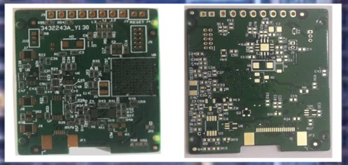
The Evolution of ArduSiPM technology : A Compact, Versatile, and Cost-effective Detector Platform for Radiation and Photon Flux Measurements


2014


2021

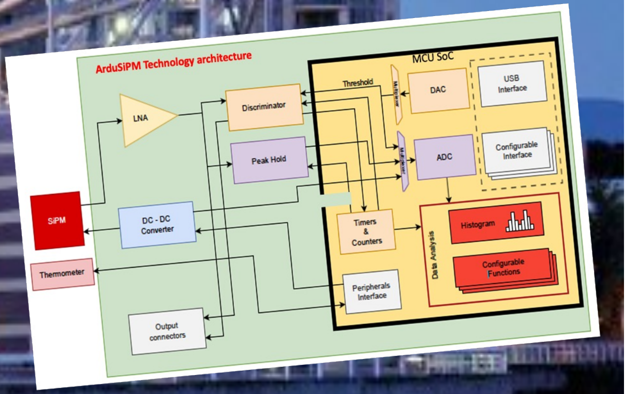

2023


2026

Valerio Bocci
(INFN Roma Sapienza)

V.Bocci[1], B. Ali[3][5], D. Badoni[2],M. Casolino[2], G. Chiodi[1], F. Iacoangeli[1], D. Kubler[3] , L. Marcelli[2], G. Rebustini[2][4], E. Reali[4], L. Recchia[1], M. Salvato[4]

(1)INFN Roma Sapienza
(2)INFN Roma2 Tor Vergata
(3)Microchip Technology
(4)Tor Vergata University
(5)Sapienza University



2023 IEEE
Nuclear Science Symposium, Medical Imaging Conference, and Room Temperature Semiconductor Detector Conference

ArduSiPM Technology

In electronics, finding technologies with decade-long growth potential is like seeking a beacon in the dark. With ever-present obsolescence risks, when a path shows promise, why not pursue it determinedly?

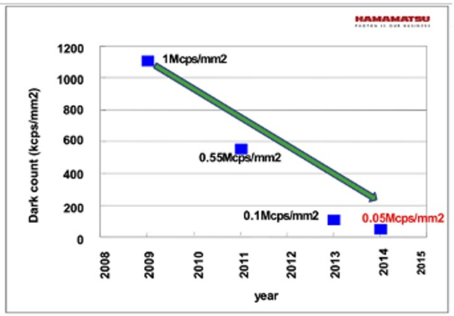
The ArduSiPM idea 2012-2014 IEEE NSS/MIC Seattle

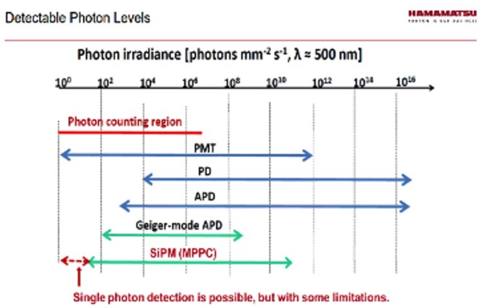
In the last years we have seen a fast increasing and positive trend of SiPMs performances

MPPC Performance Has Been Remarkably Improved — HAMAMATSU

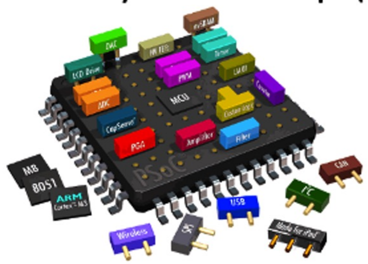
- ✓ Dark Count
- ✓ Afterpulse
- ✓ Crosstalk
- ✓ PDE (Photon Detection Efficiency)
- ✓ Timing Resolution
- ✓ Larger Area (with Assembly Technology)

Dark Counts reduction





An even greater increase is that shown by the features and peripherals available in system-on-chip (SoC)



- In early 2000s Soc featured cheaper and smaller mobile phones
- In 2001, it was the release of the iPod that was based on the twin-core ARM SoC
- The emergence of IoT further boost the evolution of SoC

SoC integrate more and more functions into a single chip!

- general-purpose microcontroller unit (MCU)
- numerous high-performance peripherals (amplifiers, ADCs, DACs, counters)
- non-volatile memory
- Network interfaces

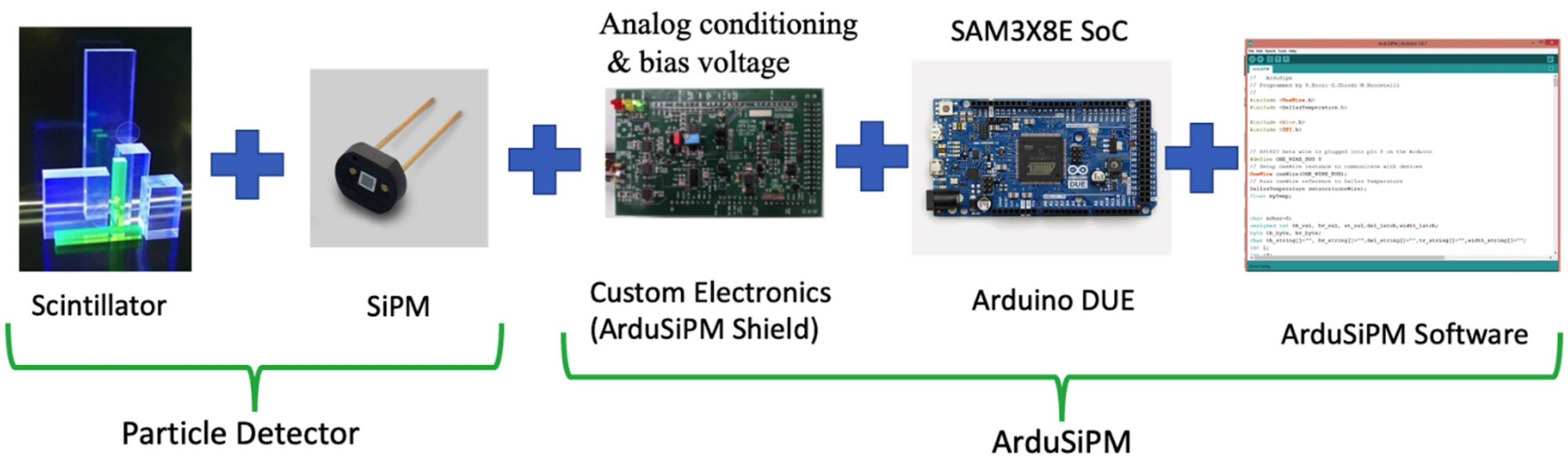
The ArduSiPM idea (Gen1)

In 2014 we have created and published a new kind of detector using the new generation of **SiPM** and System on Chip (**SoC**).

> <u>V. Bocci,</u> G. Chiodi, F. Iacoangeli, M. Nuccetelli and L. Recchia, **"The ArduSiPM a compact trasportable Software/Hardware Data Acquisition system for SiPM detector,"** *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)*, 2014, pp. 1-5, doi: 10.1109/NSSMIC.2014.7431252.

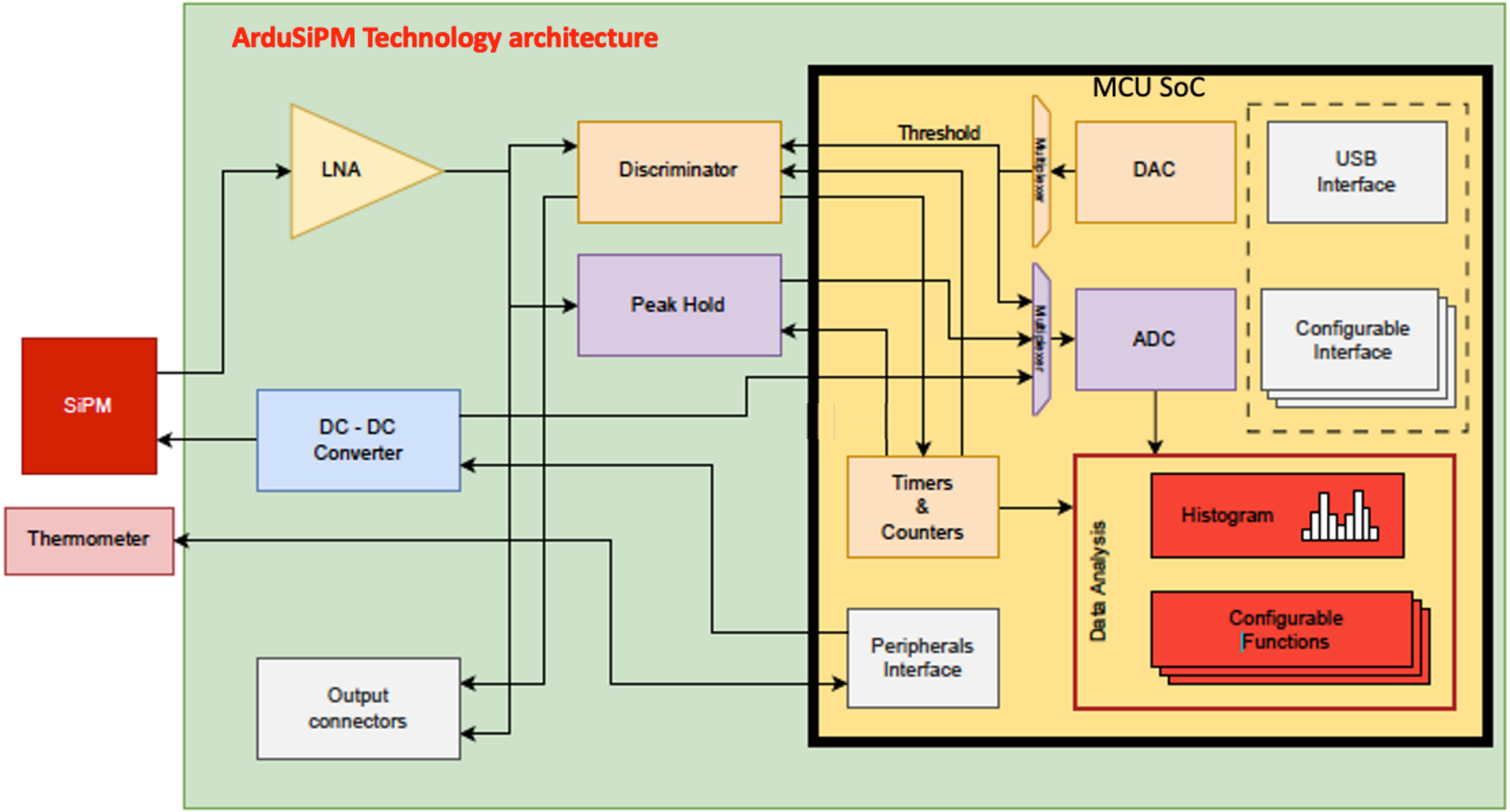
The ArduSiPM technology joins the innovation of the system on a chip (SoC) and the simultaneous improvement of Silicon photomultiplier detectors in a new generation of all-in-one scintillation detectors conceived from INFN Roma in 2014.

