Particle absorption in a medium using a CB detector

a (not so) short **introduction**
to the **CB**
and how to **observe**
particles absorption
in **Erice**!

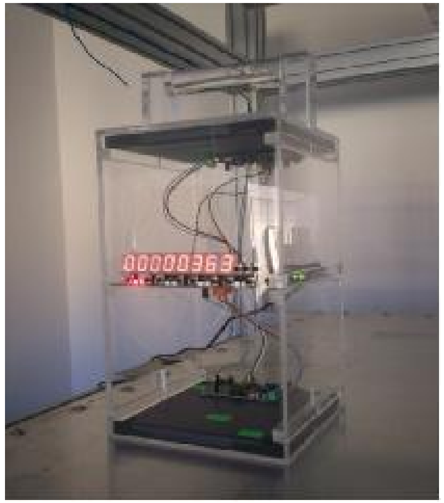
The Cosmic Box

Why a EEE - CB ?

In the early EEE times
the CB
was thought for

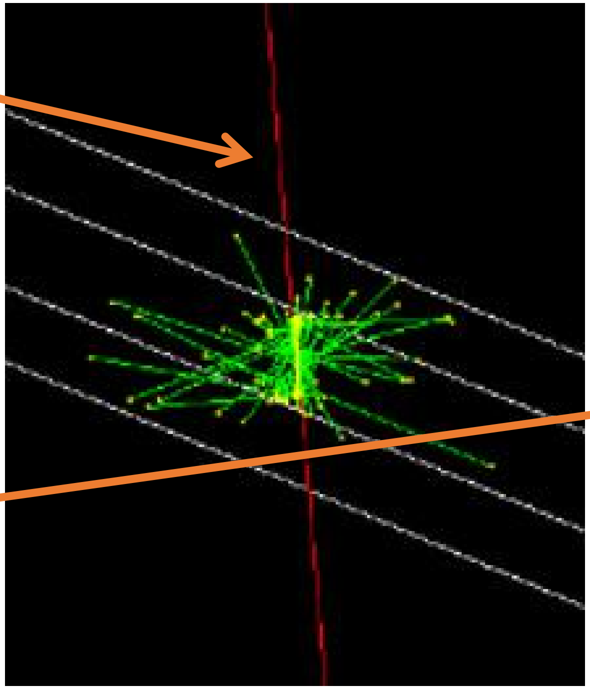
- measuring the **efficiency** of the **Alice ToF MRPCs** and later **EEE MRPCs**

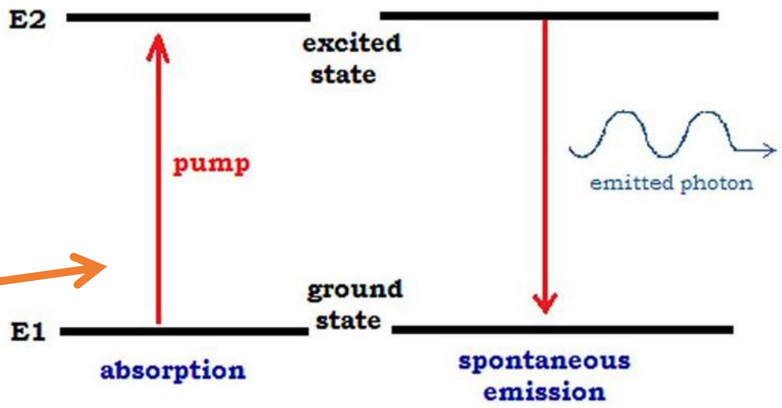
- allowing several **didactical measurements** about Cosmic Ray



How does a scintillator work ?

A scintillator emits **photons** when an **ionizing particle** deposits **energy** while passing through the material





Scintillation processes are based on the **excitation-dexcitation** of electrons on **hybrid orbitals**, typical in **organic molecules**

How does the light is collected ?

The surface of the scintillator is usually

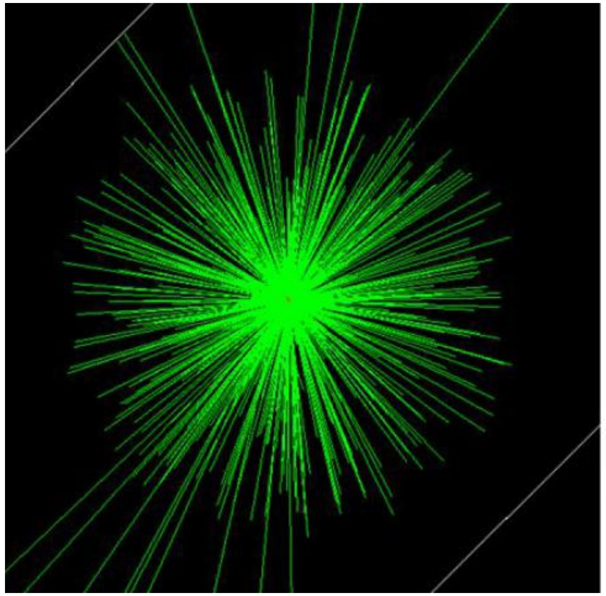
- painted

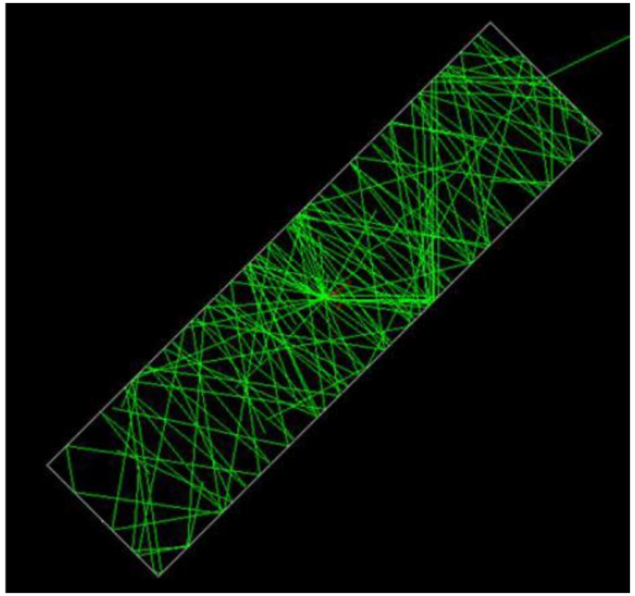
with reflective coating

- wrapped

with a reflective film

Thus **10-50%** of the emitted **light is "confined"** into the scintillator volume

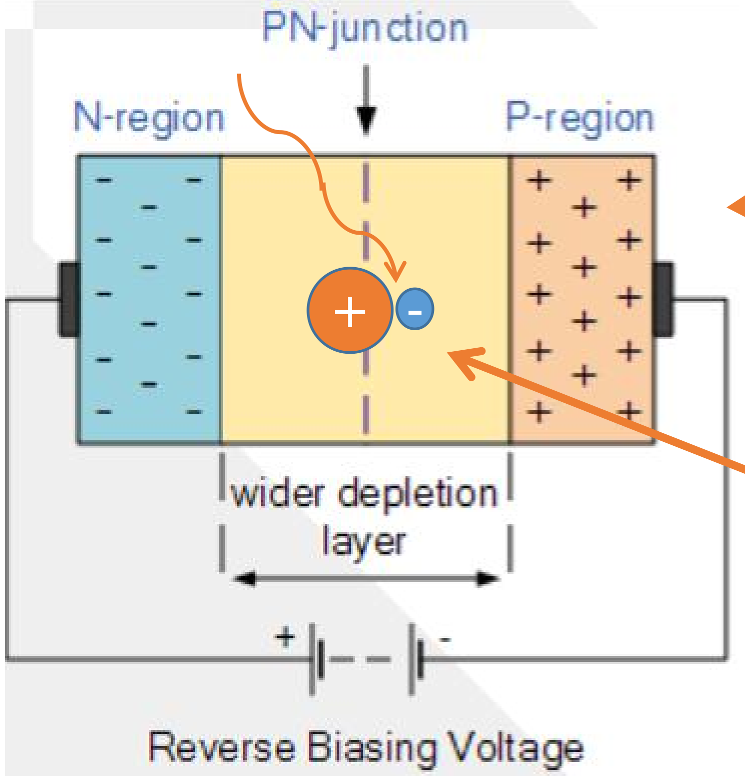




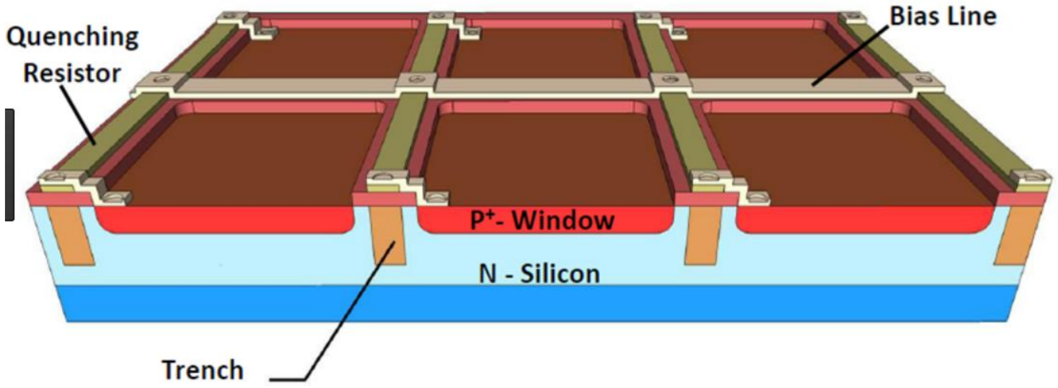
In average **10^4** to **10^5** photons are released **per cm of scintillator**, depending on

- particle energy
- particle type
- scintillating material

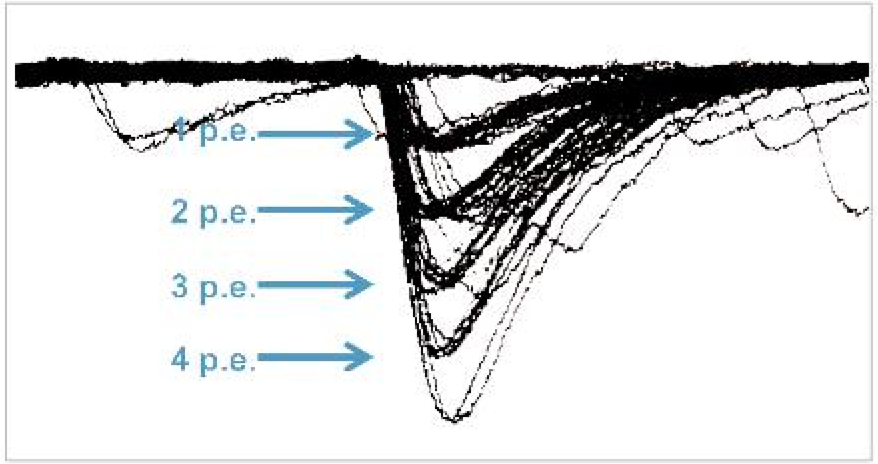
The Silicon Photomultiplier: a light amplifier



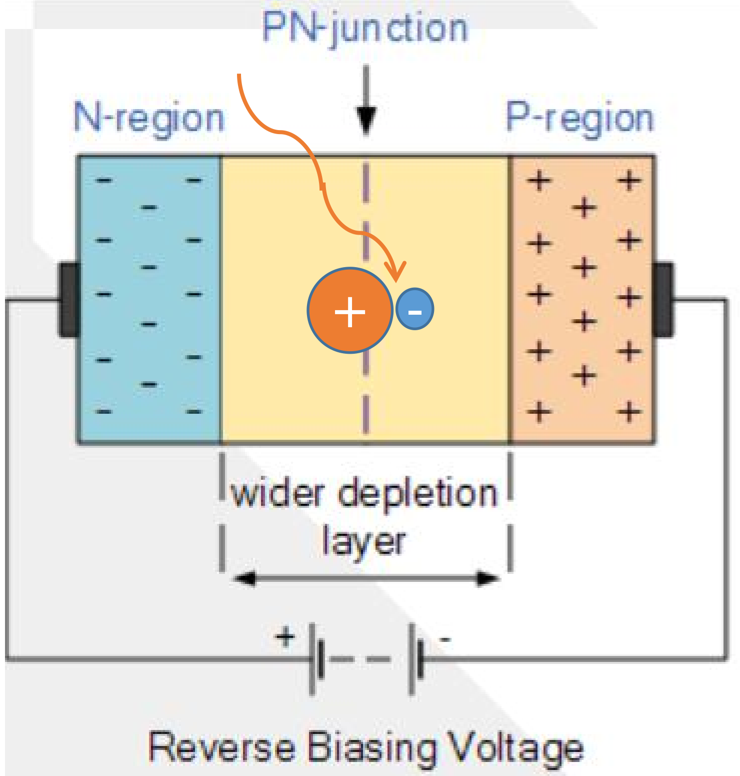
The SiPM is simply a **p-n semiconductor junction** reversed biased



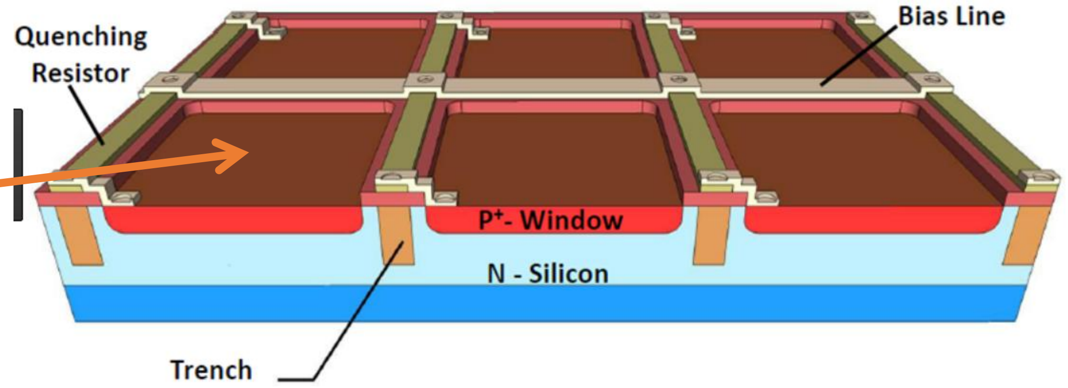
A **photon** creates **charge-hole pairs** in the depletion region the strong electric field brings to a **short and amplified** electric pulse



Photomultiplier: a light amplifier



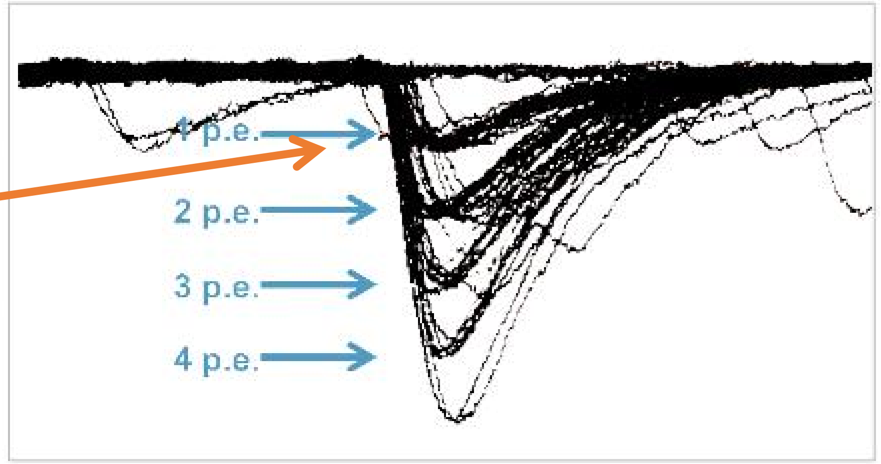
The SiPM is segmented into **little pads 10-30 µm**



the gain is **10^5-10^6**!

It is able to detect even a **single photon**!

