# Laboratorio di Segnali e Sistemi

## Tecnologia ArduSiPM

Esempi utilizzo dei microcontrollori
in Fisica delle alte energie (Atlas, LHCb)
e del rivelatore ArduSiPM in:
Fisica Medica (Chirone)
Monitor di Fascio CERN (UA9)
CERN Beam Line for School (2017 winner)
Rivelazione di radiazioni e Raggi Cosmici
Misure di Bioluminoscenza
Spazio (cubesat e nanosatelliti)
Dalla GEN1 alla Gen4

Valerio.Bocci@roma1.infn.it

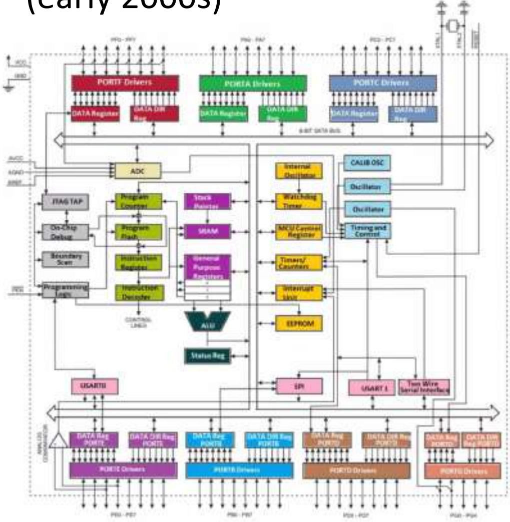
A.A. 2022-2024

# ELMB (the CERN Arduino)
# ATmega128 microcontrollers in LHC experiments
# (early 2000s)


The Development of the Embedded Local Monitor Board (ELMB)

H.Boterenbrood [1], B.Hallgren [2]

[1] NIKHEF, P.O.Box 41882, 1009 DB Amsterdam,
[2] CERN, 1211 Geneva 23, Switzerland
boterenbrood@nikhef.nl, Bjorn.Hallgren@cern.ch




ATmega128 Block Diagram

Valerio Bocci 2023

# ATLAS L1 Muon Trigger

## Detector Control System

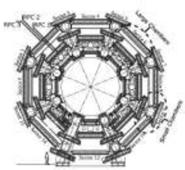
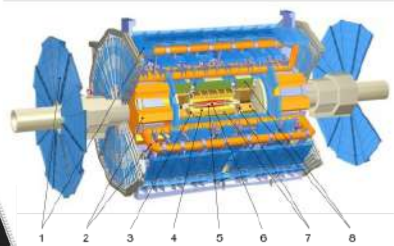


Figure 1. An ATLAS section showing RPC trigger stations. The experiment is divided in sixteen sectors, each containing three RPC trigger planes. Large chambers and Small chambers overlap between two adjacent sectors.




~1000 X


*The DCS system of the Atlas RPC detector*

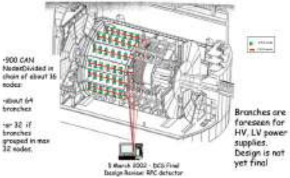
V.Bocci, G.Chiodi, E Petrolo, R.Vari, S Veneziano
INFN Roma

PAD board layout


PAD board with TTCrx ELMB XCV200 and Optical Link

5 March 2002 - DCS Final Design Review: RPC detector

Can branches in Atlas muon detector




Valerio Bocci 2023

# LHCb

(Equalization, Timing and Monitoring of the 120k Front End Channels in the LHCb Muon Detector)

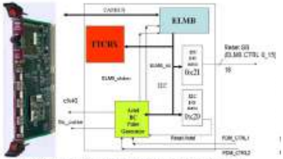


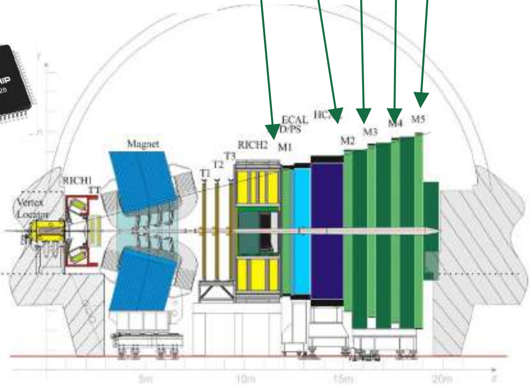

**Figure 3:** Pulse Distribution Module Block Diagram.

The Services Boards system
for the LHCb Muon Detector
(Equalization, Timing and Monitoring of the 120k Front
End Channels in the LHCb Muon Detector)

