Advanced radiation detectors and instrumentation for nuclear physics and applications

LA1: Desarrollo de instrumentación de vanguardia para futuros experimentos de Física de Partículas y Nuclear

JM Udías (GFN@IPARCOS)

IPARCOS
Plan de Recuperación, Transformación y Resiliencia
Comunidad de Madrid
gfn UCM Grupo de Física Nuclear
Universitas Complutensis Matritensis
Financiado por la Unión Europea NextGenerationEU
Astrofísica y física de altas energías

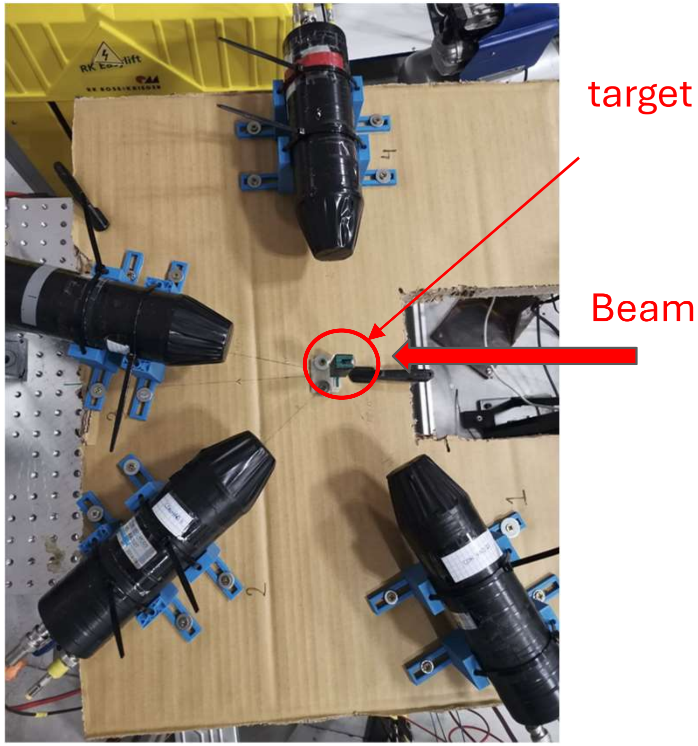
IP: Ignazio Scimemi (director of IPARCOS). Luis Mario Fraile (Nuclear Activities in LA1)

Total funds: 150 k€, 90 k€ for personnel (one electronic engineer, one electronics technician, supported until Dec 2024), 60 k€ equipment (20 Gs/s, 6 GHz bandwidth, 4 channels scope + other fast digitizers), already executed.

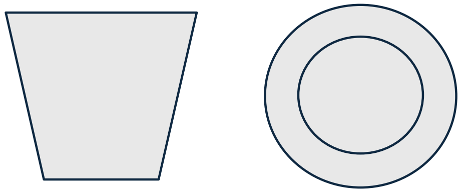
Goals: Develop compact (1.1) **trigger detectors based on sipm+plastic**, and inexpensive large area photodetectors for $LaBr_3$(Ce) Scintillators, (1.2) **optimize time-pickup for fast timing detecto**rs, with **DL** algorithms. Pave the way for (1.3) **smart fast timing detectors based on modern microcontrollers** (MCU). Explore **translation to PET electronics.**

At GFN we (LM Fraile et al) are **world leaders in nuclear fast timing measurements**, at ILL, ISOLDE, FAIR, and many other places. We use relatively large fast inorganic scintillators, coupled to good big old fashion PMTs, which we have optimized and setup for best results for timing.

The problem: (1) PMTs are becoming scarce, expensive. Old models are discontinued, and replacements are simply not as good for timing. Solution: Replace PMT by SiPMs.



LaBr3 truncated cone scintillators



PMT HAMAMATSU H10570Q

DAQ → CAEN 5751
(GSample/s)

SiPM: smaller and lighter, no HV required, more robust, insensitive to magnetic fields, increasingly available, they are becoming cheaper (2-3 times cheaper than surface-equivalent PMT)