(sunlight is 10^{20}-10^{21} photon/s)

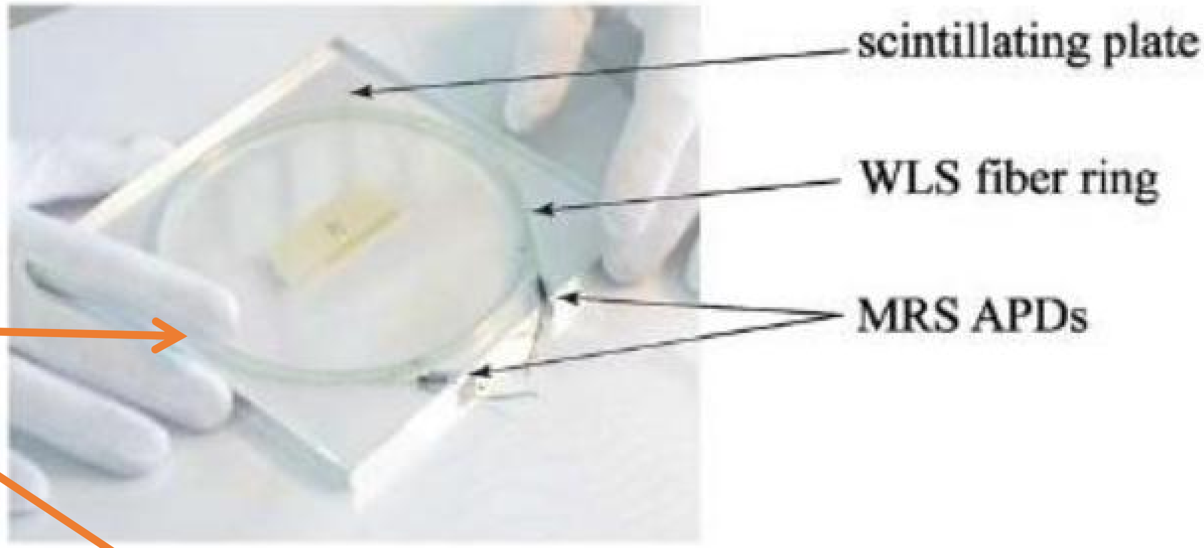


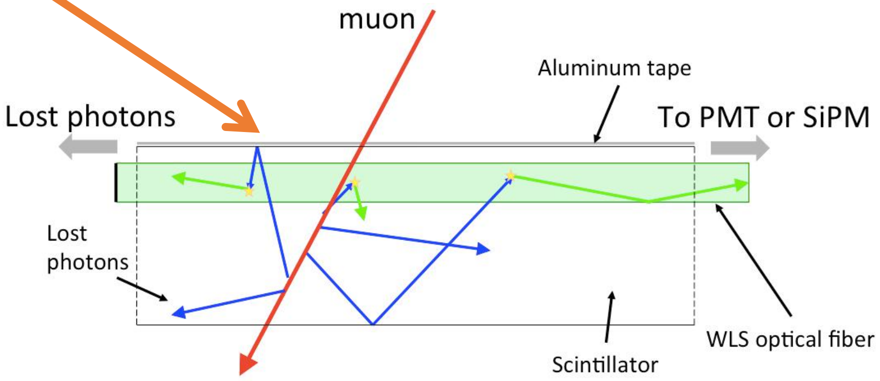
Coupling the SiPM to the scintillator

Different coupling methods

1. with **wavelenght shifter**:

"shift" the light emitted by the scintillator **to the best frequency for SiPM**





2. last CB versions:

both scintillator and SiPM are tuned on blue light

Coupling the SiPM to the scintillator

Different coupling methods

1. with wavelenght shifter:

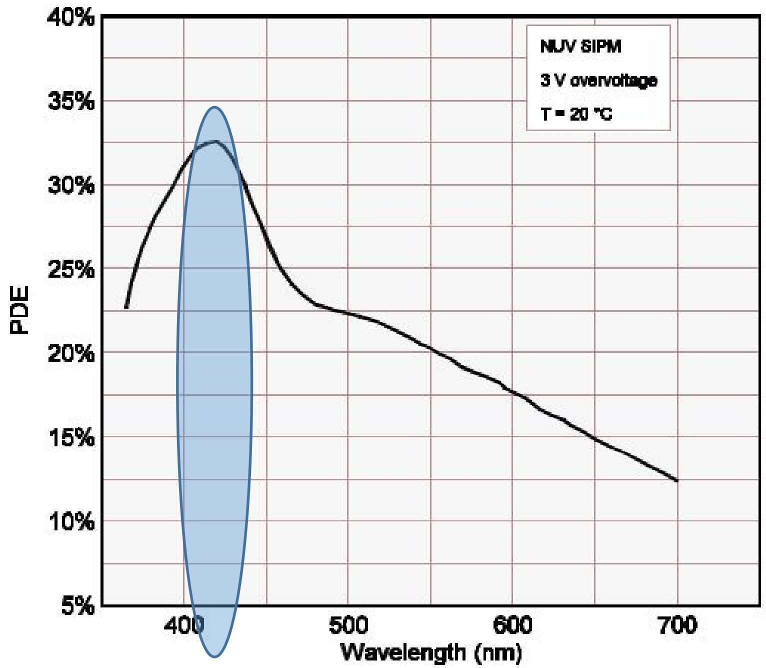
"shift" the light emitted by the scintillator to the best frequency for SiPM

2. last CB versions:

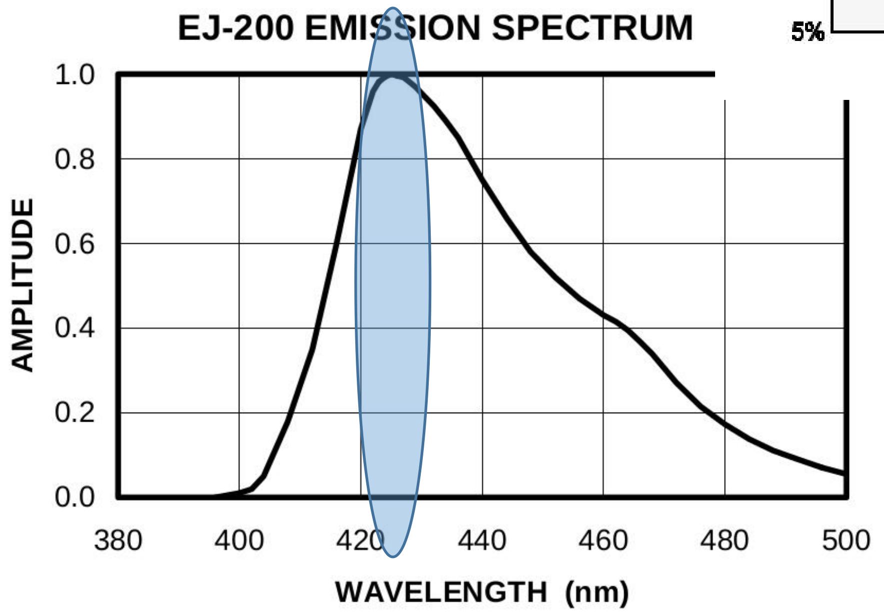
both **scintillator** and **SiPM** are tuned on

Near UV light

SiPM



Scintillator



The coincidence module: how to reduce false particle rate

$P(A \cap B) = P(A)P(B)$ uncorrelated

spurious signals in scintillator **TOP** in $\Delta T = \nu 1 \bullet \Delta T$
spurious signals in scintillator **BOT** in $\Delta T = \nu 2 \bullet \Delta T$

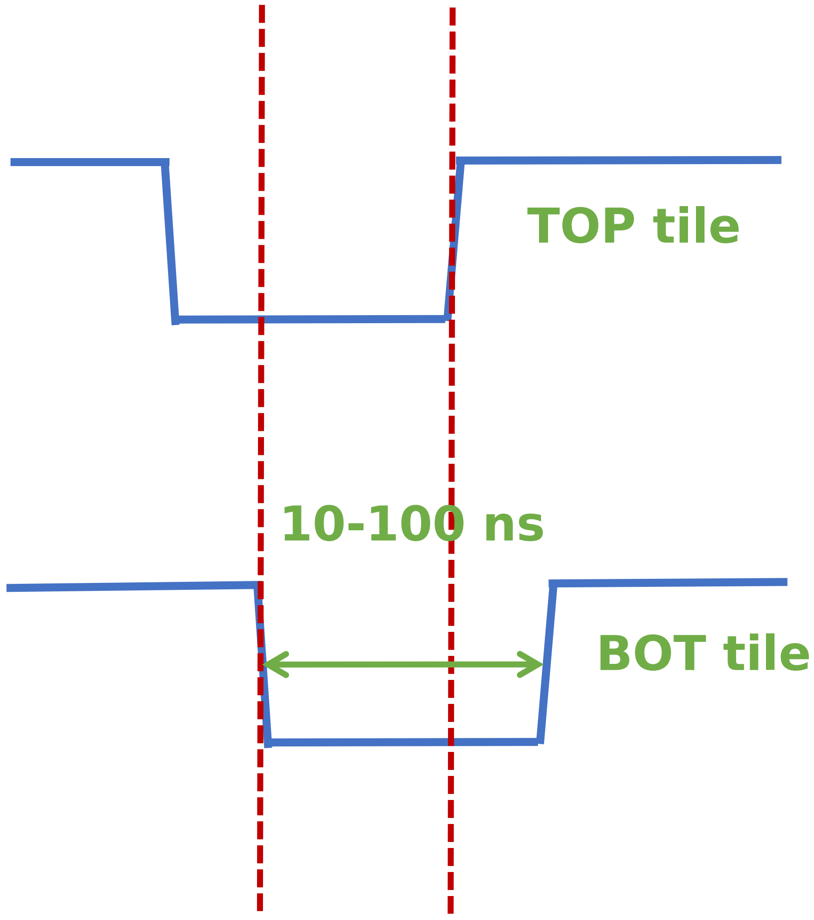
where **ν1** and **ν2** are spurious signal rate per scintillator

Rate of spurious coincidences:

ν(false coincidences) $= 2 \bullet \nu 1 \bullet \nu 2 \bullet \Delta T^2 \sim 2 \bullet (10\ \mathrm{Hz})^2 \bullet 10^{-7}\ \mathrm{s} =$

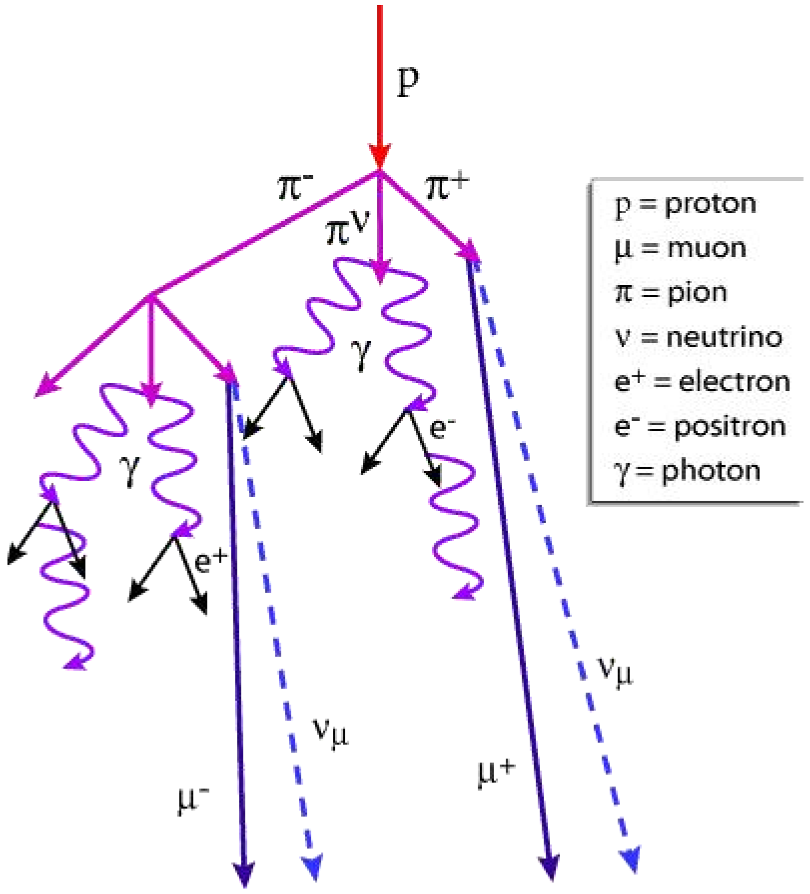
$\sim 2 \cdot 10^{-5}$ Hz

Exercise: since each scintillator tile is equipped with 2 SiPM, which is the real spurious rate for the CB detector?



Cosmic Ray absorption into a medium in a nutshell

Cosmic ray secondaries absorption in a medium

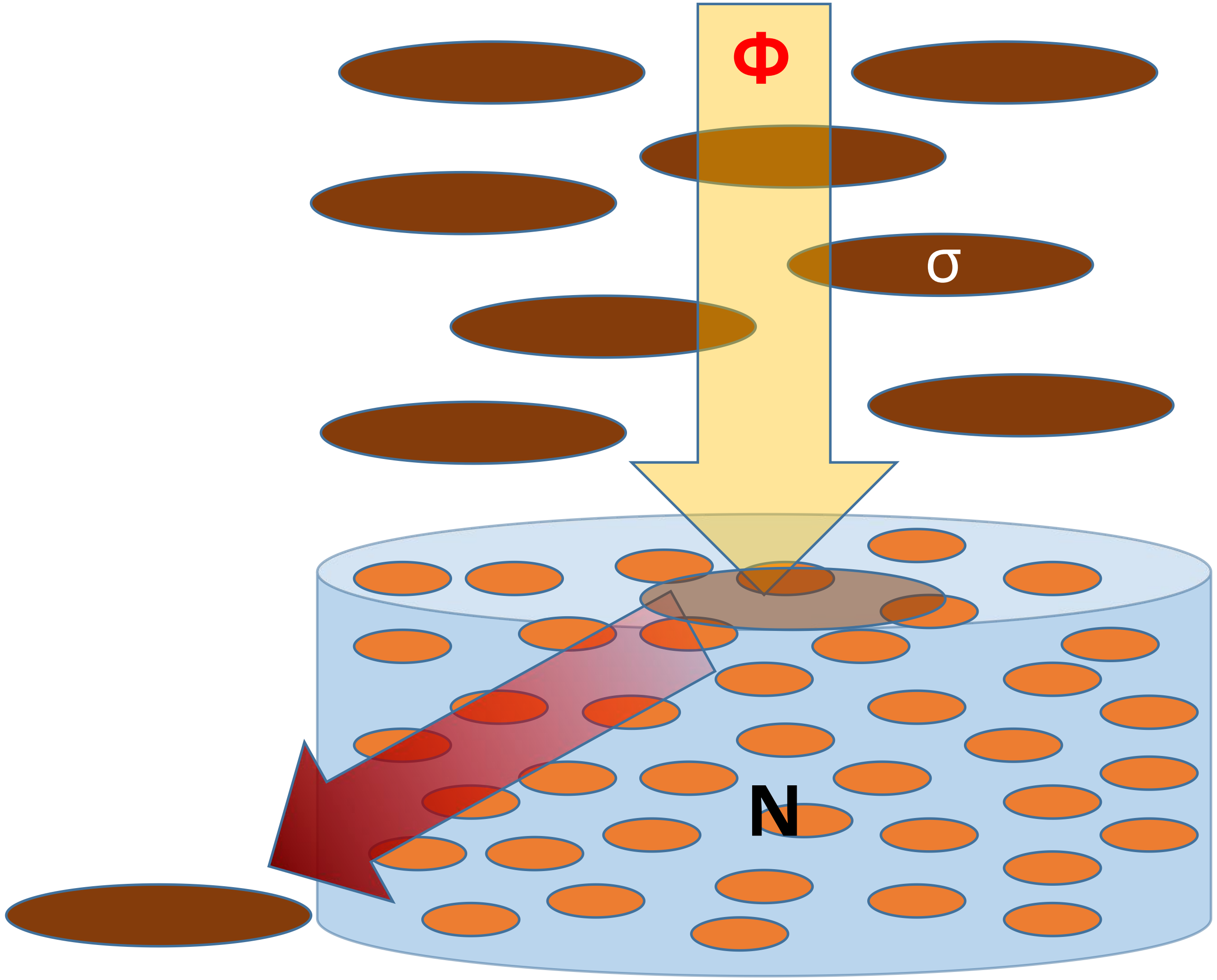


In the upper atmosphere **strong interactions** produces **π** and **K**

π and **K** **starts also electromagnetic showers** **γ**, **electrons and positrons**

π and **K** **decay into** **μ** and **ν**

Why a particle is effected by passage through matter: an **effective** (but **incomplete**) **classical** interpretation



Φ: particle flux [particles/(s m^2)]

N: number of scattering centers

σ: particle cross section (m^2)
(not really... but please be patient)