**Figure 6:** Service Board Crate

~1000 X

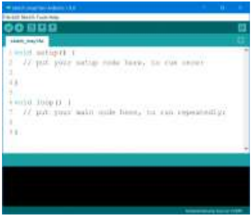

**Figure 5:** Service Board layout

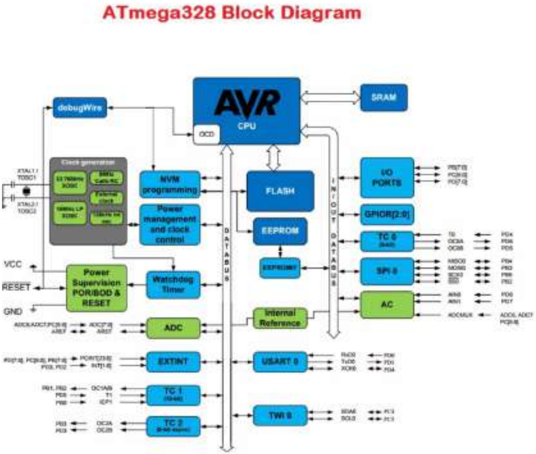



Valerio Bocci 2023

# Arduino Uno (2010)

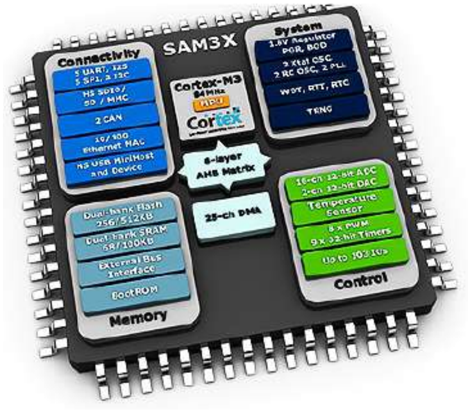

Arduino IDE

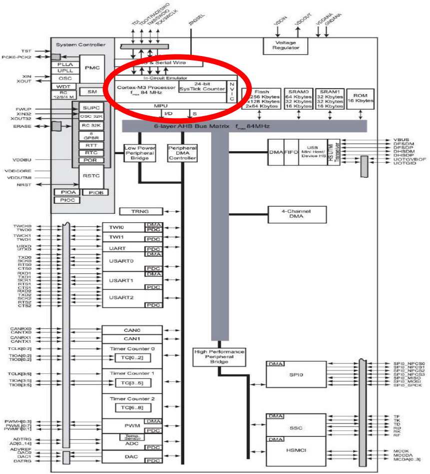




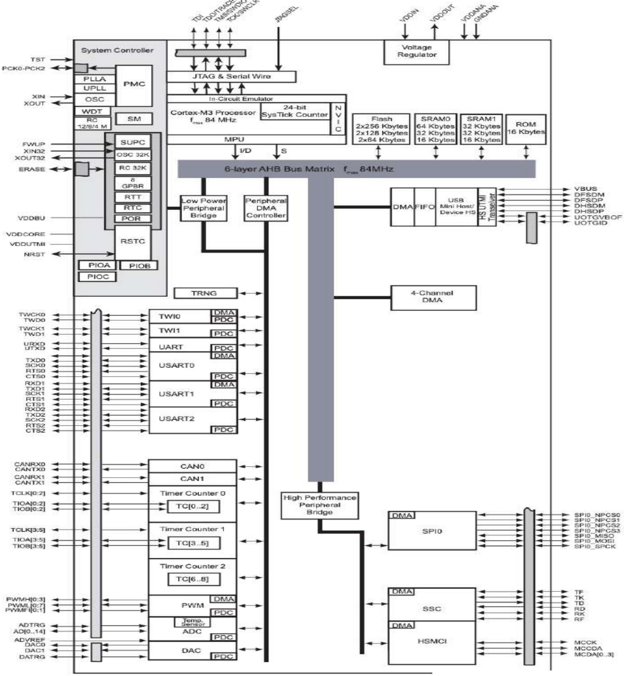

Valerio Bocci 2023

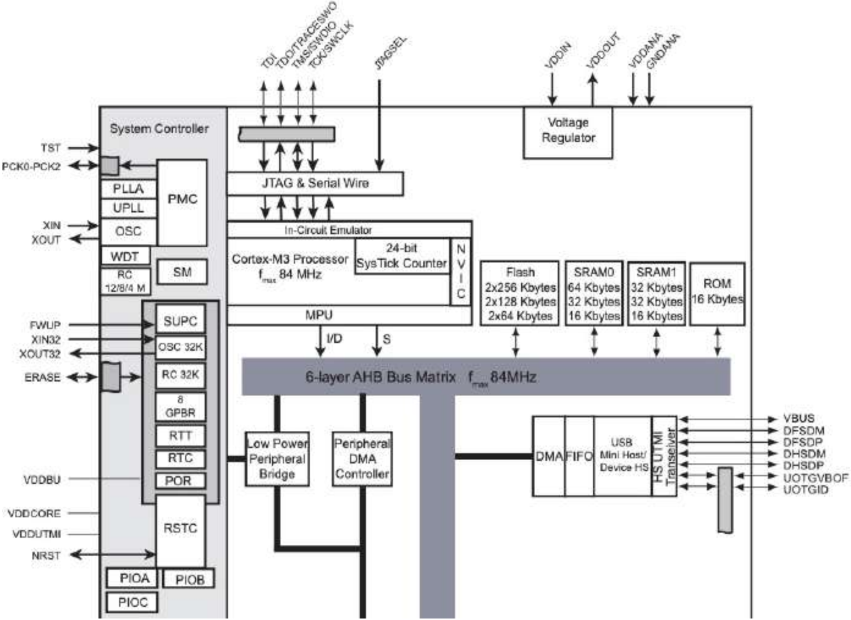
# Arduino DUE SAM3X Cortex M3

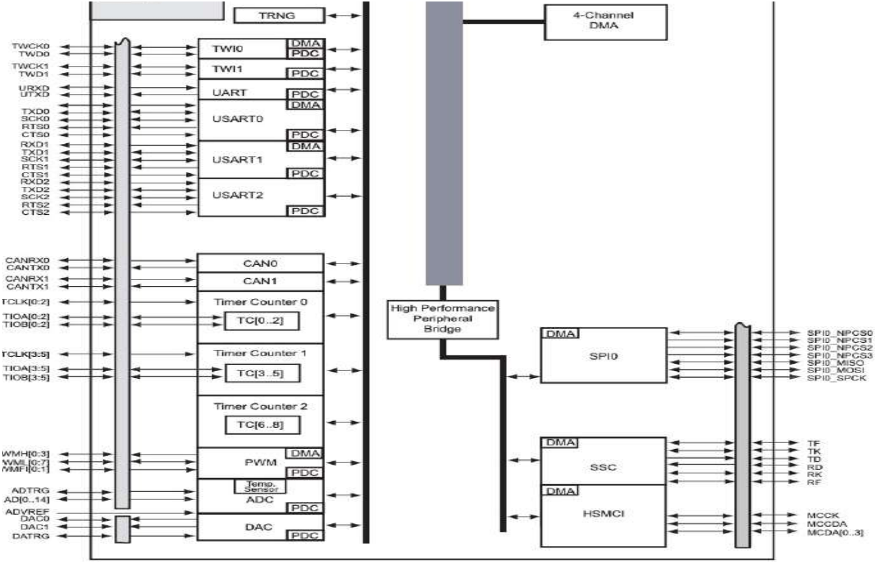



The **ARM Cortex-M** is a group of 32-bit RISC ARM processor cores licensed by Arm Holdings. They are intended for microcontroller use, and have been shipped in tens of billions of devices.

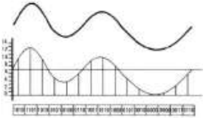

TDI
TDO/TRACESWO
TMS/SWDIO
TCK/SWCLK
JTAGSEL
VDDIN
VDDOUT
VDDANA
GNDANA
Voltage Regulator
System Controller
TST
PCK0-PCK2
PLLA
UPLL
PMC
XIN
XOUT
OSC
WDT
RC 12/8/4 M
SM
FWUP
XIN32
XOUT32
SUPC
OSC 32K
RC 32K
ERASE
8 GPBR
RTT
RTC
POR
VDDBU
VDDCORE
VDDUTMI
NRST
RSTC
PIOA
PIOB
PIOC
JTAG & Serial Wire
In-Circuit Emulator
Cortex-M3 Processor fmax 84 MHz
24-bit SysTick Counter
NVIC
MPU
I/D
S
Flash 2x256 Kbytes 2x128 Kbytes 2x64 Kbytes
SRAM0 64 Kbytes 32 Kbytes 16 Kbytes
SRAM1 32 Kbytes 32 Kbytes 16 Kbytes
ROM 16 Kbytes
6-layer AHB Bus Matrix fmax 84MHz
Low Power Peripheral Bridge
Peripheral DMA Controller
DMA
FIFO
USB Mini Host/ Device HS
HS UTMI Transceiver
VBUS
DFSDM
DFSDP
DHSDM
DHSDP
UOTGVBOF
UOTGID
TRNG
4-Channel DMA
TWCK0
TWD0
TWCK1
TWD1
URXD
UTXD
TXD0
SCK0
RTS0
CTS0
RXD1
TXD1
SCK1
RTS1
CTS1
RXD2
TXD2
SCK2
RTS2
CTS2
TWI0
TWI1
UART
USART0
USART1
USART2
PDC
CANRX0
CANTX0
CANRX1
CANTX1
CAN0
CAN1
TCLK[0:2]
TIOA[0:2]
TIOB[0:2]
Timer Counter 0
TC[0..2]
TCLK[3:5]
TIOA[3:5]
TIOB[3:5]
Timer Counter 1
TC[3..5]
Timer Counter 2
TC[6..8]
PWMH[0:3]
PWML[0:7]
PWMFI[0:1]
PWM
ADTRG
AD[0..14]
Temp. Sensor
ADC
ADVREF
DAC0
DAC1
DATRG
DAC
High Performance Peripheral Bridge
SPI0
SPI0_NPCS0
SPI0_NPCS1
SPI0_NPCS2
SPI0_NPCS3
SPI0_MISO
SPI0_MOSI
SPI0_SPCK
SSC
TF
TK
TD
RD
RK
RF
HSMCI
MCCK
MCCDA
MCDA[0..3]


TDI
TDO/TRACESWO
TMS/SWDIO
TCK/SWCLK
JTAGSEL
VDDIN
VDDOUT
VDDANA
GNDANA
System Controller
Voltage Regulator
TST
PCK0-PCK2
PLLA
UPLL
PMC
XIN
XOUT
OSC
WDT
SM
RC 12/8/4 M
JTAG & Serial Wire
In-Circuit Emulator
Cortex-M3 Processor $f_{max}$ 84 MHz
24-bit SysTick Counter
NVIC
MPU
Flash 2x256 Kbytes 2x128 Kbytes 2x64 Kbytes
SRAM0 64 Kbytes 32 Kbytes 16 Kbytes
SRAM1 32 Kbytes 32 Kbytes 16 Kbytes
ROM 16 Kbytes
FWUP
XIN32
XOUT32
ERASE
SUPC
OSC 32K
RC 32K
8 GPBR
RTT
RTC
POR
RSTC
I/D
S
6-layer AHB Bus Matrix $f_{max}$ 84MHz
Low Power Peripheral Bridge
Peripheral DMA Controller
DMA
FIFO
USB Mini Host/ Device HS
HS UTMI Transeiver
VBUS
DFSDM
DFSDP
DHSDM
DHSDP
UOTGVBOF
UOTGID
VDDBU
VDDCORE
VDDUTMI
NRST
PIOA
PIOB
PIOC

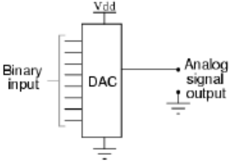

TRNG
4-Channel DMA
TWCK0
TWD0
TWCK1
TWD1
URXD
UTXD
TXD0
SCK0
RTS0
CTS0
RXD1
TXD1
SCK1
RTS1
CTS1
RXD2
TXD2
SCK2
RTS2
CTS2
TWI0
TWI1
UART
USART0
USART1
USART2
DMA
PDC
CANRX0
CANTX0
CANRX1
CANTX1
TCLK[0:2]
TIOA[0:2]
TIOB[0:2]
TCLK[3:5]
TIOA[3:5]
TIOB[3:5]
CAN0
CAN1
Timer Counter 0
TC[0..2]
Timer Counter 1
TC[3..5]
Timer Counter 2
TC[6..8]
PWM
Temp. Sensor
ADC
DAC
ADTRG
AD[0..14]
ADVREF
DAC0
DAC1
DATRG
High Performance Peripheral Bridge
SPI0
SPI0_NPCS0
SPI0_NPCS1
SPI0_NPCS2
SPI0_NPCS3
SPI0_MISO
SPI0_MOSI
SPI0_SPCK
SSC
TF
TK
TD
RD
RK
RF
HSMCI
MCCK
MCCDA
MCDA[0..3]

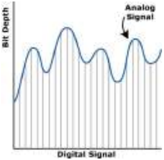
# Arduino DUE sistema di acquisizione completo (1/2).