The basic idea is to minimize the use of COTS components (typically fast analog) and develop a large part of the peripherals inside the SoC, thus obtaining compact electronics without using ASICs and an external data acquisition system.



Block diagram of the ArduSiPM technology

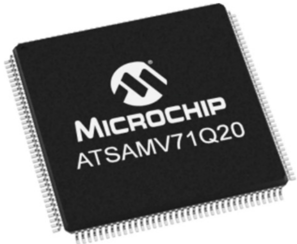
The guiding principle is that all non-strictly analog functions, such as ADC, DAC, counters, and edge computing data transmission, are entrusted to the SOC.



The ArduSiPM architecture can scale with SoC Growth

2014

2019



SAM3X8E

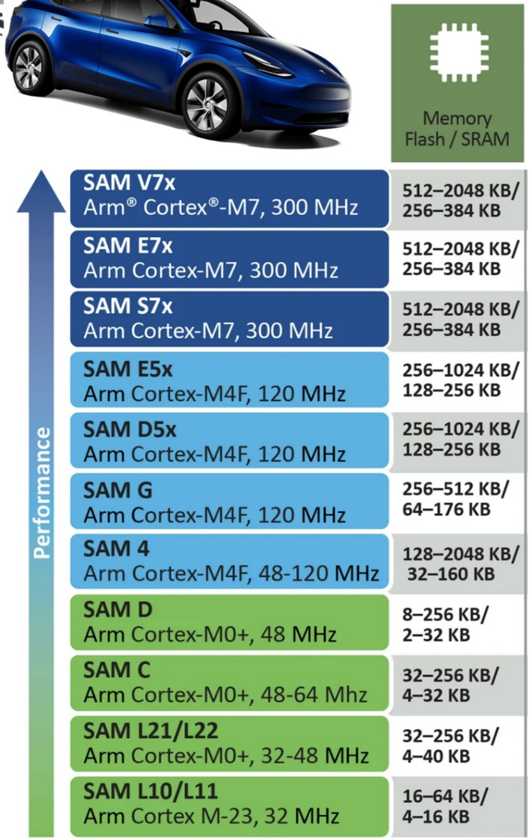
- 32-bit ARM ® Cortex®-M3 RISC
- 84 MHZ
- 12 bits 1 Msamples/s ADC
- SRAM 64 + 32 Kbytes
- Flash 2 x 256 Kbytes

SAMV71

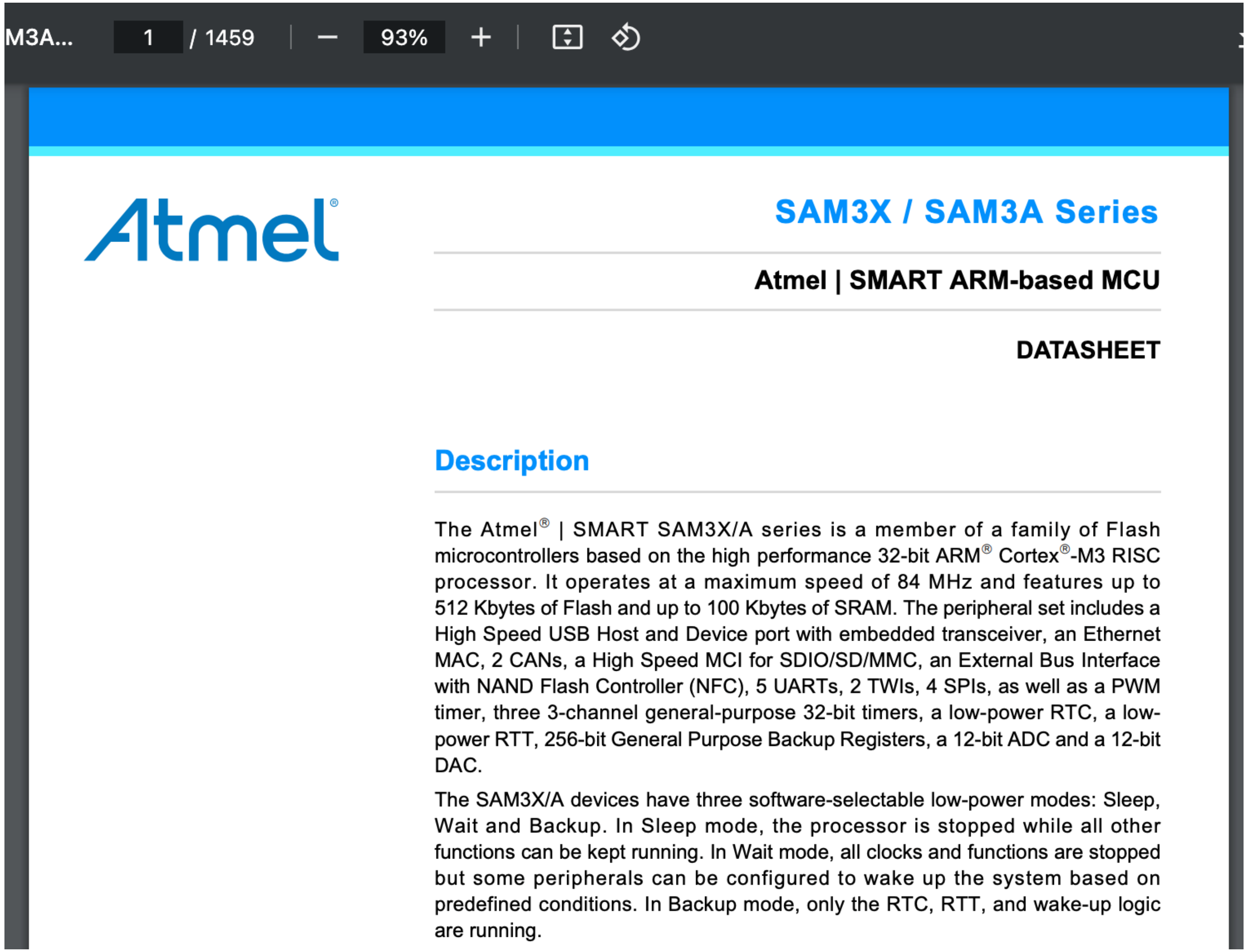
- 32-bit ARM® Cortex®-M7 RISC
- 300 MHZ
- 12 bits 2 Msamples/s ADC analog offset compensation

- 12 bits DAC with 0 offset.
- Multi port SRAM 384 Kbytes
- Flash 2048 Kbytes
- Cache 16/16 Kbytes
- Two Analog Front-End Controllers (AFEC), allowing dual sample-and-hold at up to 1.7 Msps. Offset and gain error correction feature.