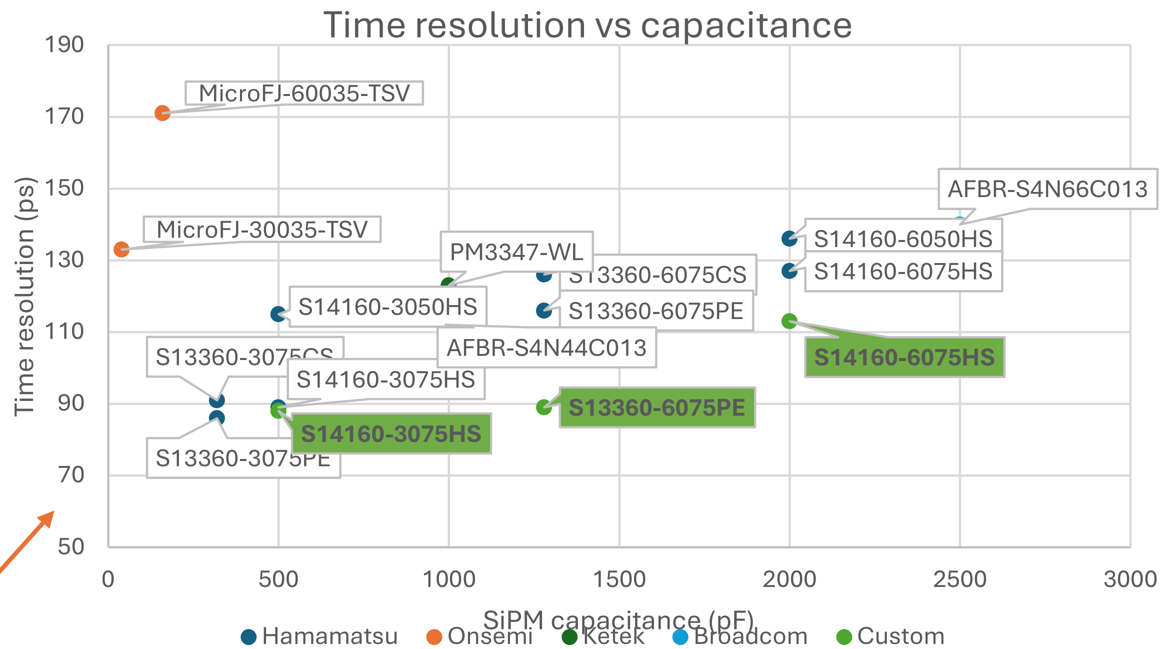
<u>But, are they any good for timing?</u> Let's test every suitable SiPM in the market

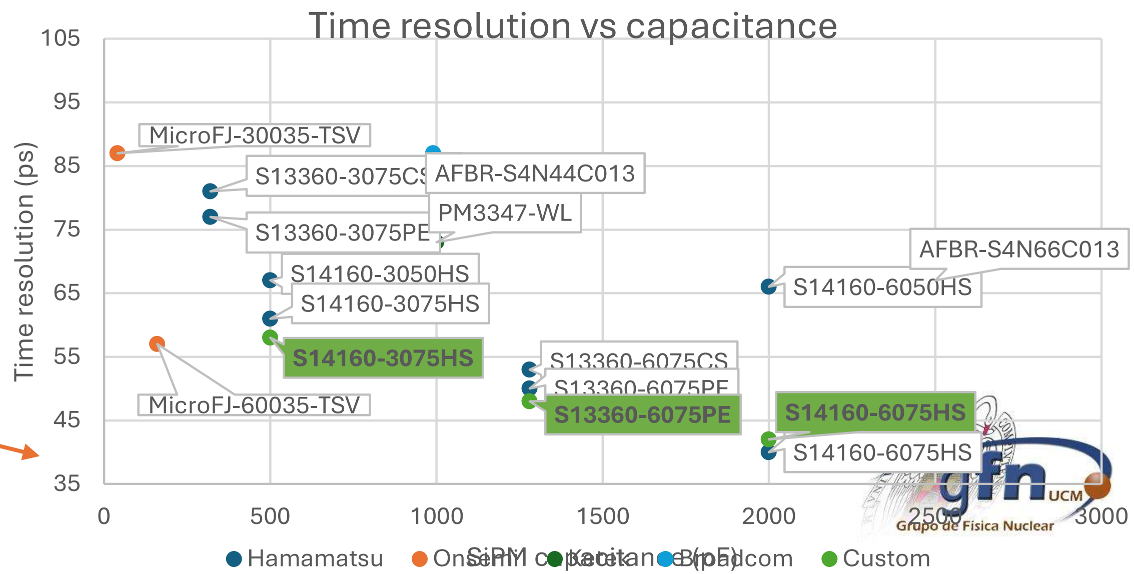
Brand	Serie	Model	Size (mm^2)	Pixel pitch (μm)	PDE (%)
Hamamatsu	S13360	3075CS	3x3	75	50
Hamamatsu	S13360	3075PE	3x3	75	50
Hamamatsu	S13360	6075CS	6x6	75	50
Hamamatsu	S13360	6075PE	6x6	75	50
Hamamatsu	S14160	3050HS	3x3	50	50
Hamamatsu	S14160	6050HS	6x6	50	50
Hamamatsu	S14160	6075HS	6x6	75	57
Onsemi	MicroFJ	30035-TSV	3x3	35	38
Onsemi	MicroFJ	60035-TSV	6x6	35	38
Broadcom	AFBR	S4N44C013	4x4	30	43
Broadcom	AFBR	S4N66C013	6x6	30	44
Ketek	WL	PM3347	3x3	47	47

