# SiPM arrays and miniaturized readout electronics for compact imaging gamma camera

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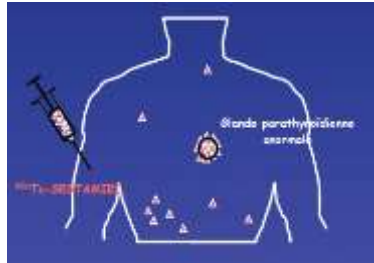
[3]Omega Microelectronics group, CNRS, Palaiseau, France

# OUTLINE

- Introduction
  - Technique of nuclear imaging
  - Radio-guided surgery
  - Per-operative detection systems

- Compact imaging gamma camera - MAGICS
  - Principle
  - SiPM arrays
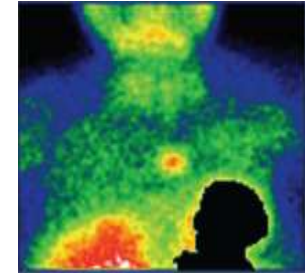  - Read-out electronics
  - Characteristics

- Conclusions

# Technique of nuclear imaging

- ## Principle



Marking

- radio-pharmaceutical product
- radioactive isotopes
  - $^{99m}Tc$, $^{123}I$, $^{201}Tl$, $^{18}F$, $^{11}C$
  - emitters $\gamma$, $\beta^+$



Detection
- $\gamma$ camera, tomographs

- ## Detection systems

Cancer diagnostic

Cancer therapy



SPECT



PET



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3
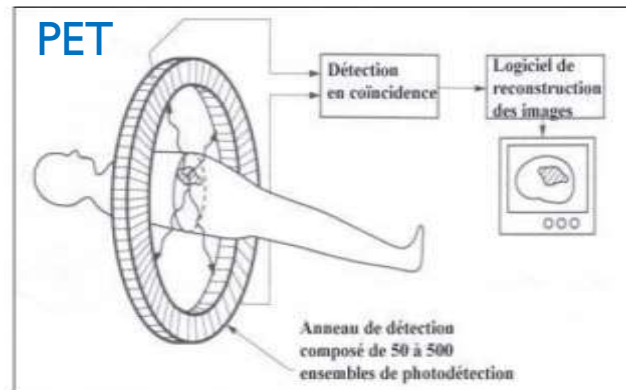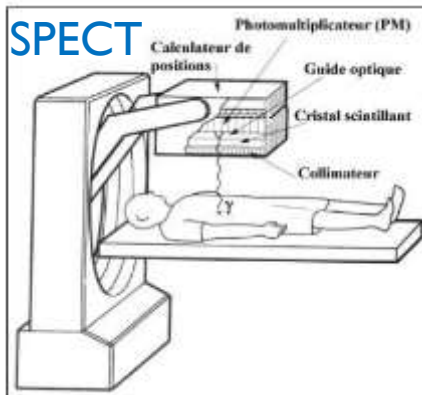
# Cancer therapy

- ## Radio-guided surgery
  - ### Surgical practice for different cancer pathologies
    - protocol of sentinel lymphatic node mapping (breast, melanoma, prostate, uterus)
    - colorectal and thyroid tumors
    - neuro-endocrines tumors and their metastatic disseminations
    - subclinical tumors (non-palpable) of breast
    - bone lesions (osteoma)
    - parathyroid adenoma

- ## Per-operative detection systems
  - ### Gamma probes
    - ergonomic shape (pencil)
    - 1-2 cm diameter, 10-20 cm length
    - sound signal proportional to counting rate
  - ### Gamma imaging cameras
    - cover larger area: 10-100 cm$^2$
    - give the spatial distribution of the radio-tracer
    - improve signal to noise ratio



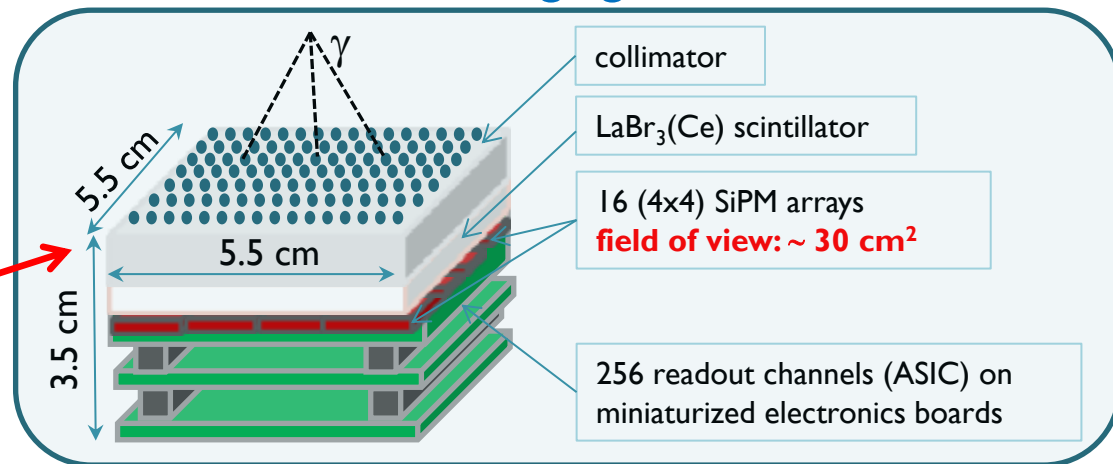Sentinella, Spain

POCI/TRECAM, France

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# Compact imaging gamma camera