- Better time resolution.
- More memory –> RT histogram



SAM3X8E



M3A... 1 / 1459 93%

Atmel

SAM3X / SAM3A Series

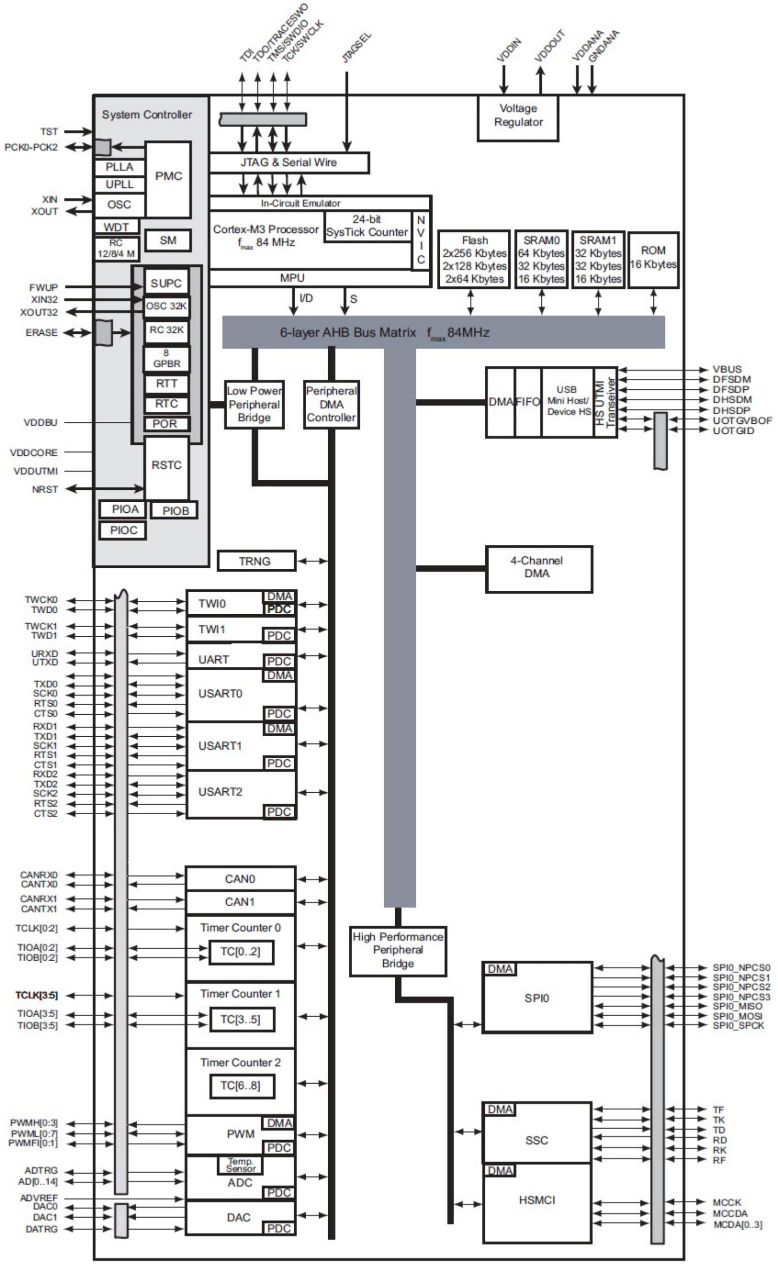
Atmel | SMART ARM-based MCU

DATASHEET

Description

The Atmel® | SMART SAM3X/A series is a member of a family of Flash microcontrollers based on the high performance 32-bit ARM® Cortex®-M3 RISC processor. It operates at a maximum speed of 84 MHz and features up to 512 Kbytes of Flash and up to 100 Kbytes of SRAM. The peripheral set includes a High Speed USB Host and Device port with embedded transceiver, an Ethernet MAC, 2 CANs, a High Speed MCI for SDIO/SD/MMC, an External Bus Interface with NAND Flash Controller (NFC), 5 UARTs, 2 TWIs, 4 SPIs, as well as a PWM timer, three 3-channel general-purpose 32-bit timers, a low-power RTC, a low-power RTT, 256-bit General Purpose Backup Registers, a 12-bit ADC and a 12-bit DAC.

The SAM3X/A devices have three software-selectable low-power modes: Sleep, Wait and Backup. In Sleep mode, the processor is stopped while all other functions can be kept running. In Wait mode, all clocks and functions are stopped but some peripherals can be configured to wake up the system based on predefined conditions. In Backup mode, only the RTC, RTT, and wake-up logic are running.



SAMV71

1 / 1960 100%

32-bit Arm Cortex-M7 MCUs with FPU, Audio and Graphics Interfaces, High-Speed USB, Ethernet, and Advanced Analog

SAM E70/S70/V70/V71

MICROCHIP

Features

Core

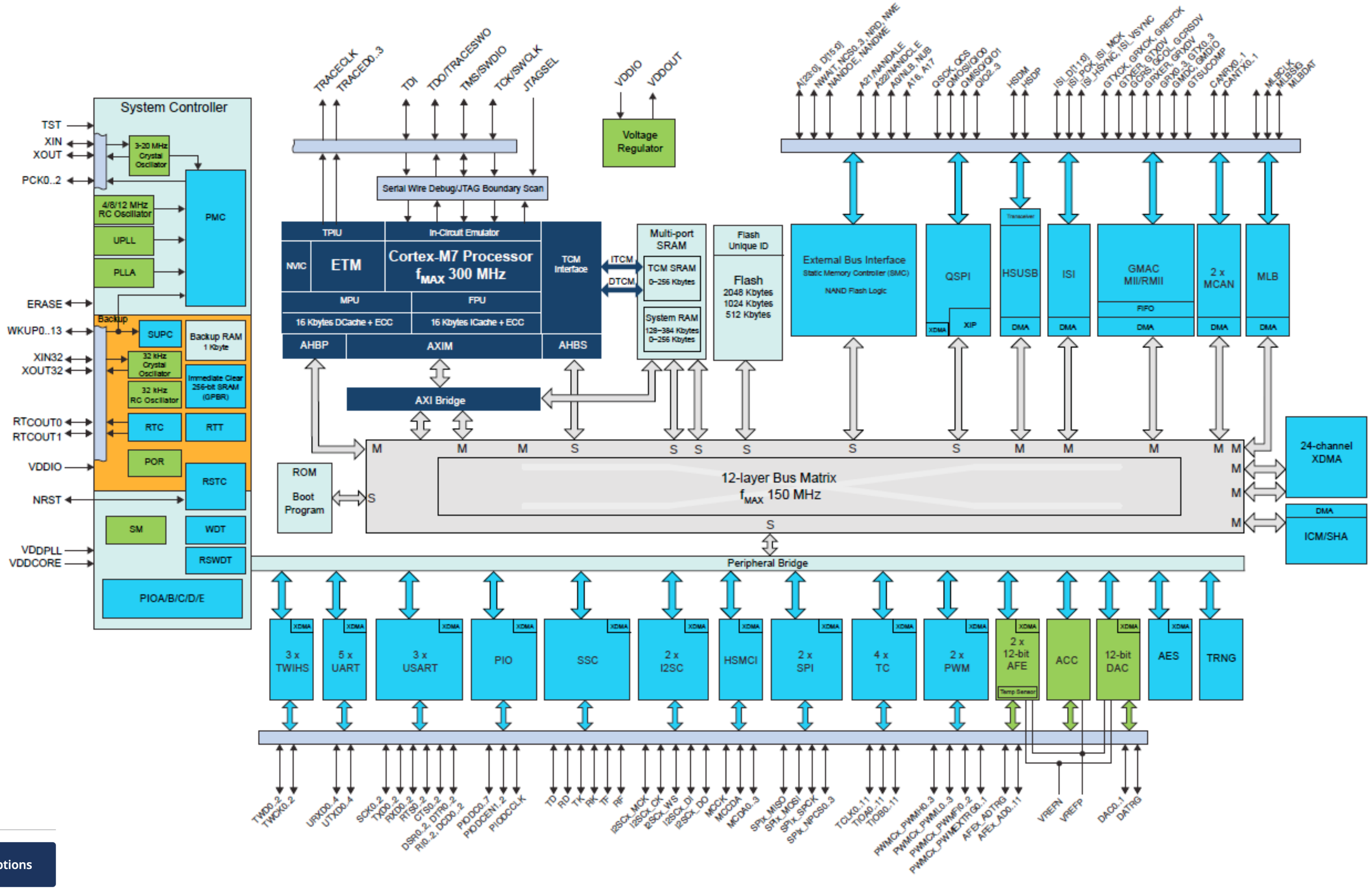
- Arm® Cortex®-M7 running at up to 300 MHz
- 16 Kbytes of I-Cache and 16 Kbytes of D-Cache with Error Code Correction (ECC)
- Single-precision and double-precision HW Floating Point Unit (FPU)
- Memory Protection Unit (MPU) with 16 zones
- DSP Instructions, Thumb®-2 Instruction Set
- Embedded Trace Module (ETM) with instruction trace stream, including Trace Port Interface Unit (TPIU)

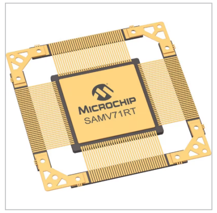
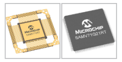
Memories

- Up to 2048 Kbytes embedded Flash with unique identifier and user signature for user-defined data
- Up to 384 Kbytes embedded Multi-port SRAM
- Tightly Coupled Memory (TCM)
- 16 Kbytes ROM with embedded Bootloader routines (UART0, USB) and IAP routines
- 16-bit Static Memory Controller (SMC) with support for SRAM, PSRAM, LCD module, NOR and NAND Flash with on-the-fly scrambling

System

- Embedded voltage regulator for single-supply operation



SAMV71Q21RT ☆

Radiation Tolerant Cortex M7 MCU

Status: In Production.

Documentation

SAMV71Q21RT Radiation-Tolerant 32-bit Arm® Cortex®-M7 Microcontroller: PDF

Purchase Options

The SAMV71Q21RT is the radiation tolerant version of the popular Microchip SAMV71Q21 based on the high-performance 32-bit ARM Cortex-M7 processor with a Double Precision Floating Point Unit (FPU). These devices operate at up to 300MHz and feature up to 2048 Kbytes of Flash, and up to 384 Kbytes of multi-port SRAM which is configurable Instruction and Data Tightly Couple Memories to leverage the advanced DSP capabilities of the core.

