LAPiS: Large Area Pixels using SiPMs

+ **Daniel Guberman**
INFN Pisa
daniel.guberman@pi.infn.it

+ Riccardo Paoletti
INFN Pisa and Università di Siena
riccardo.paoletti@pi.infn.it

INFN Pisa
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Outline

1) Why Large Area SiPMs?

2) LAPiS

3) Two possible applications

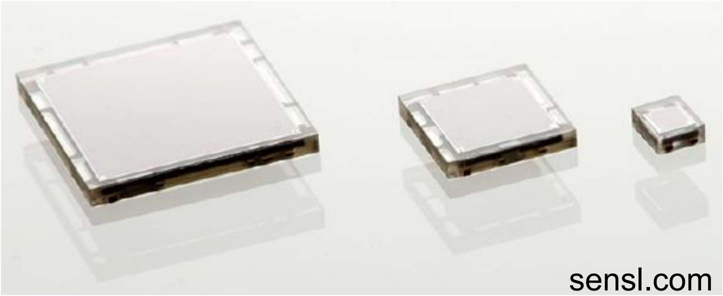
4) Summary, schedule and requested budget

From PMTs to SiPMs

Many applications in high-energy physics, astrophysics medical imaging and industry require the use of **fast photosensors**, sensible to **low photon fluxes.** For a long time this has been the domain of Photomultiplier tubes (**PMT**s).

Silicon photomultipiers (**SiPM**s) entered the game offering several advantages:

- High photodetection efficiency (PDE)
- Low voltage operation
- Insensitivity to magnetic fields
- Robustness (do not age when exposed to high background light)
- Compactness
- Their price is going down…



→ There is a general trend to replace PMTs by SiPMs when possible...

No large area SiPMs...

Having small pixels is desirable by many experiments, but it turns into a problem when going to large cameras. The **limited physical size of SiPMs** (rarely available at > 0.5 cm^2, capacitance becomes too high) is probably the main **limitation** in such cases:

- More pixels needed to fill a camera
- More readout channels needed
- Cost and complexity of the readout increases

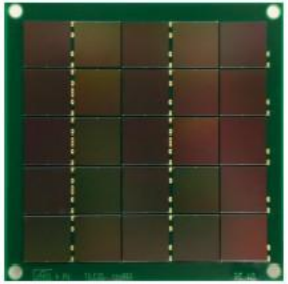
Experiments and applications requiring large pixels still go for PMTs (T2K, CTA-LST, HAWC, SPECT...)

Previous attempts to build Large pixels based on SiPMs

- Dark Side → 24 cm^2 area SiPM detector

  - Low dynamic range and time resolution

  - Only works at 80K

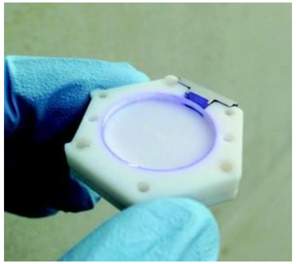


D'Inecco et al. (2017)

- Light-Trap → Prototype: ~3cm^2

  - Potentially cheap, scalable in size, simple electronics, but low efficiency

  - Timing properties are also not optimal for some applications

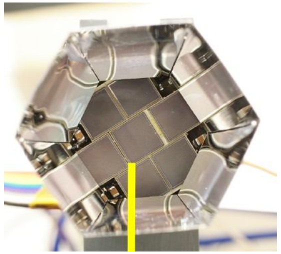


D. Guberman et al. (2019)

- Analog Sum → until now up to 3cm^2

  - using discrete components (PD, MPI)

  - using an ASIC (MUSIC by ICCUB)



A. Hahn (2017)

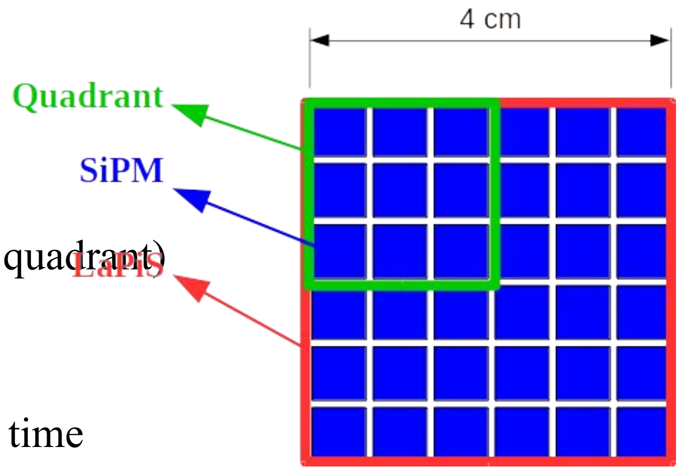
Large Area Pixel using SiPMs (LAPiS)

GOAL: Develop a pixel of >**10 cm^2** using **SiPMs**, operative at **room temperature**, that outputs **energy** and **arrival time** for each event.

