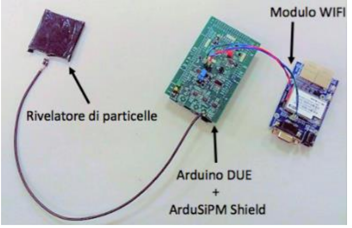
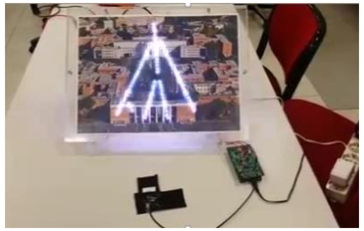
INFN Istituto Nazionale di Fisica Nucleare

Relatore: Dr Valerio Bocci
INFN Roma

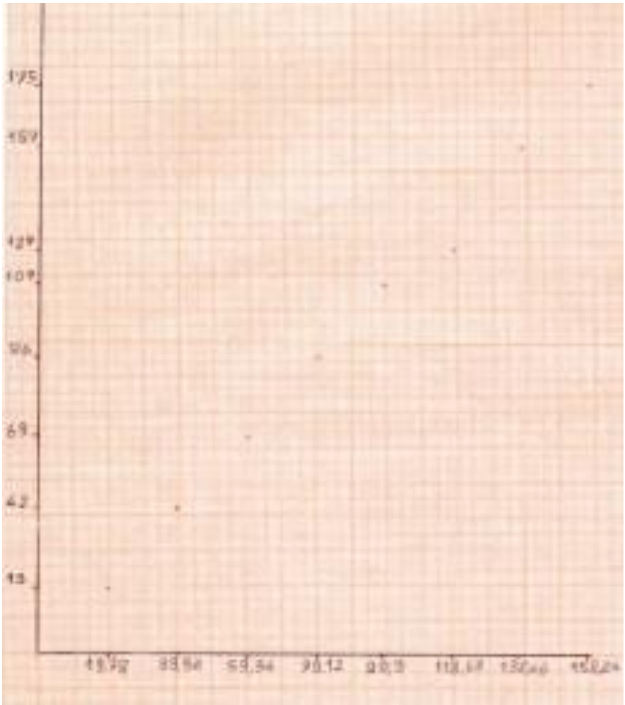




La storia moderna dei sistemi di acquisizione inizia nel 1963 con l'IBM 7700, il primo calcolatore dedicato. Da allora l'evoluzione è stata sempre più rapida fino ad arrivare alla possibilità di costruire un sistema completo in un singolo Chip.
ArduSiPM è un rivelatore di particelle che utilizza la moderna tecnologia dei microcontrollori. Dato il suo basso costo può essere utilizzato come esempio didattico di un rivelatore di particelle con annesso sistema di acquisizione.

Martedì 2 Novembre2016
Ore 16:30
Aula Amaldi
Dipartimento di Fisica
Università Sapienza

Measurement and data elaboration before 1963

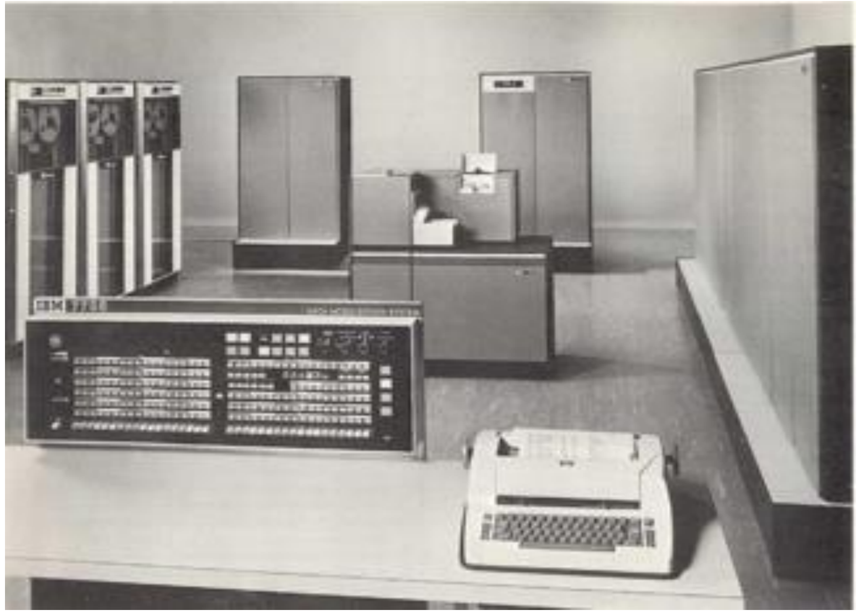


IBM 1800 Novembre 1964

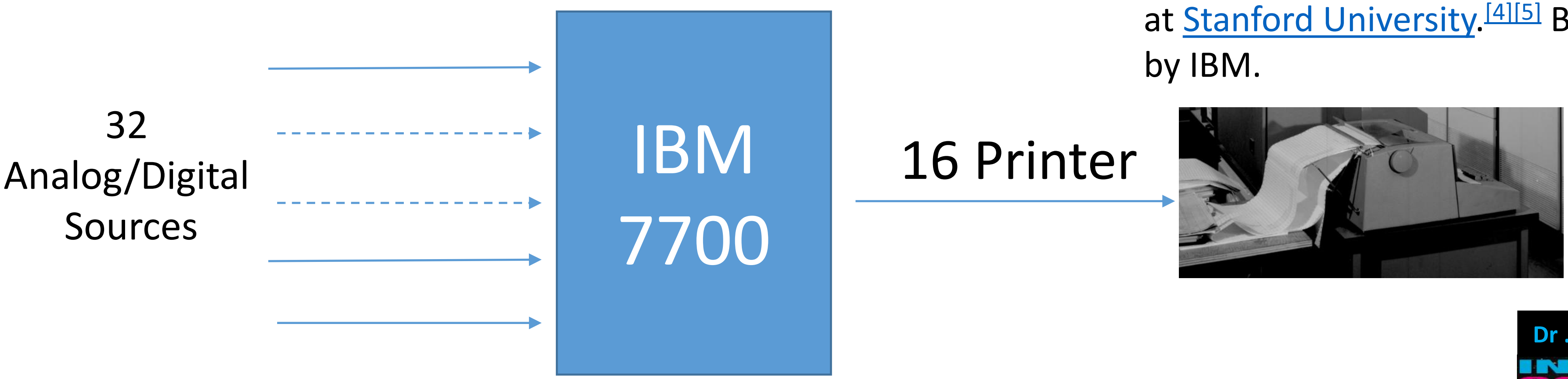
Typical 1800 systems designed for process control applications could be rented for $2,300 to $6,600 a month or purchased for between $95,000 and $274,000. When used in a data acquisition environment, the monthly rental ranged between $2,770 and $11,100, including magnetic tapes, and the purchase price varied between $125,000 and $534,000.

IBM 7700 Data acquistion System(DAS)

Dicember 1963



- The IBM 18-bit system,
- instructions 2x 18-bit words.
- Arithmetic instructions two or three machine cycles,
- Multiply, 8 cycles, and divide, 12 cycles.
- machine cycle 2 microseconds ½ MHz **(0.0005 GHz)**
- two machines known to have been built had 16,384, 32,768 or 49,152 words.
- 25 KHz ADC
- Two IBM 7700 are known to have existed: one at the University of Rochester[2][3] and the other at Stanford University.[4][5] Both were donated by IBM.

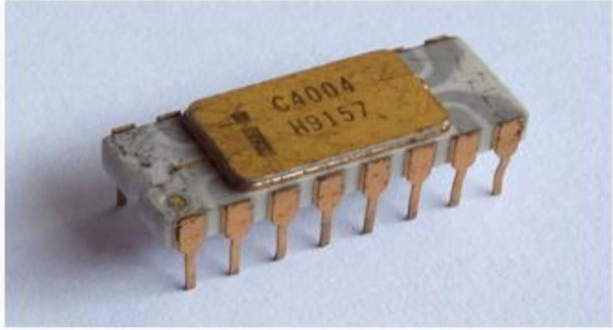


The birth of microprocessors 1971

Federico Faggin
1972

The 4004 was built for the Busicom 141-PF Desk Calculator

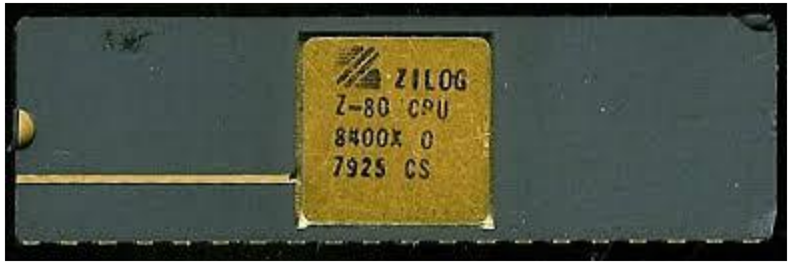
Intel 4004



Intel C4004 microprocessor

Produced	From late 1971 to 1981
Common manufacturer(s)	Intel
Max. CPU clock rate	740 kHz
Min. feature size	10 µm
Instruction set	4-bit BCD-oriented
Transistors	2300 [1]
Data width	4
Address width	12 (multiplexed)
Successor	Intel 4040 Intel 8008
Application	Busicom calculator, arithmetic manipulation
Package(s)	16-pin DIP

Federico Faggin started Zilog in 1974 .



Zilog
Z80
1974

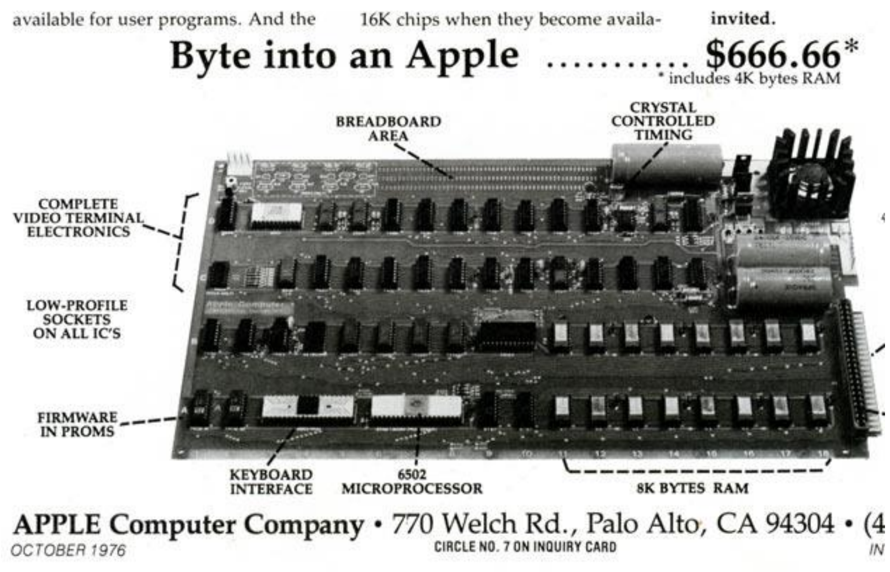
Think of your next microcomputer as a weapon against horrendous inefficiencies, outrageous costs and antiquated speeds. We invite you to peruse this chart.

Features:	8080A	Z80-CPU	Features:	8080A	Z80-CPU
Power Supplies	+5,−5,+12	+5	Instructions	78	158*
Clock	2Φ,+12 Volt	1Φ,5 Volt	OP Codes	244	696
Standard Clock Speed	500 ns	400 ns	Addressing Modes	7	11
Interface	Requires 8222, 8228 & 8224	Requires no other logic and includes dynamic RAM Refresh	Working Registers	8	17
			Throughput	Up to 5 times greater than the 8080A	
Interrupt	1 mode	3 modes; up to 6X faster	Program Memory Space	Generally 50% less than the 8080A	
Non-maskable Interrupt	No	Yes	*Including all of the 8080A's instructions.		

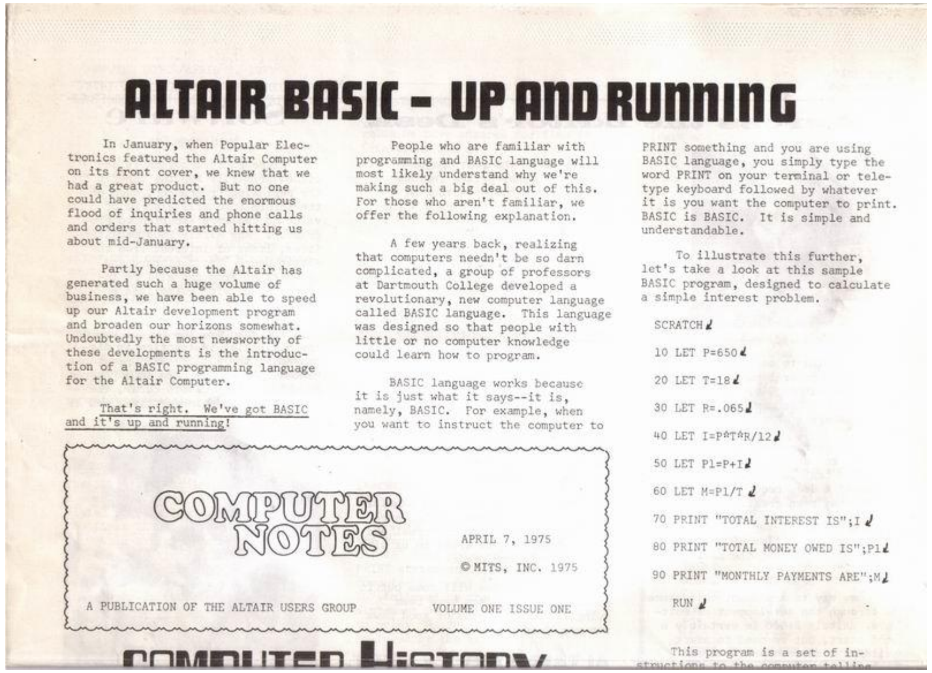
Microprocessor as building block of modern computer
1975 Homebrew Computer Club

Steve Jobs and Steve Wozniak

Hombrew computer club meeting
Stanford Linear ACCelerator (SLAC) Auditorium



1975 Not only Hardware but also software
The first BASIC language for microprocessor.



ALTAIR BASIC - UP AND RUNNING

In January, when Popular Electronics featured the Altair Computer on its front cover, we knew that we had a great product. But no one could have predicted the enormous flood of inquiries and phone calls and orders that started hitting us about mid-January.

Partly because the Altair has generated such a huge volume of business, we have been able to speed up our Altair development program and broaden our horizons somewhat. Undoubtedly the most newsworthy of these developments is the introduction of a BASIC programming language for the Altair Computer.

That's right. We've got BASIC and it's up and running!

People who are familiar with programming and BASIC language will most likely understand why we're making such a big deal out of this. For those who aren't familiar, we offer the following explanation.

A few years back, realizing that computers needn't be so darn complicated, a group of professors at Dartmouth College developed a revolutionary, new computer language called BASIC language. This language was designed so that people with little or no computer knowledge could learn how to program.

BASIC language works because it is just what it says--it is, namely, BASIC. For example, when you want to instruct the computer to PRINT something and you are using BASIC language, you simply type the word PRINT on your terminal or teletype keyboard followed by whatever it is you want the computer to print. BASIC is BASIC. It is simple and understandable.

