Il mistero della radiazione penetrante
A oltre cent'anni dalla
scoperta dei raggi cosmici.

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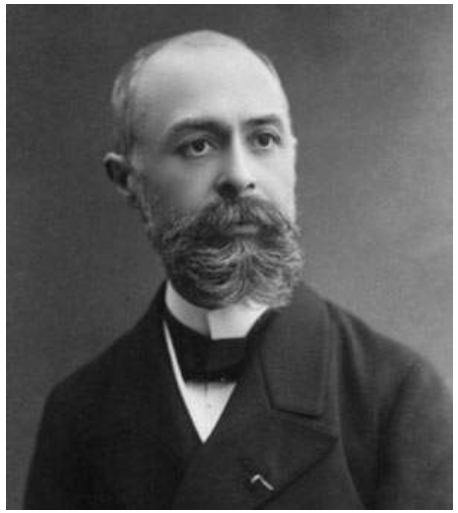
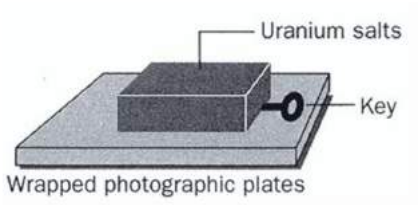
30 Novembre 2017
Dipartimento di Fisica
Università Sapienza

Valerio Bocci

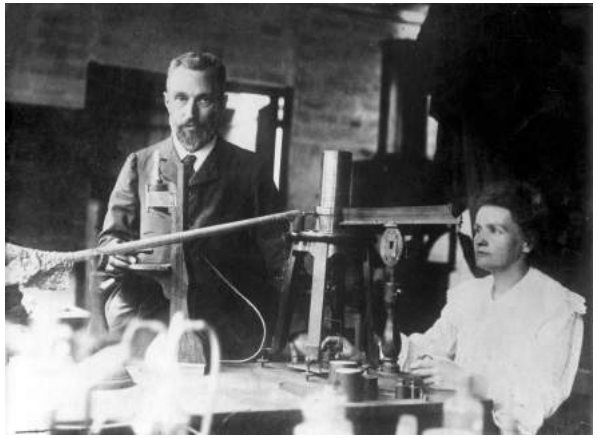
La Scoperta della radioattività naturale

Antoine Henri Becquerel
(Parigi, 15 dicembre 1852 – Le Croisic, 25 agosto 1908)

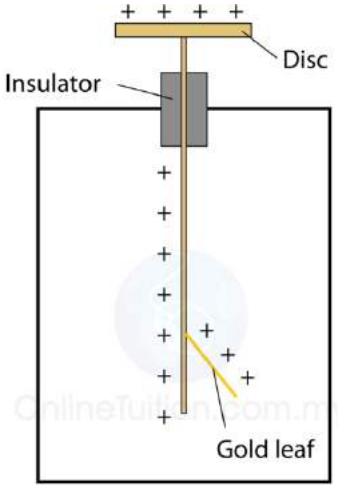


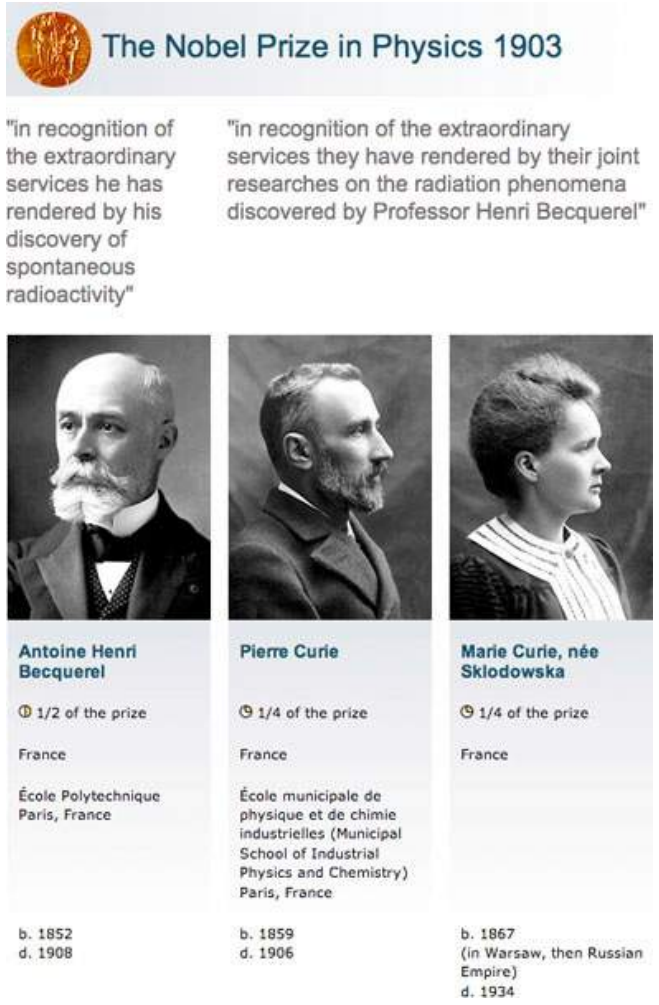


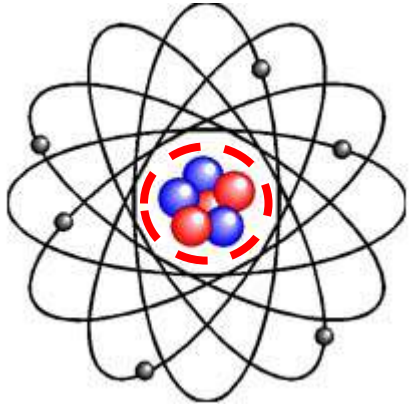
Pierre Curie
(Parigi, 15 maggio 1859 – Parigi, 19 aprile 1906)



Marie Skłodowska Curie
(Varsavia, 7 novembre 1867 – Passy, 4 luglio 1934)

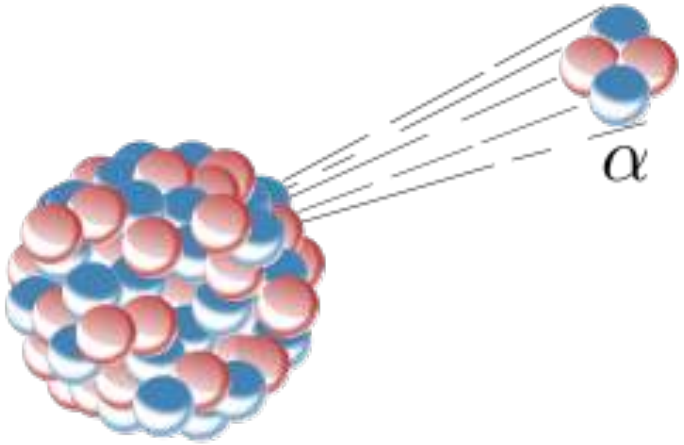




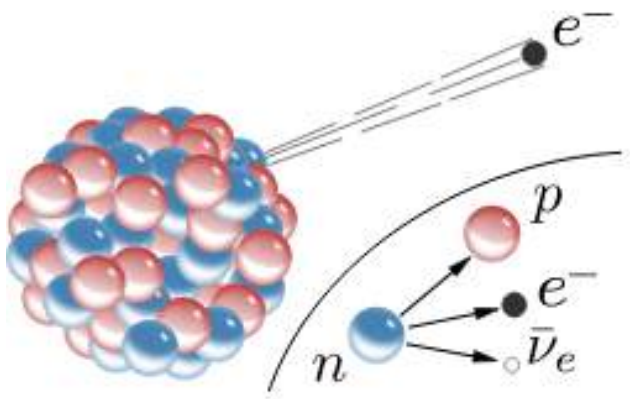


La Radioattività

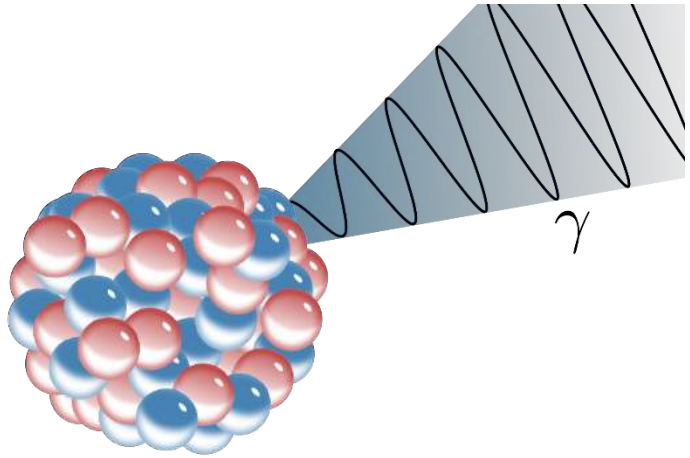
(I mal di pancia del nucleo)



Radioattività Alpha/
Decadimento Alpha



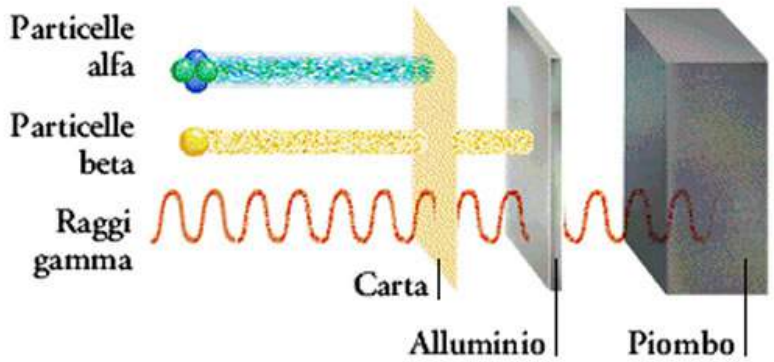
Radioattività Beta/
Decadimento Beta

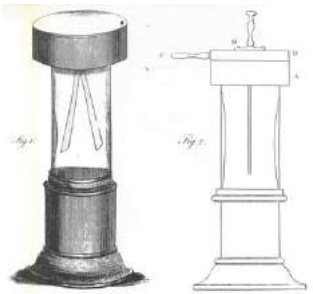


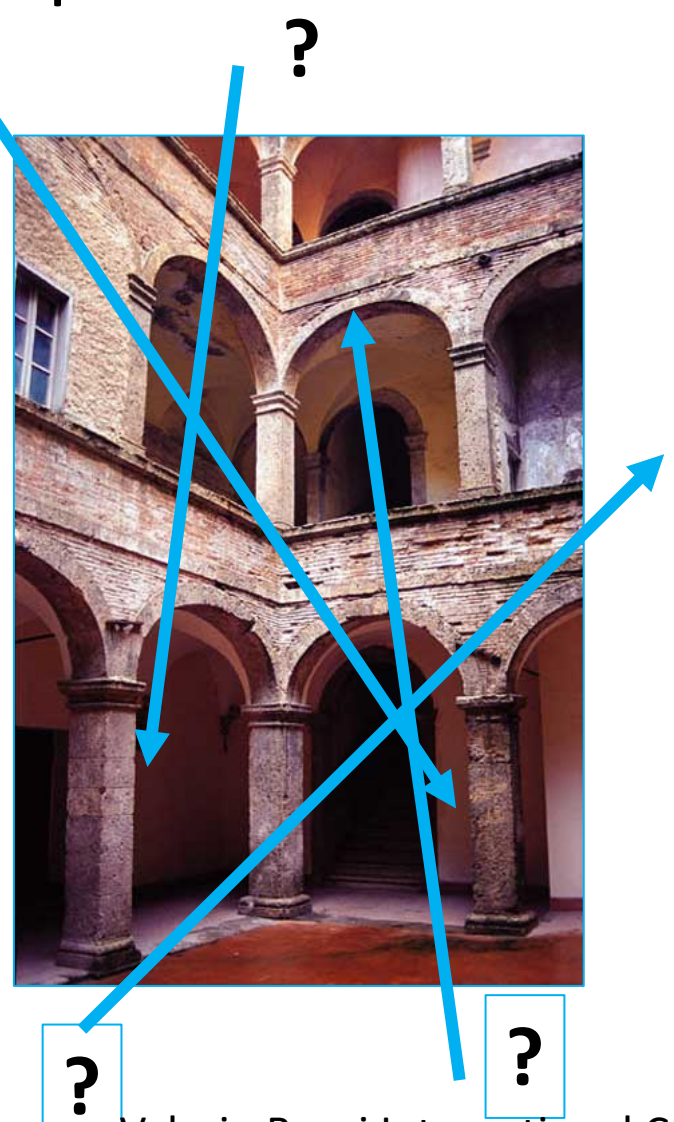
Radioattività Gamma/
Decadimento Gamma

La Scoperta di una radiazione penetrante

Radioattività naturale

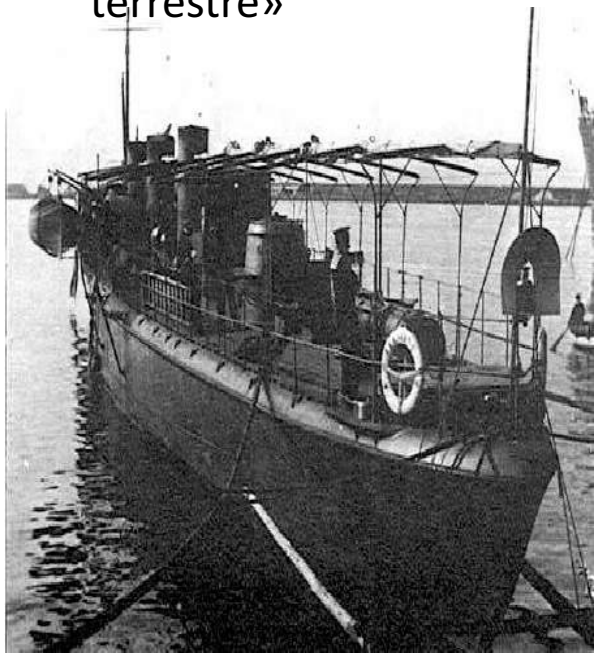






Gli esperimenti subacquei di Domenico Pacini

Durante una serie di esperimenti condotti tra il 1907 e il 1911, il fisico italiano Domenico Pacini misurò nel porto di Livorno e sul lago di Bracciano un decremento del 20 % della radiazione penetrante alla profondità di 3 metri.
Nel suo articolo del 1911 ipotizza la natura esterna di tale radiazione. «Una parte non piccola della radiazione penetrante presente nell'aria ha origine indipendente dall'azione delle sostanze attive contenute negli strati superiori della crosta terrestre»



Cacciatorpediniere Fulmine

(Marino, February 20, 1878 – Rome, May 23, 1934)

LA RADIAZIONE PENETRANTE ALLA SUPERFICIE ED IN SENO ALLE ACQUE.

NOTA DI D. PACINI.

Le osservazioni eseguite sul mare nel 1910 [1]) mi conducevano a concludere che una parte non trascurabile della radiazione penetrante che si riscontra nell'aria, avesse origine indipendente dall'azione diretta delle sostanze attive contenute negli strati superiori della crosta terrestre.

