

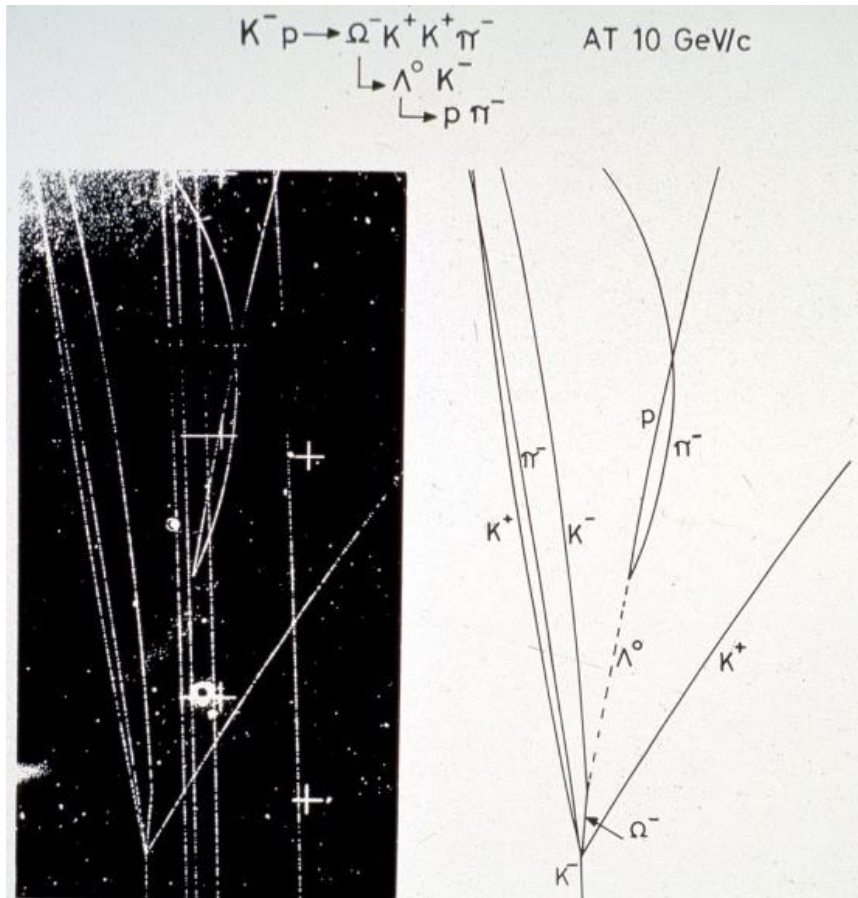
Come costruire un rivelatore di particelle

Guida alla costruzione e utilizzo di un
semplice rivelatore di particelle

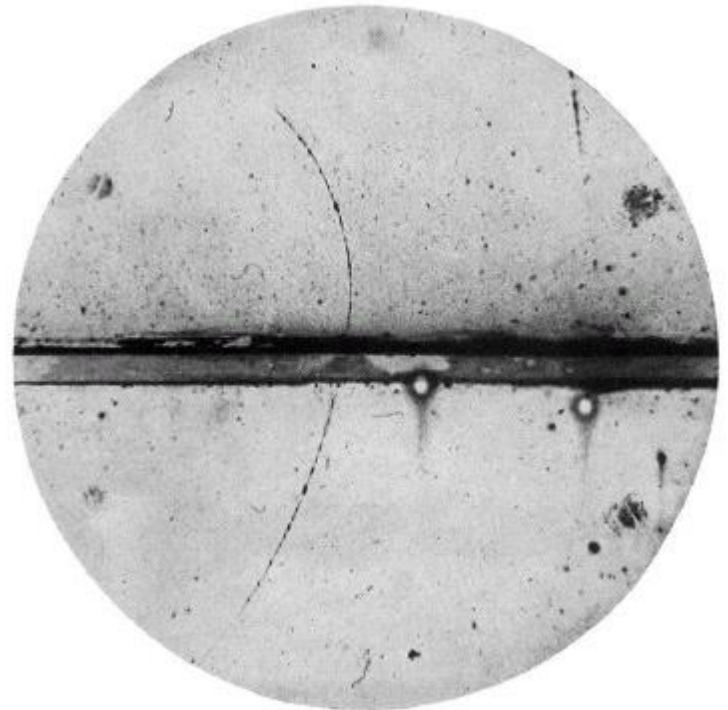
Anelli, Beretta, Dreucci, Felici, Gatta, Gatti, Papalino, Pasquali, Pileggi

I Rivelatori di Particelle

Strumento usato per **rivelare**, **tracciare** e **identificare** particelle provenienti dalla radiazione cosmica, dai decadimenti nucleari e dai processi di interazione che avvengono negli acceleratori.



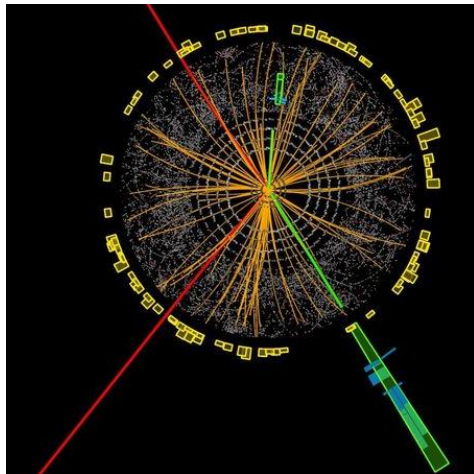
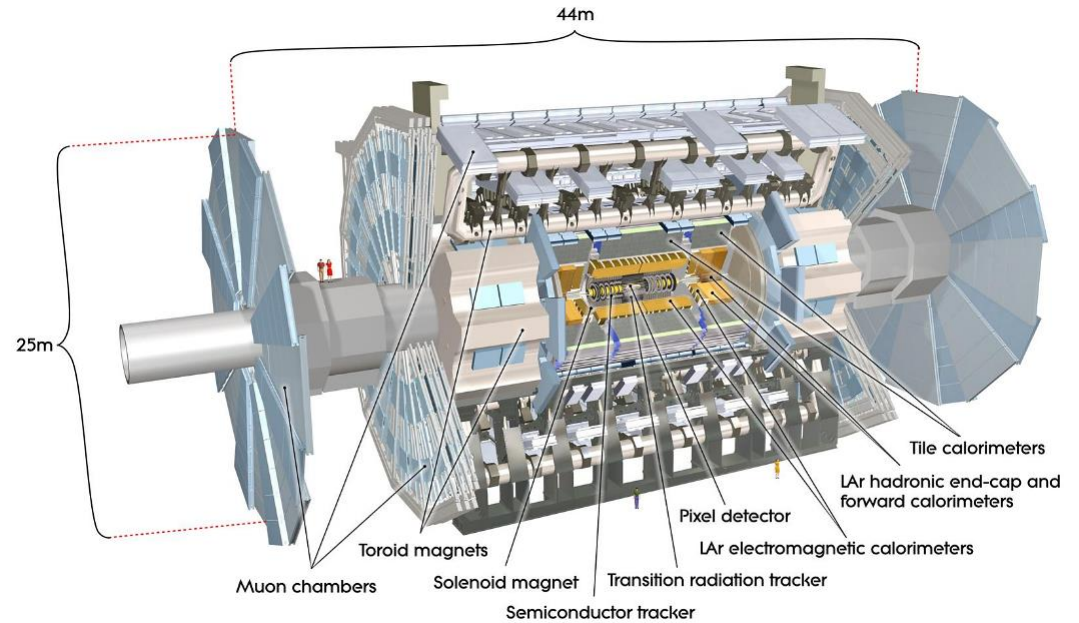
Scoperta del positrone, 1932
@camera a nebbia



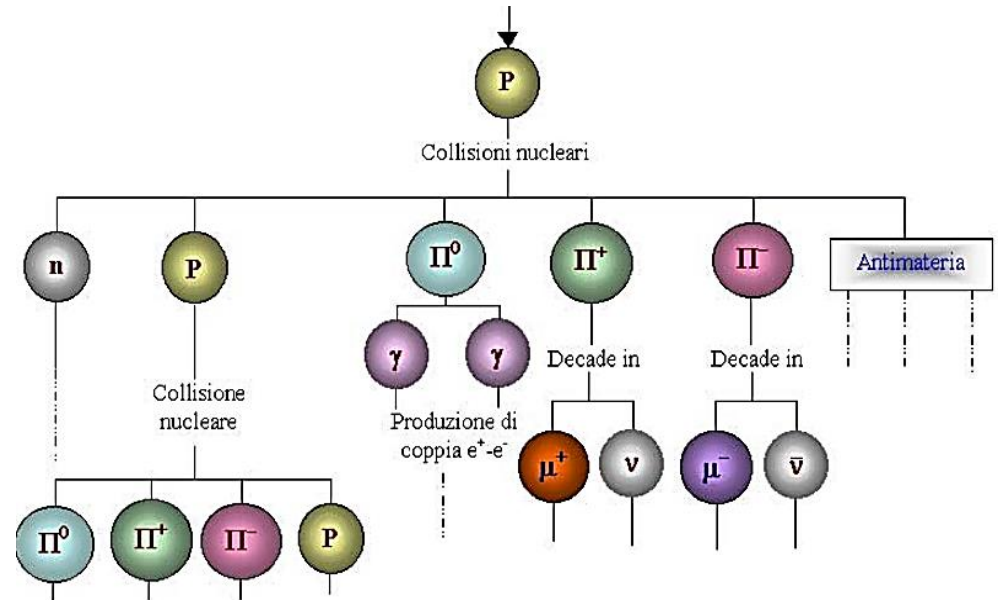
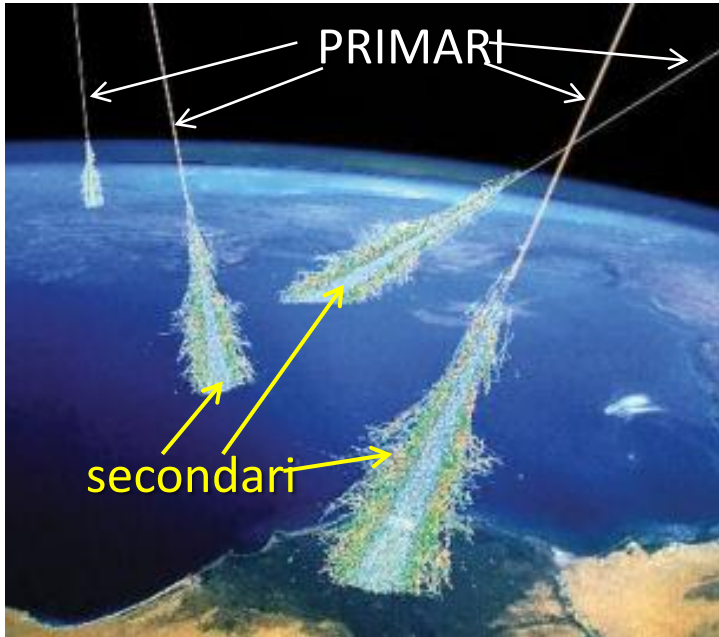
ATLAS a LHC

Informazioni
estratte da un
rivelatore :

- Posizioni
- vertici
- Tempi
- carica
- Impulso
- Energia
- PID



Raggi Cosmici



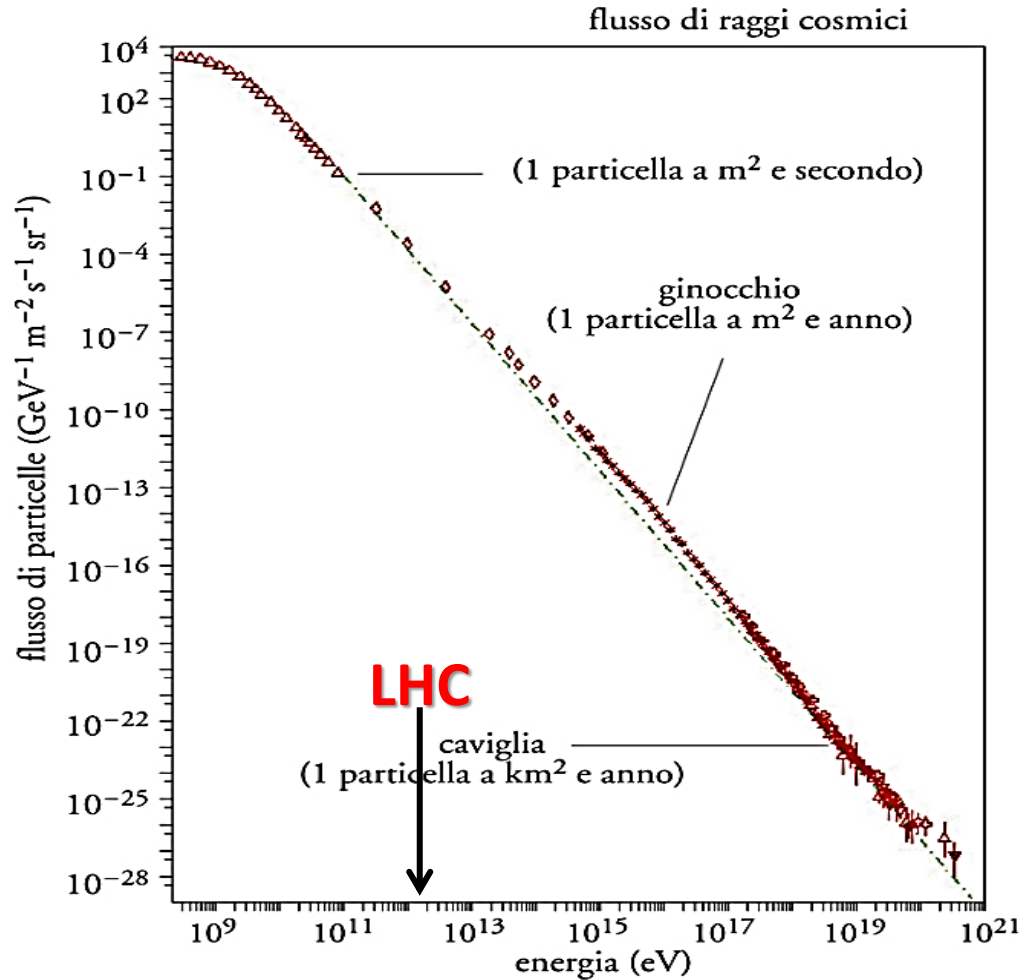
PRIMARI: $\approx 90\%$ protoni , $\approx 10\%$ He. In **alta atmosfera** $\approx 1000 \text{ m}^{-2} \text{ s}^{-1}$

SECONDARI: pioni, kaoni, protoni, neutroni, elettroni, muoni, neutrini, ecc.