One LAPiS consists on:

- 4 quadrants of ~3-4cm^2 each (total area of ~12-16 cm^2)
- Each quadrant is built by 7-9 SiPMs of 6x6 mm^2 (28-36 SiPMs in total)

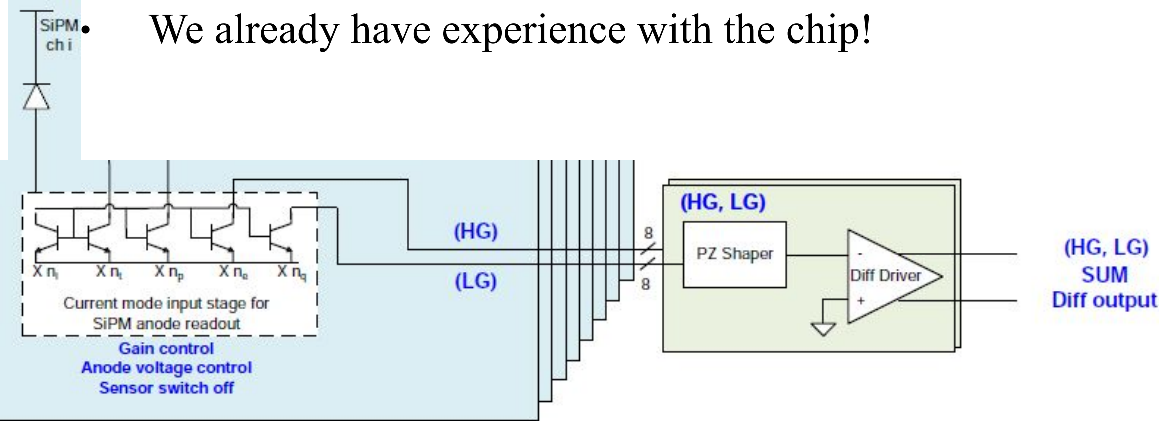
1) Analog signals inside each quadrant are summed with a MUSIC (one per quadrant)
2) Signals from each quadrant are summed (maybe with another MUSIC)
3) The analog signal from a LAPiS is digitized to output Energy and Arrival time

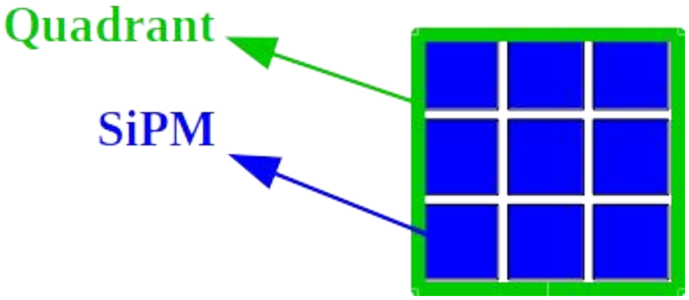


Large Area Pixel using SiPMs (LAPiS)