- High resolution hand-held radiation detector for therapeutic purposes

MAGICS imaging camera



5.5 cm
5.5 cm
5.5 cm
3.5 cm

$\gamma$

collimator

LaBr$_3$(Ce) scintillator

16 (4x4) SiPM arrays
**field of view: ~ 30 cm$^2$**

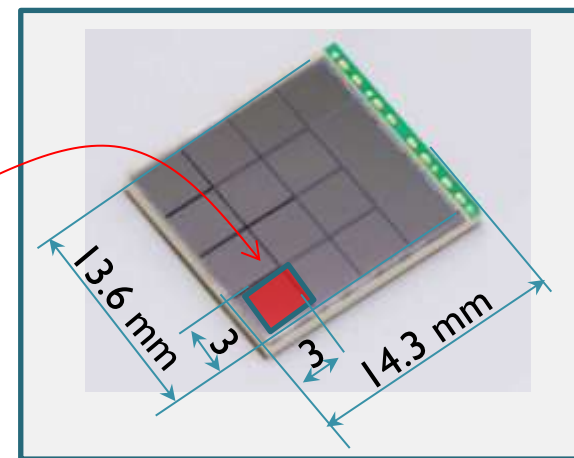256 readout channels (ASIC) on miniaturized electronics boards

*Collaboration IMNC, LAL, Hôpital Lariboisière*
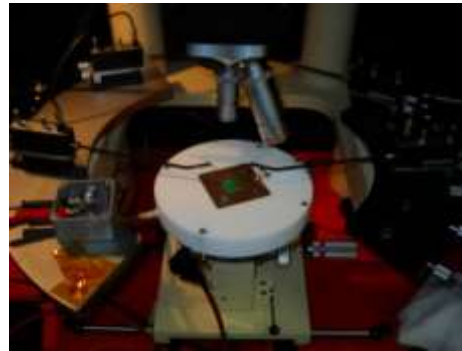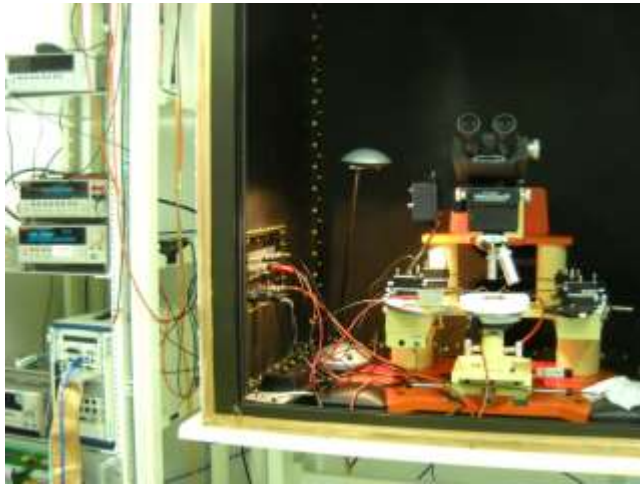
## Detection system requirements in surgical conditions
- reduced size and weight
- versatility of readout electronics
- high spatial resolution and sensitivity

## S11828-3344M Hamamatsu HPK
- 4x4 monolithic SiPM array
- mounted on a SMD package
- Each SiPM = one readout channel:
  - 3x3 mm$^2$, 3600 μcells, each μcell - 50x50 μm$^2$



13.6 mm
3
3
14.3 mm

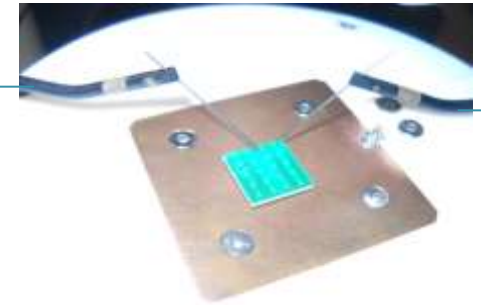*Nicoleta Dinu, LAL, Orsay, France*

# i-v measurements of monolithic SiPM arrays



Keithley 2611
Hi    Lo

I vs. $V_{Bias}$

23 arrays (368 IV's)

~1.5V $V_{BD}$

I vs. $V_{Bias}$

16 selected arrays (256 IV's)

