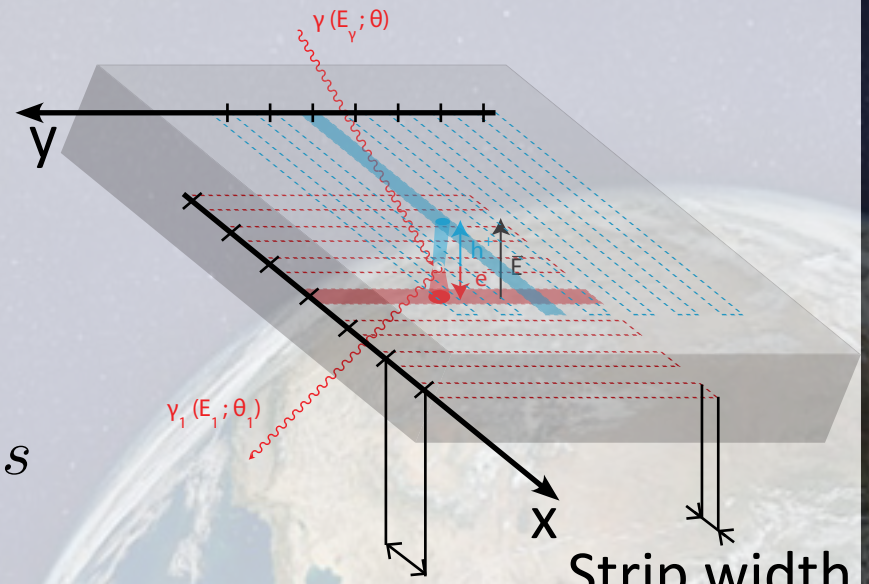
Light element : low mass

Silicon Double Sided Strip Detectors (Si-DSSD)

DSSD Principle

- Semiconductor material
  - PN Junction
    - Reverse Bias Voltage

$$E_{e-} \propto Number\ of\ hole/electron\ pairs$$



Compton scattering position and energy measurement

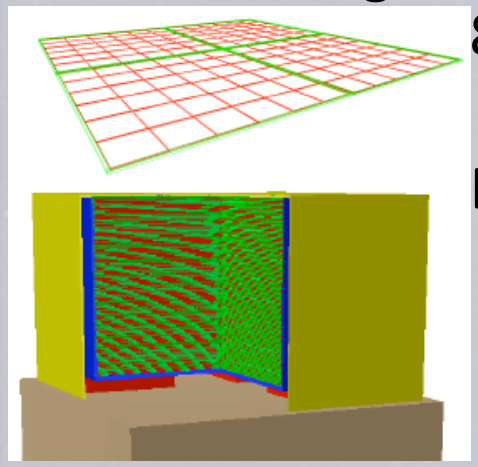
Energy and angular resolution

- **Energy resolution**
- **Angular resolution**

} Compton telescope performances ⇒ DSSD Energy resolution

MEGALIB simulation

CAPSiTT configuration :



80 layers of Si-DSSD

12 × 12 DSSDs

DSSD :

10 cm × 10 cm

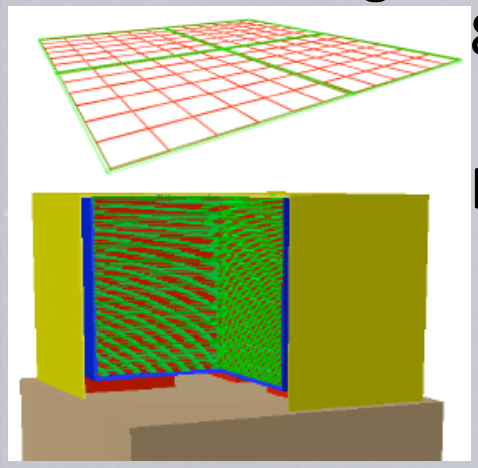
2 mm thickness

Pitch width : 1.5 mm

Energy and angular resolution

MEGALIB simulation

CAPSiTT configuration :



80 layers of Si-DSSD

12 × 12 DSSDs

DSSD :