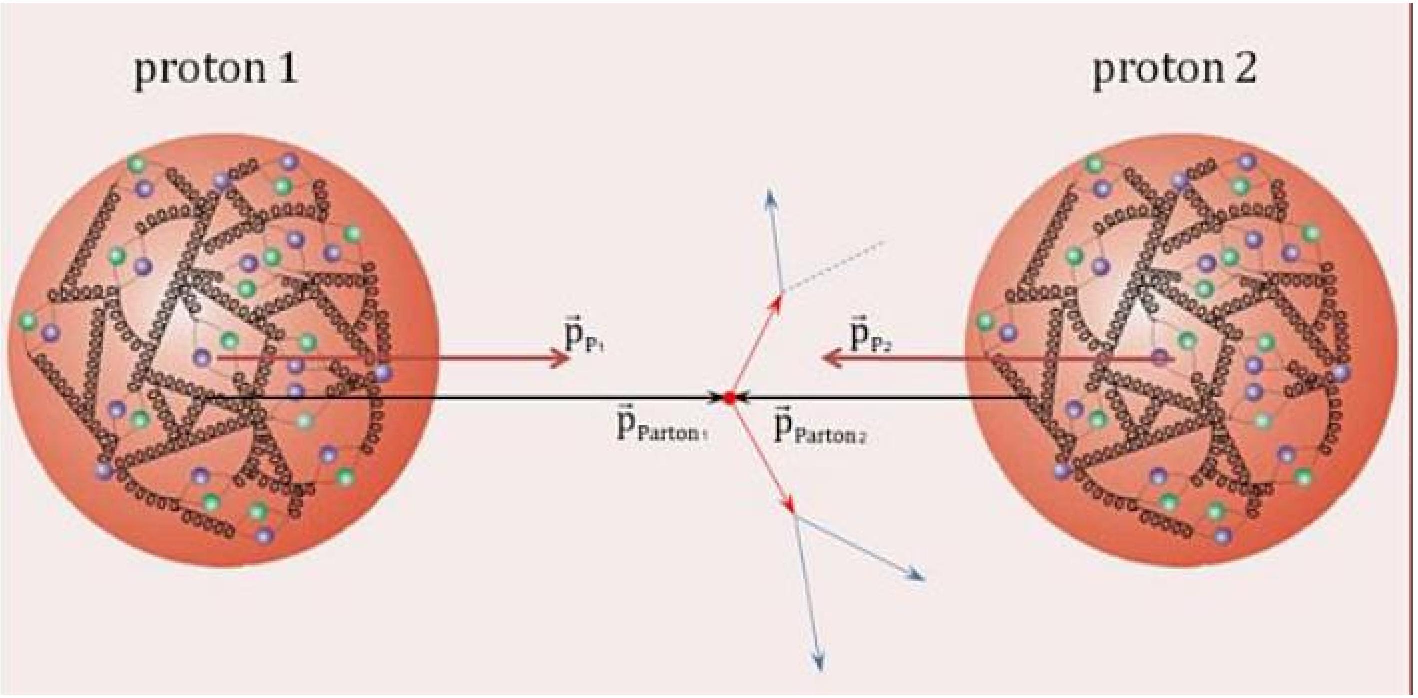
Number of scatterings per unit time:

$$I \propto N \,\Phi\, \sigma$$

$$[I]=[s^{-1}m^{-2}m^{2}]=s^{-1}$$

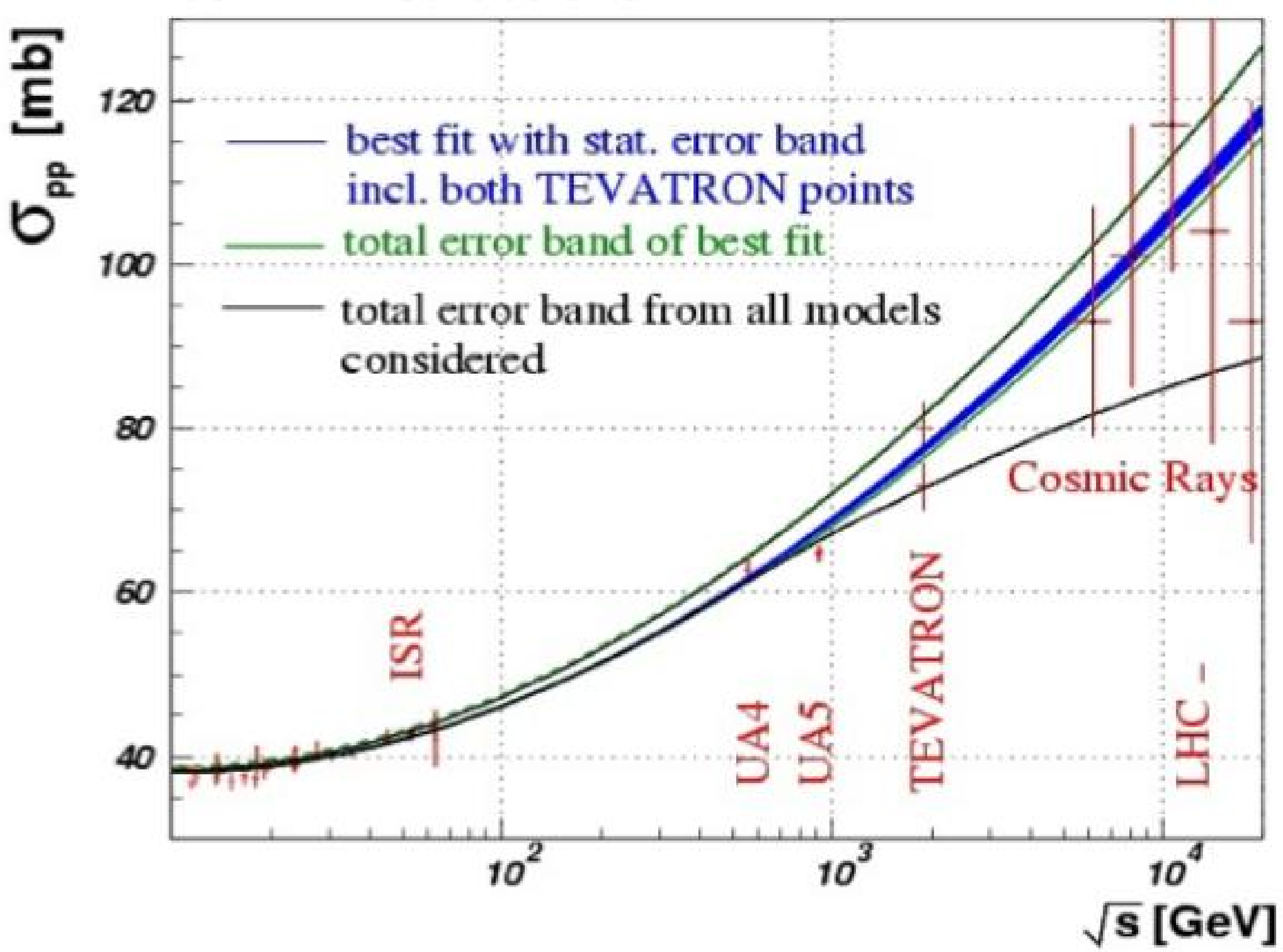
Why a particle is effected by passage through matter:
the **cross section**, an **invariant quantity:**

does **not depend on the frame** we observe the interaction from



the cross section defines
the **interaction between objects** and not the object alone!

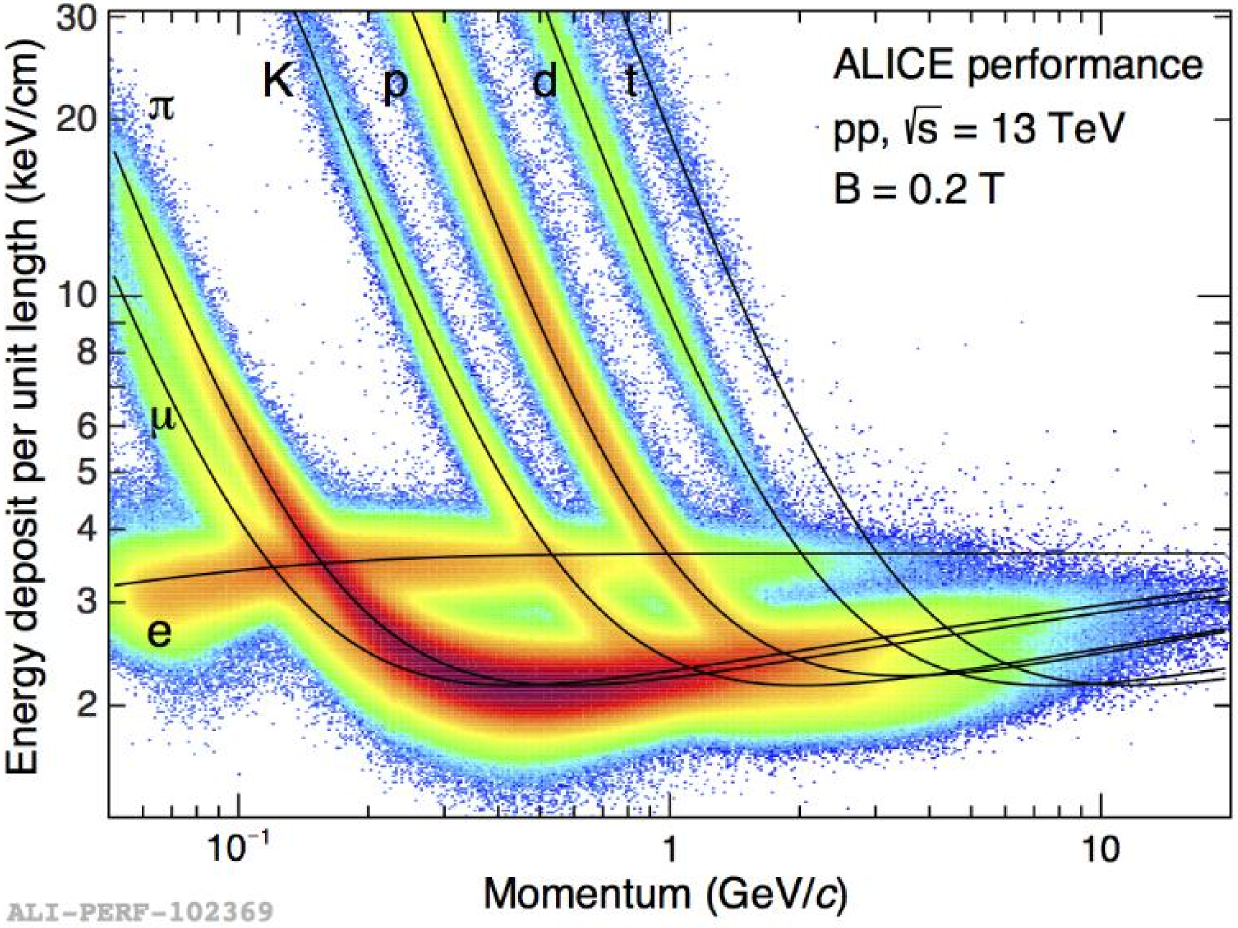
Why a particle is effected by passage through matter:
the cross section, an **invariant quantity:**
it varies with the **energy available**
during the interaction **between the objects**



Well... a bit puzzling...
same particles at different energies
means different cross sections!!!!

(1 bar = 10^{-24} cm^2)

What happens to a **charged particle through matter** ($e^{+/-}$, μ, π, p, d etc.)



Ionization Minimum ~ 3-4 particle masses

Let's measure everything in terms of **ENERGY**

1 eV = 1.6 10^{-19} J

Momentum:

$[p]=[mv]=[mv^2/v]=[E/v]=eV/c$

Mass

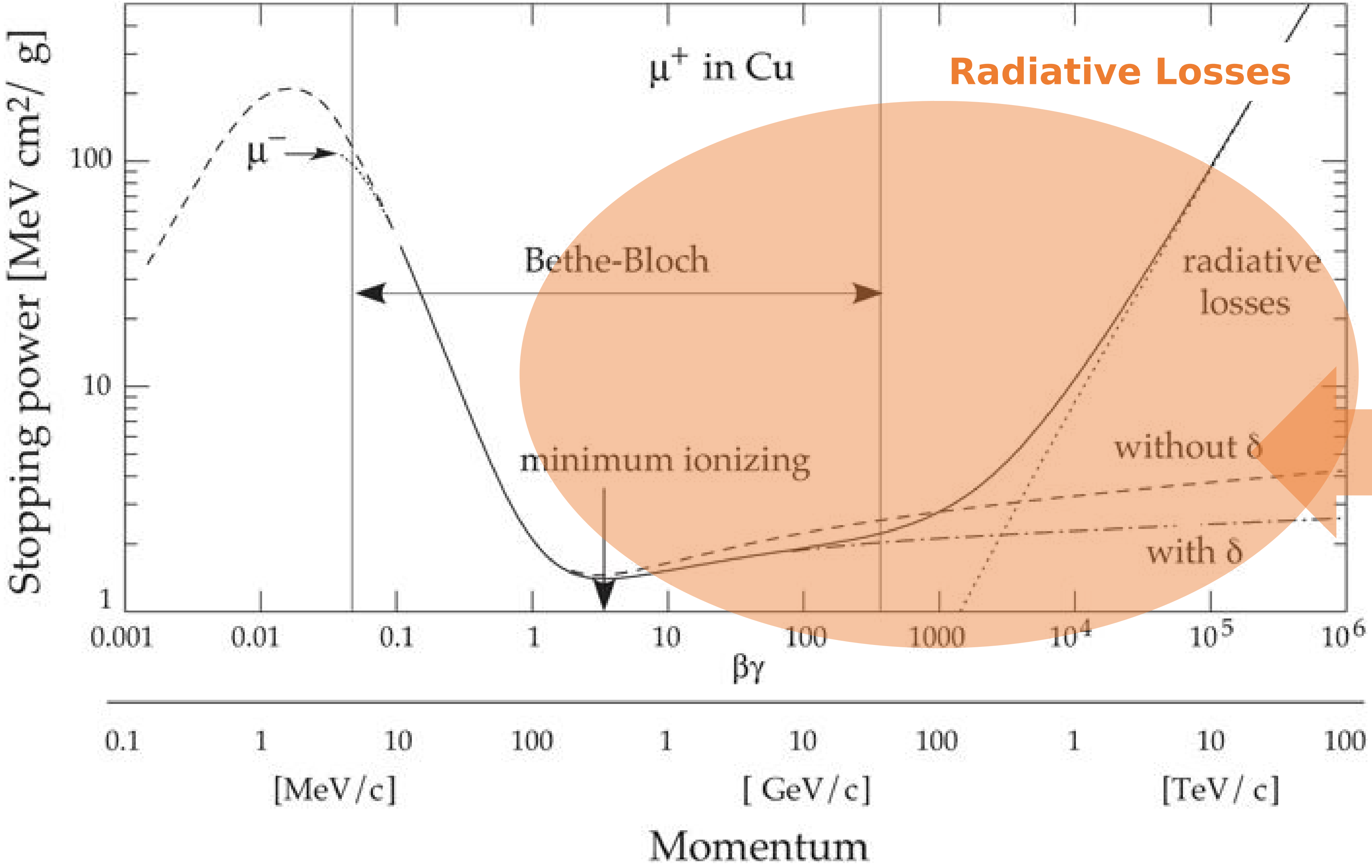
$[m]=[mv^2/v^2]=[E/v^2]=eV/c^2$

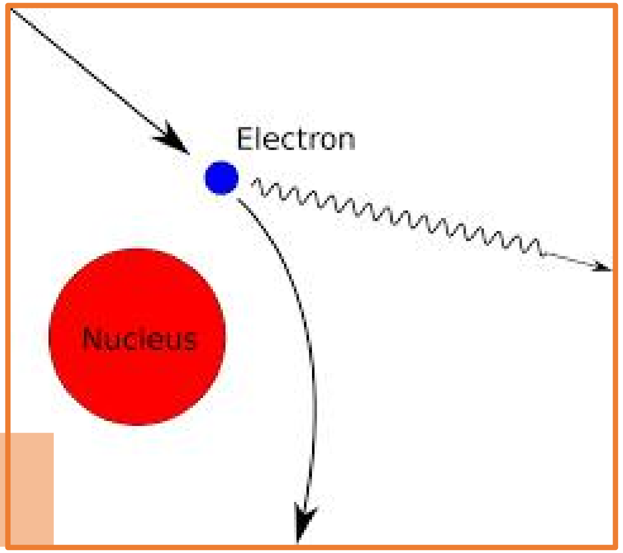
$m_p \sim 1$ GeV

$m_\mu \sim 106$ MeV

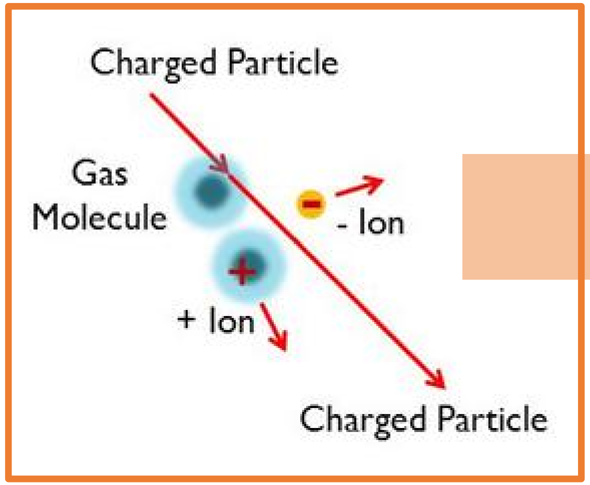
$m_e \sim 511$ keV

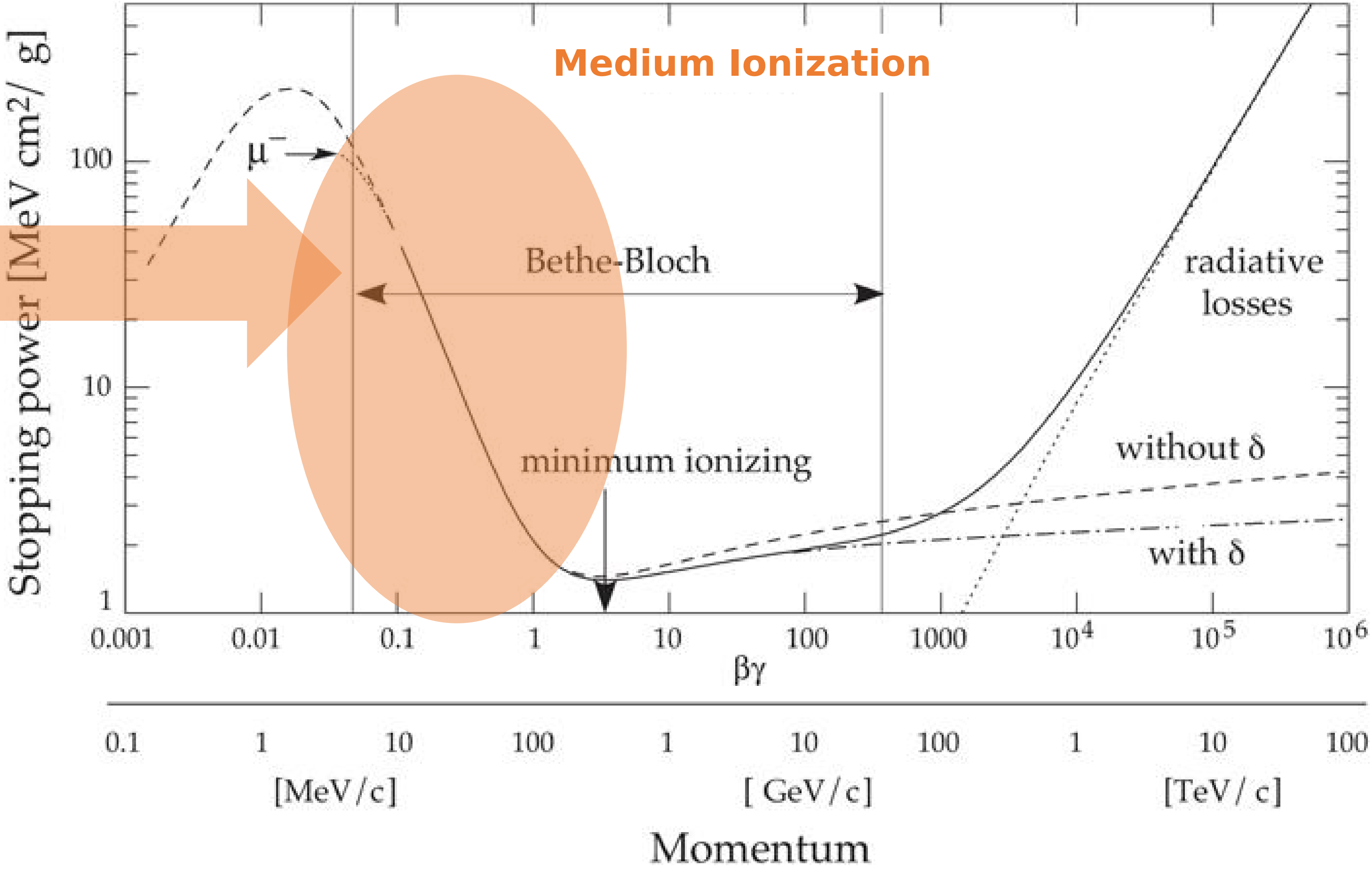
What happens to a **charged particle through matter** (e$^{+/-}$, μ, π, p, d etc.)