$I_{post-BD}$

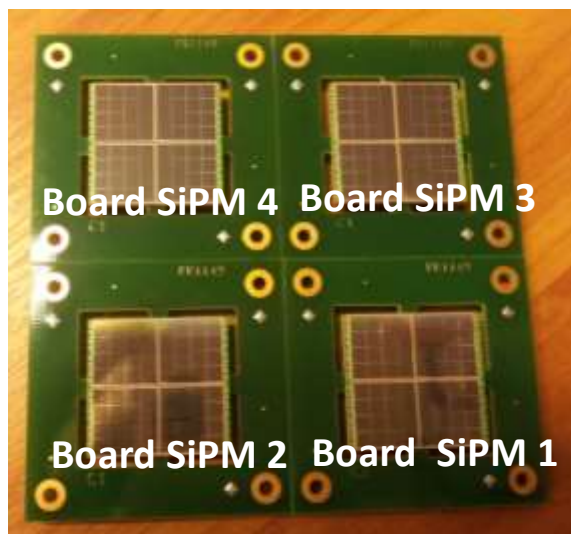$V_{BD}$    $V_{bias}$

~800 mV $V_{BD}$

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6
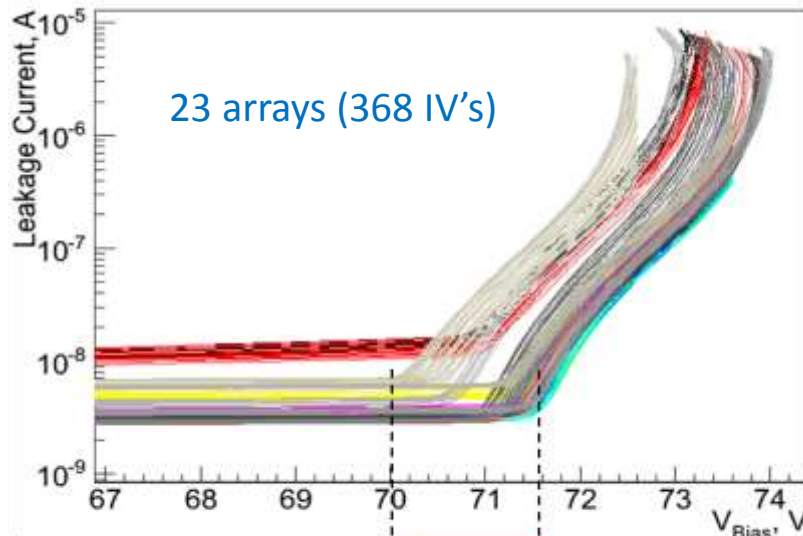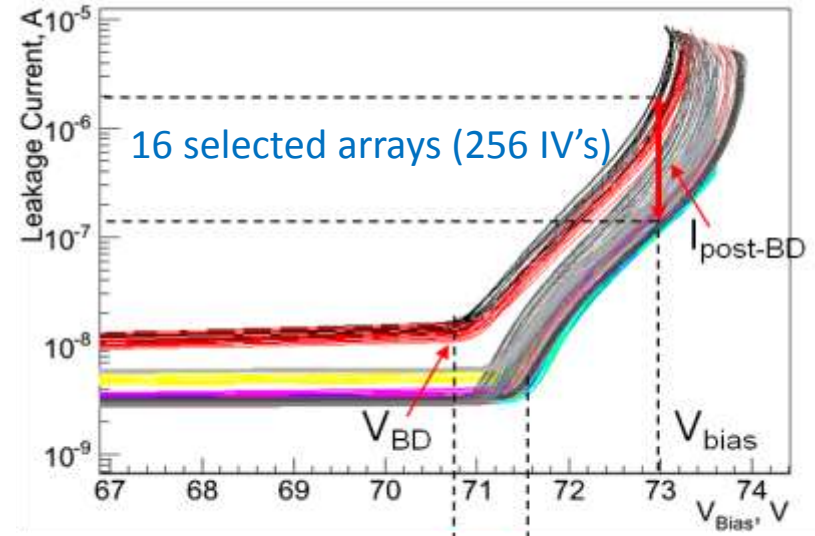
# SiPM characteristics uniformity



$V_{BD}$ MAGICS camera @ 20°C

Board SiPM 4 — Board SiPM 3
Board SiPM 2 — Board SiPM 1

| Vbd | |
|---|---|
| Entries | 256 |
| Mean | 71.4 |
| RMS | 0.2011 |
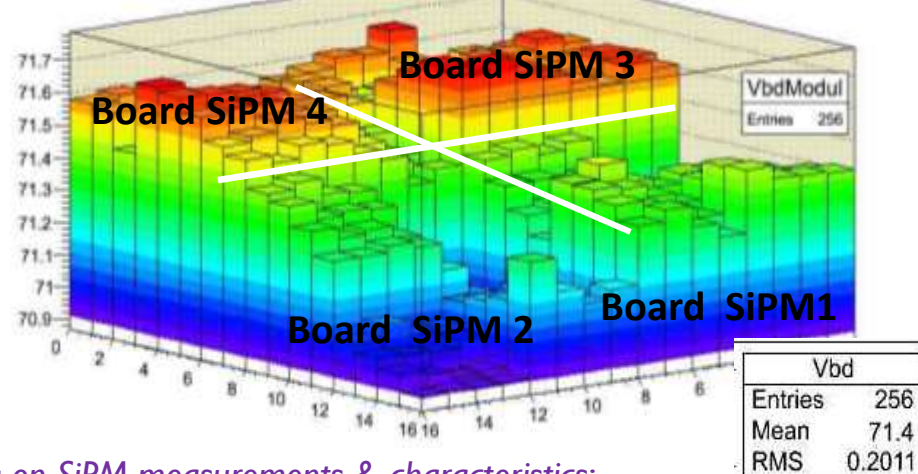
*More details on SiPM measurements & characteristics:*
*N. Dinu, HDR, LAL-13-192*