10 cm × 10 cm

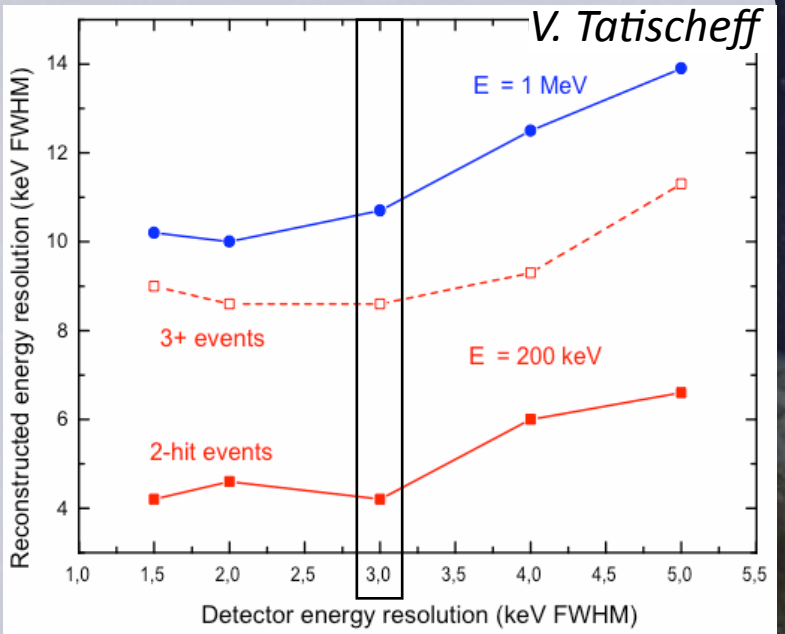
2 mm thickness

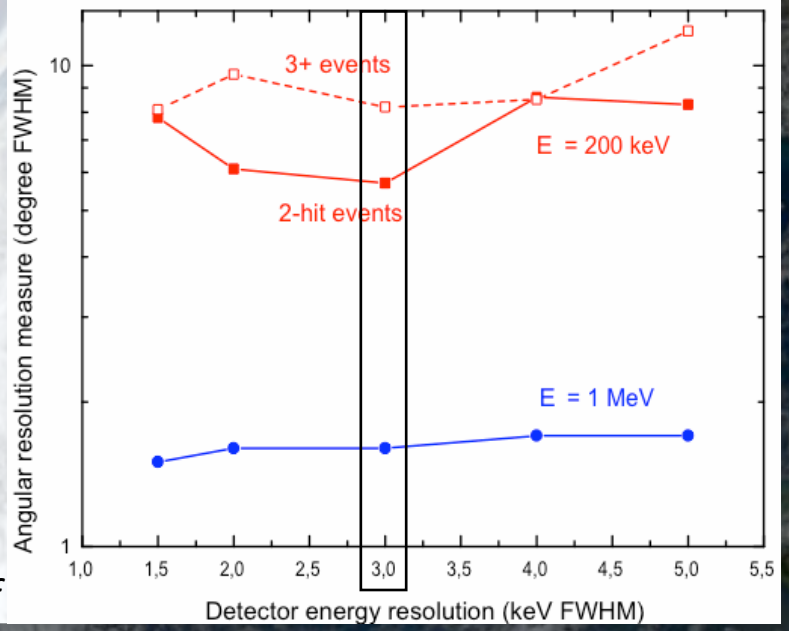
Pitch width : 1.5 mm

Energy resolution : 3keV / DSSD

V. Tatischeff

V. Tatischeff

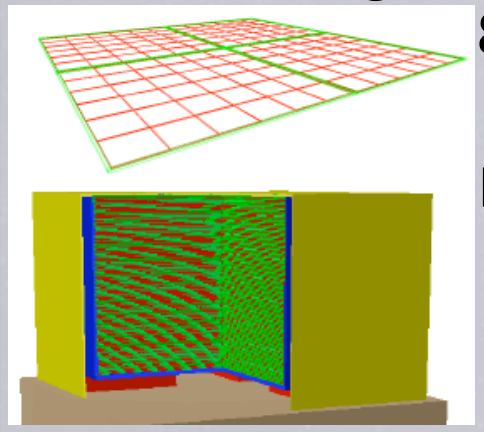




Energy and angular resolution

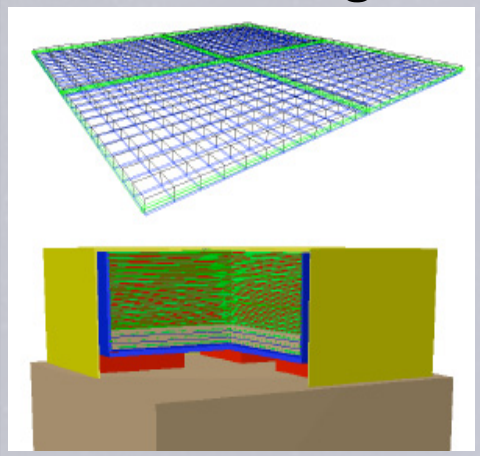
MEGALIB simulation

CAPSiTT configuration :

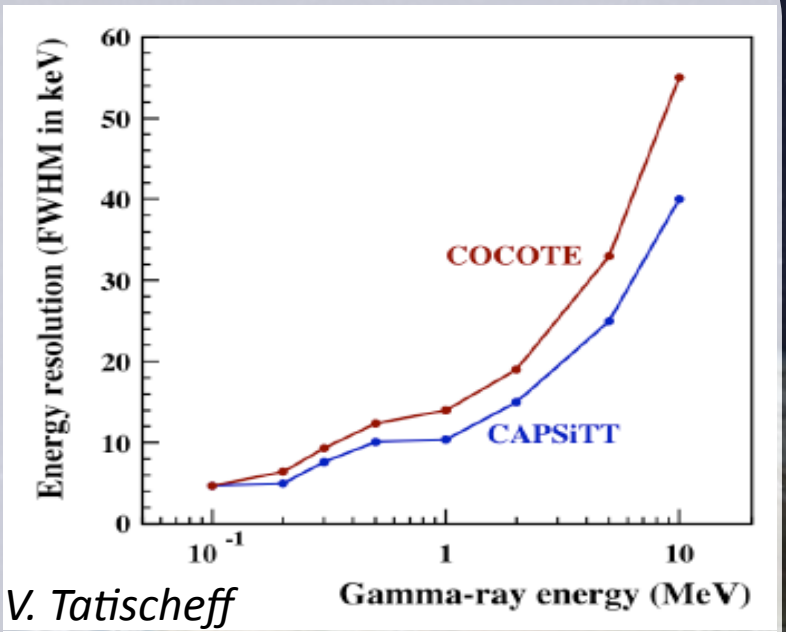


80 layers of Si-DSSD
12 × 12 DSSDs
DSSD :
10 cm × 10 cm
2 mm thickness
Pitch width : 1.5 mm

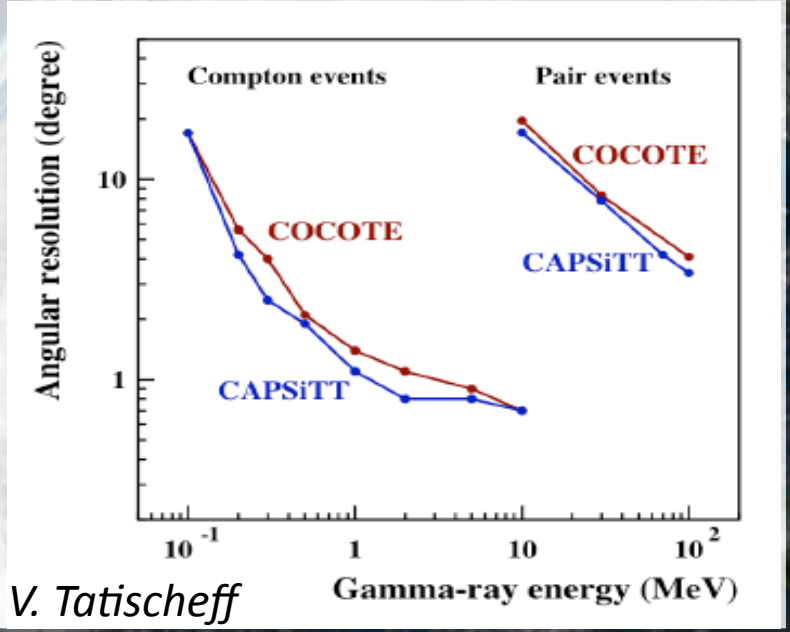
CoCoTe configuration :



30 layers of Si-DSSD
12 × 12 DSSDs
$LaBr_3$ calorimeter
DSSD :
10 cm × 10 cm
1.5 mm thickness
Pitch width : 1.5 mm



V. Tatischeff



V. Tatischeff

Energy resolution and Equivalent Noise Charge

$$\Delta E^2 = 2.35^2 \varepsilon_W^2 \cdot ENC_{tot}^2 + 2.35^2 F \varepsilon_w \cdot E_\gamma + \Delta E_{perte}^2$$

$$ENC_{tot}^2 = \frac{\alpha_s}{\tau_s} \cdot (C_{DSSD} + C_p + C_e)^2 + \alpha_f \cdot (C_{DSSD} + C_p + C_e)^2 + \alpha_p \tau_s \cdot I_{Leak.}$$