Cosmo ArduSiPM (GEN2)

ArduSIPM analog + SAMV71

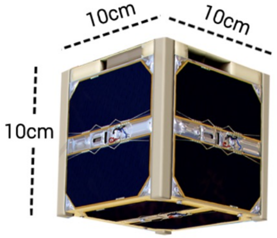
INFN

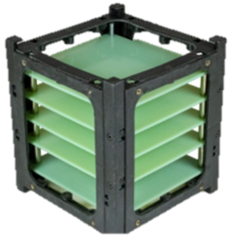
Istituto Nazionale di Fisica Nucleare

MICROCHIP

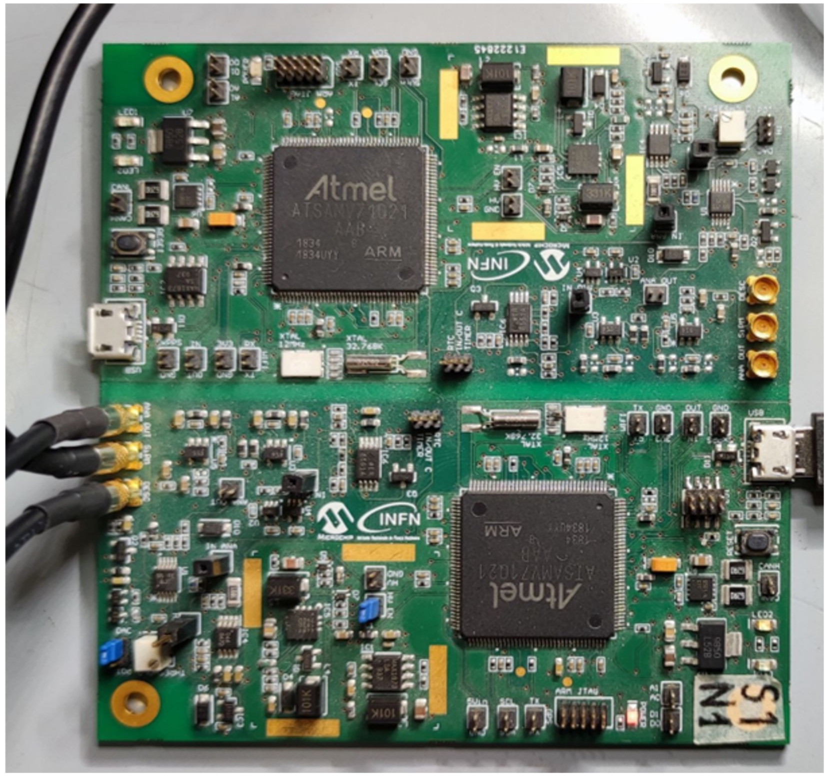
INFN-Microchip Technology

Collaboration Agreement ref. TTD 19RM1 020





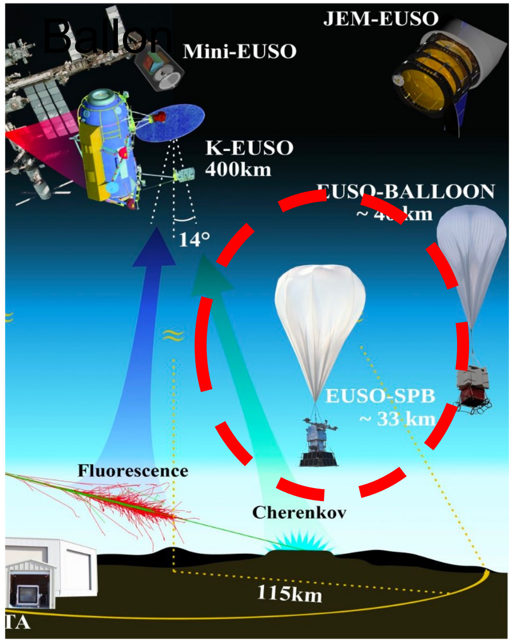
9.6 cm



- 0.1 CubeSat Unit occupancy
- 2 channels
- Weigh 42 grams
- Low Power consumption <1Wh
- Rad-tolerant version of MCU availability on market

Cubesat LEO or MEO

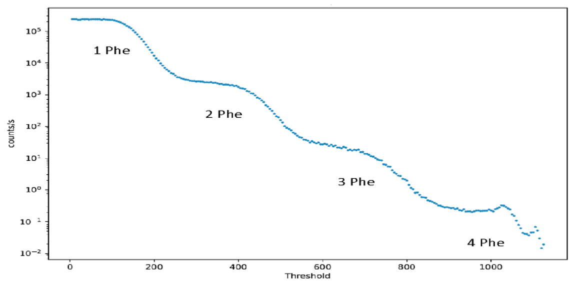
Euso SPB2 33 Km Ballon

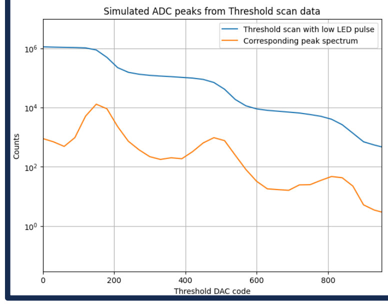


Some measurements with GEN2 (Cosmo ArduSiPM)

(see also Poster Session N-01-173)

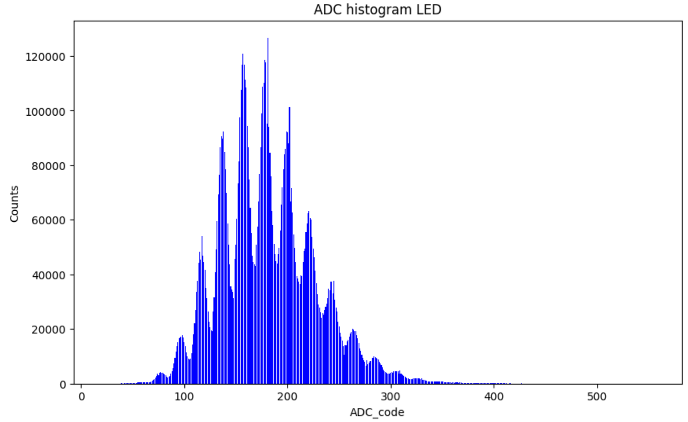
Threshold Scan Plot



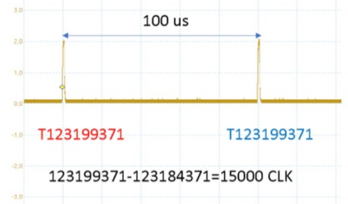


Threshold scan and its derivative (comparable to ADC spectra).

Pulsed light (centered about 10 Phe)

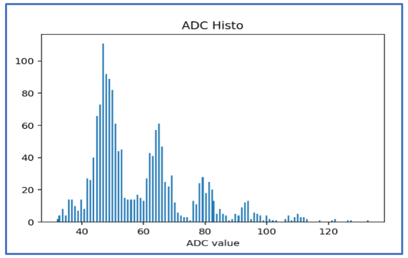


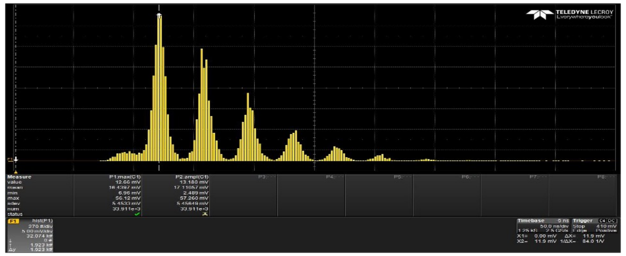
Maximum CosmoArduSiPM time resolution:
TDC_CLK= CPU_CLK/2 = 150 MHz **6.6 ns**



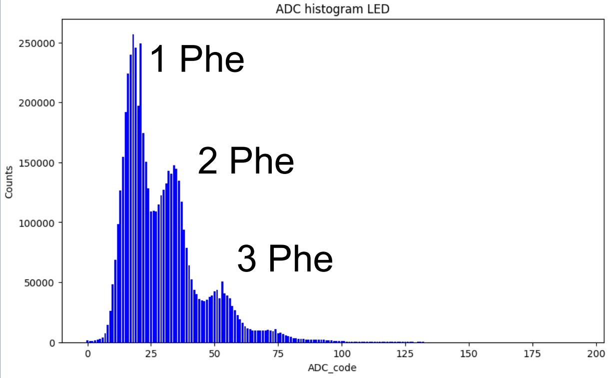
The GEN2 can measure time with a precision of 6.6 ns. Furthermore, it can be synchronized with a universal reference, such as the PPS output from a GPS system or an atomic clock.