Arduino DUE ha tutto il necessario per realizzare un sistema di acquisizione per interfacciarsi al mondo analogico.

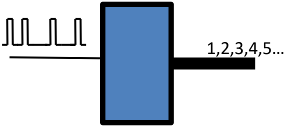
**Convertitori Analogico Digitali (ADC):**
Consentono di trasformare i segnali analogici in numeri.



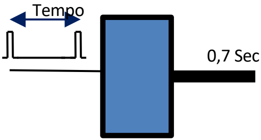




**Convertitori Digitale Analogico (DAC):**
Consentono di trasformare i numeri in segnali analogici.

# Arduino DUE sistema di acquisizione completo (2/2).

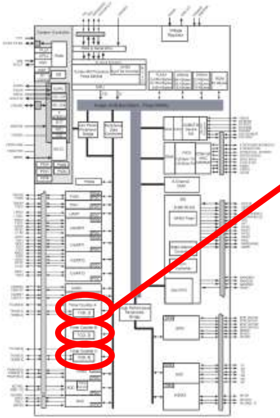


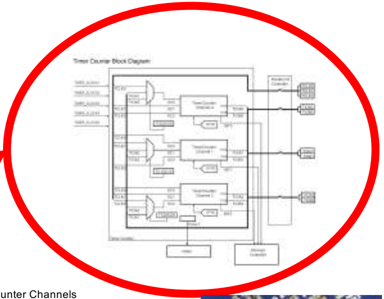

**Contatori Digitali**
Consentono di contare il numero di eventi.




**Misuratori di tempo digitali (TDC)**
Consentono di misurare il tempo tra due eventi.

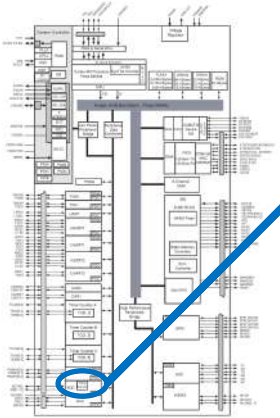
# SAM3X8E Timer Counter modules

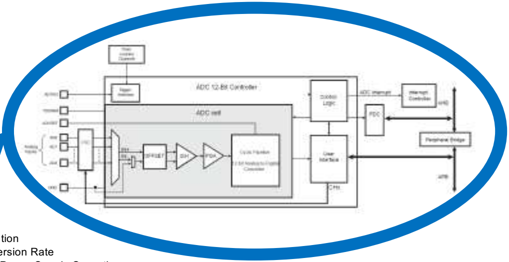




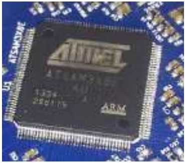
- Three 32-bit Timer Counter Channels
- A Wide Range of Functions Including:
  – Frequency Measurement
  – Event Counting
  – Interval Measurement
  – Pulse Generation
  – Delay Timing
  – Pulse Width Modulation
  – Up/down Capabilities
- Each Channel is User-configurable and Contains:
  – Three External Clock Inputs
  – Five Internal Clock Inputs
  – Two Multi-purpose Input/Output Signals
- Internal Interrupt Signal

# SAM3X8E ADC module

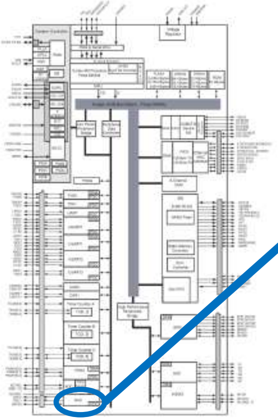


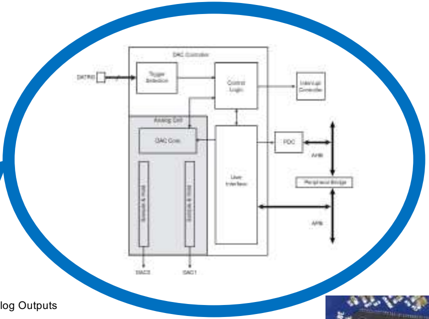



- 12-bit Resolution
- 1 MHz Conversion Rate
- Wide Range Power Supply Operation
- Selectable Single Ended or Differential Input Voltage
- Programmable Gain For Maximum Full Scale Input Range 0 - VDD
- Integrated Multiplexer Offering Up to 16 Independent Analog Inputs
- Individual Enable and Disable of Each Channel
- Hardware or Software Trigger
  – External Trigger Pin
  – Timer Counter Outputs (Corresponding TIOA Trigger)
  – PWM Event Line
- Drive of PWM Fault Input
- PDC Support
- Possibility of ADC Timings Configuration
- Two Sleep Modes and Conversion Sequencer

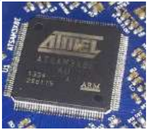


# SAM3X8E DAC module



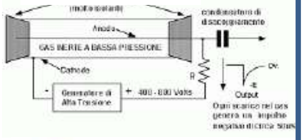



- Two Independent Analog Outputs
- 12-bit Resolution
- Individual Enable and Disable of Each Analog Channel
- Hardware Trigger
  – External Trigger Pins
- PDC Support
- Possibility of DACC Timings and Current Configuration
- Sleep Mode
  – Automatic Wake-up on Trigger and Back-to-Sleep Mode after Conversions of all Enabled Channels
- Internal FIFO

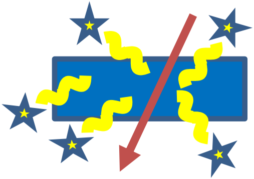


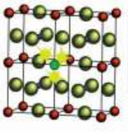
# Alcune tecniche per rivelare le particelle

Tubo Geiger

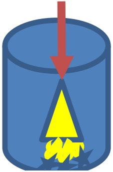


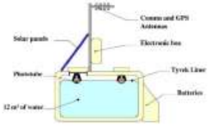

Materiali scintillanti



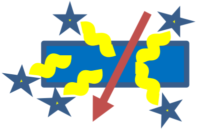


Effetto Cherenkov

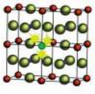




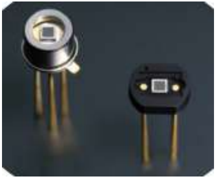
# Utilizzo degli scintillatori per costruire rivelatori.

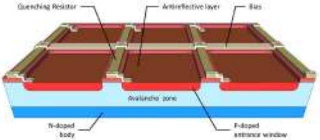


L'utilizzo degli scintillatori in passato non era alla portata di tutti.
Per rilevare i fotoni emessi era necessario uno rivelatore di luce chiamato FOTOMOLTIPLICATORE.



La tecnologia del fotomoltiplicatore, nata nel 1934 si basa sull'effetto fotoelettrico (1921 Einstein Premio Nobel) , e sull'emissione secondaria di elettroni. I fotomoltiplicatori sono oggetti costosi (Keuro) e da laboratorio, necessitano di tensioni dell'ordine dei 1000 Volt e sono molto fragili.

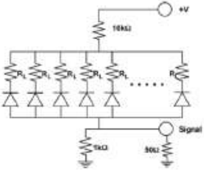


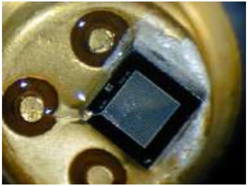



# SiPM

Il SiPM o Silicon Photomultiplier è un nuovo tipo di fotomoltiplicatore al silicio.
Diversamente dai fotomoltiplicatori tradizionali (PMT o Photomultiplier Tubes), costruiti con tubi a vuoto, i SiPM sono prodotti direttamente da un wafer di silicioimpiantando in esso matrici di microcelle lette in parallelo ciascuna delle quali è un diodo (Avalanche Photodiode o APD) che lavora in modalità Geiger.
Le dimensioni tipiche di un SiPM sono da (1mm x 1mm) fino a (3mm x 3mm) ma in linea di principio sarebbe possibile produrre geometrie arbitrarie. Le singole microcelle hanno dimensioni tipiche che vanno dai 20x20 µm ai 50x50 µm.