To illustrate this further, let's take a look at this sample BASIC program, designed to calculate a simple interest problem.

```
SCRATCH
10 LET P=650
20 LET T=18
30 LET R=.065
40 LET I=P*T*R/12
50 LET P1=P+I
60 LET M=P1/T
70 PRINT "TOTAL INTEREST IS";I
80 PRINT "TOTAL MONEY OWED IS";P1
90 PRINT "MONTHLY PAYMENTS ARE";M
RUN
```

This program is a set of instructions to the computer telling

COMPUTER NOTES

APRIL 7, 1975

A PUBLICATION OF THE ALTAIR USERS GROUP

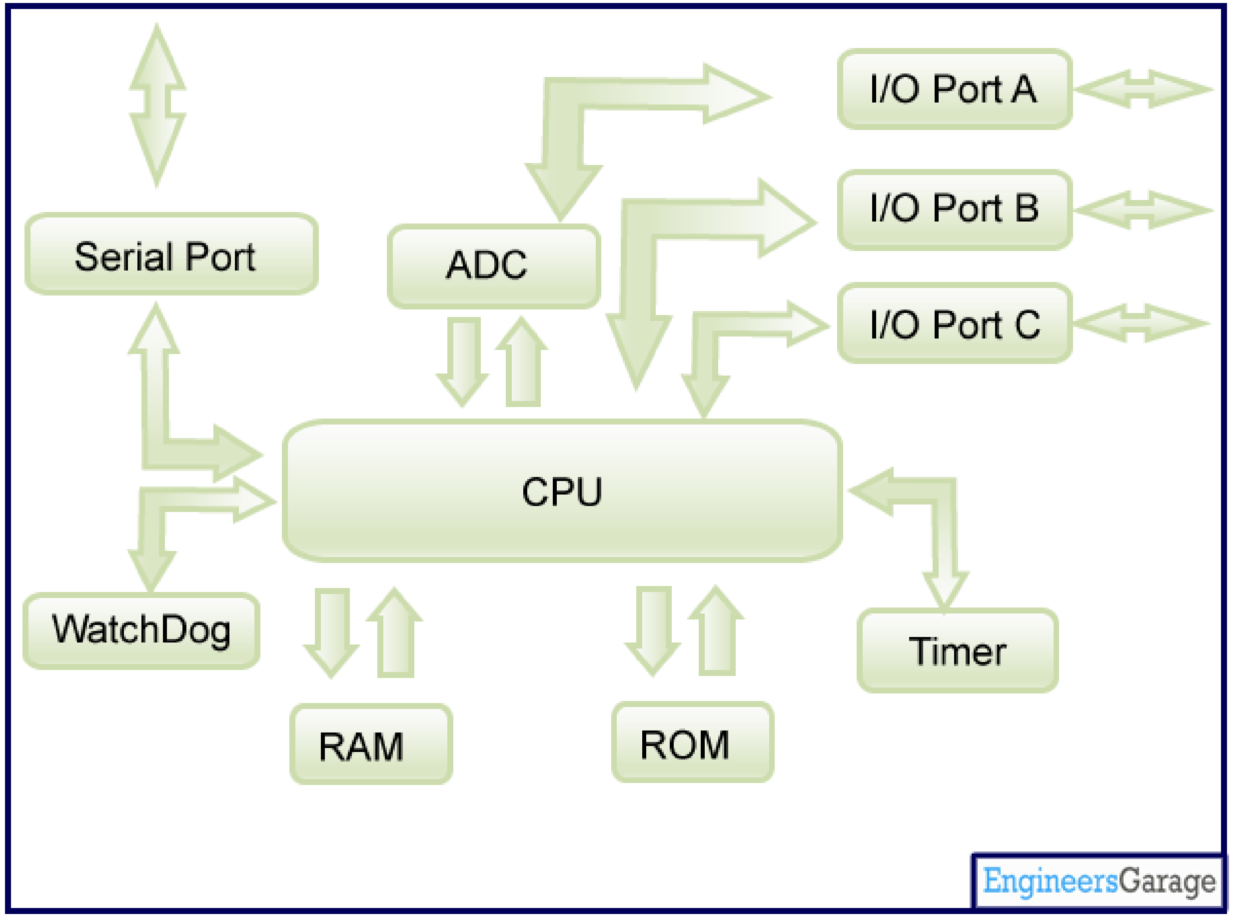
VOLUME ONE ISSUE ONE

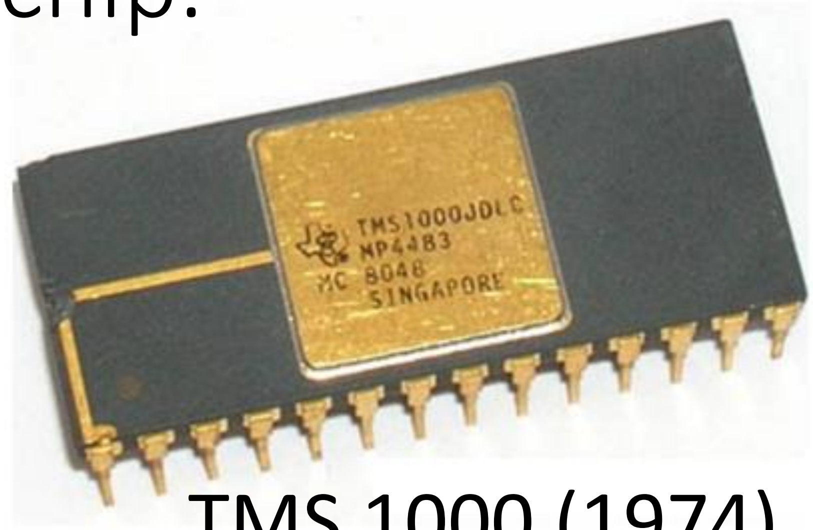
COMPUTER History

Altair Basic
The first Microsoft product

Bill Gates and Paul Allen

Microcontrollers (MCU)
System on Chip (SoC) Memory and peripheral in the same chip.

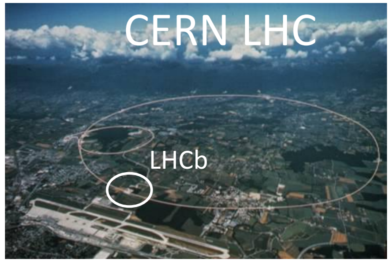




TMS 1000 (1974)

Texas Instrument 4-bit TMS 1000, was the first microprocessor to include enough RAM, and space for a program ROM, and I/O support on a single chip to allow it to operate without multiple external support chips, making it the first microcontroller.

LHCb Muon Detector Control System



IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 57, NO. 6, DECEMBER 2010

The Muon Front-End Control Electronics of the LHCb Experiment

Valerio Bocci, Giacomo Chiodi, Francesco Iacoangeli, Francesco Messi, and Rafael A. Nobrega

***Abstract*—The LHCb muon readout apparatus is made of 1368 Multi-Wire Proportional Chambers (MWPC) and 24 Gas Electron Multiplier (GEM) chambers connected to 7632 16-channel front-end boards, resulting in 122.112 channels to be read out.**

……………………………………………………………………………………

……………………………………………………………………………………

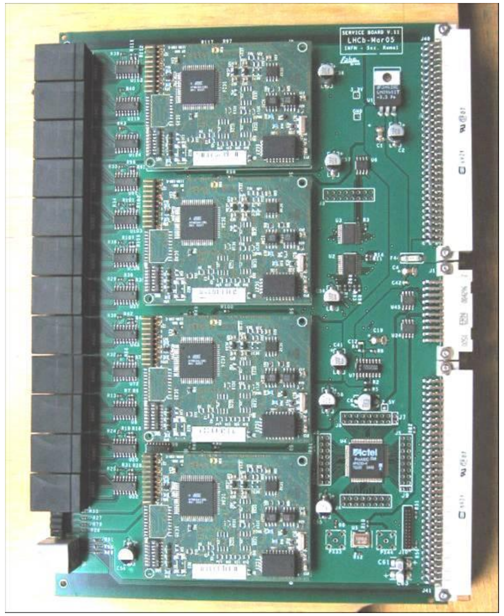
The large-scale of the system and the time constrains naturally led to the development of a custom and complex control system made of about 600 microcontrollers (μC) and 150 flash-based FPGAs which are directly connected to the front-end electronics and handled by six computers.

ELMB the Arduino of HEP (ATMega128 MCU)

Henk Boterenbrood
Nikhef

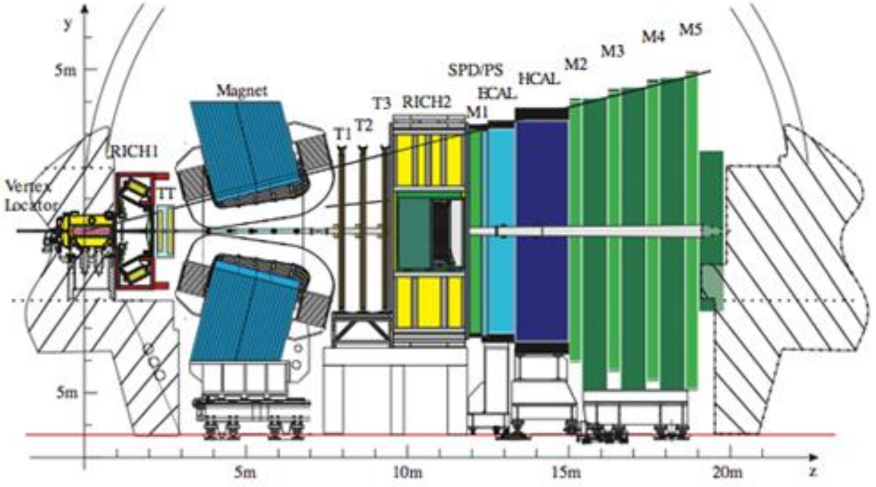
Björn Hallgren
CERN

156 x Service Board (SB)



Complex Software
only for real expert.
C programming.
Automotive CANBus in
radiation environment.

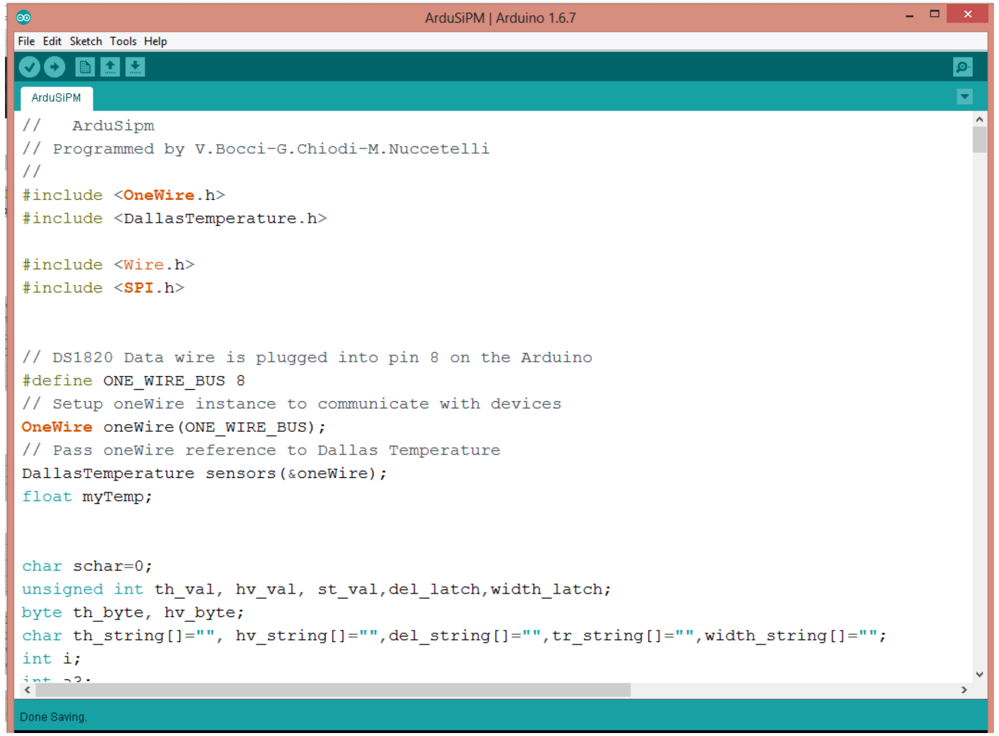
■ Muon Chambers



The Arduino revolution (2005)

Hardware: Microcontrollers boards

Software :Arduino Language

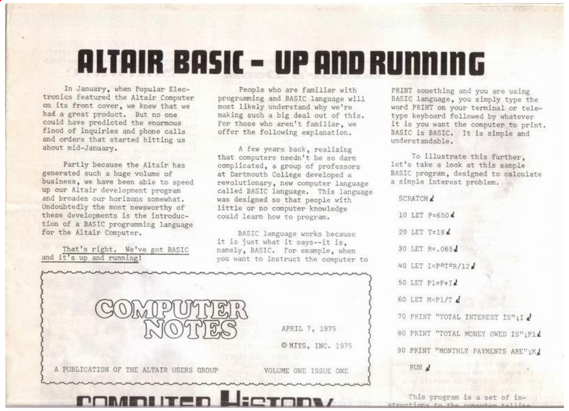


The world of microcontrollers for anybody. Simple programming language to program MCU.

Similarities with the beginning of the personal computer era

CPU

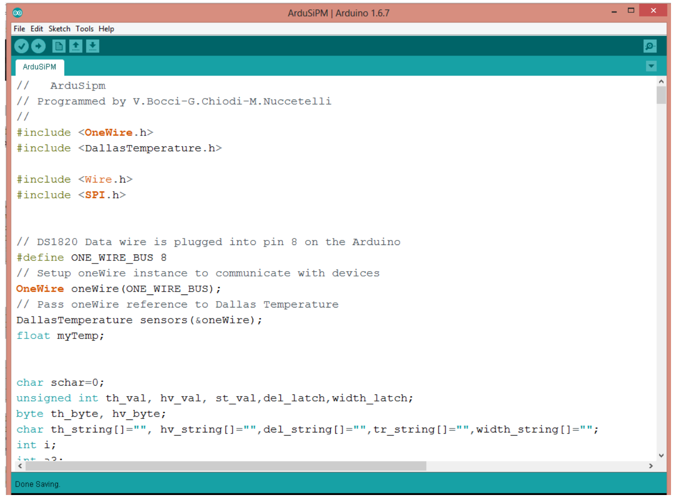
Basic



=

MCU

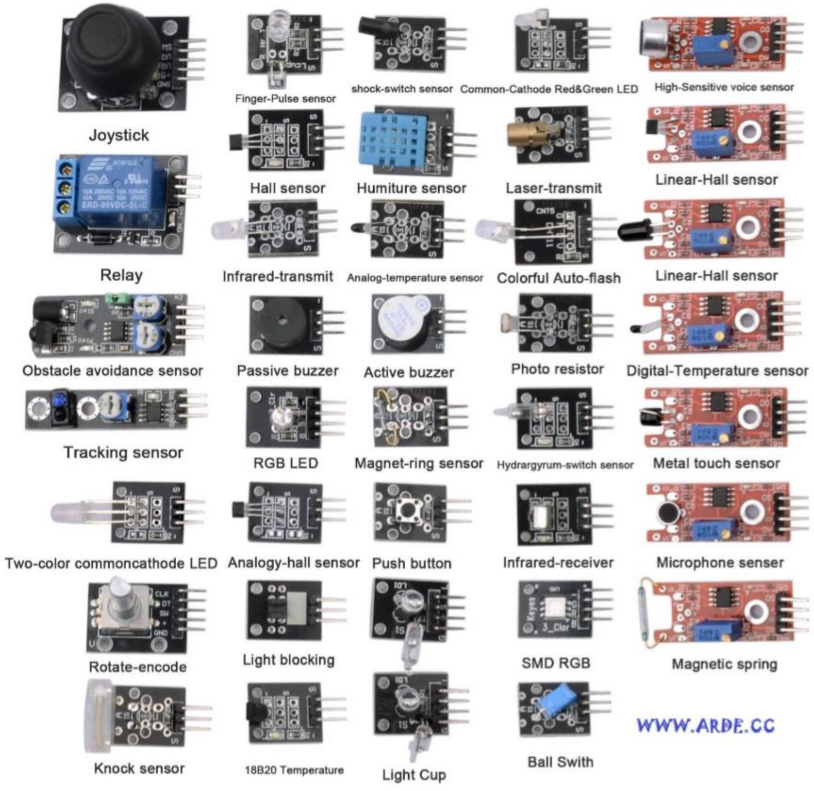
Arduino Language



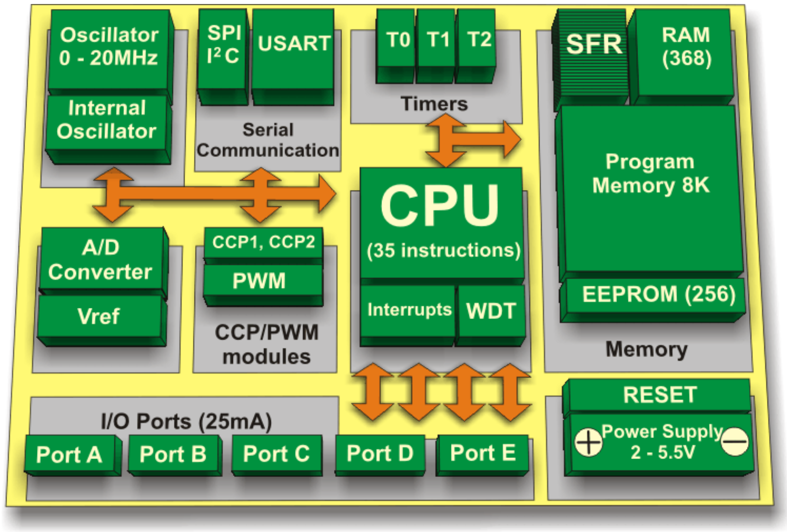
The world of microcontrollers for anybody. Simple programming language to program MCU.