Photons spectra
Cosmo ArduSiPM vs 12 bits Le Croy Scope

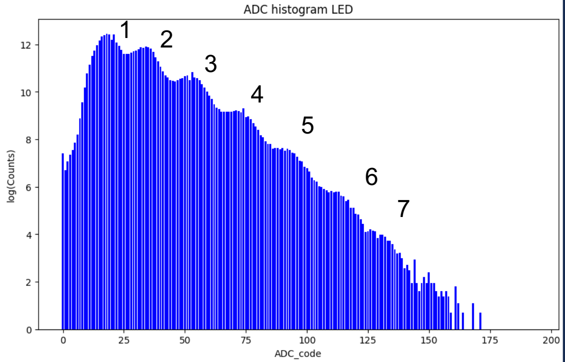




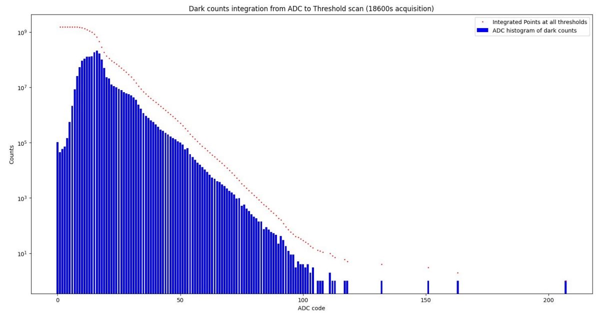
Dark noise + pulsed light >2 phe



Lin scale



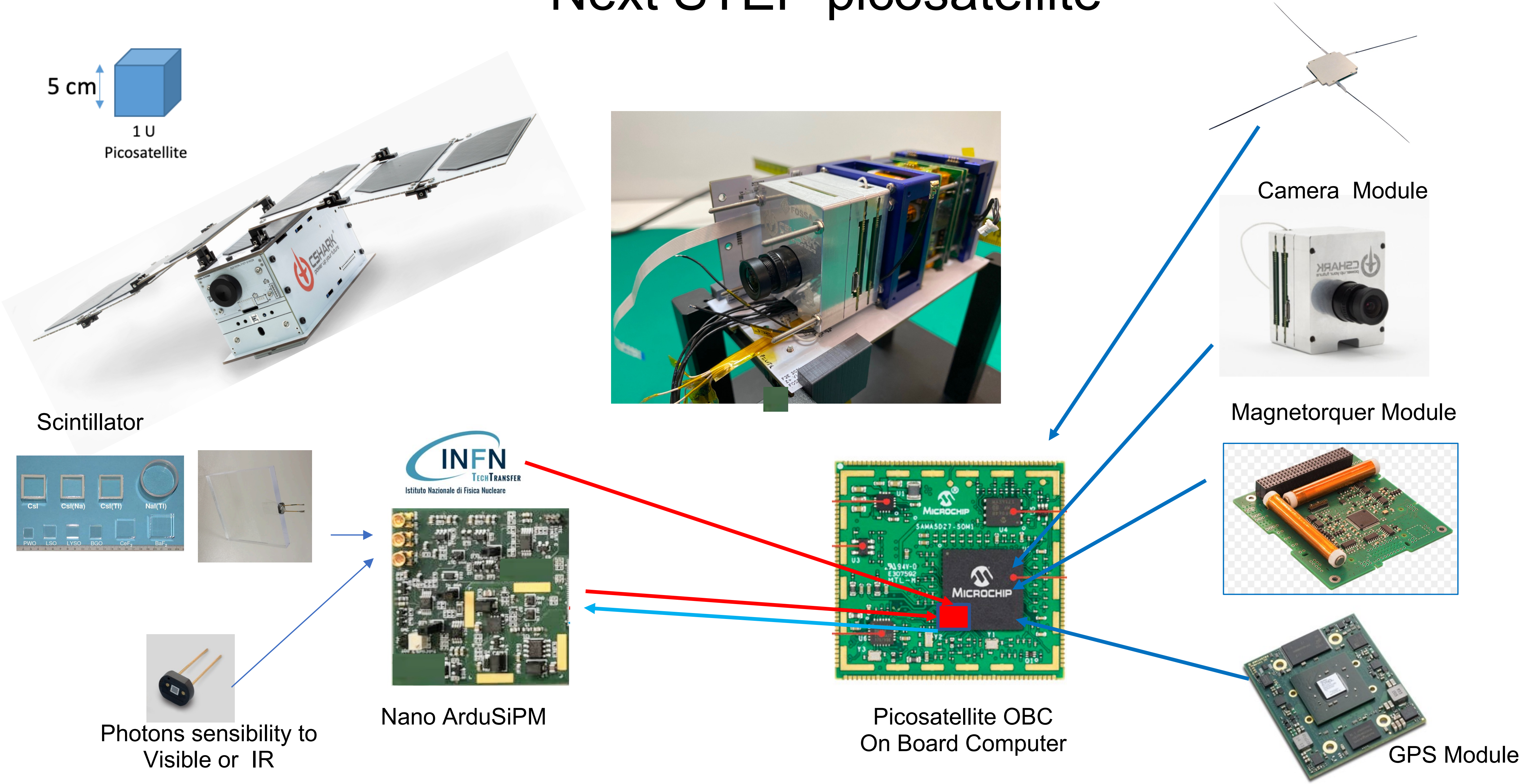
Log scale



ADC spectra the integral show to be equivalent to the scan plot

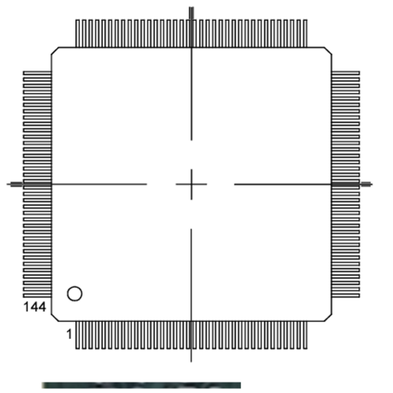
Credits to the graduating students, Simone Mariottini and Lorenza Masi

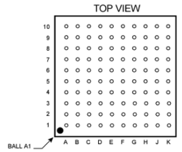
Next STEP picosatellite



Nano ArduSiPM Gen3 (2023)

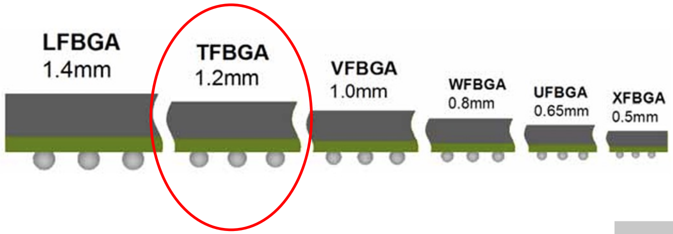
22 mm

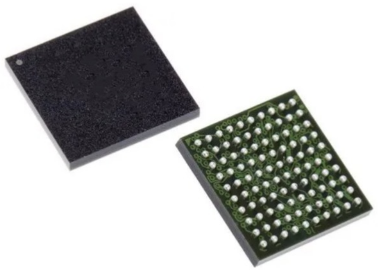


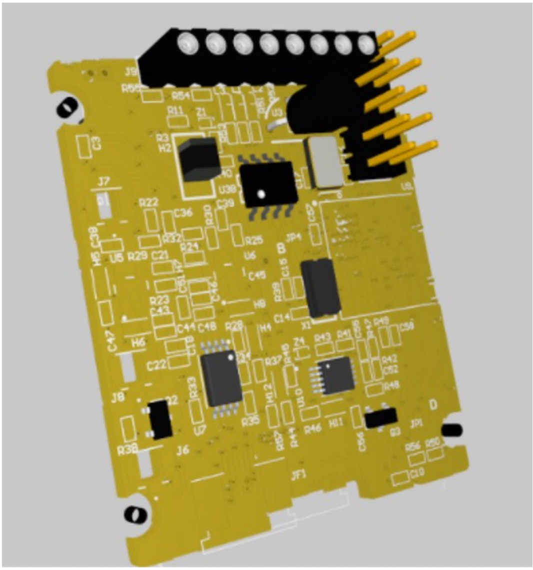


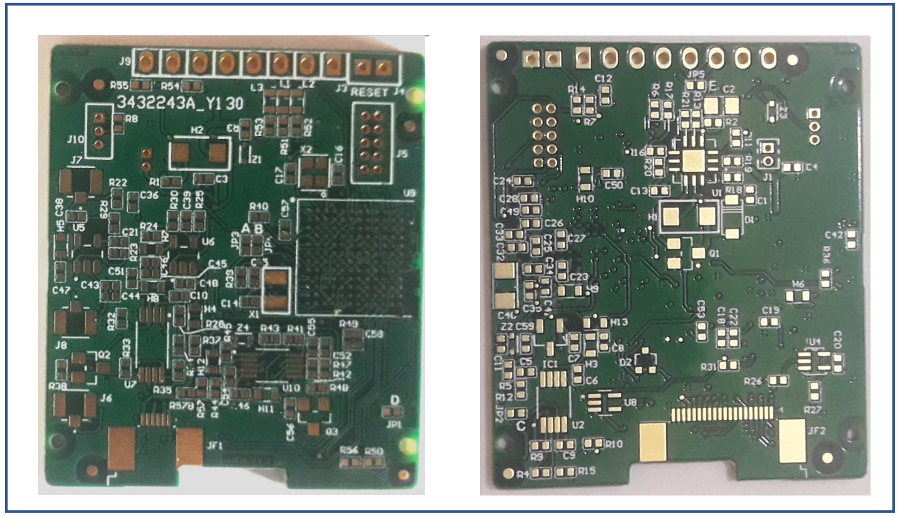
9 mm

TFBGA (**Thin Fine-Pitch Ball Grid Array**)









50 mm

ArduSiPM Technology Evolution

(Strong Performance Boost and Remarkable Density Enhancements with Lighter Channel Weight)

Reduction in Size and Weight
of the Individual Channel"

GEN1

1 channel
ArduSiPM (TT 2014)

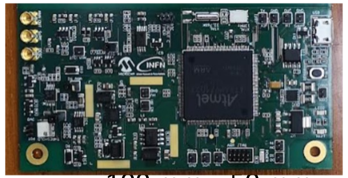
2 x 100 mm x 50 mm

2 plane x 55 cm^2
100g/ch

23 ns TDC time resolution
1 MHz ADC
Minimum adjustable digital threshold 3 photons

GEN2

1 channel
Half Cosmo
ArduSiPM (2021)



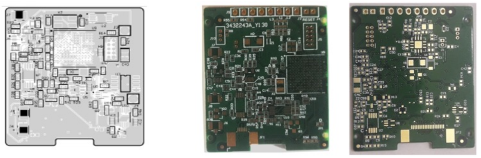
100 mm x 50 mm

50 cm^2
21 g/ch

6.6 ns TDC time resolution
2 MHz ADC
Minimum adjustable digital threshold
0.1 photons

GEN3

1 channel
Nano ArduSiPM
(2023)

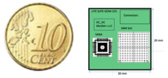


50 mm x 50 mm

25 cm^2
10 g/ch

GEN4

2 channel
LITE SPLD (2026)



20 mm x 20 mm

2 cm^2/ch
3 g/ch

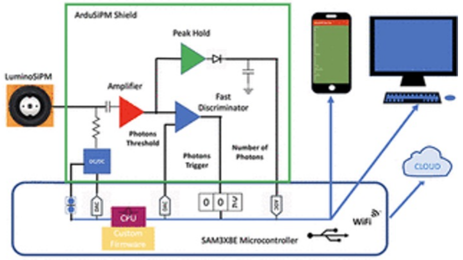
Valerio Bocci INFN Roma Vancouver 2023 NSS-MIC-RTSD

The detectors obtained are compact and lightweight and can be used in various fields.

