Nuclear instrumentation from spectroscopy to applications

IPARCOS

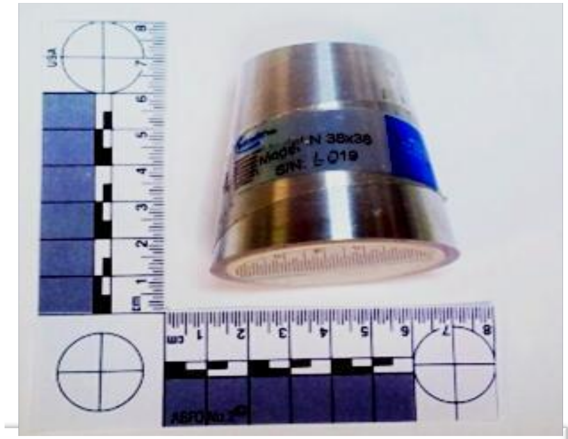
Radiation detection

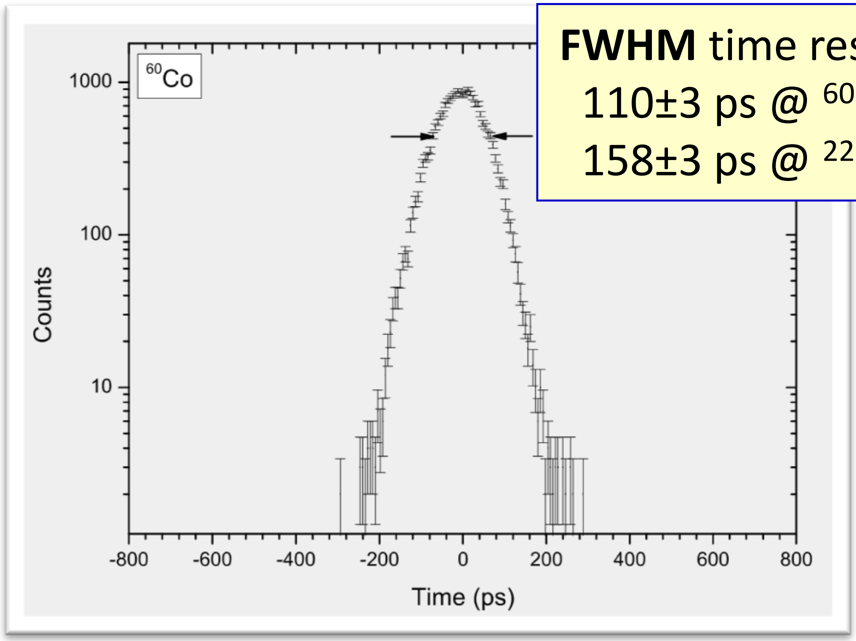
Nuclear radioactivity detectors:

- Scintillator detectors
- Silicon Photomultipliers (SiPMs)
- Digital Data Acquisition system (DDAQ)
- Signal processing

$LaBr_3(Ce)$ fast-timing crystals

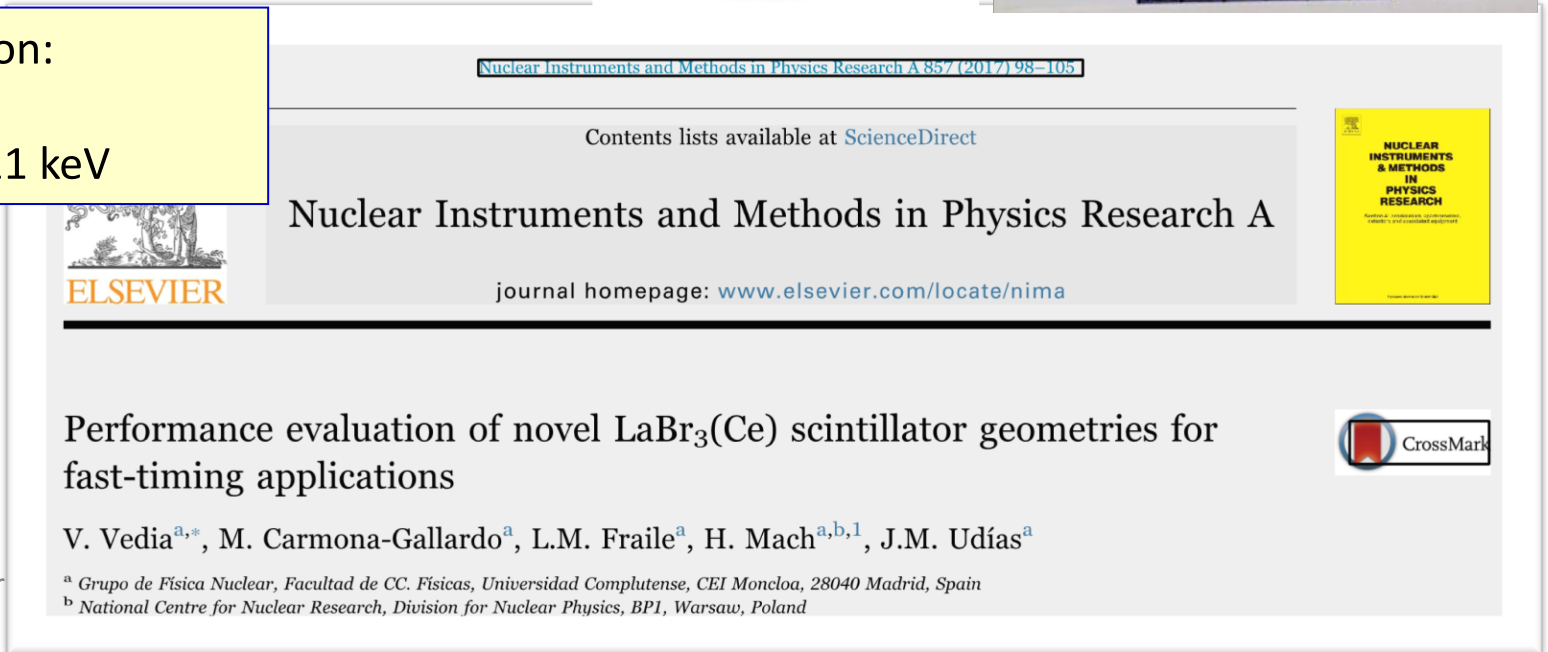
- Design of scintillator shapes and geometries for fast timing applications
- Optimization of parameters of readout using fast PMTs and analog electronics
- Best time resolution to-date obatined
- Fully-digital readout for time and energy
- Coupling to SiPM





FWHM time resolution:
110±3 ps @ ^{60}Co
158±3 ps @ ^{22}Na 511 keV

Nuclear



Nuclear Instruments and Methods in Physics Research A 857 (2017) 98–105

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ELSEVIER

Performance evaluation of novel $LaBr_3(Ce)$ scintillator geometries for fast-timing applications

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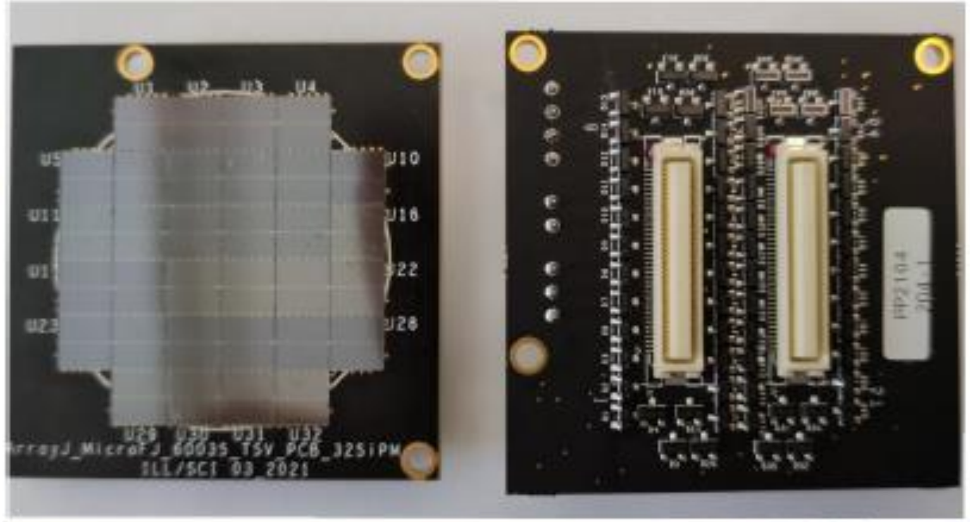
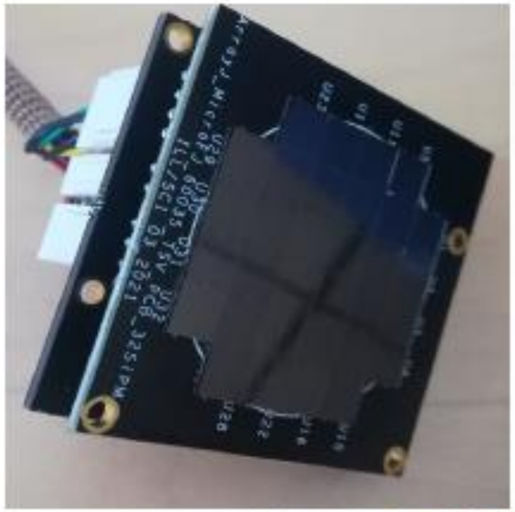
[b] National Centre for Nuclear Research, Division for Nuclear Physics, BP1, Warsaw, Poland