The MCU as building block for Internet of Things

Sensors/Actuators



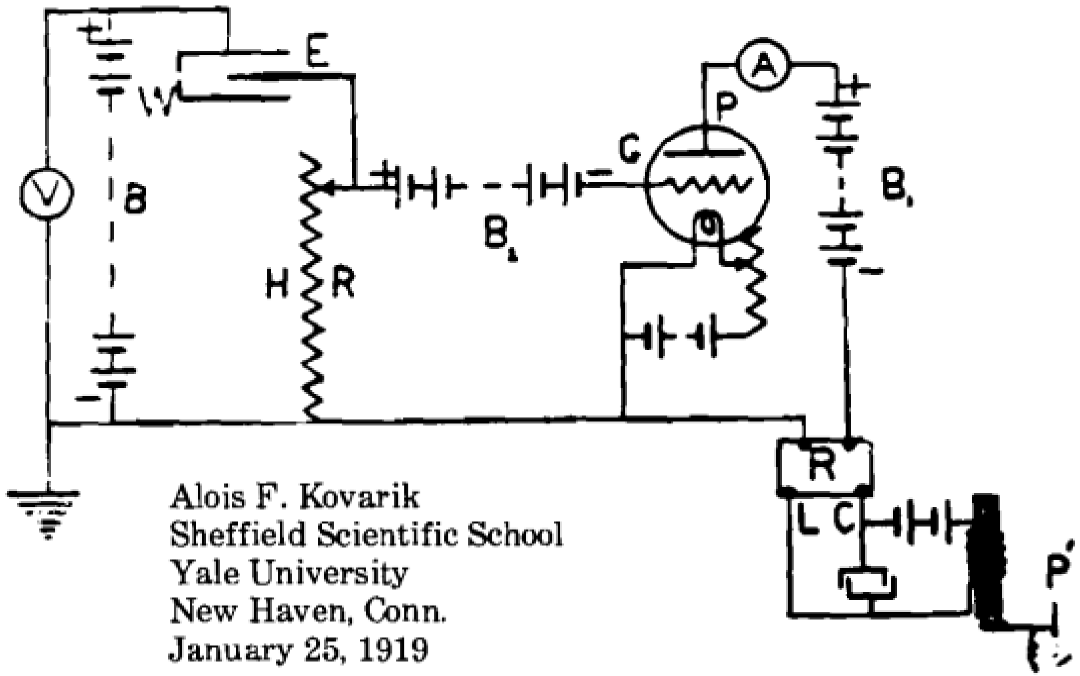
Microcontroller



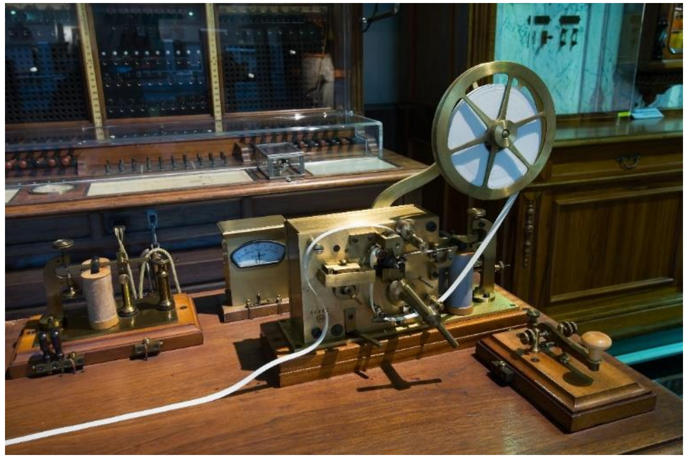
Internet Connection

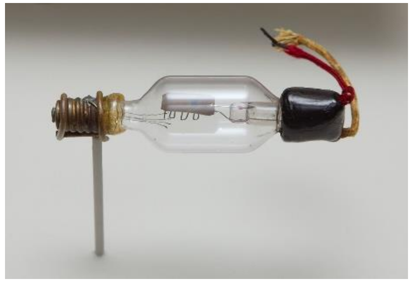
First Electronic particle detector 1919

ON THE AUTOMATIC REGISTRATION OF α-PARTICLES, β-PARTICLES AND γ-RAY AND X-RAY PULSES



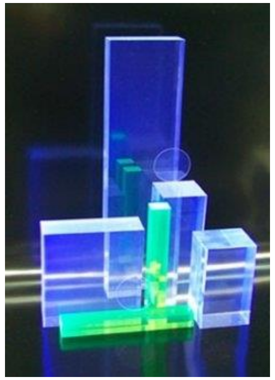
Alois F. Kovarik
Sheffield Scientific School
Yale University
New Haven, Conn.
January 25, 1919





Lee De Forest Audion tube from 1908, the first triode. its ability to amplify was recognized around 1912.

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

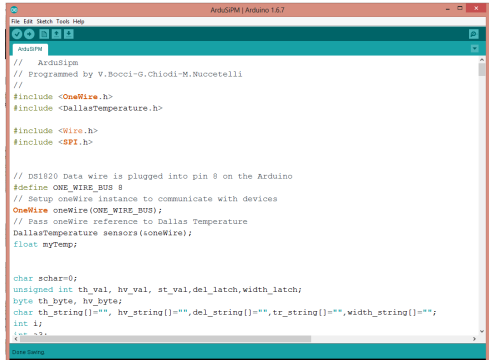


Scintillator

Photons Sensor
(SiPM)

Custom Electronics
(ArduSiPM Shield)

Arduino DUE



ArduSiPM Software

Particle Detector

ArduSiPM

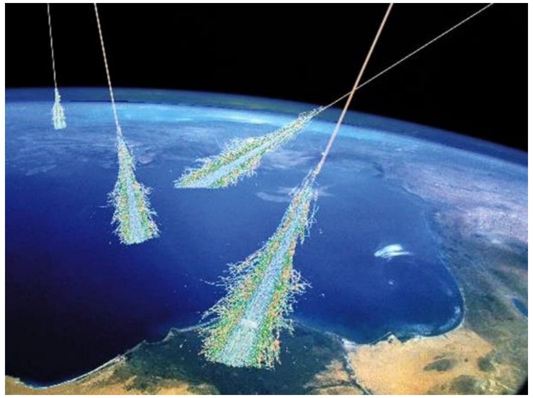
ArduSiPM a low cost particle detector

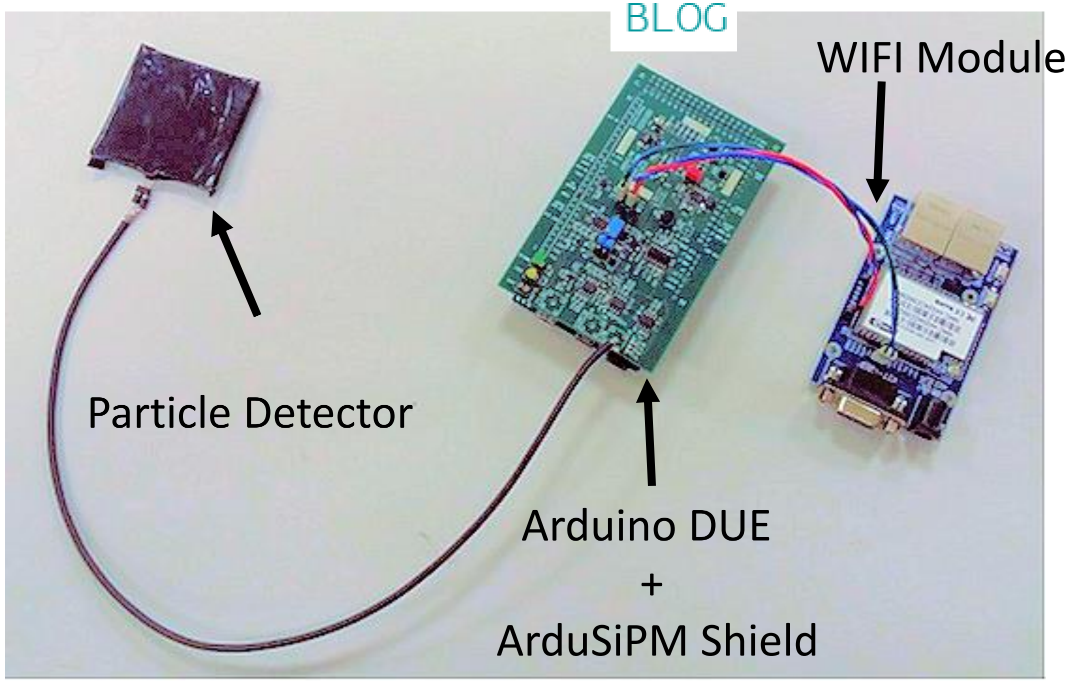
ARDUINO
BLOG

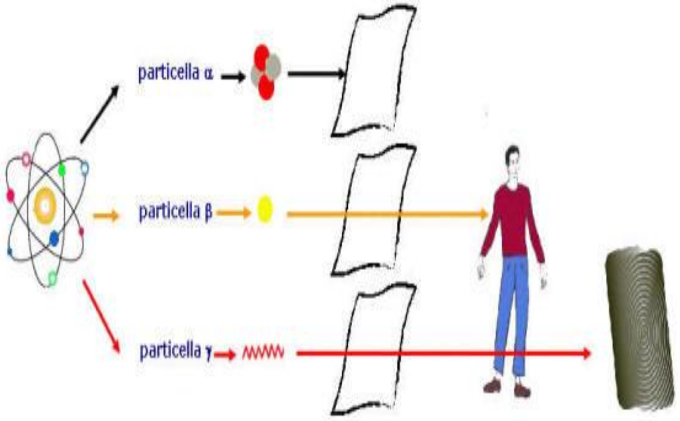
http://www.arduino.org/blog/ardusipm-solution

"The ambit of data acquisition for particle detection is a field apparently limited to top scientists from CERN in Geneva and Fermilab in Chicago. Cosmic ray and radiation detection can be a great exploration for teachers, students and science enthusiasts, and ArduSiPM was created to make it accessible."

Cosmic Ray detector

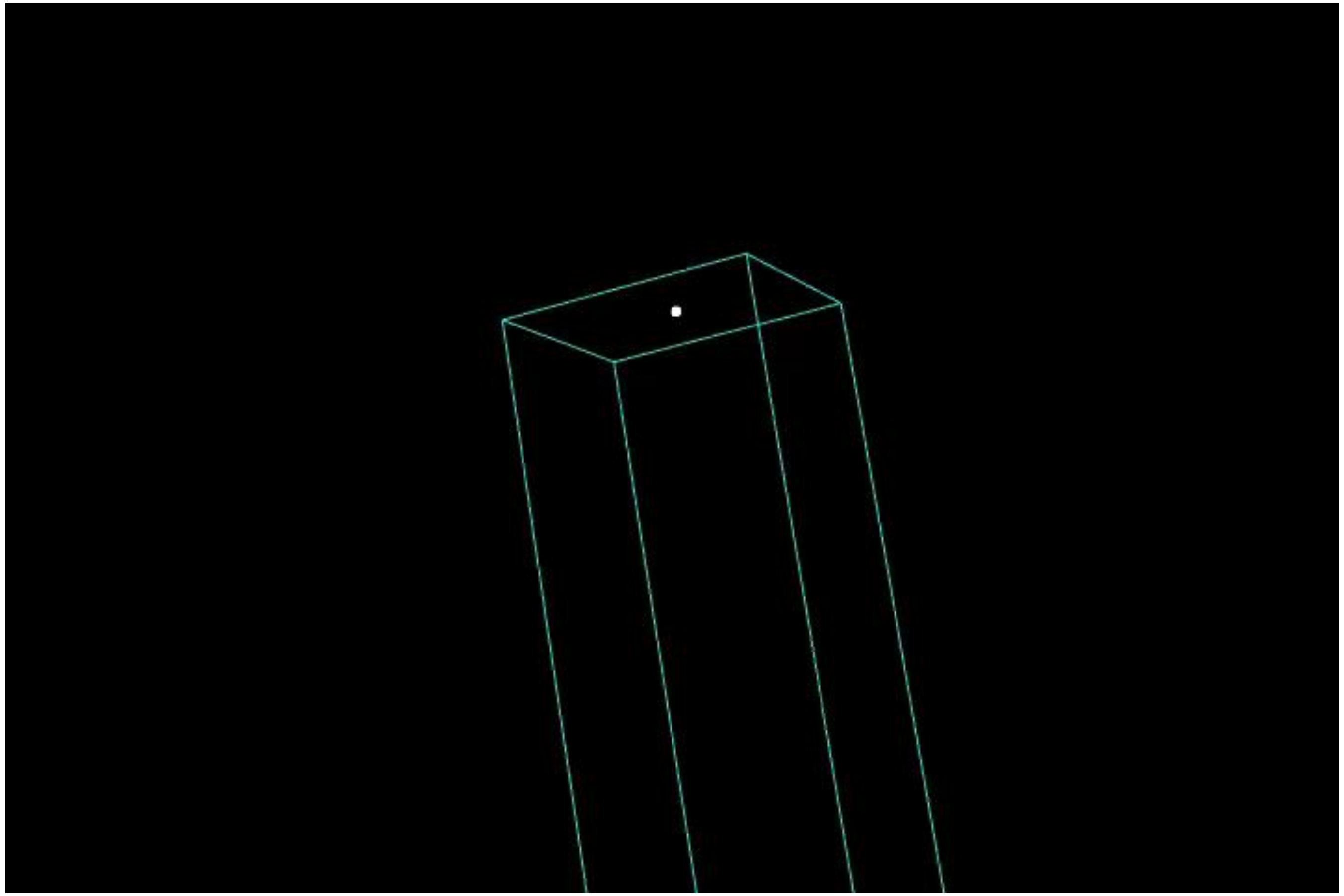


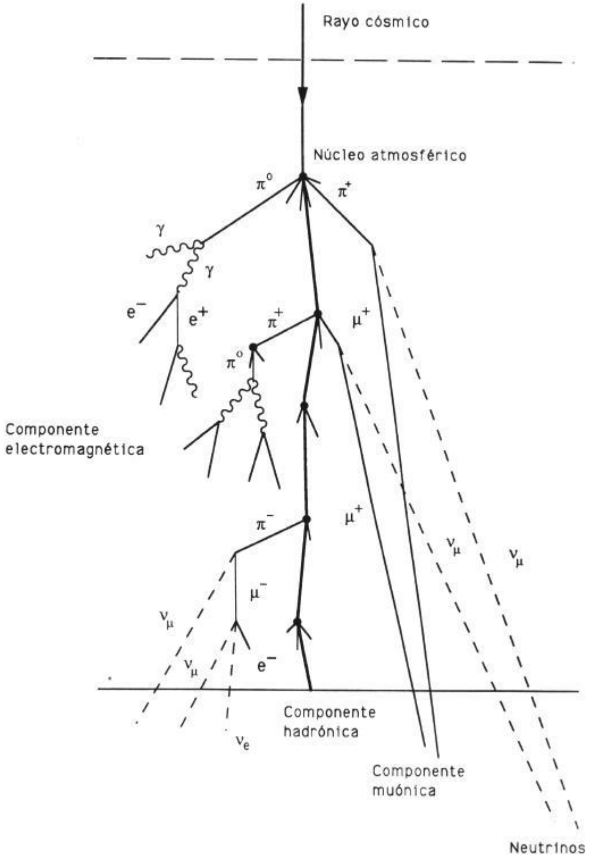


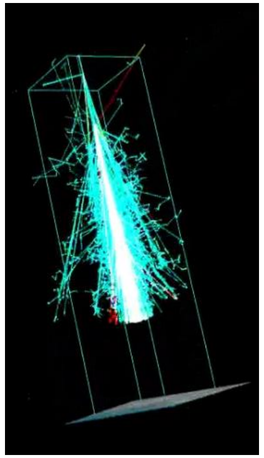


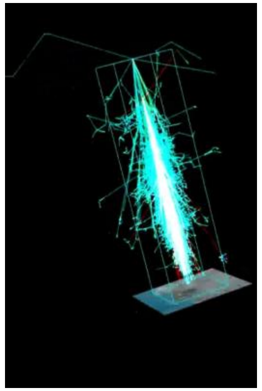
Cosmic Ray Shower animation

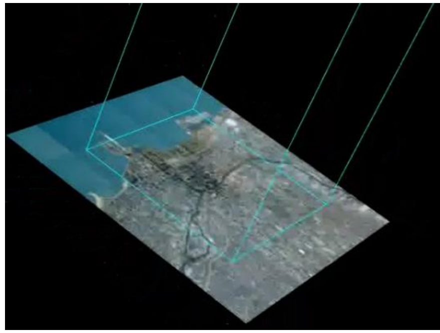
AIRES Cosmic Ray Showers
(http://astro.uchicago.edu/cosmus/projects/aires/)





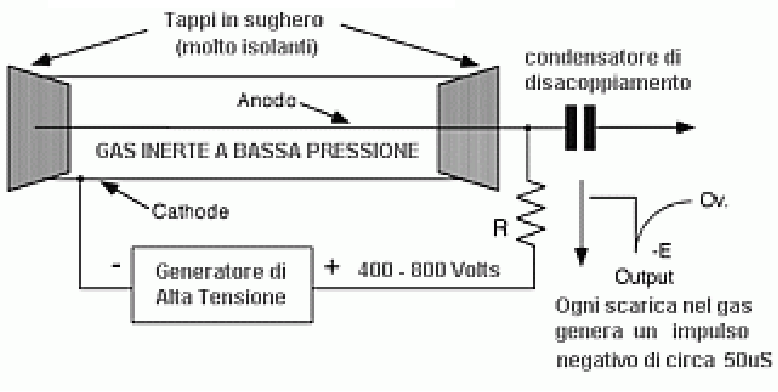




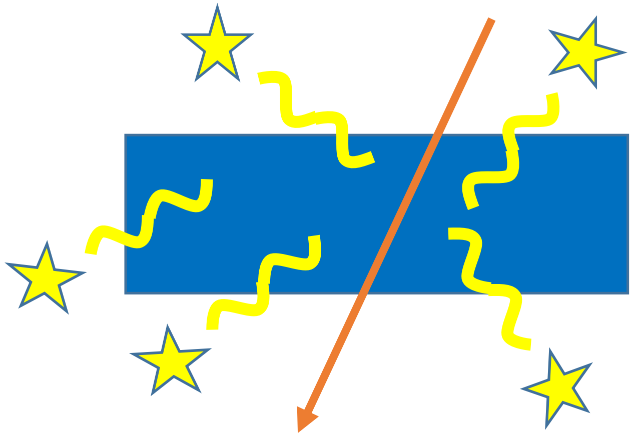


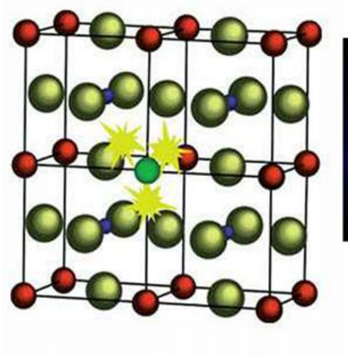
Some technics to detect ionizing particles

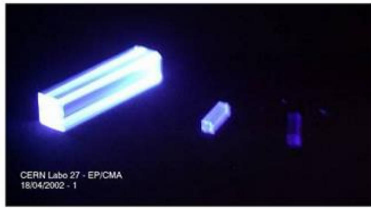
Tubo Geiger



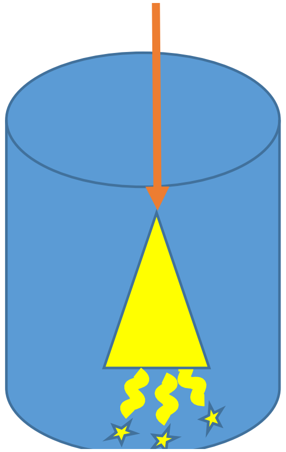
Scintillation materials

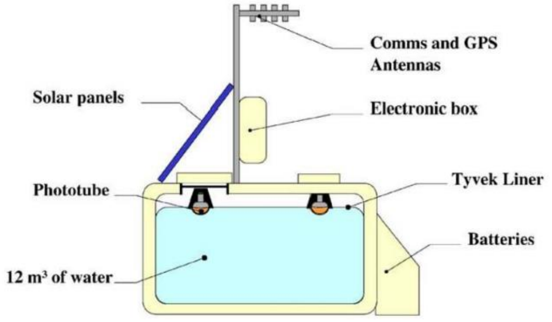






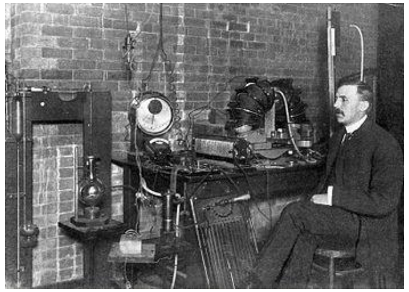
Cherenkov effects





The Geiger-Muller: A ‘900 detector.