Application have been identified, leaving the use open within the HEP community

Scintillation particle detector Application in cubesats or picosatellites. LEO orbit. Monitoring of radiation in picosatellites and in constellations of picosatellites (Space Weather).

We've developed photon flux measurements for bioluminescence, leading to portable instruments for fieldwork in collaboration with Analytical Chemistry Department at the University of Bologna and CNR IMM.



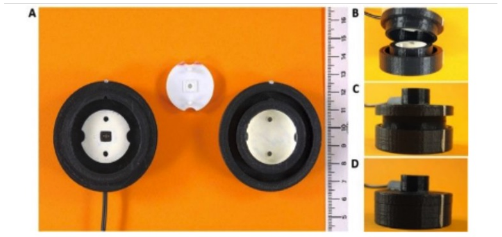


Figure S1. (A) The three components of LuminoSiPM dark box. (B) The assembly of sample holder in the dark box. (C) Mechanical protrusions and complementary alignment holes guarantee light tightness. (D) The box closed and ready for measurement.

In particle physics, these devices are perfect for triggering in test beams. They can excel in experiments with distributed detector systems. In our all-in-one detector, SiPMs connect directly to the electronics, eliminating the need for long analog cables. In this scenario, multichannel chips don't offer an apparent advantage over our digital-only wiring setup.

Mocris particle detector Instrumentation

Figura 2.6. Foto del carico del pallone aerostatico per l'esperimento MoCRiS, si distinguono i due ArduSiPM e M5Stack.

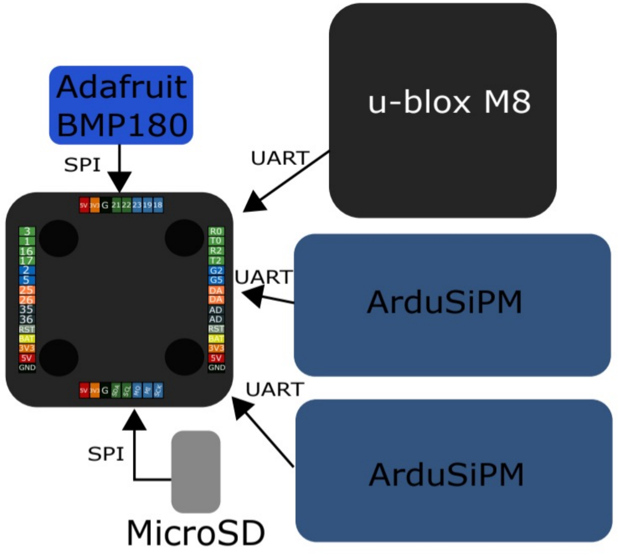
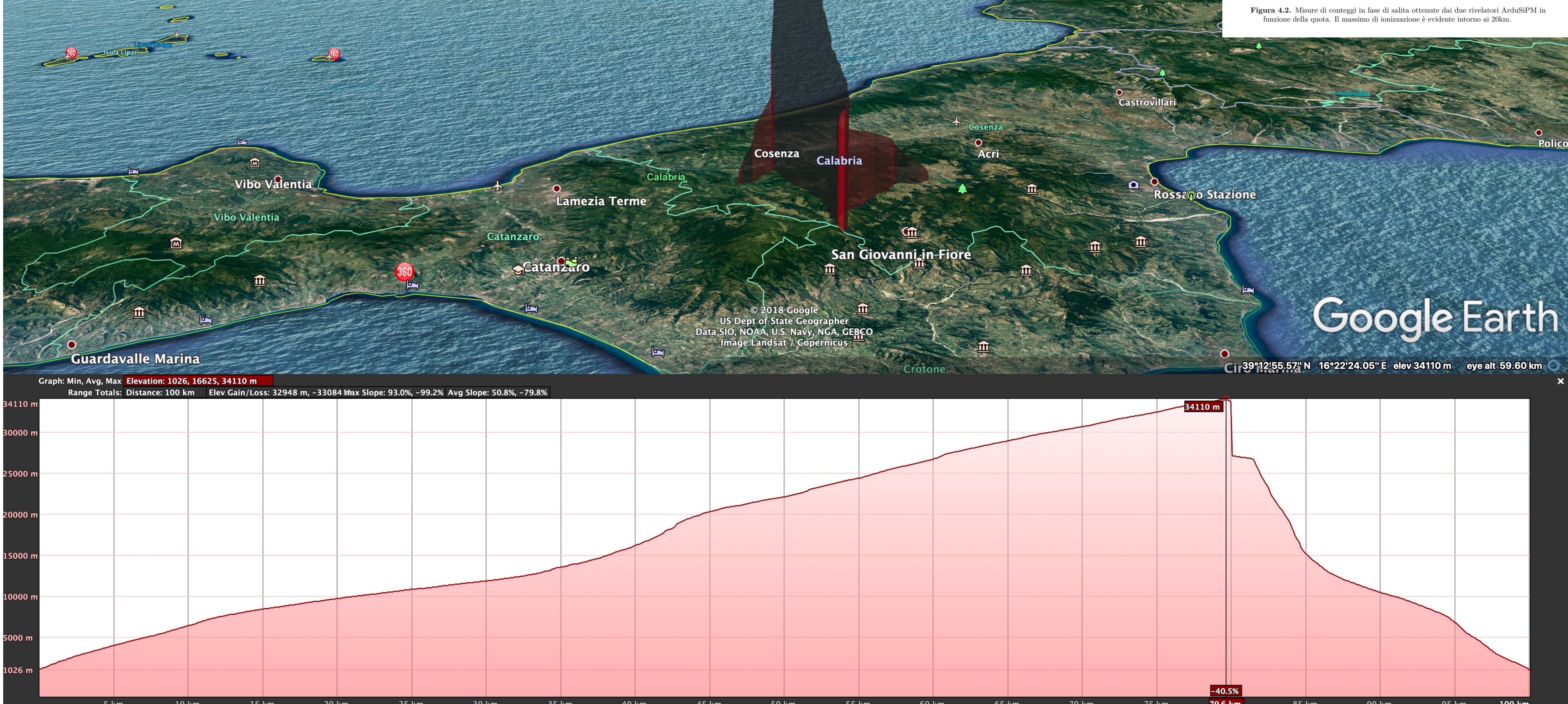


Figura 2.5. Diagramma a blocchi dell'apparato elettronico per la misura del flusso di raggi cosmici dell'esperimento MoCRiS. Sono riportati i tipi di protocolli seriali utilizzati per comunicare da ciascun elemento del sistema.



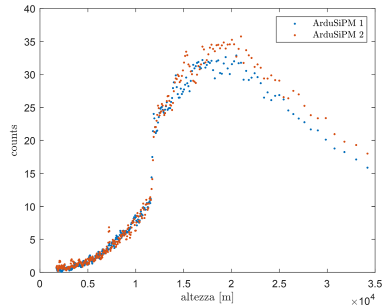
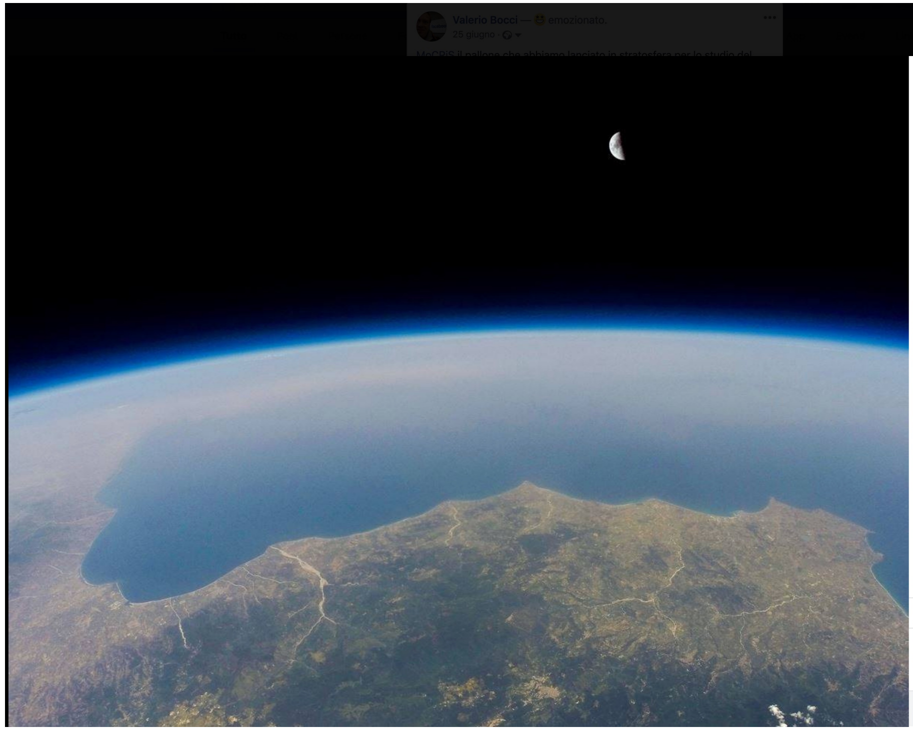


Figura 4.2. Misure di conteggi in fase di salita ottenute dai due rivelatori ArduSiPM in funzione della quota. Il massimo di ionizzazione è evidente intorno ai 20km.