DSSD capacitance

DSSD Leakage current

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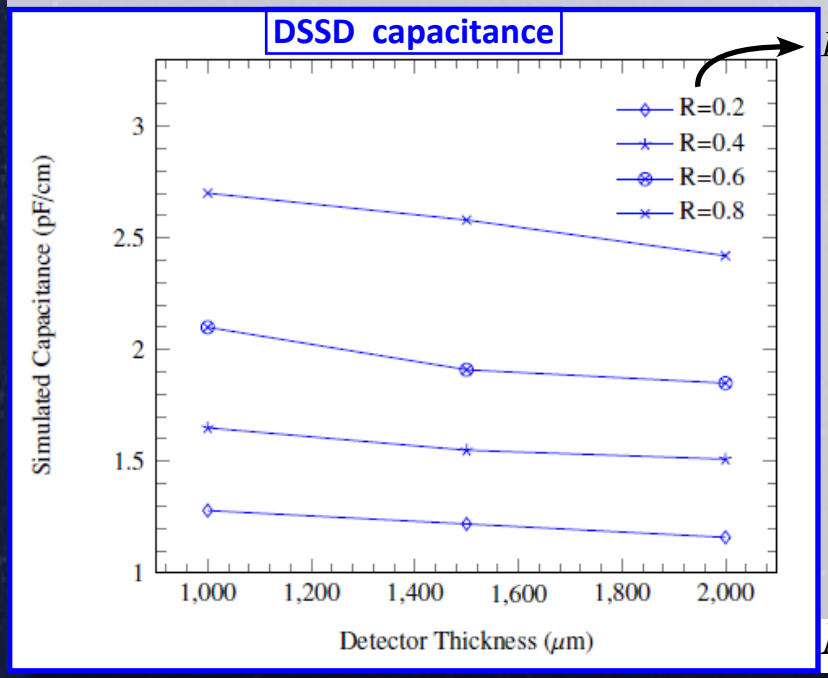
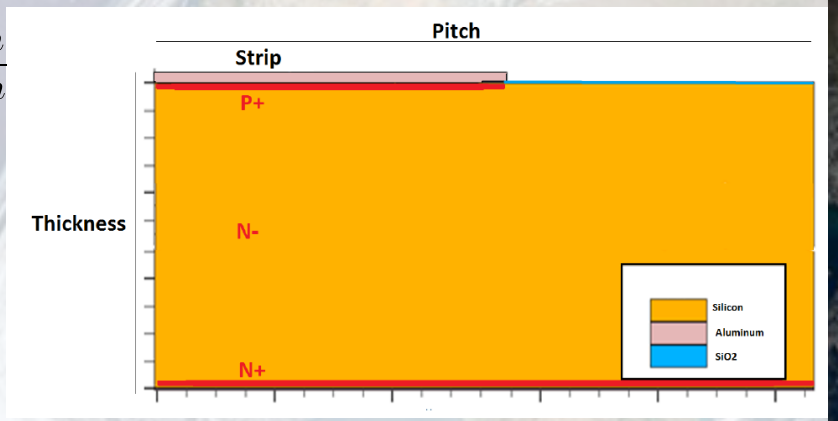
DSSD capacitance

TCAD Simulation



$$Ratio = \frac{strip\ width}{pitch\ width}$$



M. Khalil et al. (2013)

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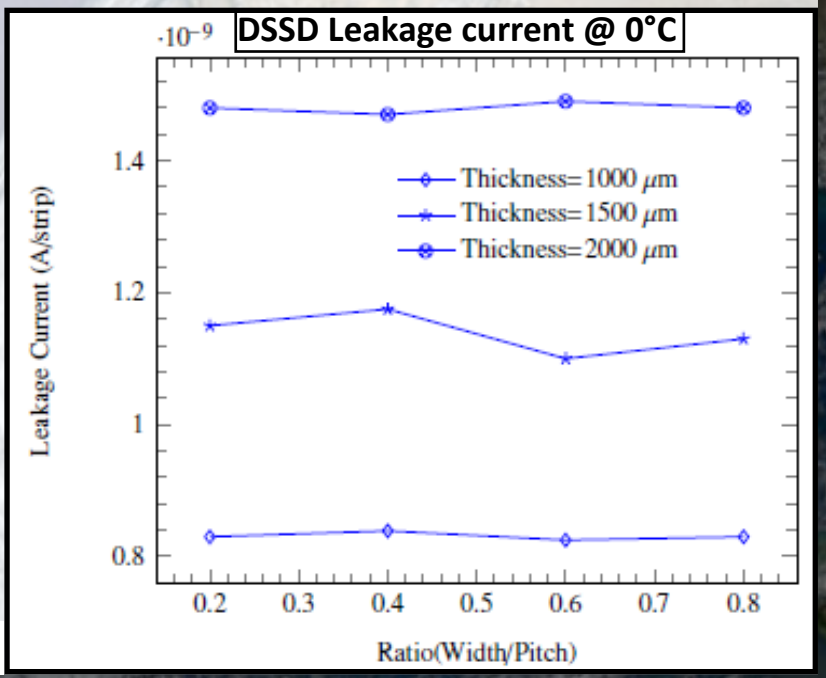
DSSD Leakage current

TCAD Simulation

Good approximation :

$$\frac{I_{Leak}(T_2)}{I_{Leak}(T_1)} = 2^{\frac{T_2 - T_1}{7}}$$



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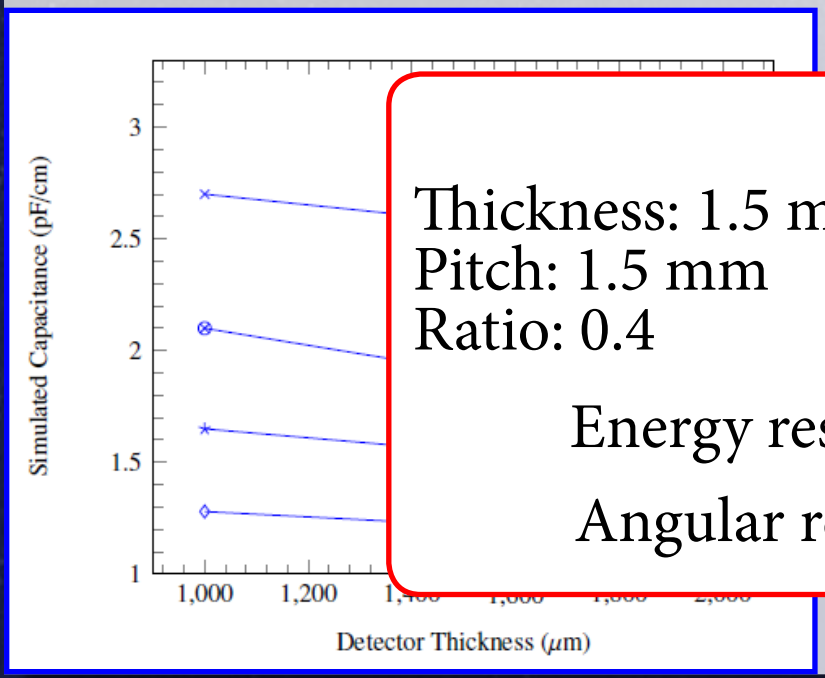
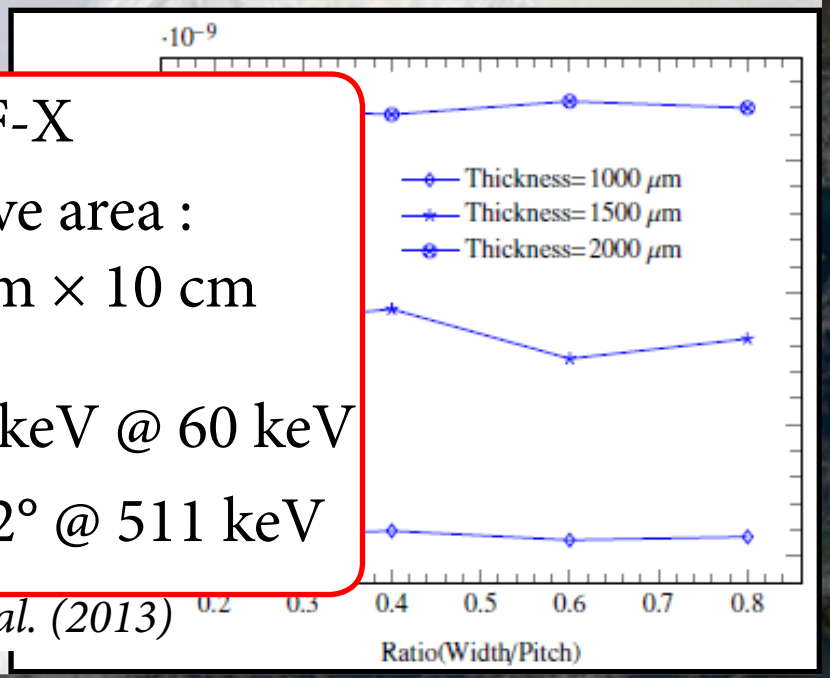
DSSD capacitance