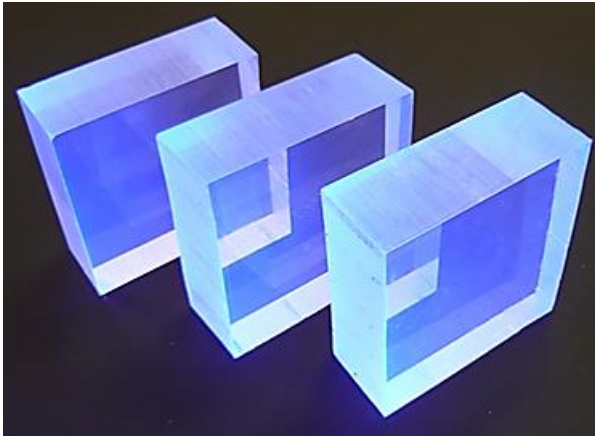
A **terra** arrivano $\approx 100 \text{ m}^{-2} \text{ s}^{-1}$

Raggi Cosmici

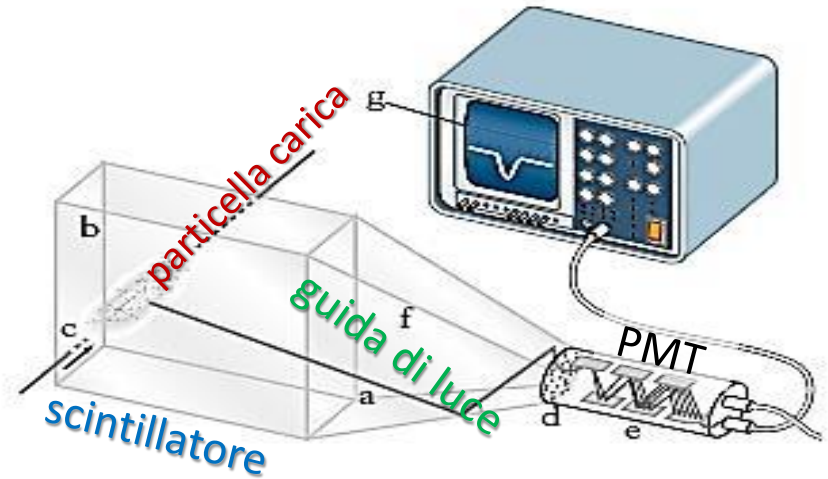
Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays



Gli Scintillatori



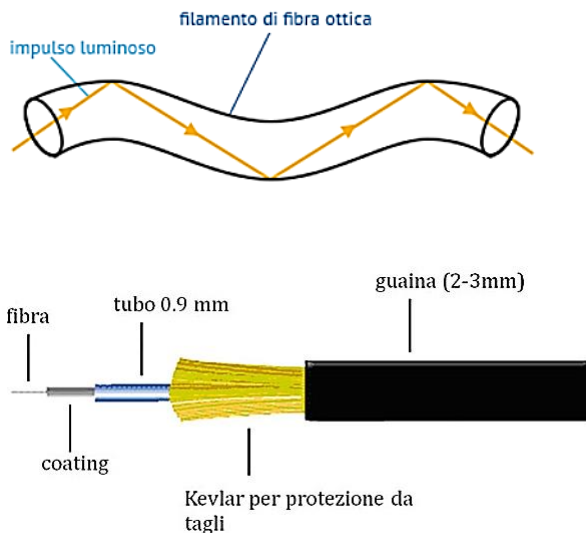
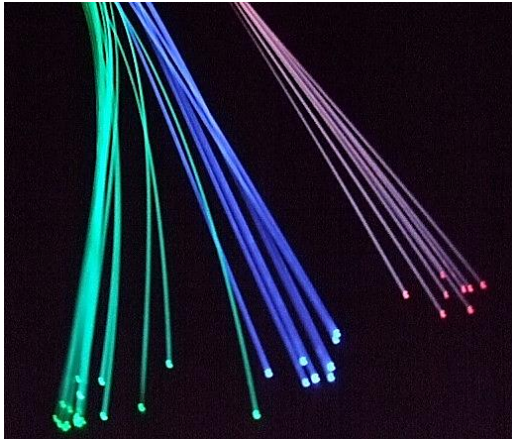
- Scintillatore plastico : materiale organico scintillante diluito in materiale plastico trasparente e facilmente lavorabile.
- Se attraversato da particella carica emette luce di *fluorescenza* $\lambda \approx 350-400$ nm (UV, al limite del visibile)



Particella carica →
luce fluorescenza →
guida di luce →
PMT →
segnale elettrico

Fibre WLS

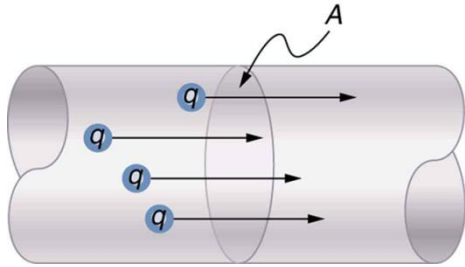
- A **wavelength shifter** (WLS) è un materiale fluorescente che assorbe fotoni di una certa energia (hf) e riemette la stessa energia sotto forma di fotoni di energia più bassa (hf'). (UV \rightarrow visibile)
- Hanno una **doppia funzione** :
 - a) guida di luce verso il sensore ;
 - b) WLS: UV \rightarrow visibile e conseguente cattura luce



sensore

Scintillatore plastico + WLS

Carica elettrica e corrente

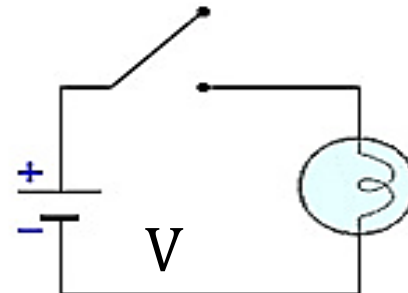
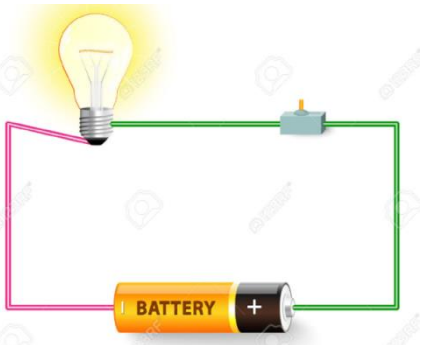


$$q = 1.6 \times 10^{-19} \text{ C}$$

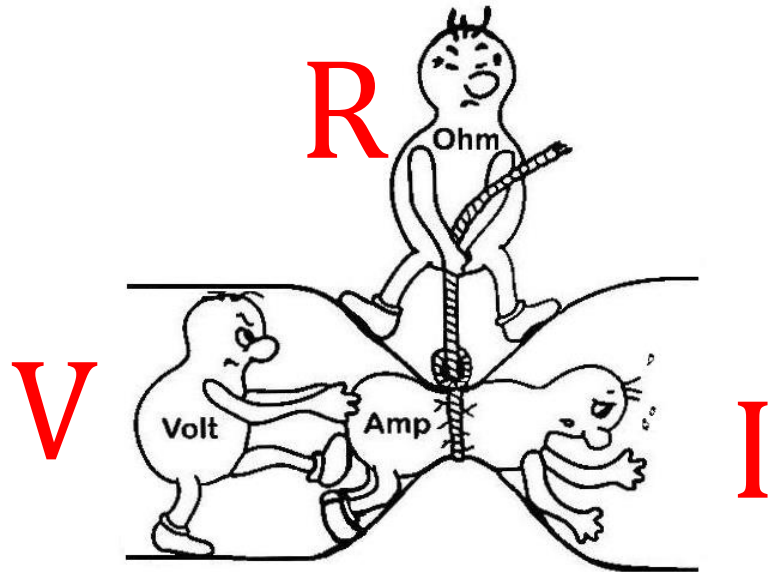
- In un filo elettrico, sotto opportune condizioni, gli **elettroni** che si trovano in esso possono muoversi in maniera ordinata, producendo quella che si chiama **corrente elettrica**.
- $I = \frac{Q}{t} \quad \rightarrow \quad 1\text{A} = \frac{1\text{C}}{1\text{s}}$

• **Esercizio.** In un filo passa una corrente di 1A per 1 minuto. Quanti elettroni hanno attraversato una generica sezione A del filo ?

• Soluzione. $Q = I \times t = \frac{1\text{C}}{\text{s}} \times 60\text{s} = 60 \text{ C} \quad \rightarrow \quad N = \frac{60\text{C}}{1.6 \times 10^{-19}} \sim 3.7 \times 10^{20}$

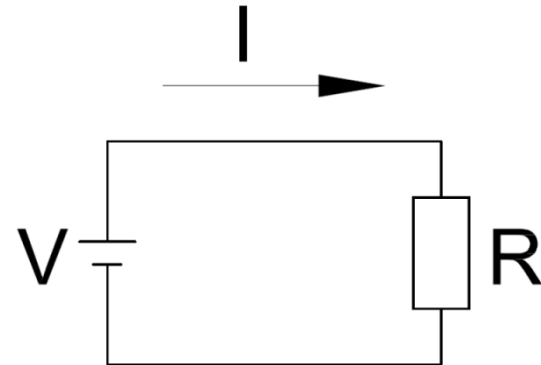
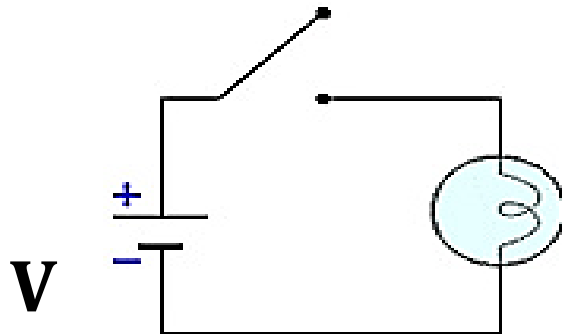


Legge di Ohm

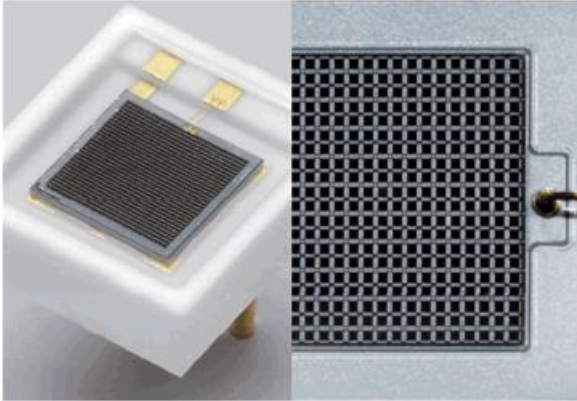


Prima legge di Ohm

$$I = V/R$$

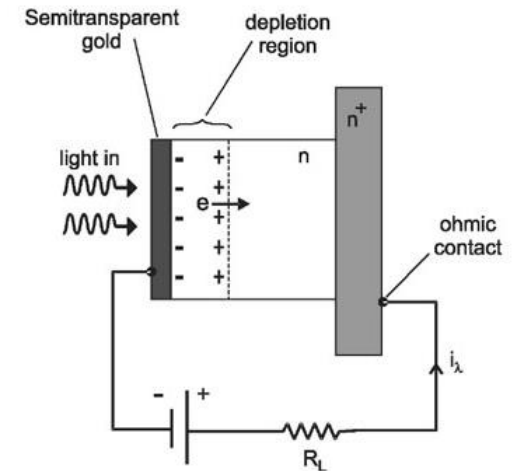


SiPM

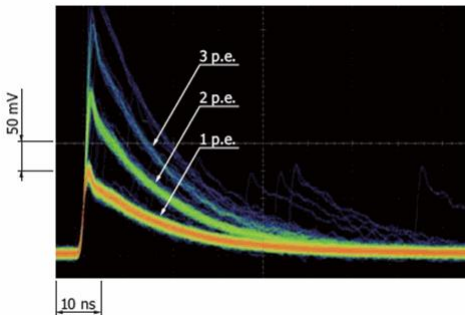


1) Il Silicon PhotoMultiplier (o MPPC multi-pixel photon counter) è un dispositivo a semiconduttori in grado di rivelare singoli fotoni. E' formato da una matrice di pixel. E' possibile applicare differenze di potenziale di circa 50 V senza che essi conducano corrente, creando così forti campi elettrici al loro interno ($50 \text{ V}/1 \mu\text{m}=5 \times 10^5 \text{ V/m}$).