$I_{dark}$ @ $V_{BIAS}$ =72.5V

Board SiPM 3
Board SiPM 4
Board SiPM 1
Board SiPM 2

| Entries | 256 |
|---|---|
| Mean | 1.115e-007 |
| RMS | 9.878e-008 |

$I_{dark}$ @ overvoltage =1V

Board SiPM 3
Board SiPM 4
Board SiPM 1
Board SiPM 2

| Entries | 256 |
|---|---|
| Mean | 7.337e-008 |
| RMS | 2.607e-008 |
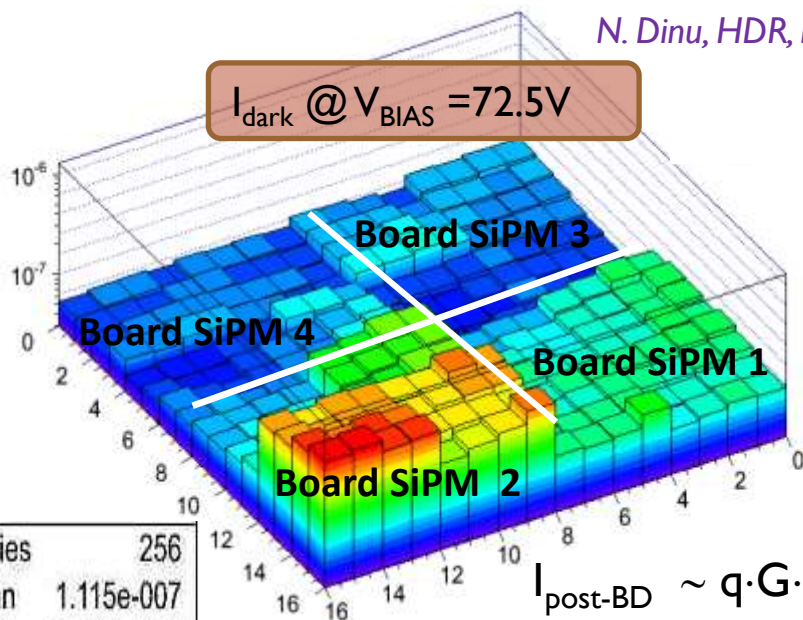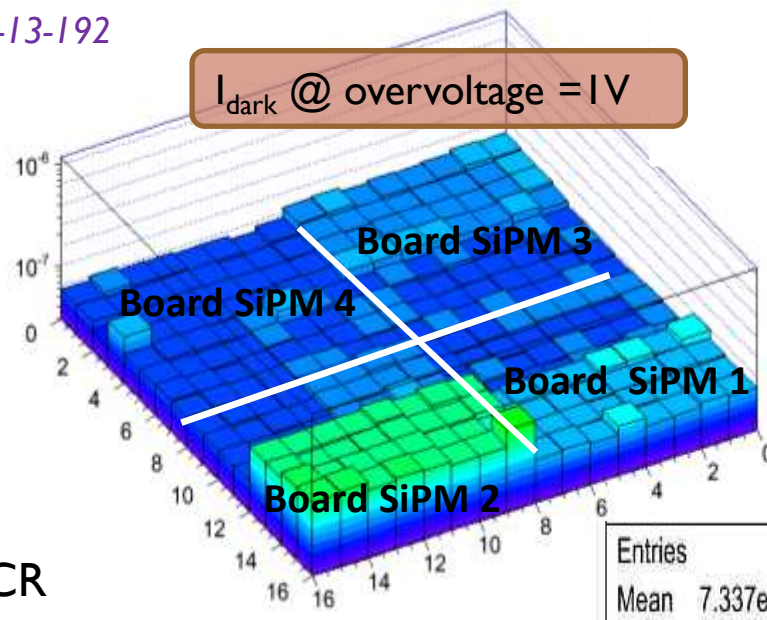
$I_{post\text{-}BD} \sim q \cdot G \cdot DCR$
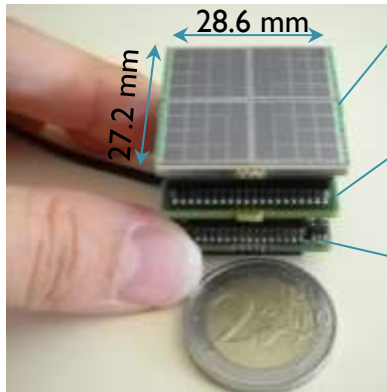
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# Elementary module of MAGICS camera
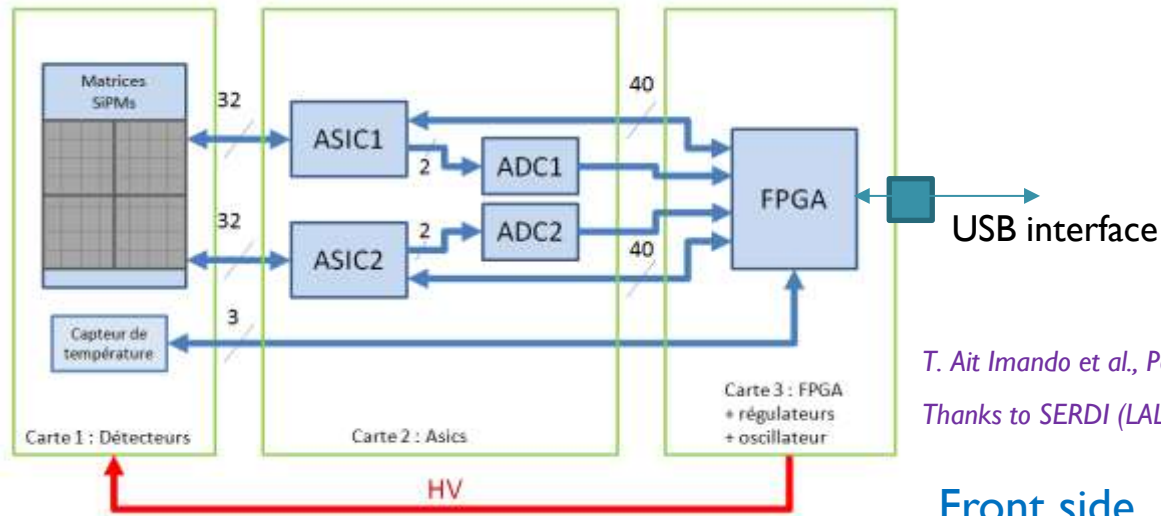