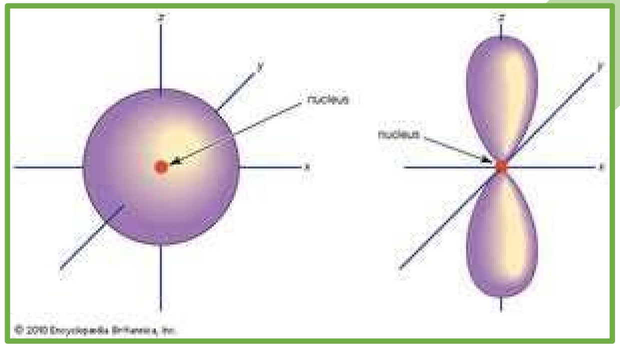
What happens to a **charged particle through matter** ($e^{+/-}$, μ, π, p, d etc.)

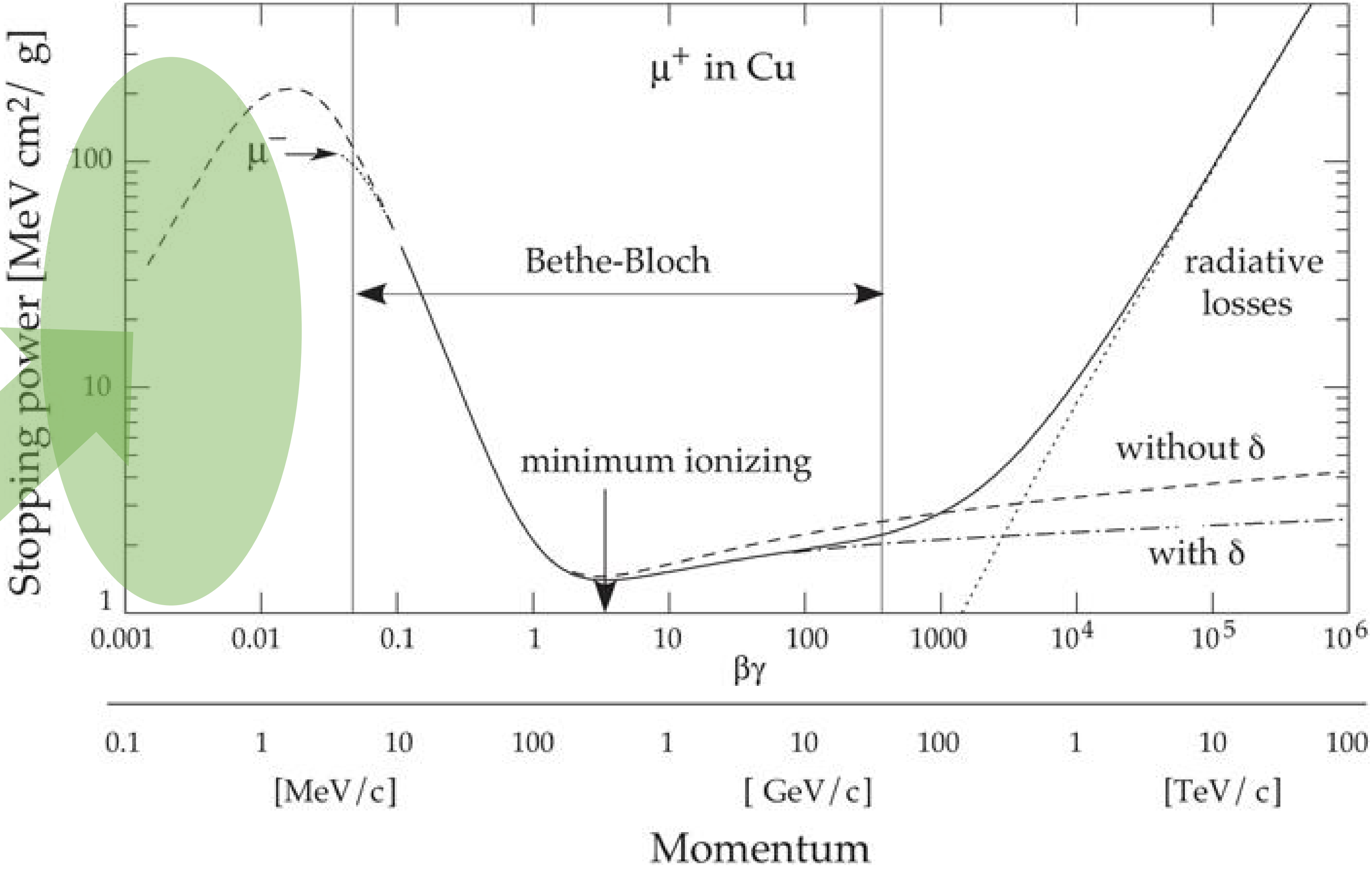




What happens to a **charged particle through matter** ($e^{+/-}$, μ, π, p, d etc.)

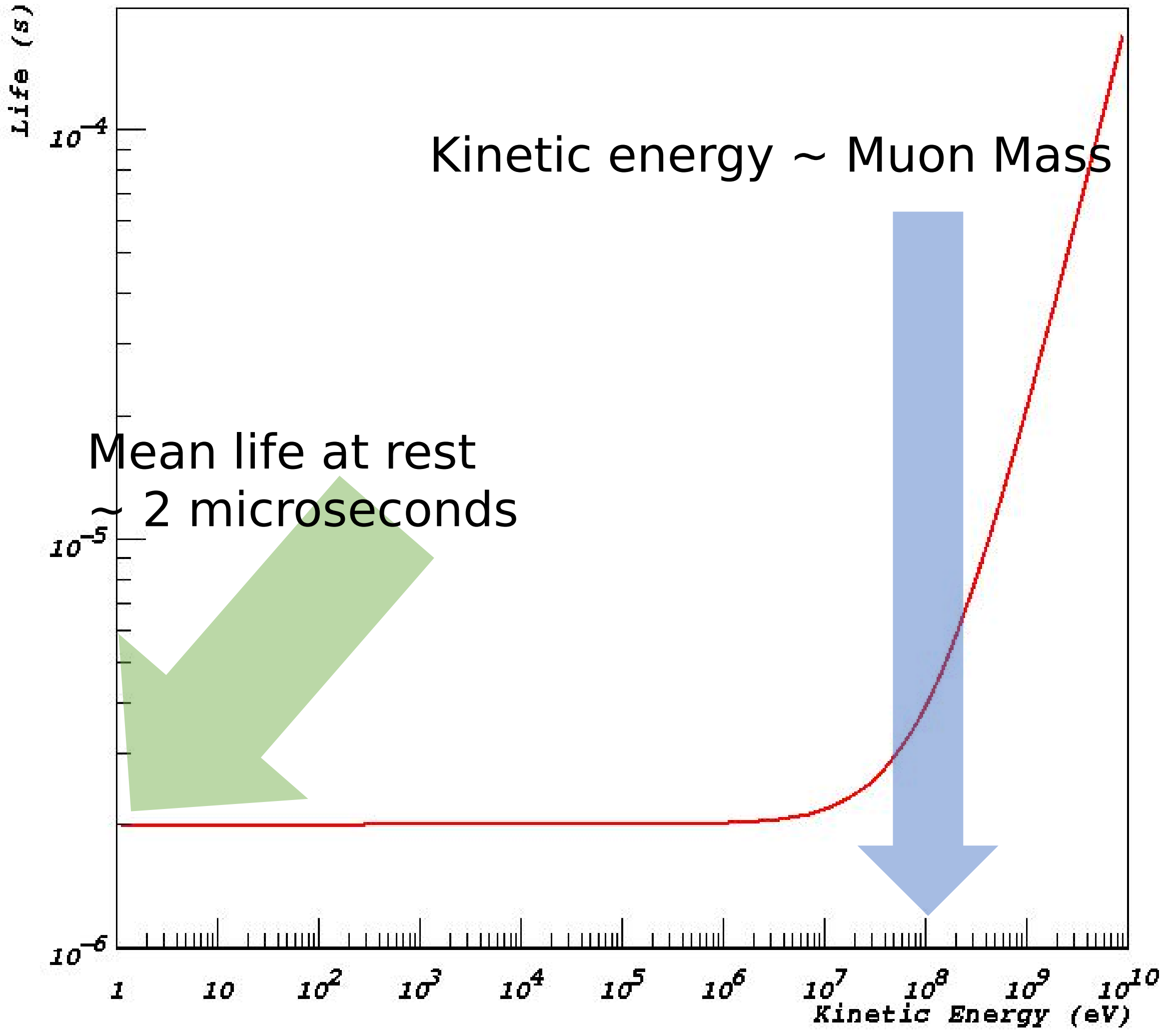
Electrons (and also muons!) are captured by an atom



