SiPM arrays and miniaturized readout electronics for compact gamma camera

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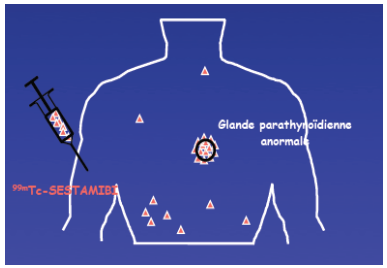
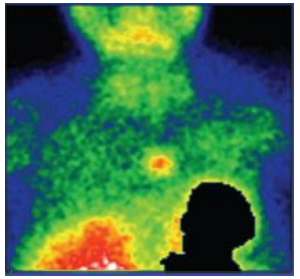
OUTLINE

- 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

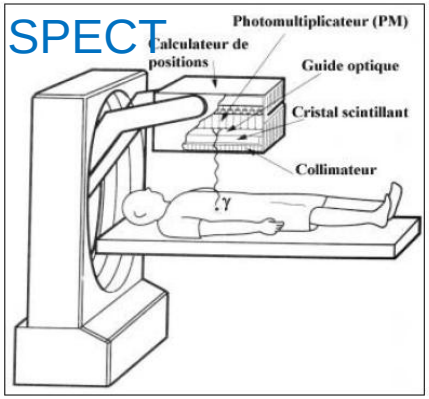
- radio-pharmaceutical product
- radioactive isotopes
  - ^{99m}Tc, ^{123}I, ^{201}Tl, ^{18}F, ^{11}C
  - emitters γ, β^+

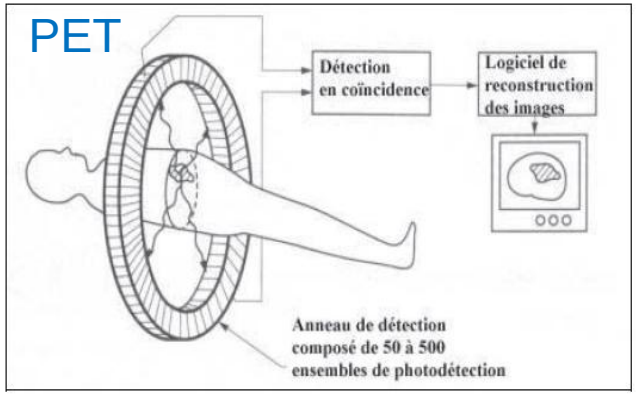
Detection

- γ camera, tomographs

- Detection systems

Cancer diagnostic





Cancer therapy

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

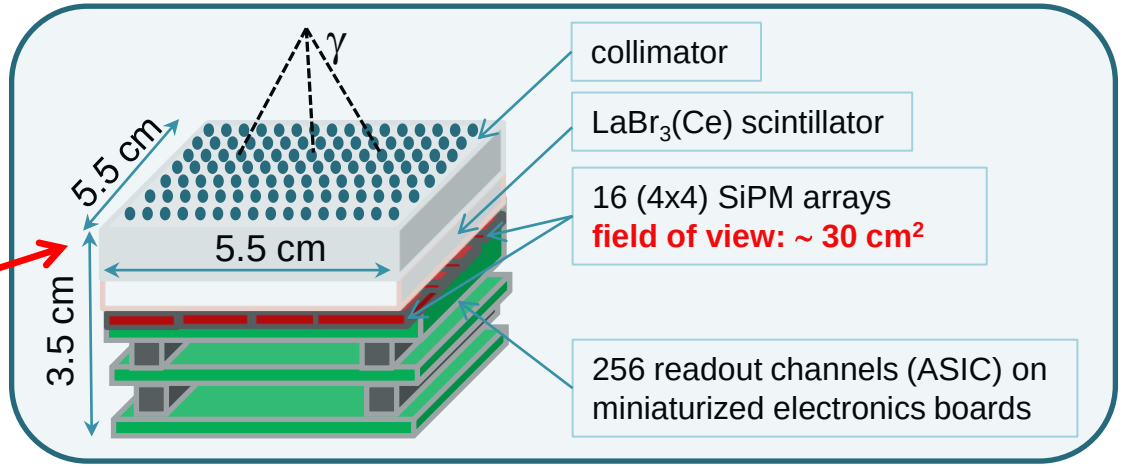
POCI/TRECAM, France

Sentinella, Spain

Compact imaging gamma camera

- High resolution hand-held radiation detector for therapeutic purposes

MAGICS imaging camera



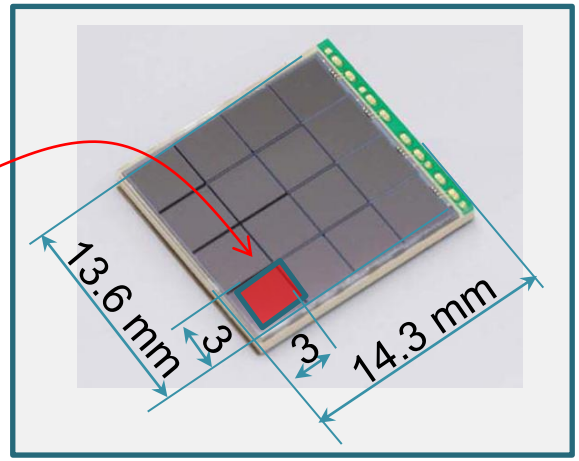
Collaboration IMNC, LAL, Hôpital Lariboisière