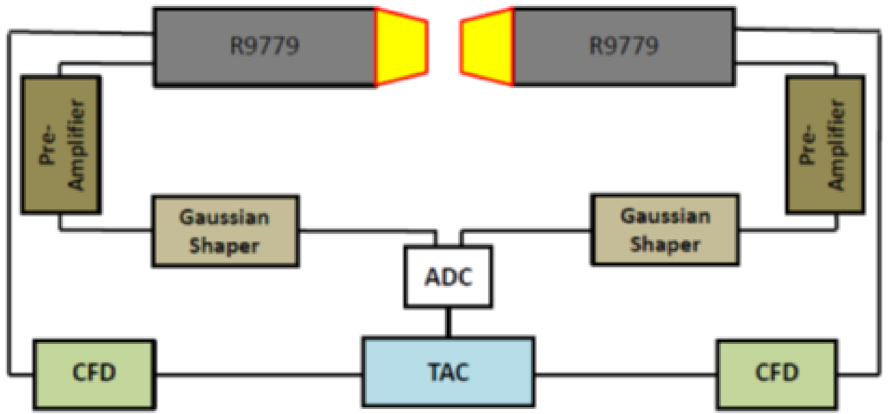
Silicon Photomultipliers

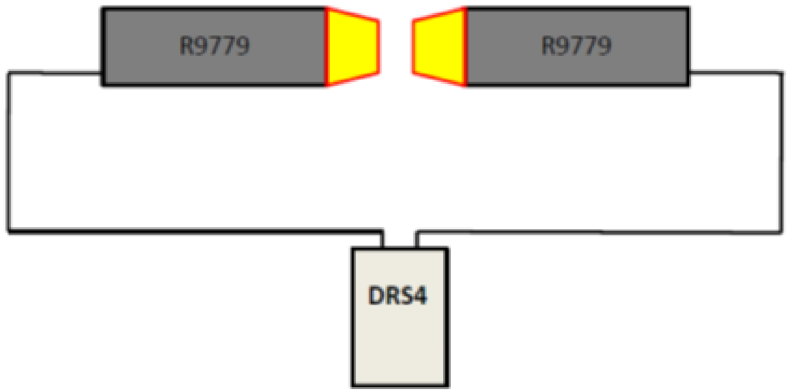




- SiPMs are an alternative to PMTs:
  - Small size
  - Low bias voltage
  - Low price
  - Insensitivity to magnetic fields
- 32 6x6mm² MicroJ ON semiconductor sensors
- 2 Output signals

Fully Digital Data Aqcuisition (DDAQ)



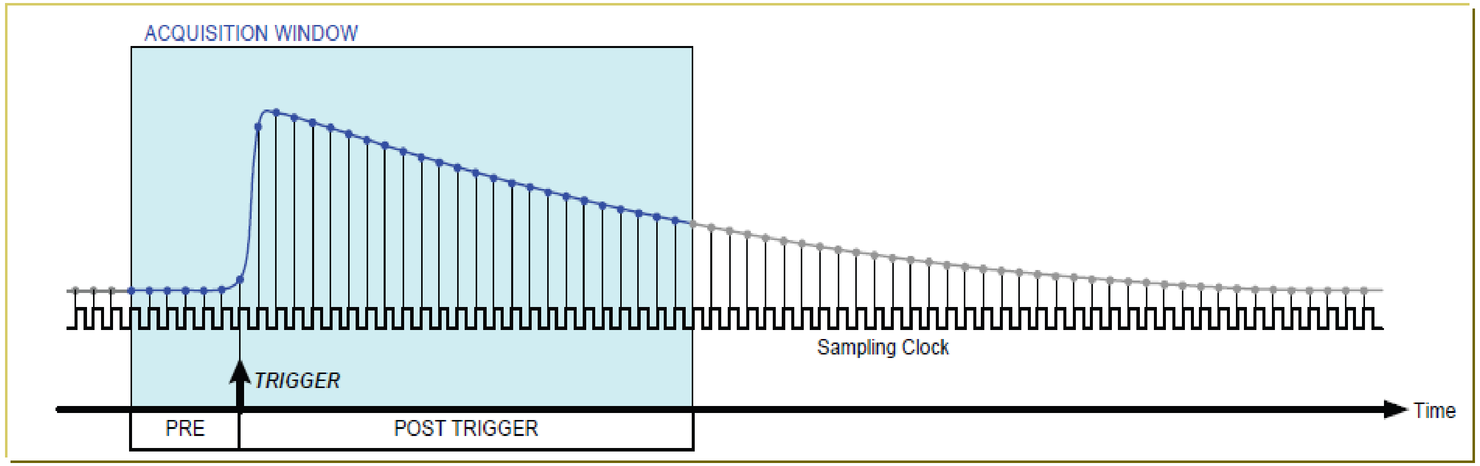


Why digital?

- **Simplicity**: one board can acquire energy and time signals.
- **Flexibility**: Any kind of processing and filter is possible, it is not limited to the analog circuits
- **Stability and noiseless**: immune to noise, temperature changes, etc.
- **Price**: Higher bandwidth, sampling rate and less price every year.

Signal processing

Performance of time filters depend on many parameters: threshold levels in both detectors, delay and amplitude of inverted signal (CFD), time filter parameters, etc.



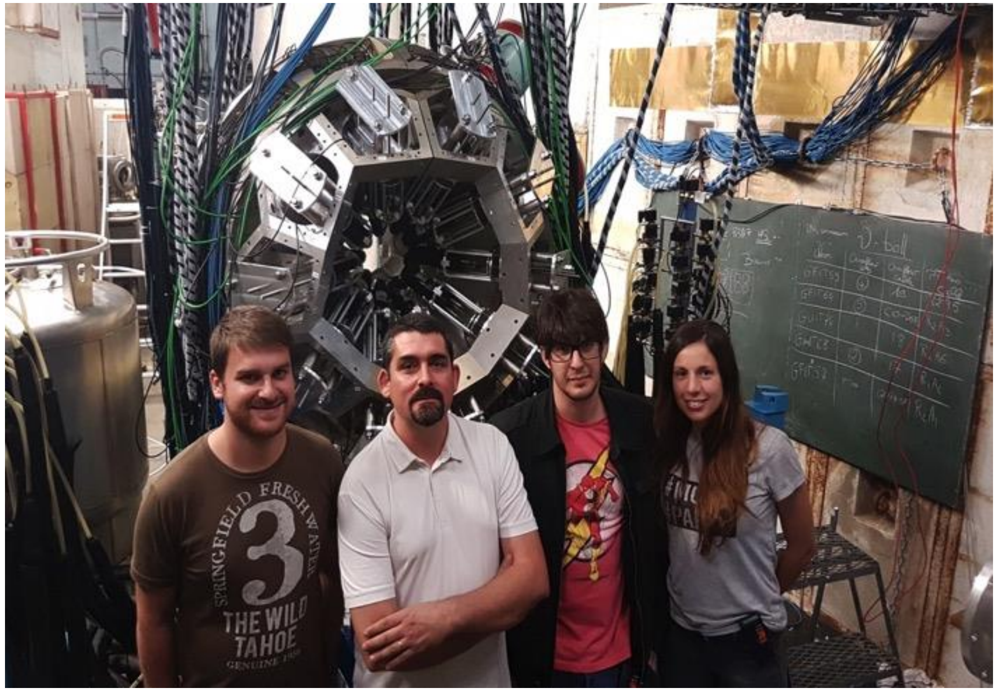
- **New filters:** 7% improvement in coincidence time resolution.

- **Genetic Algorithm (GA)**: 10 % improvement in coincidence time resolution.

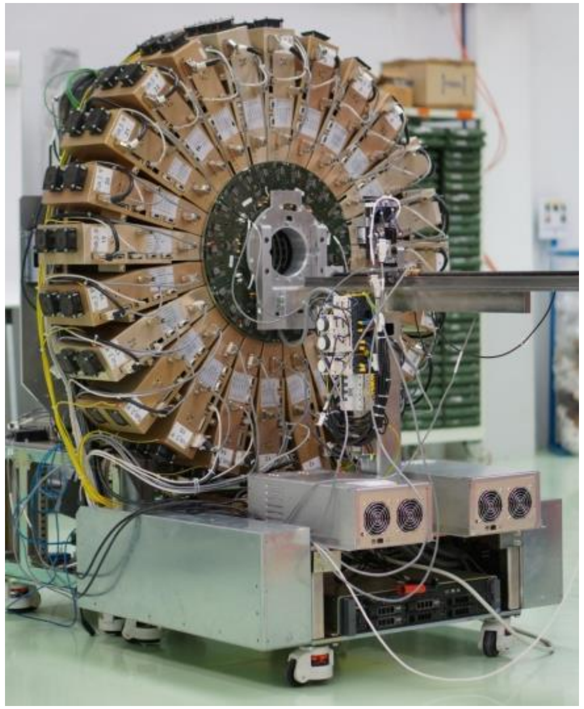
Sanchez-Tembleque V, et al. 2019 *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.* **927** 54–62