DSSD Leakage current

TCAD Simulation





M. Khalil et al. (2013)

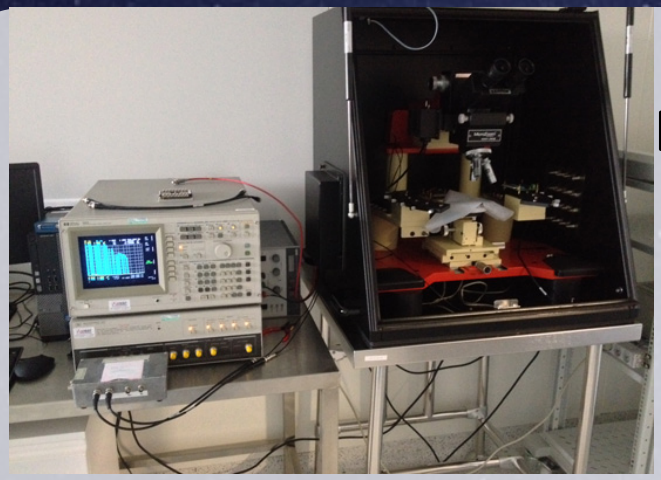
ASIC IDeF-X

Thickness: 1.5 mm
Pitch: 1.5 mm
Ratio: 0.4

Active area :
10 cm × 10 cm

Energy resolution <3 keV @ 60 keV

Angular resolution ~2° @ 511 keV

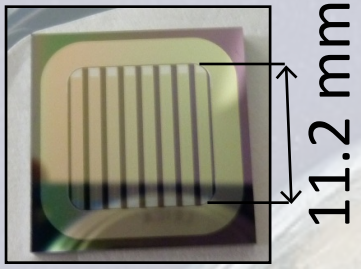


Electrical caracterizations

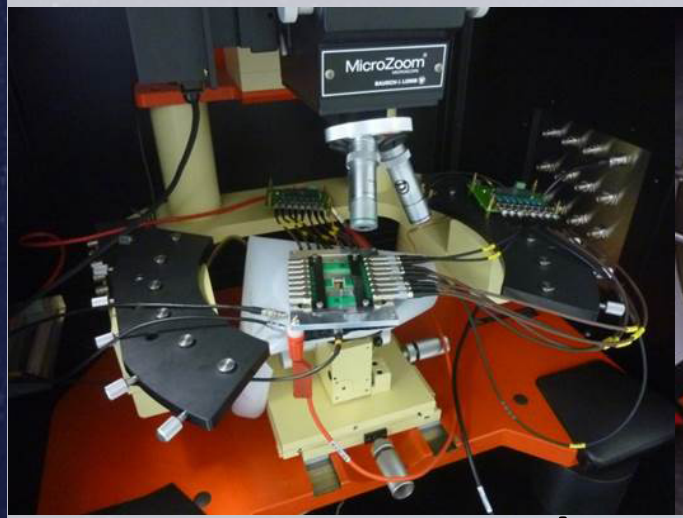
Experimental set-up at APC Laboratory

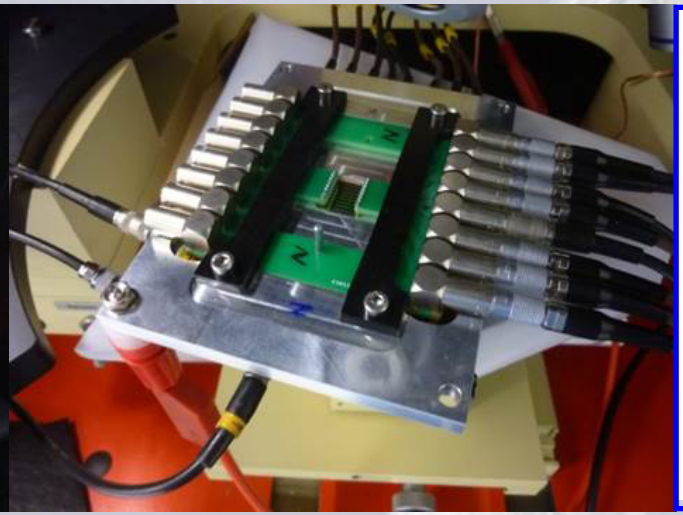
Baby DSSD (SINTEF)