Scintillator	Light yield (photons/keV)	Decay time (ns)	Size (mm^3)
LYSO	29	42	3x3x5
EJ-232Q	2,9	0,7	6x6x5

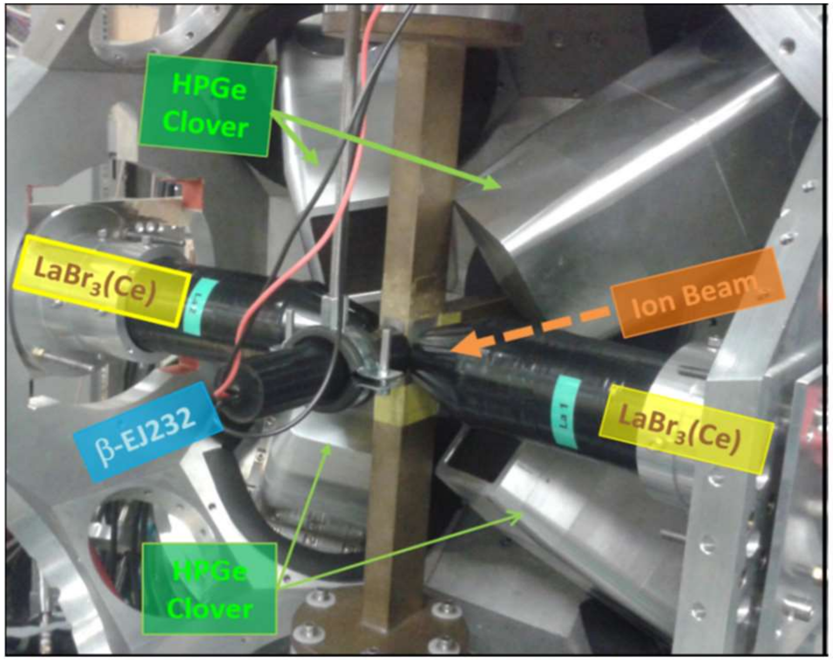
· Inorganic **Scintillator LYSO**: Na-22 source and three SiPMs+LYSO detectors in coincidence

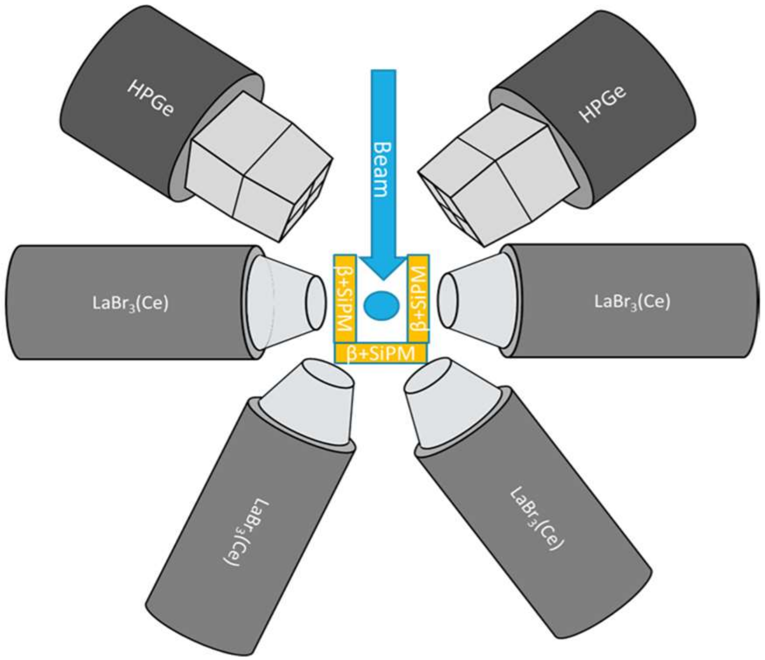
· **Plastic EJ-232Q** with Eu-152 source in coincidence against PMT R9779 (HPK) with $LaBr_3(Ce)$ 1x1".





1.1 Developed a SiPM + plastic for trigger with fast timing capabilities (IP L.M. Fraile)





Left: Example of a fast-timing setup at ISOLDE used for βγγ(t) spectroscopic measurements.