1. Analog signals inside each quadrant are summed with a MUSIC

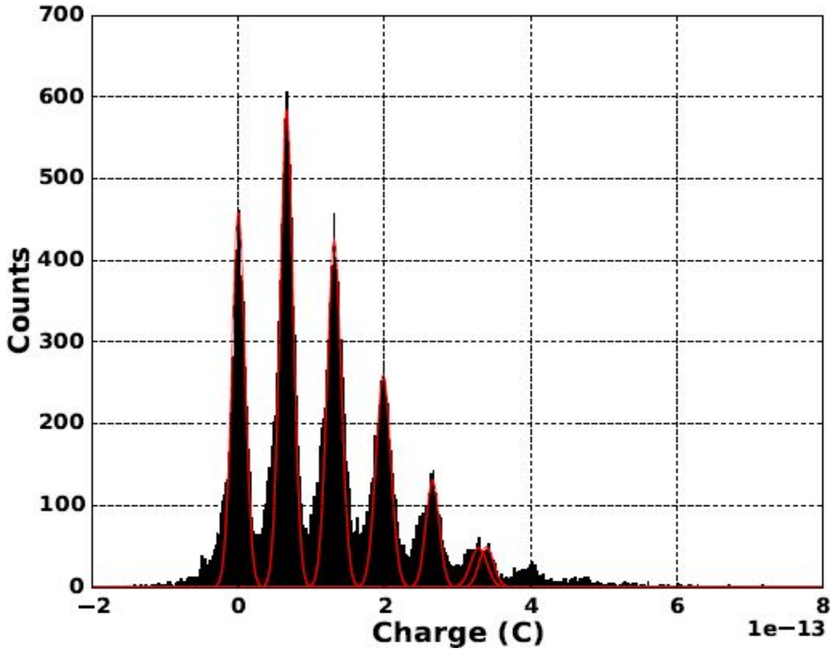
- Proved to be a plausible solution for summing ~7 SiPMs
- Integrated on a chip (compact, easy to reproduce, already available)
- Includes a tunable Pole Zero Shaper that can be adjusted depending on the application
- Includes a tunable individual channel offset for gain equalization
- We already have experience with the chip!



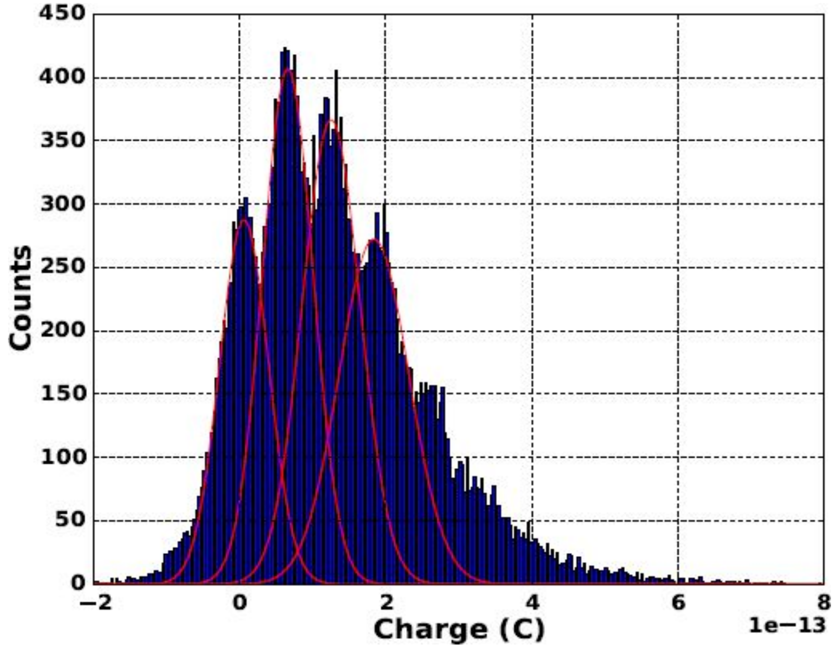


MUSIC Analog sum

1 channel

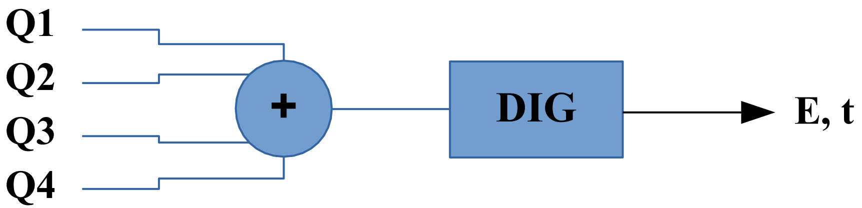


Sum of 7 channels



Large Area Pixel using SiPMs (LAPiS)