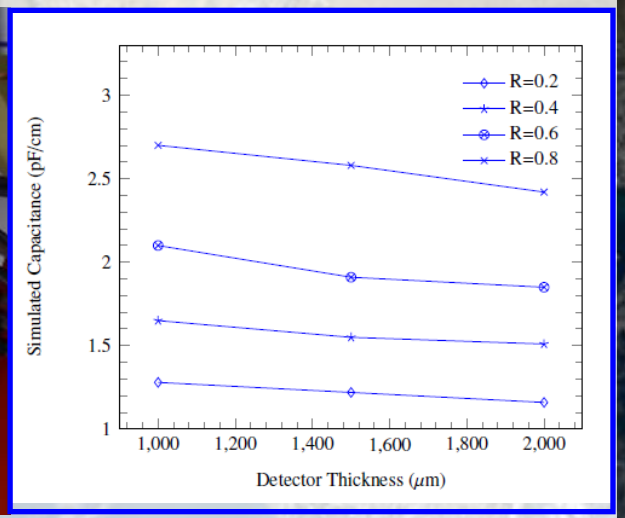
Thickness : 2 mm



C vs V curve





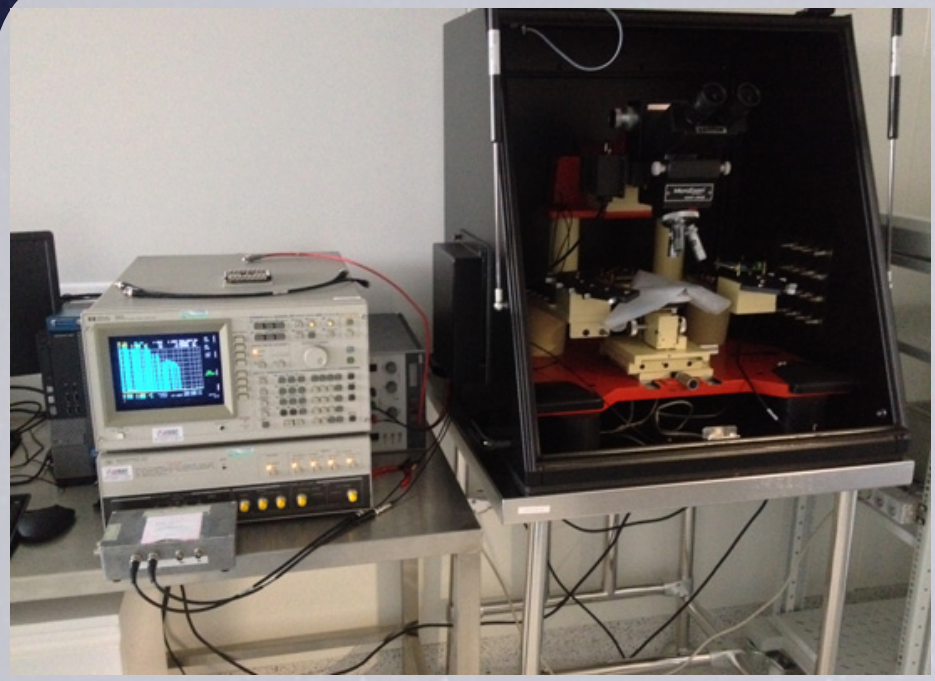


C_{DSSD} = 3.1 pF/cm @ 550 V and 1MHz

Ratio = 0.93

Simulation

Instrumental issues for detection at nucleosynthesis energy range
R&D on a Compton telescope with Si-DSSDs



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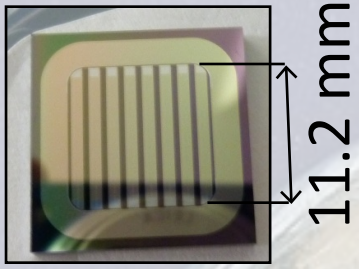
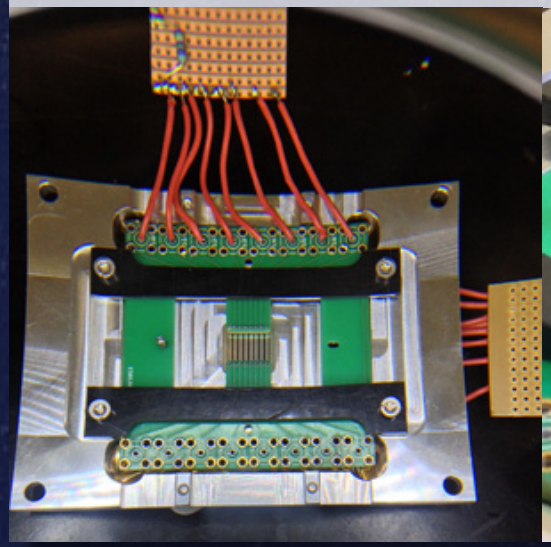
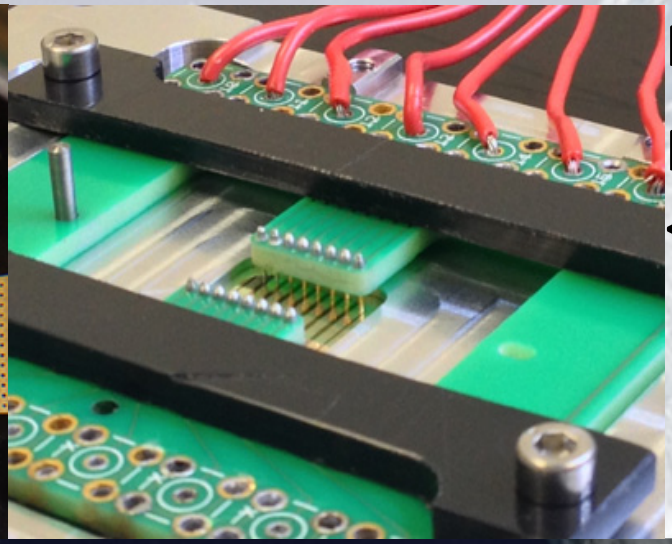






Test :

Forward or reverse bias ?

Reverse bias :

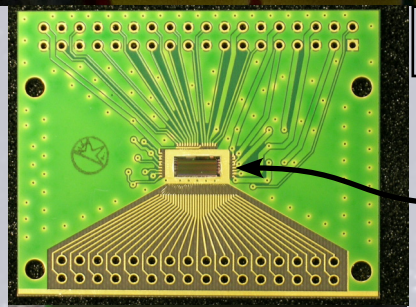
< 10 nA @ 20°C and 200 V

I vs V curve

Instrumental issues for detection at nucleosynthesis energy range
R&D on a Compton telescope with Si-DSSDs