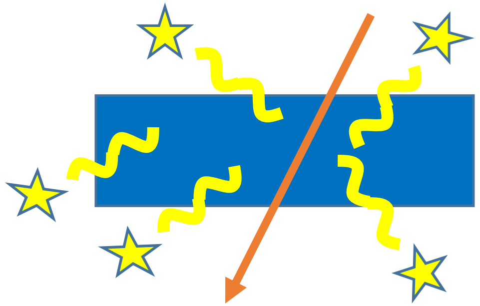
- Robust Technology 100 years old
- Economical
- Easy to find
- There are some Makers project
- The detector is preassembled from the factory



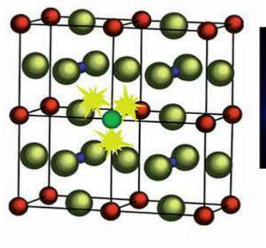
The discovery of atomic nuclei. Rutherford Hans Geiger and Ernest Marsden

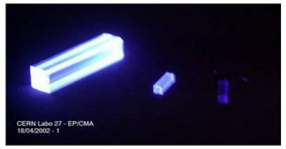
- High voltage discharge (need robust electronics)
- Low efficiency.
- Yes or No detector
- Fragile.

Using Scintillation materials



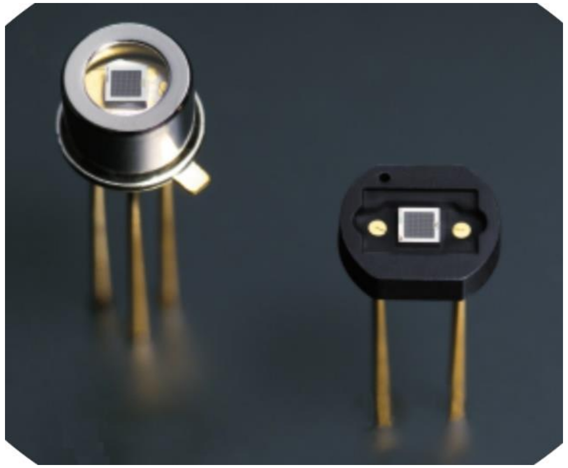
The use of scintillation materials is not for everyone in the past.
The only way was to use photomultiplier.

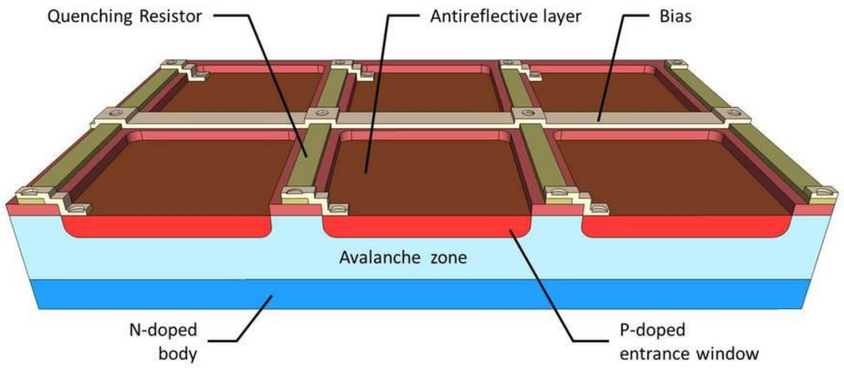


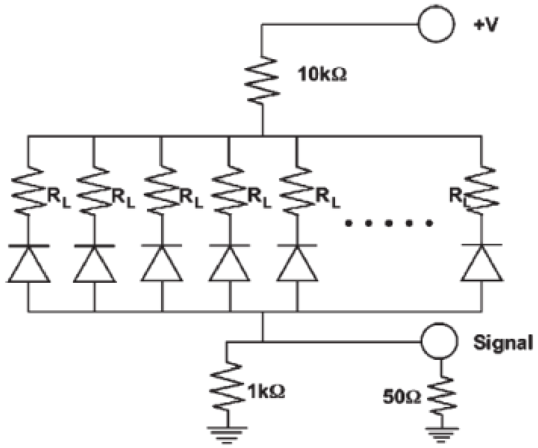


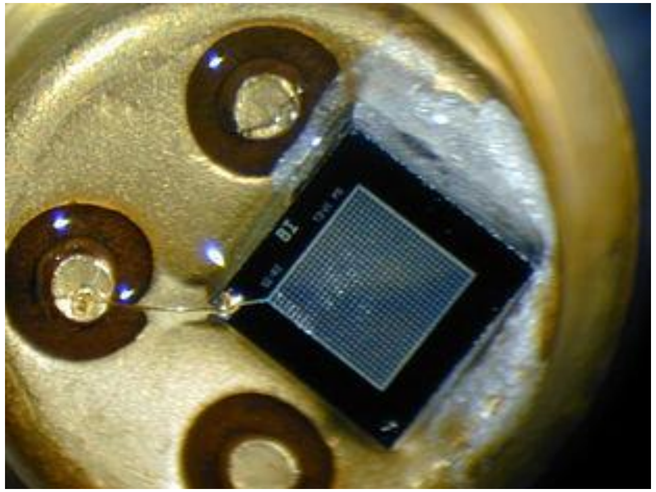
The Photomultiplier (1934).
Based on Photoelectric effect (1921 Einstein Nobel) and electron secondary emission.
The Photomultiplier are expensive and need high voltage(1000 Volt).

A solid state Photomultiplier SiPM (Silicon Photo Multiplier)





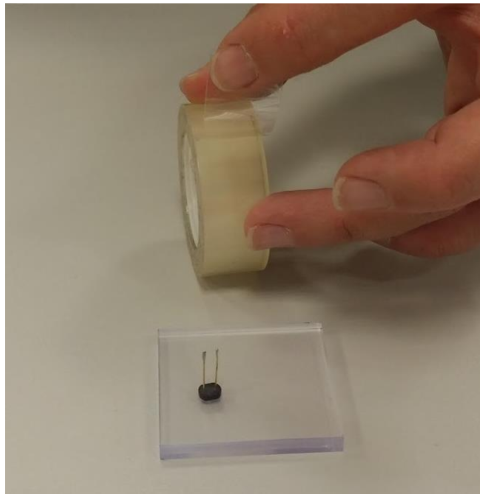


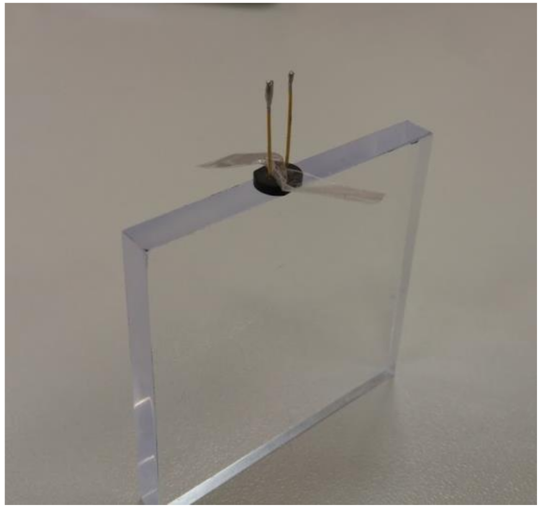


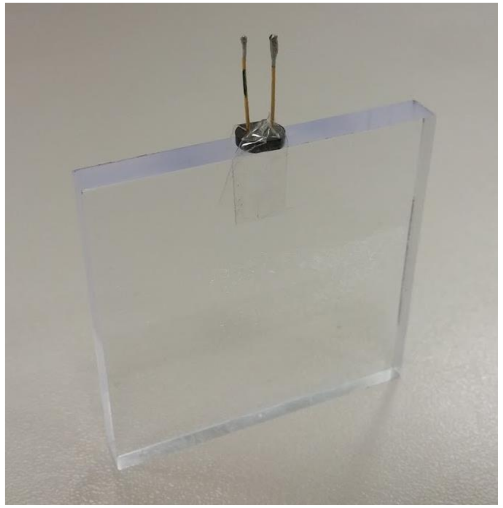
SiPM

Silicon photomultipliers, often called "**SiPM**" in the literature, are Silicon single photon sensitive devices built from an avalanche photodiode (APD) array on common Si substrate. The idea behind this device is the detection of single photon events in sequentially connected Si APDs. The dimension of each single APD can vary from 20 to 100 micrometres, and their density can be up to 1000 per square millimeter. Every APD in SiPM operates inGeiger-mode and is coupled with the others by a polysilicon quenching resistor. Although the device works in digital/switching mode, the SiPM is an analog device because all the microcells are read in parallel making it possible to generate signals within a dynamic range from a single photon to 1000 photons for just a single square millimeter area device. The supply voltage (V_b) depends on APD technology used, and typically varies between 20 V and 100 V, thus being from 15 to 75 times lower than the voltage required for a traditional photomultiplier tubes(PMTs) operation.

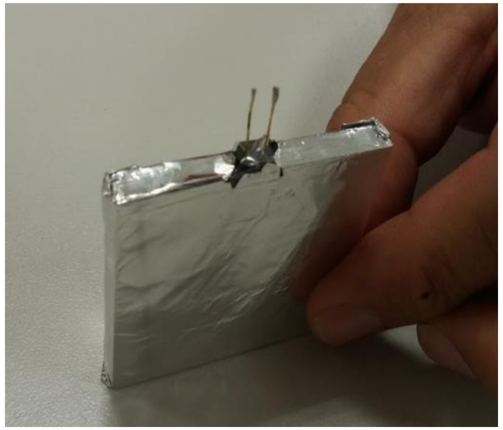
How to build a Scintillation detector with SiPM(1/2)





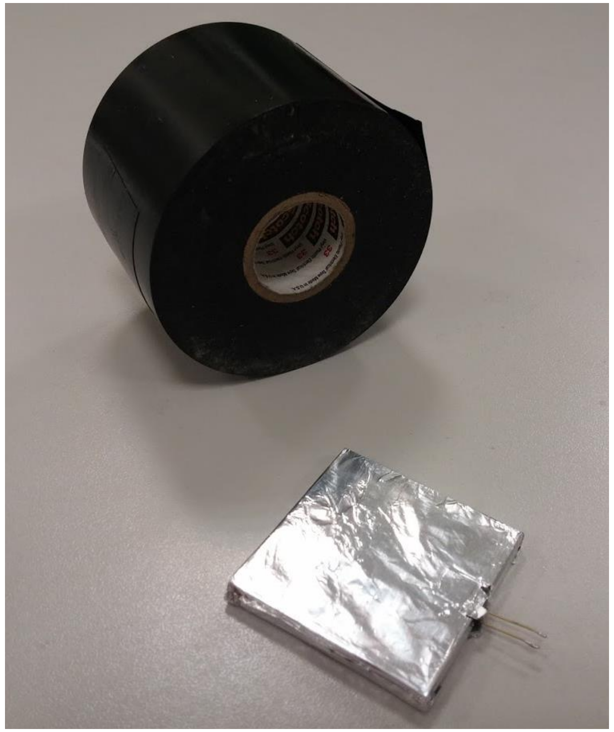


Attaching a SiPM to the scintillator with the scotch



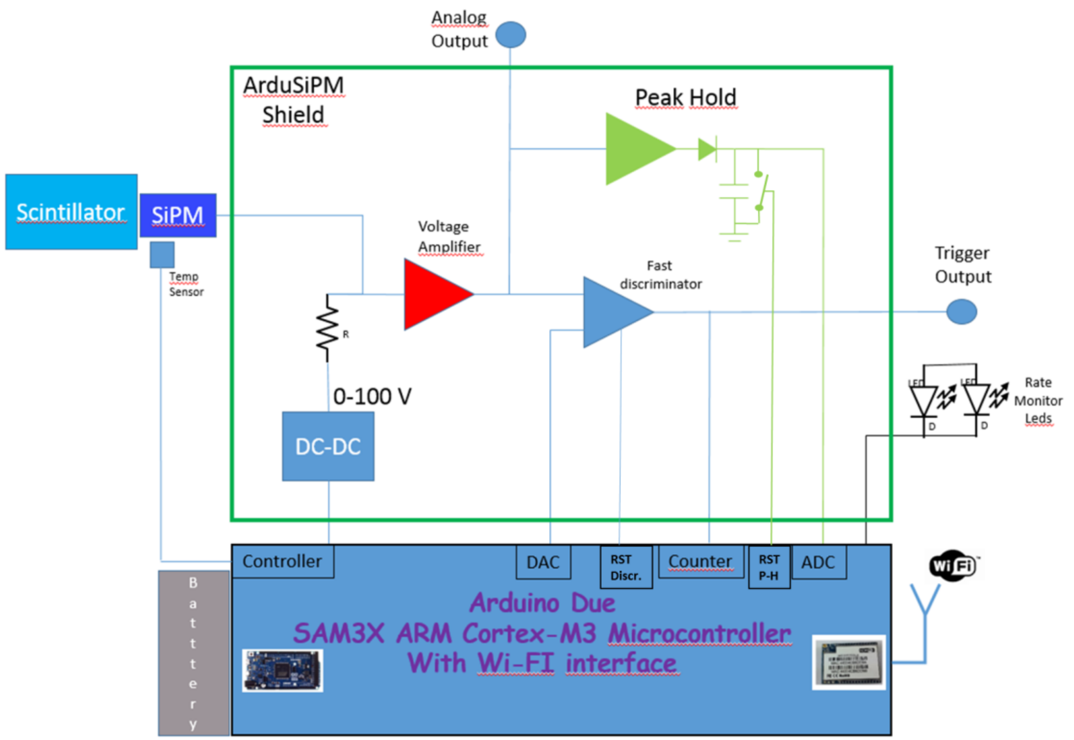
Package with cooking alluminium foil

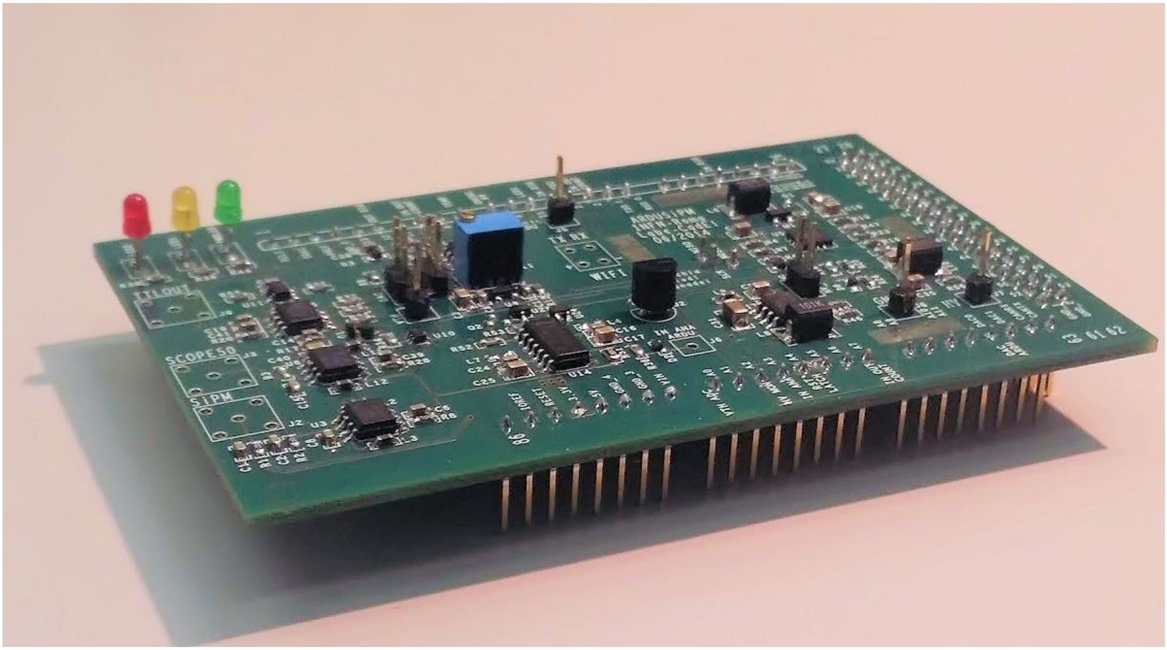
How to build a Scintillation detector with SiPM(2/2)



Using a black tape to avoid extenal ligth.