2. Signals from each Quadrant are summed (maybe with another MUSIC)
3. Signals is digitized to output Energy and time



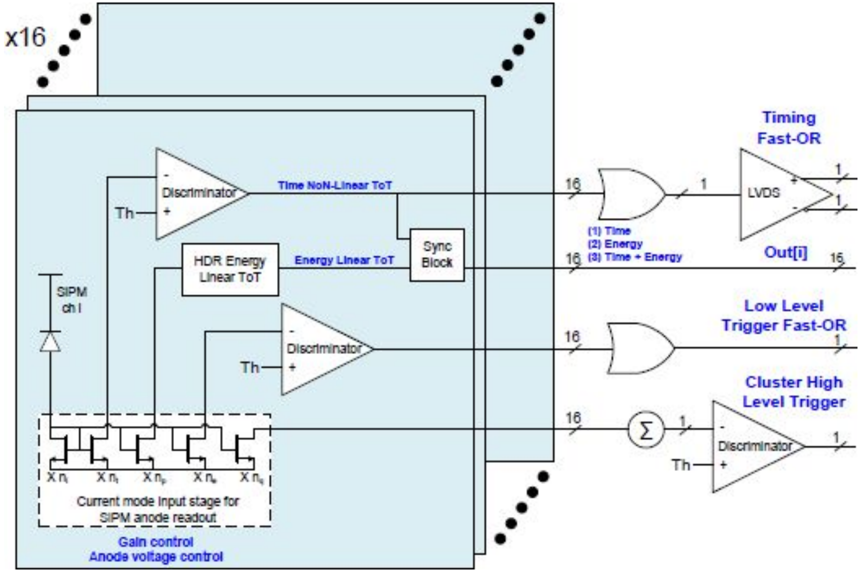
Digitalization with HRFlexTot

- 16 channels ASIC designed for PET at ICCUB (Barcelona)
- **Time** retrieved using a non-linear ToT
- **Energy** obtained with a high range linear ToT

  - Adjustable shaper to cope with different scintillators

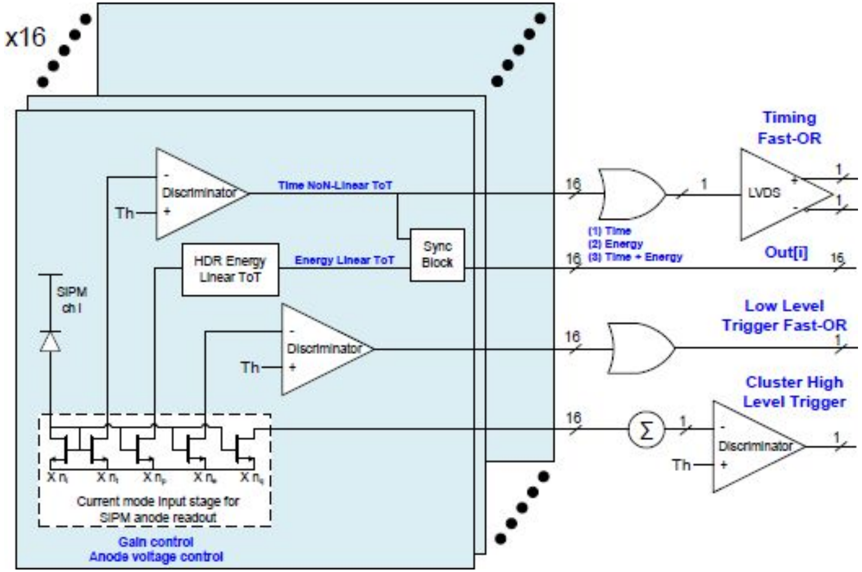
  - linearity from 0.5 to 500 ns

- **Cluster trigger** available (useful when charge is shared among different pixels)
- Another tunable trigger threshold can be set to avoid dark count events



Why using HRFlexTot?

- High **dynamic range** to process short (Cherenkov) and long pulses (scintillators)
- **Ready to be used** (tested in individual SiPMs and in arrays coupled to monolithic crystal)
- Since it has 16 input channels it can be used to **compare the energy resolution loss when digitizing** (or inversely, when doing the analog sum)
- If successful, **everything could be integrated into a single ASIC** (analog sum + digitalization)