Spectrometric test bench

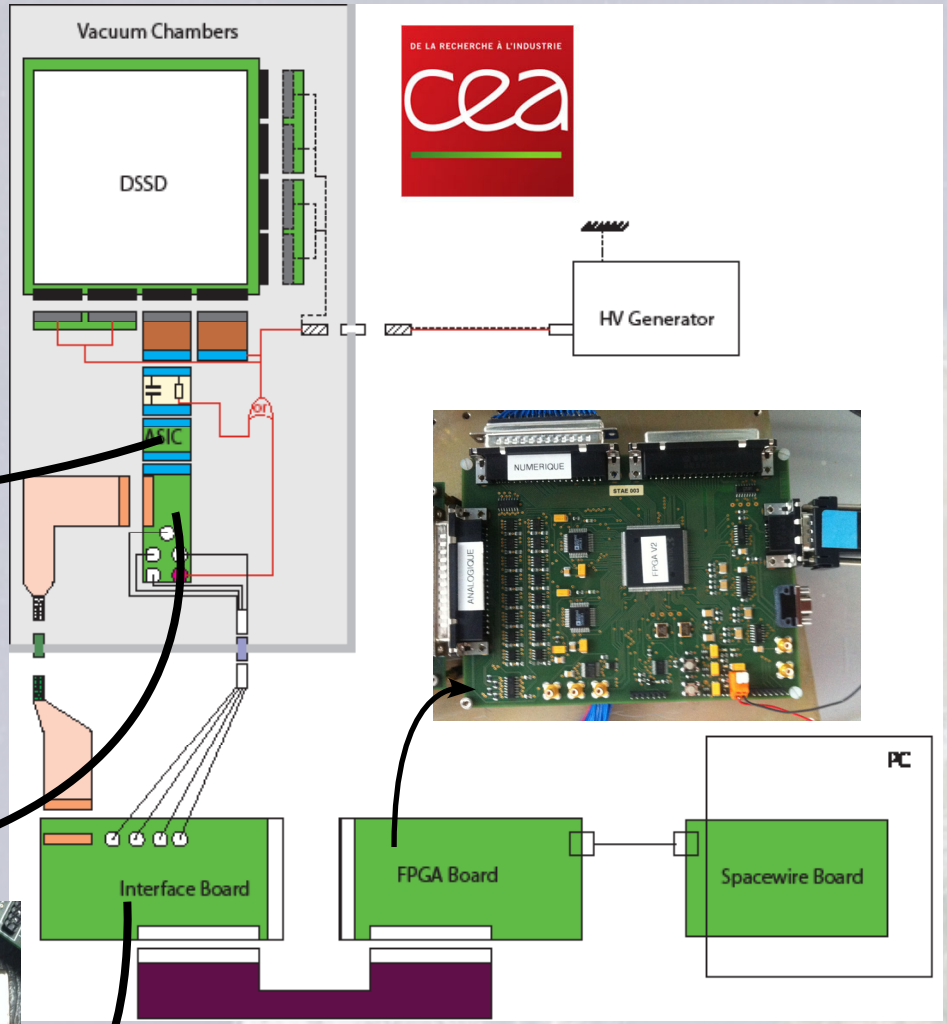
DSSD MUSETT



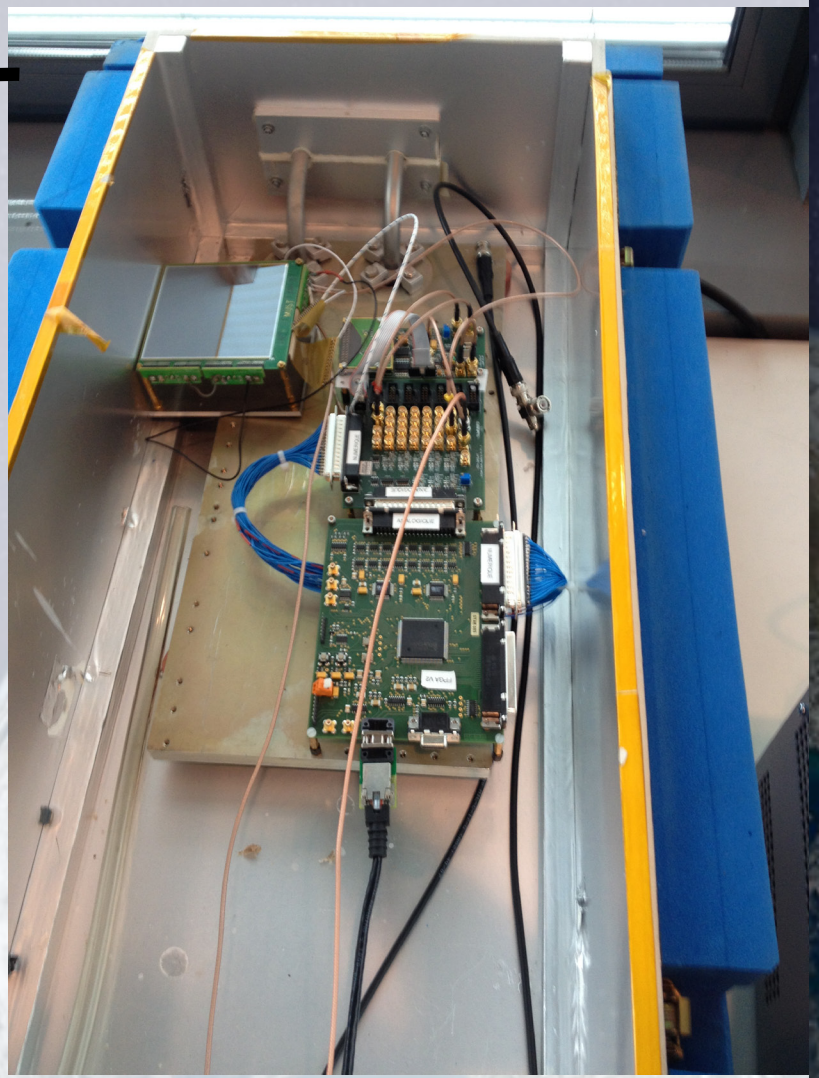
ASIC
IDeF-X BD

ASIC IDeF-X
Motherboard

Multi-ASIC Interface board



Spectrometric test bench



Installation at APC Laboratory

Spectrometric test bench
On going activities

Equip the box :

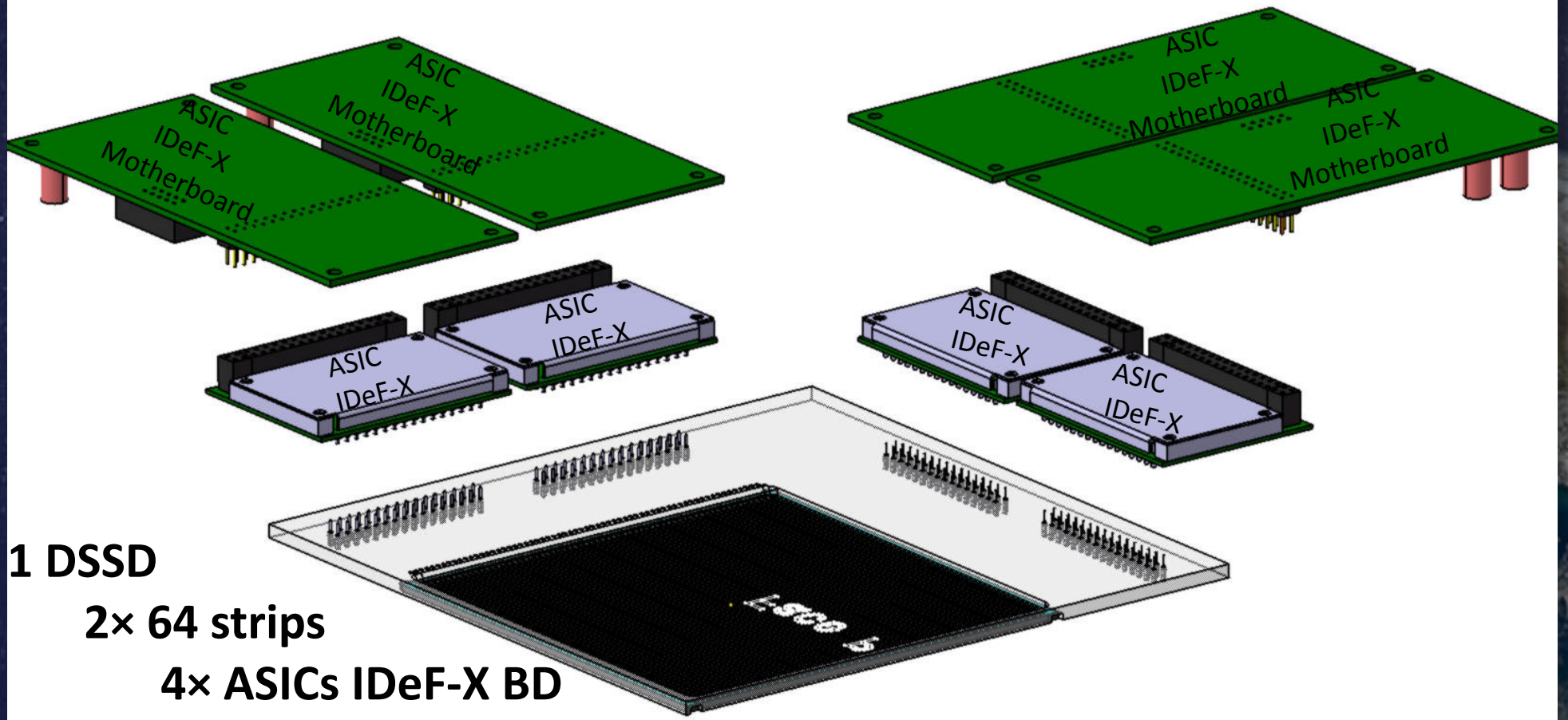
- Nitrogen flushing → ↓ dew point
- Cool down device → -20°C → $I_{Leak}/64$