T. Ait Imando et al., PoS 2012

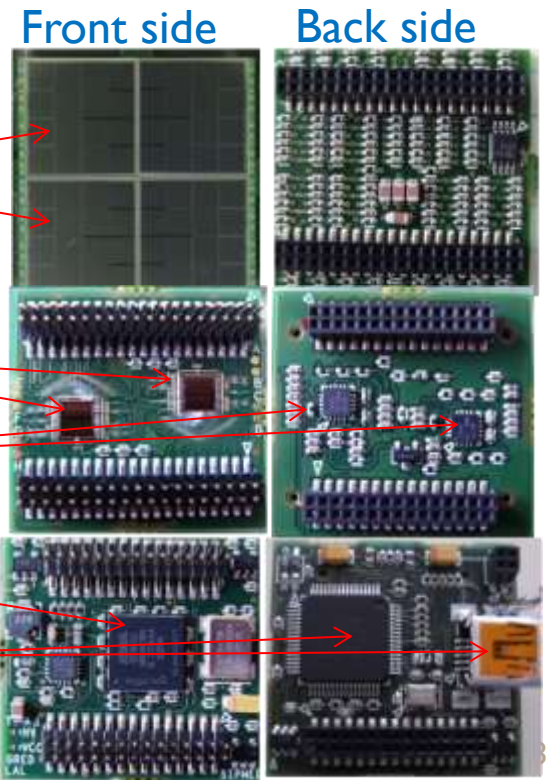Thanks to SERDI (LAL) for technical help

**Elementary module**
**Field of view: ~ 8 cm²**

28.6 mm

27.2 mm

**Front side**  **Back side**

**Board 1:**
4 (2x2) SiPM arrays
64 channels

**Board 2:**
2 EASIROC chips
64 readout channels
2 ADC 12 bits

**Board 3:**
ALTERA ciclone III FPGA
FTDI FT2232H (USB, 2.0 Hi-speed, 440MBit/s)
DC/DC converter for SiPM bias

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# Characteristics of read-out electronics