ArduSiPM the electronics



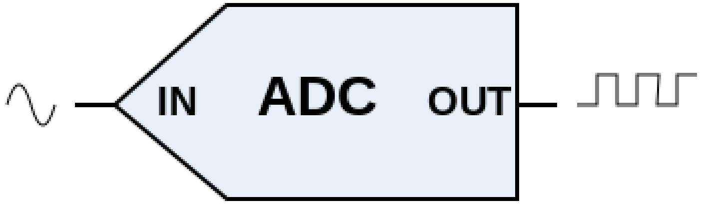


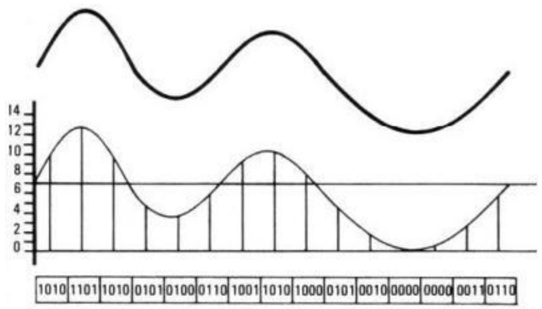
The ArduSiPM a compact trasportable Software/Hardware Data Acquisition system for SiPM detector.

http://arxiv.org/abs/1411.7814

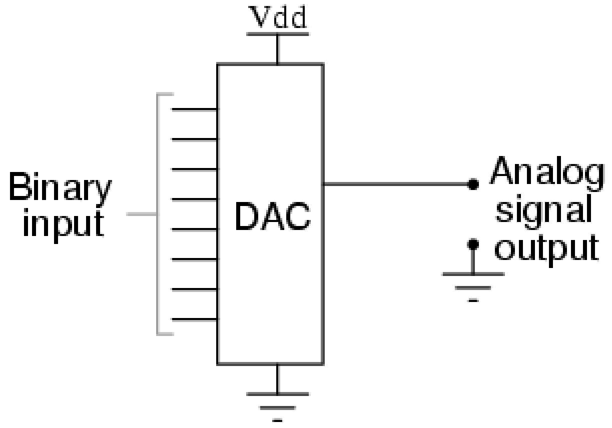
Arduino DUE a complete acquisition system (1/2).

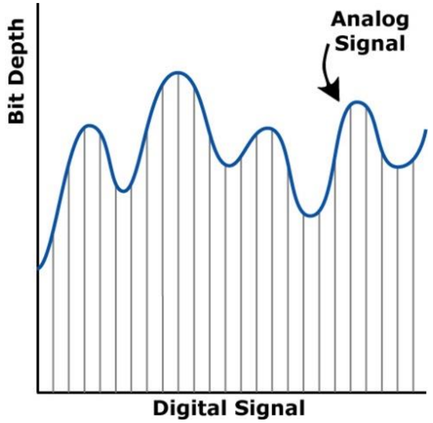
The Arduino DUE microcontroller (SAM3x8E) contains all we need to interface the external world





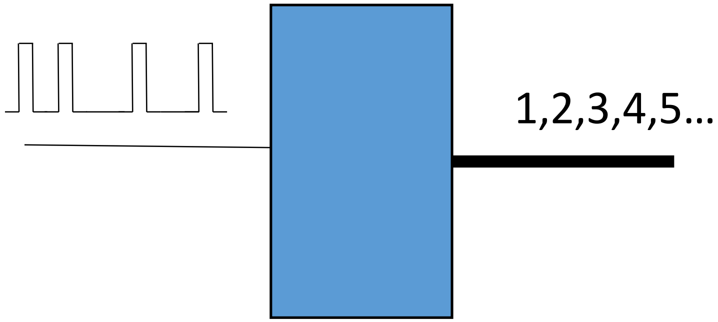
Analog Digital converter (ADC):
Transform Analog Signals in numbers



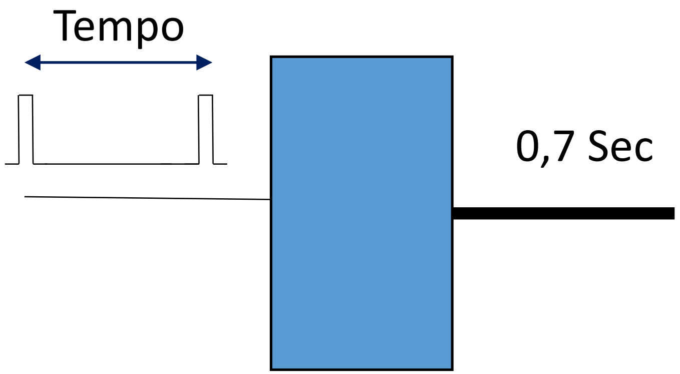


Digital to analog converter (DAC):
Transform numbers to electrical signal.

Arduino DUE a complete acquisition system (2/2).

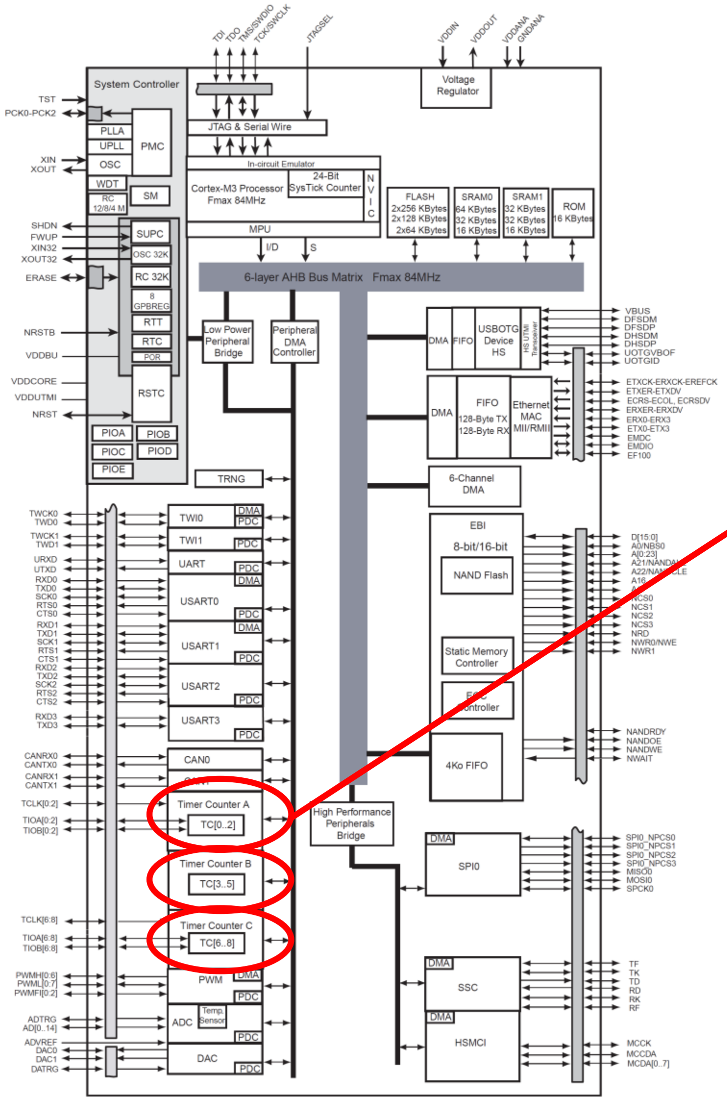


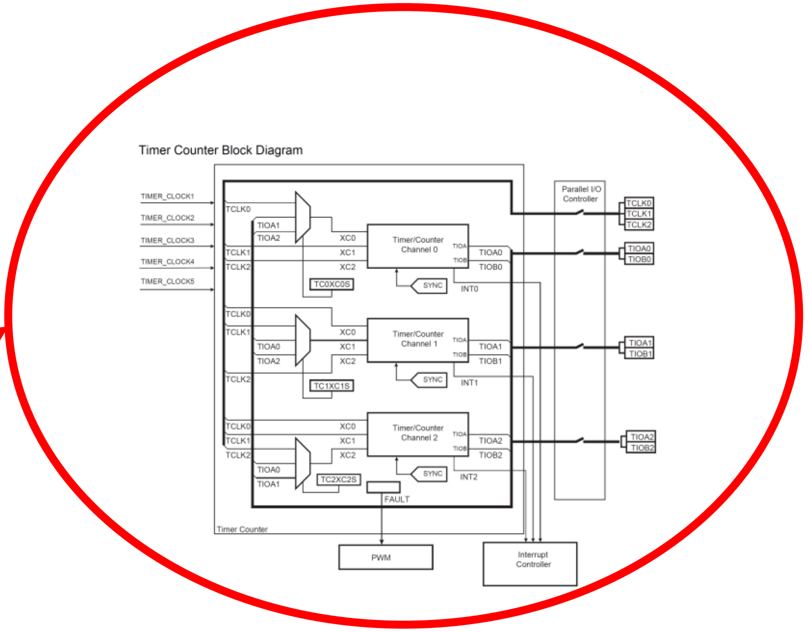
Digital Counter
Count the number of events



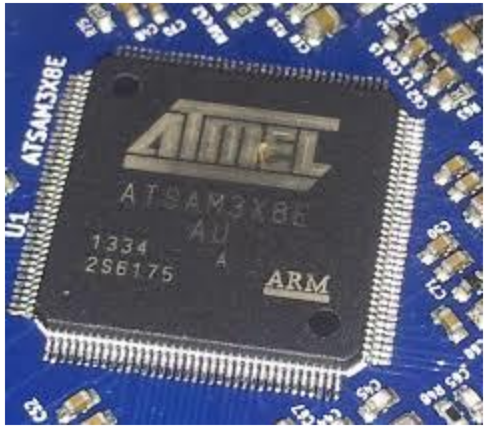
Time to Digital Converter(TDC)
Measure the time between events.

SAM3X8E Timer Counter modules

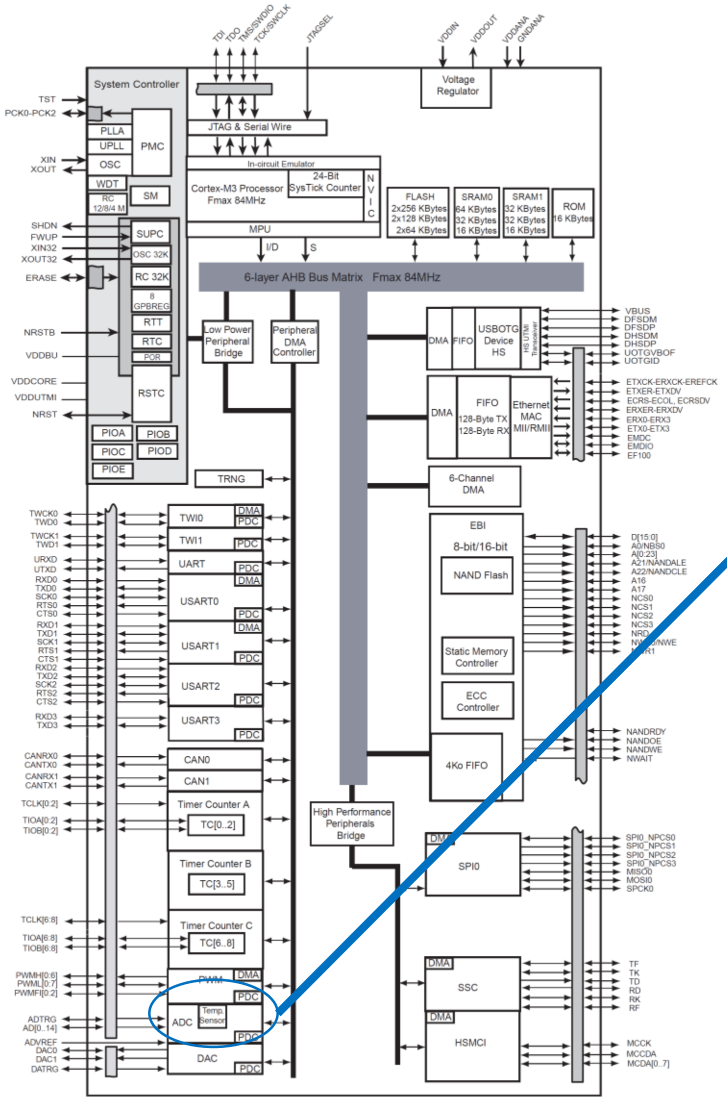


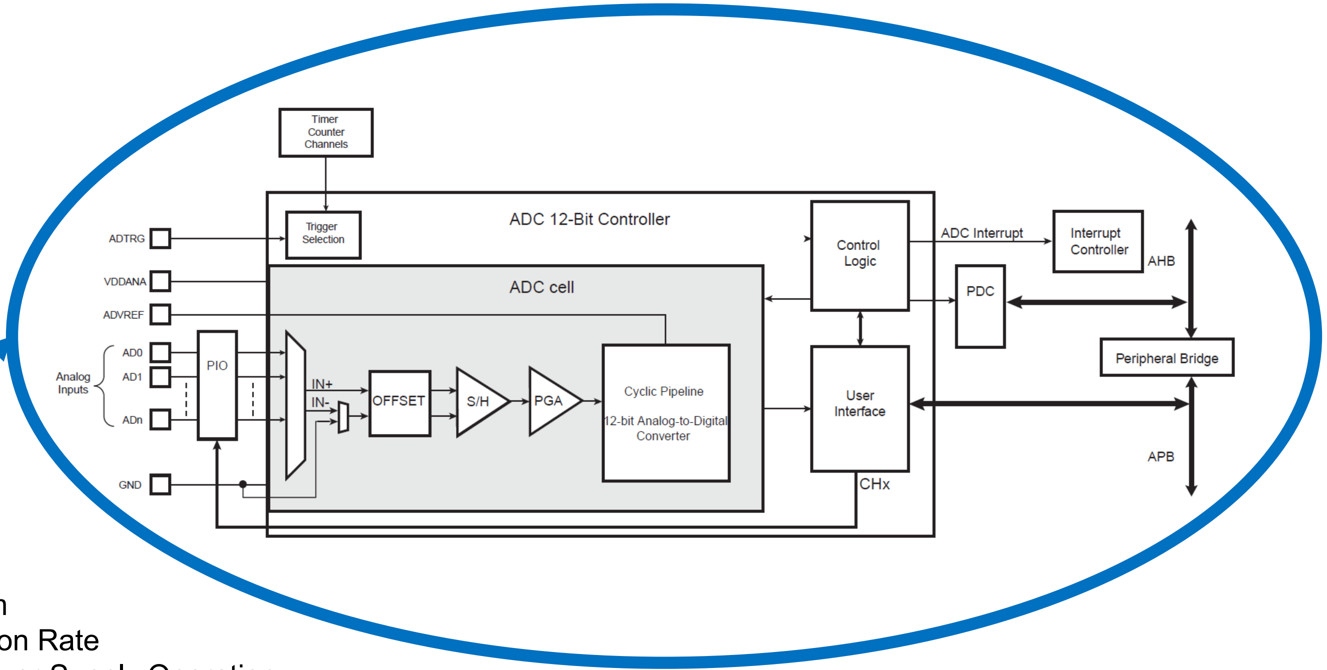


- Three 32-bit Timer Counter Channels
- A Wide Range of Functions Including:
  - – Frequency Measurement
  - – Event Counting
  - – Interval Measurement
  - – Pulse Generation
  - – Delay Timing
  - – Pulse Width Modulation
  - – Up/down Capabilities
- Each Channel is User-configurable and Contains: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