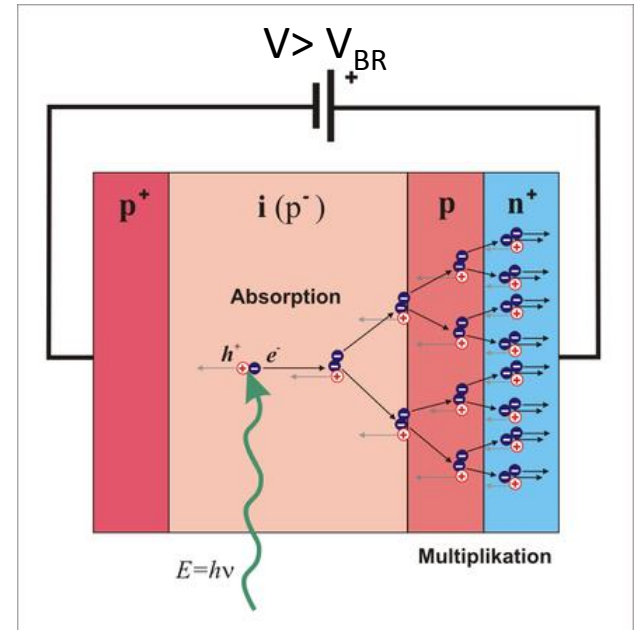
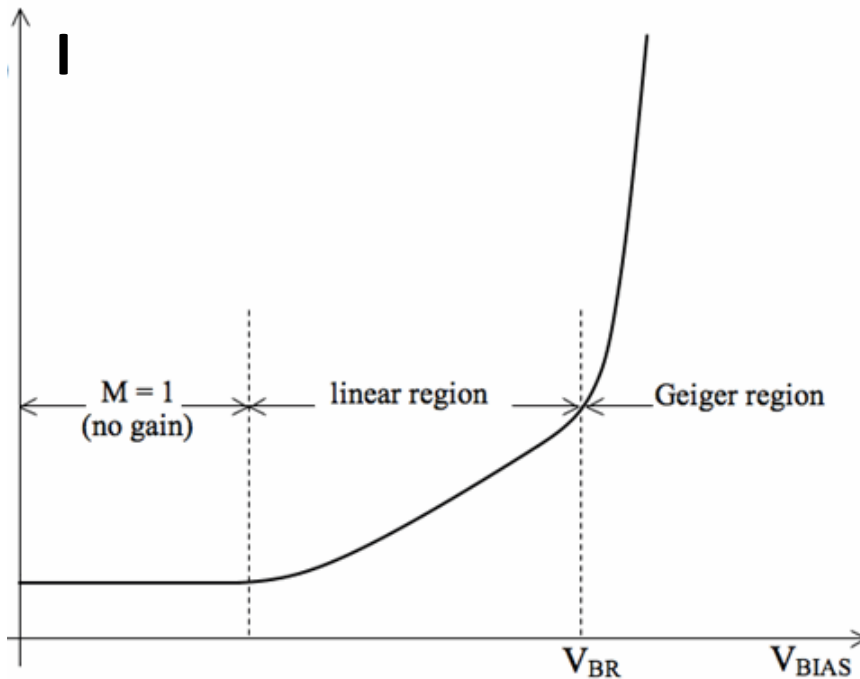
2) L'arrivo di un fotone sul pixel provoca l'estrazione di un elettrone dalla sua orbita atomica. L'elettrone trovandosi in una regione di forte campo elettrico accelera urtando ed estraendo a sua volta altri elettroni, fino a creare una vera e propria valanga di elettroni. Tali elettroni, fino ad un milione, formeranno il segnale elettrico del pixel.



3) Per ogni fotone si forma un segnale in un pixel diverso. Il segnale del SiPM è dato dalla somma dei segnali dei pixel, risultando così proporzionale al numero di fotoni incidenti.

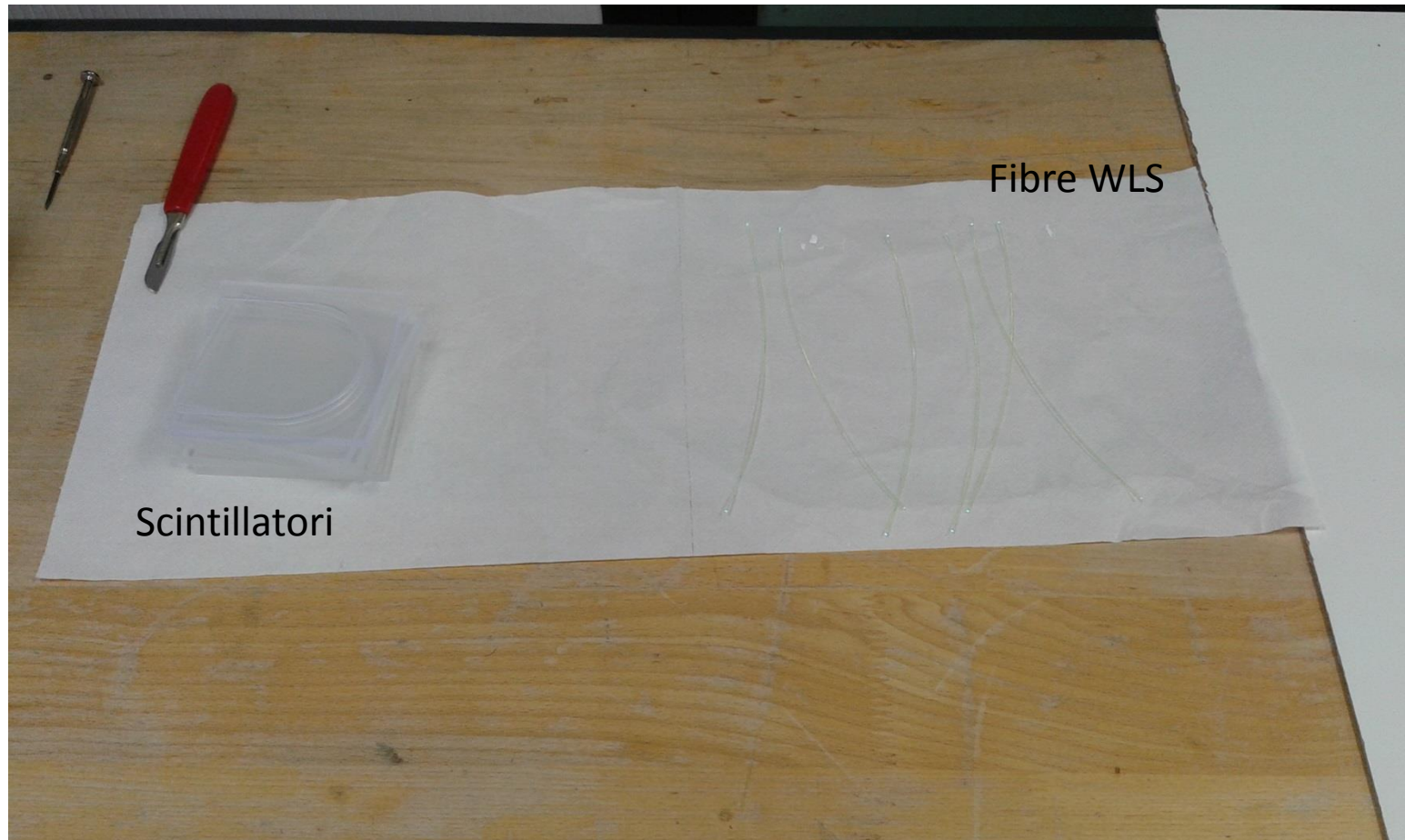


SiPM

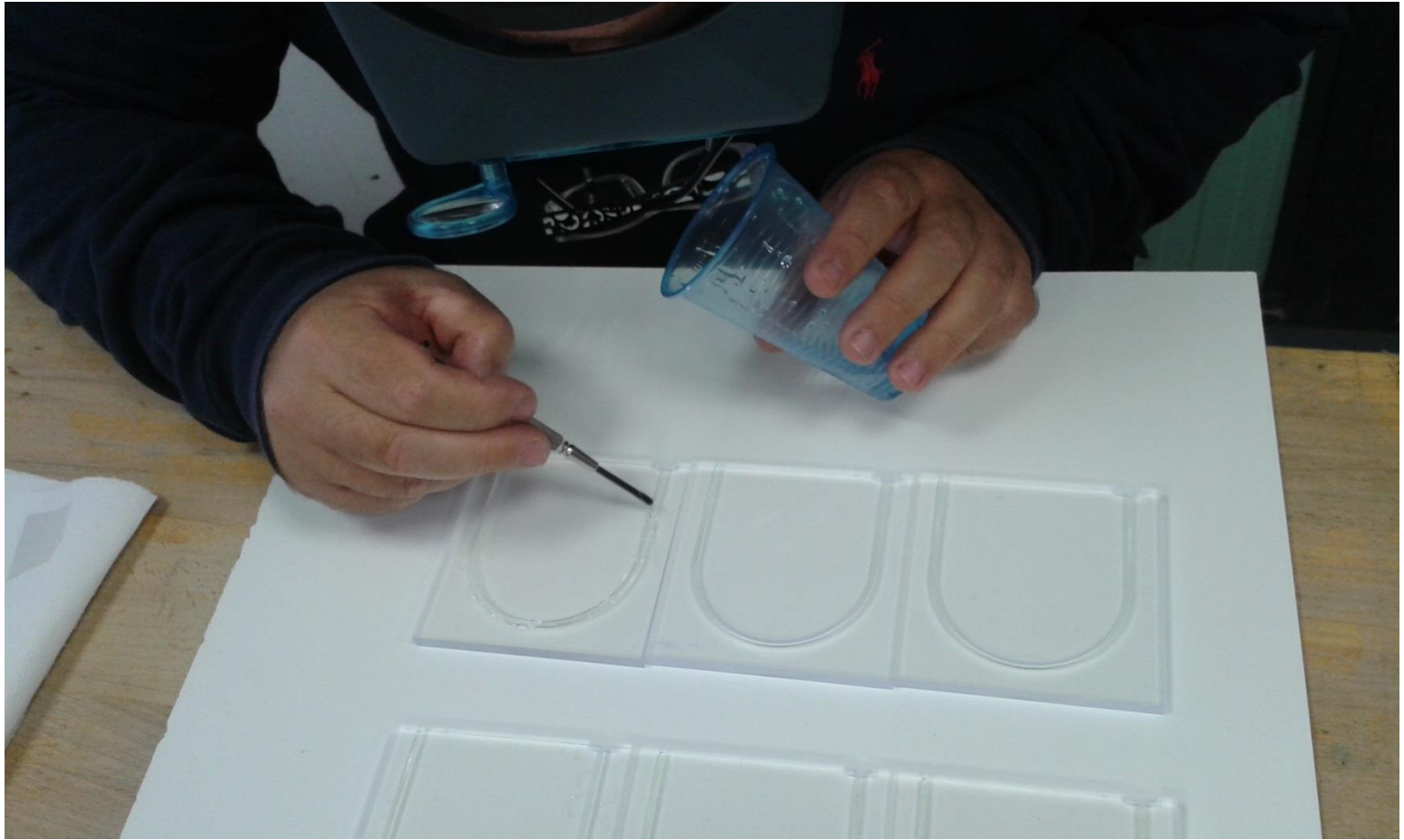


La valanga si innesta solo se la ddp applicata è maggiore di V_{BR} .
Da un singolo fotone si forma una valanga di 10^6 elettroni.