Right: Possible alternative configuration using beta-SiPM detectors from GFN

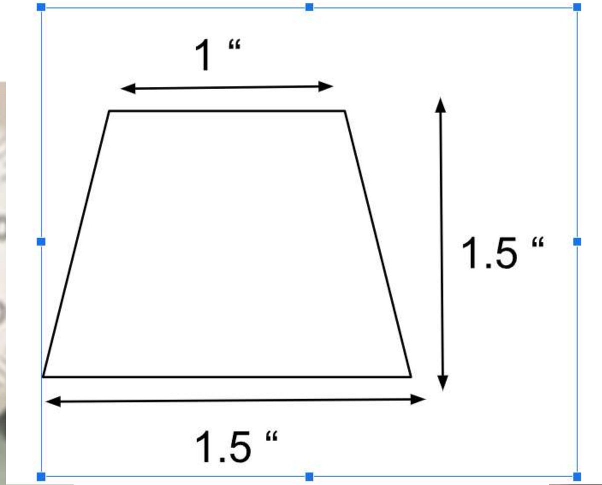
IPARCOS

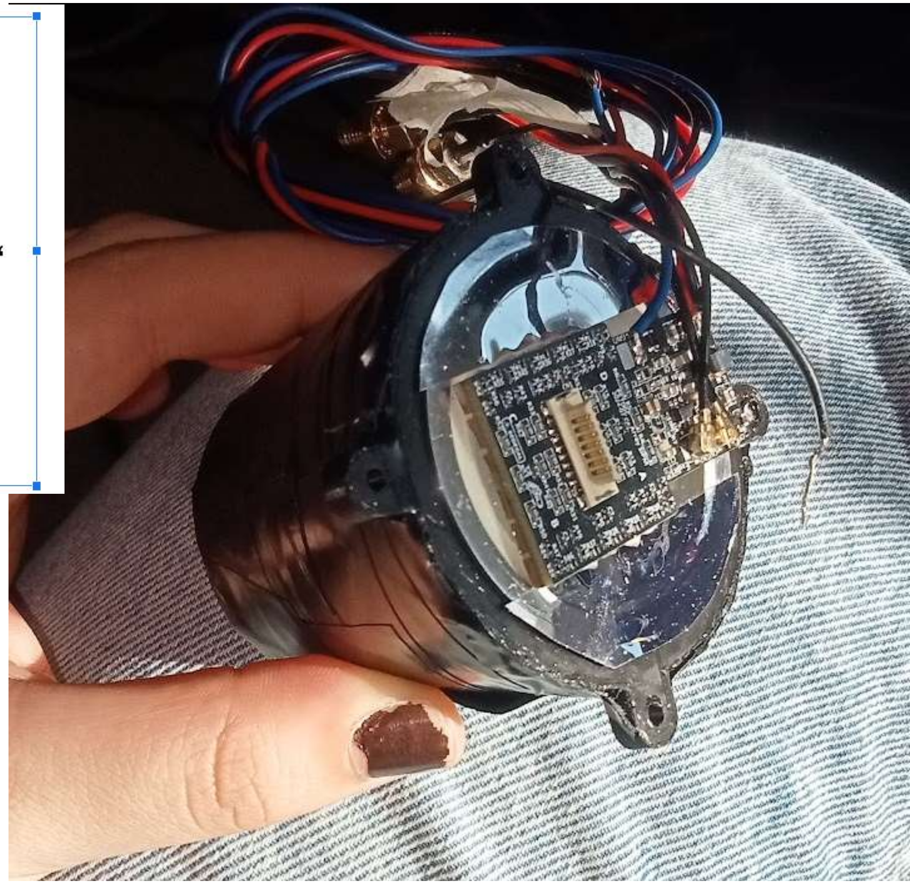
gfn UCM Grupo de Física Nuclear

Inexpensive Large Area photodetectors?

SiPM: They are small (3-6 mm), but our scintillators are large (50 mm diameter).

We need to build SiPM arrays, and connect the SiPM in parallel. The timing signal gets blurred. Read-out electronics gets complicated.



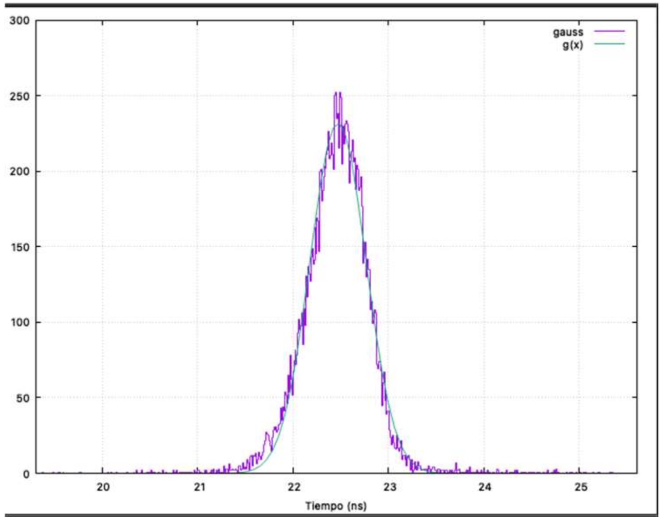


SiPMs, are they any good for timing?