Radiation detection for different applications

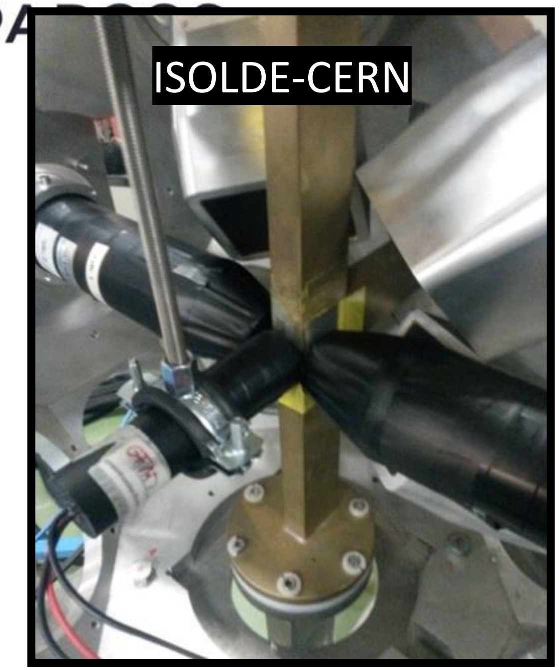
Gamma spectroscopy

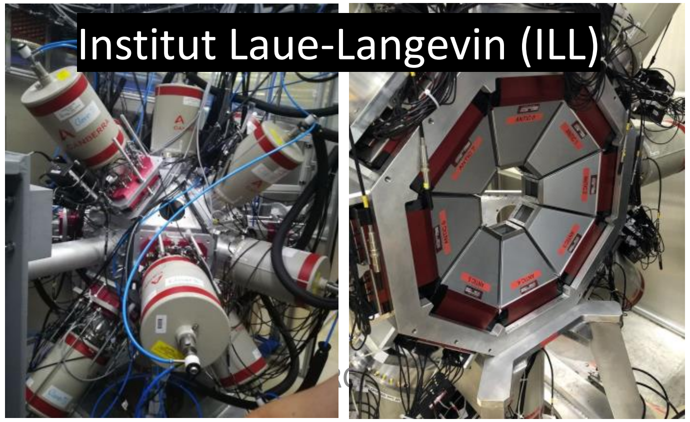


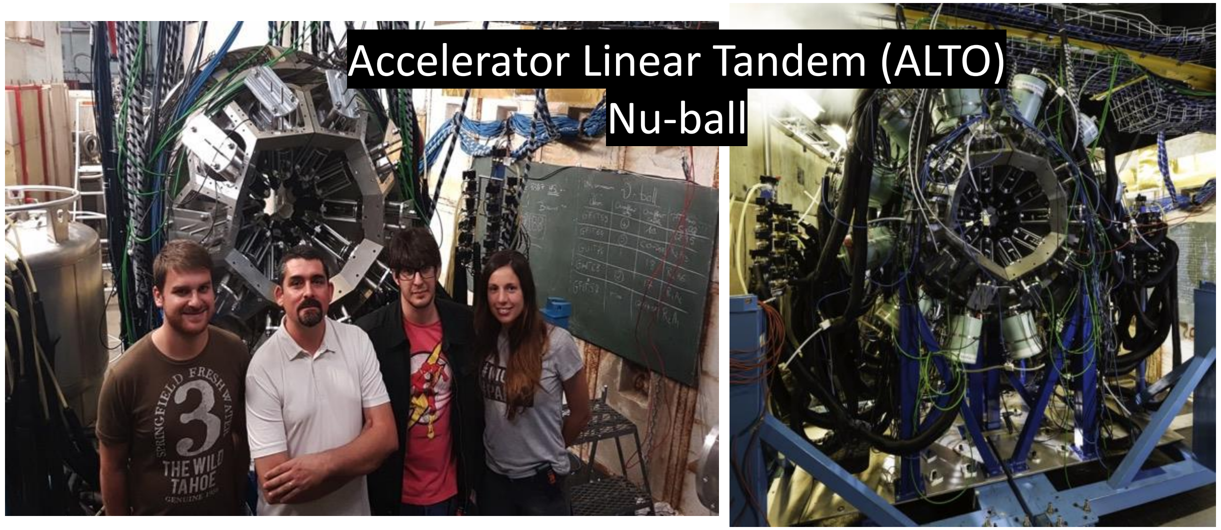
Medical applications

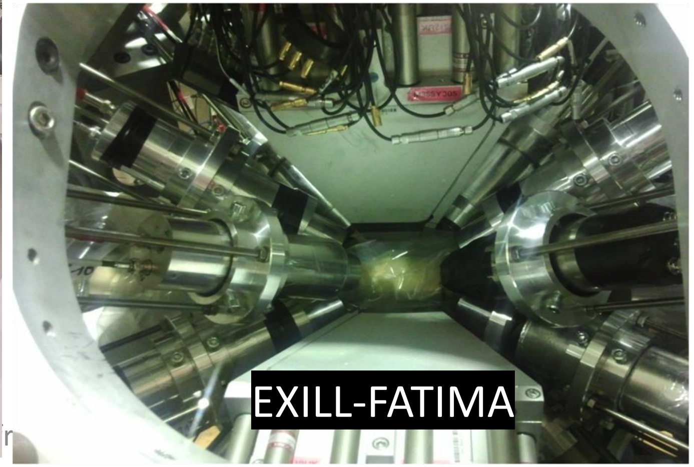


Gamma spectroscopy experiments



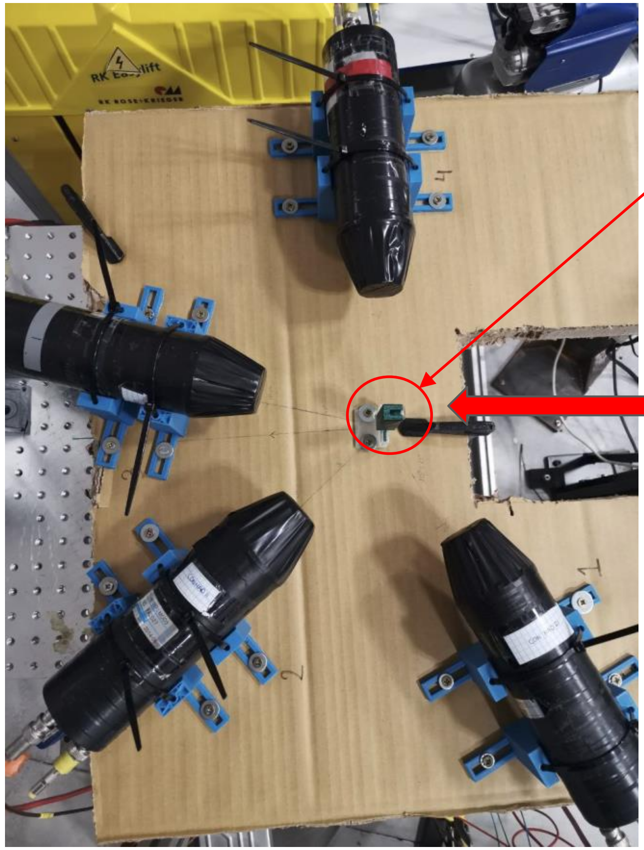




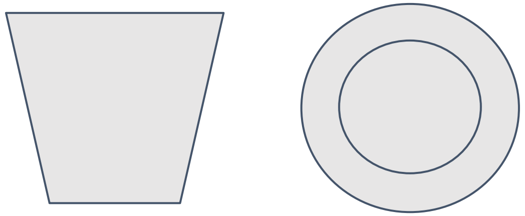


Prompt-gamma analysis in $H_2^{18}O$ proton irradiation experiment

- $H_2^{18}O$ irradiation with protons from 2MeV up to 10MeV
- On-beam measurements -> high count rates



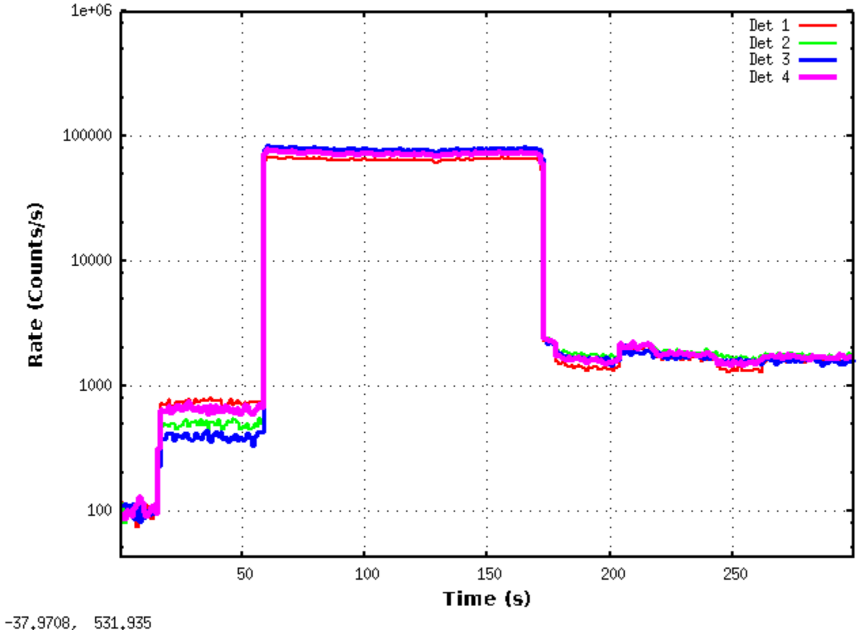
LaBr3 truncated cone scintillators



PMT HAMAMATSU H10570Q

DAQ → CAEN 5751 (GSample/s)

Target → H2O18
Energy Beam → 6 MeV
Rates ~ 80k counts/s



Beam structure measurements

Sub-μs structure?

Each pulse presents a sub- μs structre, with a characteristic frequency of 64 MHz, measured with a sampling period of **0.8 ns**