Costruzione



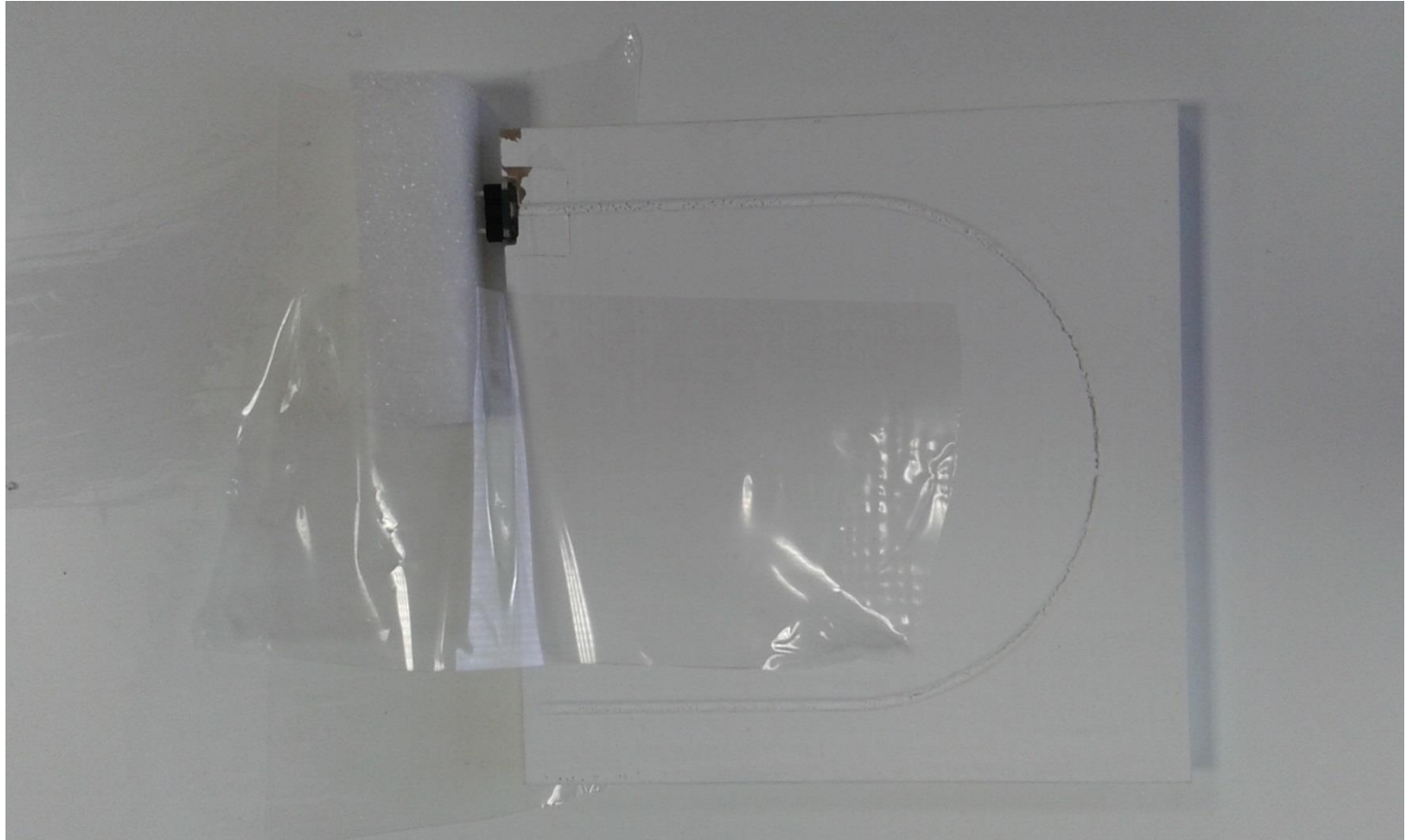
Costruzione



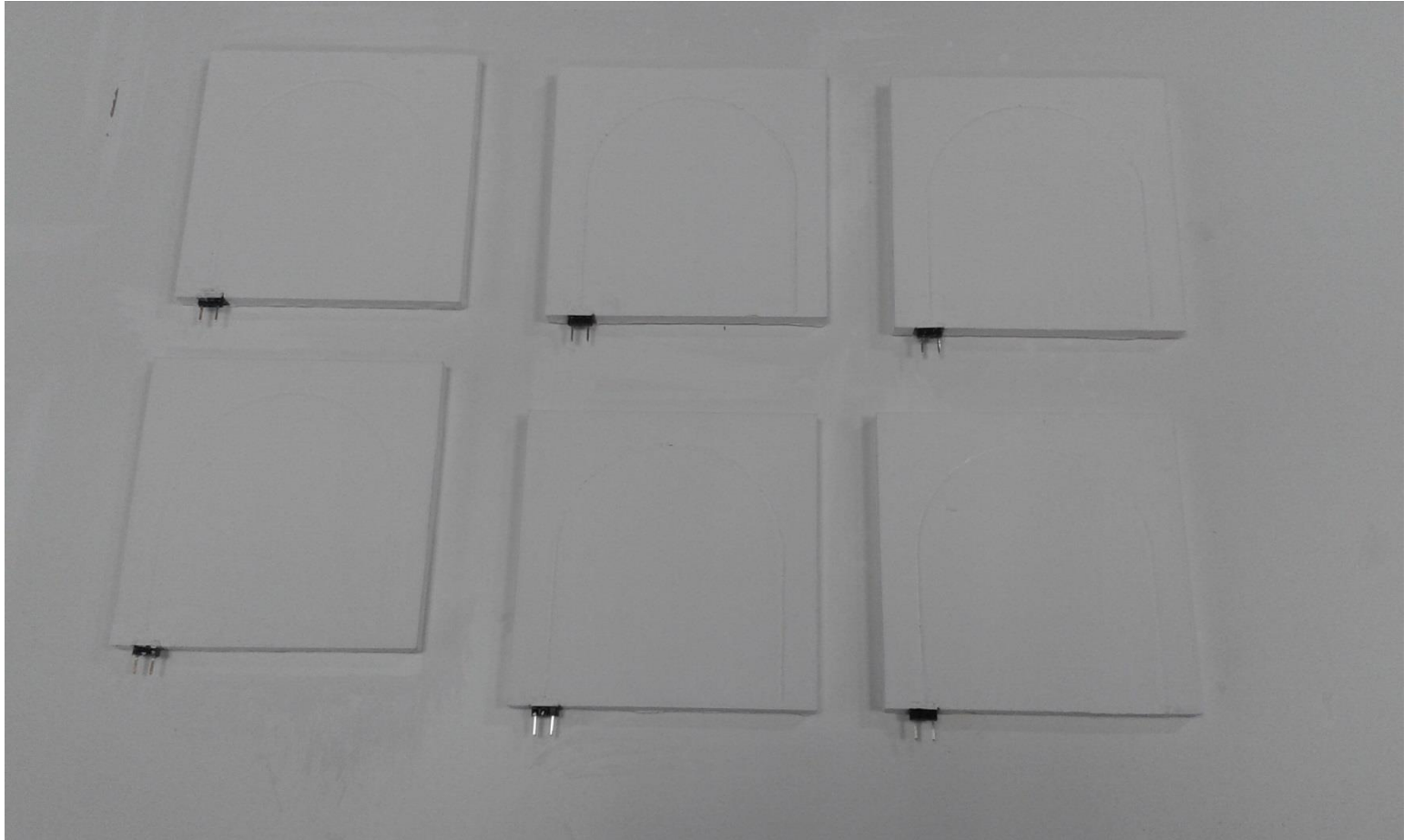
Costruzione



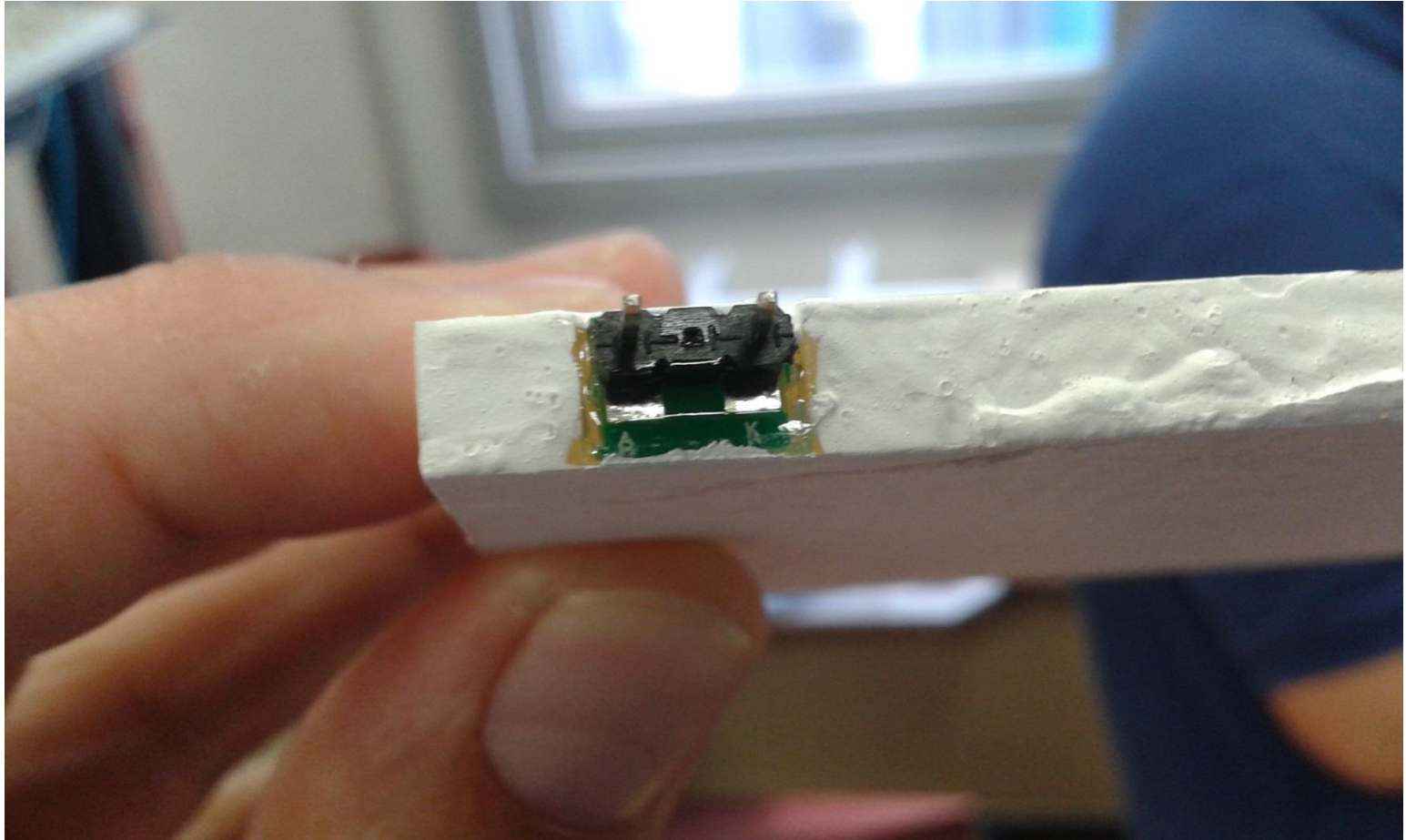
Costruzione



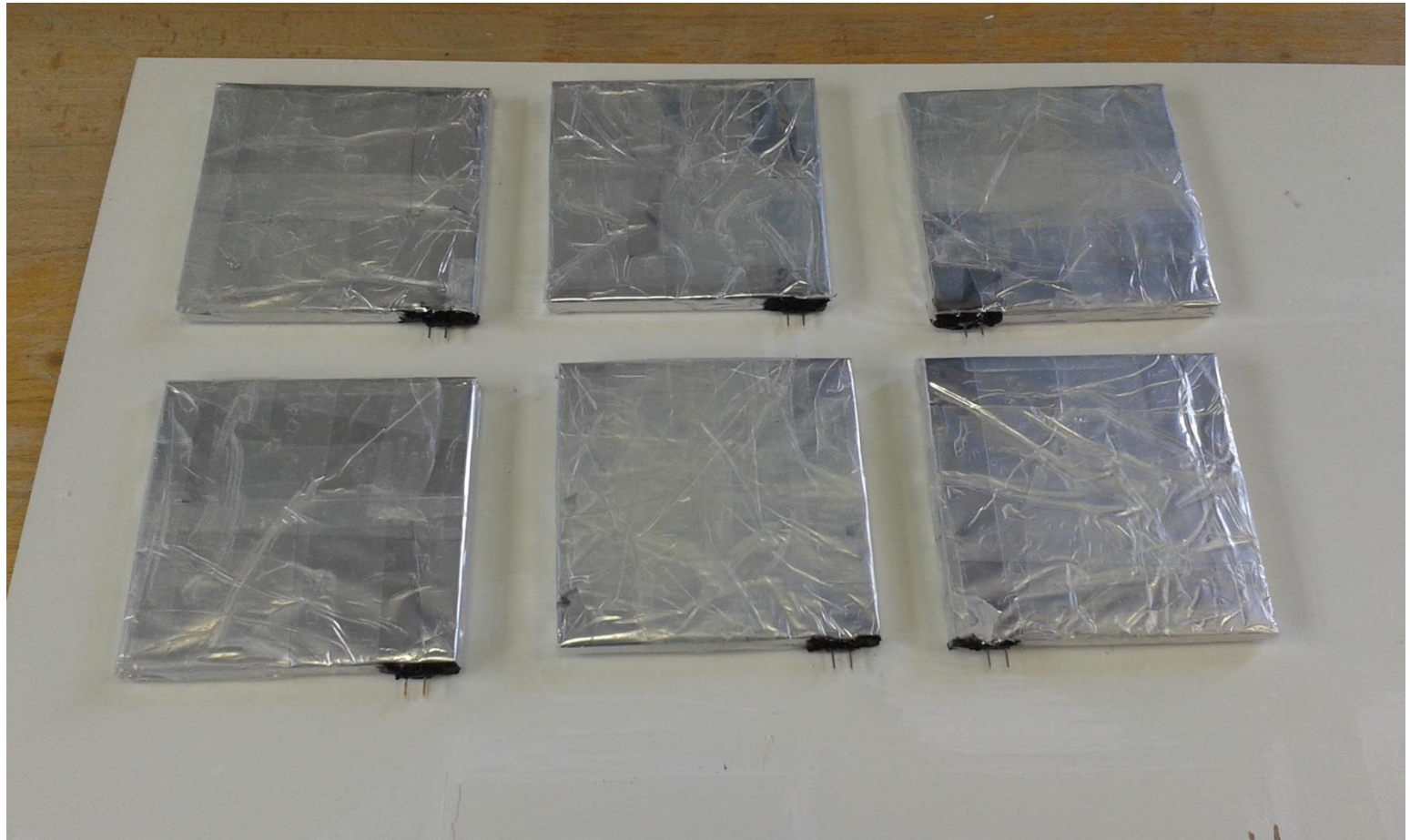
Costruzione



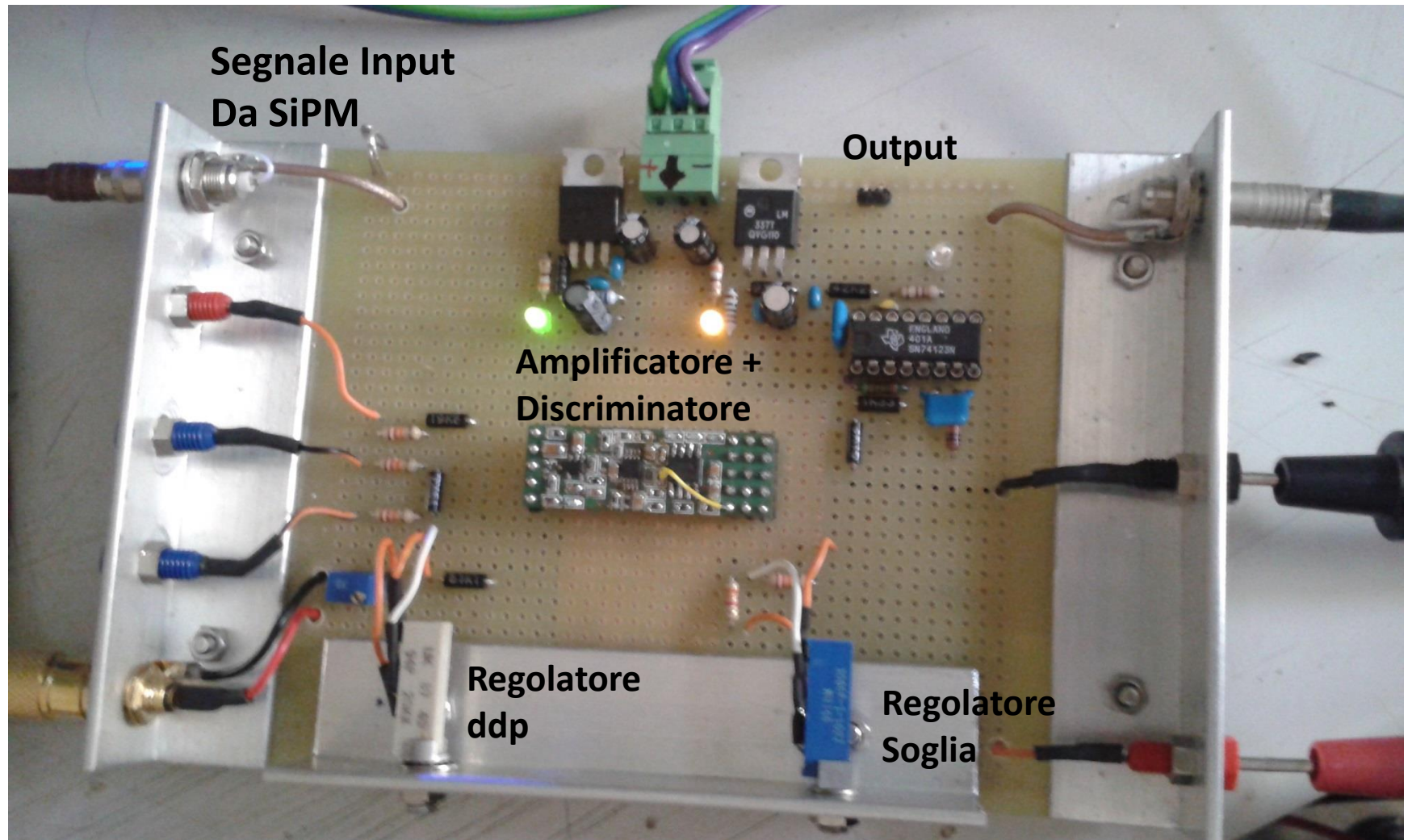
Costruzione



Costruzione



Elettronica di Read-out



Segnale Input
Da SiPM

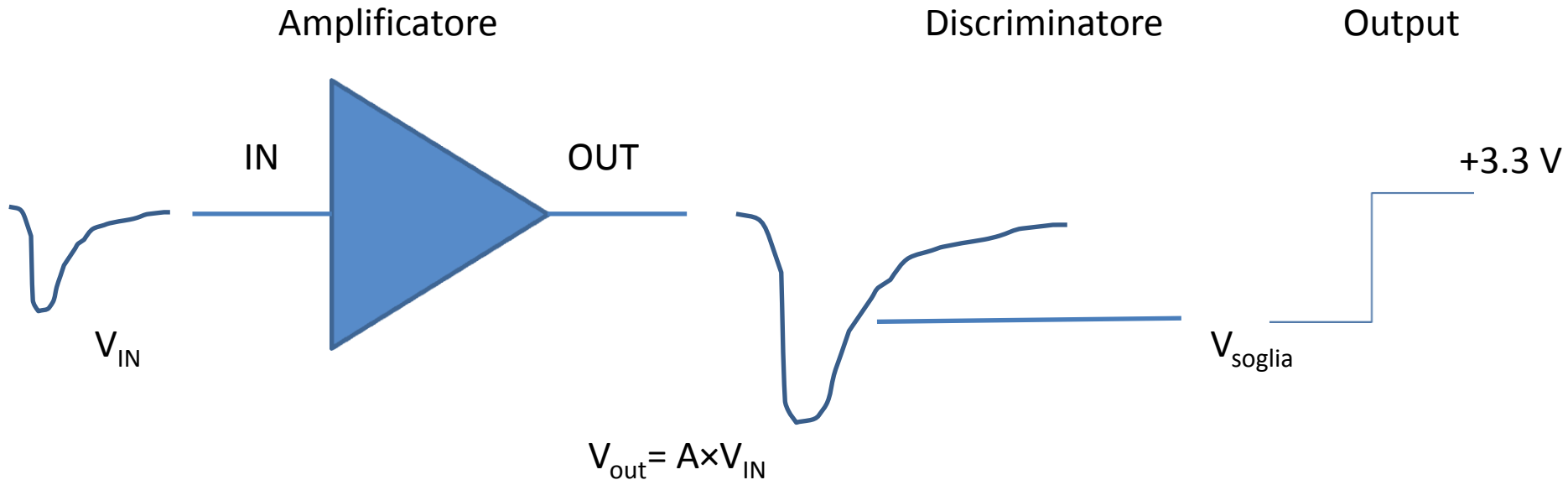
Output

Amplificatore +
Discriminatore

Regolatore
ddp

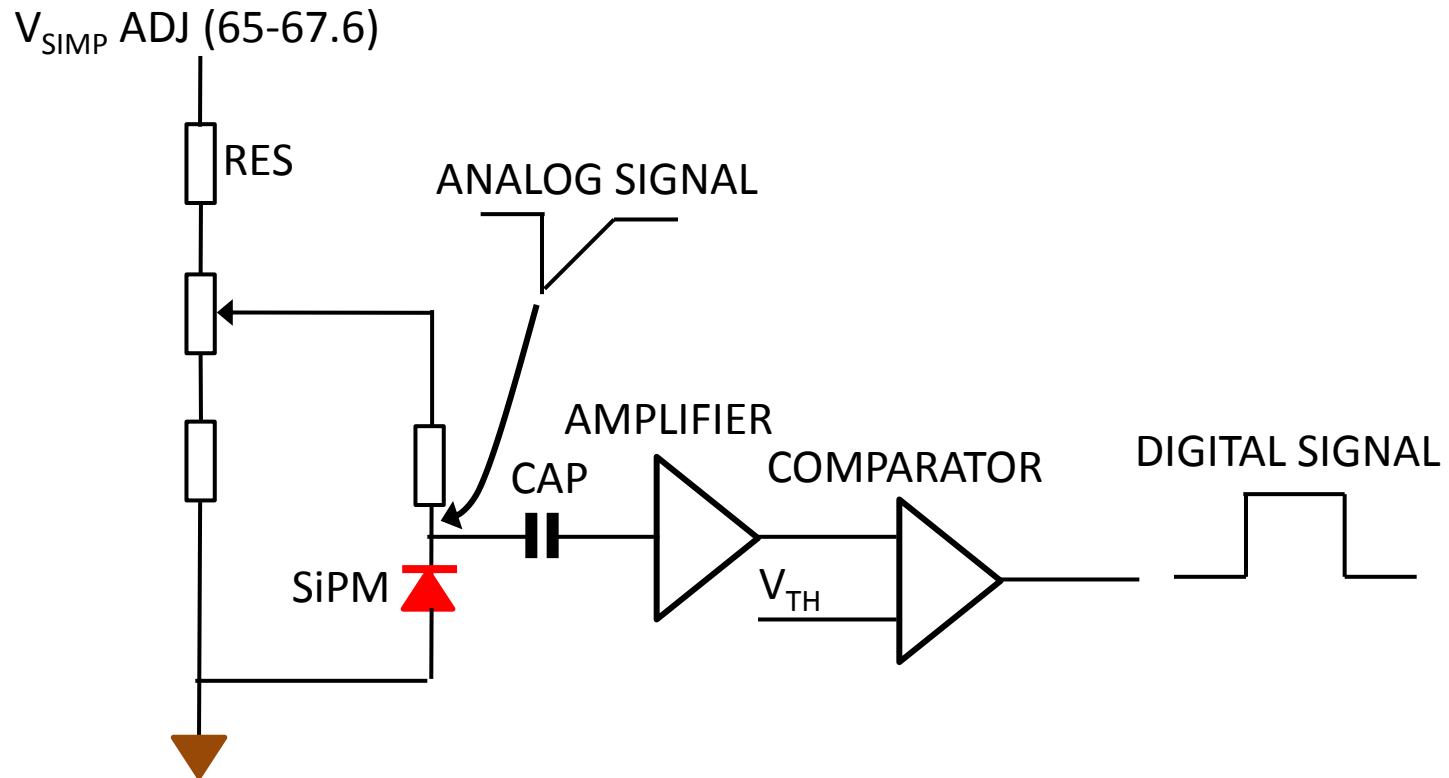
Regolatore
Soglia

Elettronica di readout



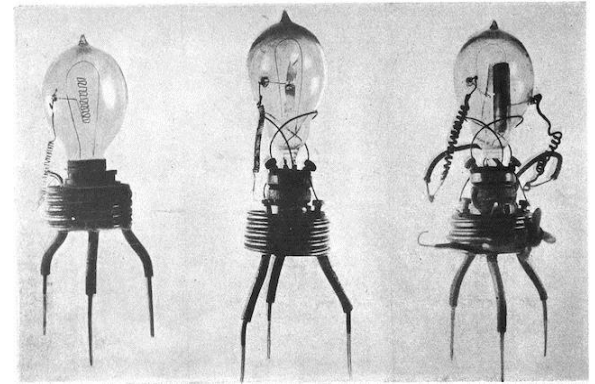
Il segnale in uscita dal SiPM viene ulteriormente amplificato di $A=20$, quindi confrontato con un valore di tensione, V_{soglia} . Solo se il segnale ha ampiezza maggiore del valore di soglia si ha un segnale in output.

The Readout Circuit



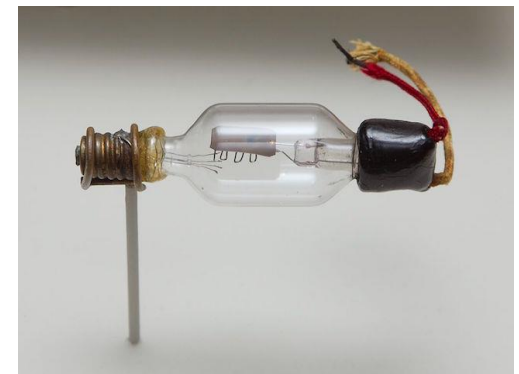
OPERATIONAL AMPLIFIER – THE BACKGROUND (I)

J. A. Fleming: step beyond Edison's filament-based lamp, by virtue of the addition of a plate electrode, which (when biased positively) captured electrons emitted from the filament (cathode). Since this device passed current in one direction only, it performed a rectification function patented in 1904



vacuum tube-based rectifier