Riferirò ora sopra ulteriori esperienze che confermano quella conclusione.

I risultati precedentemente ottenuti indicavano esistere, sulla superficie del mare, dove non è più sensibile l'azione del terreno, una causa ionizzante di tale intensità da non potersi spiegare esaurientemente considerando la nota distribuzione delle sostanze radioattive nell'acqua e nell'aria.

Difatti, come l'Eve [2]) ha mostrato, si può calcolare facilmente quale dovrebbe essere l'azione ionizzante dovuta alle radiazioni γ emesse da particelle attive nell'aria, alla superficie del mare.

Sia Q l'equivalente in Ra. C per cm^3 nell'atmosfera, espresso come in grammi di Radio in equilibrio radioattivo $Q = 8 \times 10^{-17}$

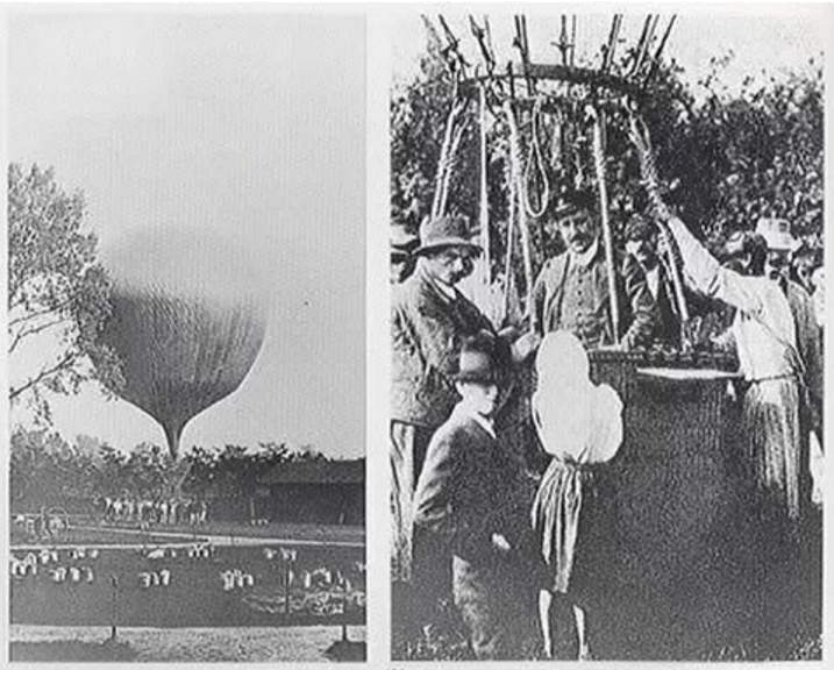
K il numero di ioni generati per cm^3 al 1" da un grammo di Radio ad 1 cm. di distanza: $K = 3{,}4 \times 10^9$ per l'aria racchiusa in elettroscopio d'alluminio; $K = 3{,}1 \times 10^9$ all'aria libera.

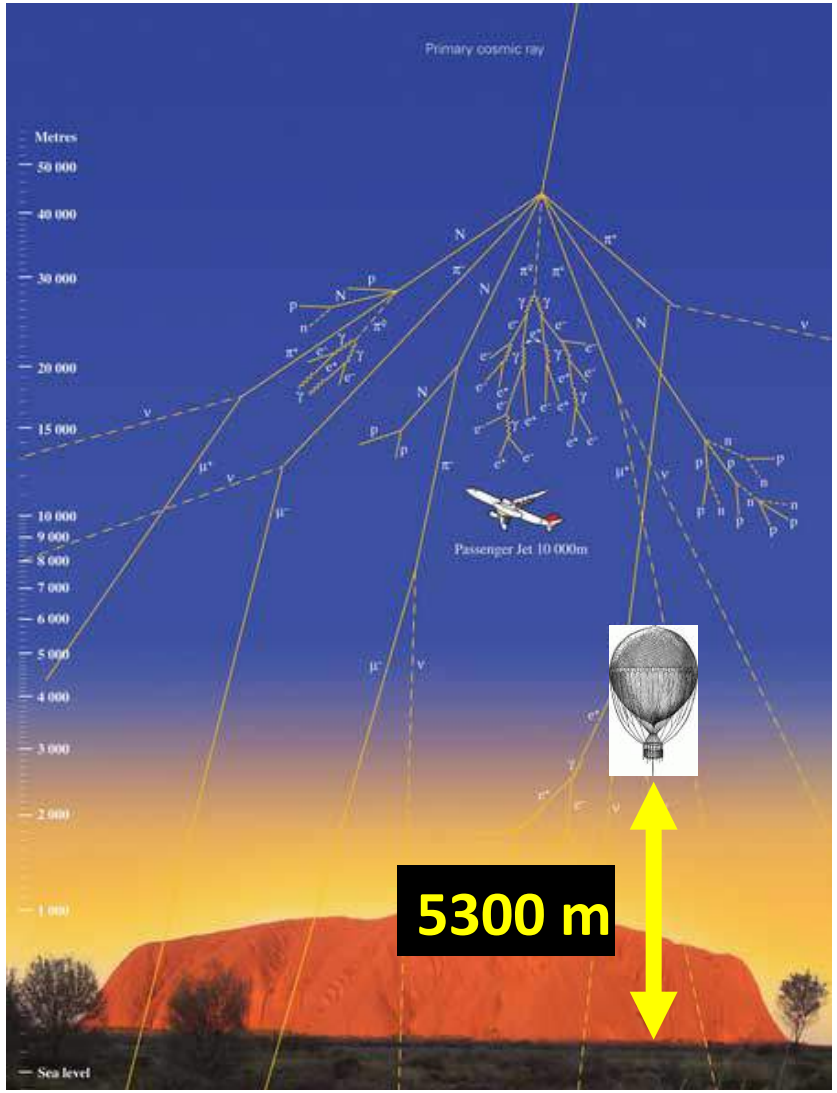
[1]) D. Pacini. *Ann. dell'Uff. Centr. Meteor.* Vol. XXXII, parte I, 1910. — *Le Radium*, T. VIII, pag. 307, 1911.
[2]) A. S. Eve. *Phil. Mag.*, 1911.

https://arxiv.org/pdf/1101.3015.pdf

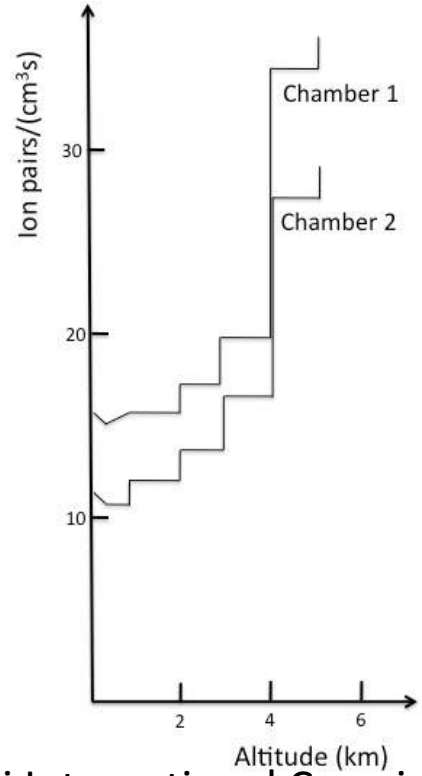
Gli esperimenti in quota di Victor Hess

Tra il 1911 e il 1912 l'Austriaco Victor Hesse misurò la radiazione penetrante in quota utilizzando dei palloni aerostatici .

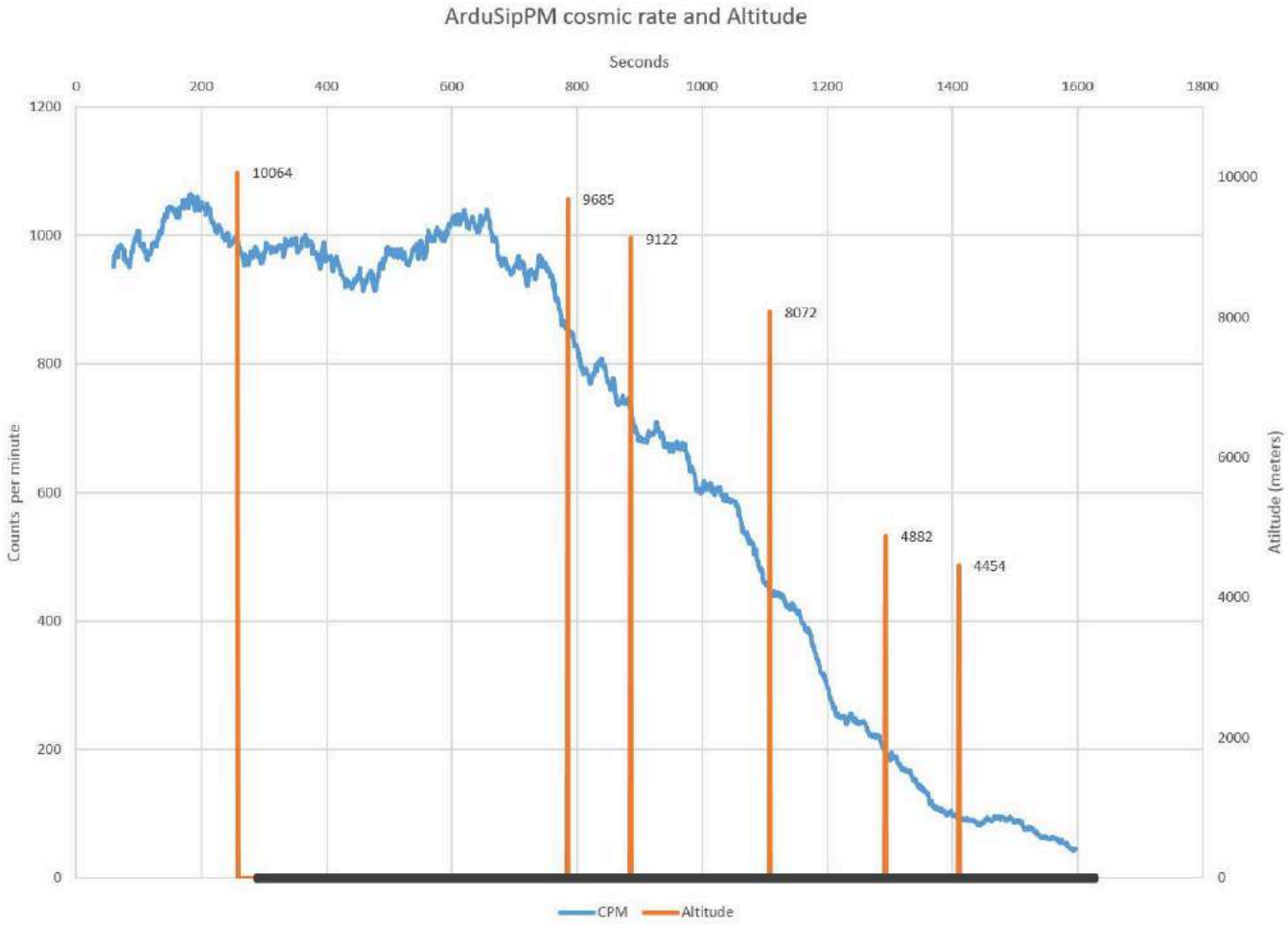




Victor Franz Hess
1883 Schloss Waldstein, Peggau
1964 Mount Vernon, New York

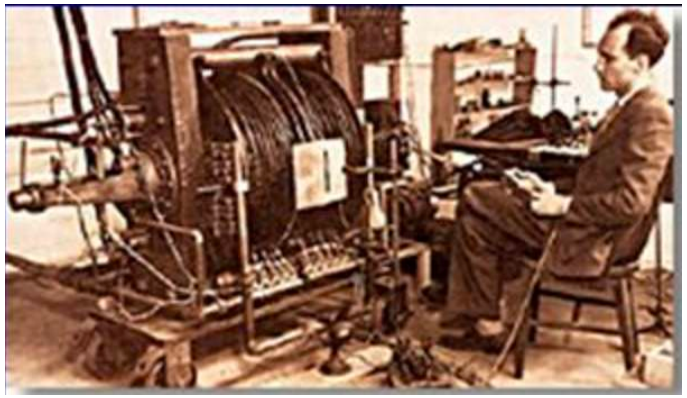


Misura dei raggi cosmici su un aereo di linea

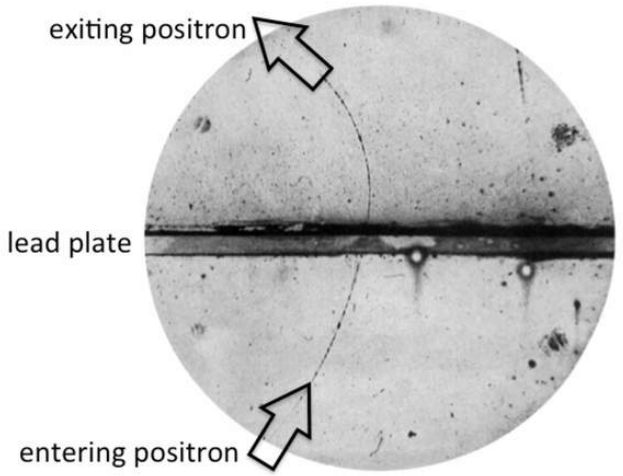


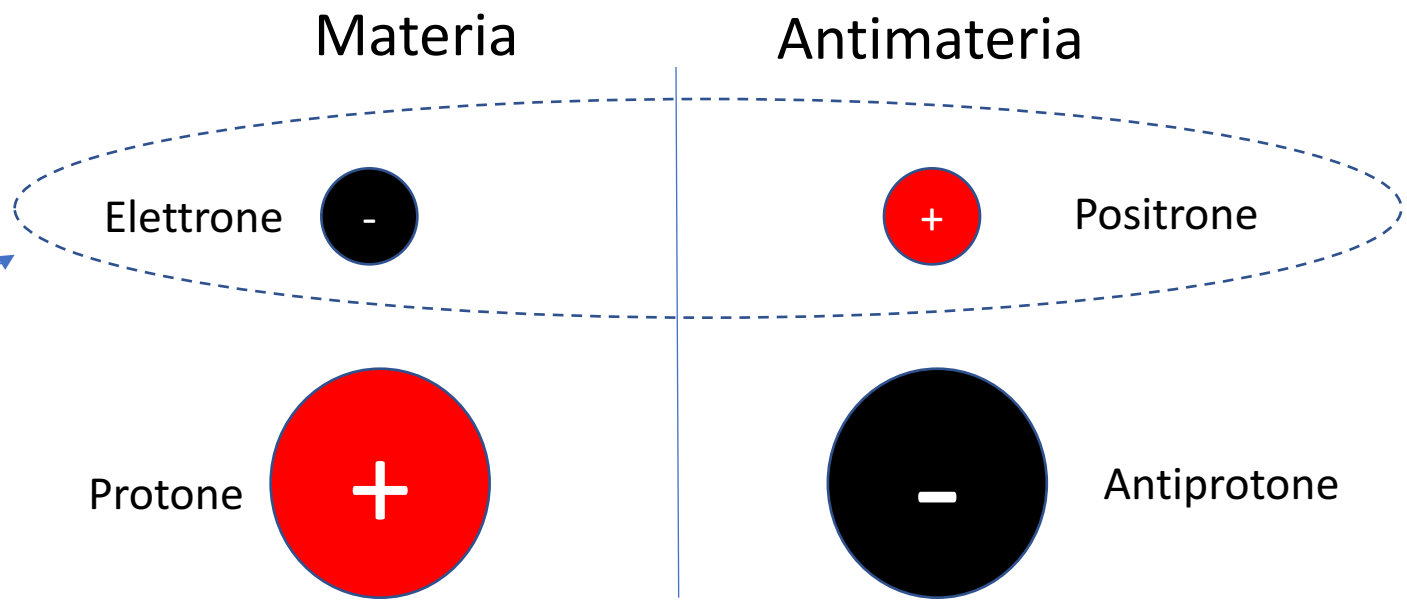
Valerio Bocci International Cosmic Day 2017