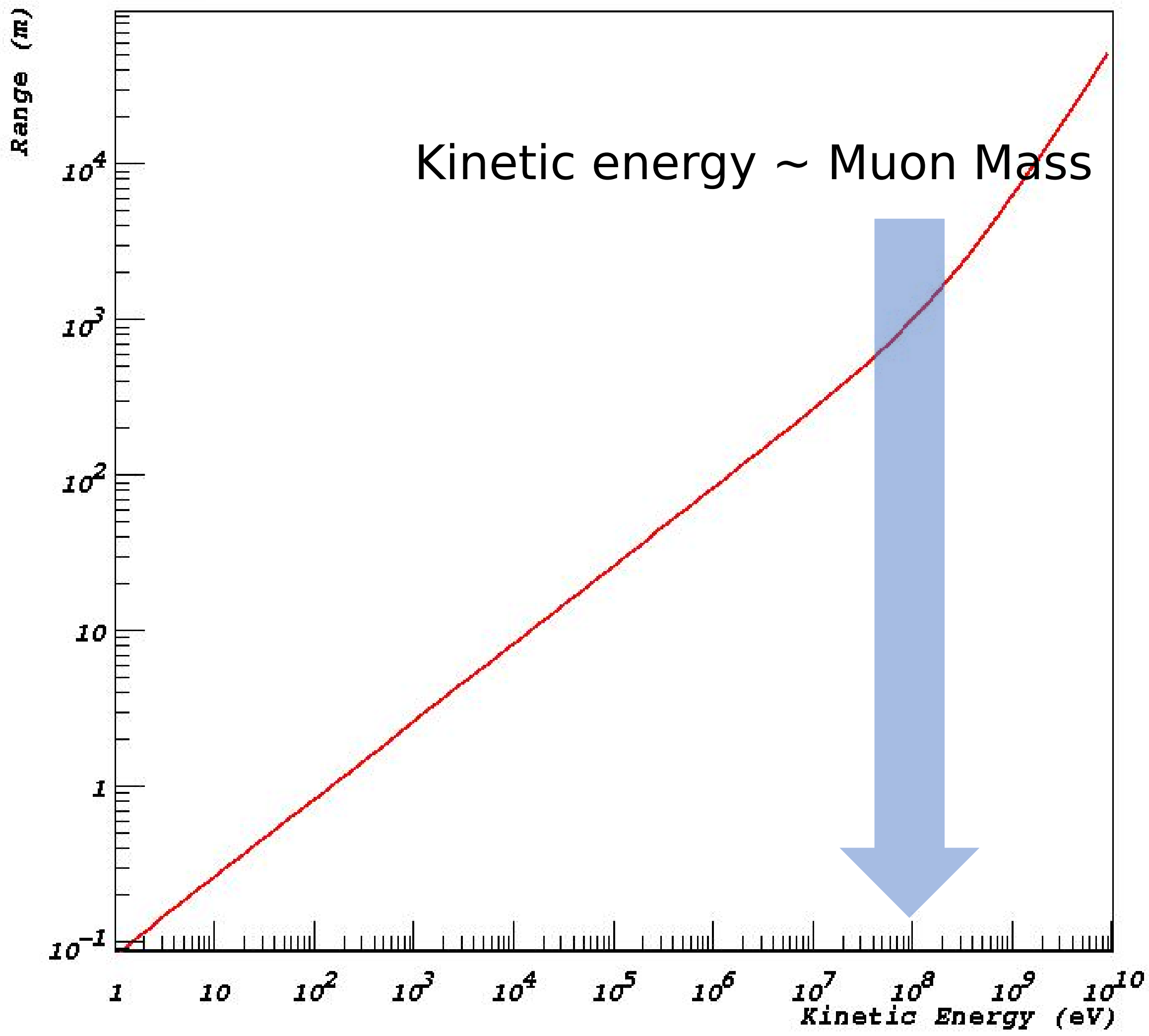


Unstable particle end of life: muon decay

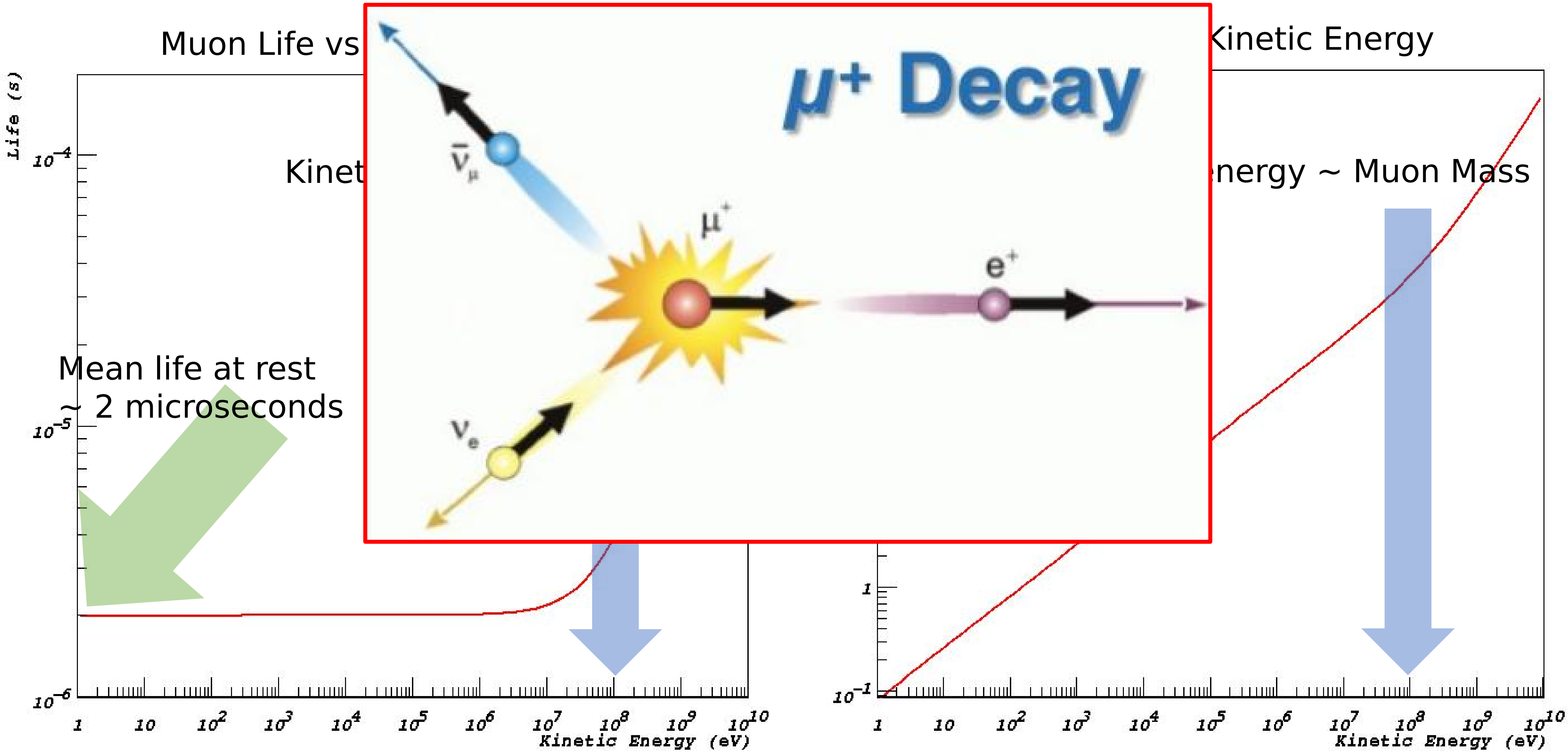
Muon Life vs Kinetic Energy



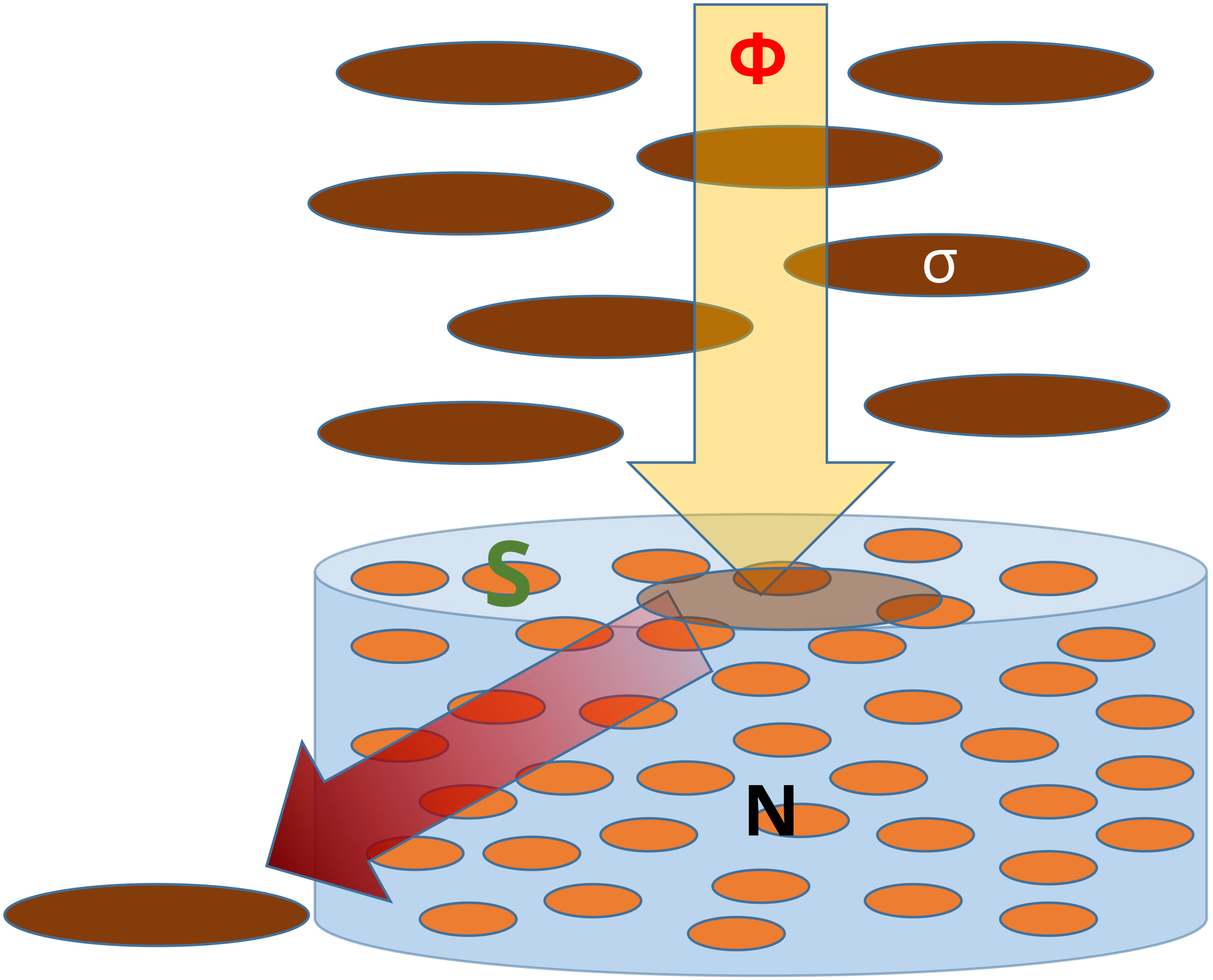
Muon Range vs Kinetic Energy



Unstable particle end of life: muon decay



Flux decrease: a (first order) expectation



Φ: particle flux [particles/(s m²)]

N: number of scattering centers

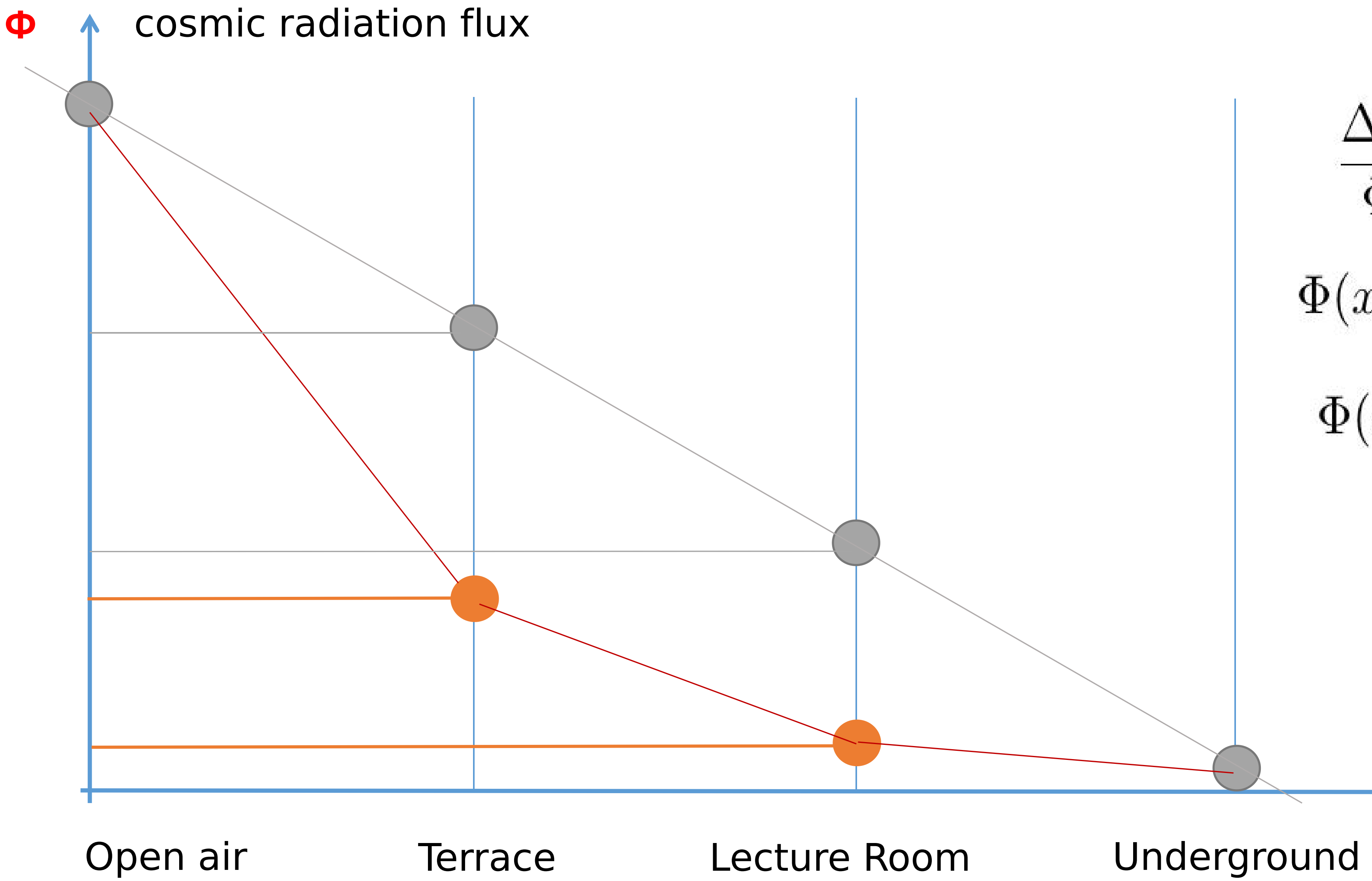
σ: particle cross section (m²)
(not really... but please be patient)

Number of particle lost per unit time:

$$\Delta\Phi\, S \propto -\, N\, \Phi\, \sigma$$

thus the flux decrease **is not constant** but it depends on the actual flux Φ

Flux decrease: a (first order) expectation



$\Delta\Phi \; S \propto - N \; \Phi \; \sigma$

$$\frac{\Delta\Phi}{\Phi} = -\frac{N\sigma}{S} = -\frac{\rho x \sigma}{S}$$

$$\Phi(x) = \Phi(0)\exp\left[-\frac{\rho\sigma}{S}x\right]$$

$$\Phi(x) = \Phi(0)\exp\left[-kx\right]$$

$$k$$

relative variation
per unit lenght

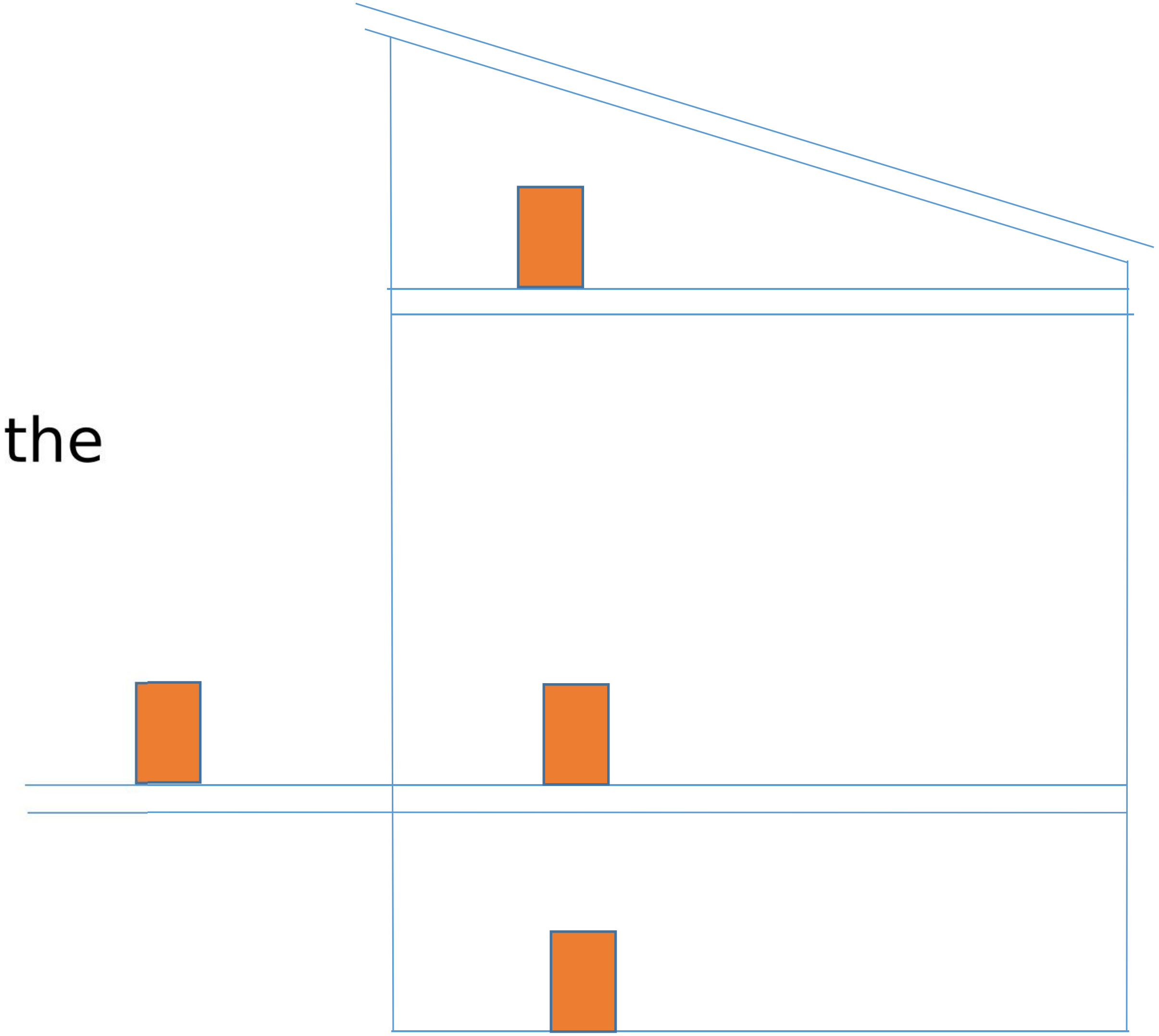
The measurement with the CB

4 measurements will be performed:

- external
- underground
- ground level
- terrace

Few questions to be discussed within the working groups.

1. **how long** the measurement should be taken
1. the best position?
2. the **uncertainties**?
3. which **variable** has to be studied? (Counts, Rate … etc)