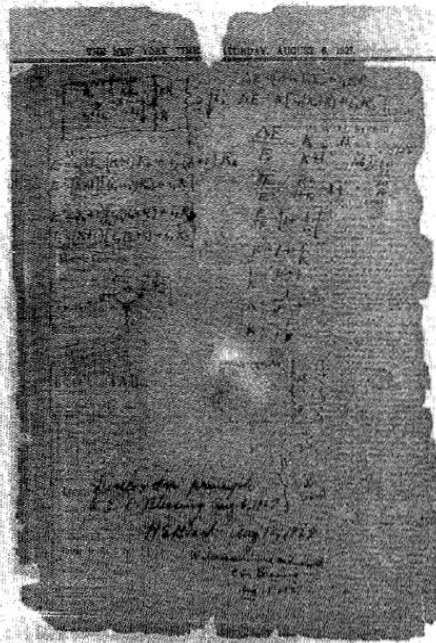
Lee de Forest (August 26, 1873 – June 30, 1961) was an American inventor, self-described "Father of Radio", and a pioneer in the development of sound-on-film recording used for motion pictures. He had over 180 patents. His most famous invention, in 1906, was the three-element "grid Audion", which, although he had only a limited understanding of how it worked, provided the foundation for the development of vacuum tube technology.



"Triode" Audion from 1908

OPERATIONAL AMPLIFIER – THE BACKGROUND (II)

Fig. 1. Legend, at least, has it that one day in 1927 a young man of 29, on his way by ferry across the Hudson to his laboratory at 463 West Street, New York City, was seized by a daring idea for a new kind of amplifier circuit. (He had been working for years, be it noted, on the problem that he hoped this new idea might solve.) Hastily, he sketched it on his newspaper, along with a few lines of mathematics. When he arrived at the laboratory, paper in one hand and pipe in the other, Harold Black proposed to the first people he came upon the negative feedback circuit, an invention now generally regarded as one of the great landmarks of discovery in engineering.



Dec. 21, 1937.