La scoperta dell'antimateria il positrone (1933)

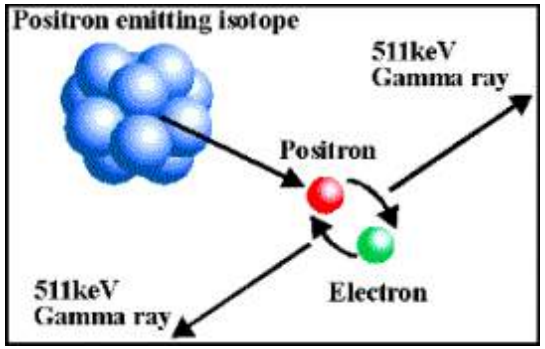


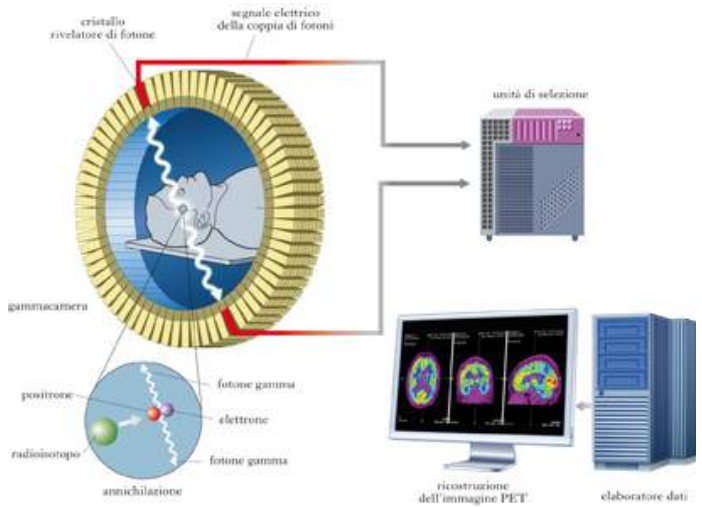
C.D. Anderson nel 1932 in una fotografia di tracce di raggi cosmici scopre il positrone un elettrone con carica positiva. La particella ipotizzata da Paul Dirac.





La tomografia a emissione di positroni (**PET**)





The Nobel Prize in Physics 1936

Victor F. Hess, Carl D. Anderson

The Nobel Prize in Physics 1936

Victor Franz Hess

Prize share: 1/2

Carl David Anderson

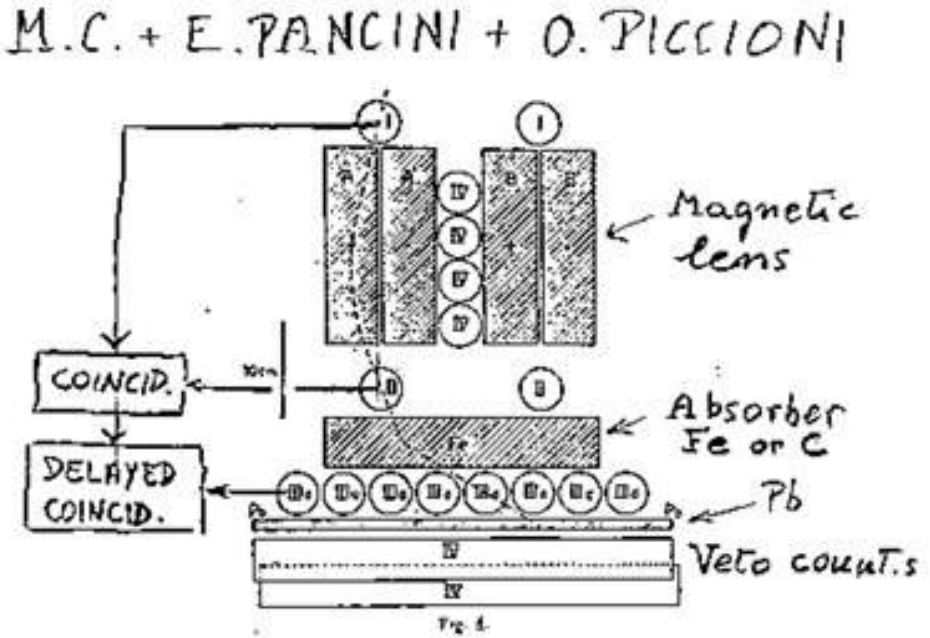
Prize share: 1/2

The Nobel Prize in Physics 1936 was divided equally between Victor Franz Hess *"for his discovery of cosmic radiation"* and Carl David Anderson *"for his discovery of the positron"*.

Esperimento Conversi, Pancini, Piccioni (CPP) sulla natura del Mesotrone

L'anno del suo nobel Anderson e Neddermeyer, con camera a nebbia comandata in campo magnetico, scoprono che le particelle cariche penetranti dei raggi cosmici hanno massa intermedia tra quelle dell'elettrone e del protone (**mesotrone**; *m* fra 100 e 300 m_e).

Viene chiamato mesotrone e in un primo tempo identificato come la particella prevista dal teorico Yukawa come mediatore della interazione forte tra nucleoni

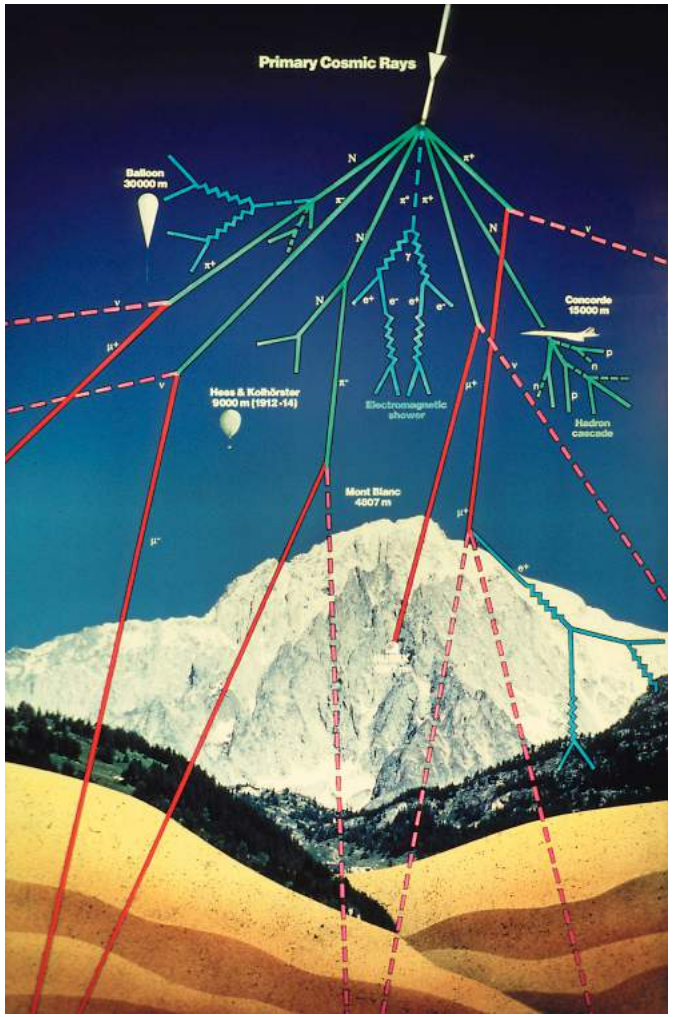


Grazie all'esperimento Conversi Pancini Piccioni si scopre
l'errore e si misura il suo tempo di decadimento. Il mesostrone dei raggi cosmici non è la particella di Yukawa
non interagisce tramite forza nucleare.
E' un nuovo leptone ..un elettrone pesante.

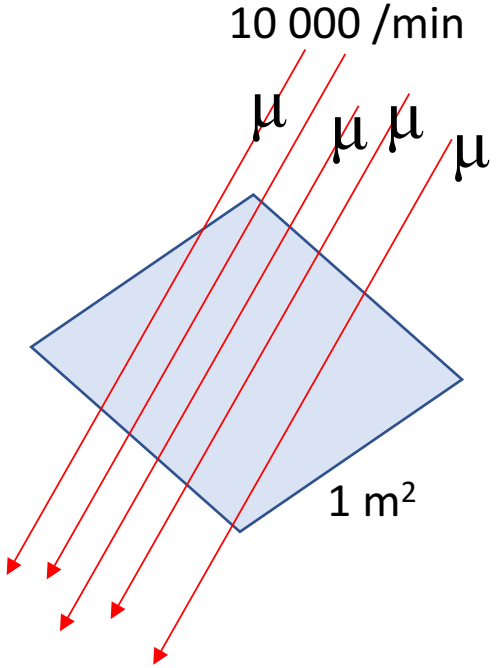
IL MUONE

La radiazione penetrante …il muone μ

nome inizale di battesimo mesotrone(*)
(Carl David Anderson, Seth Neddermeyer 1936)



Muoni μ



(*)In un primo tempo confuso con il mesone pi (pione) correttamente Identificato nel 1947, rinominato muone per evitare confusioni.

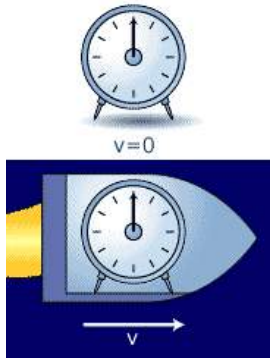
La breve vita del muone.

2.2 Milionesimi di secondo

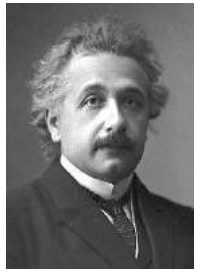
Meccanica Newtoniana

μ 660 metri

e ν



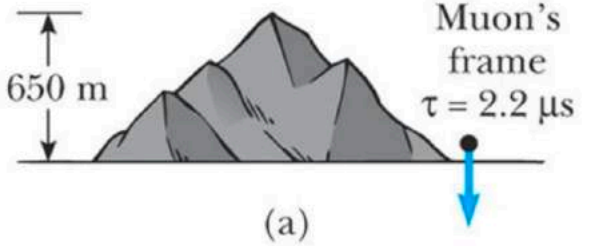
Meccanica relativistica

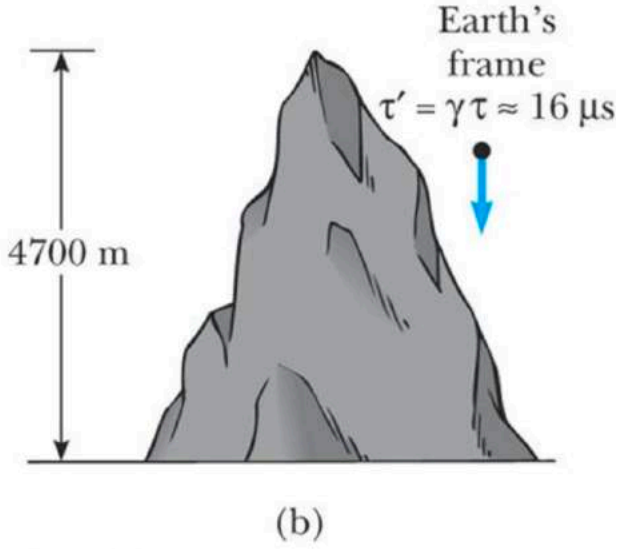


μ

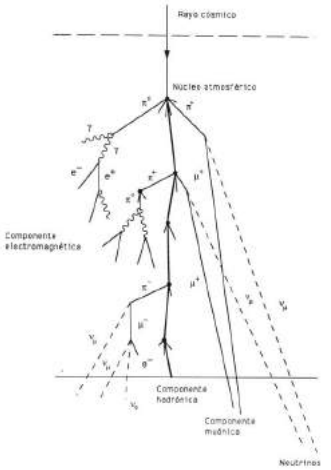
4700 metri

e ν





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.