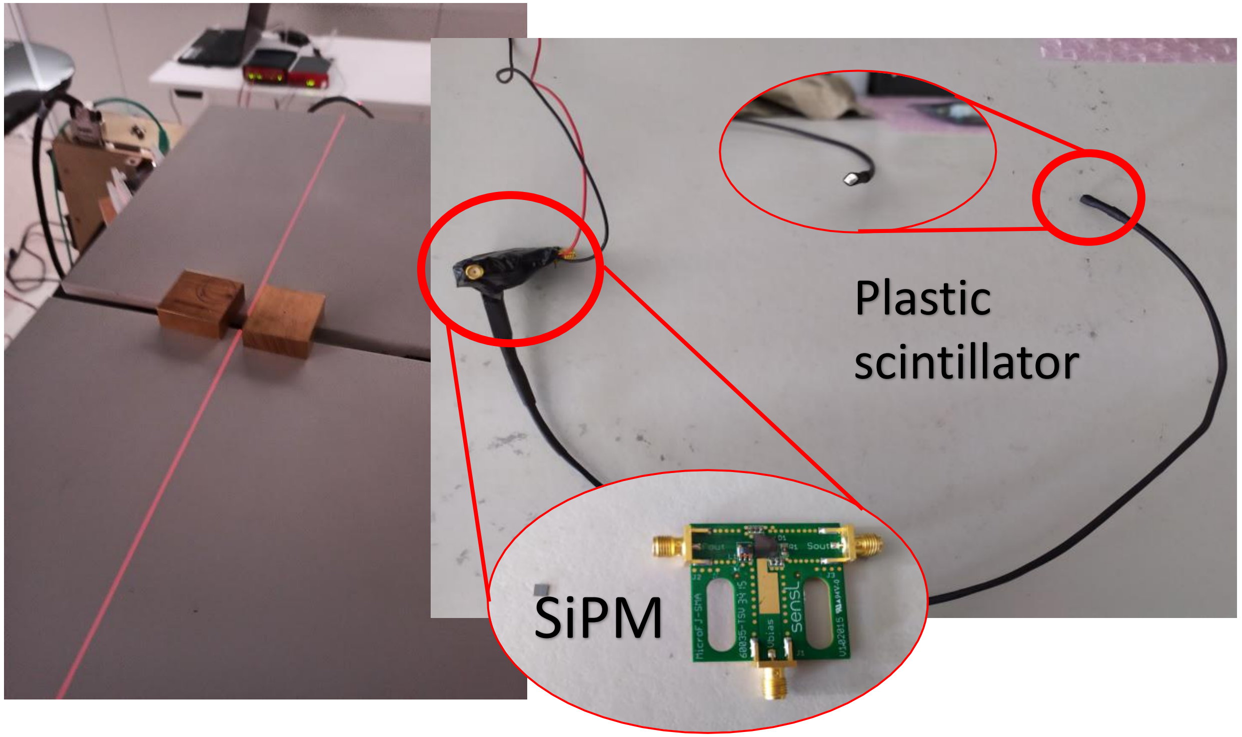
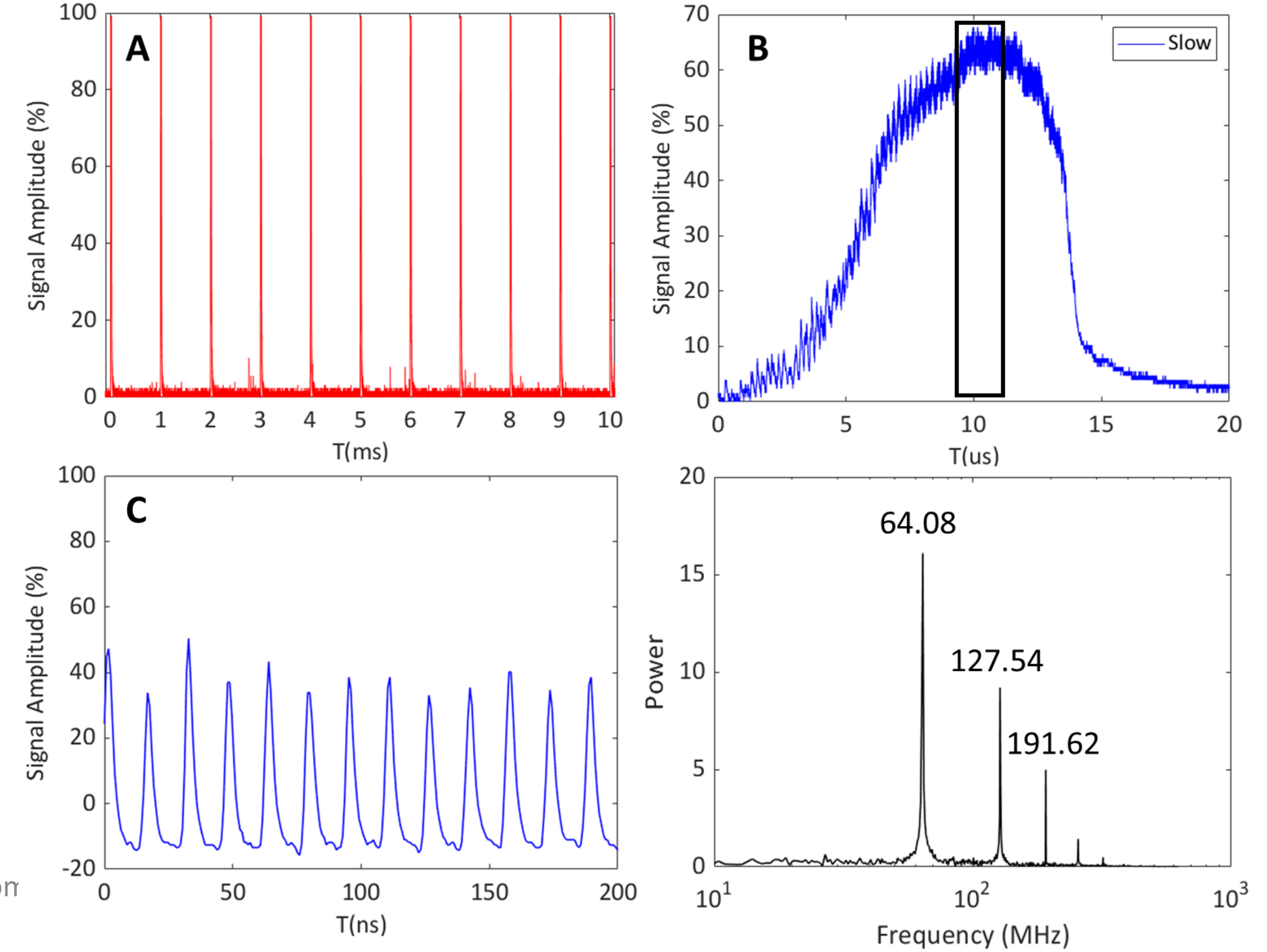


Fig. Scheme of the detector. It consists of a plastic scintillator (right) attached with grease and optical fiber to a SiPM (left). The SiPM has dimensions of 3x3 mm and the scintillating plastic of 3x3x3 mm. The plastic model is EJ-322Q and the SiPM MicroFJ-300-SMA-TSV.

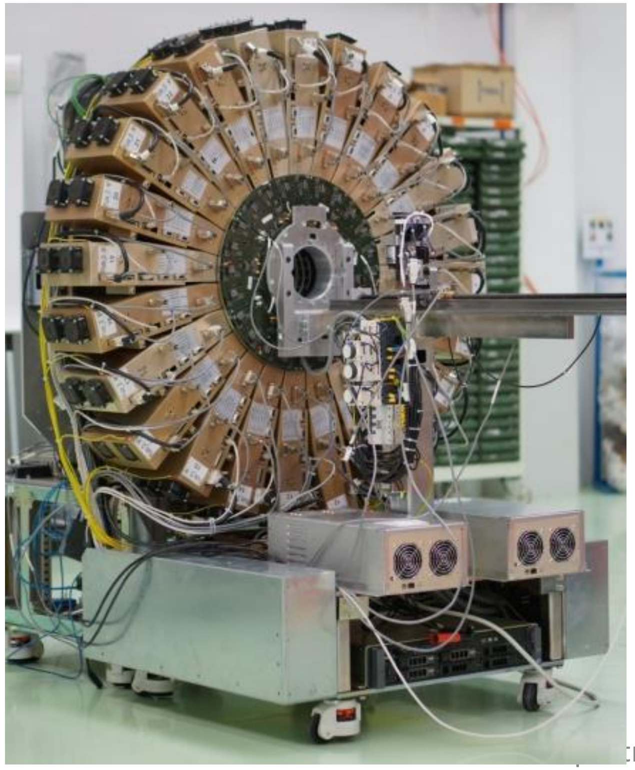


PET scanners: SuperArgus extended FOV preclinical scanner

- Designed and developed by SEDECAL in partnership with UC3M, UPM and IPARCOS

- (CDTEAM and AMIT projects, CENIT@INGENIO)

Fully modular electronics



- 144 dual layer detectors
- 42000 individual pixels
- 30 ps electronics jitter time

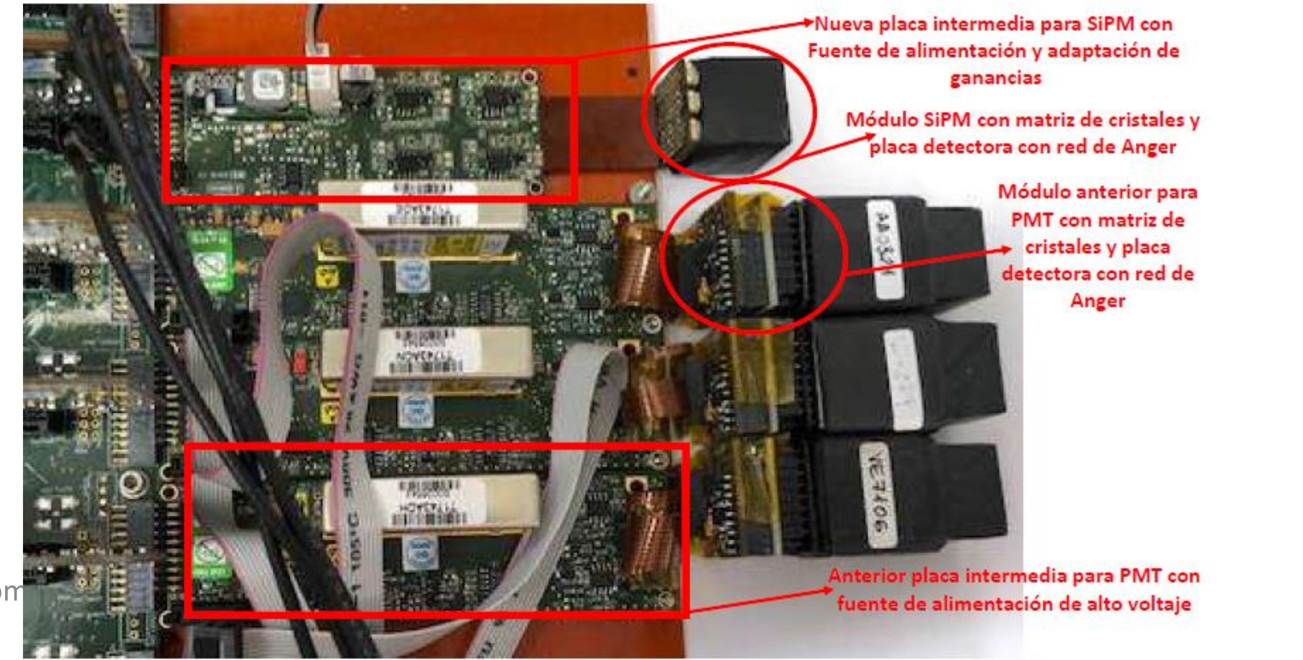
•DAQ: 48 FPGA, 128 ports 10 GB switch, 40 CPU cores + powerful GPU

•World record processing capabilities:
 •+100 millions of single events per second
 •+10 million coincidences per second sorted out to disk