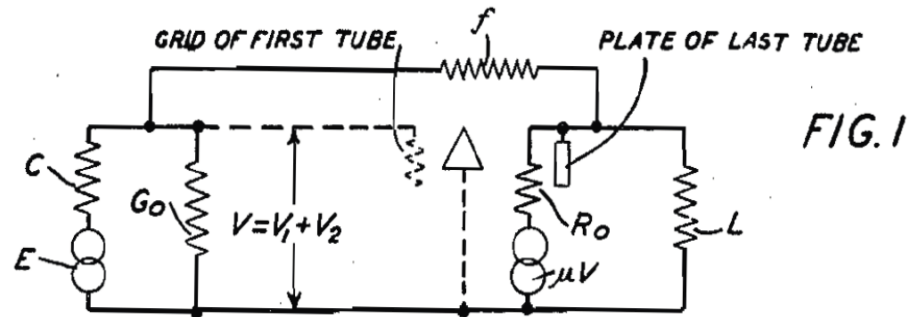
H. S. BLACK

2,102,671

WAVE TRANSLATION SYSTEM

Filed April 22, 1932

35 Sheets-Sheet 1



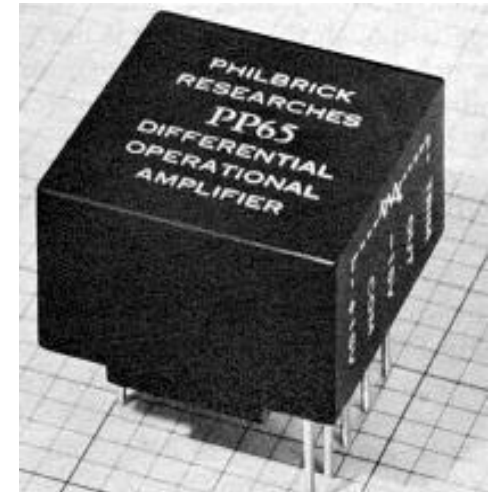
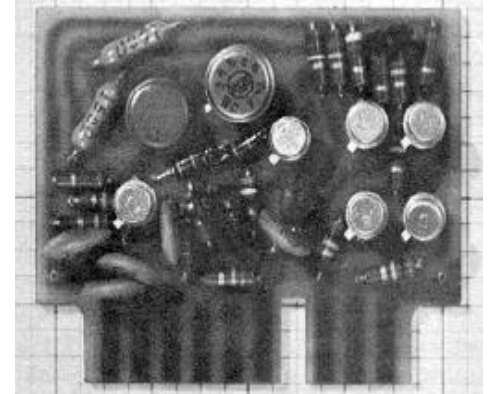
OPERATIONAL AMPLIFIER

- ❖ First op amps built in 1930's-1940's
 - Technically feedback amplifiers due to only having one useable input
- ❖ Used in WWII to help how to strike military targets
 - Buffers, summers, differentiators, inverters
- ❖ Took $\pm 300V$ to $\pm 100V$ to power



SOLID STATE DISCRETE OP-AMP

- ❖ Solid state op amps invented in 1960's
 - Possible due to invention of silicon transistors and the IC
 - Chip and discrete parts
- ❖ Reduced power input to $\pm 15V$ to $\pm 10V$
- ❖ Packaging in small black boxes allowed for integration with a circuit



MONOLITIC INTEGRATED CIRCUIT OP-AMP

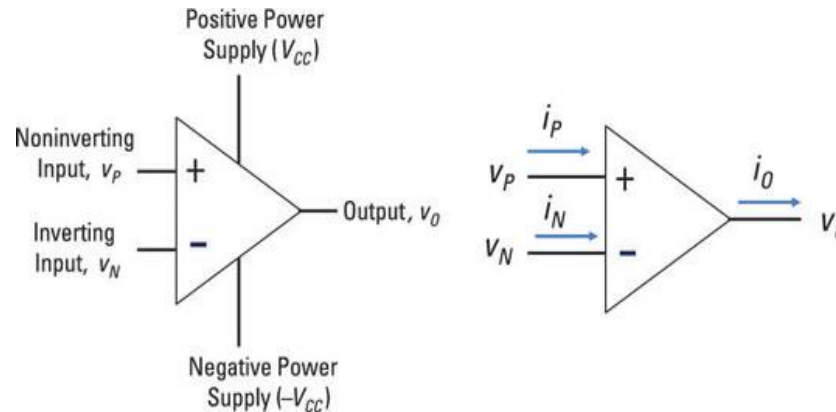
- ❖ First created in 1963
 - μ A702 by Fairchild Semiconductor
 - 9 transistors
 - 1000 open loop gain
- ❖ μ A741 created in 1968
 - Became widely used due to its ease of use
 - 8 pin, dual in-line package (DIP)



Bob Widlar - 1977

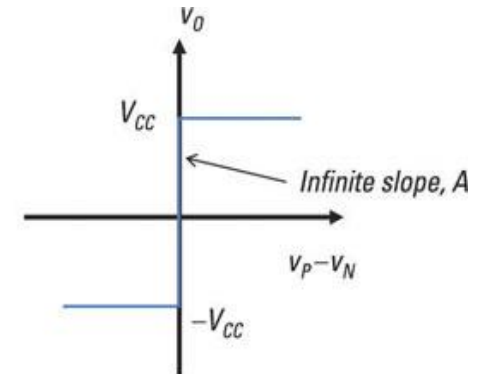
HOW DOES AN OP AMP WORK ?

- ❖ The positive terminal, called the noninverting input v_P
- ❖ The negative terminal, called the inverting input v_N
- ❖ The output terminal, resulting from the voltage applied between noninverting and inverting inputs: $v_O = A(v_P - v_N)$

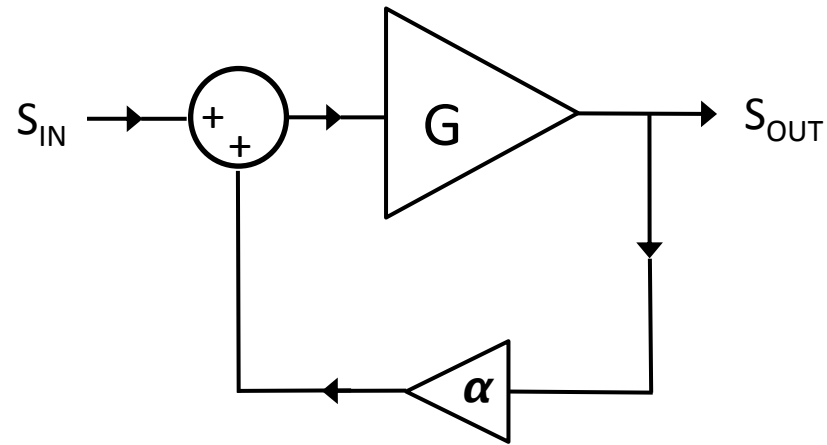


IDEAL AMP OP

1. Infinite voltage gain
2. Infinite input impedance
3. Zero output impedance
4. Infinite bandwidth
5. Zero input offset voltage (i.e., exactly zero out if zero in).



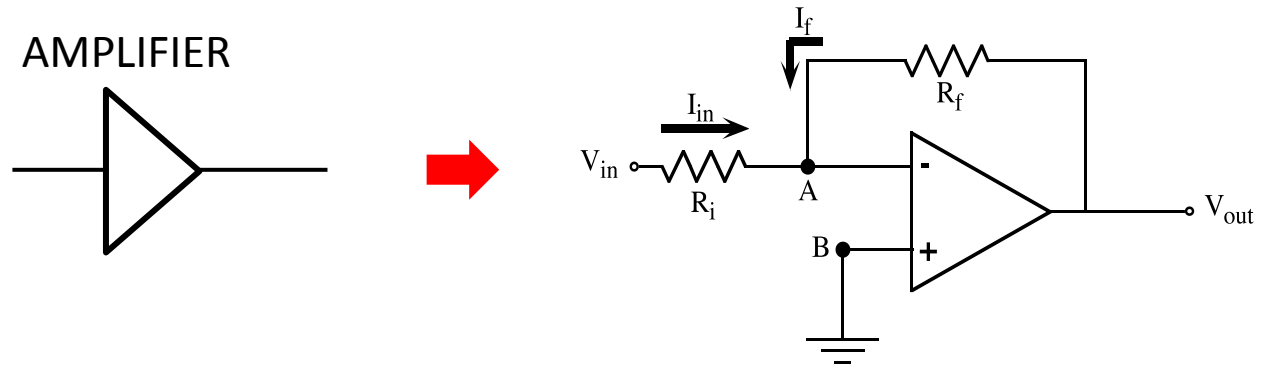
FEEDBACK



$$S_{OUT} = G * (S_{IN} + \alpha S_{OUT}) \quad \rightarrow \quad S_{OUT} = S_{IN} \frac{G}{1 - \alpha G} \quad \rightarrow \quad G' = \frac{G}{1 - \alpha G}$$

- $1 - \alpha G > 1$ ($\alpha G < 0$) \rightarrow Negative feedback
- $1 - \alpha G < 1$ ($\alpha G > 0$) \rightarrow Positive feedback
- $1 - \alpha G = 0$ \rightarrow Oscillator

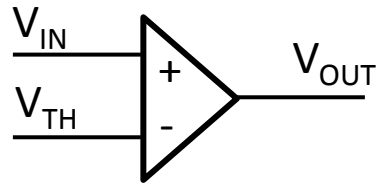
INVERTING AMPLIFIER (BREADBOARD CIRCUIT)



1. Because of feedback the A point is a virtual ground
2. Ohm law:
 1. $I_{in} = V_{in} / R_i$
 2. $I_f = V_{out} / R_f$
3. Z_{IN} very high $\rightarrow I_{in} + I_f = 0$

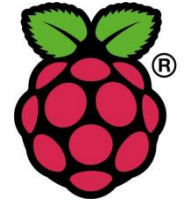
$$V_{in} / R_i + V_{out} / R_f = 0 \rightarrow V_{out} = - V_{in} * R_f / R_{in}$$

COMPARATOR (BREADBOARD CIRCUIT)

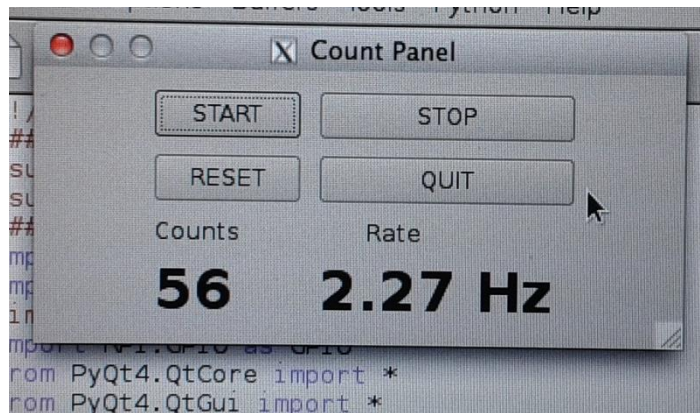


- ❖ A voltage comparator is a circuit that compares 2 voltages and let you know which one is the greater one
- ❖ The voltage applied on the negative input is the Threshold voltage (V_{TH})
- ❖ Input voltage is applied on the positive input
- ❖ Ideal Comparator behavior :
 - ❖ $V_{IN} < V_{TH} \rightarrow V_{OUT} = 0$
 - ❖ $V_{IN} > V_{TH} \rightarrow V_{OUT} = 1$

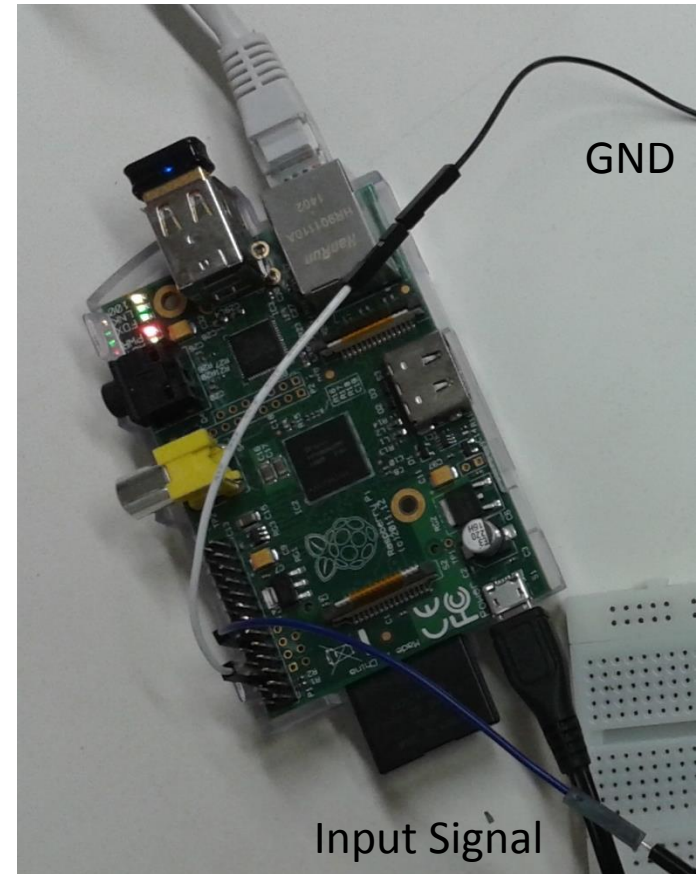
Acquisizione del segnale



Per contare gli eventi usiamo un Raspberry Pi, un «credit card» computer (acquistabile per poche decine di euro). L'Rpi è dotato di pin di comunicazione (GPIO) con il processore per inviargli segnali di ampiezza 0-3.3 V.



Usando il linguaggio di programmazione python e opportune librerie, abbiamo scritto un programma per contare i segnali che arrivano al pin GPIO e la loro frequenza di arrivo.