The measurement with the CB: **the Google sheet**

Misure di assorbimento con le Cosmic Box - Erice, Dicembre 2018

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=SUM(QUERY('Group 1'!A2),QUERY('Group 2'!A2),QUERY('Group 3'!A2),QUERY('Group 4'!A2),QUERY('Group 5'!A2),QUERY('Group 6'!A2),QUERY('Group 7'!A2),QUERY('Group 8'!A2),QUERY('Group
```

	A	B	C	D	E
1	**MI-1: Misura Interna - Livello -1**	**Errore assoluto - sqrt(N_MI-1)**	**Errore relativo - sqrt(N_MI-1)/N_MI-1**	**Durata (minuti)**	**Frequenza media di acquisizione (Hz)**
2	0	0	FALSE	30	0
3					
4					
5					
6					
7					
8	**MI0: Misura Interna - Livello 0**	**Errore assoluto - sqrt(N_MI0)**	**Errore relativo - sqrt(N_MI0)/N_MI0**	**Durata (minuti)**	**Frequenza media di acquisizione (Hz)**
9	0	0	FALSE	0	FALSE
10					
11					
12					
13					
14					
15	**MI+1: Misura Interna - Livello +1**	**Errore assoluto - sqrt(N_MI+1)**	**Errore relativo - sqrt(N_MI+1)/N_MI+1**	**Durata (minuti)**	**Frequenza media di acquisizione (Hz)**
16		0	FALSE	0	FALSE
17					
18					
19					
20					
21					
22	**ME: Misura Esterna**	**Errore assoluto - sqrt(N_ME)**	**Errore relativo - sqrt(N_ME)/N_ME**	**Durata (minuti)**	**Frequenza media di acquisizione (Hz)**
23		0	FALSE	0	FALSE
24					

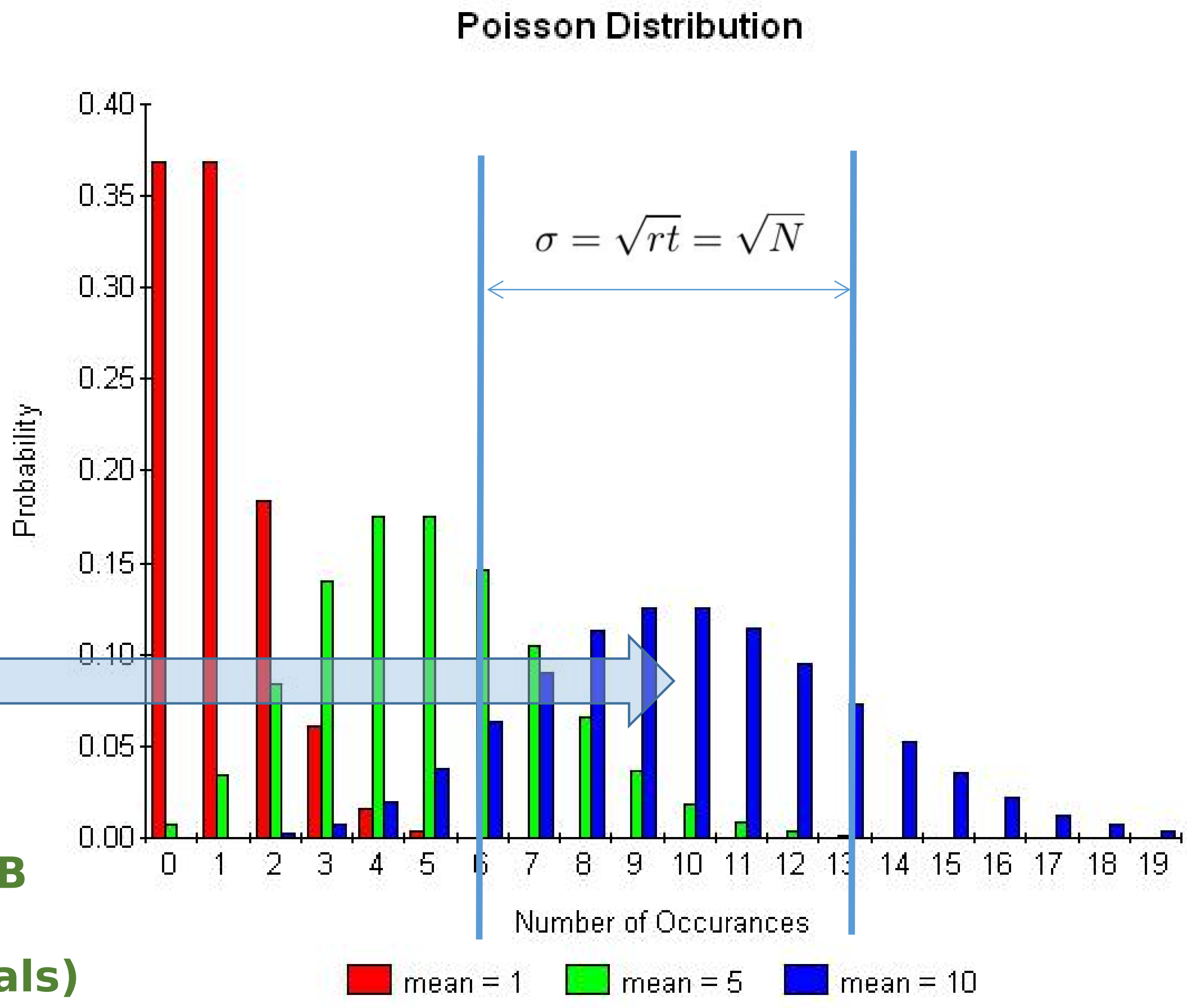
Summary | POLA-01 | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 | Group 8 | Group 9 | Gro

The measurement with the CB:
the source of uncertainties

$$P(k \text{ events in interval } t) = e^{-rt}\frac{(rt)^k}{k!}$$