Our SiPM+BrLa detector compared against our reference detector. CRT, FWHM, in ps

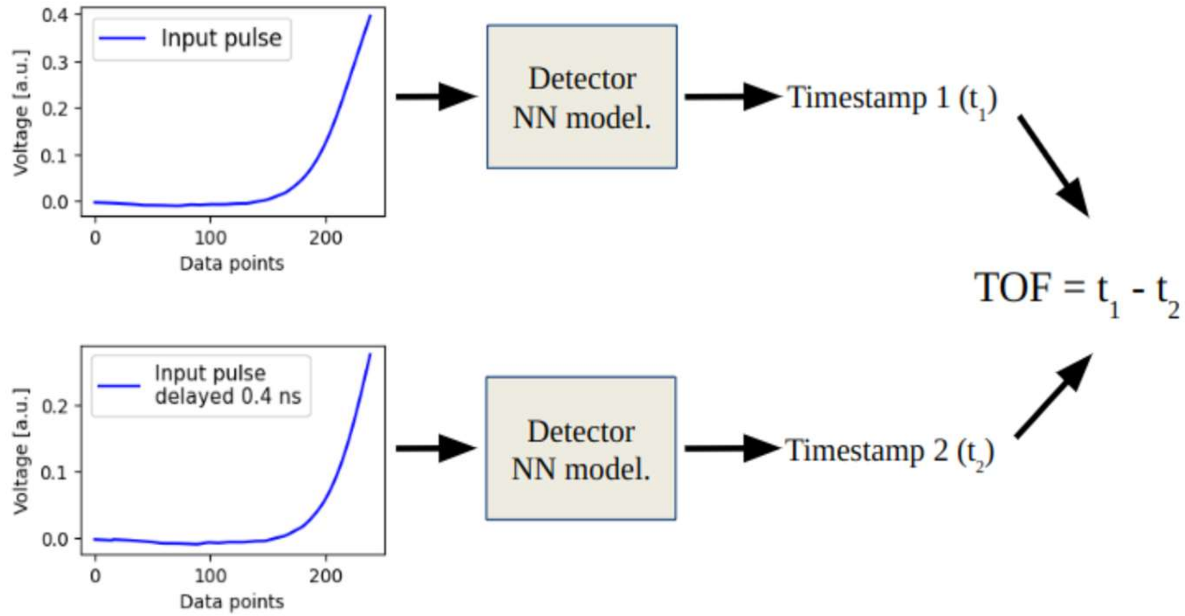
	^{22}Na	^{60}Co
SiPM+BrLa vs ref. PMT+BrLa	340	262
Ref PMT+BrLa vs ref PMT-BrLa	220	160

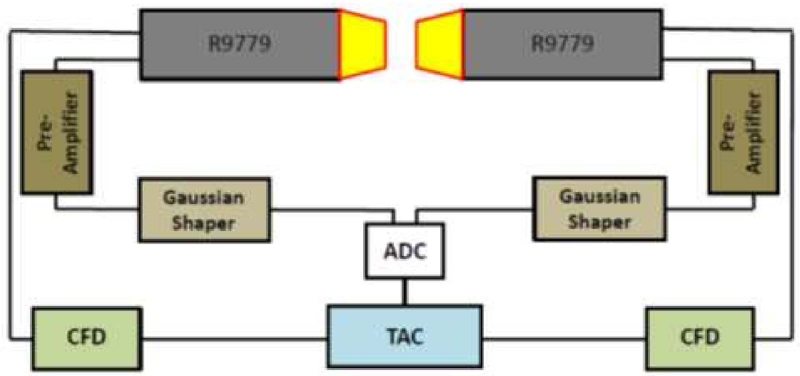
Very Preliminar…

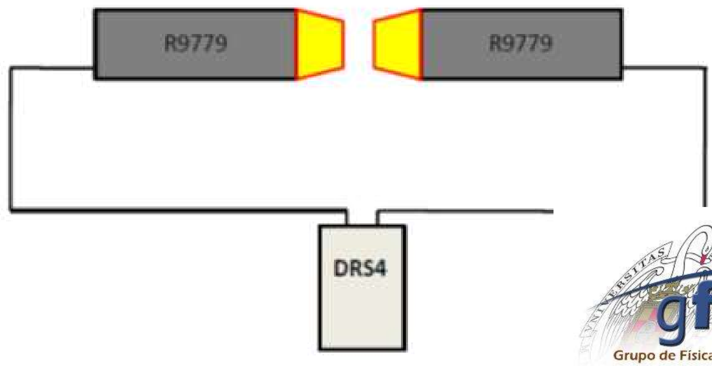


1.2 DL algorithms for timing, IP JL Herraiz.

Three layer fully-connected architecture with 32 neurons per layer ending in a fourth output single-neuron layer using a MSE loss. Benchmark against conventional optimized CFD +TAC which yields **156 ps** (Co-60, CRT, FWHM)