Detection system requirements in surgical conditions

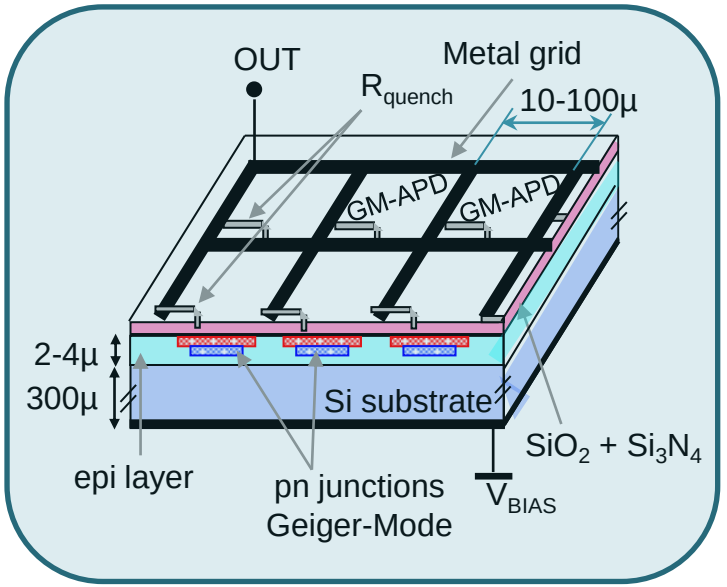
- reduced size and weight
- versatility of readout electronics
- high spatial resolution and sensitivity