where r is the rate of particles
and
t is the time of the measurements

when we measure we have
just 1 value
which we expect to be close to the
mean value

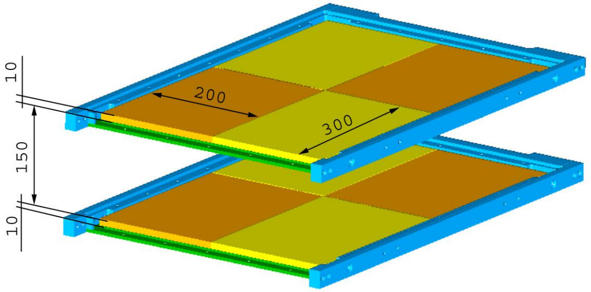


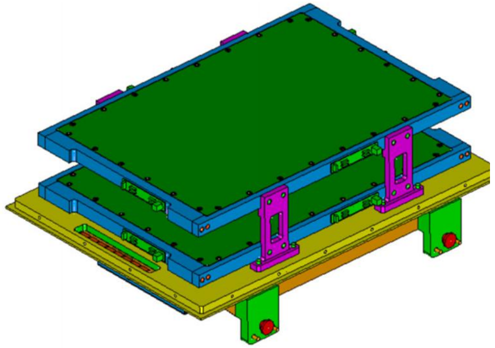
PROPOSAL:
try to obtain experimentally with a CB the Poisson distribution.
(Taking note of counts for short intervals)

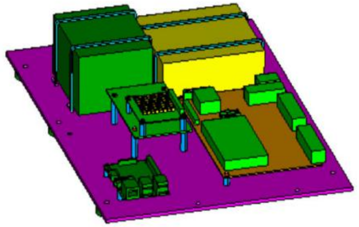
The detector

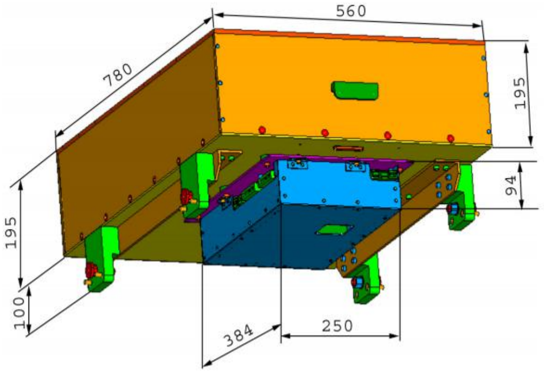
- 2 scintillator planes
- Distance between planes: 15 cm
- 4 tiles per plane 30 cm x 20 cm
- Each tile 2 SiPMs
- Efficiency > 96% (overall)

Addressing a POLAR detector

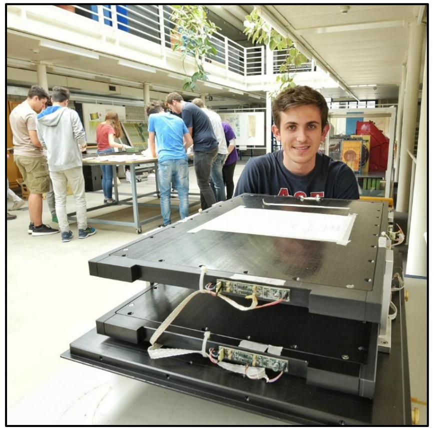








Detector construction @CERN



POLA-01 installation on Nanuq

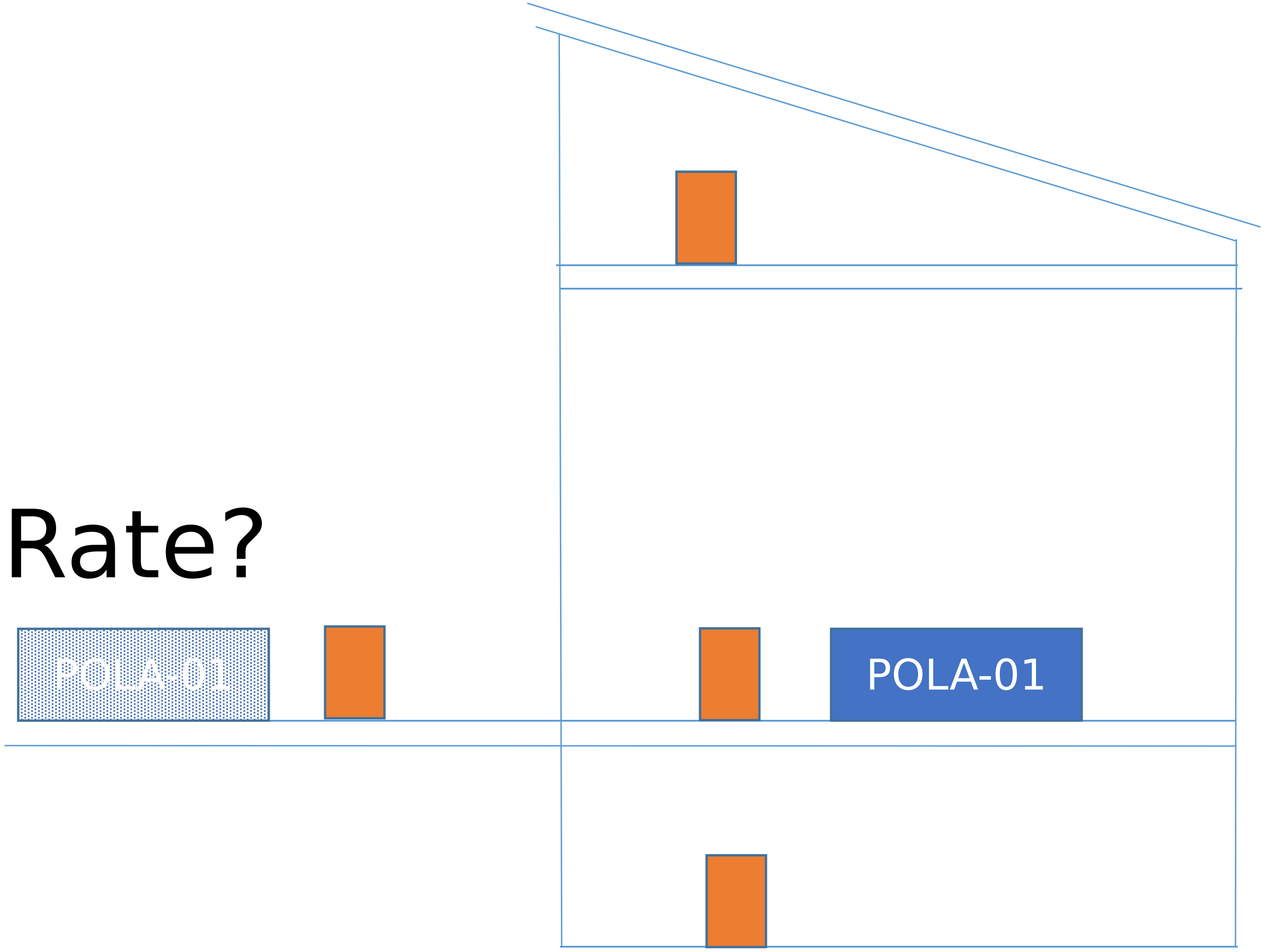
Correction to POLA-01: bringing POLA-01 outside!

Scientists often have to correct their experimental data using data coming from other experiments.

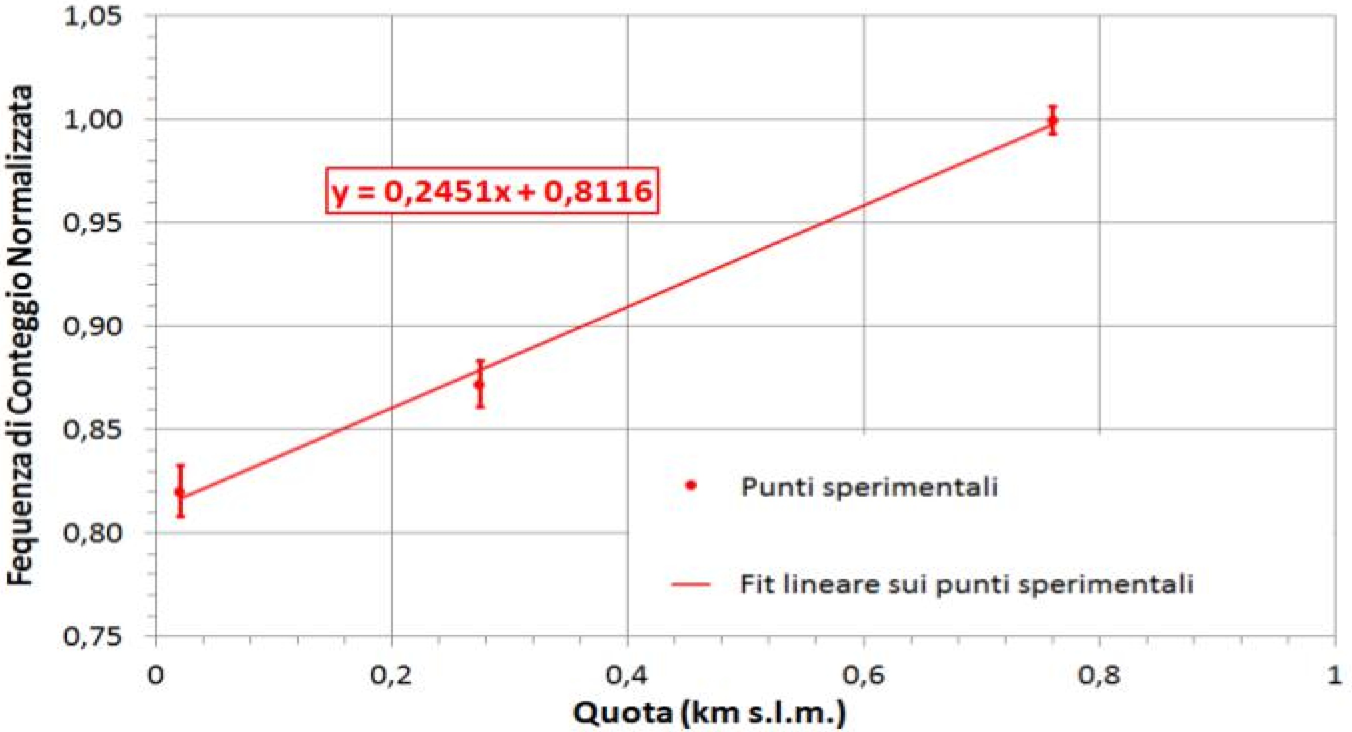
Let's think how to correct POLA-01 rate measured inside the building in order to guess which rate would be measured by **POLA-01 outside**.

Using the **CB data** collected during the 4 measurements:

- which positions for CB for the best corrections to POLA-01 data?
- how to perform the correction?



Correction to POLA-01: bringing POLA-01 at the sea level (EEE paper)!



EEE students already measured the abosrption of CR by the atmosphere.

~25%/km

Let's think how to make use of this measurement to guess what POLA-01 would see at the sea level