- **EASIROC chip**
  - 32-channels fully analog front-end readout
  - 8-bit DAC (0-2.5 V) for individual SiPM gain adjustment
  - energy measurement from 160 fC to 320 pC
    - 1 to 2000 pe @ SiPM gain of $10^6$
    - variable gain pre-amplifier tuned to 4 bits
    - variable shaping time from 25 to 175 ns
    - 2 multiplexed analog outputs (high gain, low gain)
    - 1 pe signal/noise ratio $\approx$ 9
  - Low power consumption
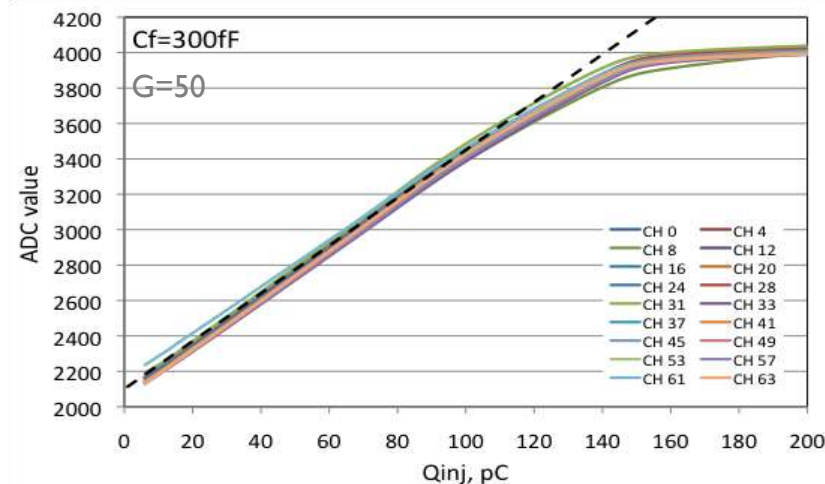    - 4.84 mW/channel, 155 mW/chip
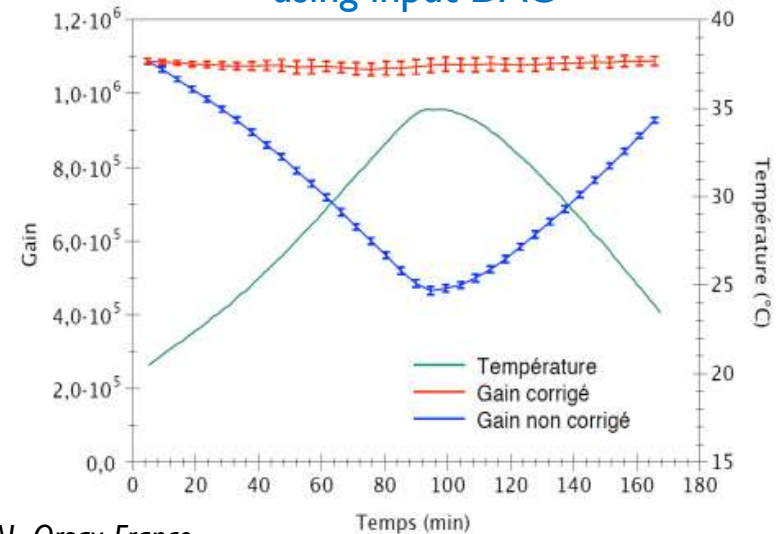
Channels uniformity for HG output
$\sigma < 1\%$
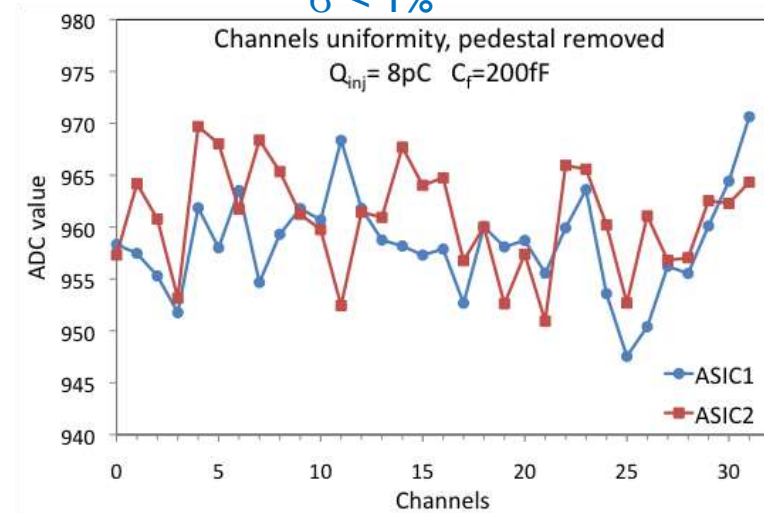