Electromagnetic compatibility

Flashing issues

Test with Musett and the 60 keV ray of ^{241}Am source with 2 ASICs IDeF-X BD

DSSDs & PCB - design



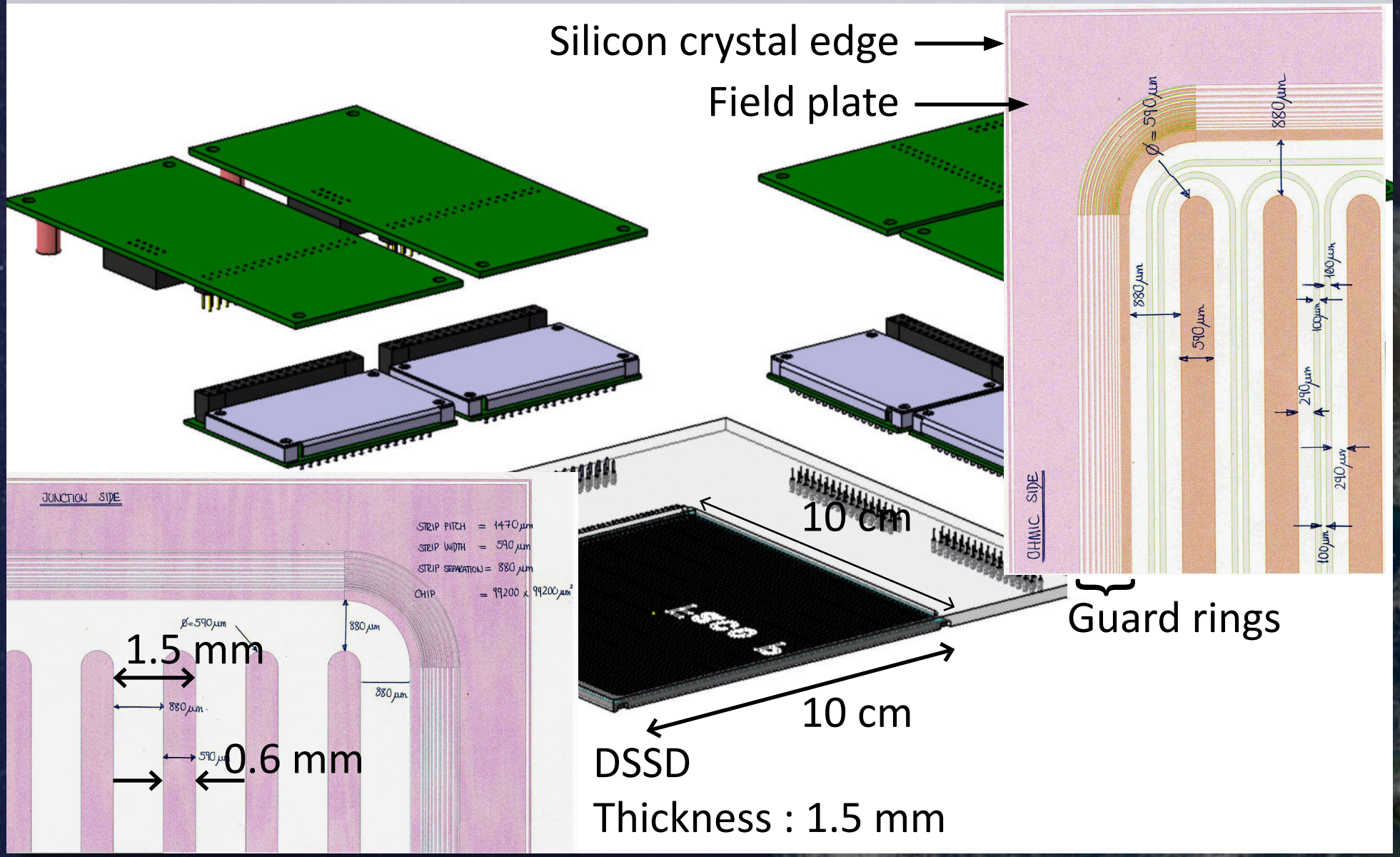
1 DSSD

2× 64 strips

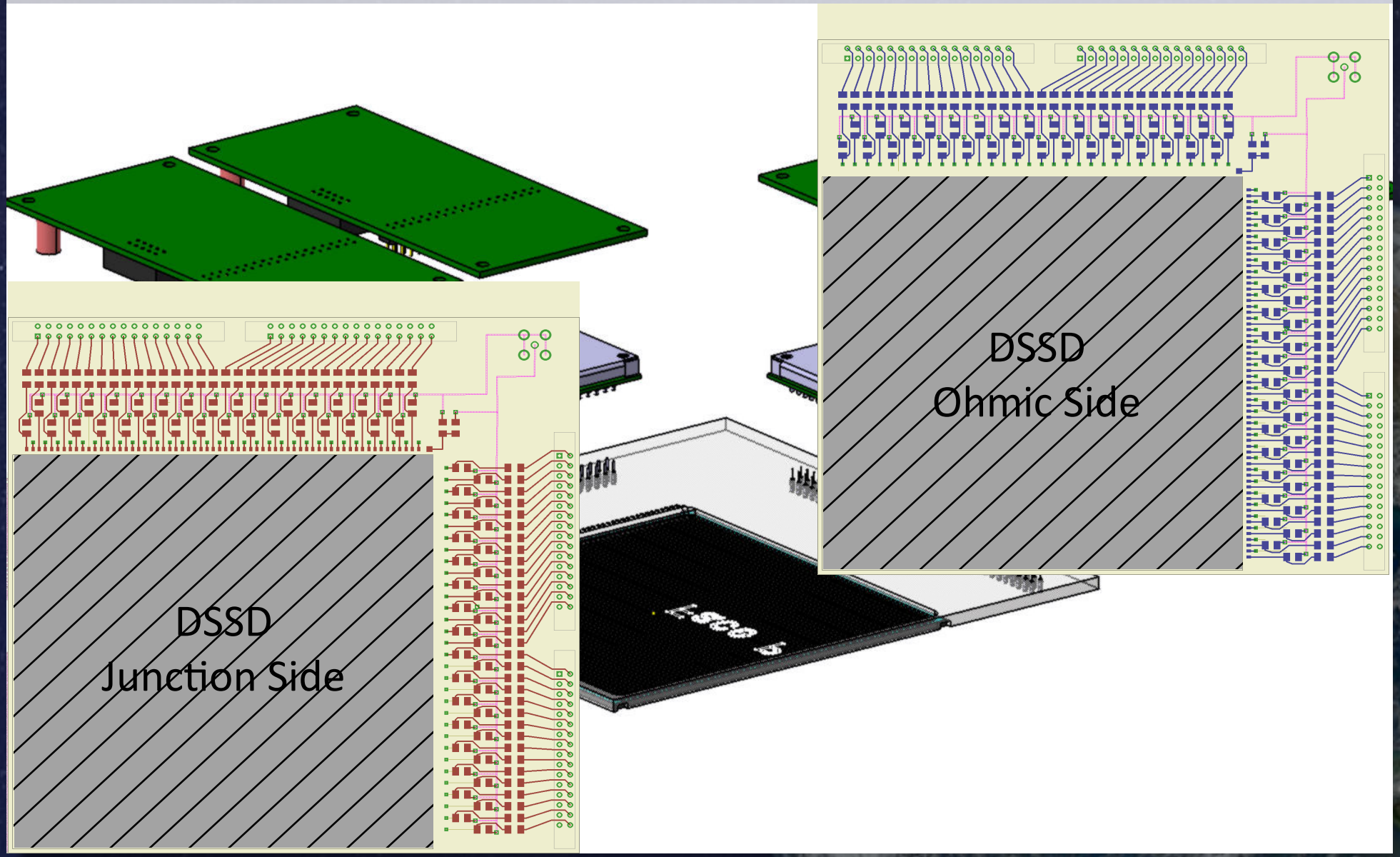
4× ASICs IDeF-X BD

4× ASIC Motherboard

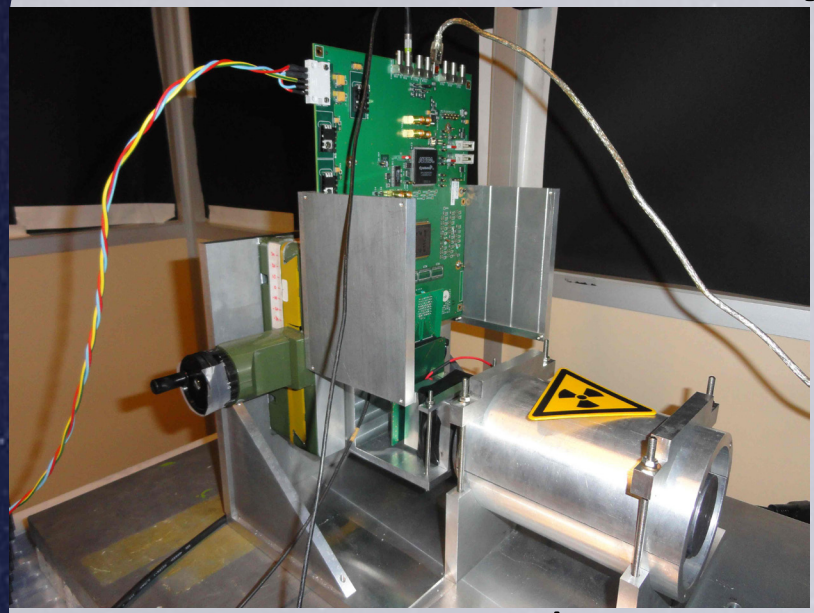
DSSDs & PCB - design



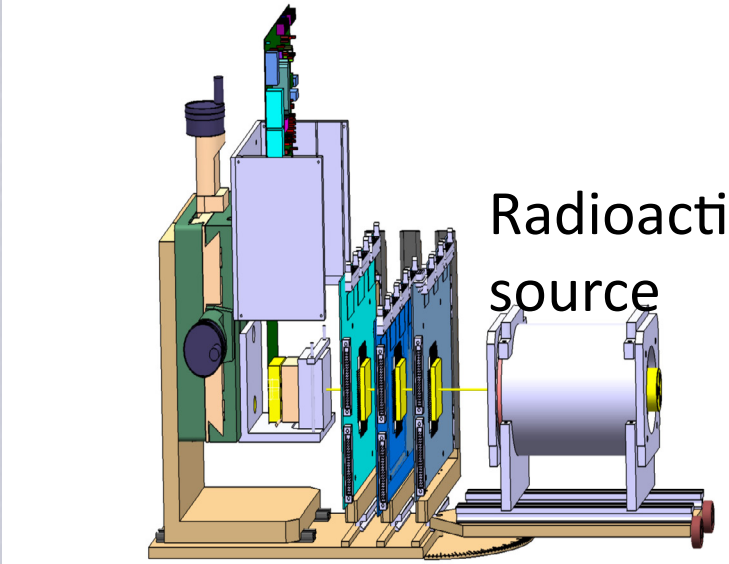