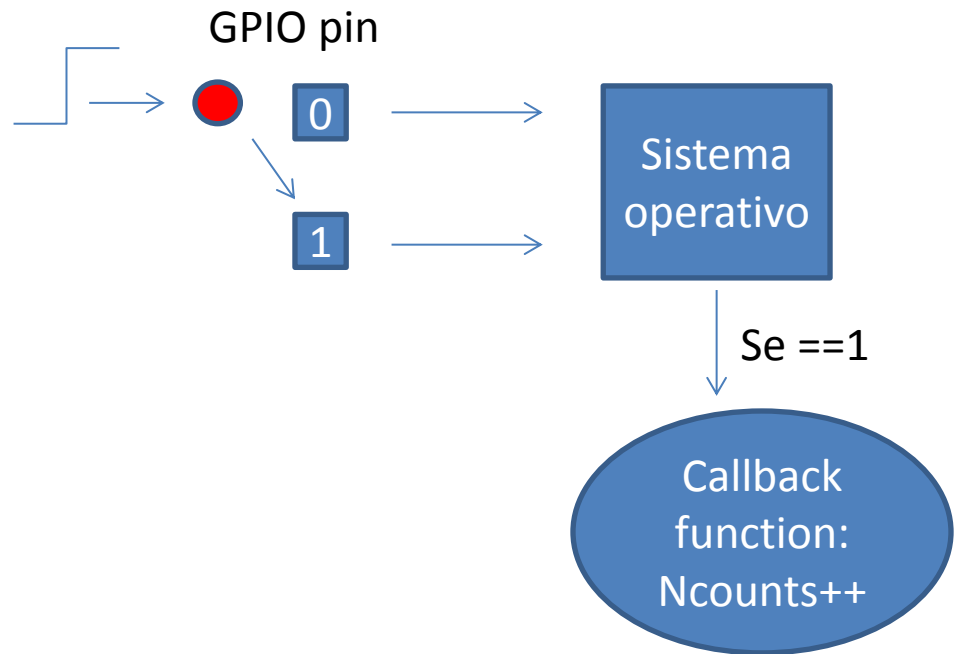


Interrupt

Pin 1	Pin 2
+3V3	+5V
GPIO2 / SDA1	+5V
GPIO3 / SCL1	GND
GPIO4	TXD0 / GPIO 14
GND	RXD0 / GPIO 15
GPIO17	GPIO 18
GPIO27	GND
GPIO22	GPIO 23
+3V3	GPIO 24
GPIO10 / MOSI	GND
GPIO9 / MISO	GPIO 25
GPIO11 / SCLK	CE0# / GPIO8
GND	CE1# / GPIO7
GPIO0 / ID_SD	ID_SC / GPIO1
GPIO5	GND
GPIO6	GPIO12
GPIO13	GND
GPIO19 / MISO	CE2# / GPIO16
GPIO26	MOSI / GPIO20
GND	SCLK / GPIO21
Pin 39	Pin 40

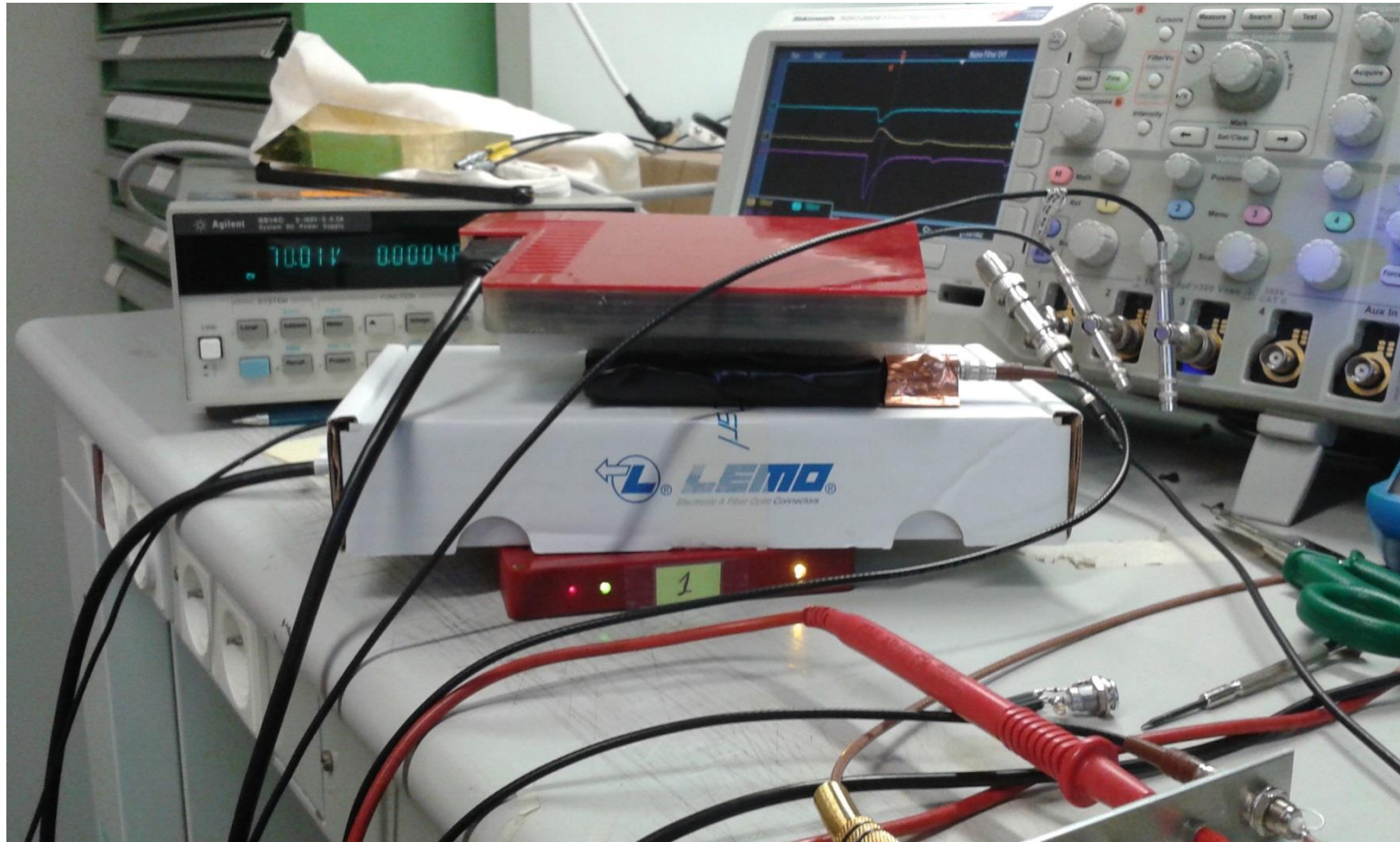
GND

0-3.3 V input signal



Il sistema operativo legge periodicamente la memoria associata al pin GPIO. Se trova 1 esegue una funzione di «callback» definita in un programma.

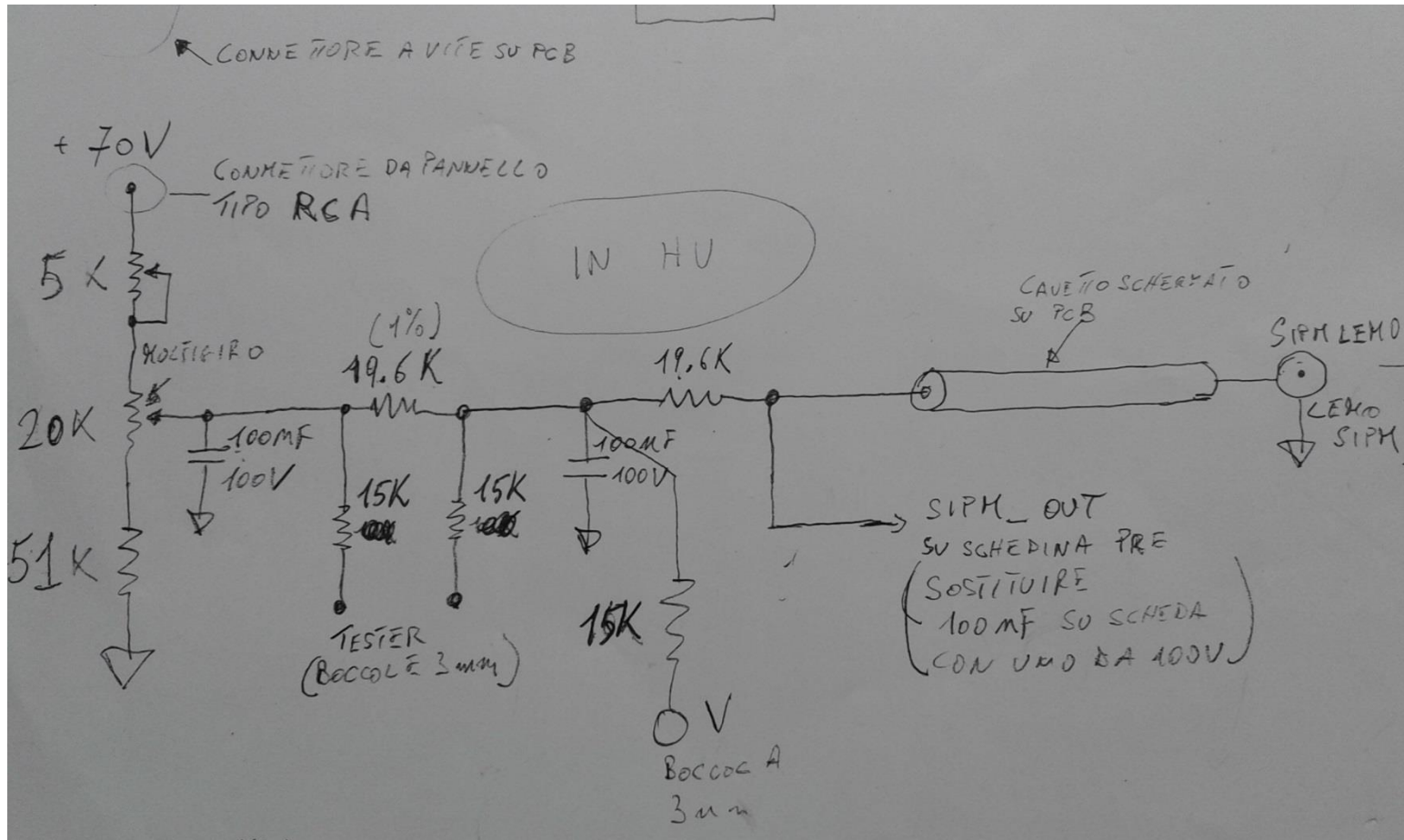
Istruzioni Esperienza



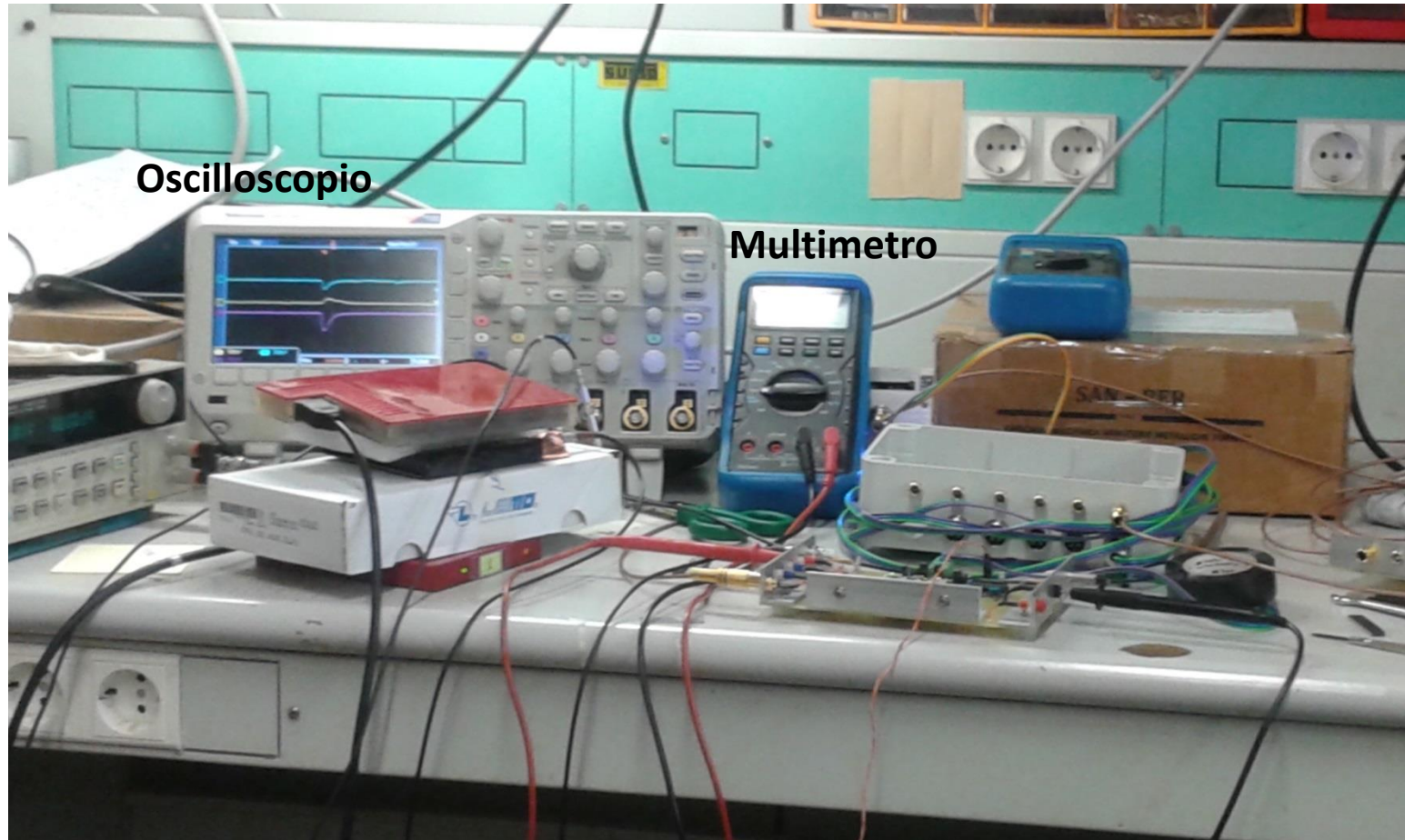
Outline Esperienza

1. Connettere cavi
2. Accendere alimentazione (con Sipm scollegato). Verificare valori con tester
3. Provare i potenziometri
4. Spegnerne, collegare SiPM e riaccendere tensioni
5. Osservare il segnale all'oscilloscopio
6. Misurare tensione e corrente
7. Osservare segnale al variare della tensione
8. Misurare corrente al variare della tensione (I vs V)
9. Calcolare amplificazione SiPM da forma segnale e da numero fotoni e A amplificatore
10. Connettiamo uscita TTL a RPi
11. Accendere Rpi, collegarsi via ssh, cd dir e lanciare programma acquisizione
12. Osservare conteggi al variare della soglia (Plot frequenza vs soglia)
13. Coincidenze
14. Calcolare il flusso di raggi cosmici al minuto e cm^2
15. Esperienze ad libitum