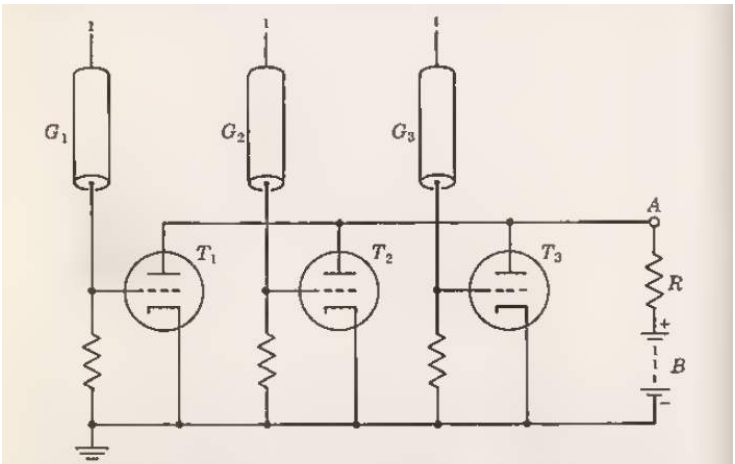


Fig. 4-1 Vacuum-tube coincidence circuit greatly reduces the number of chance coincidences recorded by G-M counters (see text). Under operating conditions, current flows from the positive terminal of the battery B through the resistor R and three tubes T_1, T_2, T_3 to a ground. This current produces 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

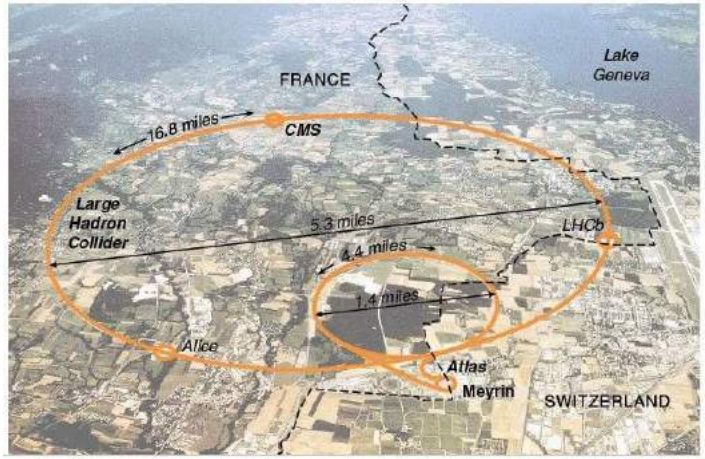
The discovery of air showers

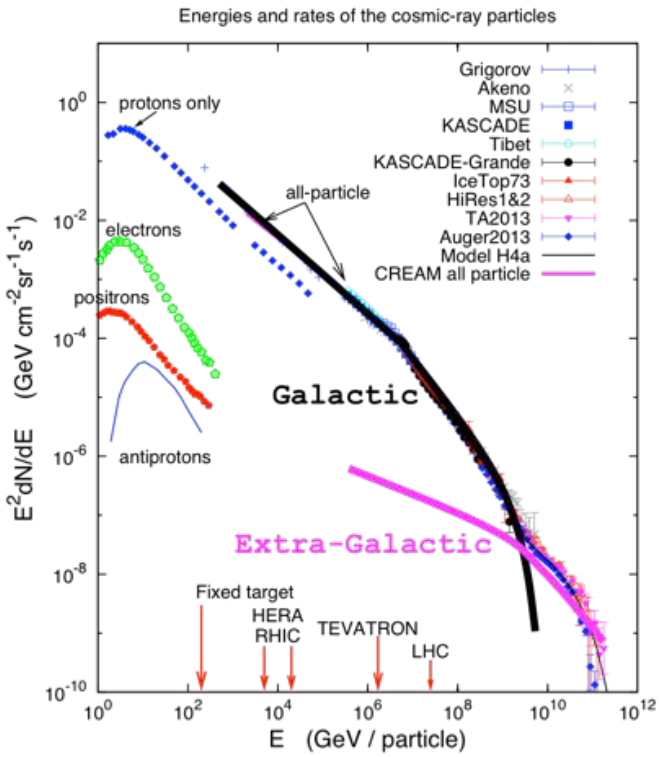
Air showers were discovered, more or less by chance, through the widespread application of coincidence-counter arrangements to the experimental study of cosmic rays. The devices used to detect coincidences will record as simultaneous the pulses of two or more counters if these pulses arrive within a 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.

Gli Acceleratori di particelle

Dagli anni 50 I fisici delle particelle hanno pensato di costruire I loro produttori di raggi cosmici.

LHC
CERN Ginevra



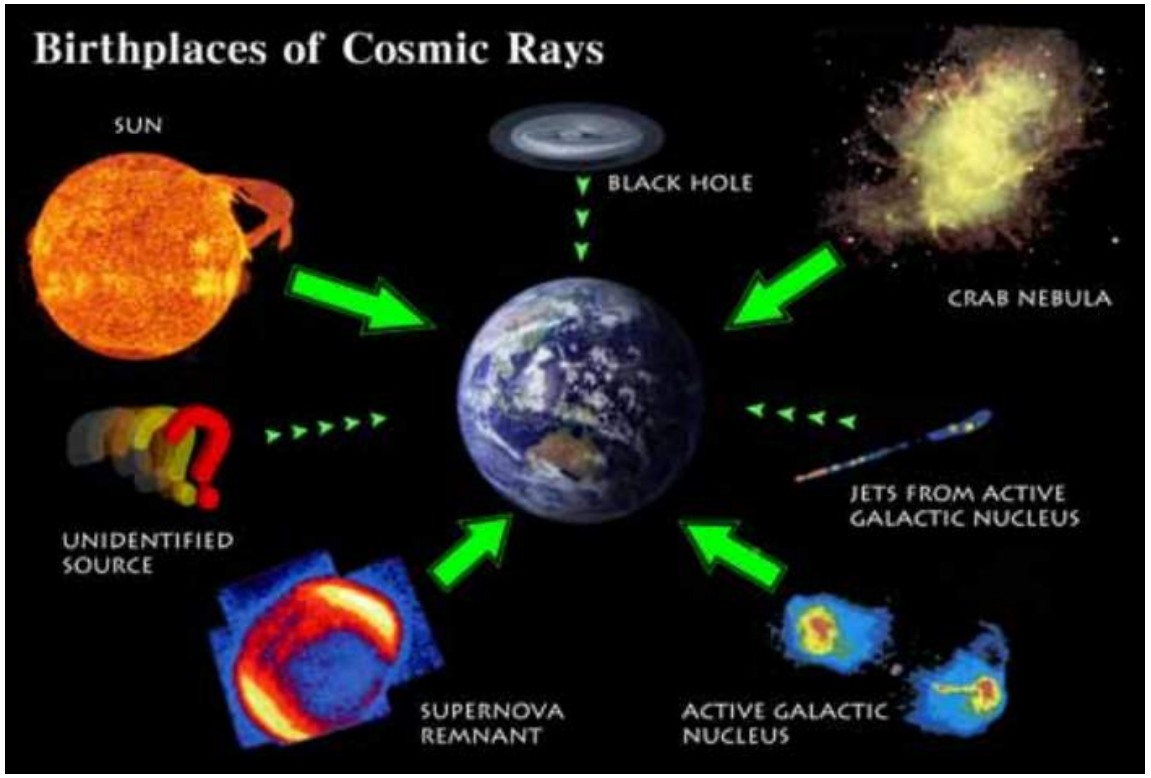


Tevatron Fermilab Chicago

CNAO acceleratore per adroterapia

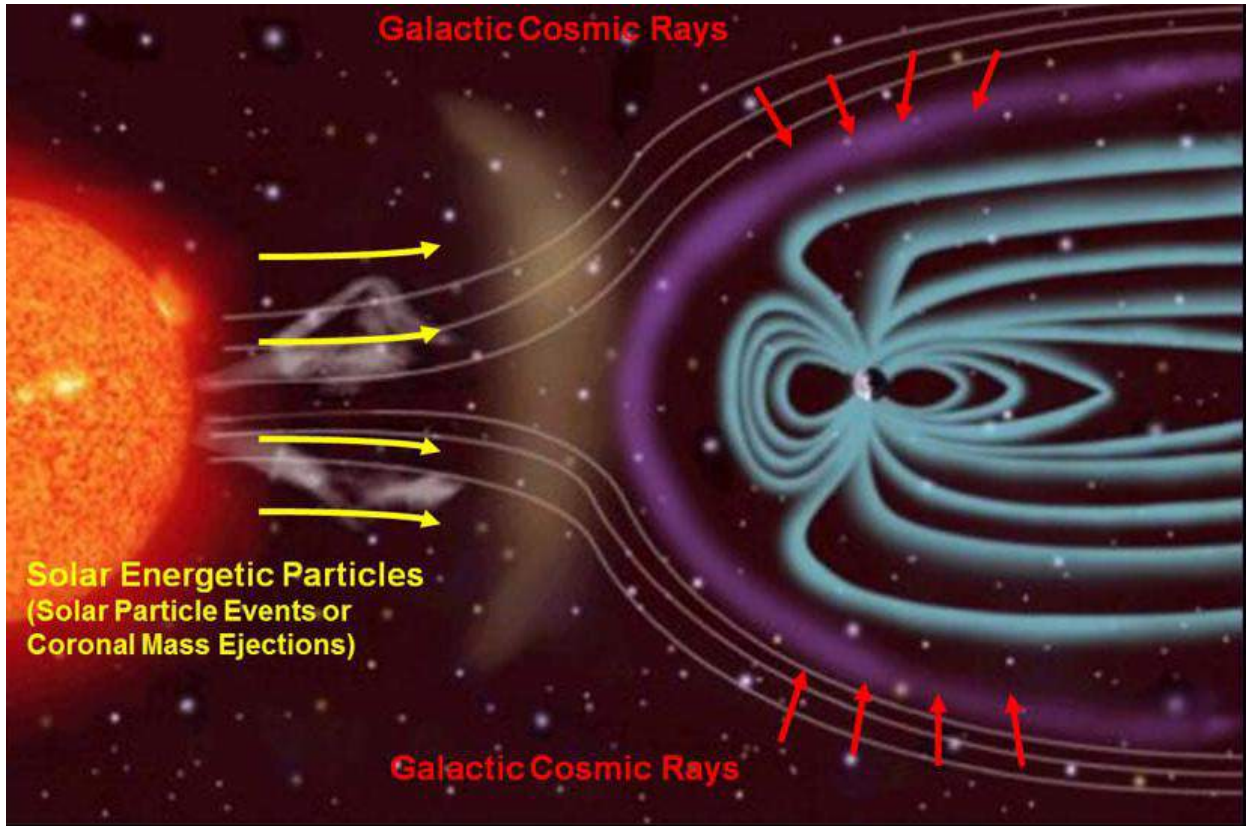
Cosmic Ray

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

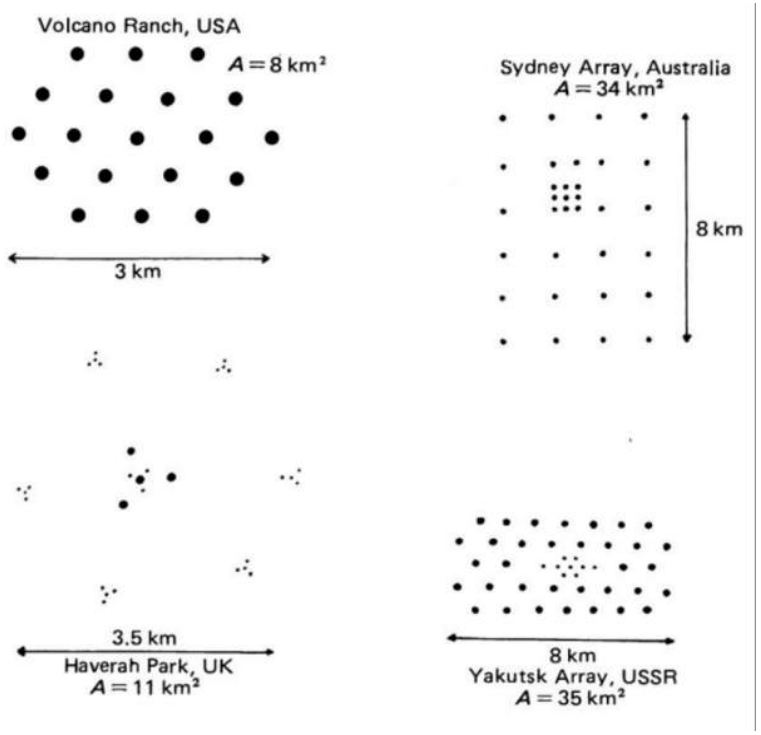


Sometimes particle coming from the Sun can traverse the Magnetic Field

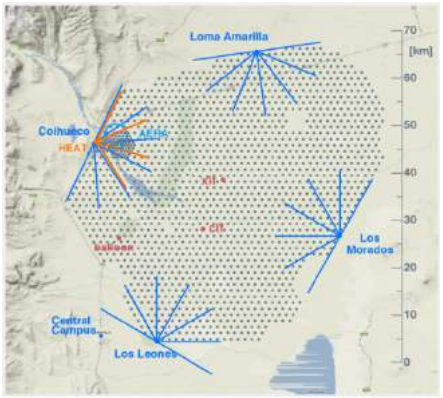
Auroras are produced when the magnetosphere is sufficiently disturbed by the solar wind that the trajectories of charged particles in both solar wind and magnetospheric plasma, mainly in the form of electrons and protons, precipitate them into the upper atmosphere. (Wikipeda)

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

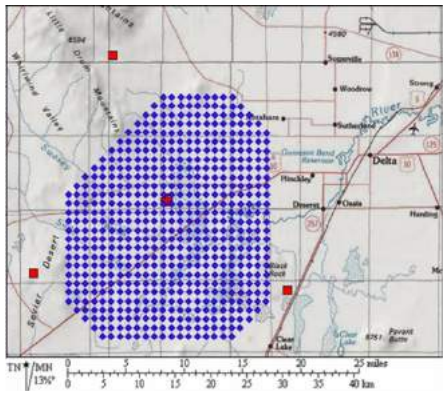
On February 22, 1962, John David Linsley observed an air shower at Volcano Ranch created by a primary particle with an energy greater than 10^{20} eV

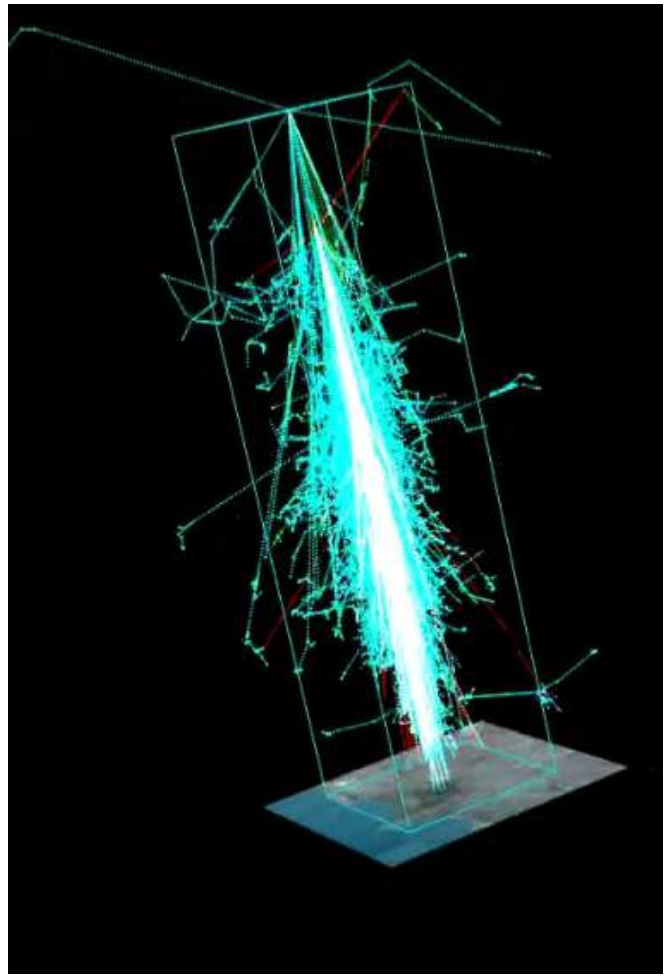


Pierre Auger Observatory (Argentina)