DSSD & PCB - design

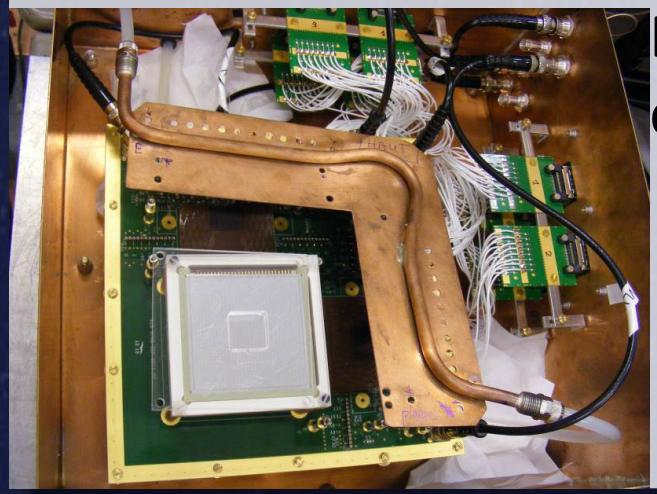


CoCoTe : Compact Compton Telescope



Existing experimental set-up at CSNSM for $LaBr_3$ tests





Experimental setup developed at IPNO

3 or 4 DSSDs :
- 2 from IPNO
- 2 from APC Lab.

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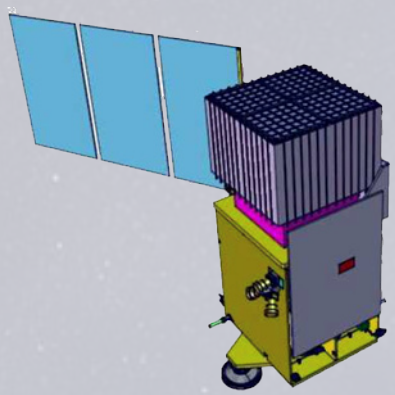

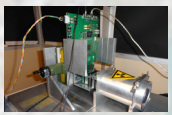

THANK YOU