Channels linearity for HG output
$\sigma < 1\%$ from 160 fC to 100 pC



SiPM gain correction vs temperature
using input DAC



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# MAGICS camera

4 elementary modules
256 SiPM's = 256 readout channels

## Architecture



Power supply board

WiFi board

1 mother board
FPGA, USB interface

4 ASIC's boards

4 SiPM's boards

LaBr$_3$(Ce) scintillator

collimator
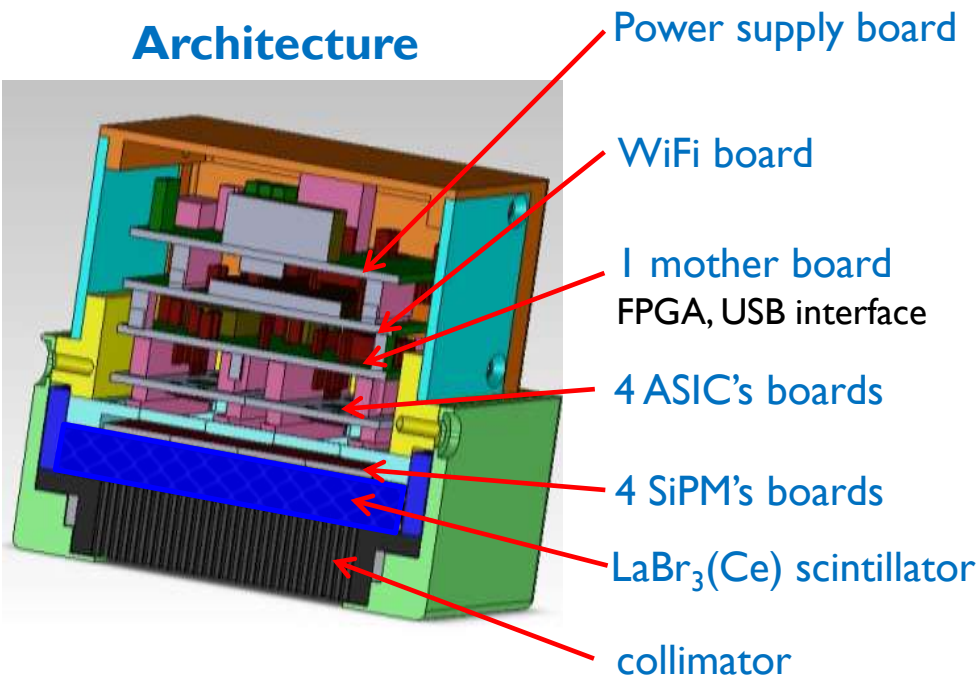
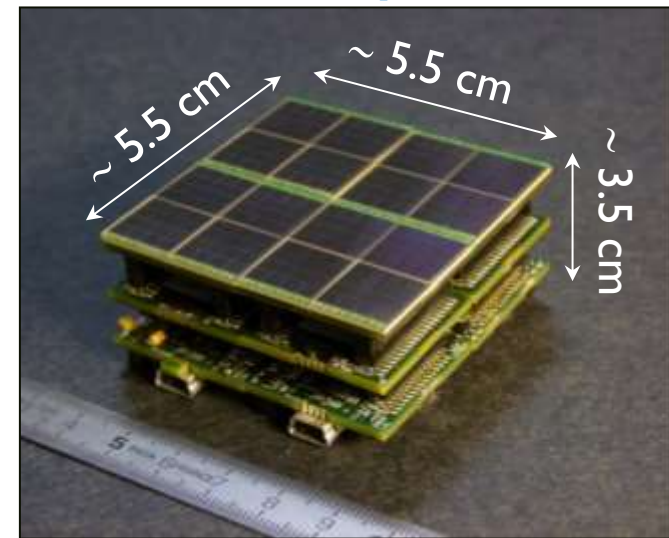*Mechanics*
- *alignment and assembling*

*Software*
- *boards driving, data acquisition and treatment*

## 4 elementary modules



~ 5.5 cm
~ 5.5 cm
~ 5.5 cm
~ 3.5 cm

## MAGICS camera final view



7.3 cm
8.35 cm
8.3 cm
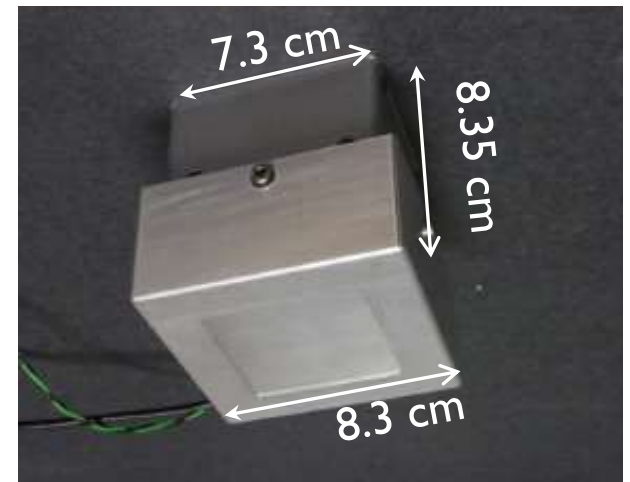
*Dimensions: 8.3 x 8.3 x 8.35 cm$^3$*
*Weight: 1.2 kg*
*Field of view : 5.1x5.1 cm$^2$*

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# Characteristics of MAGICS camera

Sources of $^{241}$Am & $^{57}$Co
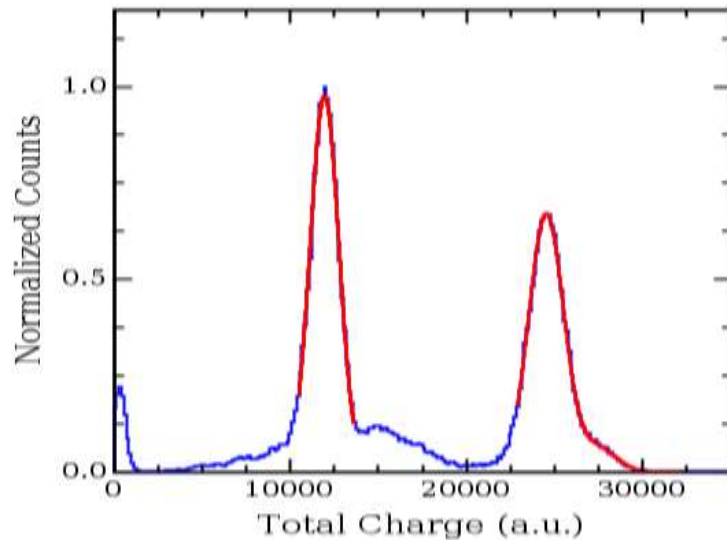
Energy resolution:
• 9.5% @ 122 keV