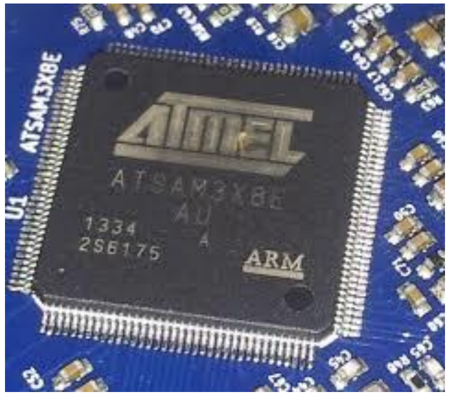


SAM3X8E ADC module

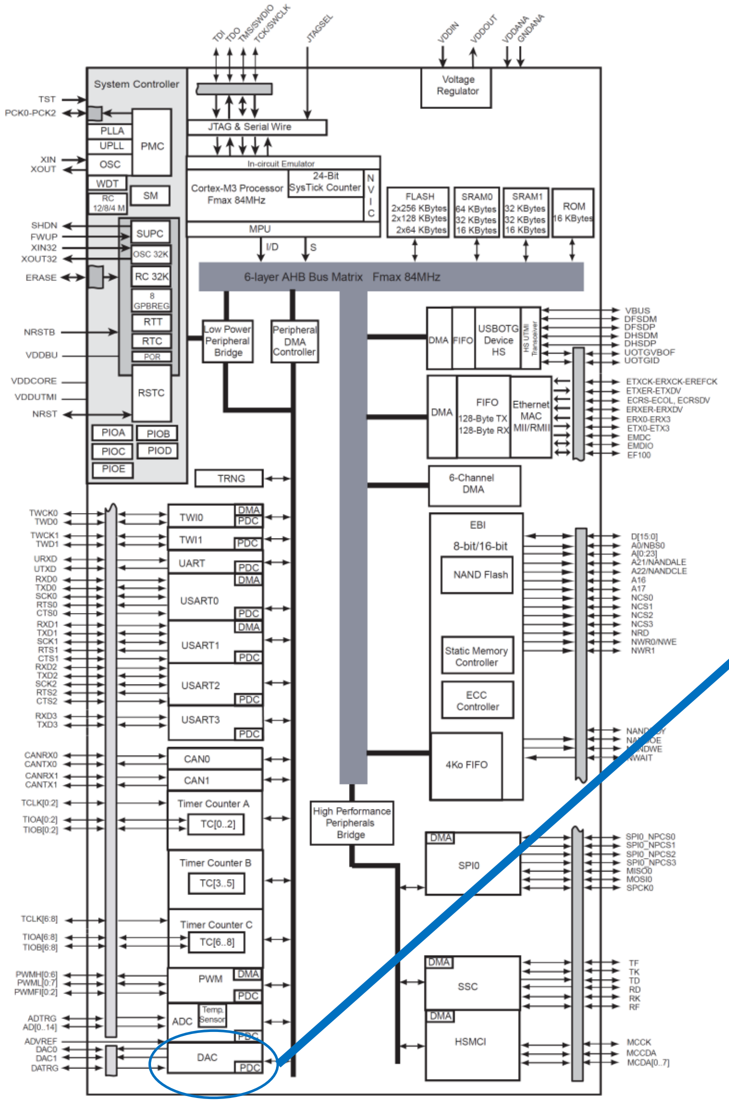


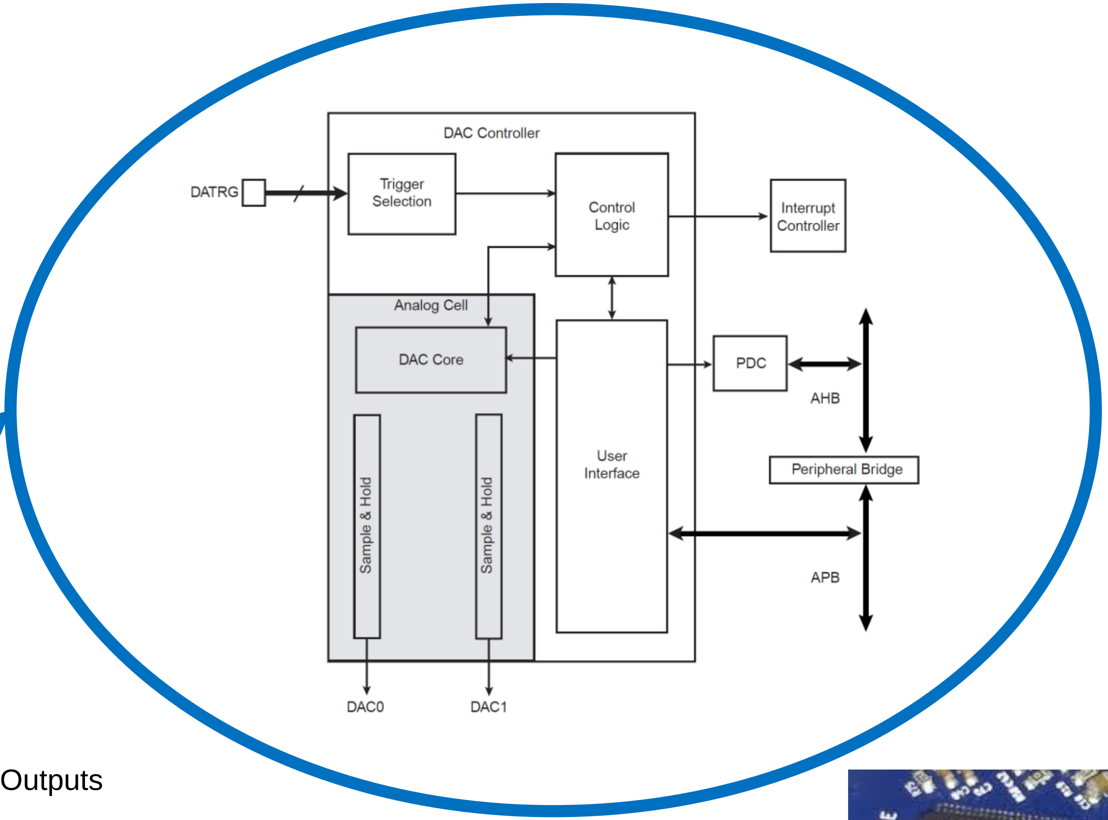


- 12-bit Resolution
- 1 MHz Conversion Rate
- Wide Range Power Supply Operation
- Selectable Single Ended or Differential Input Voltage
- Programmable Gain For Maximum Full Scale Input Range 0 - VDD
- Integrated Multiplexer Offering Up to 16 Independent Analog Inputs
- Individual Enable and Disable of 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

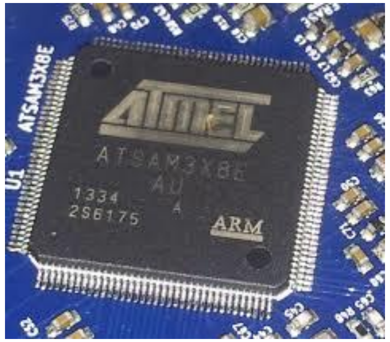


SAM3X8E DAC module

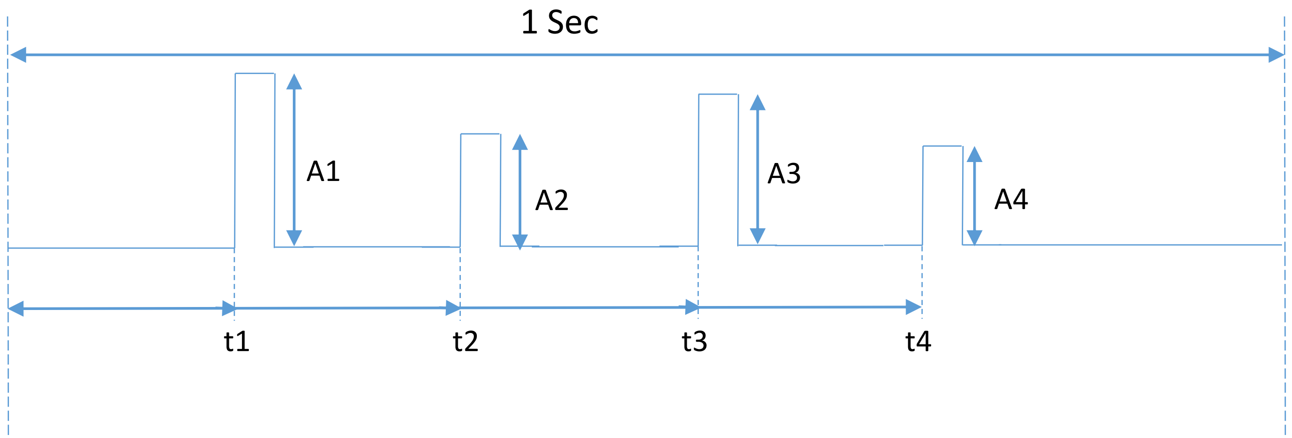




- Two Independent Analog Outputs
- 12-bit Resolution
- Individual Enable and Disable of Each Analog Channel
- Hardware Trigger
  – External Trigger Pins
- PDC Support
- Possibility of DACC Timings and Current Configuration
- Sleep Mode
  – Automatic Wake-up on Trigger and Back-to-Sleep Mode after Conversions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



Measurament with ArduSiPM



Tunable acquisition window
For each window we can acquire
Number of pulses, pulse amplitude, distance between pulse.

Data acquisition speed 200 Kbit/sec

Possiamo trasmettere i dati con le seguenti velocità:

- Counts up to 40 MHz
- ADC value 4-6 KHz
- ADC and TDC value 1 -2 KHz

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

Application Example 1:
Intraoperative β- Detecting Probe

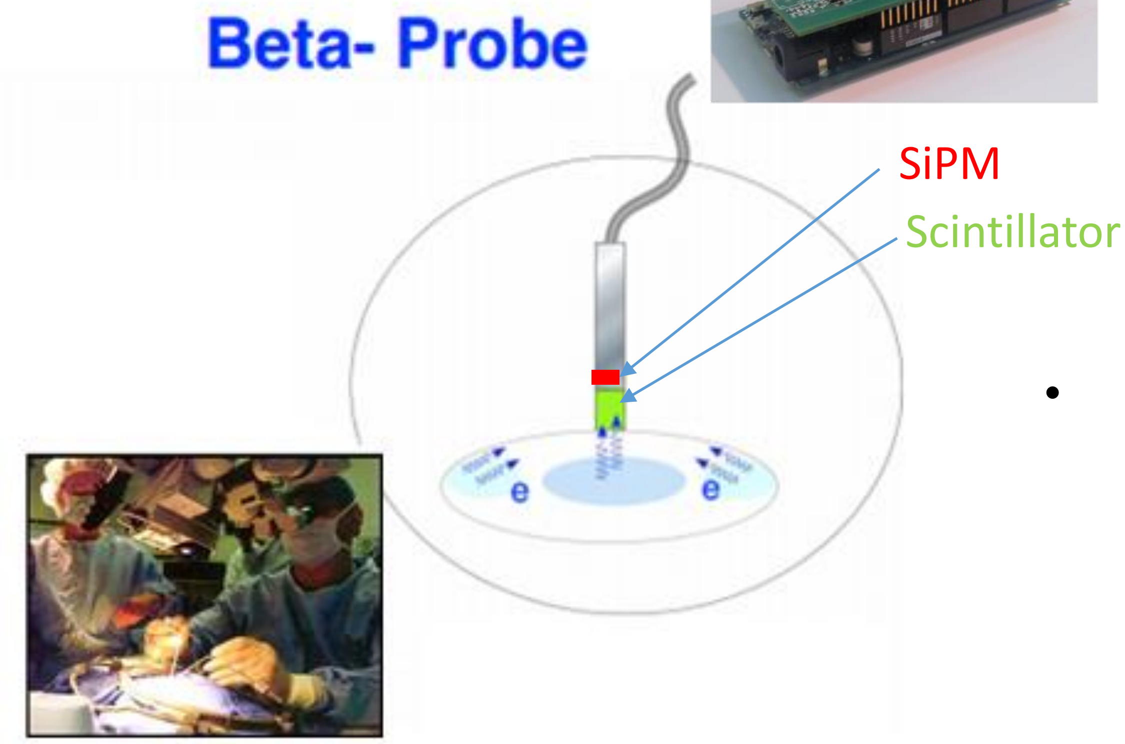

nature.com > scientific reports > articles > article

SCIENTIFIC REPORTS

A novel radioguided surgery technique exploiting β^- decays

E. Solfaroli Camillocci, G. Baroni, F. Bellini, V. Bocci, F. Collamati, M. Cremonesi, E. De Lucia, P. Ferroli, S. Fiore, C. M. Grana, M. Marafini, I. Mattei, S. Morganti, G. Paganelli, V. Patera, L. Piersanti, L. Recchia, A. Russomando, M. Schiariti, A. Sarti, A. Sciubba, C. Voena & R. Faccini

ArduSiPM

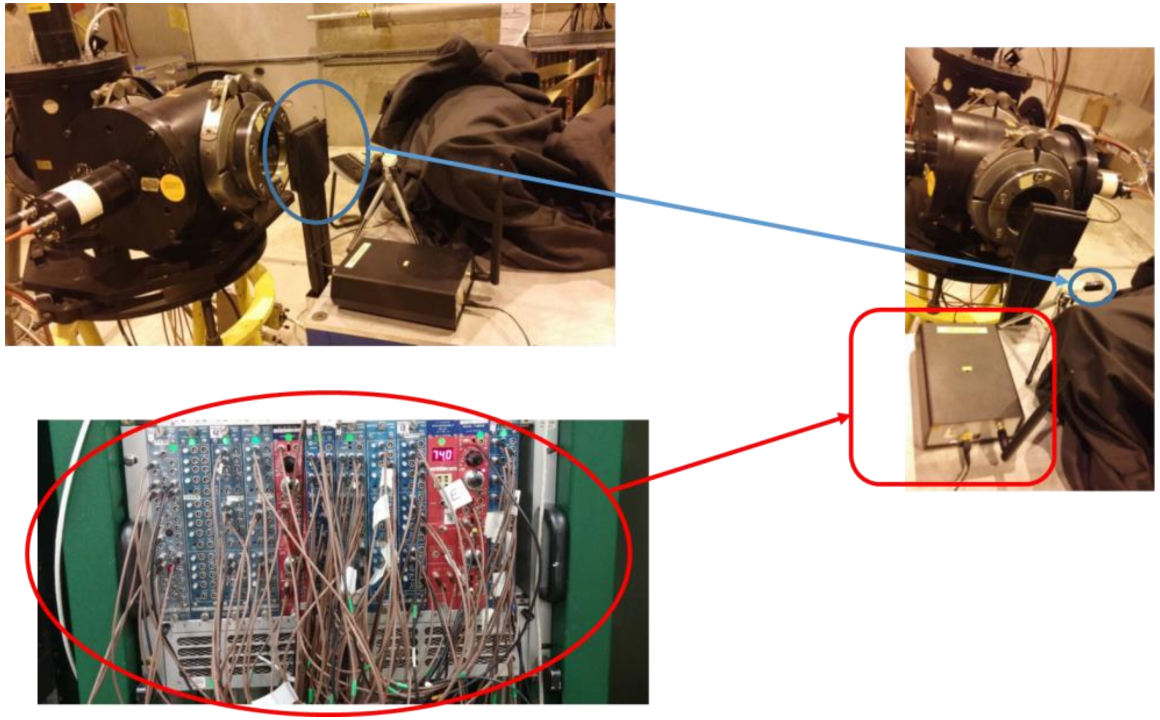


Control and readout
Android App

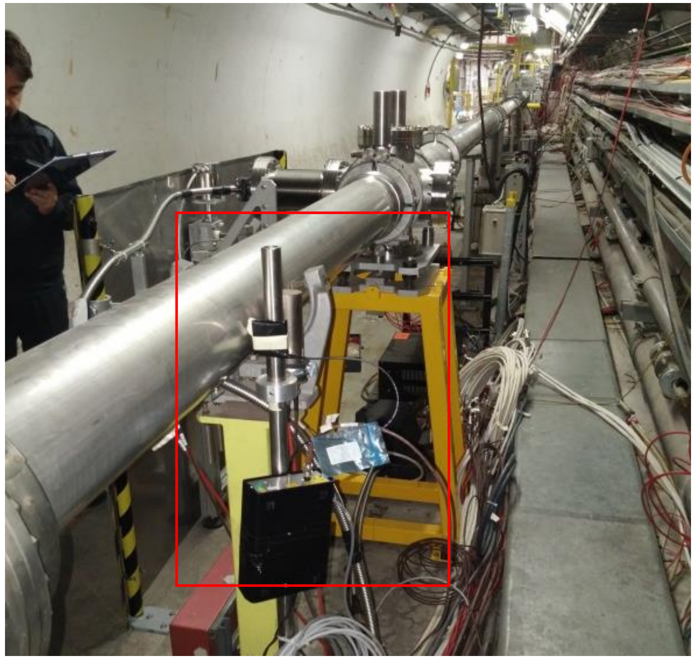
- Radioguided **intraoperative beta probe**, with scintillation material coupled with SiPM detector.

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

(substitute old Scintillator and electronics for PM)



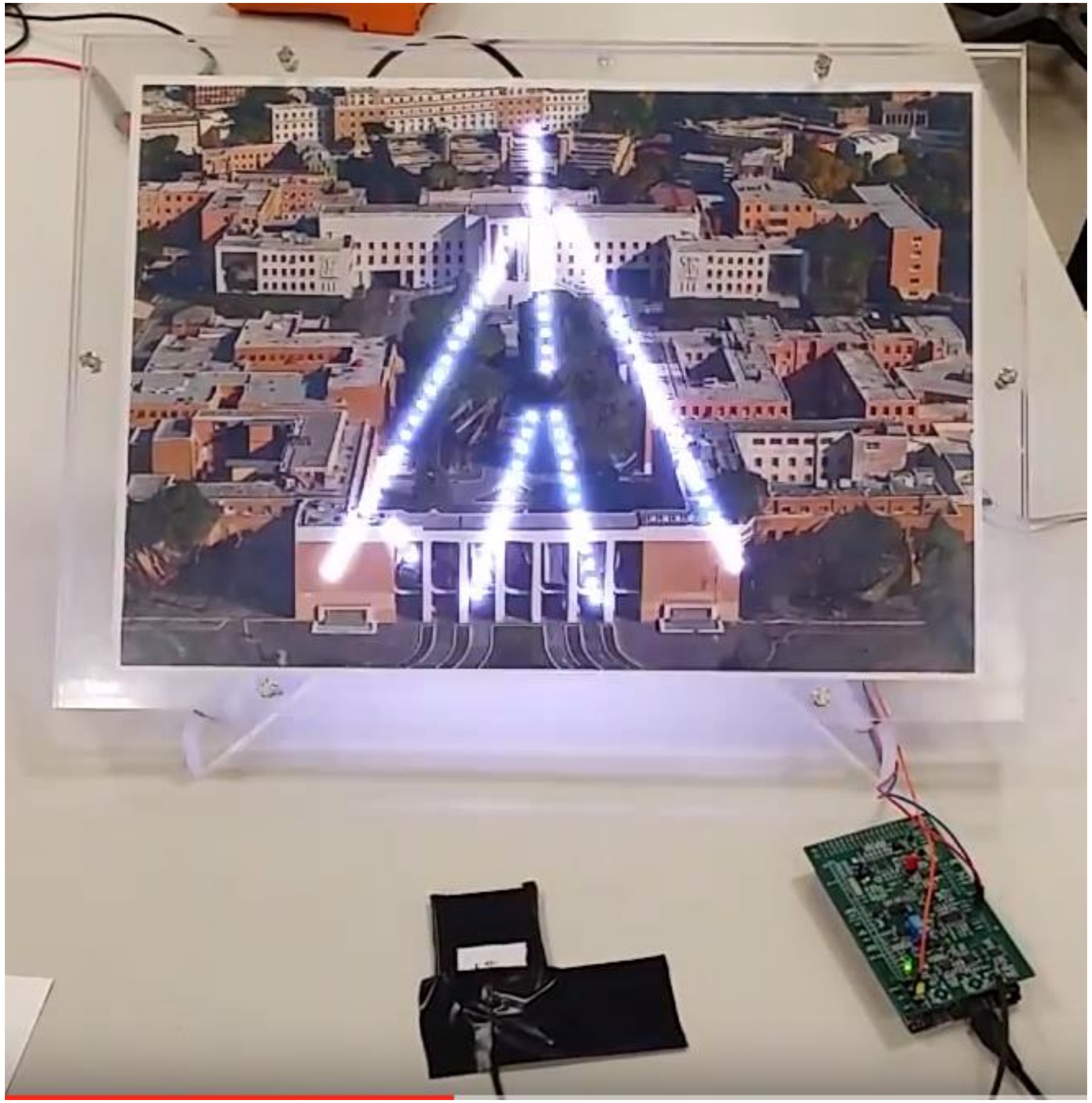
- As beam trigger @ extracted beam line H8 (CERN)