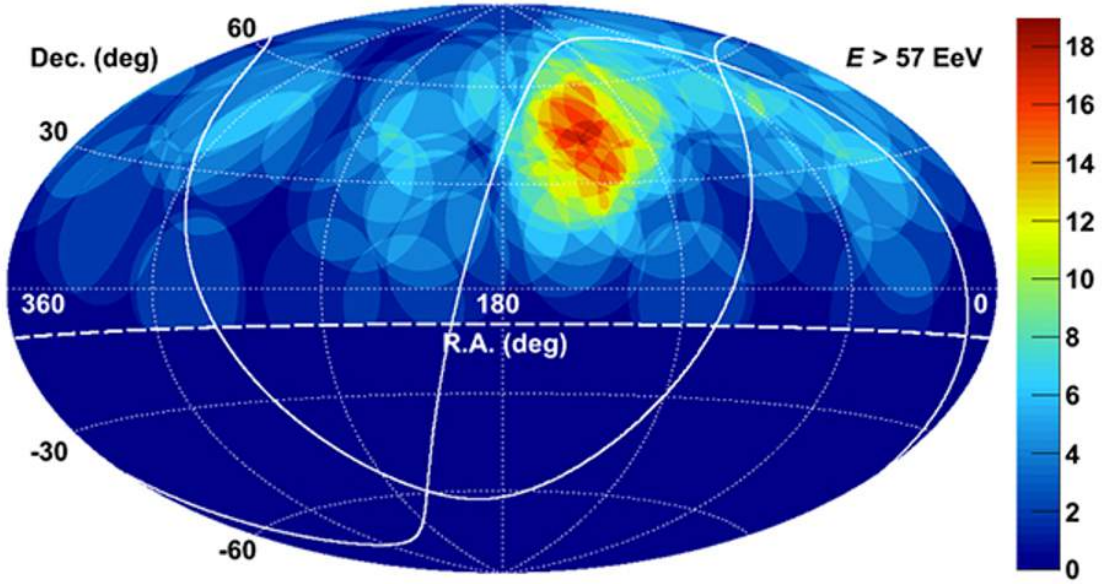
Telescope Array Project (Utah)





La misura dei raggi cosmici ad alta energia (UHECR)

Uno degli argomenti aperti dei raggi cosmici è quale è il limite massimo della loro energia , secondo la teoria i raggi cosmici sopra 5×10^{19} eV di energia (GZK cutoff) non possono viaggiare per percorsi lunghi a causa dei processi di interazione con la radiazione di fondo (CMB), si aspetta quindi secondo la teoria da dimostrare sperimentalmente che tutte le sorgenti sopra il GZK cut off siano ad una distanza inferiore ai 50-100 Megaparsec (1 Mpc circa tre milioni di anni luce).



K. Kawata, University of Tokyo Institute for Cosmic Ray Research

Of the 87 cosmic rays surpassing 57 EeV detected thus far by the Telescope Array, 27 percent come from 6 percent of the sky. The hotspot centers on the constellation Ursa Major.

Breaking News from Auger Observatory

Science

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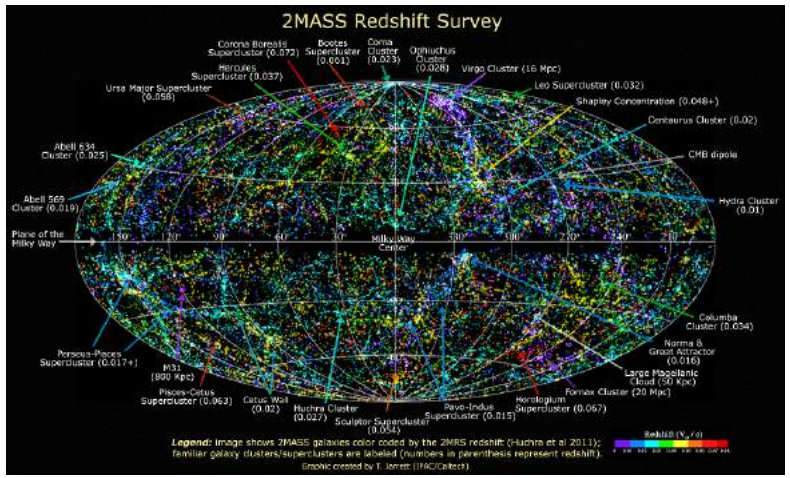
RESEARCH

COSMIC RAYS

Observation of a large-scale anisotropy in the arrival directions of cosmic rays above 8×10^{18} eV

The Pierre Auger Collaboration*†

Cosmic rays are atomic nuclei arriving from outer space that reach the highest energies observed in nature. Clues to their origin come from studying the distribution of their arrival directions. Using 3×10^4 cosmic rays with energies above 8×10^{18} electron volts, recorded with the Pierre Auger Observatory from a total exposure of 76,800 km^2 sr year, we determined the existence of anisotropy in arrival directions. The anisotropy, detected at more than a 5.2σ level of significance, can be described by a dipole with an amplitude of $6.5^{+1.3}_{-0.9}$ percent toward right ascension $\alpha_d = 100 \pm 10$ degrees and declination $\delta_d = -24^{+12}_{-13}$ degrees. That direction indicates an extragalactic origin for these ultrahigh-energy particles.



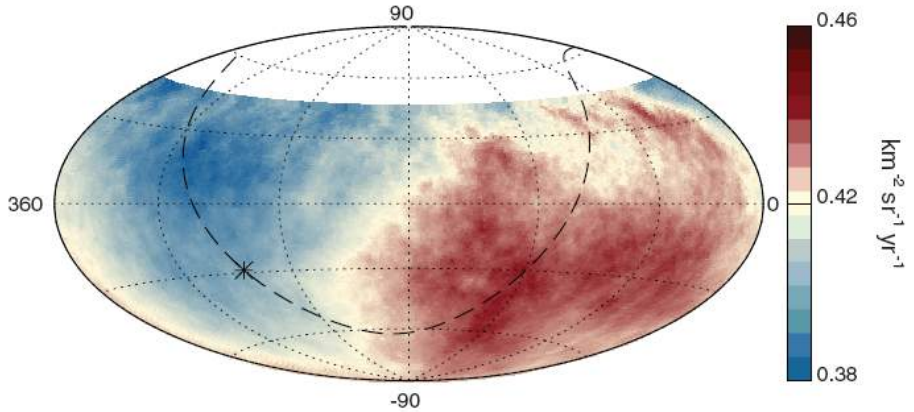


Fig. 2. Map showing the fluxes of particles in equatorial coordinates. Sky map in equatorial coordinates, using a Hammer projection, showing the cosmic-ray flux above 8 EeV smoothed with a 45° top-hat function. The galactic center is marked with an asterisk; the galactic plane is shown by a dashed line.

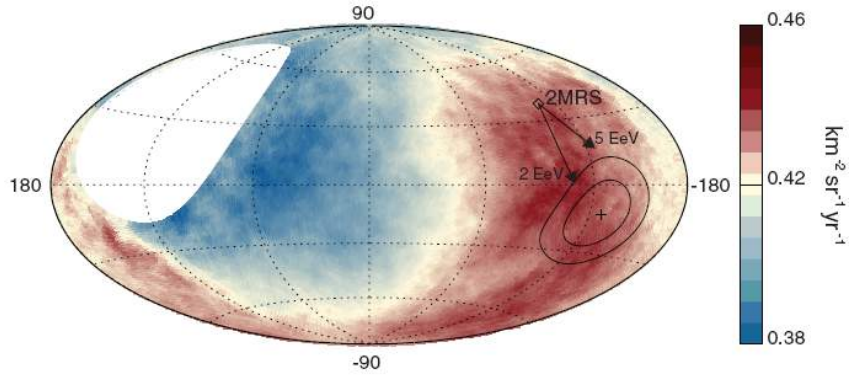
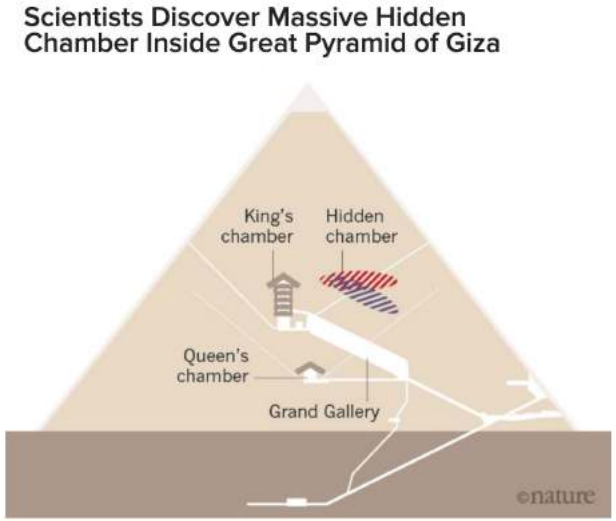
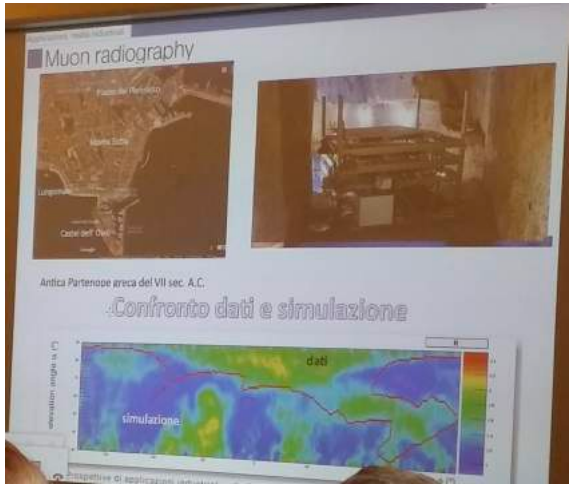


Fig. 3. Map showing the fluxes of particles in galactic coordinates. Sky map in galactic coordinates showing the cosmic-ray flux for $E \geq 8$ EeV smoothed with a 45° top-hat function. The galactic center is at the origin. The cross indicates the measured dipole direction; the contours denote the 68% and 95% confidence level regions. The dipole in the 2MRS galaxy distribution is indicated. Arrows show the deflections expected for a particular model of the galactic magnetic field (*8*) on particles with $E/Z = 5$ or 2 EeV.

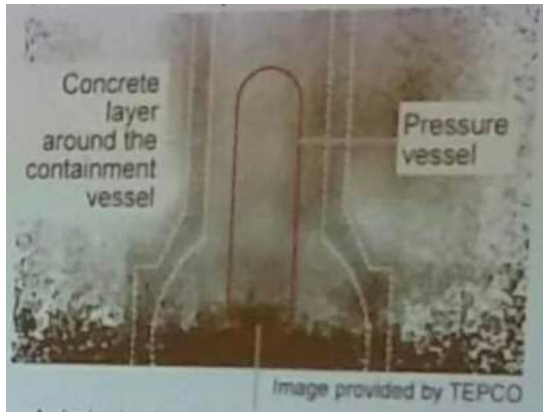
Muon tomography

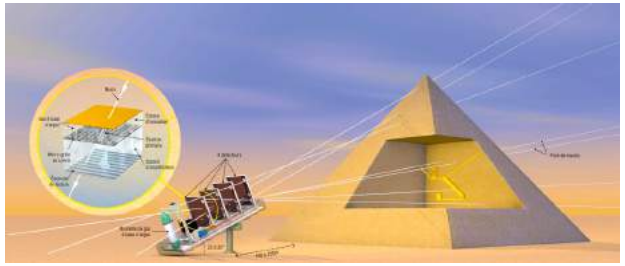


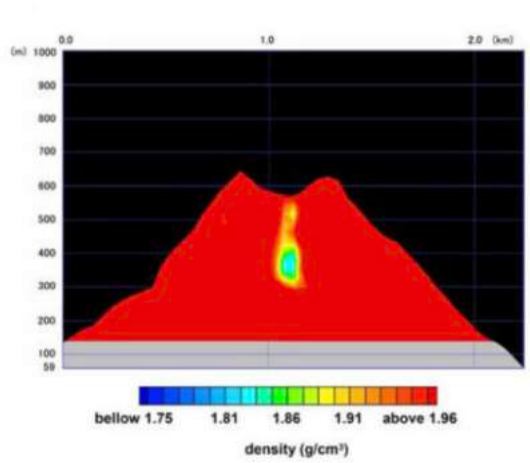


Monte Echia Napoli

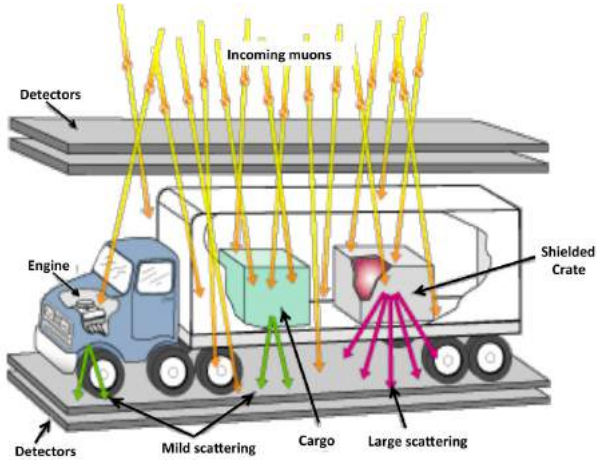
imaging the core of fukushima reactor with muons







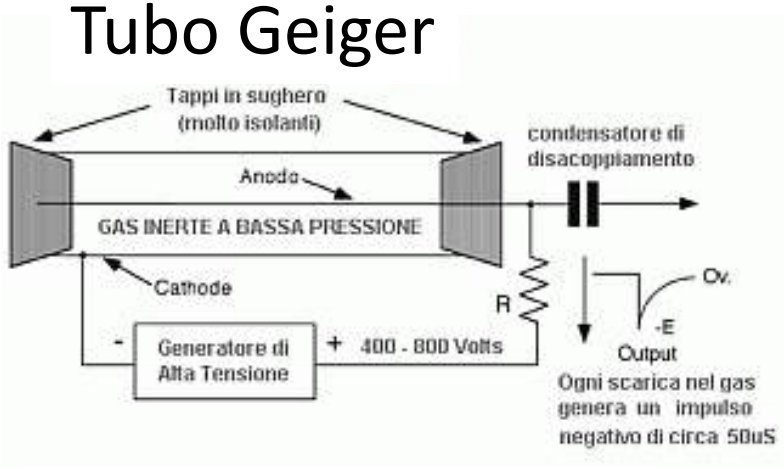
Muon radiographic map of Satsuma-Iwojima Volcano, Japan



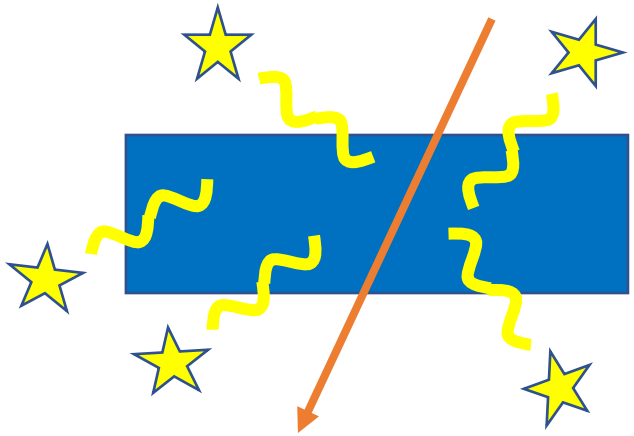
Valerio Bocci International Cosmic Day 2017