Earth Science Picture of the Day
· 25 giugno ·

Today's Earth Science Picture of the Day
Moon Imaged from the MoCRiS Payload
http://bit.ly/EPOD_FQKZ
Image Creators: Antonino Brosio and the MoCRiS Team
Summary Author: Antonino Brosio
Shown above is the waxing crescent Moon above the Italian regions of Calabria, Puglia and Basilicata. The photo was taken from a height of 20 miles (32 km) from the Measurement of Cosmic Rays in Stratosphere (MoCRiS) Balloon. This is a project in collaboration between OCRA (Outreach Cosmic Ray Activities) of National Institute for Nuclear Physics (INFN) and Liceo Scientifico Cariati.
The MoCRiS payload, consisting of two special detectors, will facilitate research on variations of the flow of cosmic rays in the Earth's atmosphere, portrayed on this image as the blue/violet veneer atop the Earth. Launch was on June 8 (2019), from near Sila Mountain in Calabria, Italy.
Sila Mountain, Italy Coordinates: 39.366667, 16.5

View today's Earth Science Picture of the Day at
https://epod.usra.edu/
To contribute your images go to
https://epod.usra.edu/blog/contribute-to-epod.html
Instagram @earthpicoftheday
Twitter @EarthPic

161 Commenti: 2 Condivisioni: 64

Mi piace Commenta Condividi

Meno recenti

Richard Scudder Great shot. Really shows how thin the atmosphere is.
Mi piace · Rispondi · 15 s

Scrivi un commento...

EARTH SCIENCE PICTURE OF THE DAY
A SERVICE OF UNIVERSITIES SPACE RESEARCH ASSOCIATION

Moon Imaged from the MoCRiS Payload

June 25, 2019

« Previous | Today's | Next »

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Sila Mountain, Italy Coordinates: 39.366667, 16.5

Related Links
High Altitude Balloon Flight Over Mt. Olympus, Greece

Student Links
How to detect cosmic rays
Composition of Earth's Atmosphere

Earth Observatory
Probing the Electric Space Around Earth

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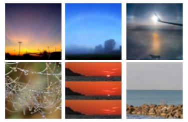
Related EPODs



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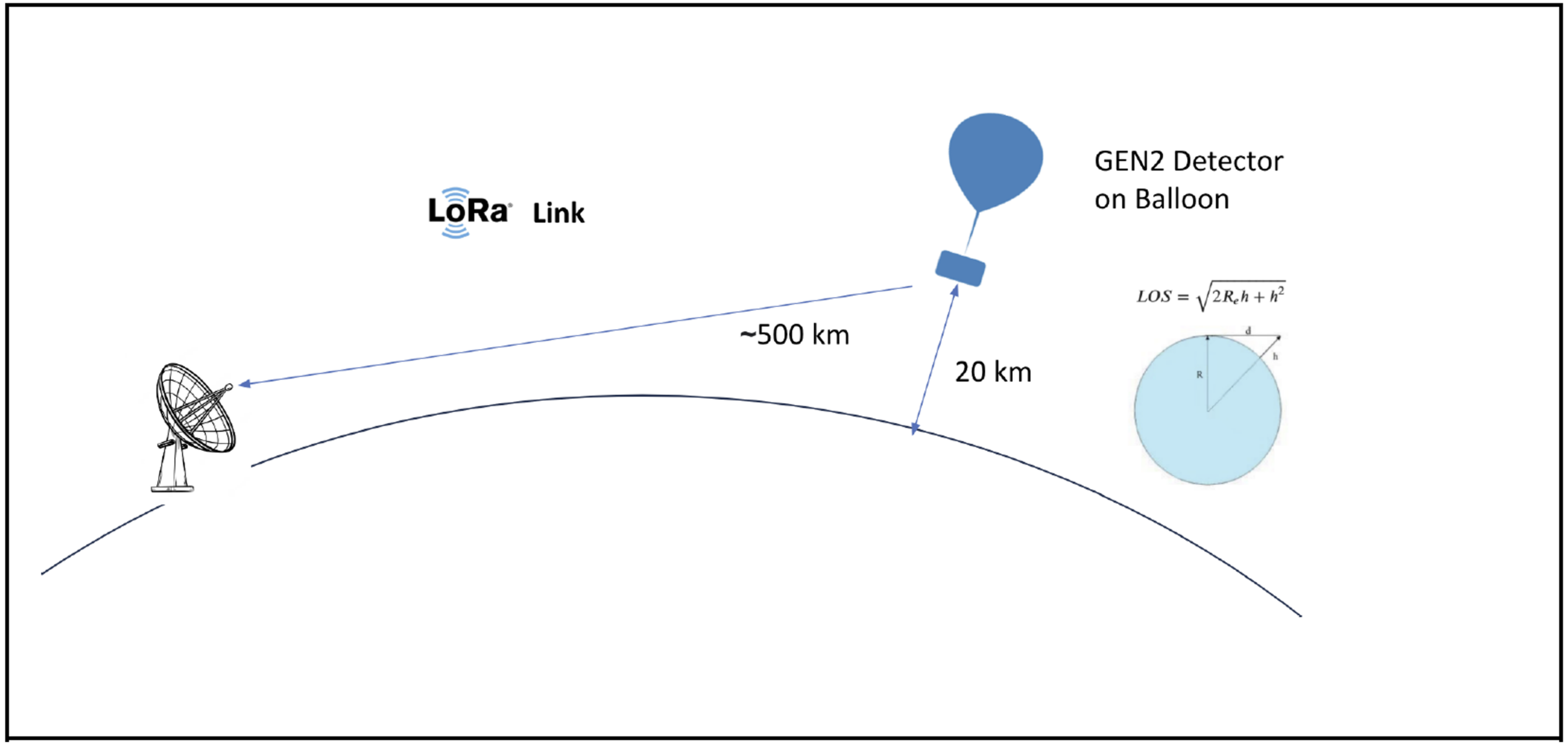
Atmospheric Effects Links

- Atmospheric Optics
- Color and Light in Nature
- The Colors of Twilight and Sunset
- Refraction Index
- Image Gallery: Atmospheric Effects
- What is a Rainbow?

Testing of the electronics and communication system using stratospheric Light Balloon

(Total weight < 4 Kg)



Employing stratospheric balloons to conduct altitude-based detector tests and to evaluate LoRa transmitters for data transmission from LEO orbit to Earth.

On-field experience
in synergy with schools in
OCRA INFN (Outreach Cosmic ray Activity)
https://sites.google.com/view/particle-detectors/loom-platform

EOS
Participating parties: INFN Roma, ABproject, Istituto "A. Russo" Nicotera

Launch Location: Nocera Scalo (CZ) Italy (Lat:39.02693,Long:016.10657)

Launch time: 09:04:24 UTC June 30, 2018

Max altitudine: 27000 meters

Landing Location: Badolato Marina (CZ) Italy (Lat:38.57403,Long:016.60350)

Landing Time: 10:38:12 UTC June 30, 2018,

Crow flies distance: 66.5 Km

MoCRiS (Measurement of Cosmic Ray in Stratosphere)

Participating parties: INFN Roma, ABproject, Liceo Scientifico Cariati

Launch Location: Camigliatello Silano (CS) Italy (Lat:39.36704, Long:16.48968)

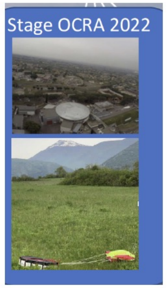
Launch time: 09:22:48 UTC June 8, 2019

Max altitudine: 34.111 meters

Landing Location: Parenti (CS), Italy, (Lat:039.15436,Long:16.40214)

Landing time: 11:09:30 UTC June 8, 2019

Crow flies distance: 24.8 Km



Stage INFN OCRA 2022
Participating parties: INFN OCRA,INFN Roma, ABproject

Launch Location: INFN Laboratori Nazionali di Frascati (LNF) (RM) Italy (Lat:041.82436,Long: 012.67331)

Launch time: 09:02:24 UTC 5 May, 2022

Max altitudine: 28381 meters

Landing Location: Capistrello AQ Italy (Lat:42.00009,Long:13.40148)

Landing Time: 10:32:54 UTC 5 May, 2022
Crow flies distance: 63.4 Km

MiraCosmos 2022
Participating parties: Liceo Scientifico R. Steiner Milano,INFN Roma, ABproject

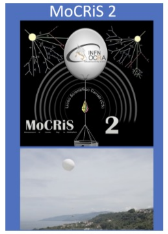
Launch Location: Abbazia Mirasole, Opera (MI) Italy (Lat:045.38743,Long: 09.20188)

Launch time: 09:11:06 UTC 27 Sep, 2022

Max altitudine: 30225 meters

Landing Location: Alfiano Nuovo (CR) Italy (Lat:42.00009 045.23732,Long: 010.13041)

Landing Time: 10:48:42 UTC 27 Sep, 2022
Crow flies distance: 74.4 Km



MoCRiS2 2023

Participating parties: INFN Roma, ABProject Space, Liceo Scientifico Cariati, Dipartimento di Fisica UNICAL, ADA Project Laboratory, ArpaCal, Lab. Fisico E. Majorana, Catanzaro, OCRA Collaboration

Launch Location: Stadio Comunale di Paola (CS) Italy (39°22'24"N 16°1'40"E)