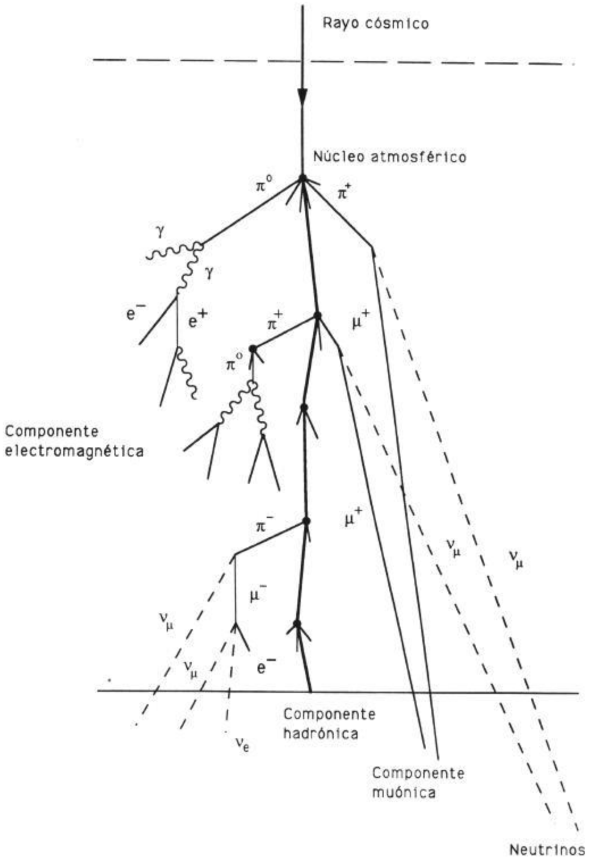


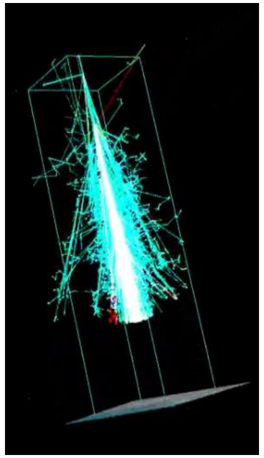
- As beam losses counter @ SPS

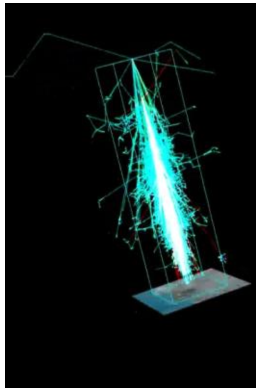
- *This work has been supported by the ERC Ideas Consolidator Grant*
- *No.615089 "CRYSBEAM".*

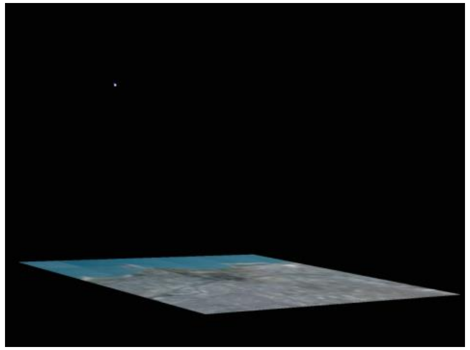
Application Example 3:A cosmic ray detector





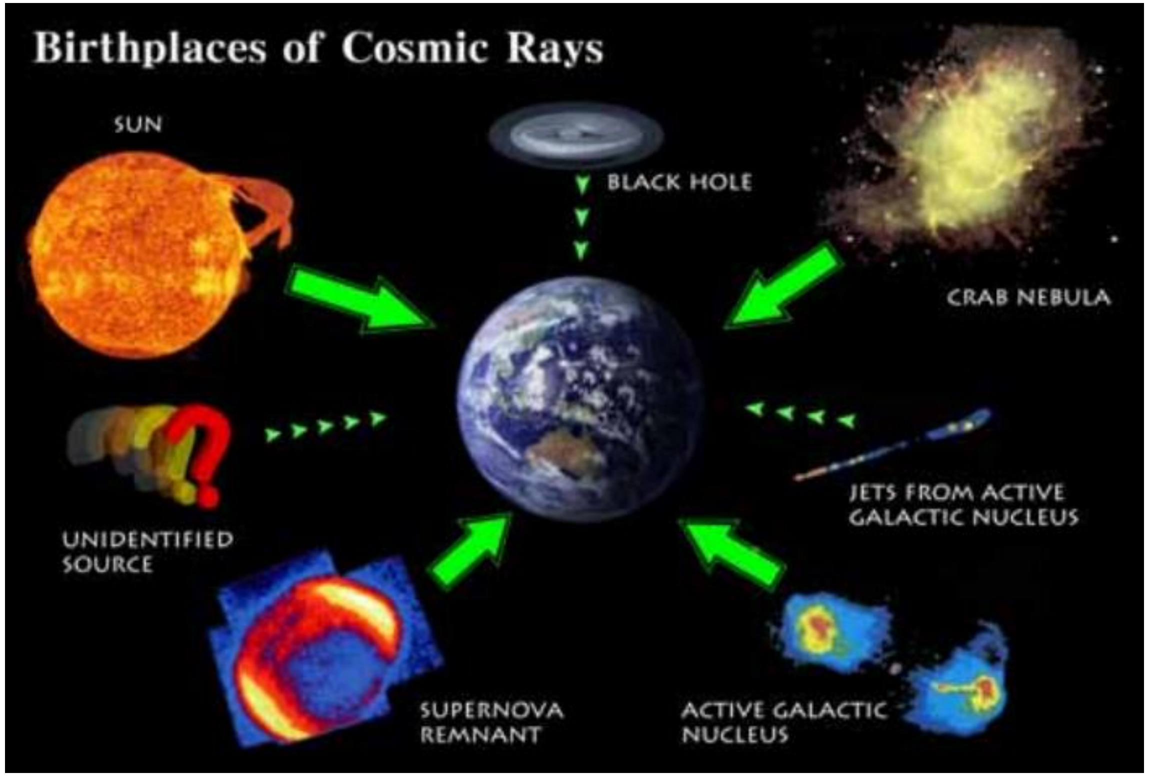






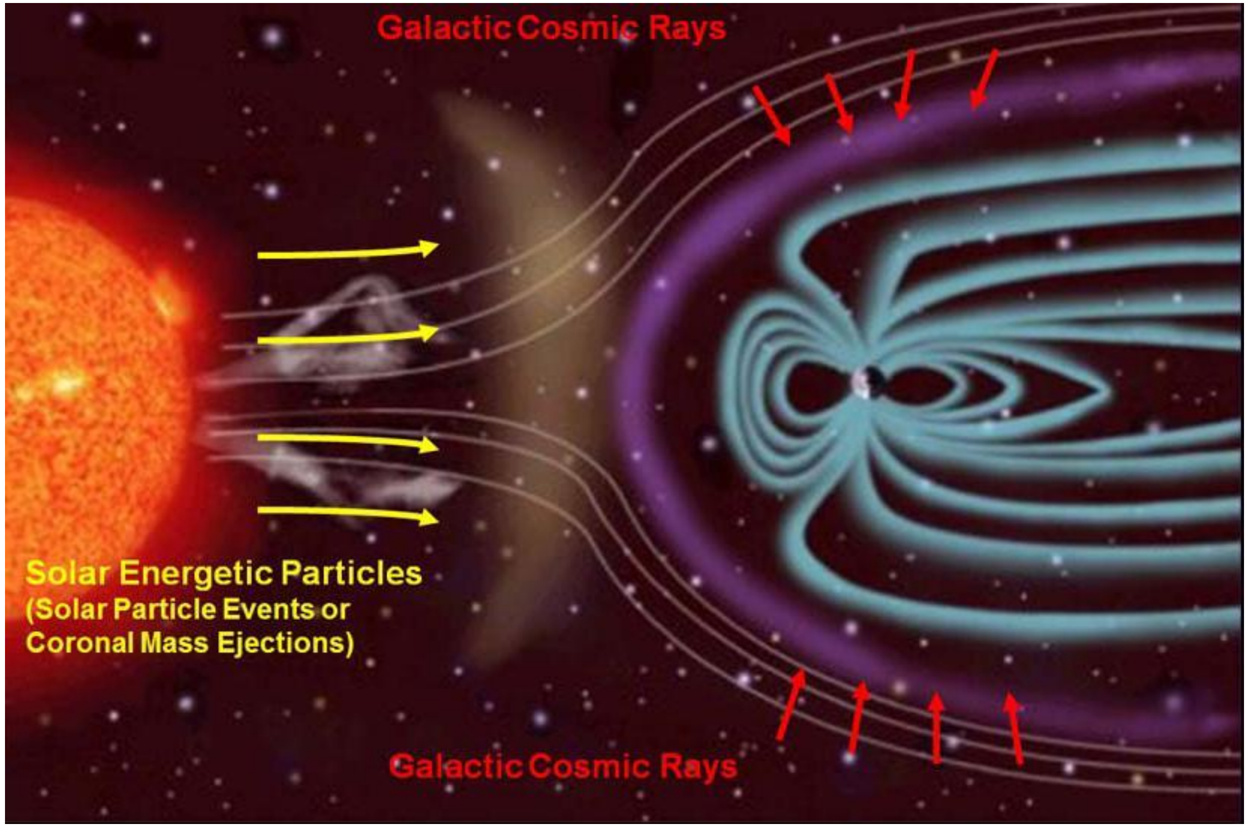
Cosmic Ray

In the universe exist Big Particle Accelerator more powerful of LHC at CERN.
These accelerator shoot cheap particle bullets (tipically protons or iron nuclei).



Some of these bullets reach our Earth

The Earth Magnetic Field Our Shield

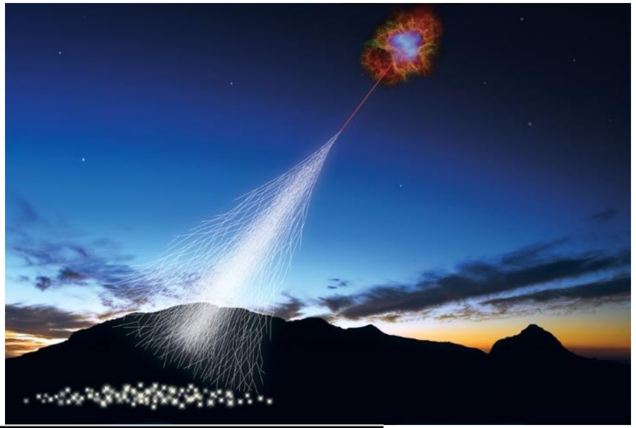


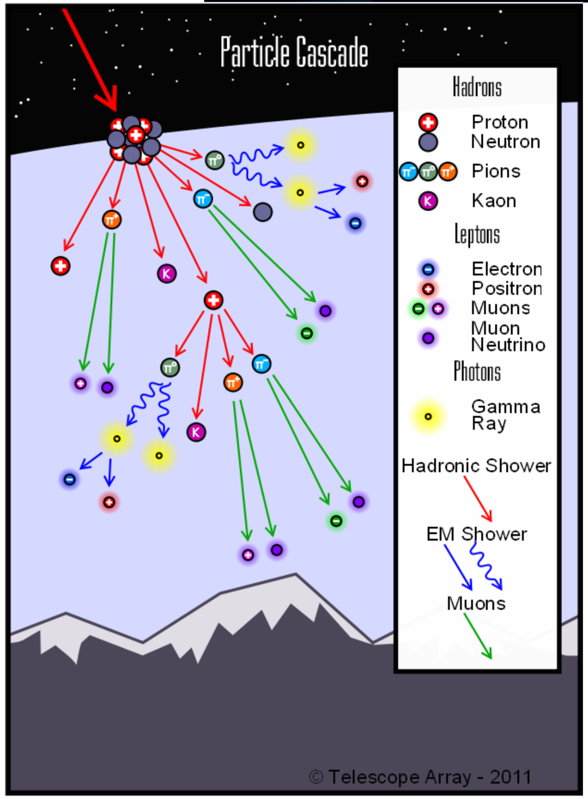
Sometimes particle coming from the Sun can traverse the Magnetic Field

Auroras are produced when the magnetosphere is sufficiently disturbed by the solar wind that the trajectories of charged particles in both solar wind and magnetospheric plasma, mainly in the form of electrons and protons, precipitate them into the upper atmosphere. (Wikipeda)

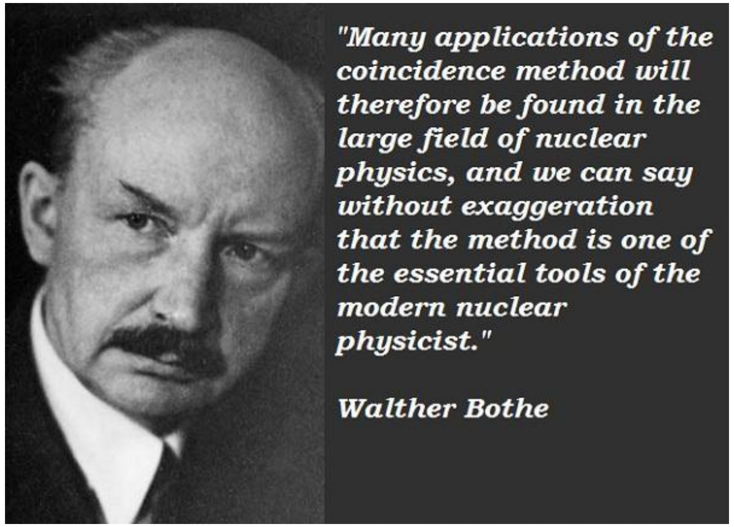
The Cosmic Shower

When an high energy cosmic ray hit the atmosphere create a shower of particle. The shower comes larger reaching the earth surface. The dimension of the shower at ground level depends from the energy of the primary particle. In this way the atmosphere absorb the energy of the cosmic ray acting as another shield.
Thousands of particles reach the Earth tipically ar Muons !!

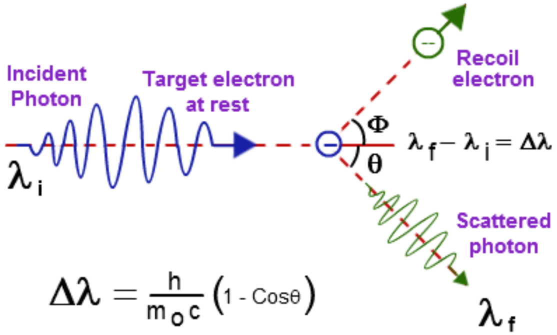




The Coincidence Method
(Walther Boethe Hans Geiger 1924)



The coincidence technique, 1rst used by Hans Geiger and Walther Bothe in 1924 to verify that Compton scattering produces a recoil electron simultaneously with the scattered-ray.



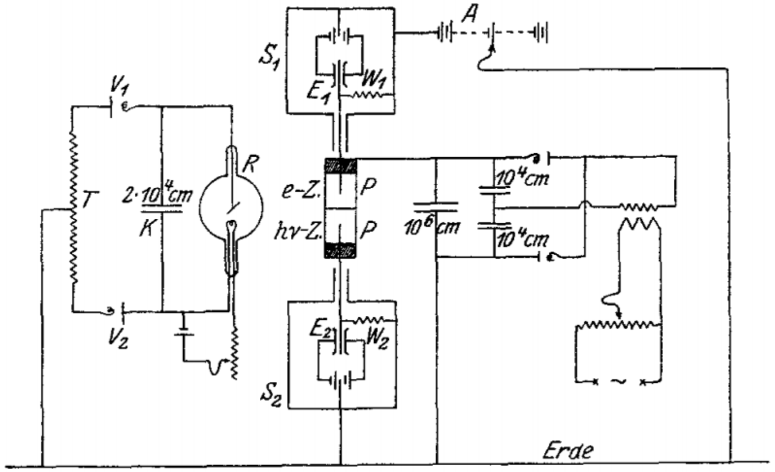


Fig. 3. Schaltungsschema.

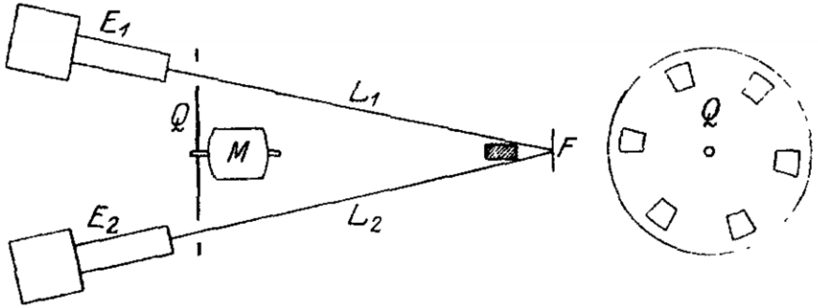


Fig. 4. Photographische Registrierung.

The first Electronic AND Bruno Rossi coincidence circuit and the discovery of Air Shower.

1.2 Discovery of Extensive Air Showers

It was Bruno Rossi [19], who as early as 1934, had noticed coincidences between several counters placed in a horizontal plane, far in excess of chance coincidences. He had noted in one of his papers "It would seem that occasionally very extensive groups of particles arrive upon the equipment". The most systematic investigation on these showers were undertaken by Pierre Auger and his collaborators [20]. They recorded coincidences between counters separated horizontally by as far as 75 meters. While the counting rate dropped sharply in going from 10 cms to 10 meters, the rate decreased very slowly at larger distances.