Experimental conditions:
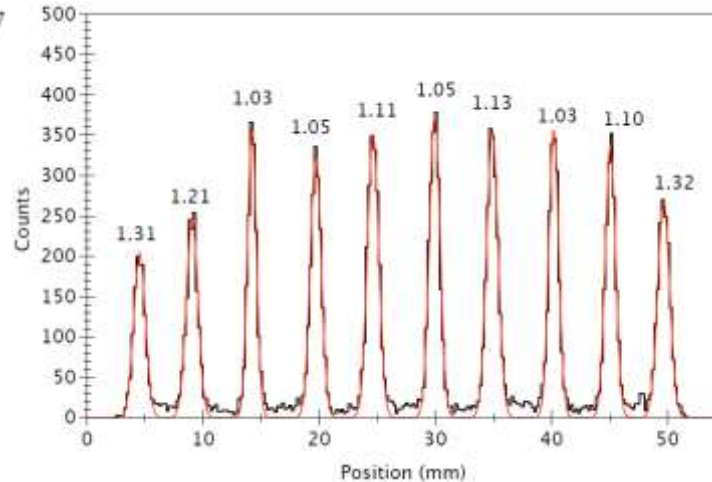• LaBr$_3$(Ce) – 6 mm thickness
• Sources of $^{57}$Co(122 keV) and $^{241}$Am(60 keV)
• central collimation hole of 4 mm diameter
• V$_{BIAS}$ = 75.52V, T=40°C

Spatial resolution:
• 1.13 mm @ 122 keV

Experimental conditions:
• LaBr$_3$(Ce) – 6 mm thickness
• $^{57}$Co(122 keV)
•  1 mm irradiation spots spaced 5 mm apart
• V$_{BIAS}$ = 75.52V, T=40°C
• Levenberg-Marquard reconstruction algorithm

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11
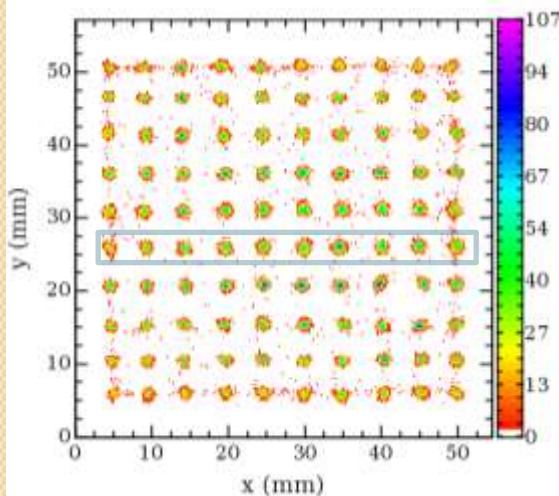
# Conclusions

- **MAGICS**
  - Miniaturized hand-held gamma camera
  - Therapeutic purposes: assisting the surgeon on locating and removing tumors

- **MAGICS main components**
  - 256 SiPM's: 4x4 monolithic arrays, 4x4 SiPM's each array
  - 8 EASIROC chips for analogue front-end read-out
  - Dedicated miniaturized readout electronics boards for data acquisition

- **MAGICS main characteristics**
  - Geometry:
    - *8.3 x 8.3 x 8.35 $cm^3$*
    - *Field of view: 5.1x5.1 $cm^2$*
  - Weight: 1.2 kg
  - Detection:
    - Energy resolution of 9.5% @ 122 keV
    - Spatial resolution of less than 1 mm @ 122 keV on the whole field of view

- **Future improvements**
  - Decrease the lateral dimensions and weight by using non-hygroscopic scintillator (GaGG)
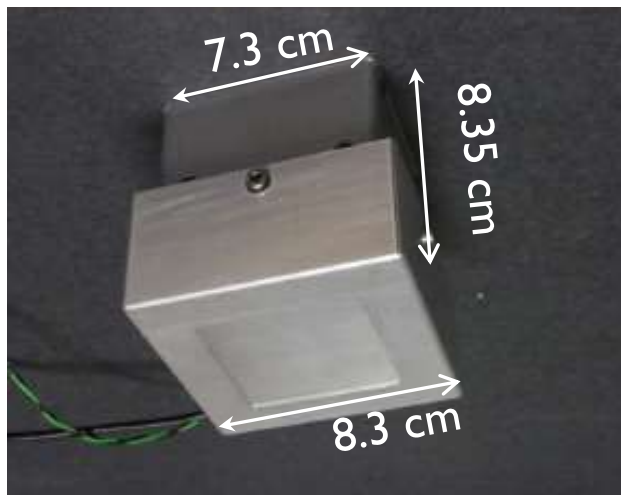  - Improve the reconstruction algorithm

# Additional slides

# Comparison of MAGICS and TRECaM cameras

## MAGICS camera



7.3 cm

8.35 cm

8.3 cm

*Weight: 1.2 kg*

## TRECaM camera based on MAPMT



14 cm

11.7 cm

8.3 cm

*Weight: 2.2 kg*

MAGICS energy resolution:9.5% @ 122 keV
TRECaM energy resolution:12.9% @ 122 keV

MAGICS spatial resolution: less then 1 mm@ 122 keV
TRECaM spatial resolution:1.36 mm @ 122 keV

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# Uniformity adjustments

- Uniform illumination of SiPM's by green LED
- Standardization of responses by DACs adjustments



Avant correction

Après correction

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