Launch time: 09:00:00 UTC June 14, 2023

Max altitudine: 33.205 meters

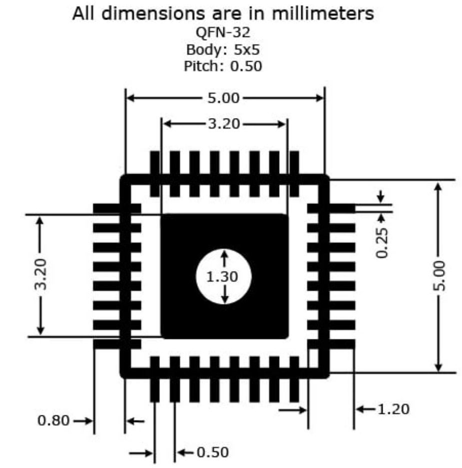
Landing Location: Acri (CS), Italy, (Lat: 39,4679 ,Long: 16,4917)

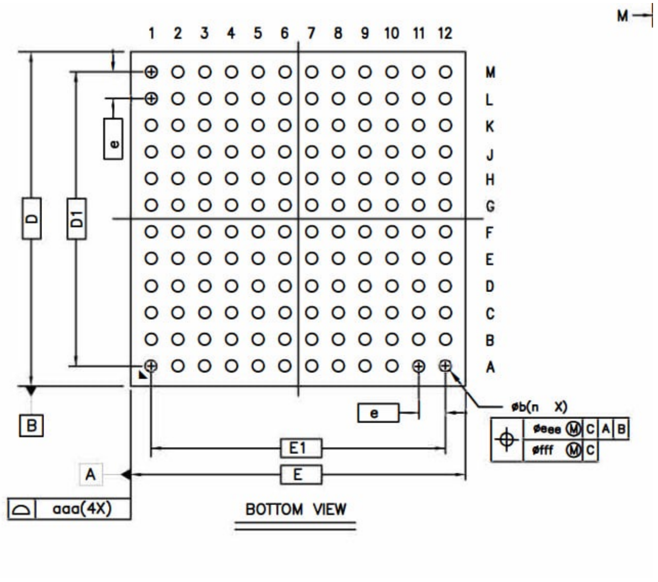
Landing time: 10:40:00 UTC June 14, 2023

Crow flies distance: 46 Km

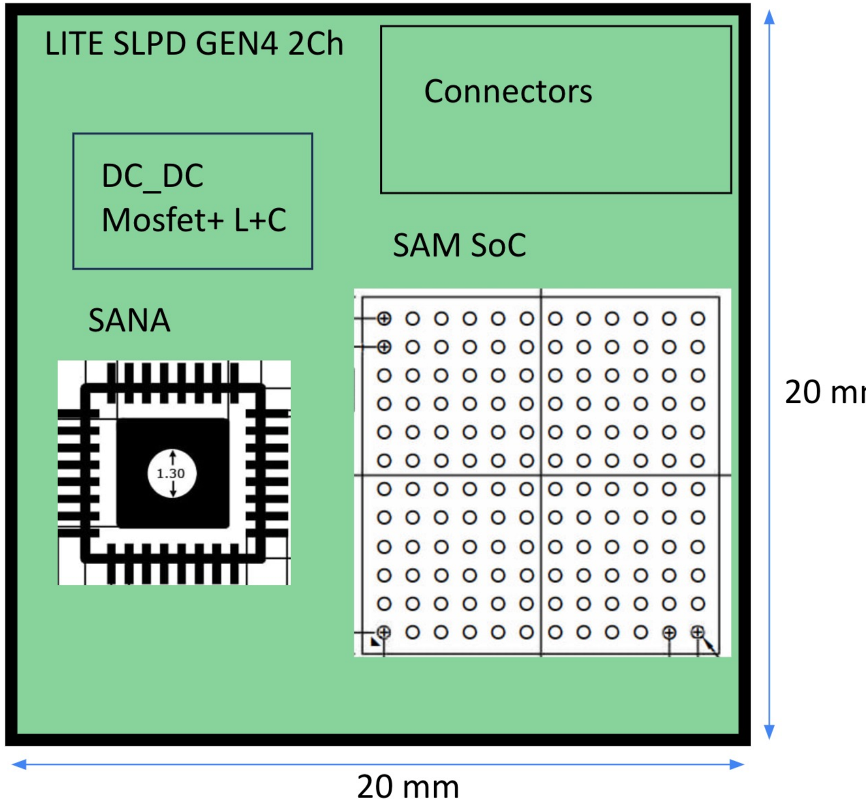
The Upcoming 4th Generation:
LITE-SPLD Project

(Lightweight Integrated Technology for Space Luminescence and Particle Detection)



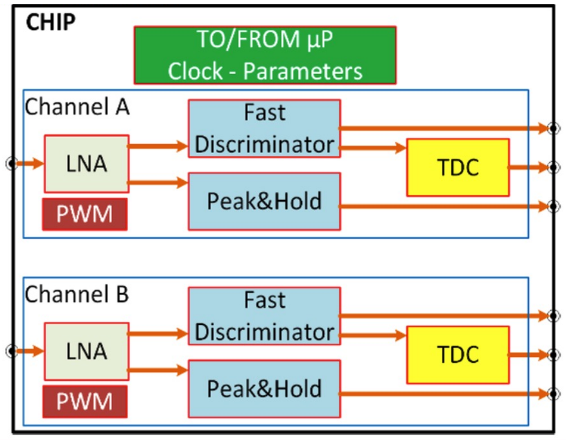


		Symbol	Common Dimensions		
			MIN.	NOM.	MAX
Package :				TFBGA	
Body Size:	X	E		10.000	
	Y	D		10.000	
Ball Pitch :		e		0.800	
Total Thickness :		A			1.20

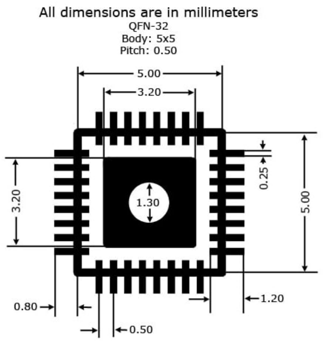


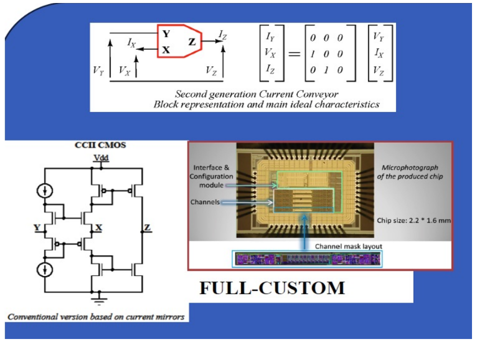
LITE-SPLD Project:The Chip

(under CSN5 INFN)

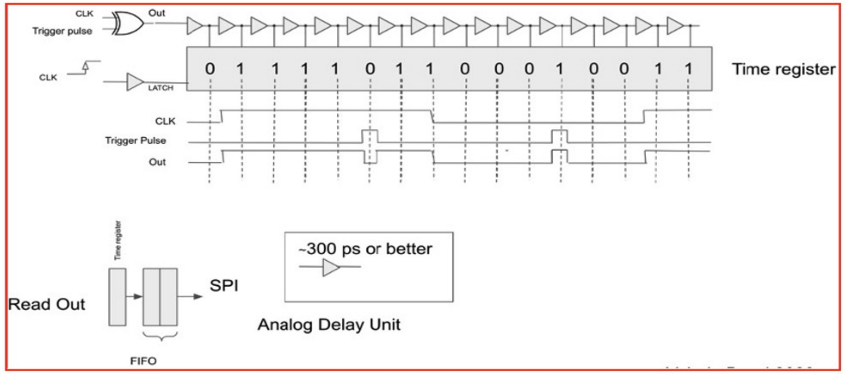


The idea is to start from an already developed 'Front-End for MPPC' chip project devolped in INFN Tor Vergata, which includes all the GEN2 analog features and is optimized in terms of size and number of channels. The initial chip was intended for TOF applications and will need to be modified (significantly), while still maintaining the chosen technology for economic convenience and design familiarity.





Front-End chip for MPPC in standard 0.35 um CMOS technology:
Low input impedance to reduce the reset time as much as possible
All signals and thresholds are processed in the current domain using fast current comparators and a modified version of the second generation Current Conveyors (CCII) based on current mirror as building blocks for the amplifiers.



One of the notable innovations introduced by this chip is the inclusion of a segmented Time-to-Digital Converter (TDC). This advanced TDC design is segmented, meaning it is divided into smaller sections, each capable of performing time-to-digital conversions independently. This segmentation enables the chip to achieve a temporal resolution that is significantly finer than the duration of a single clock cycle used by the system. Essentially, it can precisely measure time intervals that are a fraction of the clock period, leading to enhanced timing accuracy in digital signals.

Conclusions on the ArduSiPM Technology

- *Introduced in 2015 by INFN's tech transfer, the first version of ArduSiPM is still purchasable online through an INFN non-exclusive license from RobotDomestici and CShark. Popular in labs and among global students, it's won numerous awards, especially in outreach and with makers.*
- *Thanks to the rapid advancement and adoption of MCU SOC technology in sectors like IoT, automotive, and space, ArduSiPM has experienced significant development and growth.*
- *Since the first ArduSiPM was introduced at NSS MIC in Seattle 2014, we have developed two additional generations: "Cosmo ArduSiPM GEN2 " and "Nano ArduSiPM GEN3".*
- *We will soon have third-generation nano ArduSiPM prototypes.In the near future, we plan to send the Gen2/Gen3 versions into space on board of Cubesat e Picosatellite.*
- *The Second and Third generation, continuously updated in firmware, will be available to select users and experiments through scientific collaboration for particle detection, luminescence, and other potential applications.*
- *A Fourth generation is in the works, featuring 2 channels in 10 Euro Cent size. This can also be utilized in HEP experiments due to its minimal occupancy per channel and the lack of necessity to transmit analog signals over long distances.*