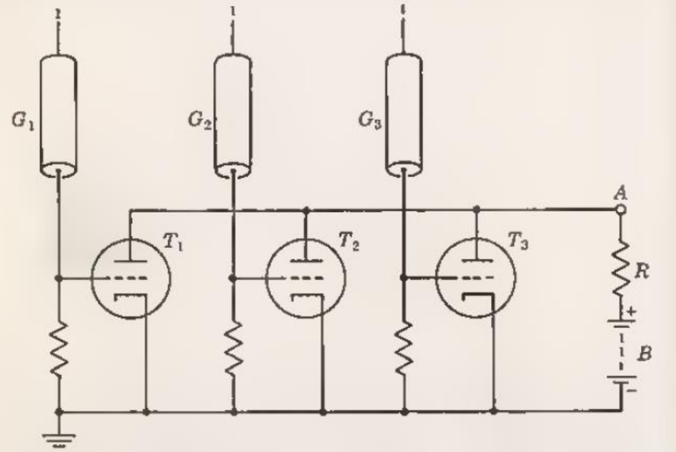
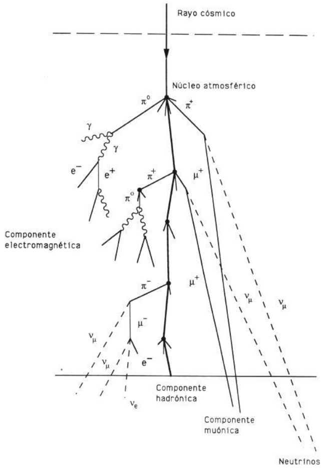


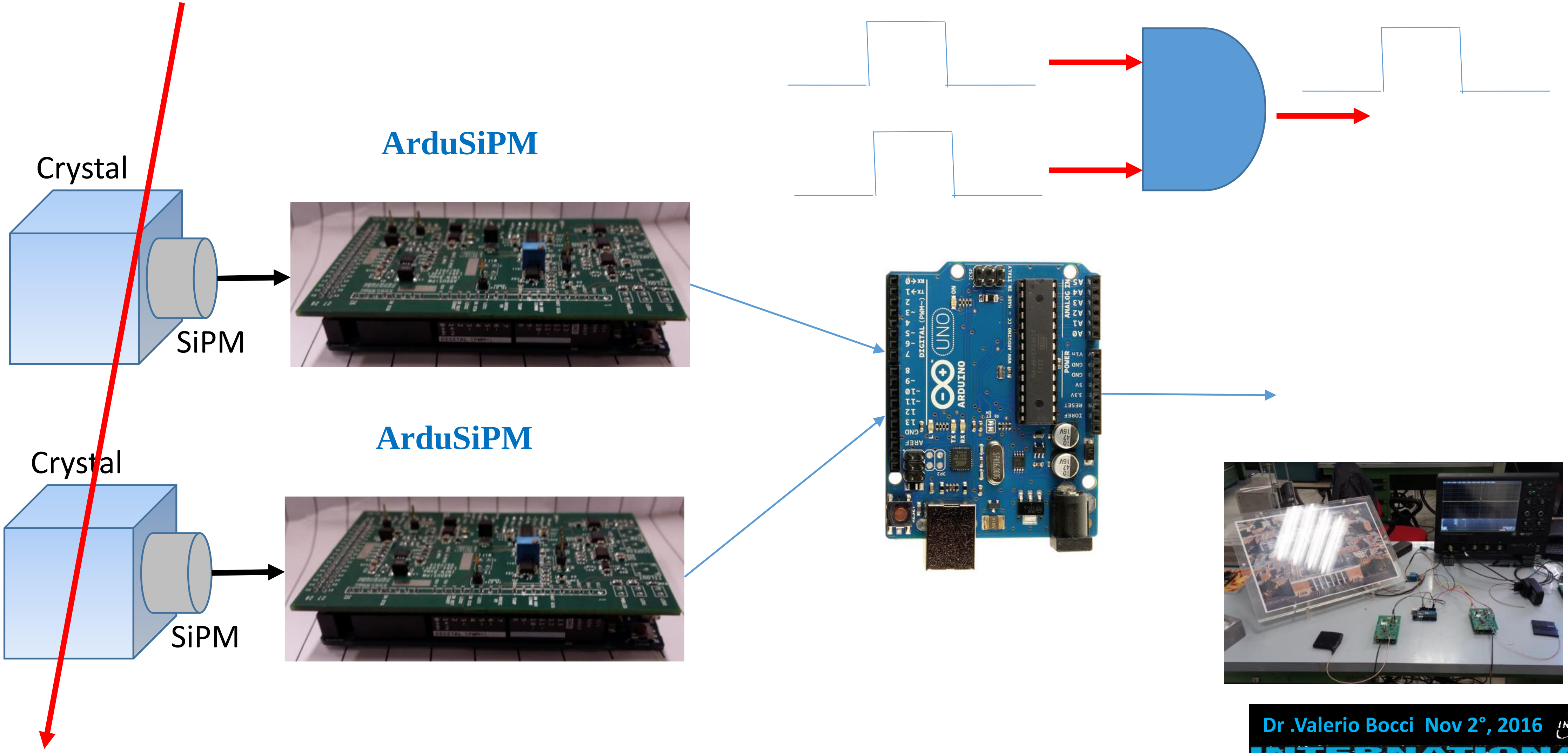
Fig. 4-1 Vacuum-tube coincidence circuit greatly reduces the number of chance coincidences recorded by G-M counters (see text). Under operating conditions, current flows from the positive terminal of the battery *B* through the resistor *R* and three tubes T_1, T_2, T_3 to a ground. This current produces a large voltage drop across the resistor, and at point *A* the potential is nearly that of the ground. When one of the G-M counters, G_1, say, is discharged, the



The discovery of air showers

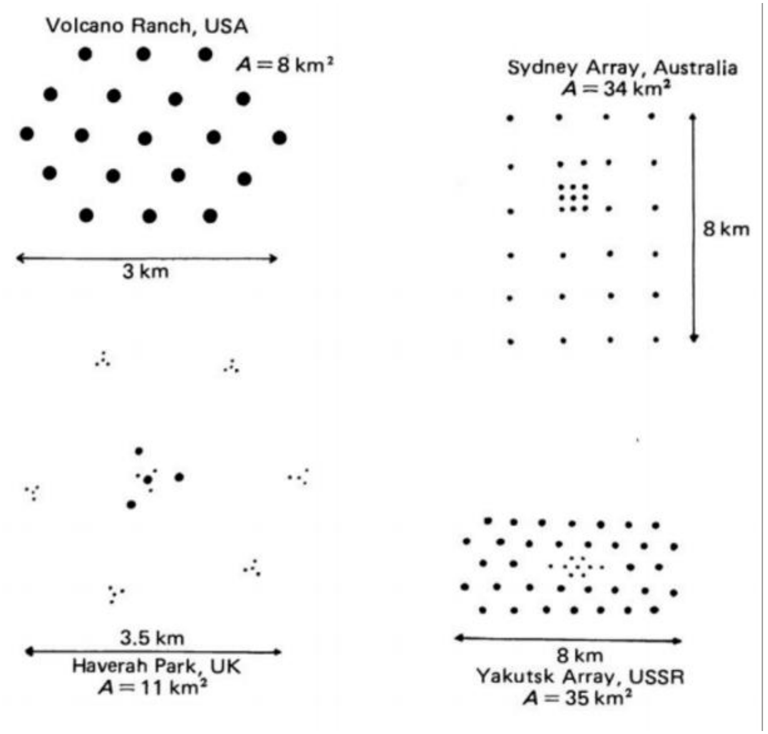
Air showers were discovered, more or less by chance, through the widespread application of coincidence-counter arrangements to the experimental study of cosmic rays. The devices used to detect coincidences will record as simultaneous the pulses of two or more counters if these pulses arrive within a certain small time interval. This interval, the *resolving time*, was of the order of 0.01 second in the early experiments of Bothe and Kohlhörster. The development of vacuum-tube circuits of increasing sophistication eventually reduced the resolving time to considerably less than 1 microsecond. But, however short the interval, there is always a possibility that unrelated particles will cross the counters in such quick succession as to produce a coincidence.

Simple coincidence of ArduSiPMs using another Arduino.

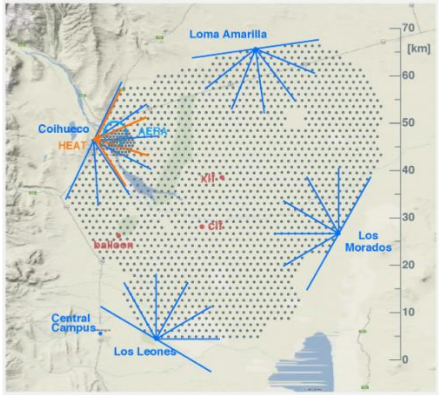


The search of Ultra Energetic Cosmic Ray
E> 10^{19} eV

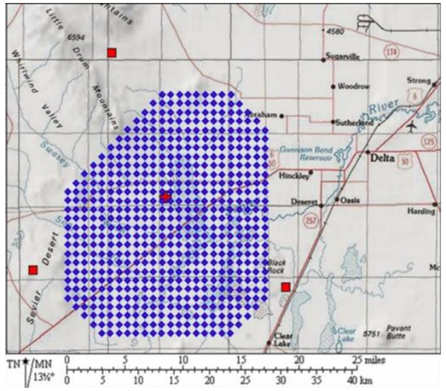
On February 22, 1962, John David Linsley observed an air shower at Volcano Ranch created by a primary particle with an energy greater than 10^{20} eV

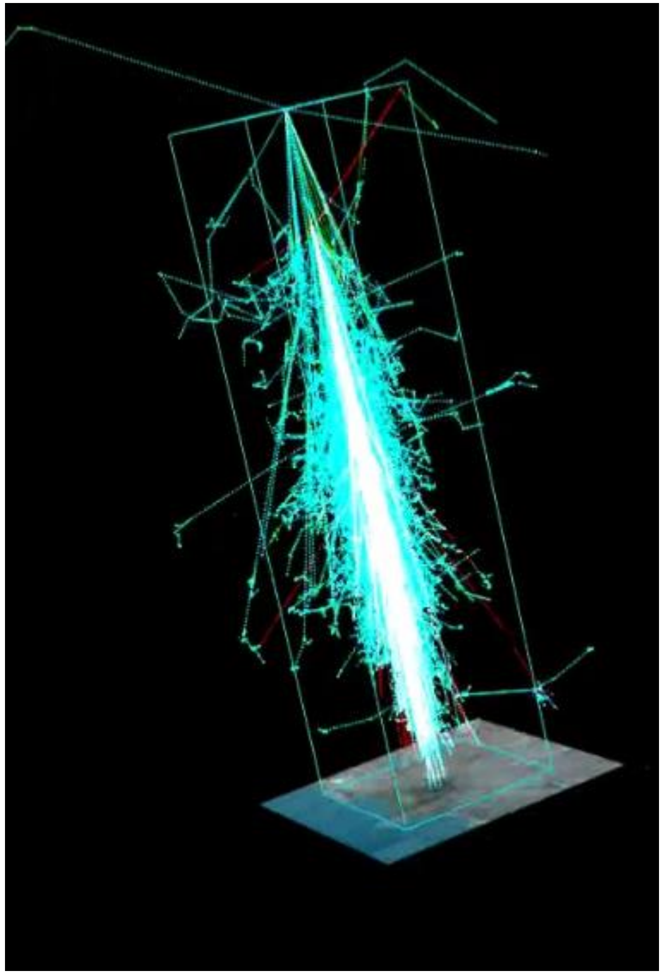


Pierre Auger Observatory (Argentina)



Telescope Array Project (Utah)

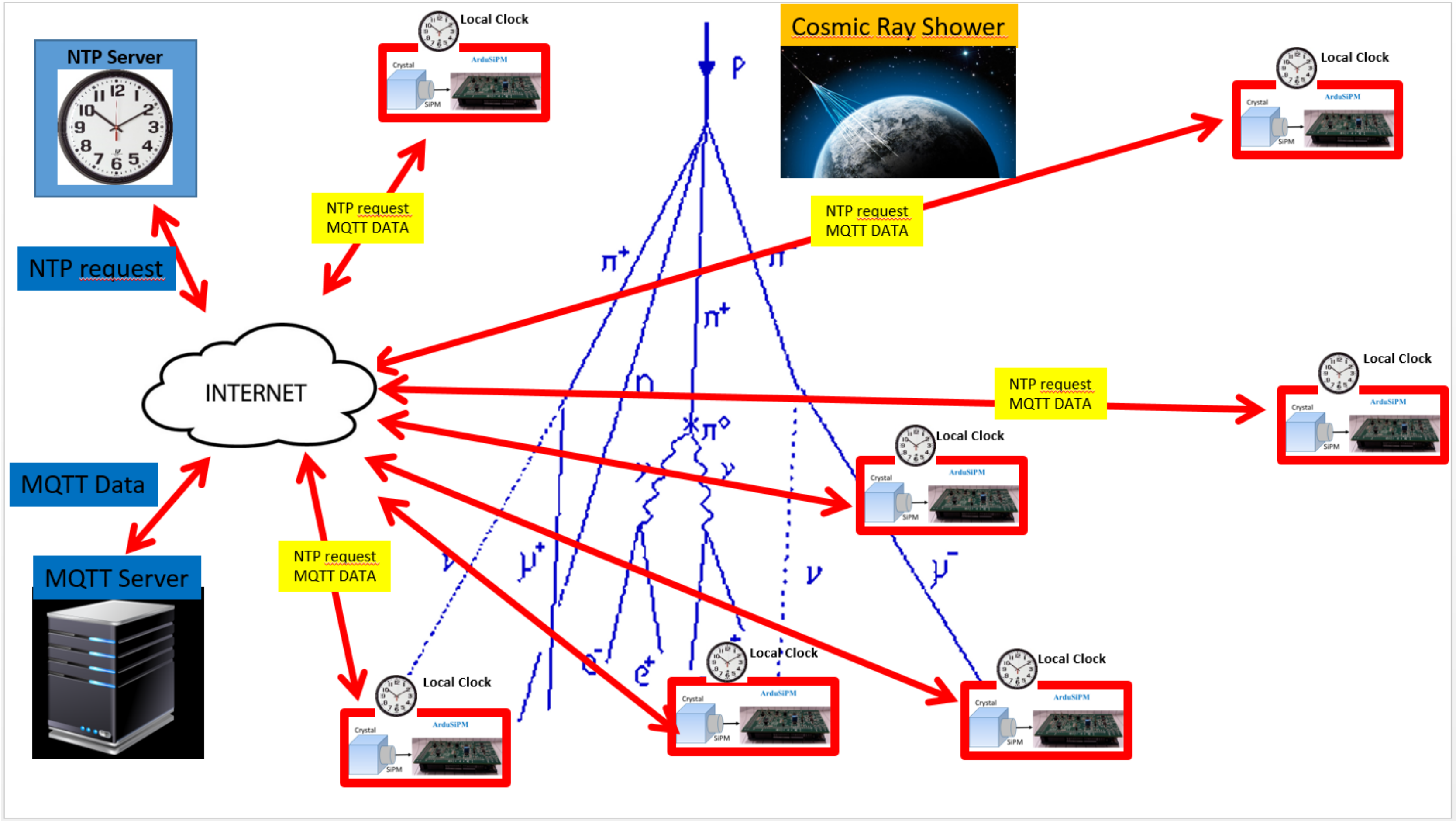




Search of cosmic Airshower in a wide area using ArduSiPM

Multiple ArduSiPM can be used for the research extended AirShower

The advent of microcontrollers with enough CPU power and with analog and digital peripherals give the possibility to design a complete acquisition system in one chip. The existence of an world wide data infrastructure as internet allows to think at distributed network of detectors capable to elaborate and send data or respond to settings commands.
The internet infrastructure allow us to do things unthinkable a few years ago, like to distribute the absolute time with tens of milliseconds precision to simple devices far apart from a few meters to thousands of kilometers and to create a Crowdsourcing experiment platform using simple detectors.



Dr .Valerio Bocci Nov 2°, 2016

INTERNATIONAL COSMIC DAY

ArduSiPM Social Media

https://www.facebook.com/groups/ardusipm/

@ardusipm

@ArduinoSiPM

https://groups.google.com/forum/#!forum/ardusipm

Bibliography

- “The ArduSiPM a compact trasportable Software/Hardware Data Acquisition system for SiPM detector”
  http://arxiv.org/abs/1411.7814 (**DOI:** 10.1109/NSSMIC.2014.7431252)
- “A low cost network of spectrometer radiation detectors based on the ArduSiPM a compact transportable Software/Hardware Data Acquisition system with Arduino DUE.»

  http://arxiv.org/abs/1506.01915” (**DOI:** 10.1109/ANIMMA.2015.7465621)
- “Nuclear interaction detector system for UA9 experiments based on ArduSiPM prototype”
  http://ieeexplore.ieee.org/abstract/document/7581889/
- First ex vivo validation of a radioguided surgery technique with β-radiation.
  http://www.sciencedirect.com/science/article/pii/S1120179716309164
- Rivista INFN "Asimmetrie"
  http://www.asimmetrie.it/index.php/as-illuminazioni-rivelatori-fai-da-te
- Arduino BLOG http://www.arduino.org/blog/ardusipm-solution
- Elettronica Open Source: http://it.emcelettronica.com/ardusipm-shield-kit-un-rivelatore-di-raggi-cosmici-e-radiazioni-nucleari