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



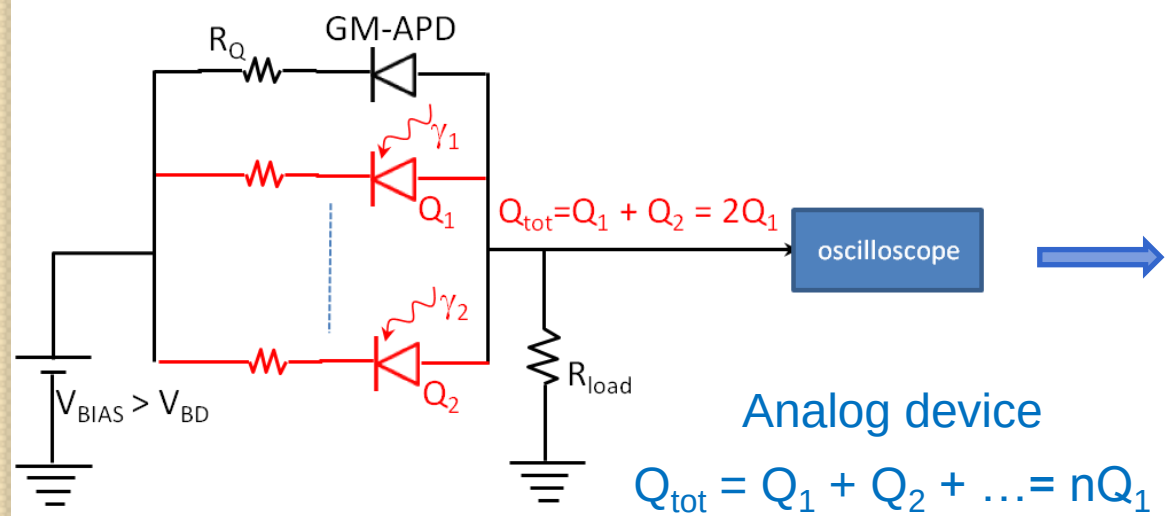
SiPM – design & physics principle



'90s by V.M.Golovin & Z.Sadygov

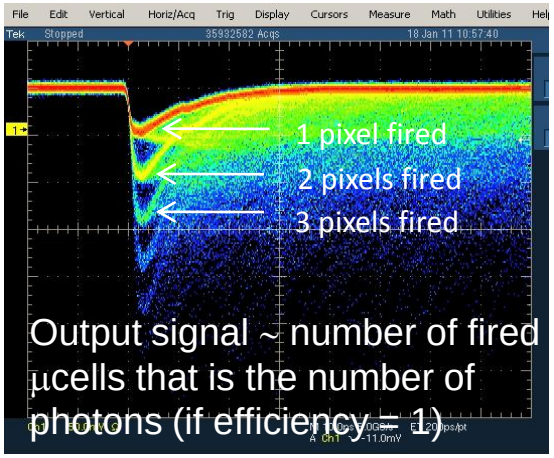
Russian patents

- SiPM: parallel array of μcells



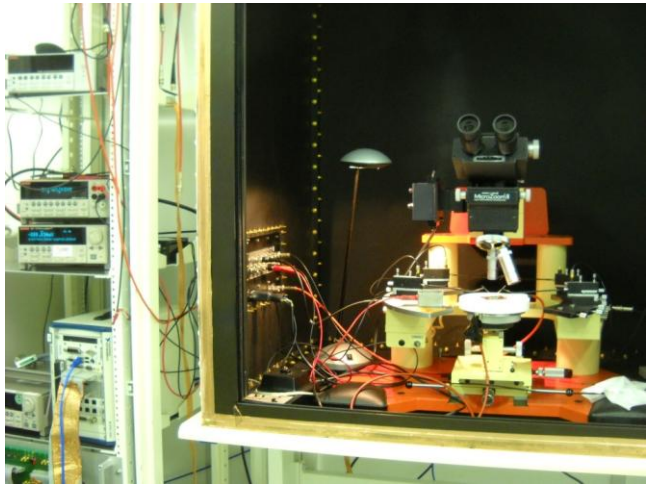
Analog device

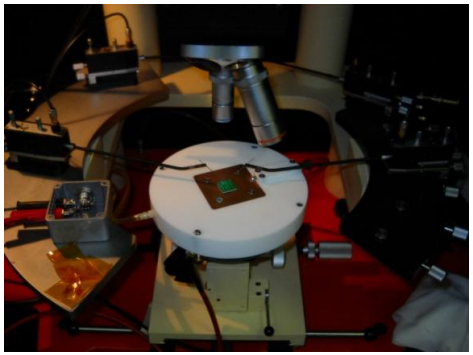
$Q_{tot} = Q_1 + Q_2 + \ldots = nQ_1$

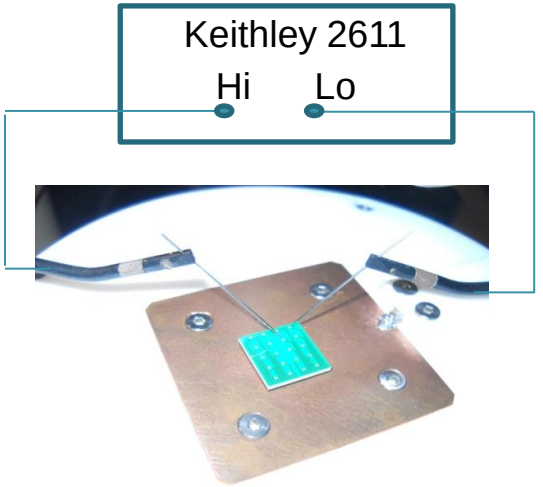


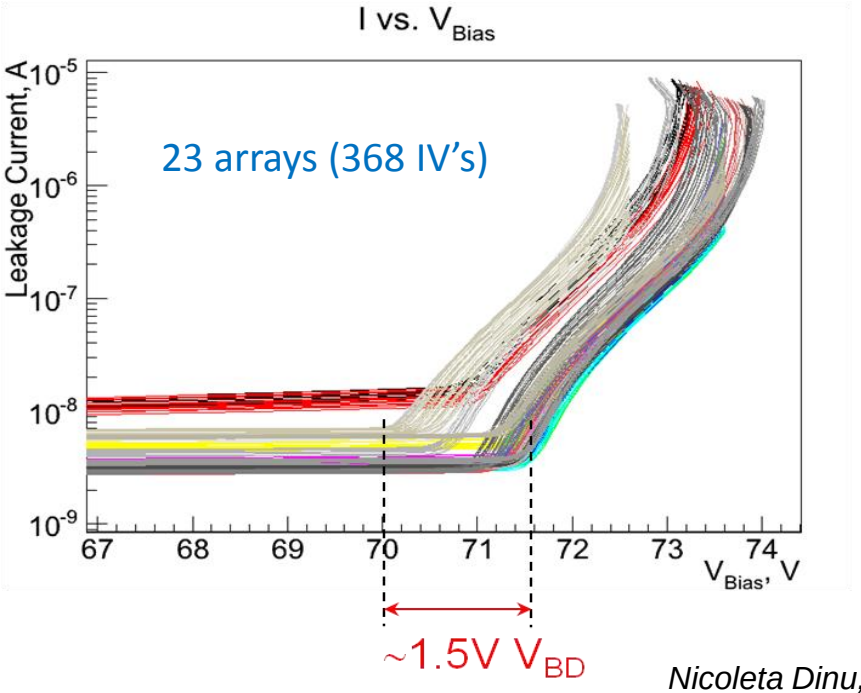
Output signal ~ number of fired μcells that is the number of photons (if efficiency = 1)