Position	Centroid	CRT
8cm - 2cm	0.174 ns	148 ps
5cm - 5cm	0.003 ns	146 ps
2cm - 8cm	-0.185 ns	152 ps

IPARCOS

gfn UCM Grupo de Física Nuclear

1.3 Inexpensive electronics DAQ for timing and Smart detectors, IP JM Udías.

		ARM family of MCU		
FAMILY	STM32	NXP	NXP	Raspberry Foundation
MCU MODEL	STM32H747	i.MX RT1060	i.MX RT1170	RP2040
# cores	2: M7+M4	1	2:M7+M4	1
freq.	480 MHz / 240 MHz	600 MHz	800 MHz / 400 MHz	133 MHz
Board example	Portenta-lite	Teensy 4.1	several vendors	Raspberry Pico Pi
eth	100 Mbit	100 Mbit	Gbit	10 Mbit
flowtensor ready	YES	YES	YES	?
Power (W)	2	0,4	0,5	0,2
Price per TIME+ENERGY channel at max rates (€)	75	50	60	20
Events per second to computer (8 bytes	1 Mcps	1Mcps	2,5 Mcps (3 MS/s ADCs)	100 kcps

Widely available, very low jitter (<20ps) comparators designed for LIDAR (3 €) aiming to autonomous cars. Very high quality ADCs (true 12 bits, up to 10 MS/s, <3€ per channel) also designed for automotive applications. Inexpensive MCUs (ST32, NXP, Raspberry Pi PICO).

Use MCUs in a **‘from analog detector to ethernet data stream’** DAQ. Conventional GI or GS for energy, TAC for time.

Take advantage of additional tensor cores in multi-core MCUs.

We demonstrated >1 Mcps per detector, **25 ps time jitter in the TAC, 4096 useable channels** in energy histograms. More tan 70 Mevents per second aggregated in a 40 cores PC, with our parallel, scalable software.

IPARCOS

gfn UCM Grupo de Física Nuclear

1.3 **Inexpensive** electronics DAQ for timing and Smart detectors, IP JM Udías.

		ARM family of MCU		
FAMILY	STM32	NXP	NXP	Raspberry Foundation
MCU MODEL	STM32H747	i.MX RT1060	i.MX RT1170	RP2040
# cores	2: M7+M4	1	2:M7+M4	1
freq.	480 MHz / 240 MHz	600 MHz	800 MHz / 400 MHz	133 MHz
Board example	Portenta-lite	Teensy 4.1	several vendors	Raspberry Pico Pi
eth	100 Mbit	100 Mbit	Gbit	10 Mbit
flowtensor ready	YES	YES	YES	?
Power (W)	2	0,4	0,5	0,2
Price per TIME+ENERGY channel at max rates (€)	75	50	60	20
Events per second to computer (8 bytes	1 Mcps	1Mcps	2,5 Mcps (3 MS/s ADCs)	100 kcps

Widely available, very low jitter (<20ps) comparators designed for LIDAR (3 €) aiming to autonomous cars. Very high quality ADCs (true 12 bits, up to 10 MS/s, <3€ per channel) also designed for automotive applications. Inexpensive MCUs (ST32, NXP, Raspberry Pi PICO).

Use MCUs in a **'from analog detector to ethernet data stream'** DAQ. Conventional GI or GS for energy, TAC for time.

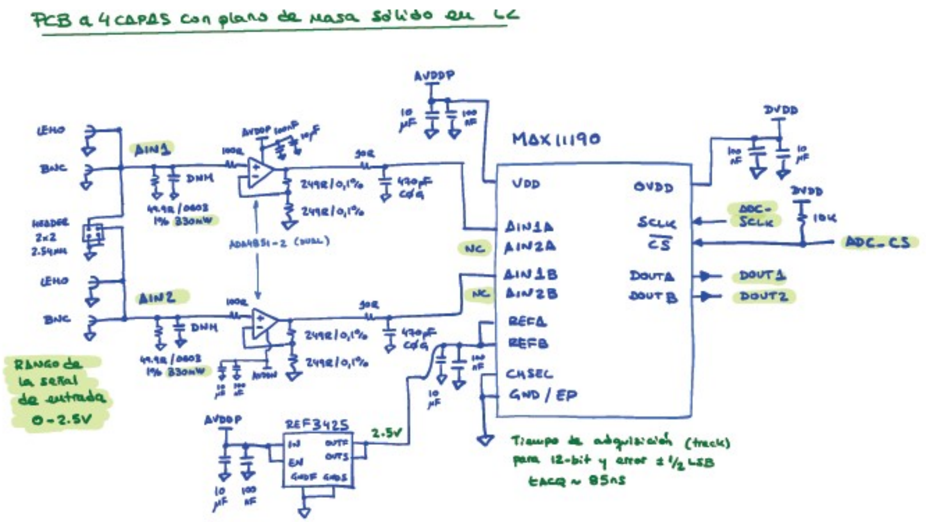
Take advantage of additional tensor cores in multi-core MCUs.