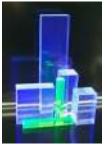
Rispetto ai tradizionali PMT presentano numerosi vantaggi quali ad esempio la bassa tensione di funzionamento (da 30 a 80 V a seconda del modello e del costruttore).



# 2014

## Is it possible to build a complete particle detector and data acquisition system using Arduino microcontroller and Arduino Language ?



Scintillator

Photons Sensor (SiPM)

Custom Electronics (ArduSiPM Shield)

Arduino DUE

ArduSiPM Software

Particle Detector

ArduSiM

# Application Example 1: Intraoperative β- Detecting Probe


nature.com > scientific reports > articles > article

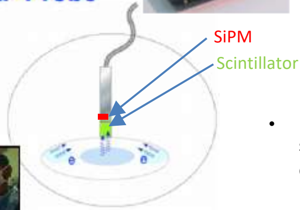
SCIENTIFIC REPORTS

A novel radioguided surgery technique exploiting $\beta^-$ decays

**Beta- Probe**

ArduSiPM

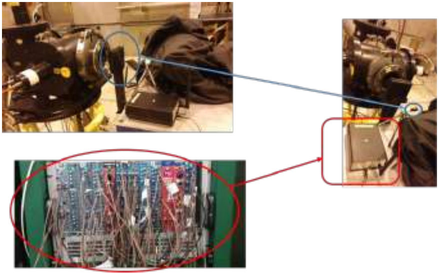

Control and readout Android App




- Radioguided **intraoperative beta probe**, with scintillation material coupled with SiPM detector.

# Application Example 2:
# Use of ArduSiPM in the CERN UA9 and CRYSBEAM activity

(substitute old Scintillator and electronics for PM)

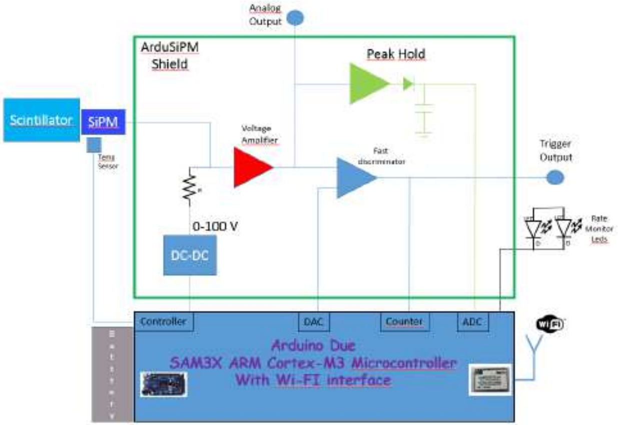


- As beam trigger @ extracted beam line H8 (CERN)

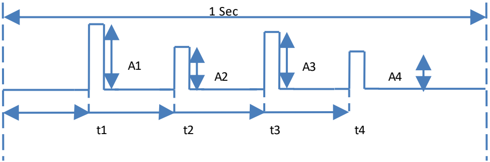
- As beam losses counter @ SPS


- *This work has been supported by the ERC Ideas Consolidator Grant*
- *No.615089 “CRYSBEAM”.*

# ArduSiPM Block Diagram



# ArduSiPM measuraments




We split the measuraments in 1 second windows,
acquiring number of pulses, amplitude and time of each one.

Using a 200KBits/s serial stream

We can meausure and dump (depending from amplitude and distribution of pulses):

- Only the frequency up to 40 MHz
- ADC value up to 4-6  KHz
- ADC,TDC and rate 1 -2 KHz

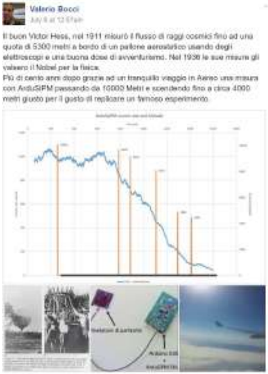
Using the SAM3X8 built-in ethernet it is possible to increase data acquisition performance.

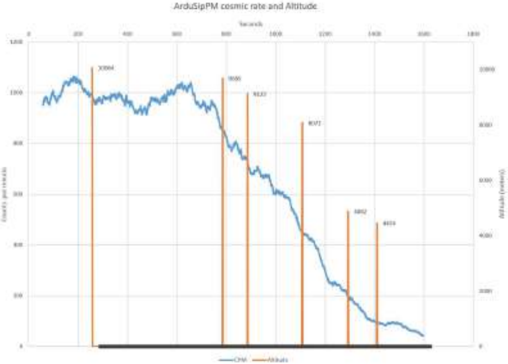
Data Stream example:

```
Only rate:
$10
$50
$244

ADC+Rate:
v1Fv1Dv22v27v1Dv19v20v23v20v1Cv19v1F$12
v18v1Ev1Ev1Bv19v1Bv29v19v1Av1Dv1Bv1Dv2Av18v1B$15
v15v20v21v21v1Dv1Fv1Av1Av1A$9
v19v17v1Bv18v1Cv1Dv1D$7

TDC+ADC+RATE:
taedvataf0v7tv9v3$3
```

Legend:
vXXX ADC Value in HEX MSB zero suppressed
tXXXXXXXX TDC value in HEX MSB zero suppressed
$XXX rate in Hz

# Misura dei raggi cosmici su un aereo di linea



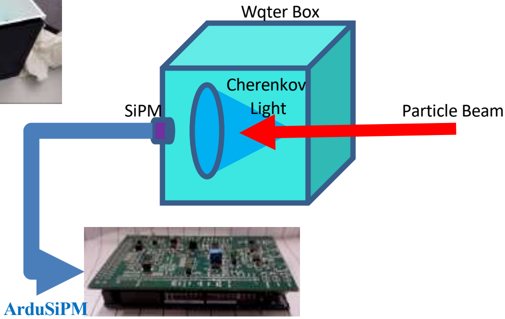




Valerio Bocci International Cosmic Day 2017

# A School made Cherenkov light detector

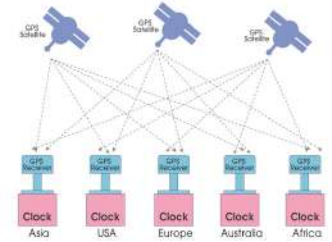
(Winner of CERN “A beamline for schools”2017)

LICEO SCIENTIFICO STATALE T. C. ONESTI  (prof Maria Rita Felici)



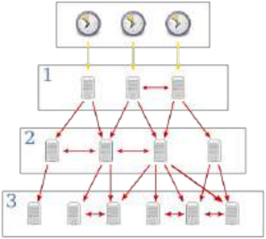
# Precise time distribution methods

GPS time (from Global Position Systems satellite)



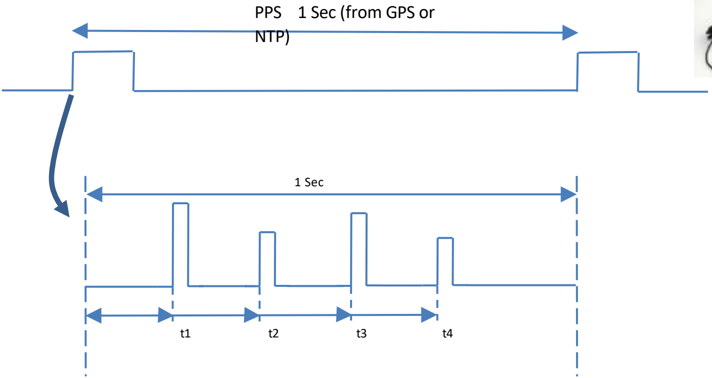

Low cost GPS module (<30 Euro) 25 ns precision

Network Time Protocol (from internet)