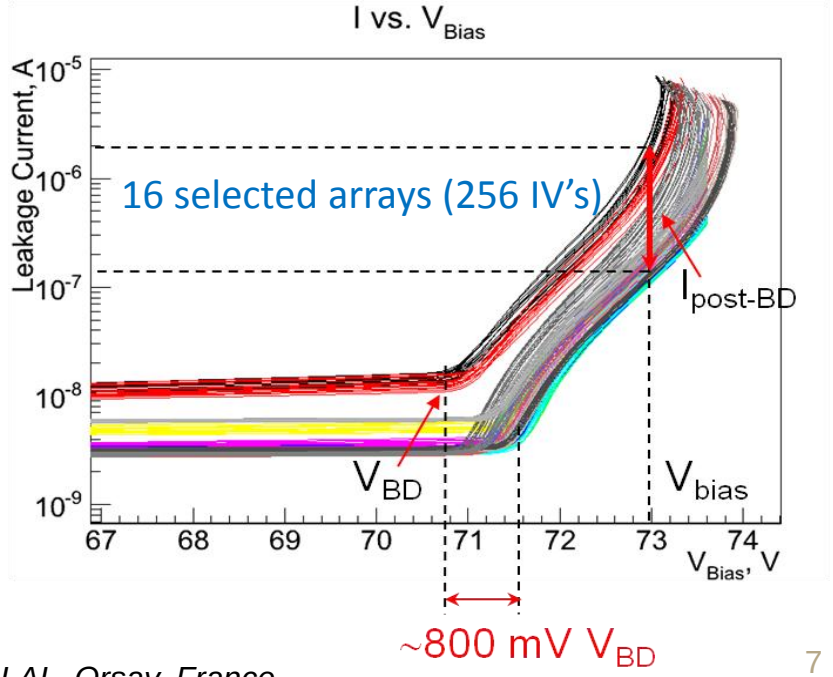
i-v measurements of monolithic SiPM arrays