•Only existing PET scanner with real time imaging capability

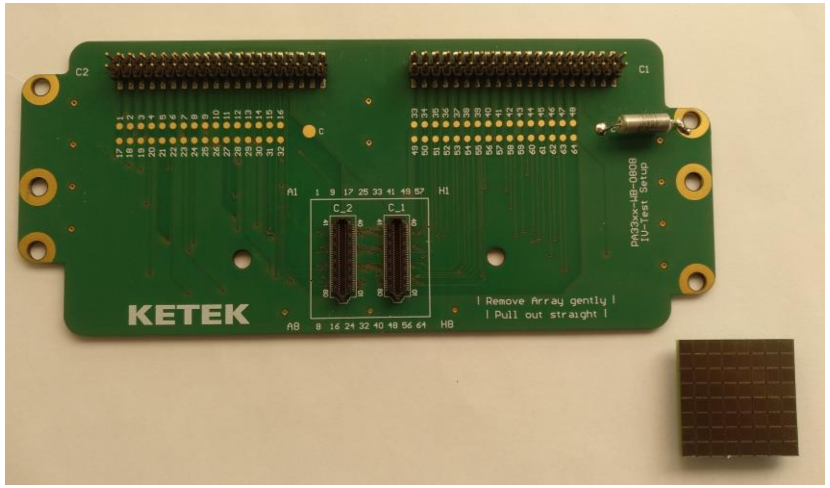
PET scanners: MRI Compatible DOI-TOF PET Detector

- **High sensitivity, high spatial (< 1 mm) and time resolution (< 250 ps) detector, MRI compatible**
- **Substitute PMT by SiPM**
- **New array of scintillators and electronics**
- **New RF and magnetic materials and shieldings**
- **Tested in a system, with new and old detectors**



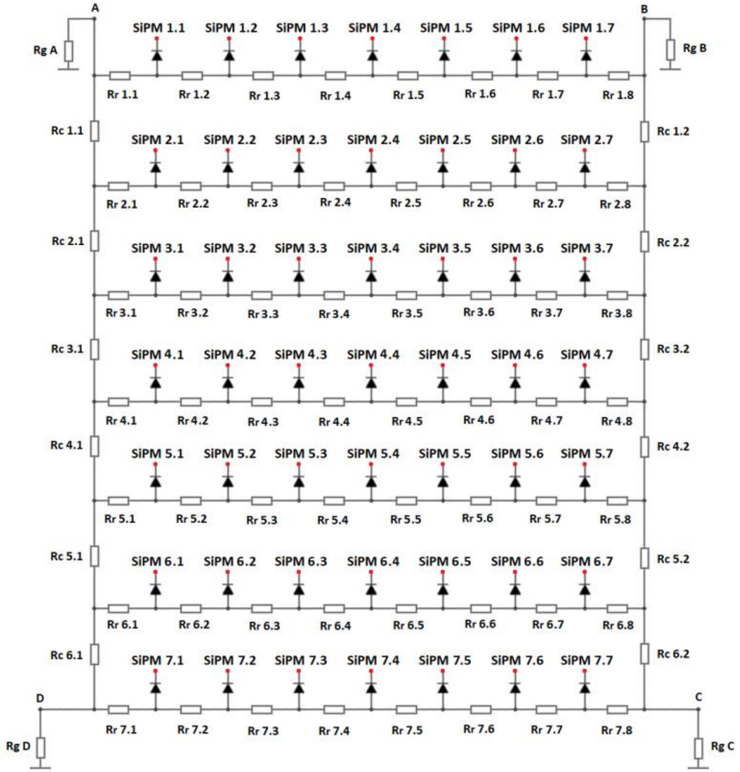
PET scanners: Phoswich LYSO/GSO array readout with an array of SiPMs

Array of 8x8 SiPMs from Ketek



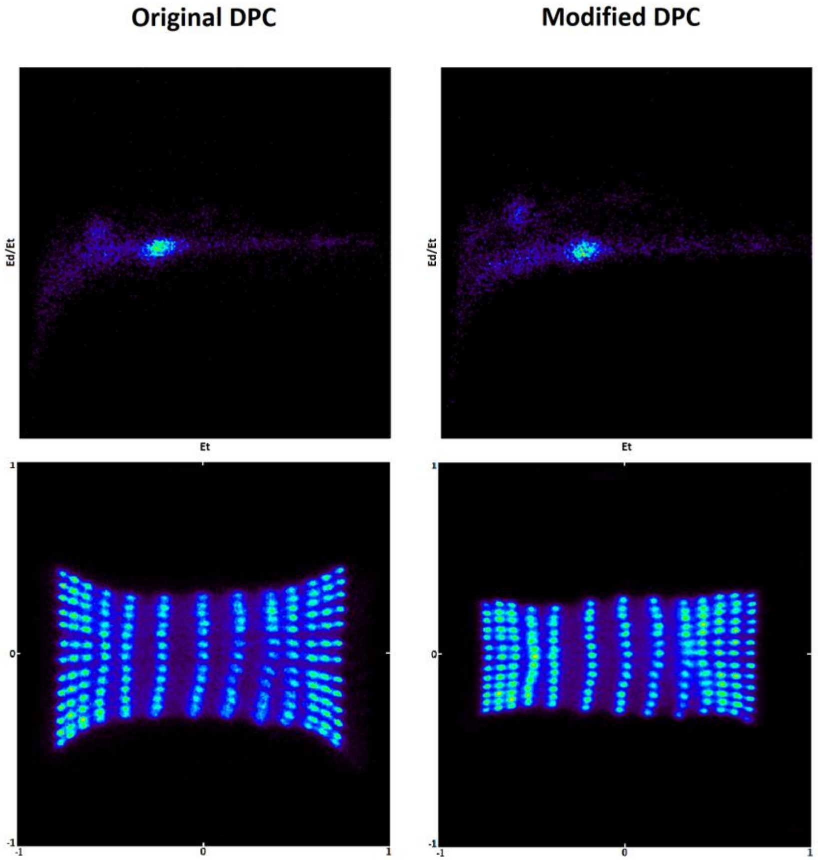
Phoswich array of LYSO/GSO crystals

Discretized positioning circuit (DPC)

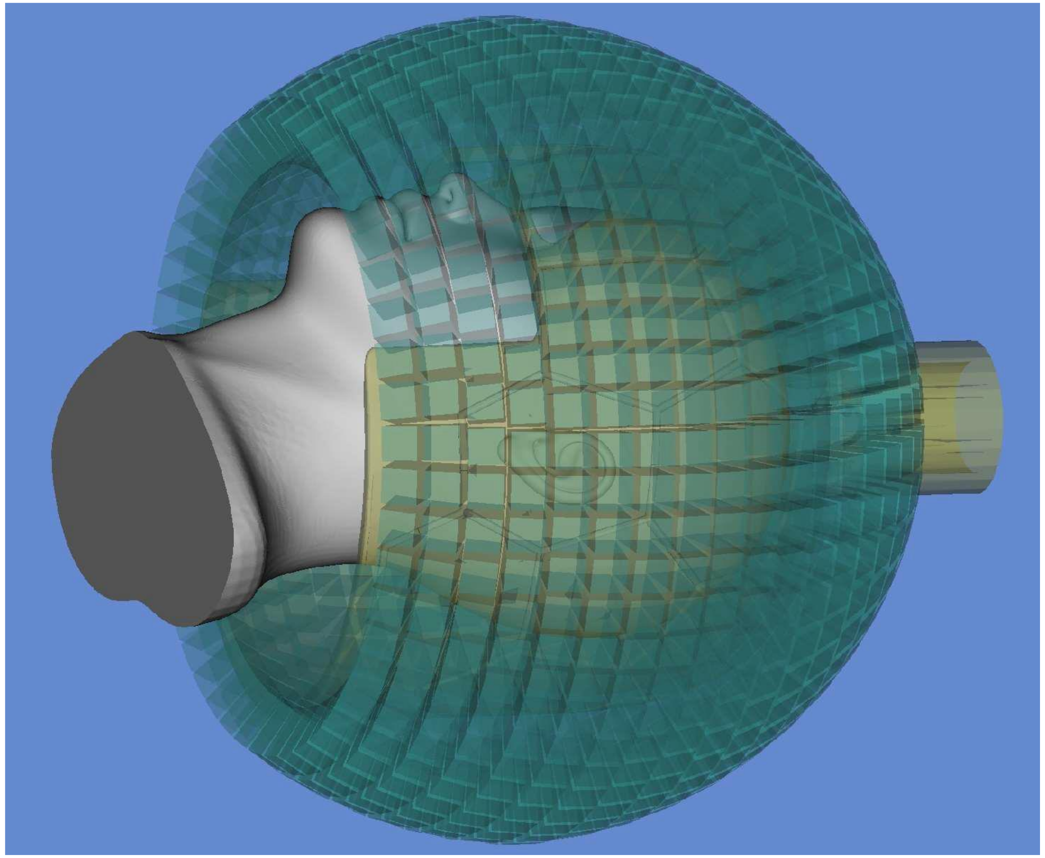


Multiplexing the SiPMs of the array to reduce the 8x8 outputs to 4, taking the signals from each corner

Phoswich and cristal pixel discrimination based on retarded energy and floodfiled map



PET scanners: High Spatio-Temporal Resolution Brain PET (HSTR BrainPET)



[NIH GRANT] (1R01EB026995-01) *Development of 7-T MR-compatible TOF-DOI PET Detector and System Technology for the Human Dynamic Neurochemical Connectome Scanner*

Goals:

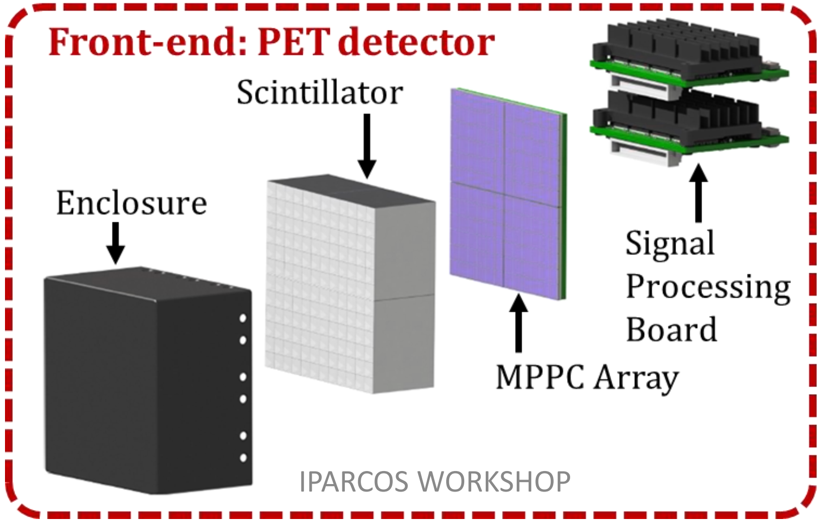
- Crystal identification
- Depth of interaction
- Timing performance and energy resolution

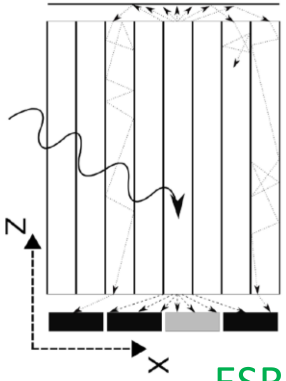
PET scanners: High Spatio-Temporal Resolution Brain PET (HSTR BrainPET)

PET module for DOI estimation

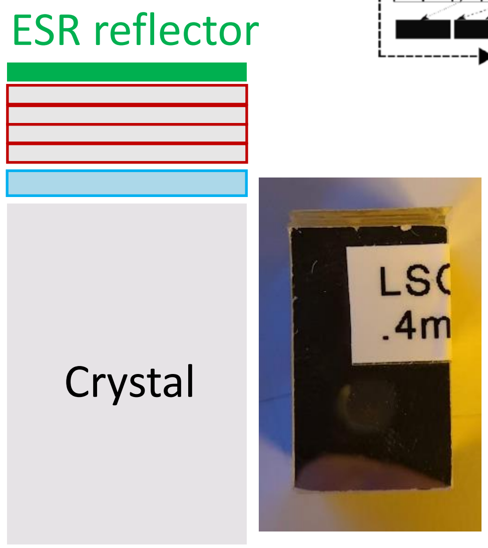
<u>Scintillation Crystal Blocks</u>

- Pixellated array (10x10)
- Crystal size 1.6mm
- 26mm depth
- Stacked Dual Layer
- 4x4 SiPMs with 50µm pixel size
- Different Light Guide Configurations

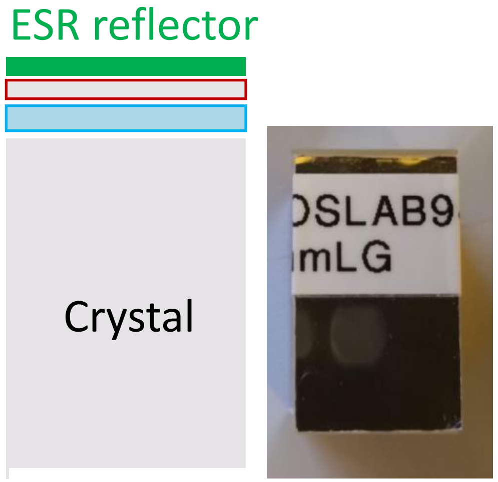




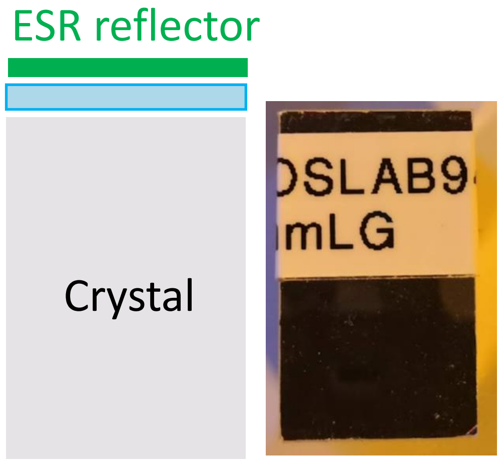
Pizzichemi 2016, Phys. Med. Biol.



4 layers optical patch ~380µm=1.52mm



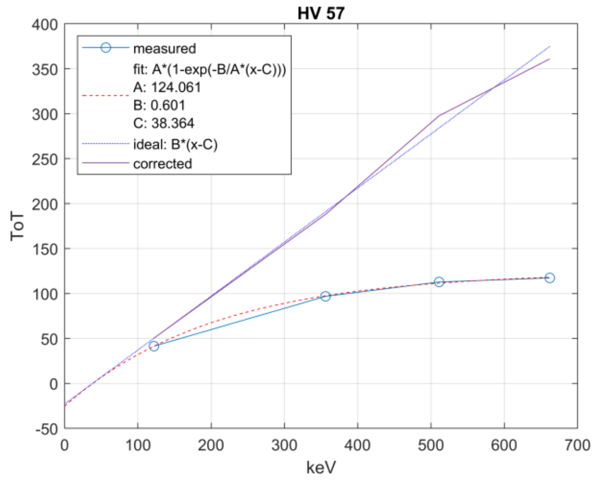
1 layer optical patch ~380µm



Glass 0.4 mm

PET scanners: High Spatio-Temporal Resolution Brain PET (HSTR BrainPET)

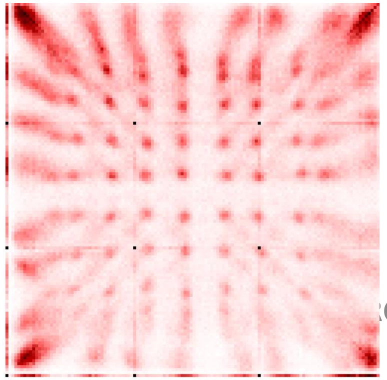
Crystal identification



Saturation correction (inverse of exponential fit function)

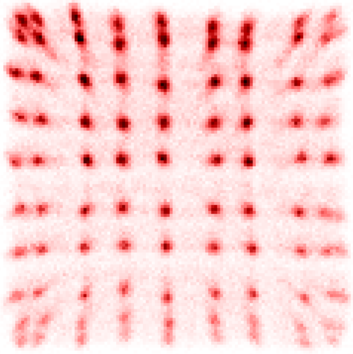
- Individual MPPC channel correction
- Global correction based on center MPPC

Original LUT

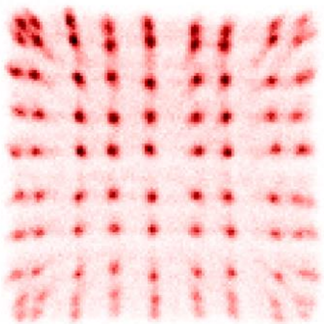


Linear correction

Linear correction (Q metric)

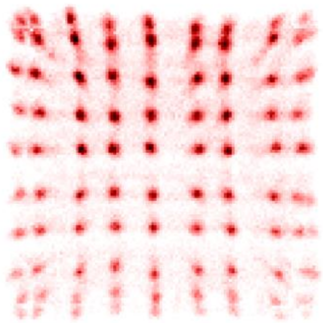


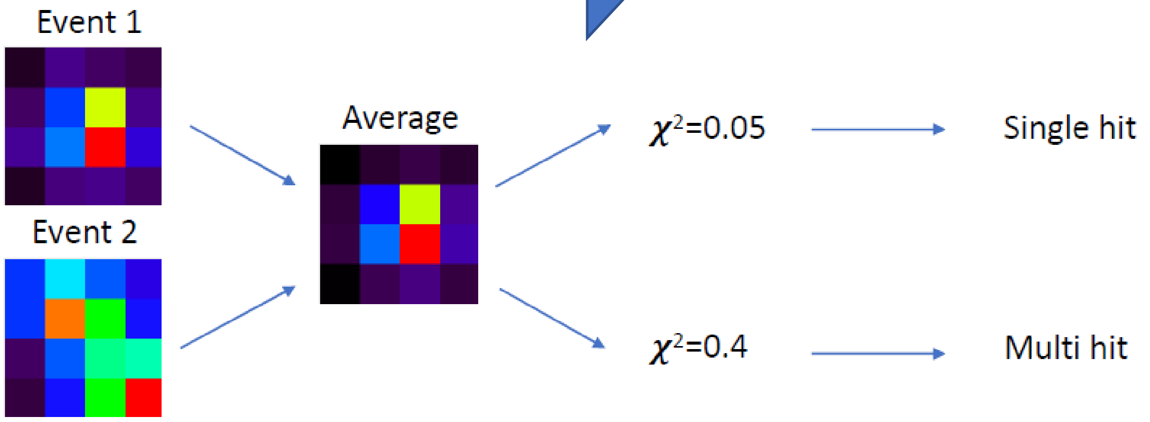
Linear correction (Q-metric)



$\chi 2$ analysis to select 80% best $\chi 2$ events in every crystal to remove multi-crystal events

New LUT

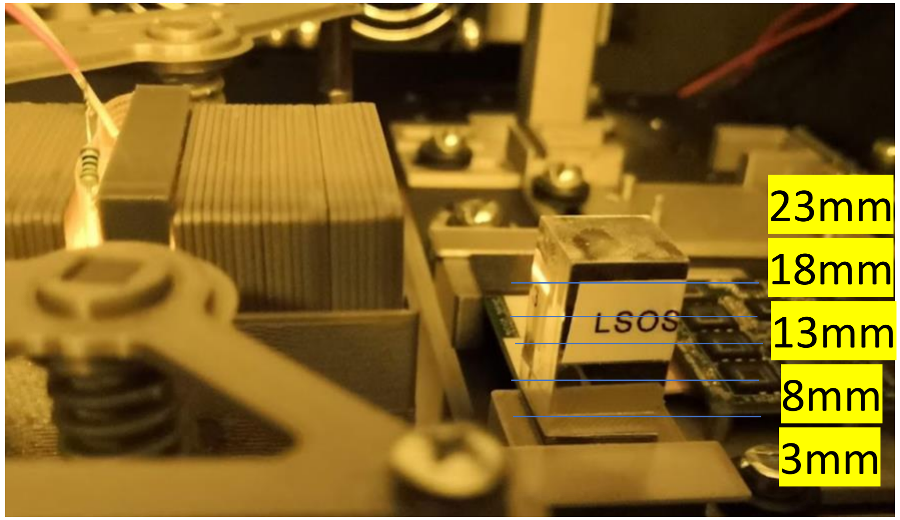




PET scanners: High Spatio-Temporal Resolution Brain PET (HSTR BrainPET)