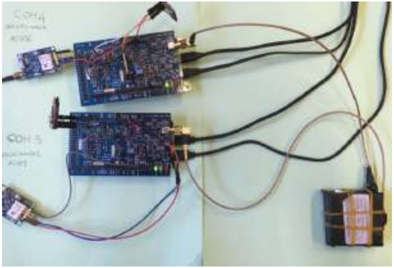

Low cost wi-fi internet processor precision <10 ms

# Synchronization with ArduSiPM




# Sincronizzazione tramite GPS di rivelatori di particelle ArduSiPM per lo studio di sciami di raggi cosmici.

Tesi triennale Gaia Muti



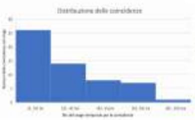


**Figura 5.3.** Prima presa dati con scintillatori sovrapposti.

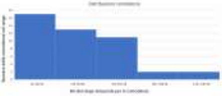


**Figura 5.4.** Seconda presa dati con scintillatori sovrapposti.

**Figura 4.2.** Ricevitore GPS.

**Figura 4.3.** Antenna.

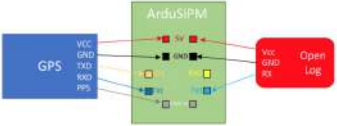



**Figura 5.1.** Schema dei collegamenti eseguiti tra l'ArduSipm, l'Open Log e il GPS.

# Lancio Mocris 2019


# Mocris particle detector Instrumentation

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

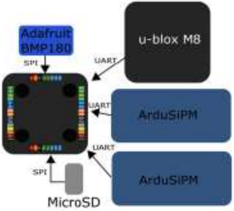
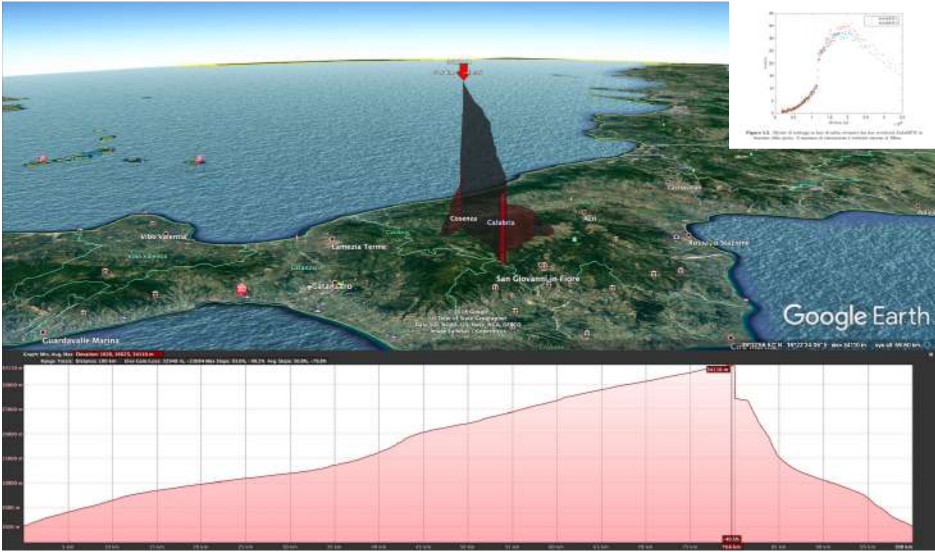



**Figura 2.5.** Diagramma a blocchi dell'apparato elettronico per la misura del flusso di raggi cosmici dell'esperimento MoCRiS. Sono riportati i tipi di protocolli seriali utilizzati per comunicare da ciascun elemento del sistema.


Cosenza
Calabria
Acri
Vibo Valentia
Lamezia Terme
San Giovanni in Fiore
Guardavalle Marina
Google Earth


EARTH SCIENCE PICTURE OF THE DAY
UNIVERSITIES SPACE RESEARCH ASSOCIATION
Moon Imaged from the MoCRiS Payload
June 25, 2019
« Previous | Today's | Next »
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 Canale.
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
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
Related EPODs
More...
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?
VIEWER'S CHOICE
Earth Science Picture of the Day
June 2019


**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 39.26704, Long 16.40948)

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

**Max altitudine:** 36.111 meters

**Landing Location:** Rovito (CS), Italy, (Lat 039.15434,Long 16.40216)

**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 Sept 2022:**
Participating parties: Liceo Scientifico Steiner Milano, INFN Roma, INFN Milano.

**Launch Location:** Abbazia Mirasole Opera(Mi),Italy (Lat:45.38588,Long:9.20182)

**Launch time:** 09:11:06 UTC September 27, 2022

**Max altitudine:** 30225 meters

**Landing Location:** Corte de' Frati (CR) ,Italy (Lat:45.23733,Long:10.13075)

**Landing Time:** 10:48:42 UTC September 27, 2022

**Crow flies distance**: 72.6 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)

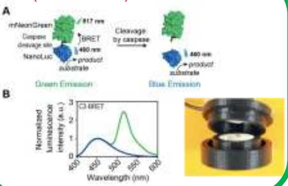
**Landing time:** 10:40:00 UTC June 14, 2023

**Crow flies distance:** 46 Km

Video: [illegible]

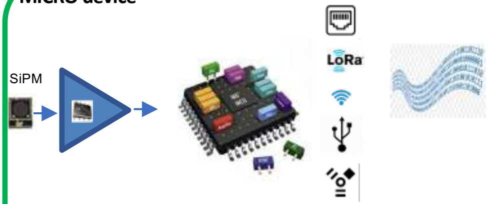
# Bio(luminoscence) flux measurements

Bio(luminoscence) flux measurements

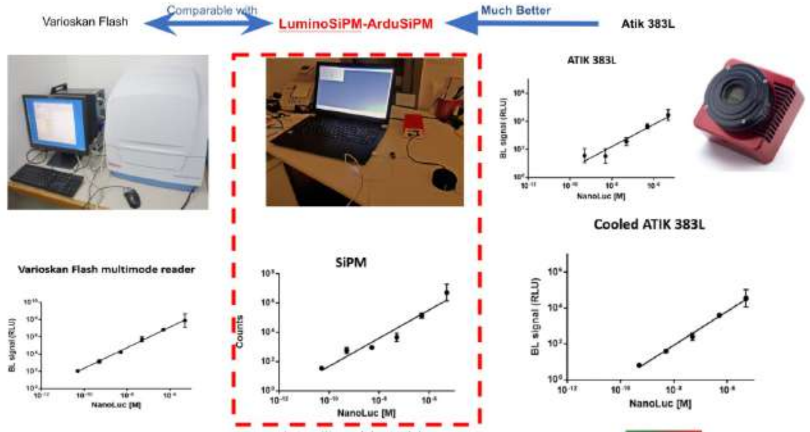



~$10^5$-$10^6$photons/s

**MICRO device**



# Applicazioni in Chimica Analitica alma mater studiorum Univ Bologna




In collaboration with analytical chemistry uniBo

*Luminescent biosensors for forensic applications based on new ultrasensitive Silicon PhotomultiPlier detector* **(PhD thesis Marcello D'Elia)**

Valerio Bocci INFN Roma

# Ultrasensitive On-Field Luminescence Detection Using a Low-Cost Silicon Photomultiplier Device

Maria Maddalena Calabretta, Laura Montali, Antonia Lopreside, Fabio Fragapane, Francesco Iacoangeli, Aldo Roda, Valerio Bocci, Marcello D'Elia*, and Elisa Michelini*

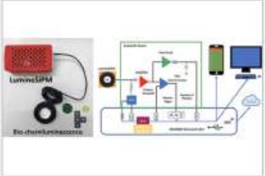
**Cite this:** *Anal. Chem.* 2021, 93, 20, 7388–7393
Publication Date: May 11, 2021
https://doi.org/10.1021/acs.analchem.1c00899


**SUBJECTS:** Bioluminescent probes, Sensors, Peptides and proteins, Light, Calibration


Analytical Chemistry

## Abstract

The availability of portable analytical devices for on-site monitoring and rapid detection of analytes of forensic, environmental, and clinical interest is vital. We report the development of a portable device for the detection of biochemiluminescence relying on silicon photomultiplier (SiPM) technology, called LuminoSiPM, which includes a 3D printed sample holder that can be adapted for both liquid samples and paper-based biosensing. We performed a comparison of analytical performance in terms of detectability with a benchtop luminometer, a portable cooled charge-coupled device (CCD sensor), and smartphone-integrated complementary metal oxide semiconductor (CMOS) sensors. As model systems, we used two luciferase/luciferin systems emitting at different wavelengths using purified protein solutions: the green-emitting *P. pyralis* mutant Ppy-GR-TS ($\lambda_{max}$ 550 nm) and the blue-emitting NanoLuc ($\lambda_{max}$ 460 nm). A limit of detection of 9 femtomoles was obtained for NanoLuc luciferase, about 2 and 3 orders of magnitude lower than that obtained with the portable CCD camera and with the smartphone, respectively. A proof-of-principle forensic application of LuminoSiPM is provided, exploiting an origami chemiluminescent paper-based sensor for acetylcholinesterase inhibitors, showing high potential for this portable low-cost device for on-site applications with adequate sensitivity for detecting low light intensities in critical fields.