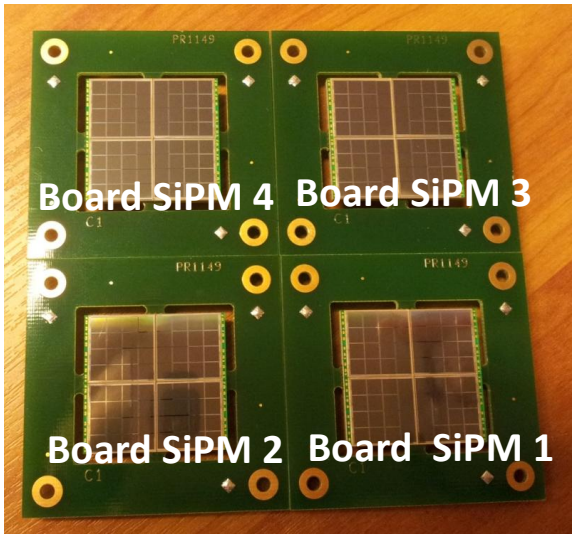




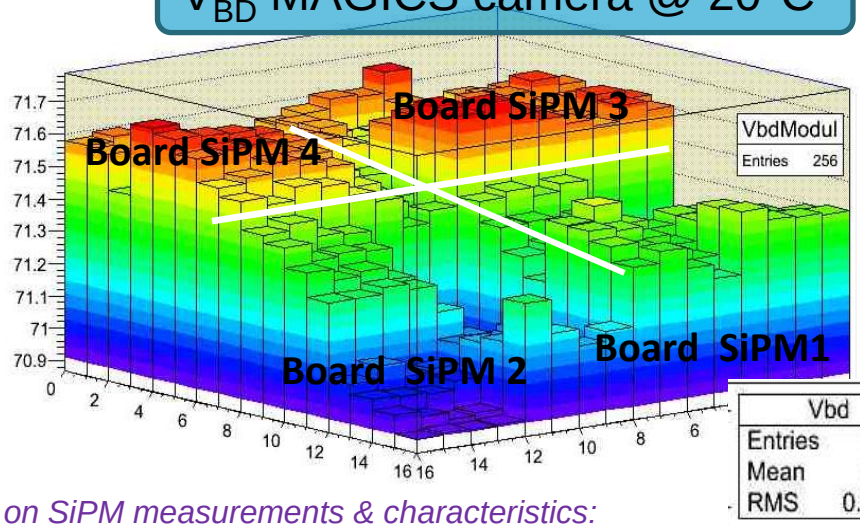




SiPM characteristics uniformity

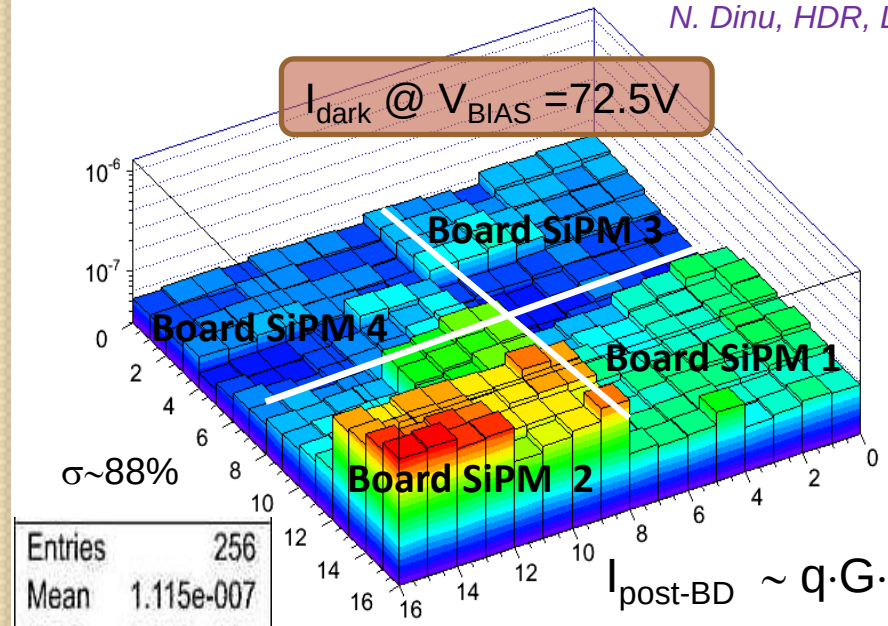


V_{BD} MAGICS camera @ 20°C

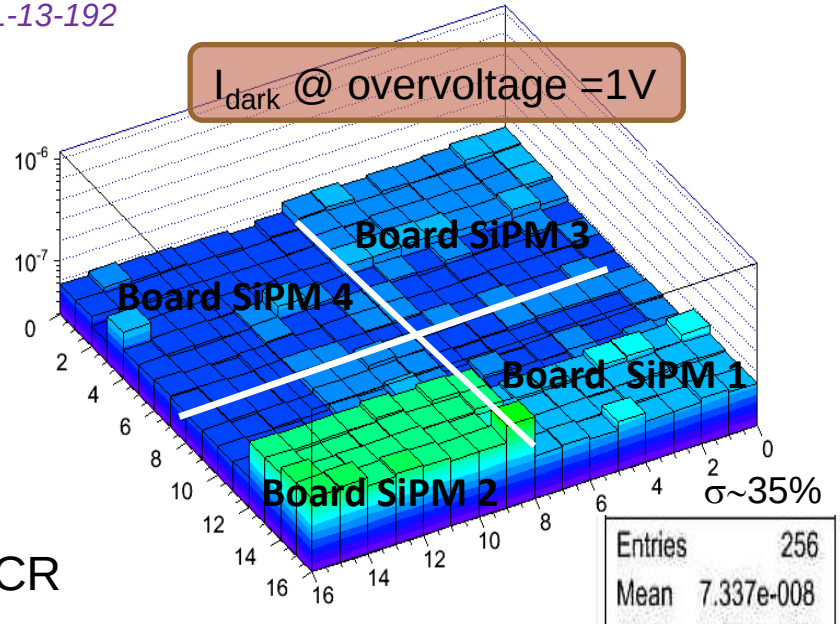


More details on SiPM measurements & characteristics:
N. Dinu, HDR, LAL-13-192

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



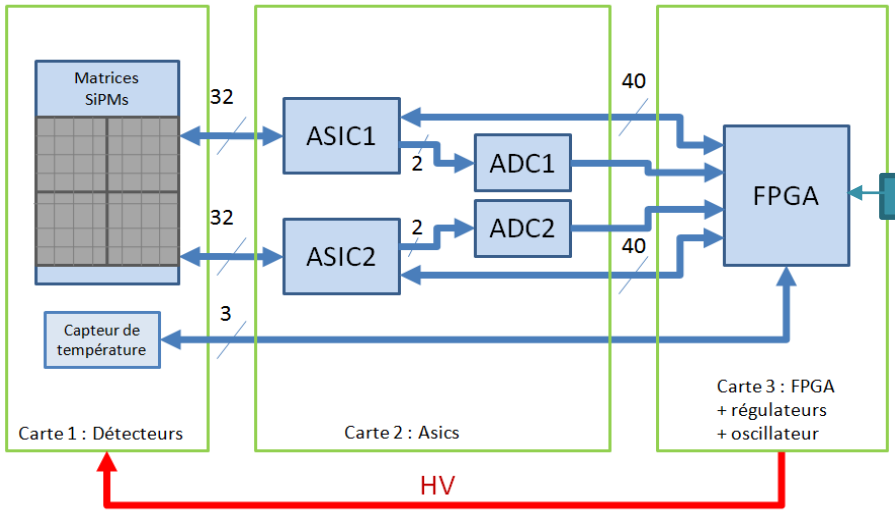
I_{dark} @ overvoltage =1V



$I_{post\text{-}BD} \sim q \cdot G \cdot DCR$

Nicoleta Dinu, LAL, Orsay, France

Elementary module of MAGICS camera

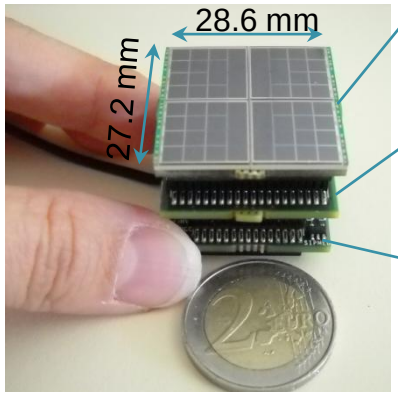


USB interface

T. Ait Imando et al., PoS 2012

Thanks to SERDI-LAL (D. Breton, D. Cuisy, M. Gaspard, S. Trochet, P. Favre, B. Debennerot, C. Cheikali) for technical contributions