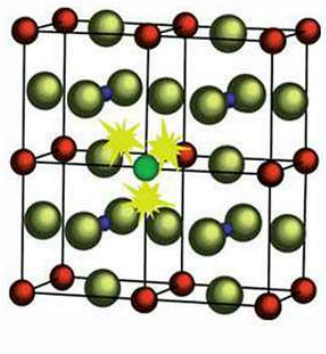
Some technics to detect ionizing particles

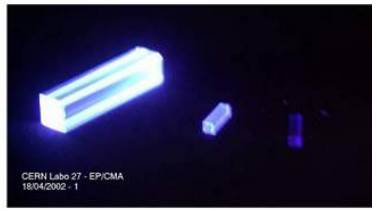
Tubo Geiger



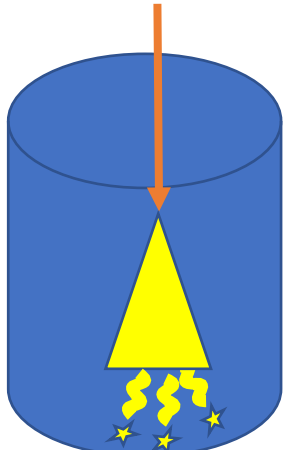
Scintillation materials

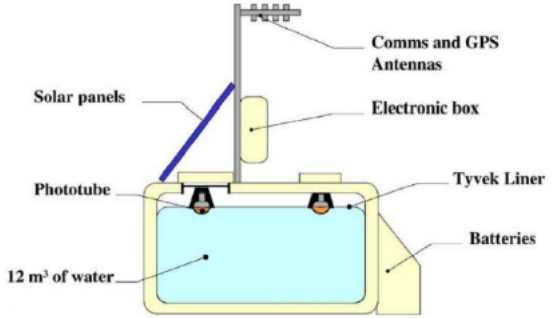






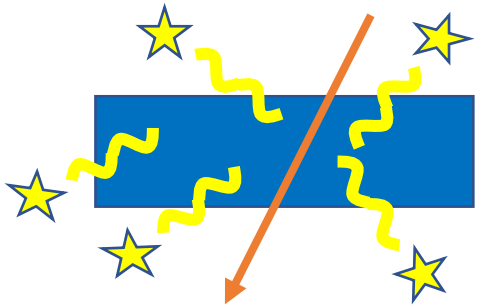
Cherenkov effects

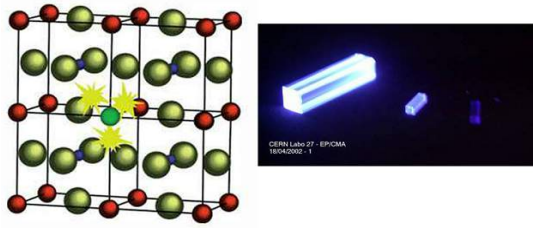




Using Scintillation materials

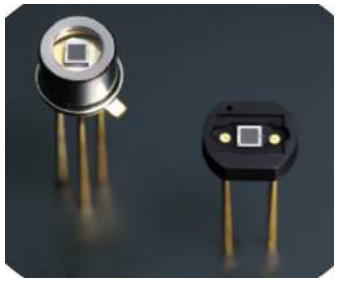
The use of scintillation materials is not for everyone in the past.
The only way was to use photomultiplier.

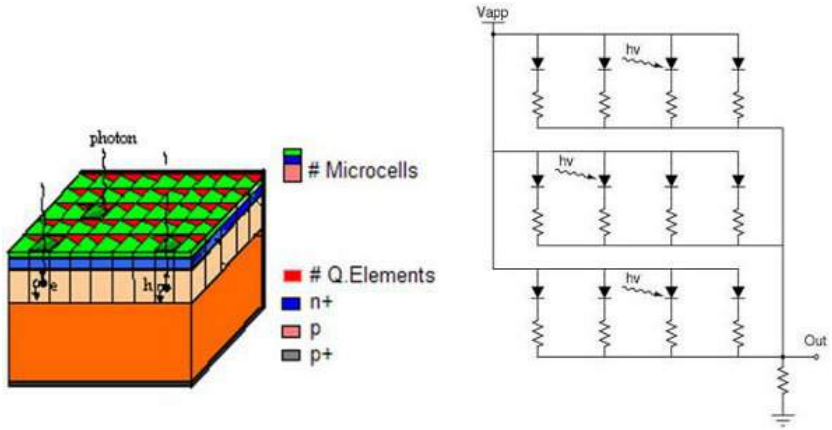


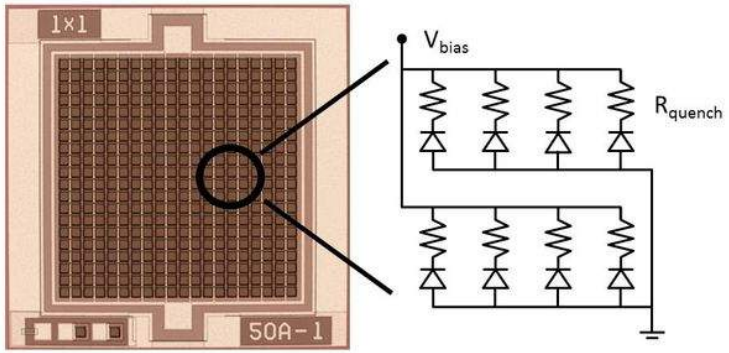


The Photomultiplier (1934).
Based on Photoelectric effect (1921 Einstein Nobel) and electron secondary emission.
The Photomultiplier are expensive and need high voltage(1000 Volt).

SiPM
(Silicon Photo Multiplier)







The idea behind this device is the detection of single photon events in sequentially connected SiAPDs.

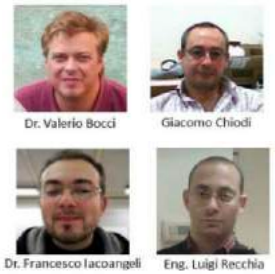
The dimension of each single APD can vary from 20 to 100 micrometres, and their density can be up to 1000 per square millimeter.

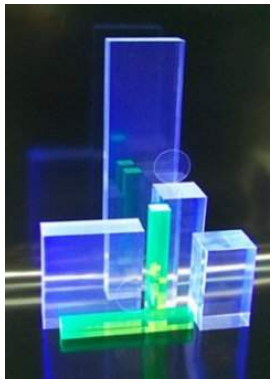
Every APD in SiPM operates in Geiger-mode and is coupled with the others by a polysilicon quenching resistor.

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 (Vb) 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.

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



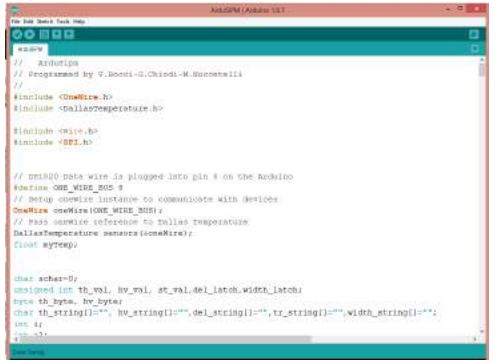


Scintillator

Photons Sensor (SiPM)

Custom Electronics (ArduSiPM Shield)

Arduino DUE

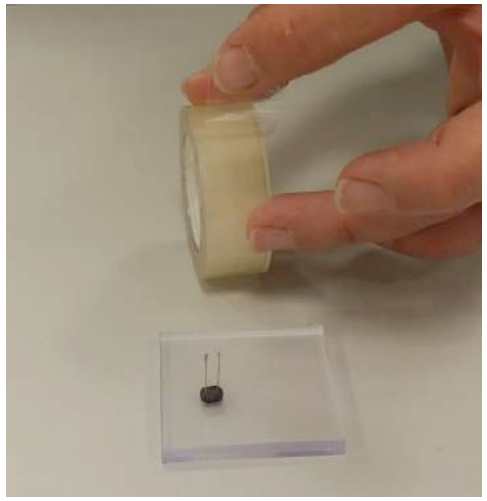
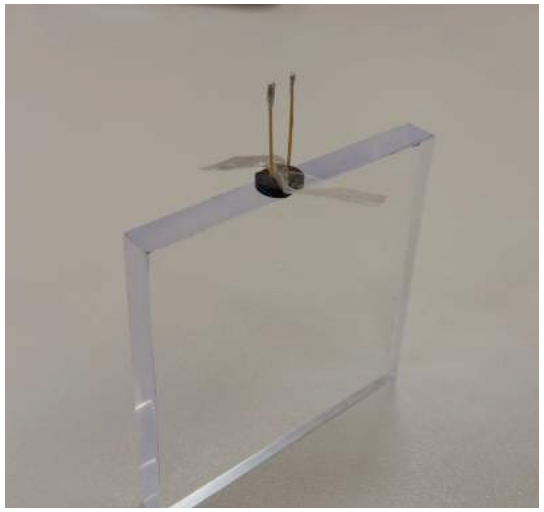
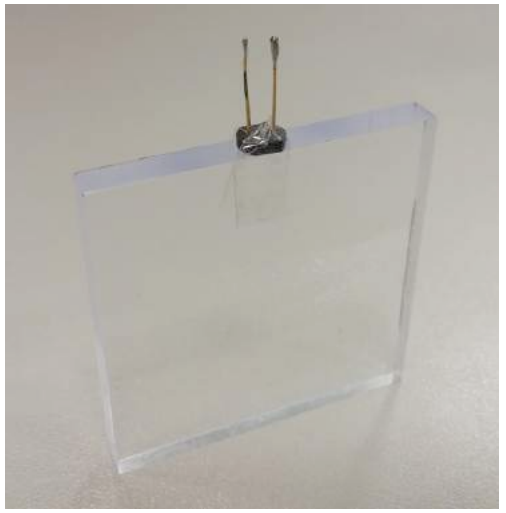


ArduSiPM Software

Particle Detector

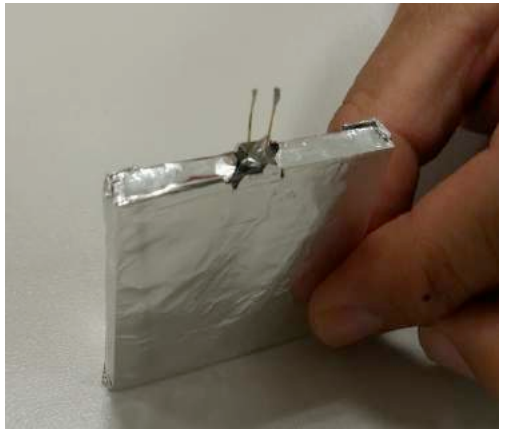
ArduSiPM

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.

Application Example 1: Intraoperative β- Detecting Probe

nature.com > scientific reports > articles > article

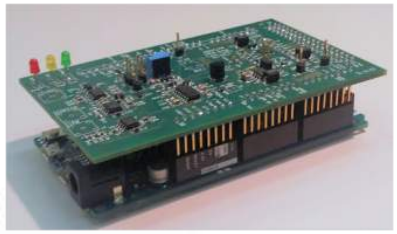
SCIENTIFIC REPORTS

A novel radioguided surgery technique exploiting β^- decays

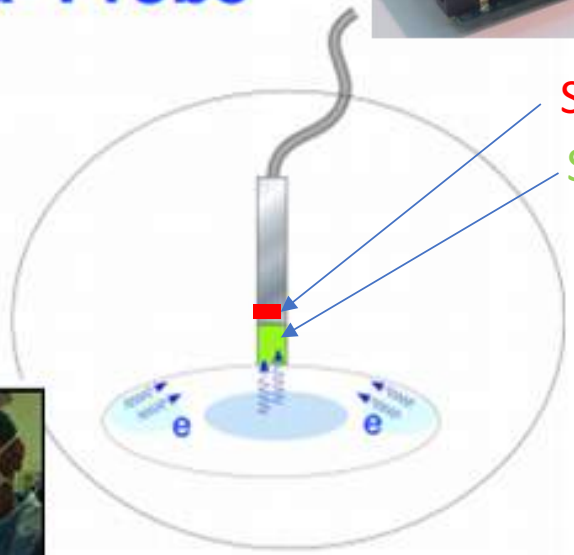
E. Solfaroli Camillocci, G. Baroni, F. Bellini, V. Bocci, F. Collamati, M. Cremonesi, E. De Lucia, P. Ferroli, S. Fiore, C. M. Grana, M. Marafini, I. Mattei, S. Morganti, G. Paganelli, V. Patera, L. Piersanti, L. Recchia, A. Russomando, M. Schiariti, A. Sarti, A. Sciubba, C. Voena & R. Faccini

Beta- Probe

ArduSiPM



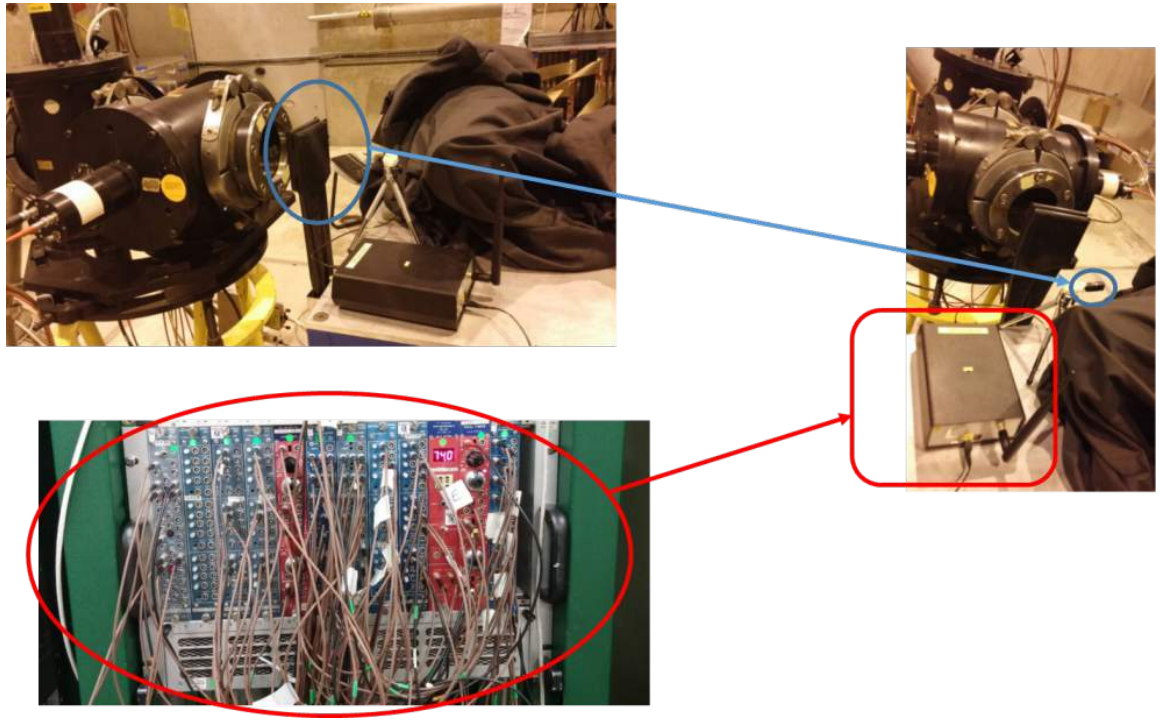
Control and readout
Android App



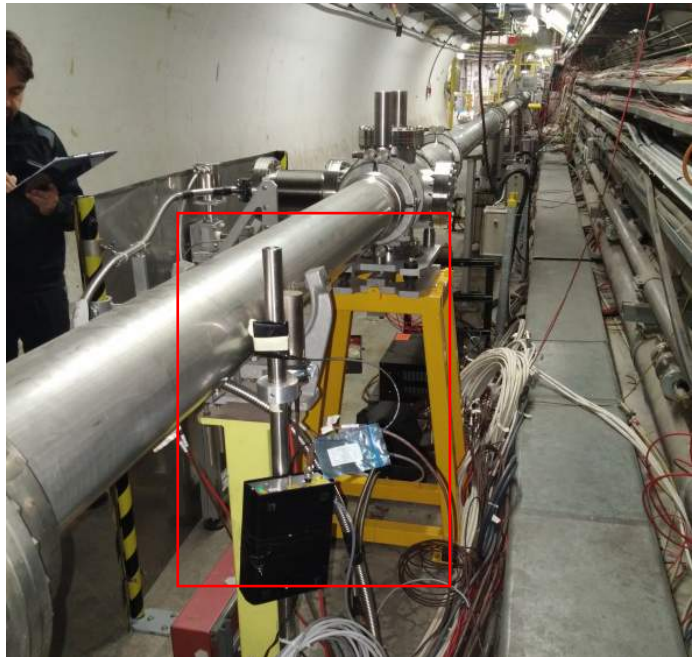
- Radioguided **intraoperative beta probe**, with scintillation material coupled with SiPM detector.