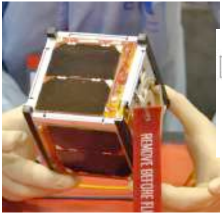


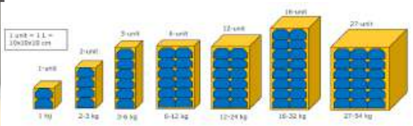
CUBESAT

- I Cubesat sono una classe di **nanosatelliti** che rispettano lo standard definito nel Cubesat design specification

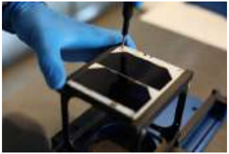
- Il concetto del Cubesat è nato nel 1999 dalla collaborazione tra la California Polytechnic State University e lo Stanford University's Space Systems Development Laboratory.

- L'idea di base è quella di poter effettuare **lanci frequenti** di un satellite **economico** e con brevi tempi di sviluppo, **accessibile** università ed aziende , sfruttando lo spazio disponibile sui lanciatori di payload molto più costosi.

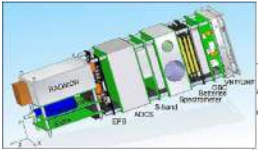


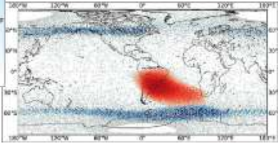



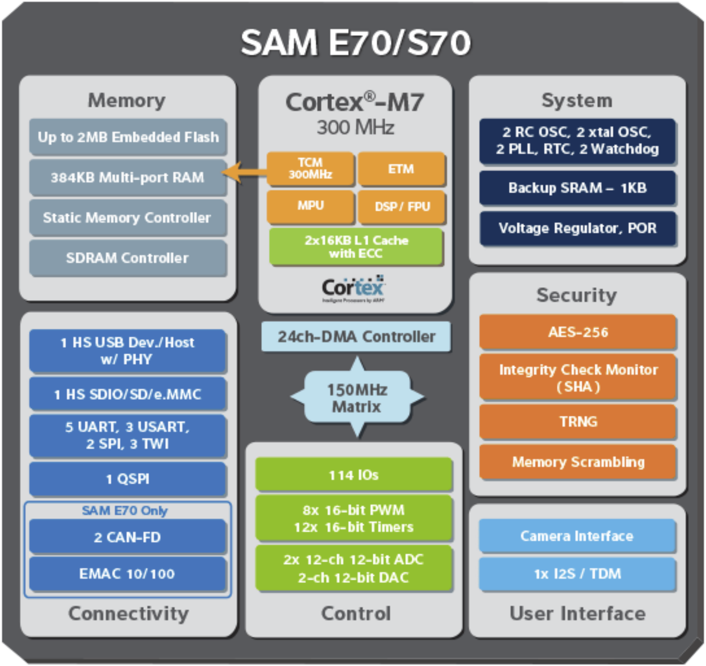

# Cubesat example




Example :AALTO Finland 3U Cubesat 3U



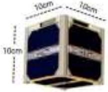




SAM E70/S70
Memory
Up to 2MB Embedded Flash
384KB Multi-port RAM
Static Memory Controller
SDRAM Controller
Cortex®-M7
300 MHz
TCM 300MHz
ETM
MPU
DSP / FPU
2x16KB L1 Cache with ECC
Cortex
System
2 RC OSC, 2 xtal OSC, 2 PLL, RTC, 2 Watchdog
Backup SRAM – 1KB
Voltage Regulator, POR
Security
AES-256
Integrity Check Monitor (SHA)
TRNG
Memory Scrambling
24ch-DMA Controller
150MHz Matrix
1 HS USB Dev./Host w/ PHY
1 HS SDIO/SD/e.MMC
5 UART, 3 USART, 2 SPI, 3 TWI
1 QSPI
SAM E70 Only
2 CAN-FD
EMAC 10/100
Connectivity
114 IOs
8x 16-bit PWM
12x 16-bit Timers
2x 12-ch 12-bit ADC
2-ch 12-bit DAC
Control
Camera Interface
1x I2S / TDM
User Interface

# Cosmo ArduSiPM (GEN2)

ArduSIPM analog + SAMV71

INFN-Microchip Technology
Collaboration Agreement ref. TTD 1008M1 020




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

9.6 cm


Cubesat LEO or MEO

Euso SPB2 33 Km

ArduSiPM



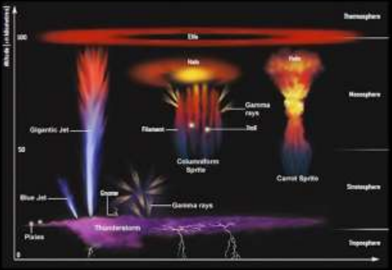
Grams

TGF, TLEs (elves)

ELVES toward the limb

ToO events, GRB, Cherenkov

Charged particles





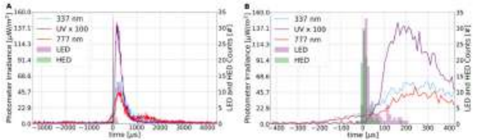
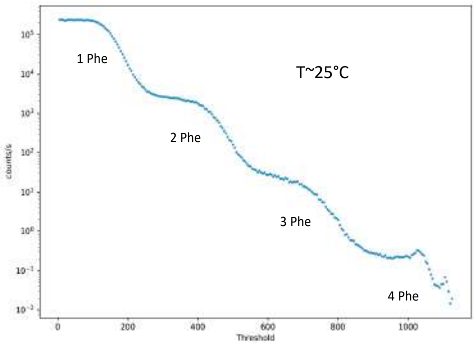
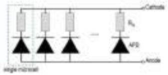




**Fig. 2. Light curves of the event.** The gamma-flash trigger time is at $t = 0$ which corresponds to 13:01:33.100080 UTC. (**A**) Photometer (left axis), X-ray and gamma-ray (right axis) measurements around the time of the event. LED is the low-energy X-ray detector (50-350 keV) and HED the high-energy detector (300 keV-30 MeV). The UV photometer measures 180-235 nm and is multiplied by 100 to show on the same scale as the optical photometers. All three photometers sample at 100 kHz. (**B**) The same data shown zoomed in further at the time of the TGF.

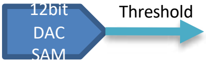
# Cosmo ArduSiPM : SiPM Automatic Characterization




$3.3V/2^{12} \sim 0.8mV$ / step

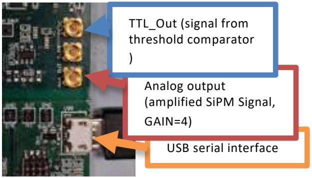


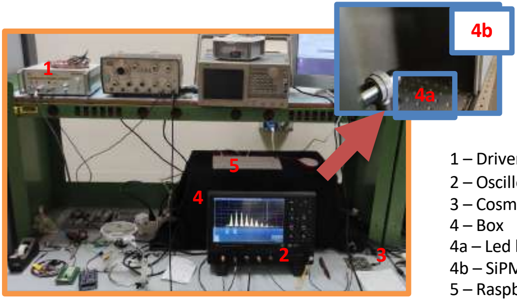
- SiPM is a matrix of almost identical APD in Geiger-mode!
- The information in SiPM signal is basically discrete: the amplitude of signal is function of number of switched-on cells.
- Automatic scan of dark count as function of threshold allows to characterize the SiPM and measure the single cell signal amplitude



# CosmoArduSiPM Optical test Bench

- The hardware was studied in an optical testbench.
- Comparator output was used for timing characterization
- Analog output was used to compare measure with 12bit Lecroy oscilloscope



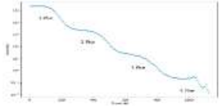




1 – Driver LED Picoquant PDL 800-B (pulse width 800 ps)
2 – Oscilloscope LECROY 12bit, 2Gsample/s, 4000Mhz Bandwidth
3 – Cosmo ArduSiPM
4 – Box
4a – Led heads 460nm
4b – SiPM 13360-1325CS Hamamatsu
5 – Raspberry PI

# Some measurements with GEN2 (Cosmo ArduSiPM)

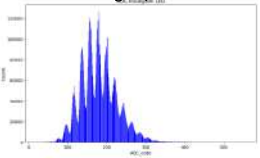
(see also Poster Session N-01-173)

## Threshold Scan Plot



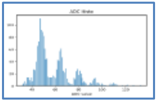

Threshold scan and its derivative (comparable to ADC spectra)

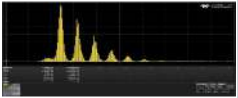
## Pulsed light (centered about 10 Phe)