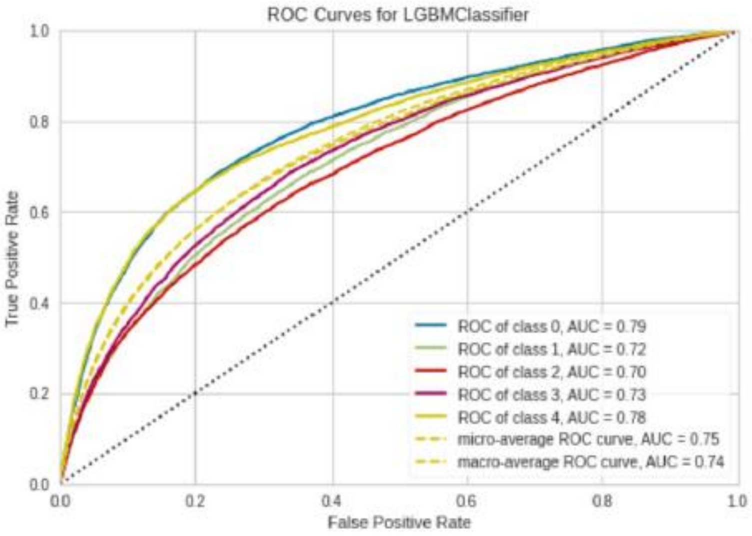
- Compare methods for DOI determination

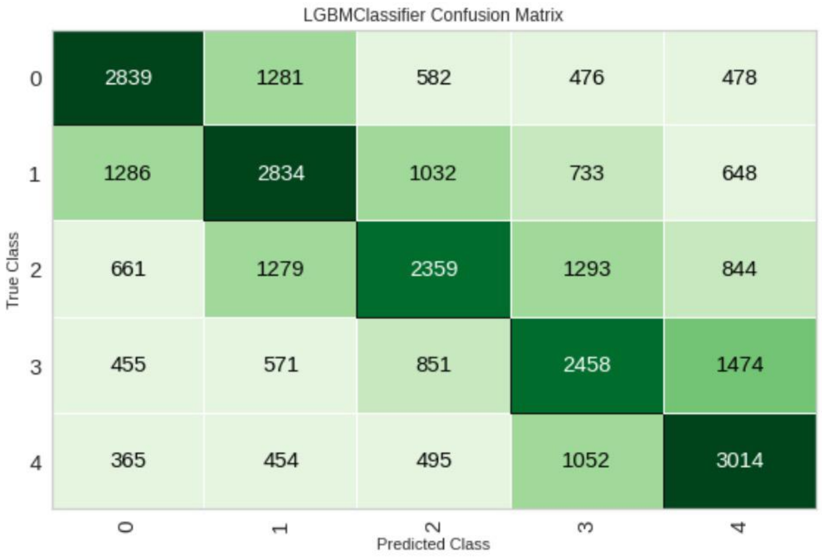
  Collimated source at different positions



- Characterize all crystals of array with DOI resolution → number of possible DOI bins
  - ➢ Light Gradient Boosting Machine
  - ➢ Random forest

FWHM of 7mm





Gamma-MRI: a game changer in molecular imaging

New imaging modality that mixes up MRI spatial resolution with PET sensitivity in a low-cost system of small size.

IP: Luis Mario Fraile
Partners: U. de Geneve, Escuela Superior Suiza-Norte, U. Lovaina, UCM, CERN, RS2D, Inspiralia.
Funded (3.4M euros) by openFET program of the UE H2020.
Agreement with the UE signed in January 2021.
Started in April.

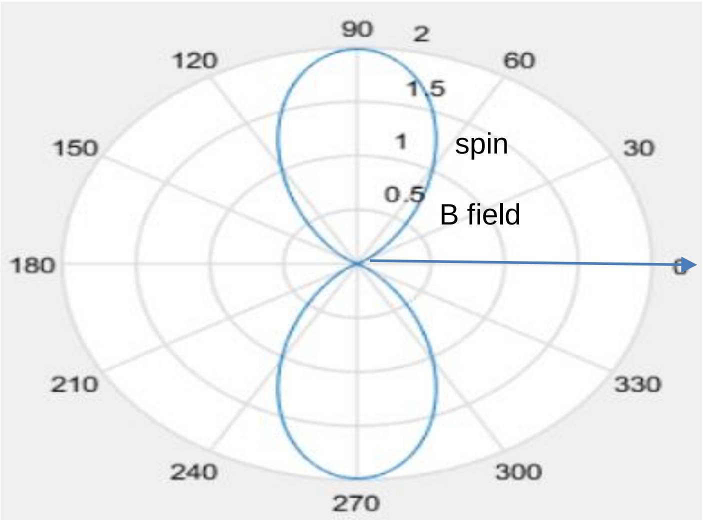
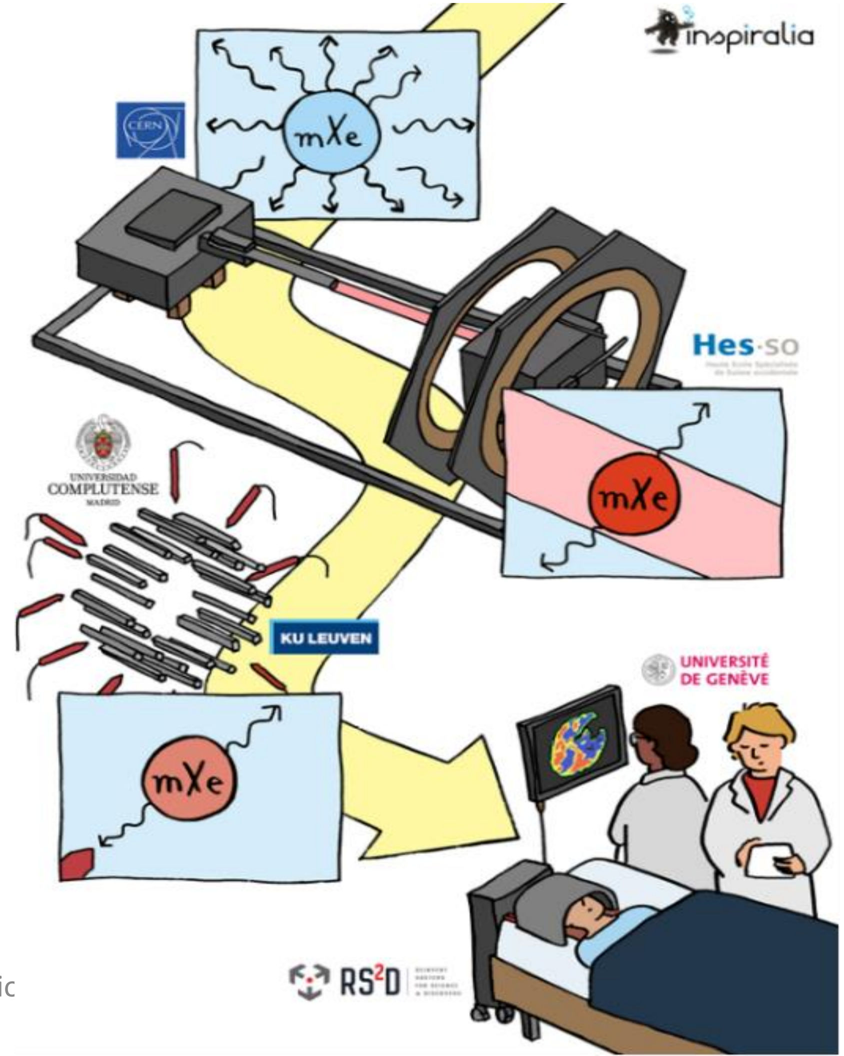


Fig. 2 Asymmetric γ-emission from polarised nuclei with spin > ½.



Gamma-MRI: a game changer in molecular imaging

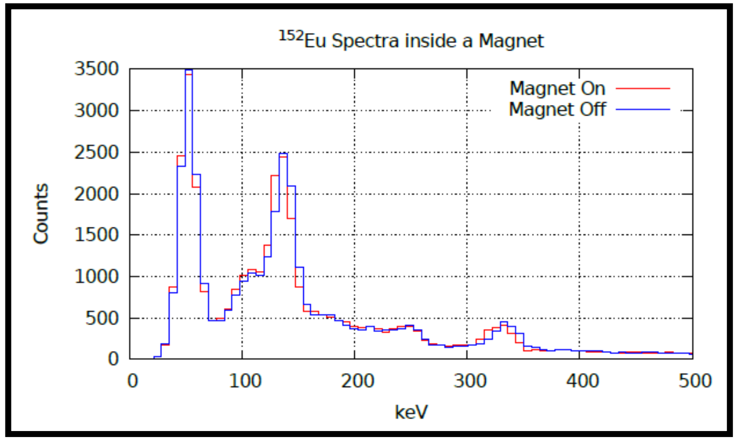
MRI compatible, High resolution Gamma detectors+ fully digital DAQ