Elementary module
Field of view: ~ 8 cm^2

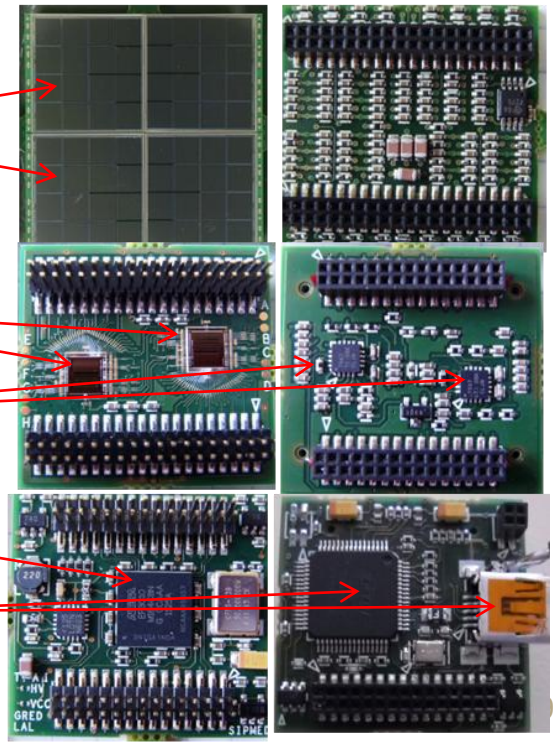


Board 1:
4 (2x2) SiPM arrays
64 channels

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

Front side Back side

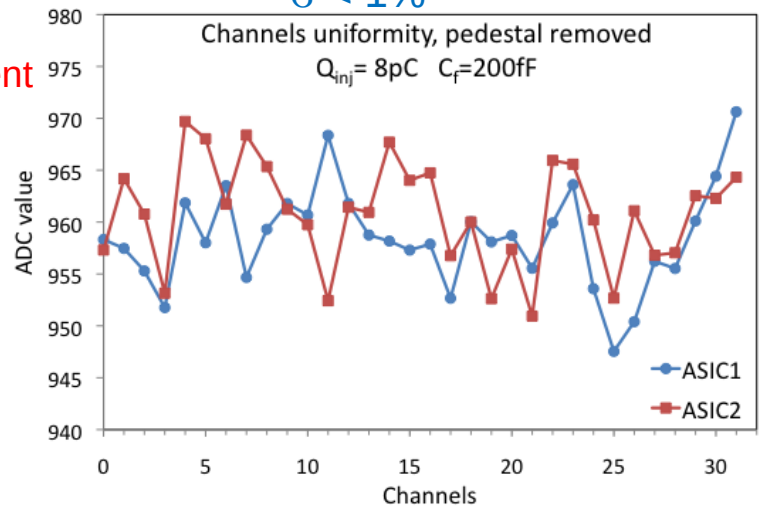


Nicoleta Dinu, LAL, Orsay, France

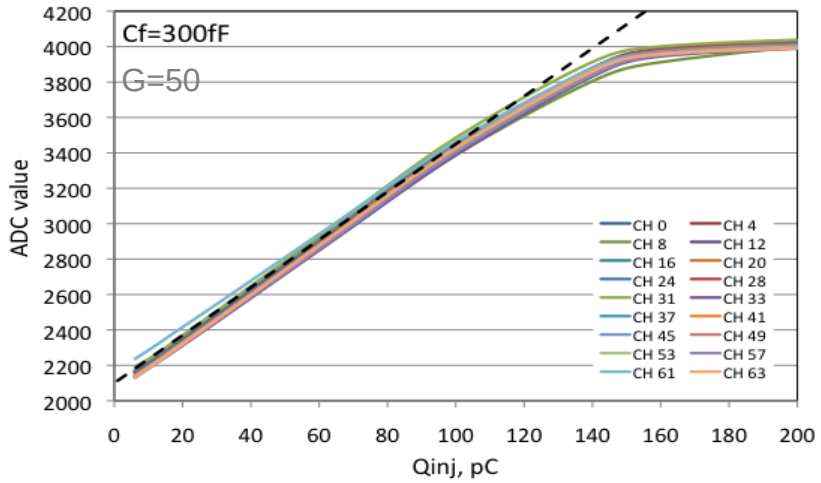
Characteristics of read-out electronics

- EASIROC chip
  - 32-channels fully analog front-end readout
  - 8-bit DAC (0-2.5 V) for individual SiPM gain adjustment
  - charge 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 ≈ 9
  - Low power consumption
    - 4.84 mW/channel, 155 mW/chip

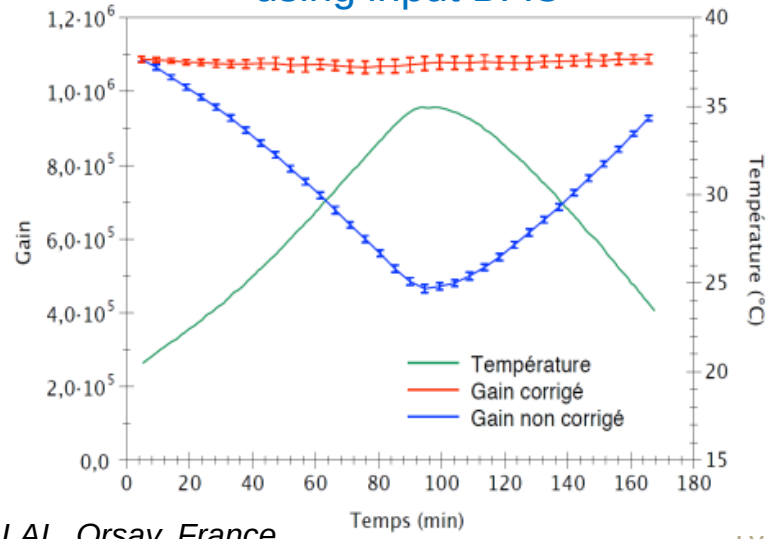
Channels uniformity for HG output
σ < 1%