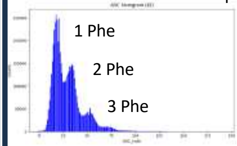
## Photons spectra

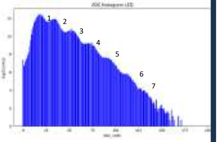
Cosmo ArduSiPM vs 12 bits Le Croy Scope





## Dark noise + pulsed light >2 phe

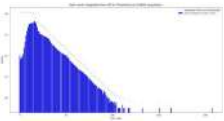



Lin scale

Log scale


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

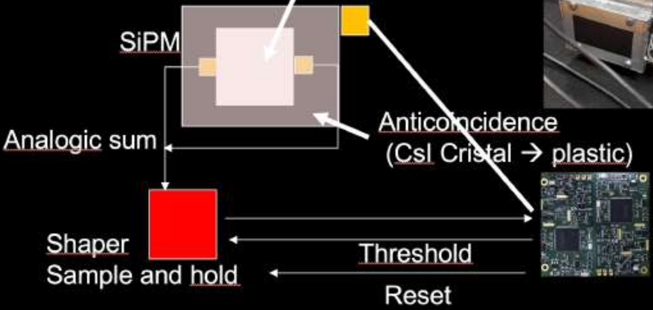


ADC spectra the integral show to be equivalent to the scan plot

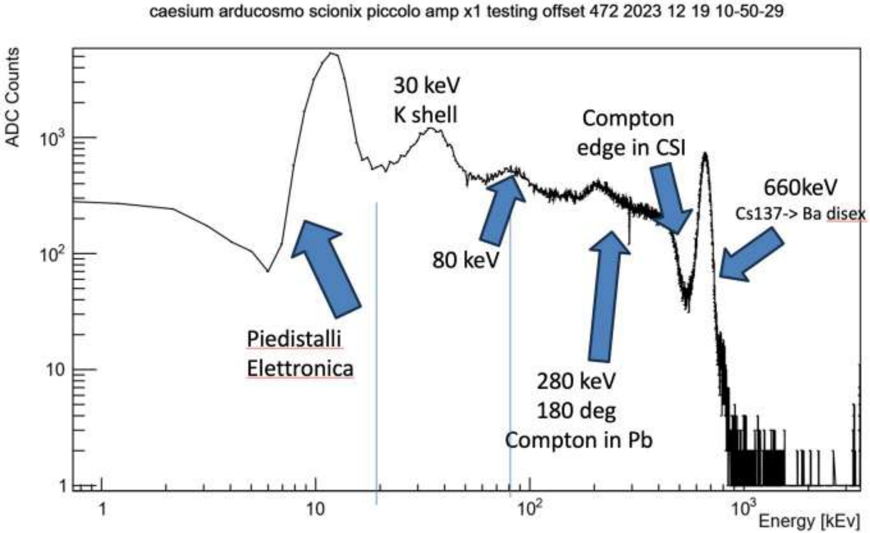
Credits to the graduating students, Simone Mariottini and Lorenza Masi