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)



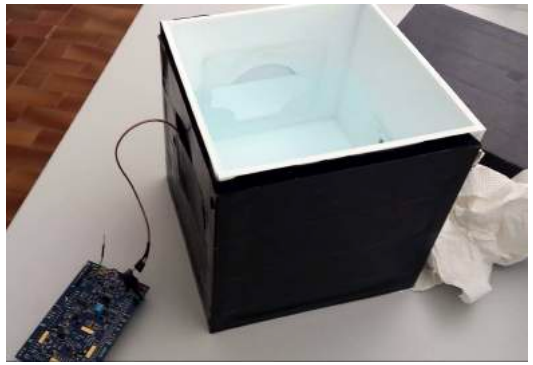
- As beam losses counter @ SPS

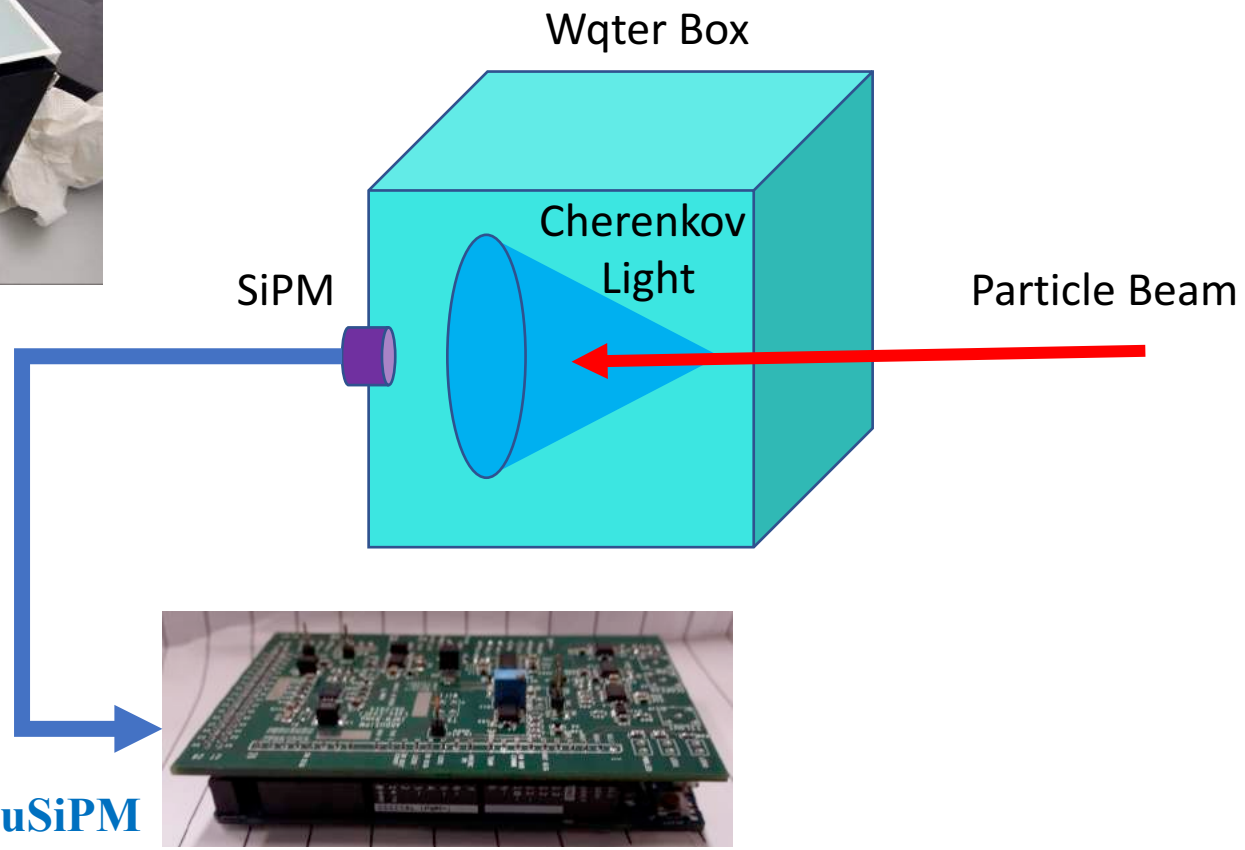
- *This work has been supported by the ERC Ideas Consolidator Grant*
- *No.615089 "CRYSBEAM".*

A School made Cherenkov light detector

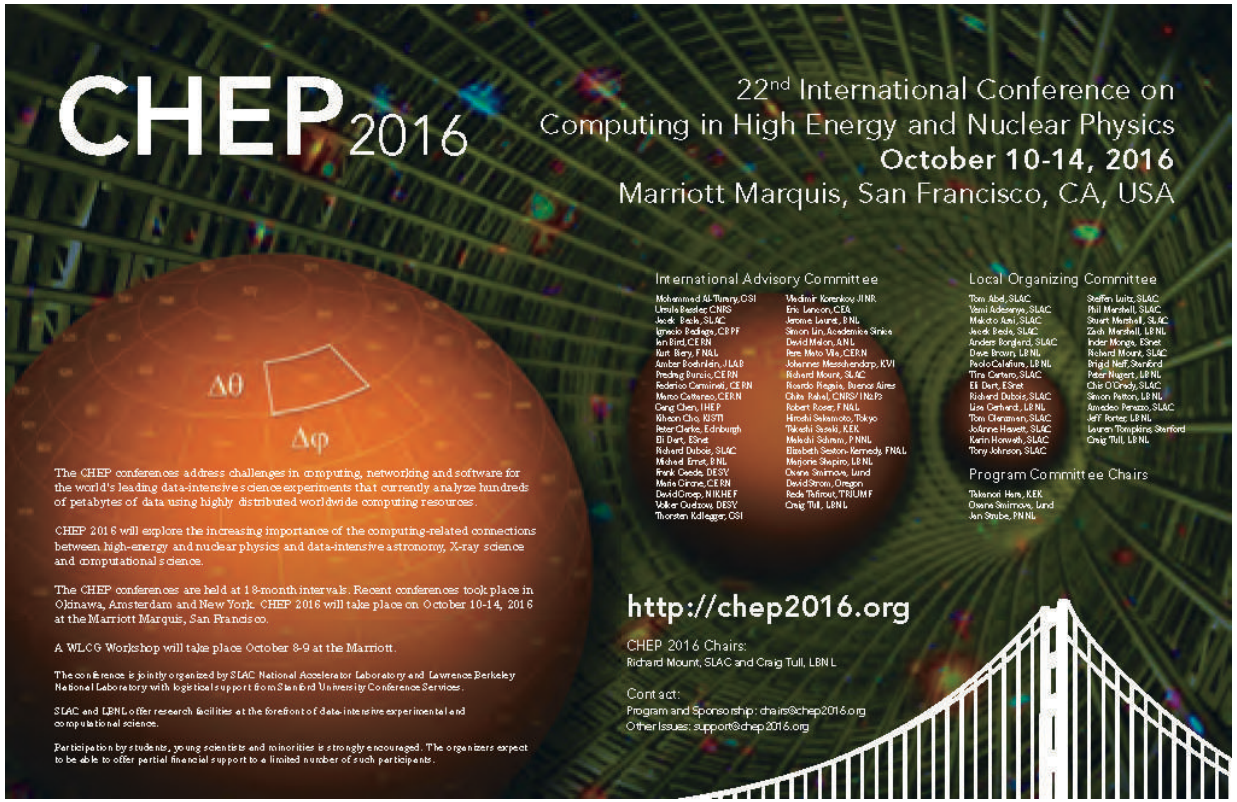
(Winner of CERN “A beamline for schools”2017)

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





Valerio Bocci International Cosmic Day 2017



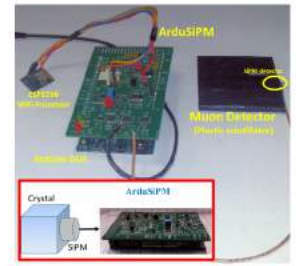
INFN
Istituto Nazionale di Fisica Nucleare

An educational distributed Cosmic Ray detector network based on ArduSiPM using microcontrollers as data acquisition node NTP protocol as time distribution and IoT technology for data aggregation.

Valerio Bocci , Giacomo Chiodi, Paolo Fresch, Francesco Iacoangeli, Luigi Recchia

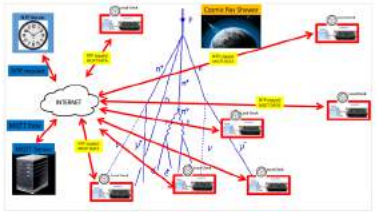
INFN Roma, Piazzale A.Moro, 2 - 00185 Roma
valerio.bocci@roma1.infn.it

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.

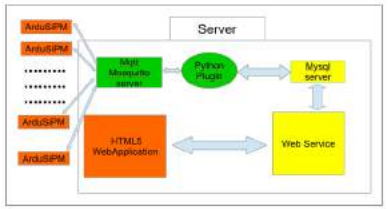


The ArduSiPM (1) is an easy hand-held battery operated data acquisition system based with an Arduino board, which is used to detect cosmic rays and nuclear radiation. The ArduSiPM uses an Arduino DUE (an open Software/Hardware board based on an ARM Cortex-M3 microcontroller) as processor board and a piggyback custom designed board (Shield), these are controlled by custom developed software and interface. The Shield contains different electronics features both to monitor, to set and to acquire the SiPM signal using the microcontroller board. The SiPM photon counting detector can be coupled to a cheap plastic scintillator to realize a cosmic ray detector (mainly muon particles). An ArduSiPM channel give informations about rate of events, arrival time and number of photons produced by muons, it contains all the feature from controls to data acquisition typical of High Energy Physics channel at a cost affordable for single user or school.

(1) The ArduSiPM a compact trasportable Software/Hardware Data Acquisition system for SiPM detector V. Bocci et al. IEEE NSS/MIC 2014 Pages: 1 - 5. DOI: 10.1109/NSSMIC.2014.7431252 arXiv:1411.7814

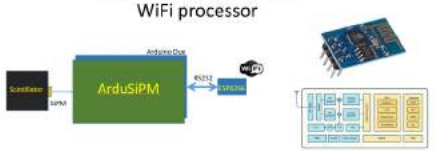


Using Network Time Protocol (NTP) the absolute time from the network, with a precision of tens milliseconds. The network time can be used from a cloud of ArduSiPMs to detect offline coincidence events linked to Ultra High Energy Cosmic Ray



The terms of IoT (Internet of Things) define a set of data communication protocols and the capability of single embedded electronics objects to communicate using the internet .
The MQTT (Message Queue Telemetry Transport) is one of the main protocol used in IoT device for data transmission over TCP/IP, the client version can run easily in nowadays microcontrollers, the MQTT broker (the server version) can run also in credit card–sized single-board computers as well in big server.

ESP8266 MQTT, NTP and WiFi processor



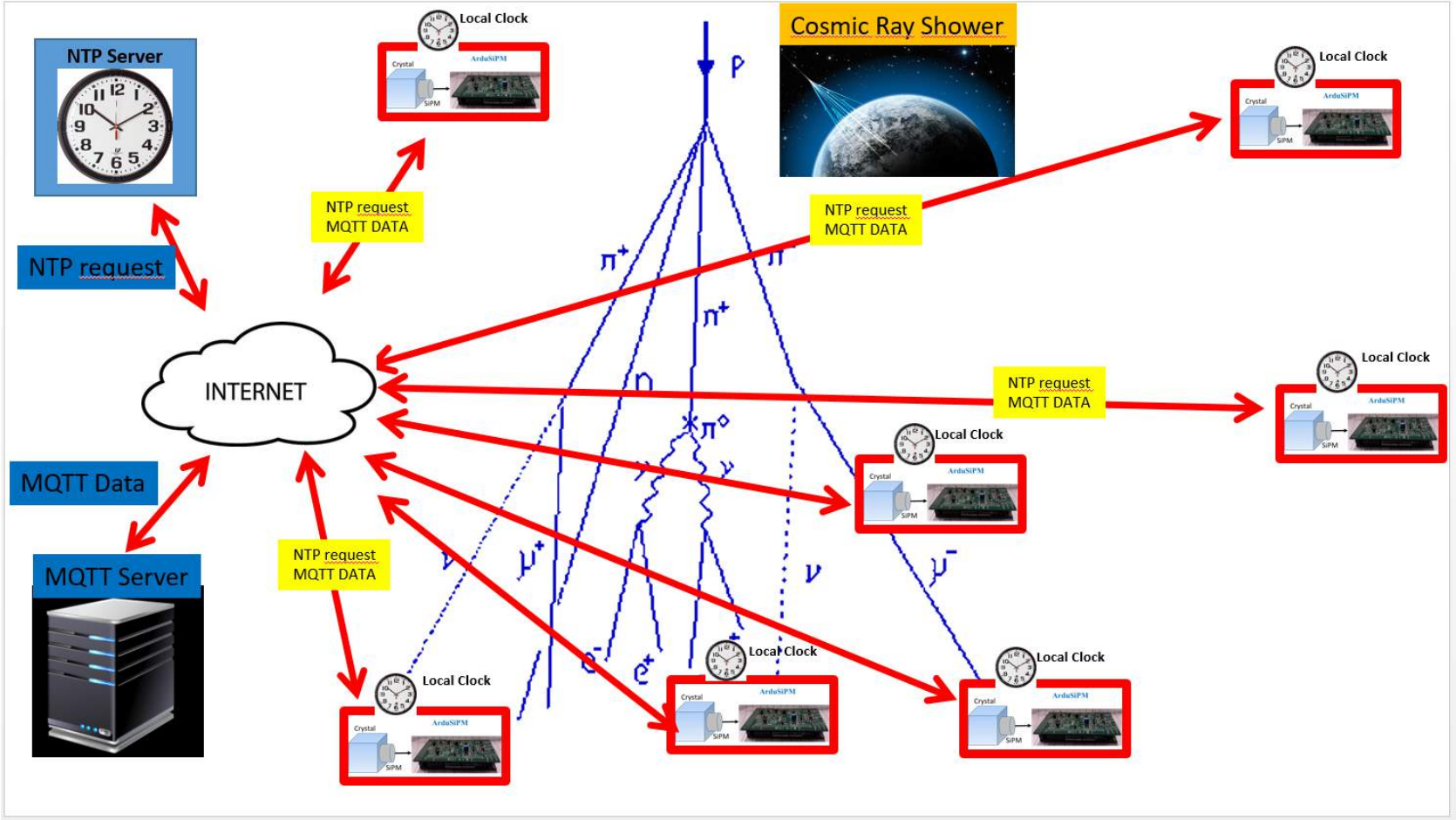
The ArduSiPM sends data over rs232, the Wifi Processor elaborate the data and send them using the MQTT protocol to the server. We use as network processor the Espressif ESP8266 a low-cost Wi-Fi chip with full TCP/IP stack and a 32-bit RISC CPU running at 80 MHz. The ESP8266 can be used to send and configure MQTT packets, NTP request and configure ArduSiPM device.