Two possible Applications

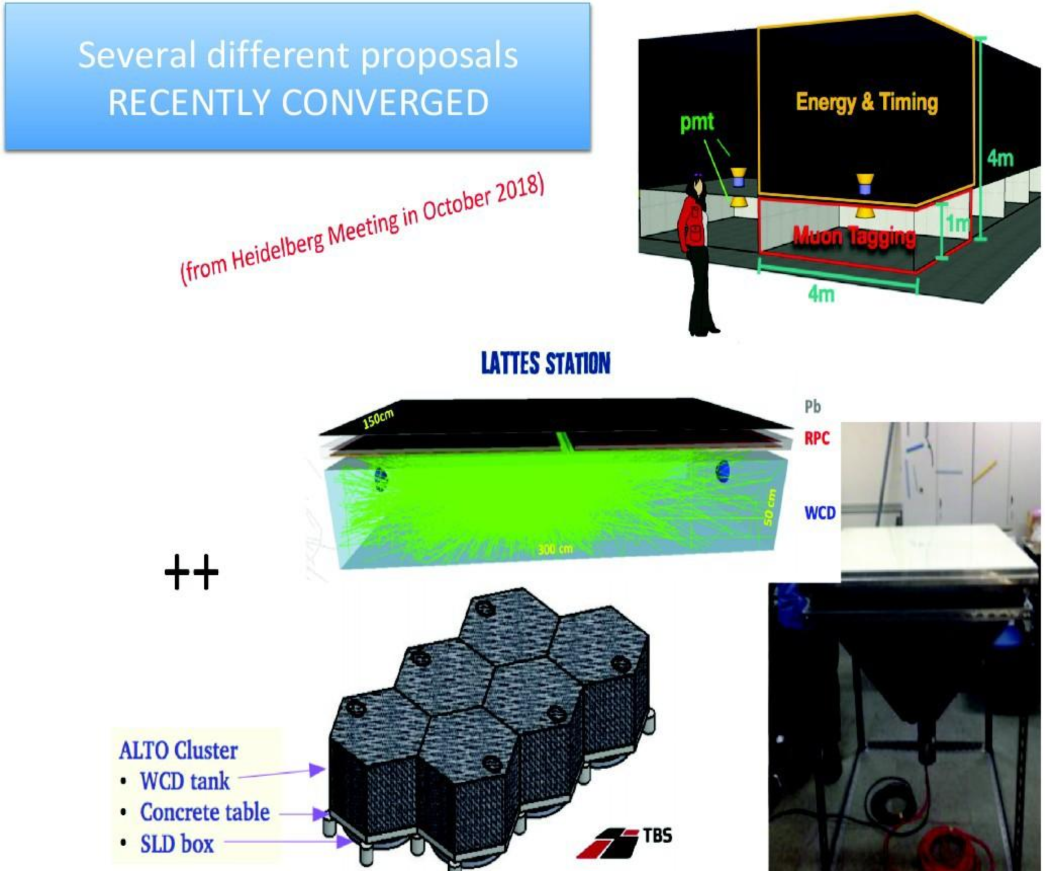
(hopefully many more will come)

SWGO

Southern Wide-field Gamma-ray Observatory

- Extensive Air Shower array planned for the Southern hemisphere
- Gamma-ray observations from ~100s GeV to ~100s TeV
- Larger area and better sensitivity than HAWC
- INFN involved (PD, TO, CT, PG… the list is longer...)
- **Based on water Cherenkov detectors coupled to large fast photosensors...**

SWGO



A. De Angelis

- **Large and fast photodetectors** sensible to UV-blue light are needed (desired pixel size ~ 10 cm^2)
- **Light** generated by the particles entering the water tank is **shared** between detectors.
- **Charge** (energy) an **arrival time** information on each photodetector is used to reconstruct energy and direction of gamma rays
- Final decision on the design to be made in ~3 years

SPECT

- **Single gamma-ray** emitter (typically ^{99}Tc, 140 keV)
- **Direction** information retrieved by means of a **collimator** (block of ~20 kg of lead with holes)
- Large crystal, **~50 x 40 cm²**, typically **NaI(Tl)**. The emitted scintillation light is **shared** by an array of **~30 to ~100 PMTs** (~ **2-8 cm diameter**)
- The whole camera is **shielded** by a thick (~1 cm) layer of **lead**

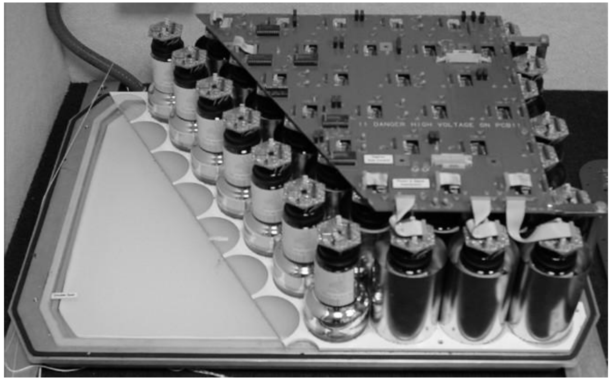
→ A SPECT camera is a heavy and bulky system...