# Gamma Spectrometer with anticoincidence

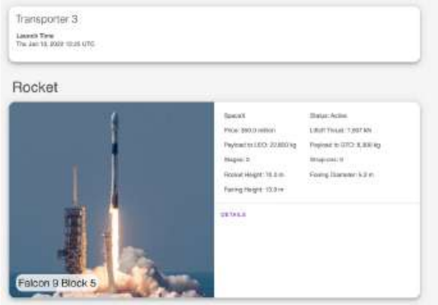
CsI scintillator

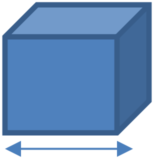



# Spectrum of Cs137



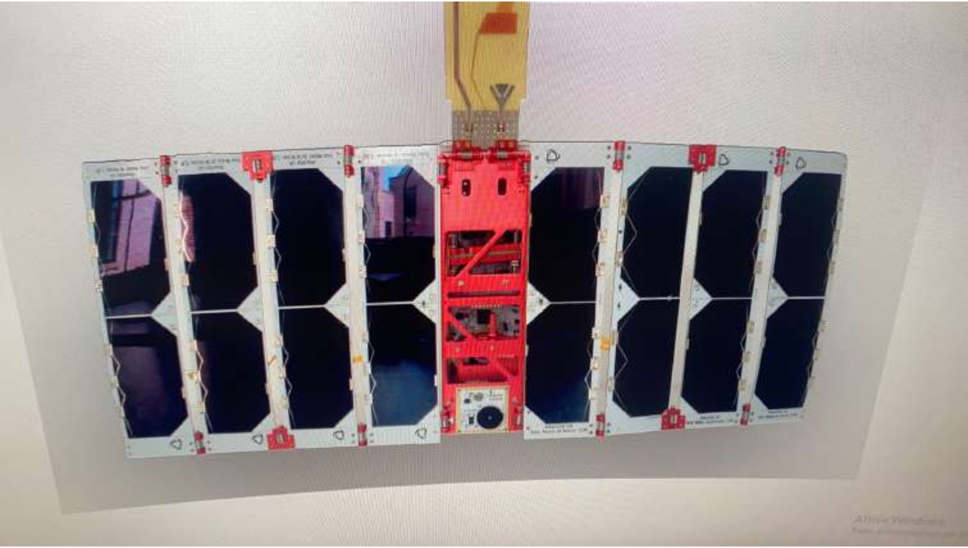
# Picosatelliti

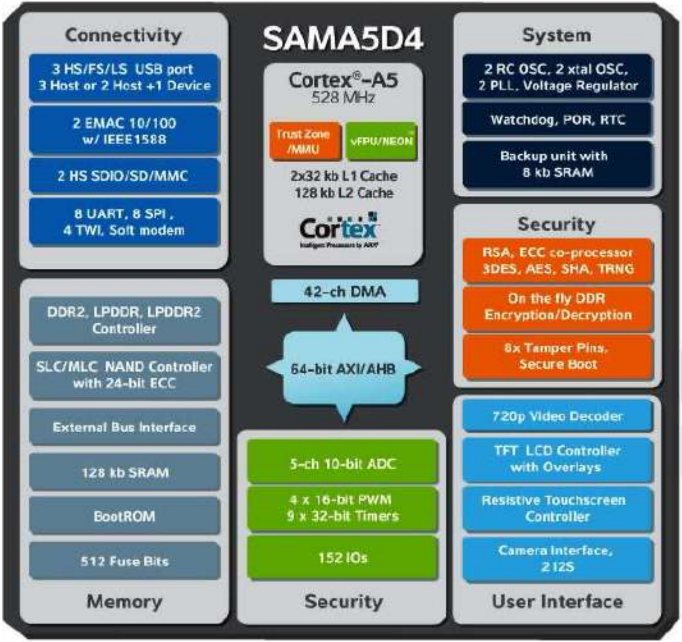



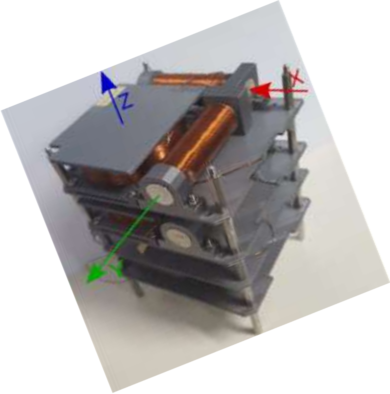
1P

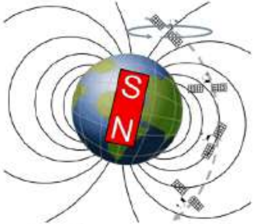
5 cm



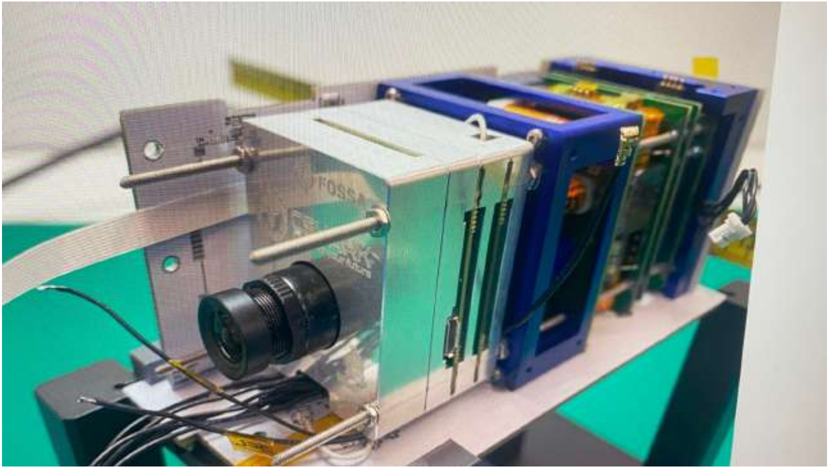

SAMA5D4
Connectivity
3 HS/FS/LS USB port
3 Host or 2 Host +1 Device
2 EMAC 10/100
w/ IEEE1588
2 HS SDIO/SD/MMC
8 UART, 8 SPI,
4 TWI, Soft modem
Cortex®-A5
528 MHz
Trust Zone /MMU
vFPU/NEON
2x32 kb L1 Cache
128 kb L2 Cache
Cortex
System
2 RC OSC, 2 xtal OSC,
2 PLL, Voltage Regulator
Watchdog, POR, RTC
Backup unit with
8 kb SRAM
Security
RSA, ECC co-processor
3DES, AES, SHA, TRNG
On the fly DDR
Encryption/Decryption
8x Tamper Pins,
Secure Boot
42-ch DMA
64-bit AXI/AHB
DDR2, LPDDR, LPDDR2
Controller
SLC/MLC NAND Controller
with 24-bit ECC
External Bus Interface
128 kb SRAM
BootROM
512 Fuse Bits
Memory
5-ch 10-bit ADC
4 x 16-bit PWM
9 x 32-bit Timers
152 IOs
Security
720p Video Decoder
TFT LCD Controller
with Overlays
Resistive Touchscreen
Controller
Camera Interface,
2 I2S
User Interface

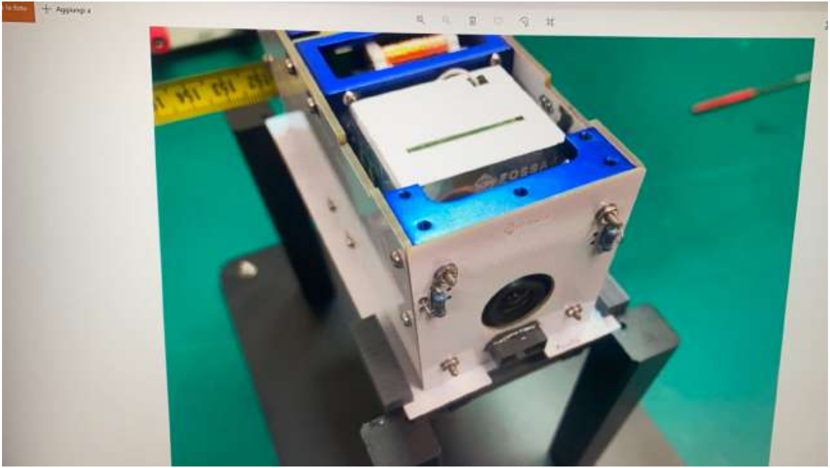
# Magnetorquer



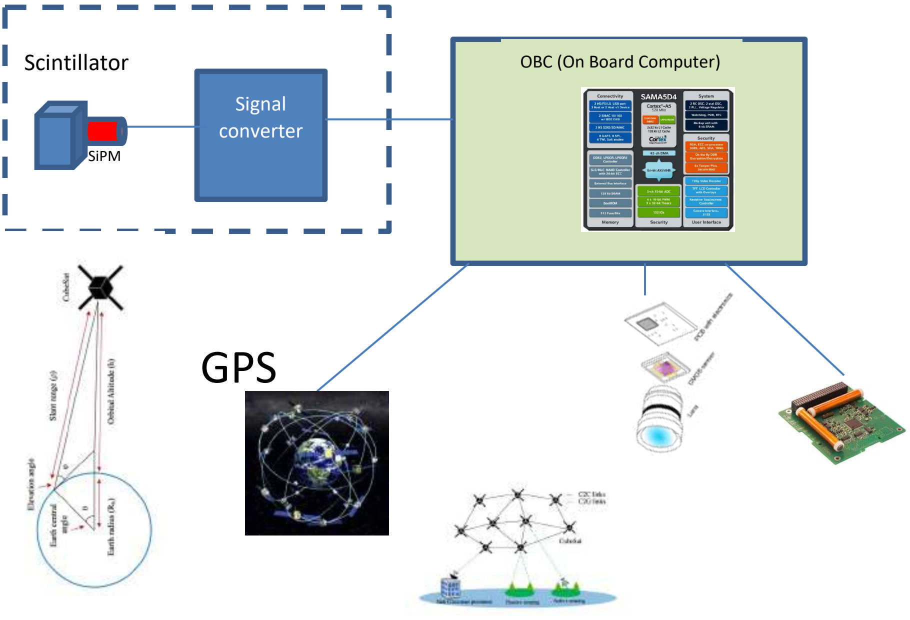




Credits: ESA/Lusospace

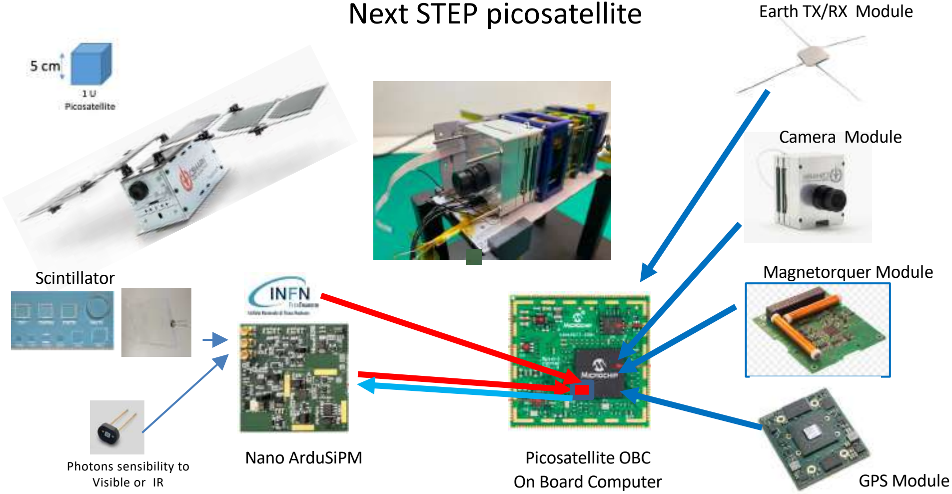

FOSSA


Aggiungi a

# ArduSiPM Detector technology for nanosatellite Radiation monitor

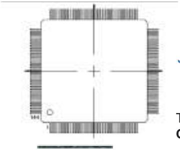


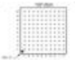
# Next STEP picosatellite



# Nano ArduSiPM  Gen3 (2023)

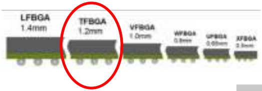
22 mm

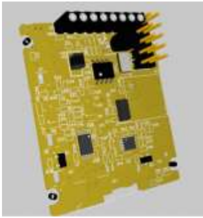


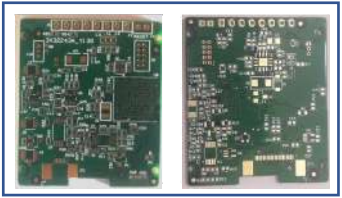


9 mm

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

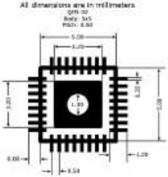
2 $cm^2$/ch
3 g/ch

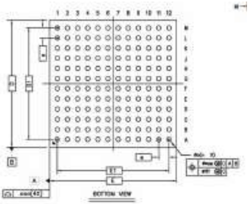
**Valerio Bocci INFN Roma Vancouver 2023 NSS-MIC-RTSD**

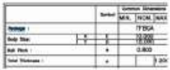
The Upcoming 4th Generation:

LITE-SPLD Project

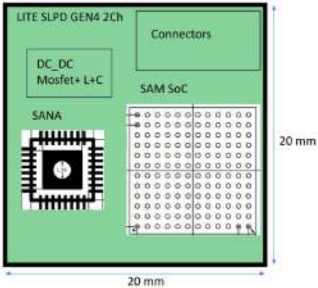
(Lightweight Integrated Technology for Space Luminescence and Particle Detection)



| | Symbol | MIN. | NOM. | MAX. |
|---|---|---|---|---|
| Package : | | | TFBGA | |
| Body Size | | | 10.000 | |
| Ball Pitch : | e | | 0.800 | |
| Total thickness : | A | | | 1.20 |

# Tesi triennali e magistrali disponibili:

Valerio.bocci@roma1.infn.it
Valerio.bocci@uniroma1.it
Valerio.bocci@cern.ch

Telegram:
https://t.me/ValerioBocci

https://cern.zoom.us/my/valeriobocci

Tesi svolte:
https://sites.google.com/view/particle-detectors/thesis