Channels linearity for HG output
σ < 1% from 160 fC to 100 pC



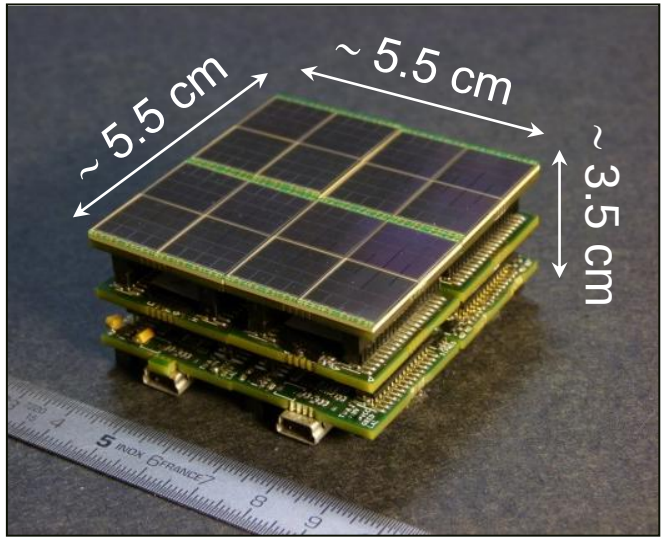
SiPM gain correction vs temperature using input DAC