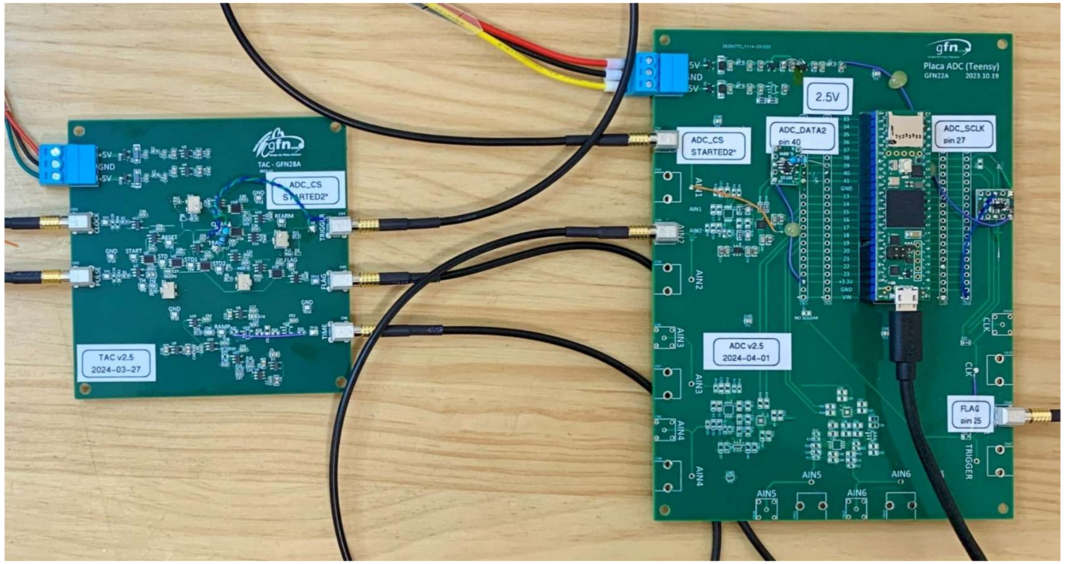
We demonstrated >1 Mcps per detector, **25 ps time jitter in the TAC, 4096 useable channels** in energy histograms. More tan 70 Mevents per second aggregated in a 40 cores PC, with our parallel, scalable software.