If we could **replace** those bulky PMTs by **SiPMs** the camera would be:

➔ More compact

➔ Lighter

➔ Cheaper (+ Higher PDE, LV operation, insensitivity to MF…)



But you would need a few thousand pixels to equip a full camera if using 6x6 mm^2 SiPMs ...

2-year working plan, people involved and budget

- Year 1:
  - Month 6:
    - Build and characterization of a single LAPiS (PD, TO/BA and LIP)
  - Month 12:
    - Design of a cluster of 16 LAPiS coupled to scintillator - essential for the two applications presented - (PD and LIP)
- Year 2:
  - Design and characterization of ASIC with sum and digitization (collaboration with ICCUB)
  - Performance of 16 LaPiS readout with SWGO prototype (PD and LIP)

Personnel

Nome		%
Daniel Guberman	INFN Postdoc (stranieri)	100
Riccardo Paoletti	PA	20
Andrea Rugliancich	INFN Postdoc	30
Stefano Truzzi	PhD student	30
Roberto Cecchi	Tecn. laur. elettronico	30
Leonardo Stiaccini	Tecnico meccanico	30

Richieste di risorse della sezione

- Stampa 3D per prototipazione veloce

Financial Requests

Capitolo		Richieste (k€)	Totale (k€)
Missioni	Contatti Italia (PD, TO)	3	
	Contatti EU (Lisbona, Barcellona)	9	12
Consumi	SiPM (32x16, 30€ / cm2 con spare)	5	
	MUSIC ASICs (5x16)	8	
	Sensor board	15	
	Readout board	2	30
Inventariabile	Strumentazione laboratorio	10	
	PC laboratorio	3	13
		TOTALE	55

Backup

Summary

- A proposal to build a large area pixel using SiPMs was presented.
- A large pixel is built by doing the analog sum of 32 pixels using 5 MUSIC chips
- The prototype relies on existing technology (MUSIC, HRFlexToT), but their combination to produce larger pixels still needs to be validated
- The CTA-Pisa group has large experience in SiPMs and electronics design
- We also have experience on building "medium area" pixels using SiPMs (MUSIC, LightTrap)

SPECT

- **Single gamma-ray** emitter (typically ^{99}Tc, 140 keV)
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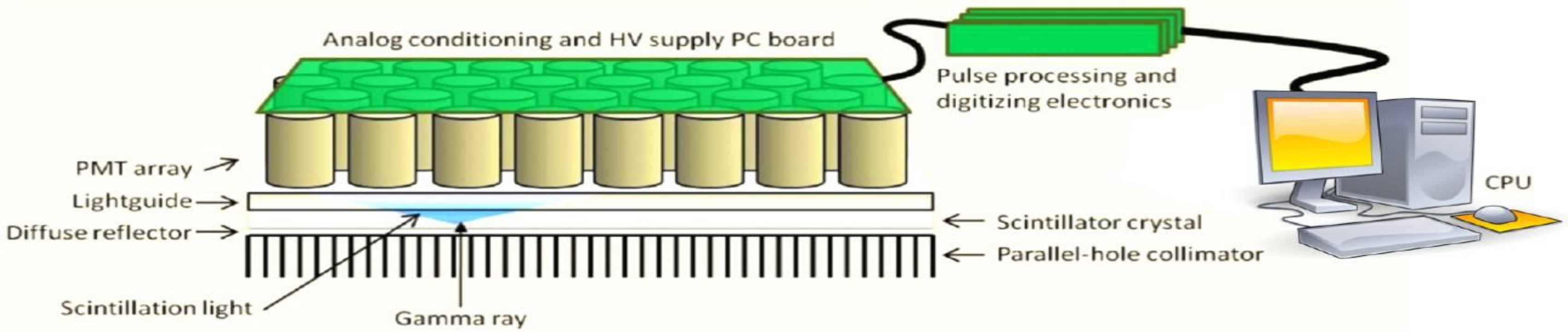

Occhipinti, 2015