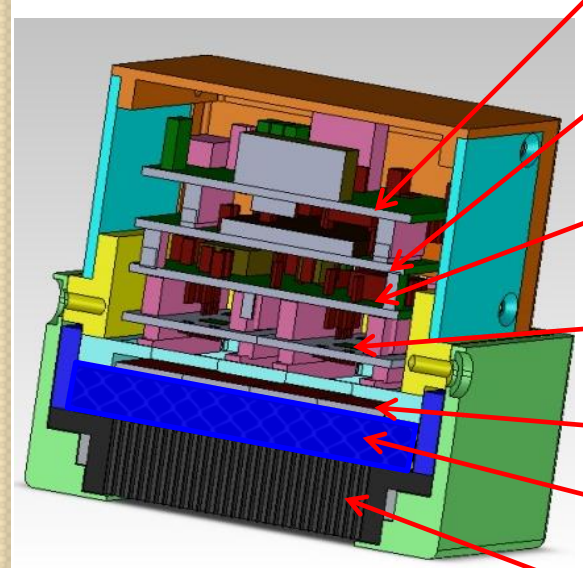
MAGICS camera

4 elementary modules
256 SiPM's = 256 readout channels

4 elementary modules



Architecture



Power supply board

WiFi board

1 mother board
FPGA, USB interface

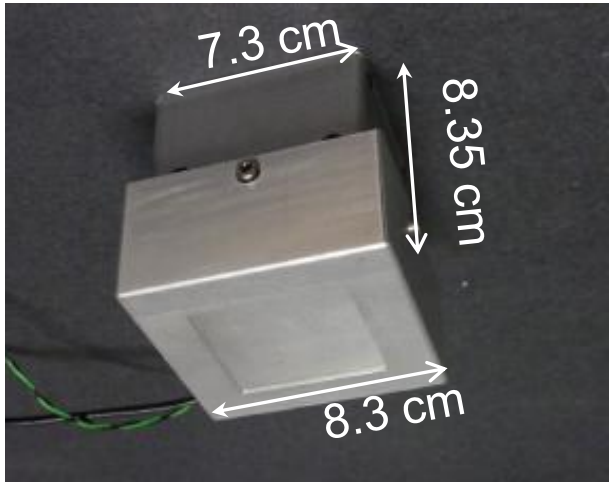
4 ASIC's boards

4 SiPM's boards

$LaBr_3(Ce)$ scintillator

collimator

MAGICS camera final view

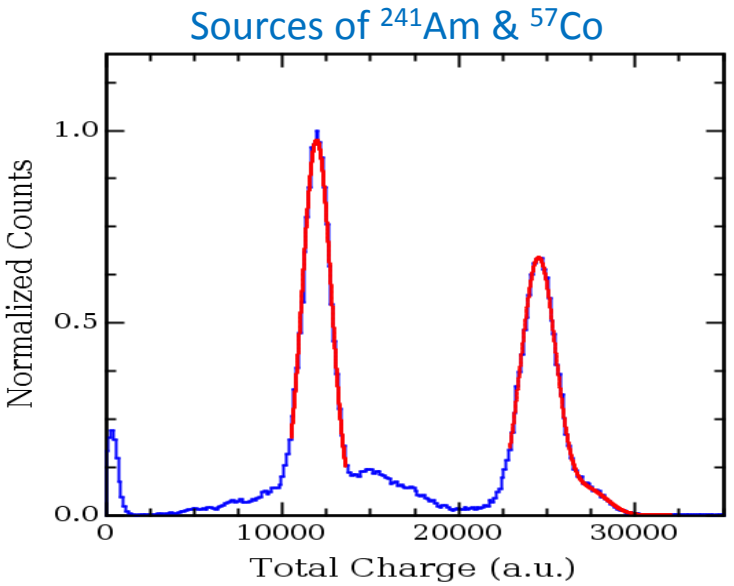


Mechanics
- *alignment and assembling*

Software
- *boards driving, data acquisition and treatment*

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

Characteristics of MAGICS camera

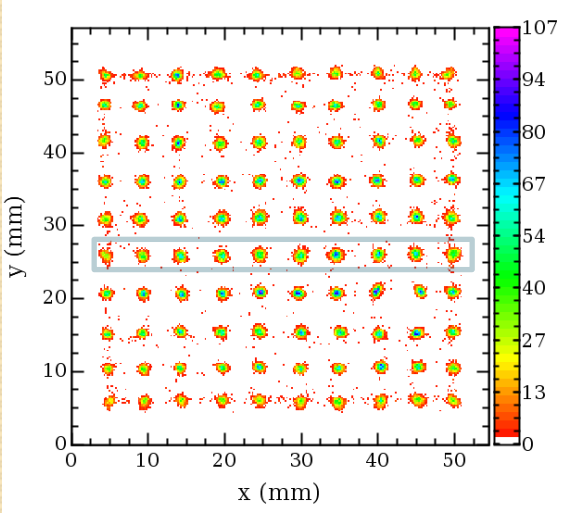


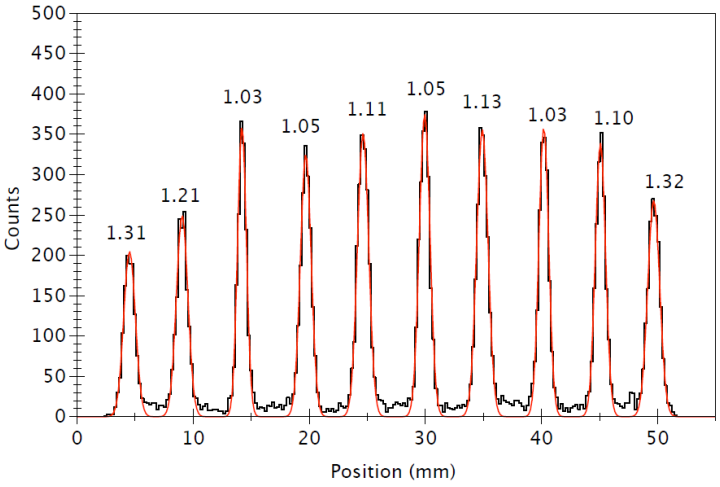
Energy resolution:

- 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:

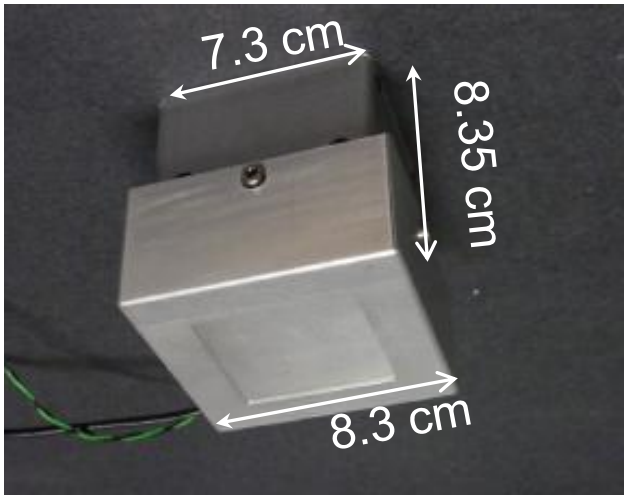
- $LaBr_3(Ce)$ – 6 mm thickness
- ^{57}Co(122 keV)
- 1 mm irradiation spots spaced 5 mm apart
- V_{BIAS} = 75.52V, T=40°C
- Levenberg-Marquard reconstruction algorithm

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

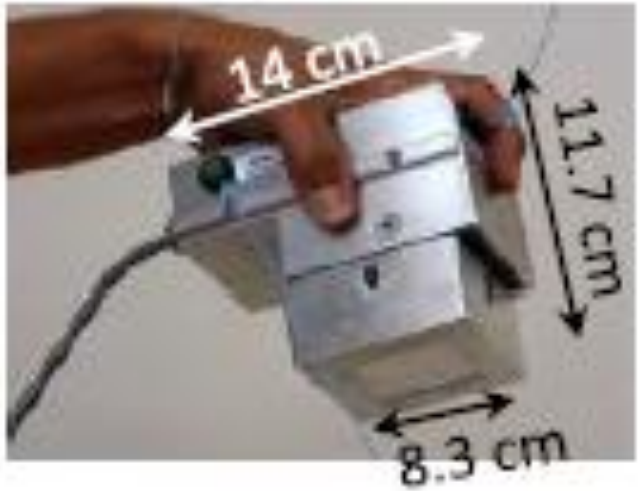
Comparison of MAGICS and TRECaM cameras

MAGICS camera



Weight: 1.2 kg

TRECaM camera based on MAPMT



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

Uniformity adjustments

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