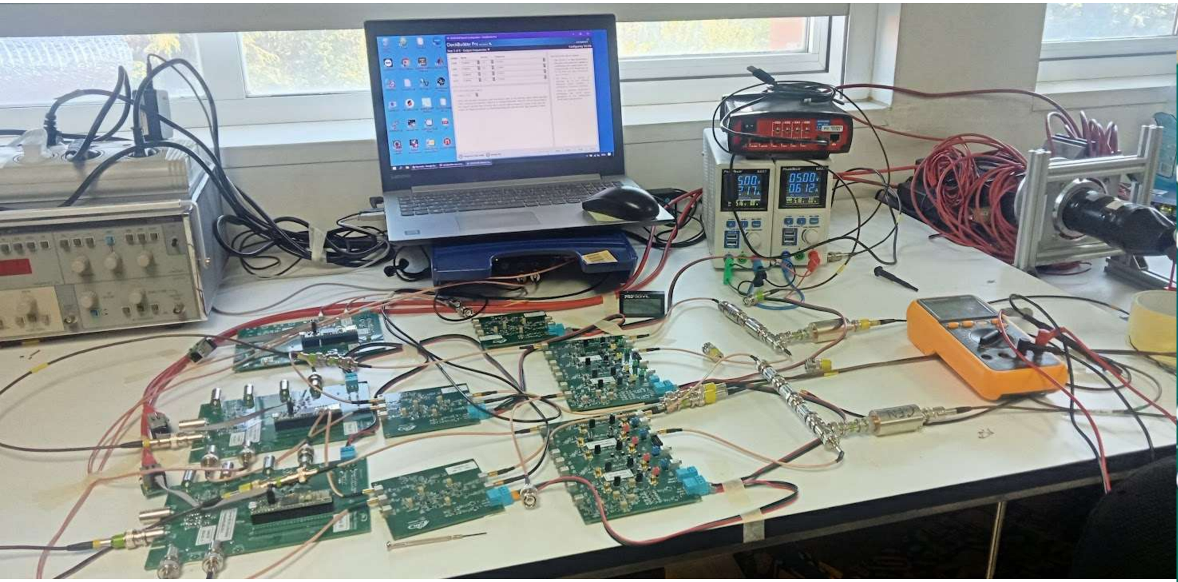
IPARCOS

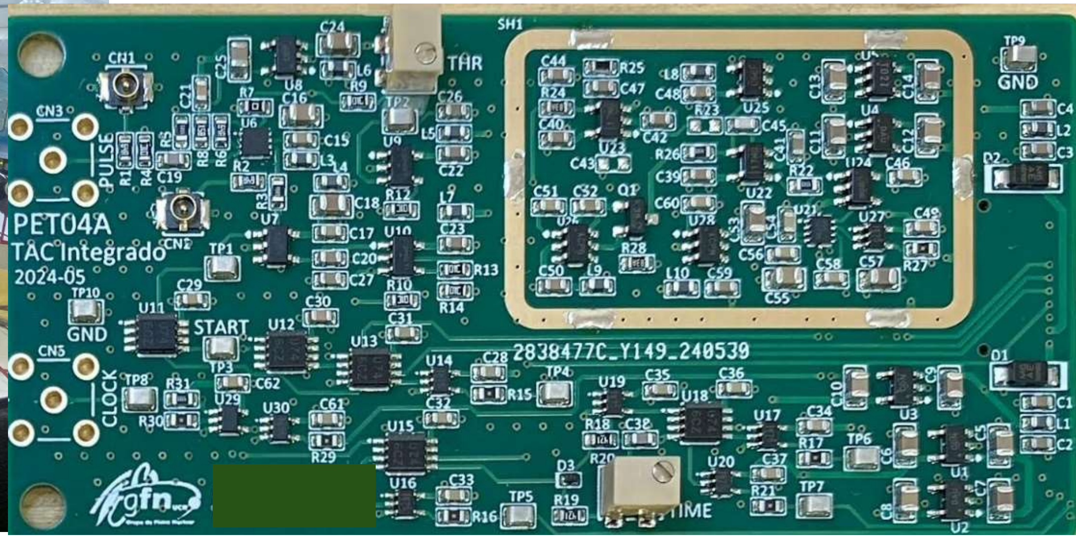
DAQ: Under 100 euros per Energy+Timing detector+300 euros of SiPM. Tenfold Reduction in Price compared to our current PMT+comercial (CAEN, PIXIE, ...) DAQ

gfn UCM Grupo de Física Nuclear


PCB a 4 CAPAS con plano de masa sólido en LC
MAX11190
AVDDP
DVDD
AIN1
AIN2
LEMO
BNC
HEADER 2x2 2.54mm
ADA4851-2 (DUAL)
VDD
OVDD
AIN1A
AIN2A
AIN1B
AIN2B
REFA
REFB
CHSEL
GND / EP
SCLK
CS
DOUTA
DOUTB
ADC-SCLK
ADC-CS
DOUT1
DOUT2
NC
REF3425
2.5V
RANGO de la señal de entrada 0-2.5V
Tiempo de adquisición (track) para 12-bit y error ± 1/2 LSB
tACQ ~ 85ns


TAC v2.5
2024-03-27
ADC v2.5
2024-04-01
Placa ADC (Teensy)
2.5V
ADC_CS
STARTED2*
ADC_DATA2
ADC_SCLK
pin 27
FLAG
pin 25




PET04A
TAC Integrado
2024-05
THR
GND
PULSE
START
CLOCK
TIME
2838477C_Y149_240539

Summary

LA1 related to Nuclear Physics, at IPARCOS, has developed activities in fast timing and applications:

- 1.1 Working on a SiPM alternative to PMTs. Much cheaper and easy to handle. Not yet as good timing resolution as PMTs, but improving steadily.
- 1.2 DL algorithms have been developed which improve timing resolution.
- 1.3 SiPM combined with a classical concept of electronics DAQ, but based on common and inexpensive mass produced electronic components, combined with modern MCUs for data processing, made it possible to develop a inexpensive DAQ+photodetector system, extremely flexible and modular, able to replace our PMT+branded DAQ, at one tenth of the cost.

GOBIERNO DE ESPAÑA
Financiado por la Unión Europea
NextGenerationEU