ArduSiPM web configuration pages.

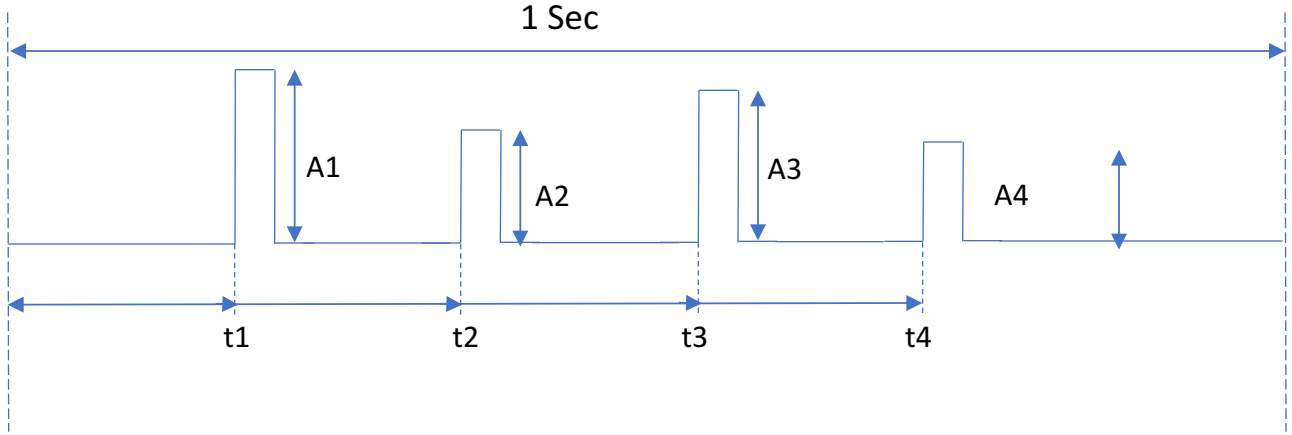
Search of cosmic Airshower in a wide area using ArduSiPM

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.



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

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

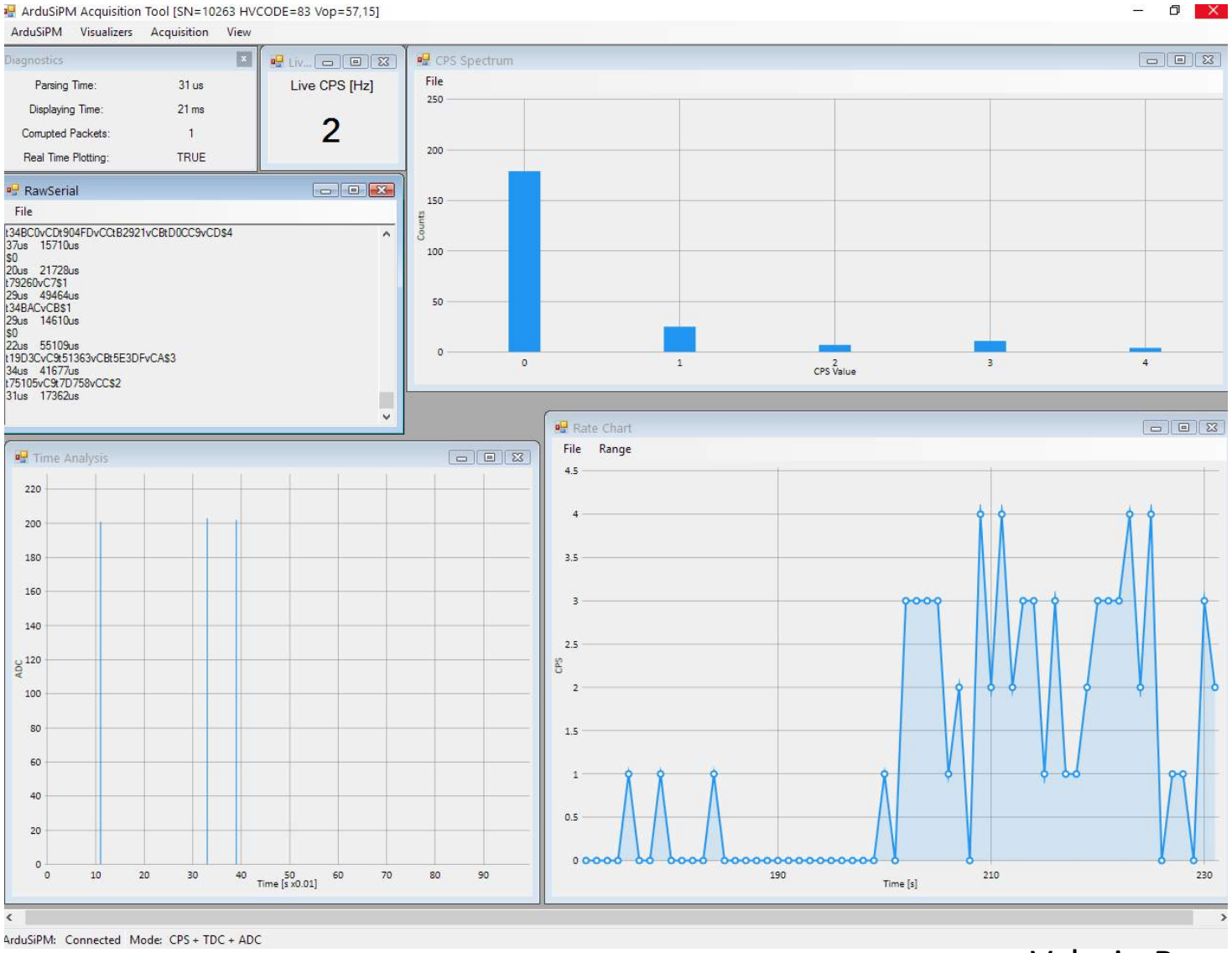
We can meausure and dump (depending from amplitude and distribution of pulses):

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

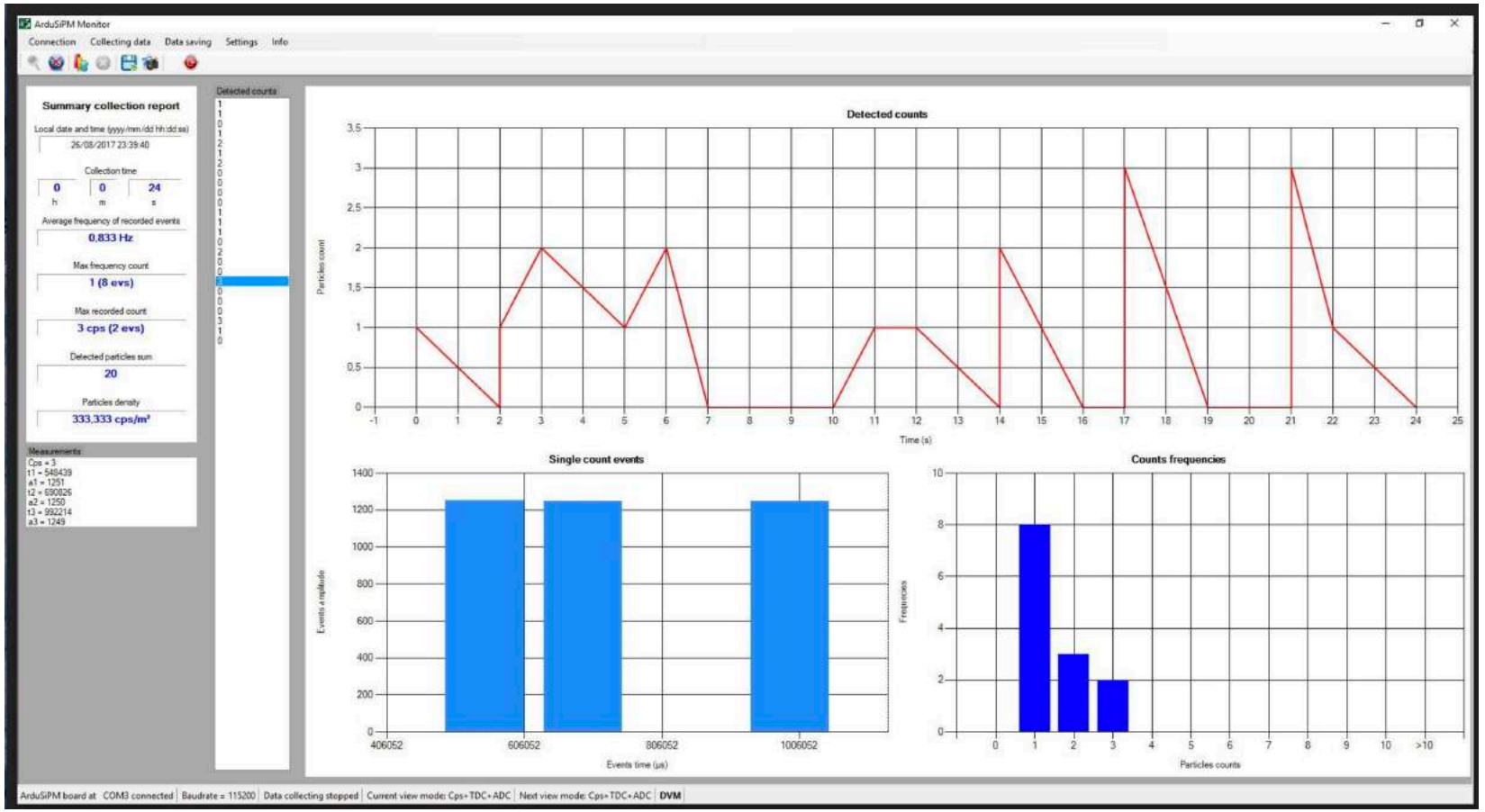
Using the SAM3X8 built-in ethernet it is possible to increase data acquisition performance.

The ArduSiPM Data format is open…Users can write custom programs for data aquisition and visualization.

Example 1. **ArduSiPM Acquisition Tool** by Filippo Curti (Filippo.curti1@gmail.com)
(written in C#, fast running also with high rate, at the moment poor in documentation freeware)



Example 2. **ArduSiPM Monitor** by Ciro e Dario Chiaiese (cirochiaiese@gmail.com)
Written in VisualBasic (slow good for cosmic and low rate source) well documented.



ArduSiPM Monitor 1.2.0.2

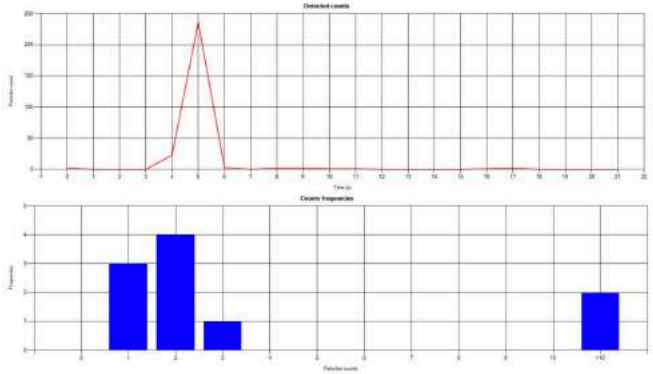
realizzato da Ciro e Dario Chiaiese

GUIDA UTENTE

Questo software è stato realizzato per interfacciarsi con la scheda ArduSiPM (da cui il nome) equipaggiata con firmware 2.1.5. Non è stato testato sul firmware precedente e probabilmente andrebbe in errore. Si sconsiglia assolutamente di tentare di usare il software con altri tipi di schede (la qual cosa non avrebbe alcun significato, fra l'altro).

Il programma ha una funzione di riconoscimento della corretta versione di scheda (Autodetect) che è fortemente consigliata. E' comunque possibile usare il *manually detect* ( ) per visualizzare tutti i dispositivi connessi alle USB e scegliere la porta cui è collegata ArduSiPM.

A connessione avvenuta, si può richiedere di raccogliere e graficare i dati tramite apposito pulsante ( ) o voce di menu. La raccolta che si richiede può, precedentemente, essere stabilita in 4 diverse modalità, in seguito descritte, dal menu *Settings/Measurements*. Le modalità più ricche d'informazioni hanno una raccolta dati con frequenza più bassa (perché richiedono più tempo). La durata della raccolta può essere prima stabilita con un timer (in s) o fermata manualmente. Appena inizia la raccolta vengono visualizzati i grafici dei conteggi delle particelle rilevate per ogni secondo (Cps) e, sotto, è riportato il grafico delle frequenze dei conteggi registrati (i conteggi superiori a 10 sono accomunati in un'unica classe di frequenze ">10").



The ArduSiPM in the World

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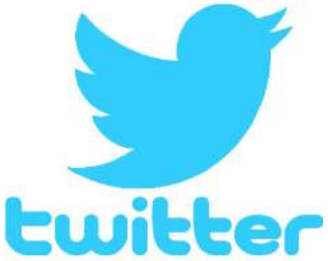

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