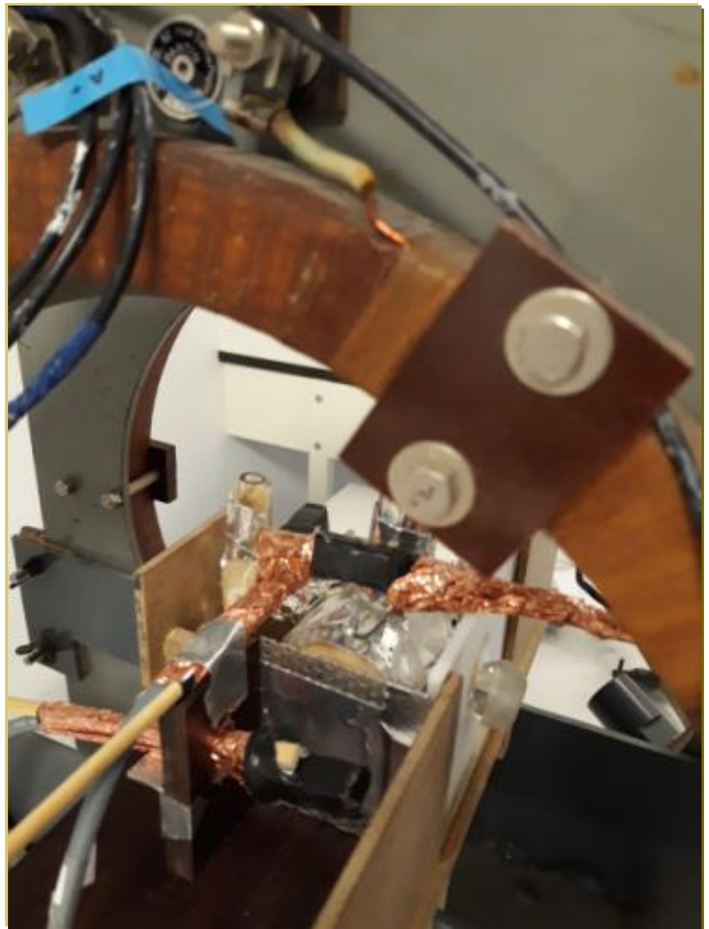
	CeGAGG	$LaBr_3(Ce)$
Photon Yield (Phothon/kev)	57	63
Peak Emision (nm)	520	380
Decay Time (ns)	88	16
Z_{eff}	53,4	46,9
Size	10x10x30 mm^3	20x25,4 mm (cylinder shape)
Density (g/cm^3)	6,63	5,08

Pipelined algorithm: two threads reading the scope data, another thread identifying the trigger condition and processing the pulse, and finally another one performing histograms and plots

SiPM S13360-6075CS 6x6 mm2, from Hamamatsu coupled to 1cmx3 cm prysm CeGAGG

2x2 MicroFJ-60035 SiPMs matrix, each pixel of 6x6 mm2 from SensL coupled to 2x2.5 cm $LaBr_3(Ce)$ cylinder

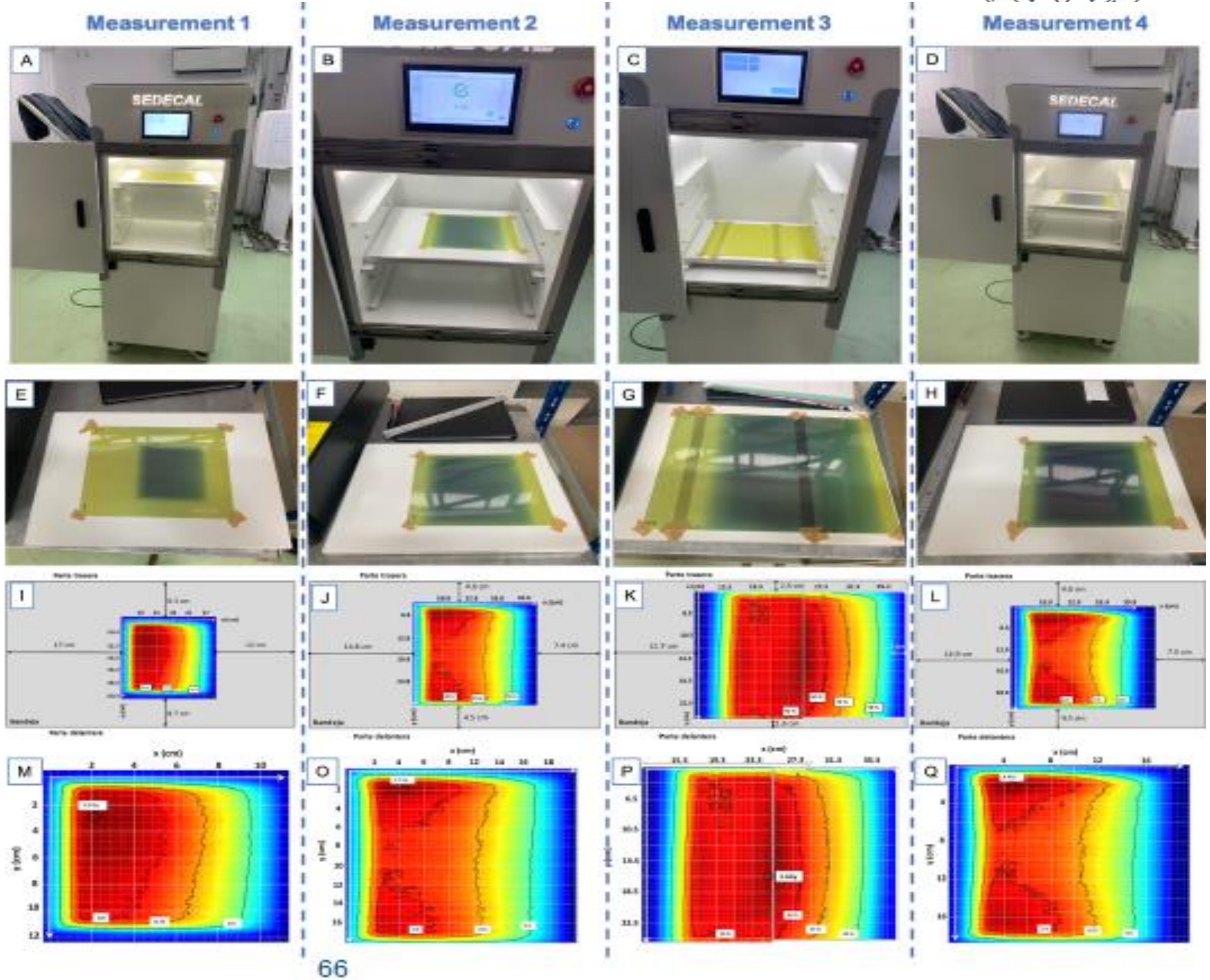




Not only radiation detectors...

In collaboration with SEDECAL:

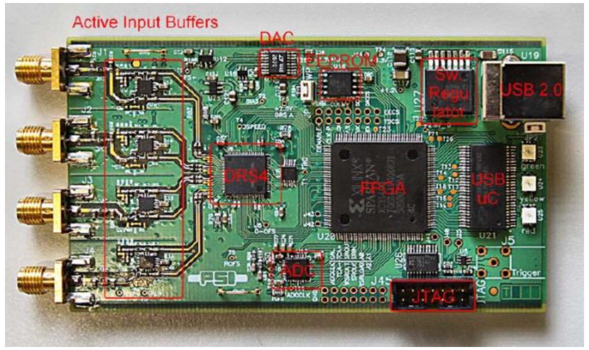
- Designed, tested and characterized a self-shielded X-ray irradiator with FLASH potential.



Thank you!

Digital Data Aqcuisition (DDAQ)

	DRS4 Evaluation Board	Picoscope 6403C	Picoscope 2406B
Bandwidth	**950 MHz**	350 MHz	50 MHz
Sampling Rate (Maximum)	**5 Gs/s**	5 GS/s	1 GS/s
Sampling Rate (Streaming)	**No**	>150 MS/s	>30 MS/s
Resolution	**14 bits**	8 bits	8 bits
Input Impedance	**50 Ω ±1%**	50 Ω ±1% 1M Ω ±1%, DC coupled	1 MΩ ±1%, DC coupled
Price	**1500 €***	4000 €	500 €

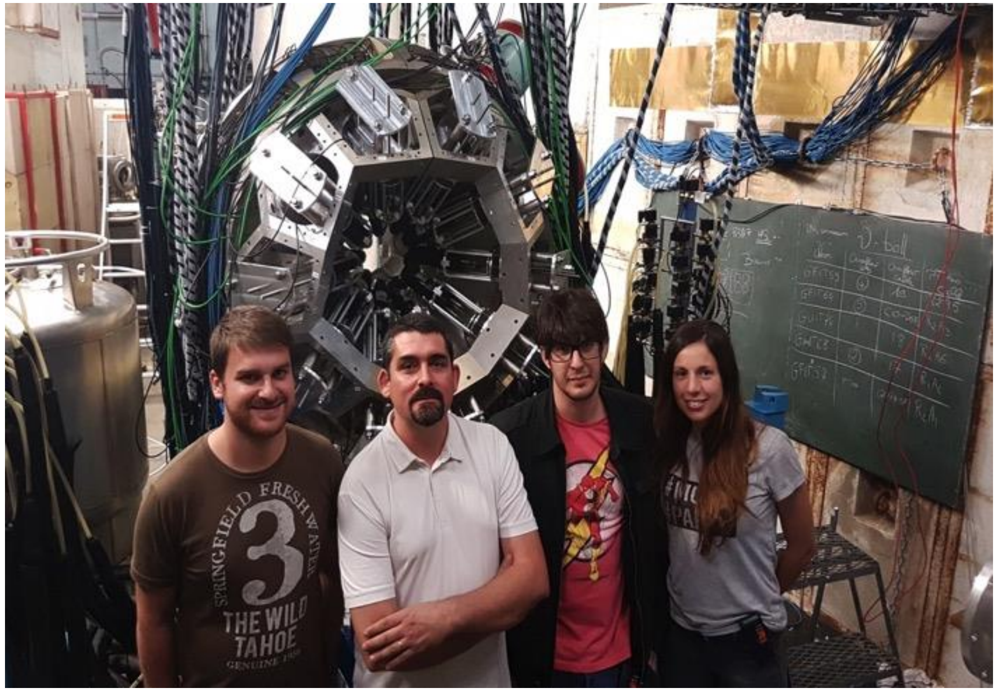


DRS4: Based on the Domino Ring Sampling
4 channels, 1024 samples per channel and pulse
Limited to 500 pulses/s in the PC, full 4 channels, 14 bits at 5 GS/s

VME versions starting at 8k€ (CAEN),
depending on the number of channels, and allowing for 10-100 kcounts/s in the PC

Radiation detection for different applications

Gamma spectroscopy



Medical applications