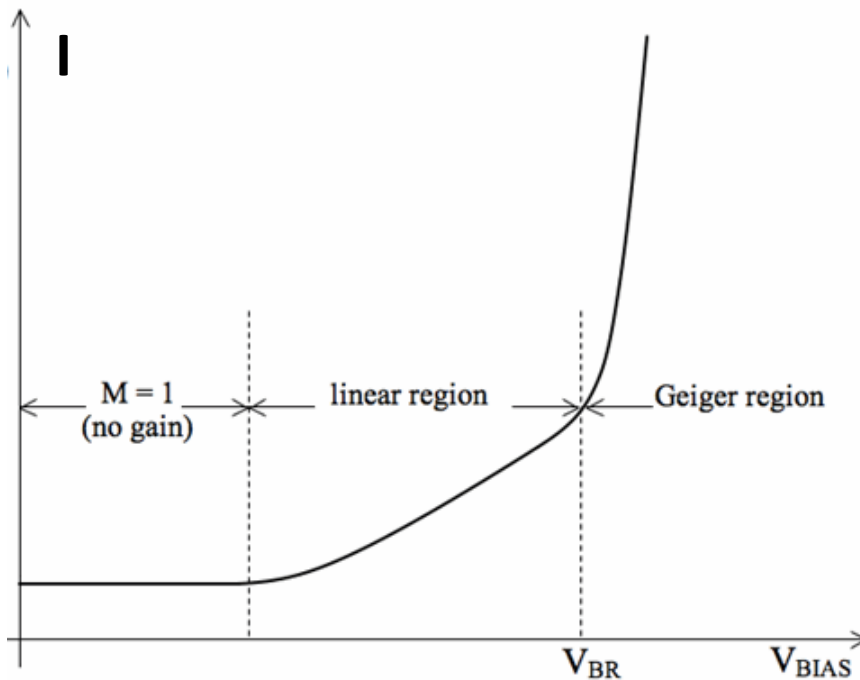
Schema circuito



Strumenti di Misura



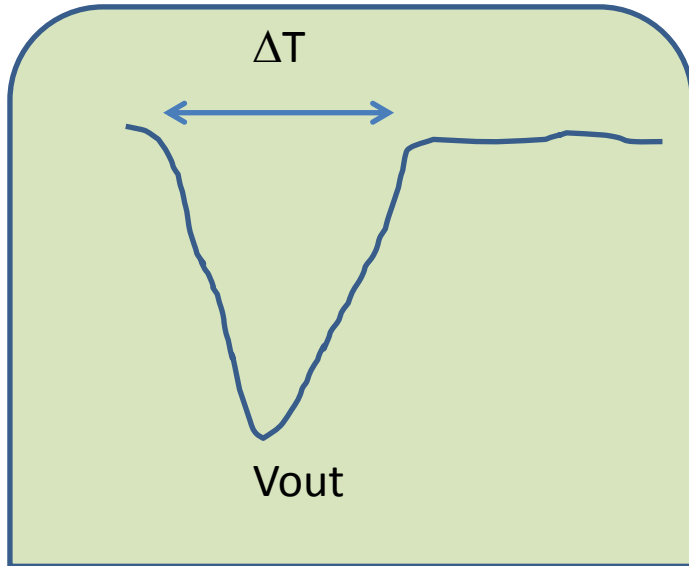
Misure I-V



Variare la ddp applicata al SiPM e misurare di volta in volta la corrente in uscita. Si deve osservare che arrivati alla soglia V_{BR} la corrente aumenta bruscamente. E' il momento in cui si innesca la valanga di elettroni e si ha amplificazione nel SiPM.

Calcolo amplificazione SiPM

oscilloscopio



Segnale adattato a 50Ω

Carica totale del segnale

$$Q = V_{out} / 50 \Omega \Delta T$$

Numero totale di elettroni

$$N = Q / e \quad e = 1.6 \times 10^{-19} \text{ C}$$

Tenendo conto che il segnale è amplificato di un fattore $A=20$, calcolare il fattore di amplificazione del SiPM.

Rpi - Istruzioni

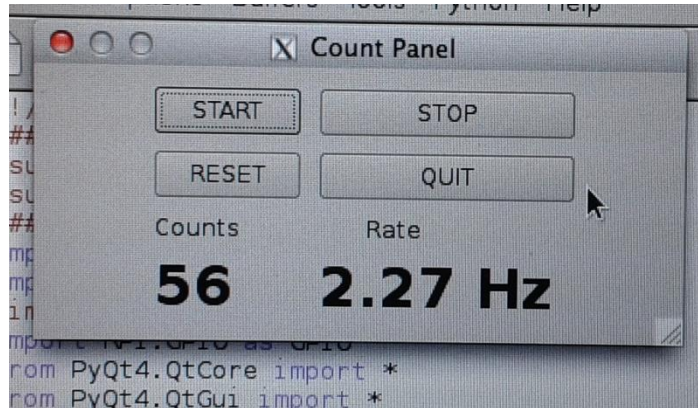
```
>ssh -X pi@ip_number
```

```
RPi$ cd nome_direcotry (per cambiare directory/cartella)
```

```
RPi$ ls (per vedere cosa c'è nella cartella)
```

```
RPi$ sudo cp ~pi/.Xauthority ~root/ (per far funzionare X con ssh)
```

```
RPi$ sudo ./SignalCounterGPIO.py (per lanciare programma)
```



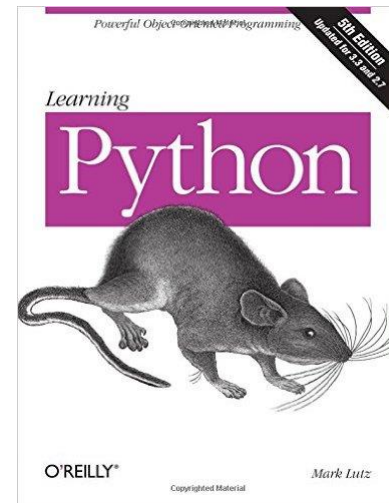
Di Eben Upton
co-creatore di RPi

Python (Hello World)

```
Rpi> python
Python> print «Hello World!!»
Hello World!!
```



```
Python 2.7.2 (default, Jun 12 2011, 14:
Type "help", "copyright", "credits" or
>>> for i in range(1,10): print i
1..
2..
3..
4..
5..
6..
7..
8..
9..
>>>
```



Codice GPIO per RPi

```
import sys
```

```
import time
```

```
#import urllib2
```

```
import RPi.GPIO as GPIO
```

Import delle librerie GPIO e grafiche PyQt

```
from PyQt4.QtCore import *
```

```
from PyQt4.QtGui import *
```

```
GPIO.setmode(GPIO.BOARD)
```

Set del pin 12 GPIO con input

```
channel = 12# RPi model dependent
```

```
GPIO.setup(channel, GPIO.IN)
```

```
counts=0
```

Inizializzazione del numero di conteggi a 0

```
def my_callback(chan):
```

La funzione di Callback eseguita dal sistema operativo quando riceve un interrupt

```
    print('This is a edge event callback function!')
```

```
    print('Edge detected on channel %s'%chan)
```

```
    print('This is run in a different thread to your main
```

```
program')
```

```
    global counts
```

```
    counts=counts+1
```

Aggiorna numero di conteggi

```
    print('Event %s'%counts)
```

Codice GPIO per RPi

```
# Main
```

Dice al sistema operativo di ascoltare gli interrupt dal pin 12 e specifica il numer della funzione di callback (my_callback)

```
GPIO.add_event_detect(channel, GPIO.FALLING, callback=my_callback, bouncetime=200)
```

```
app = QApplication(sys.argv)
```

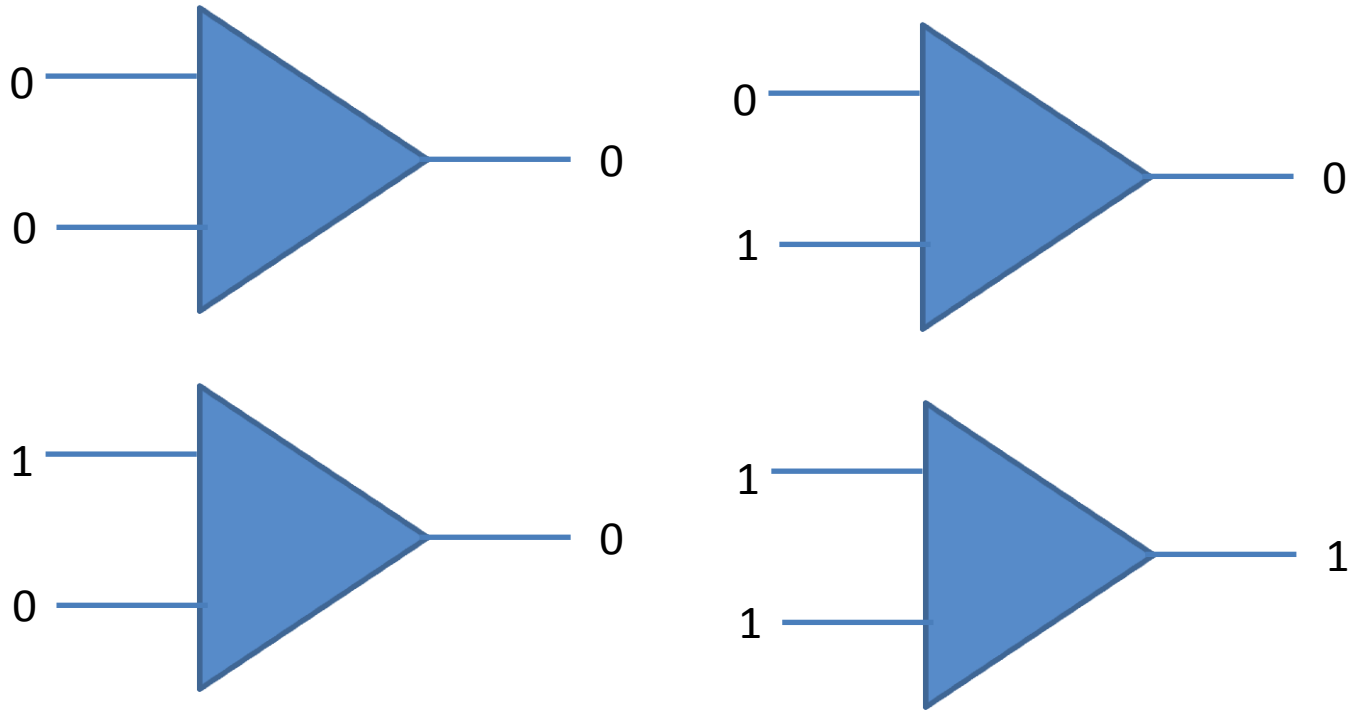
```
form = Form()
```

```
form.show()
```

Crea e lancia l'applicazione grafica

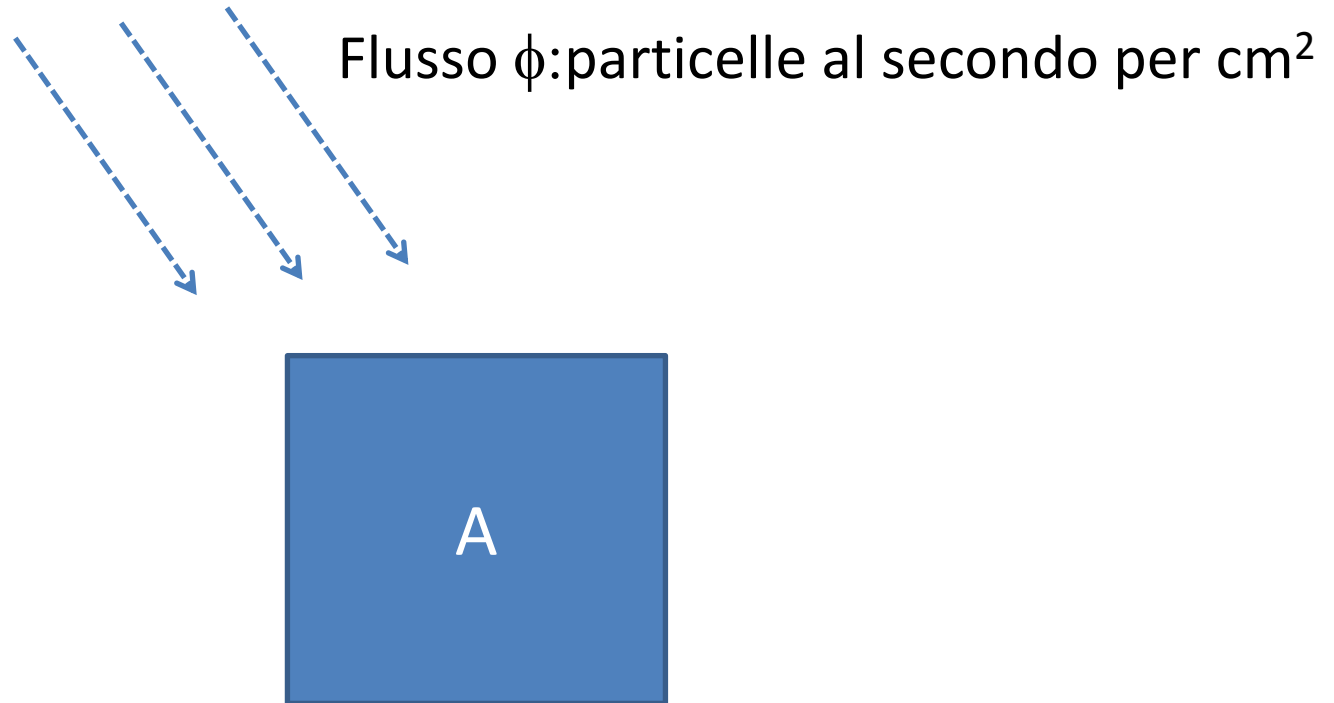
```
app.exec_()
```

Coincidenze



Frequenza finte coincidenze: $\nu_{\text{fake}} = 2\nu_1\nu_2 \Delta T$

Misura del flusso dei Cosmici



Numero di cosmici (coincidenze) contate in un tempo T:

$$N = \phi \times A \times T$$

FINE