GIORNALE DI FISICA VOL. XLII, N. 2 February 2018

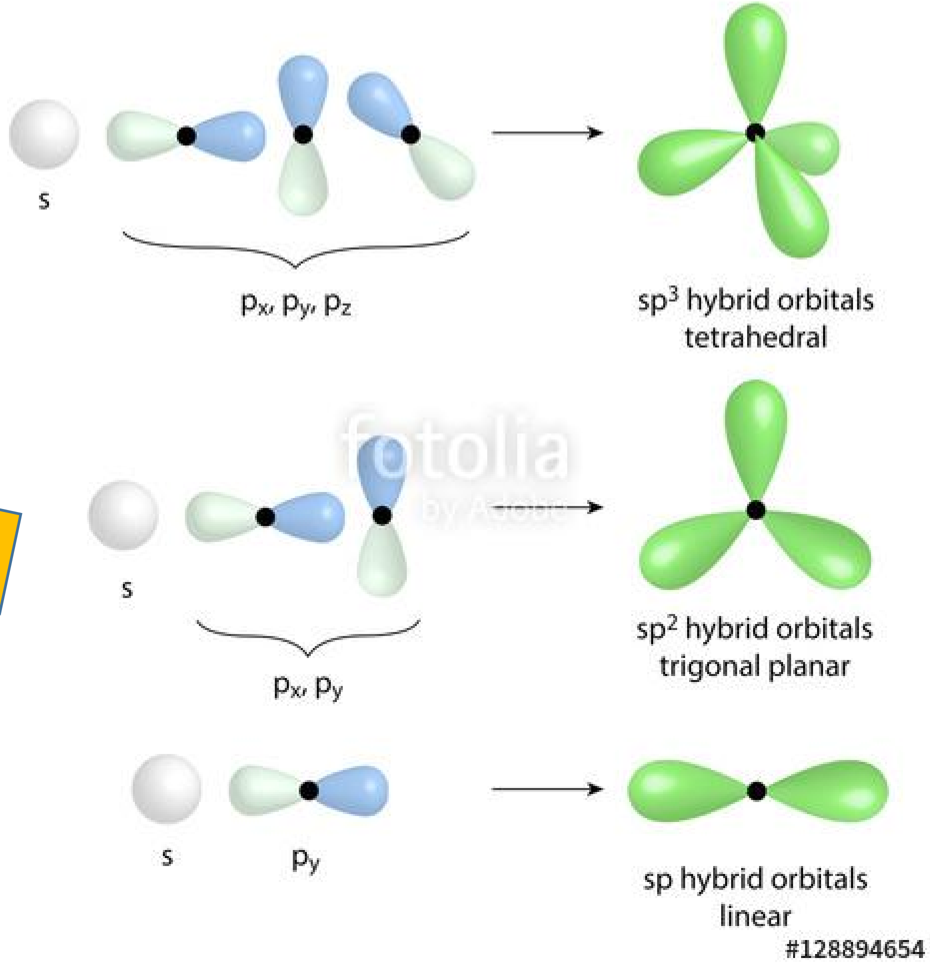
Come varia il flusso dei raggi cosmici con la quota? Basta chiederlo agli studenti del progetto EEE

- BACKUP

How does a scintillator work ?

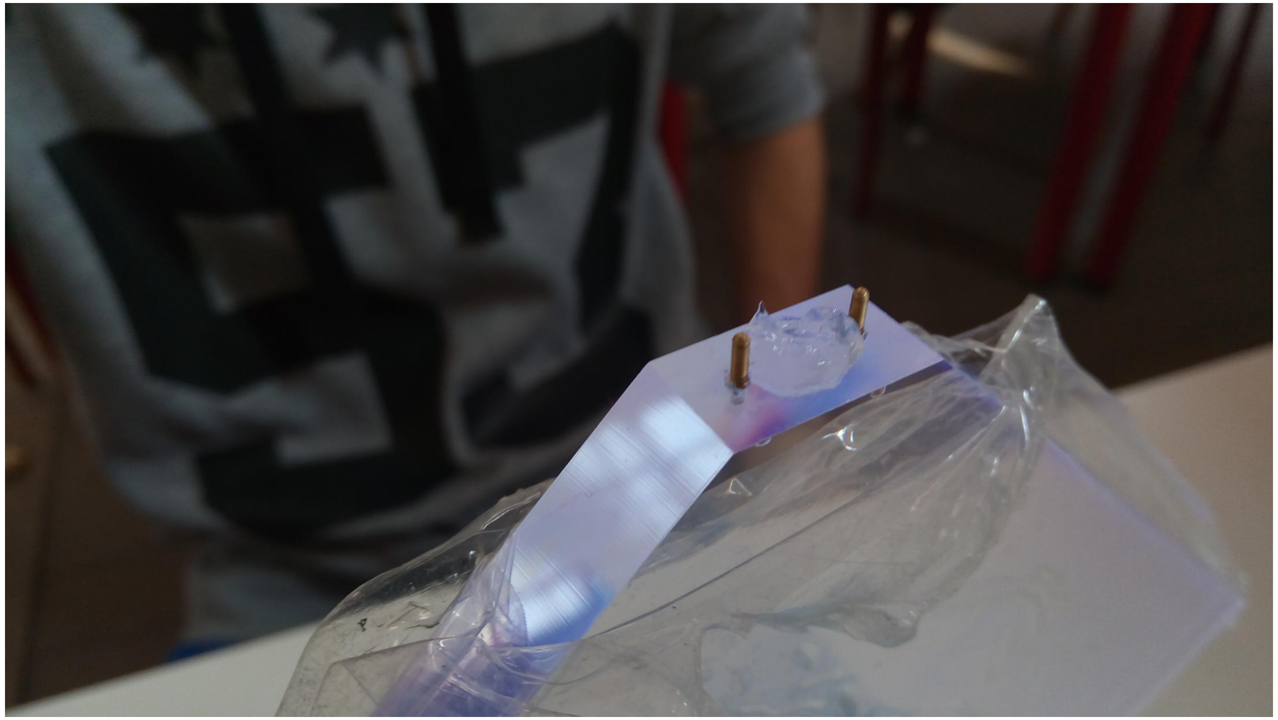
A scintillator emits **photons** when an **ionizing particle** deposits **energy** while passing through the material

Scintillation processes are based on the **excitation-dexcitation** of electrons on **hybrid orbitals**, typical in **organic molecules**



The CB construction

The **optical grease**



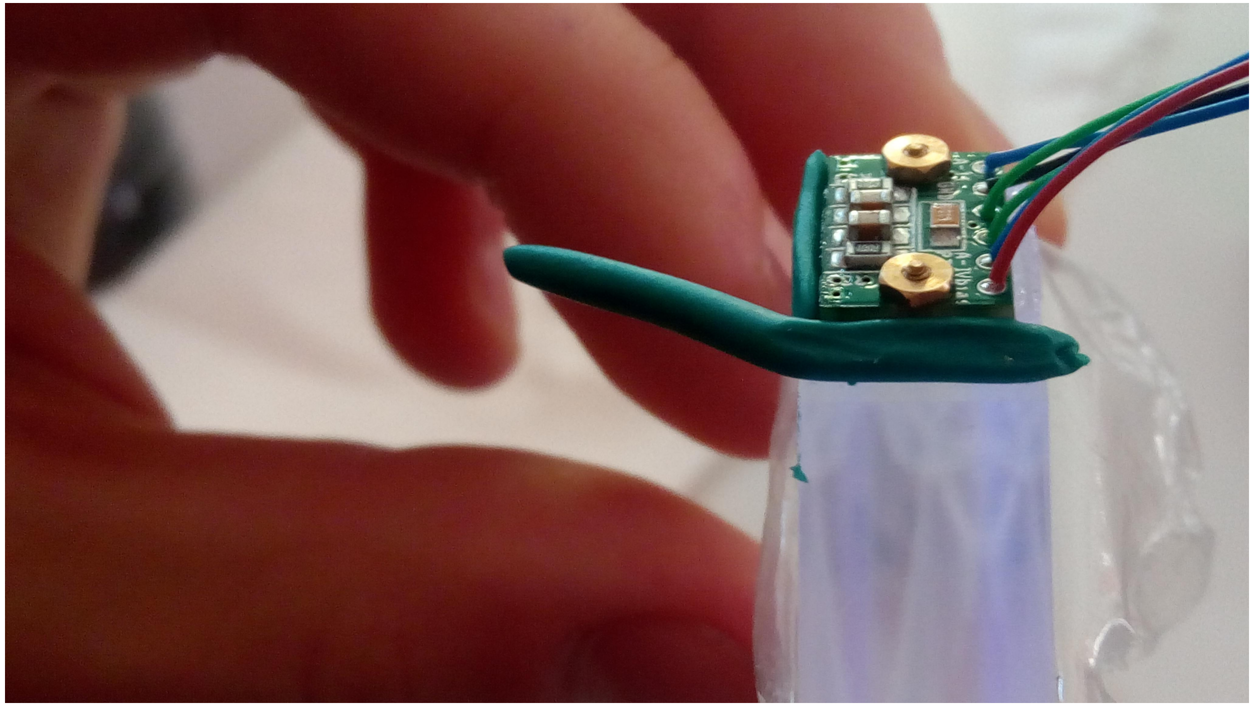
... for the **light coupling** between scintillator and SiPM

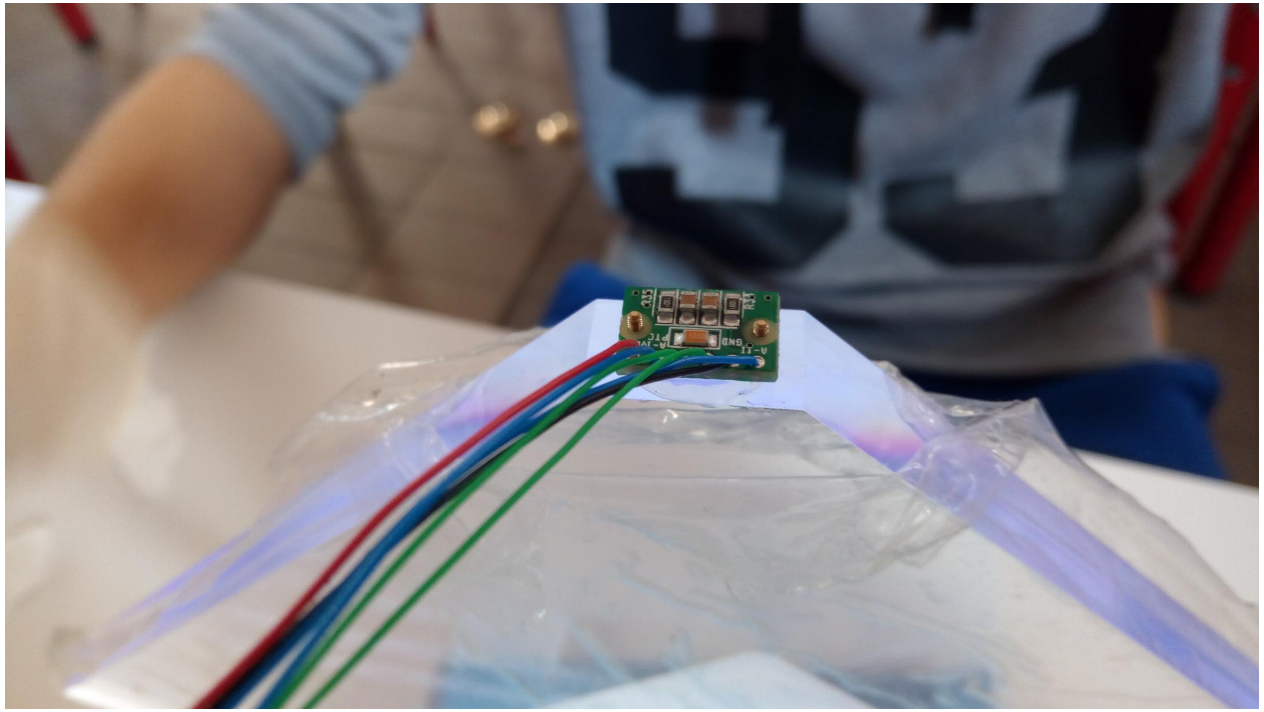
The CB construction

The **SiPM on the scintillator:**

2 SiPMs per scintillator tile are installed

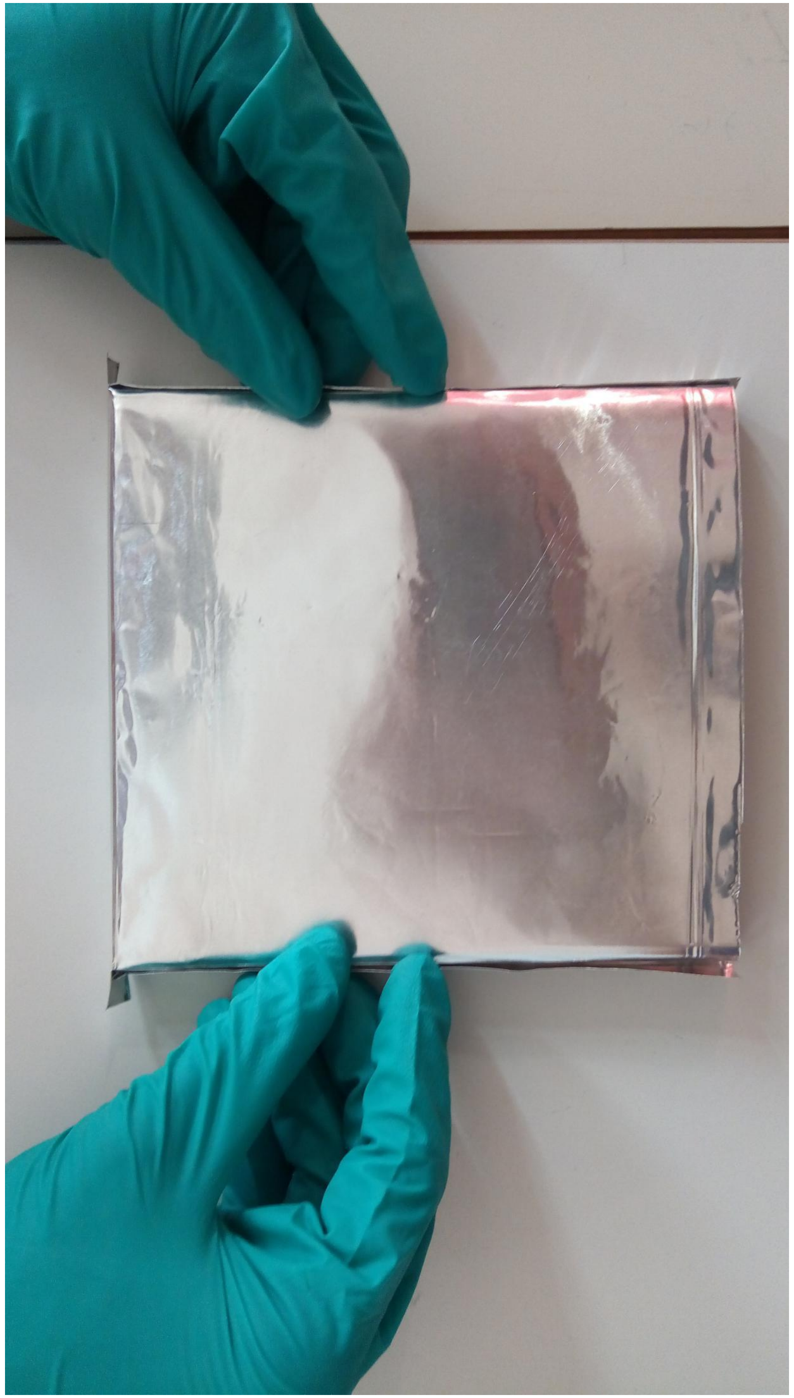
for reducing the **noise** (see later)



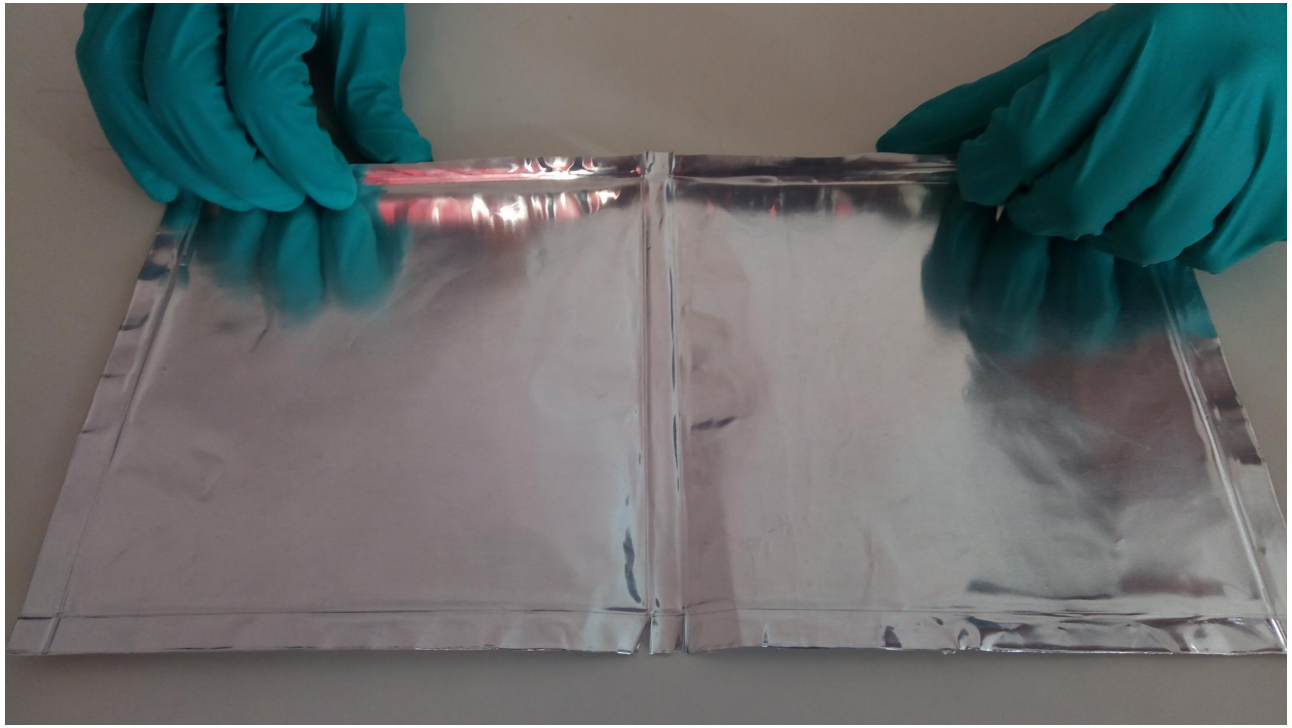


modeling clay for

keeping out the light

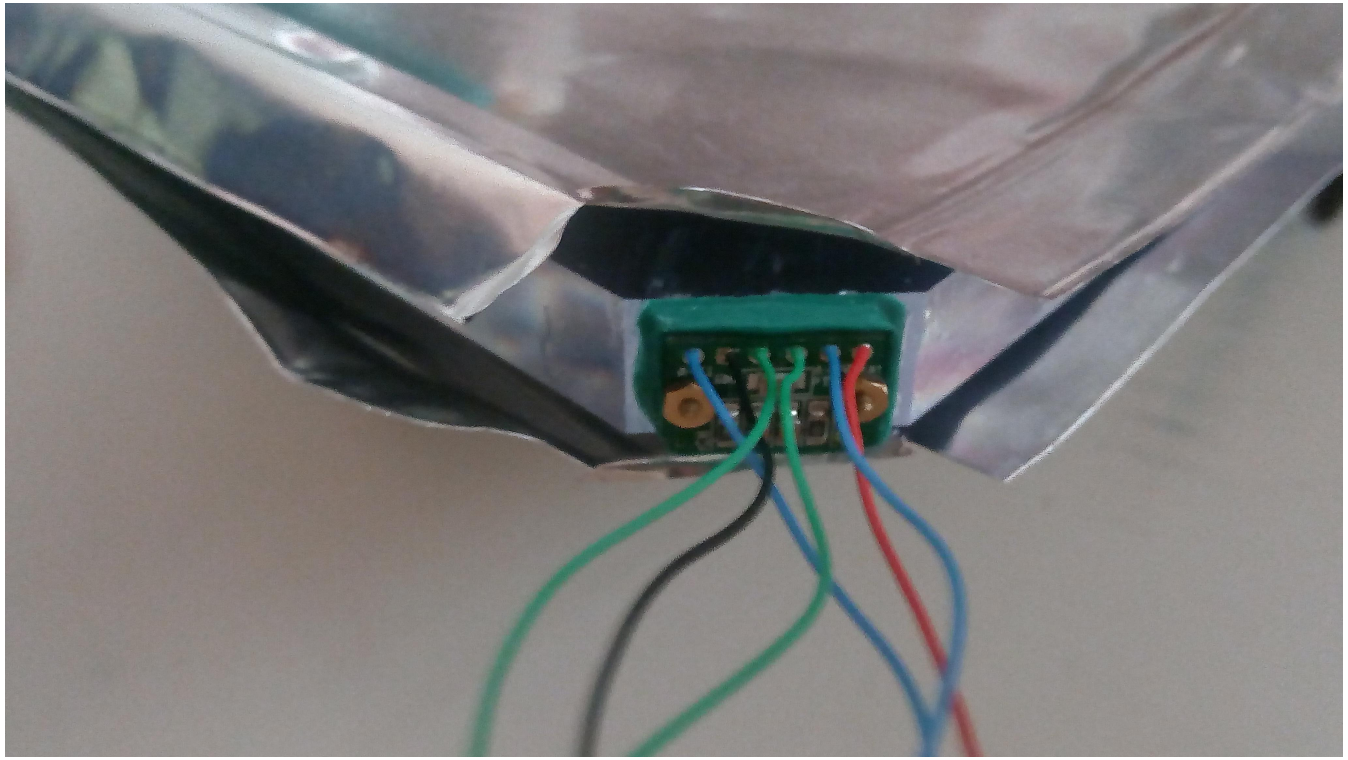


The CB construction



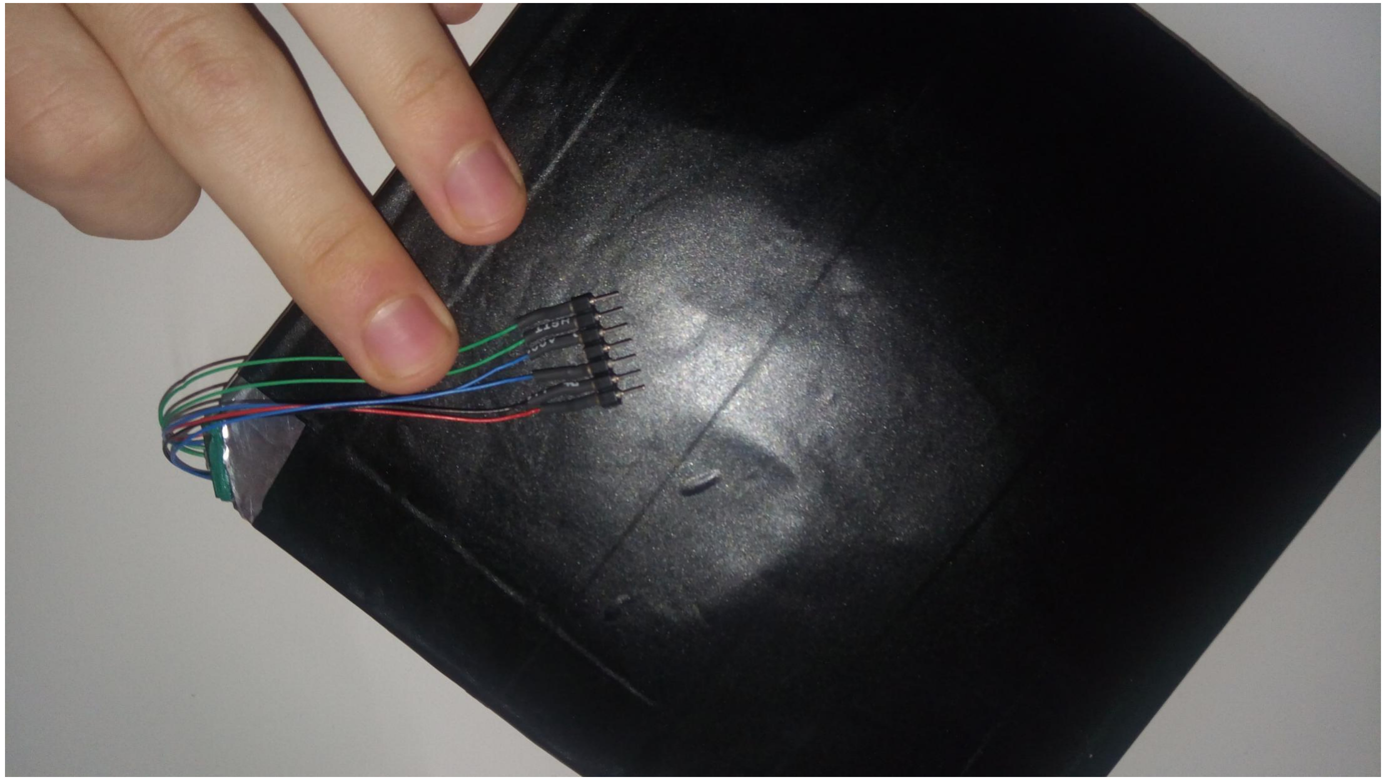
The **mylar reflective coating**

The CB construction

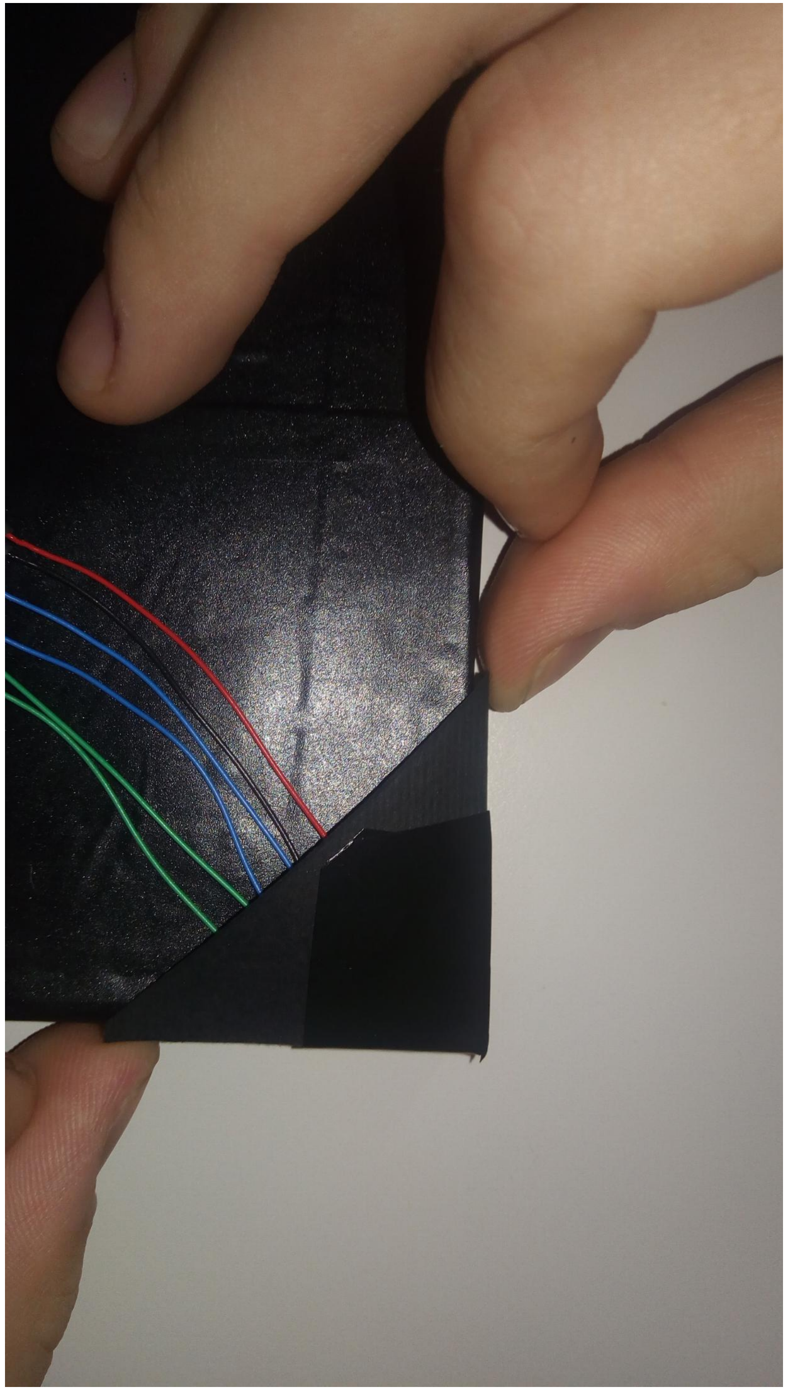


Closing the scintillator

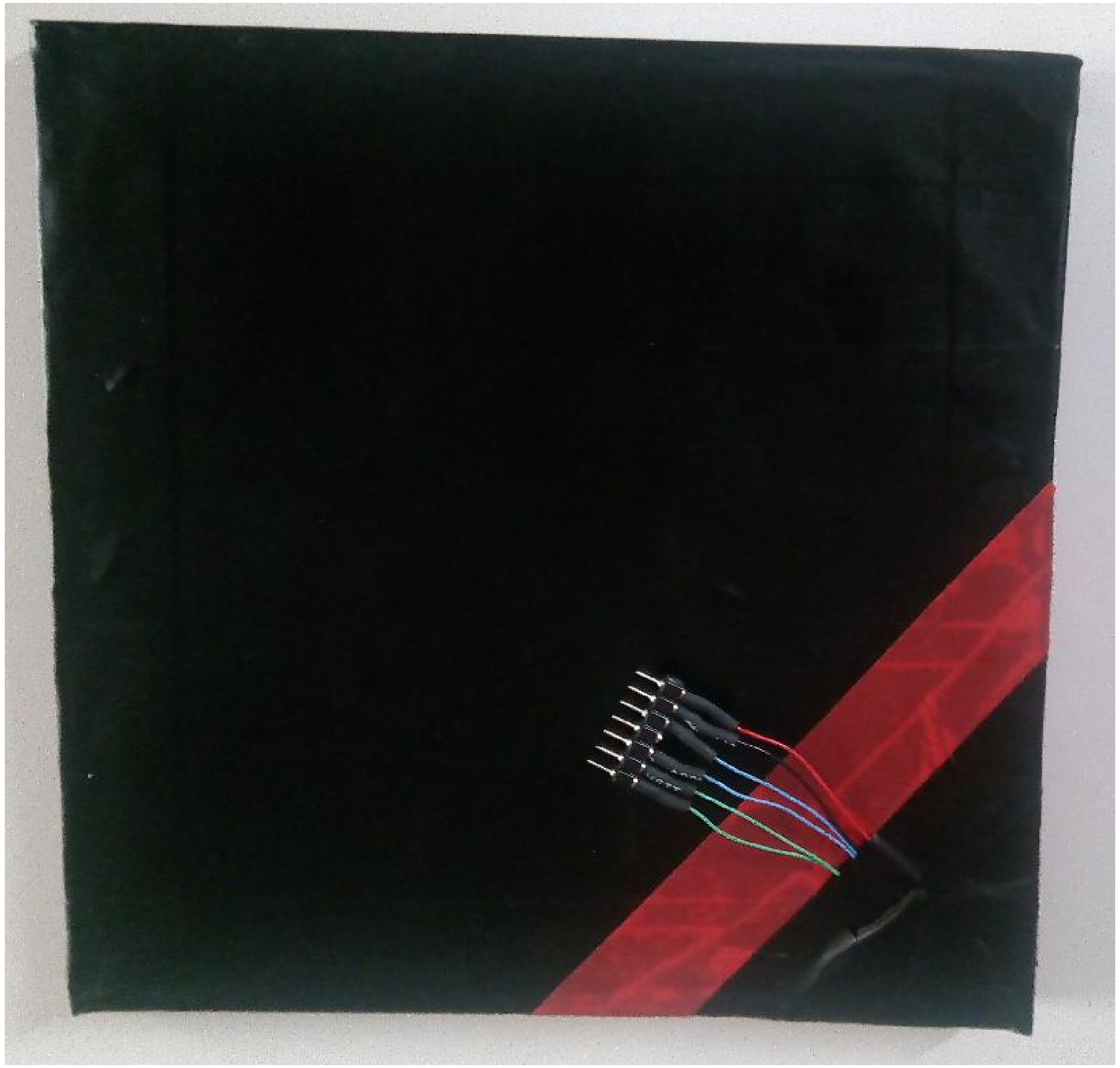
The CB construction



Closing the SiPM

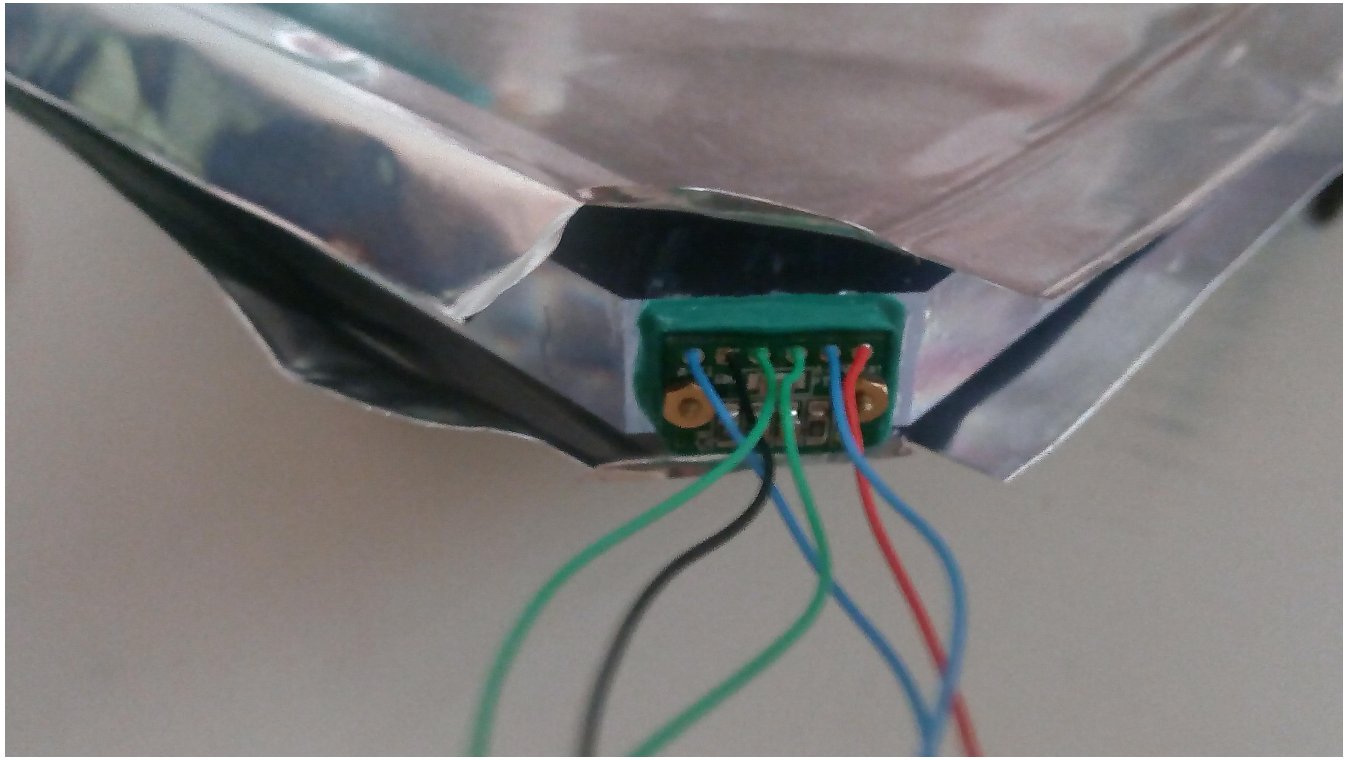


The CB construction

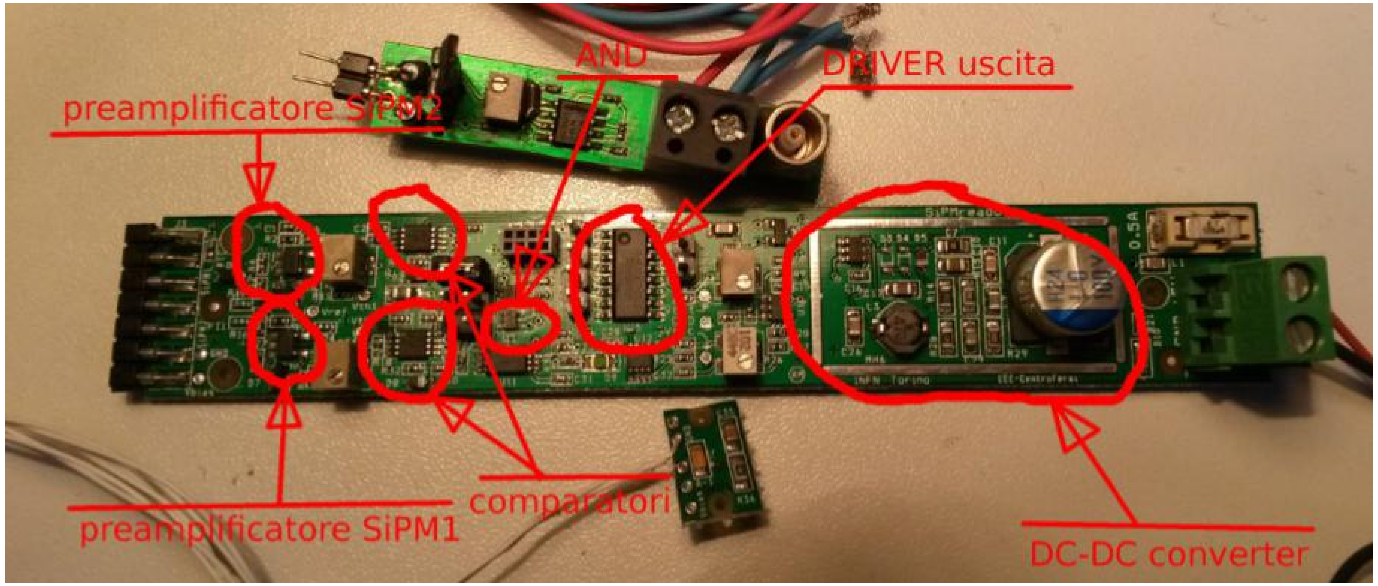


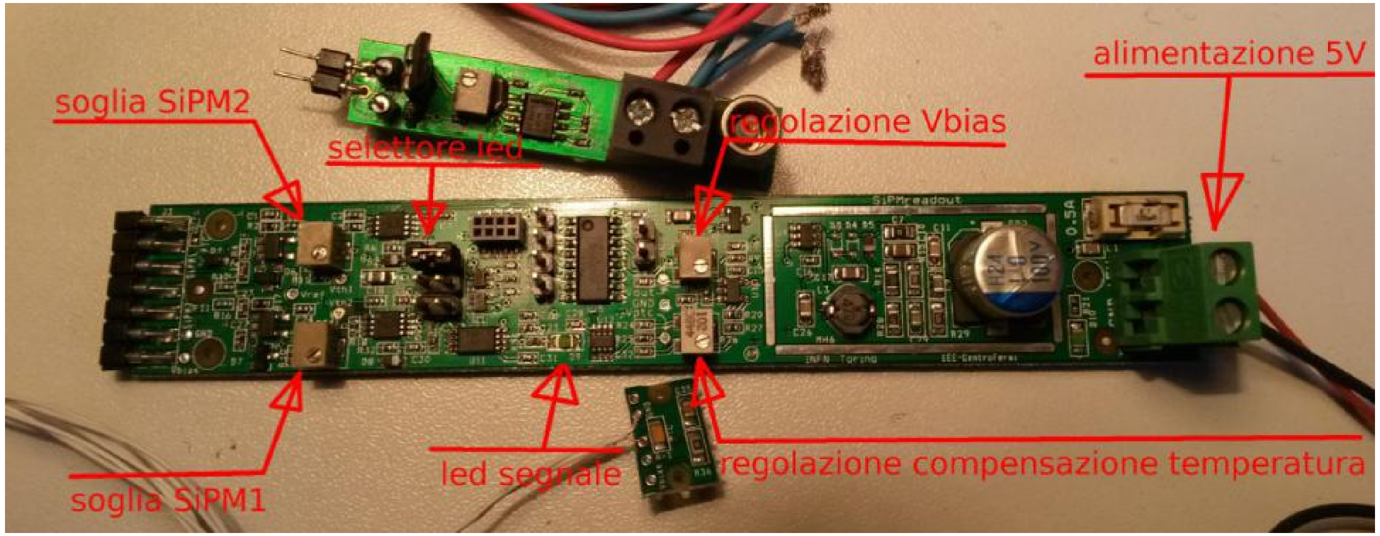
A scintillator ready for calibration !

The CB construction



The Front-End electronics

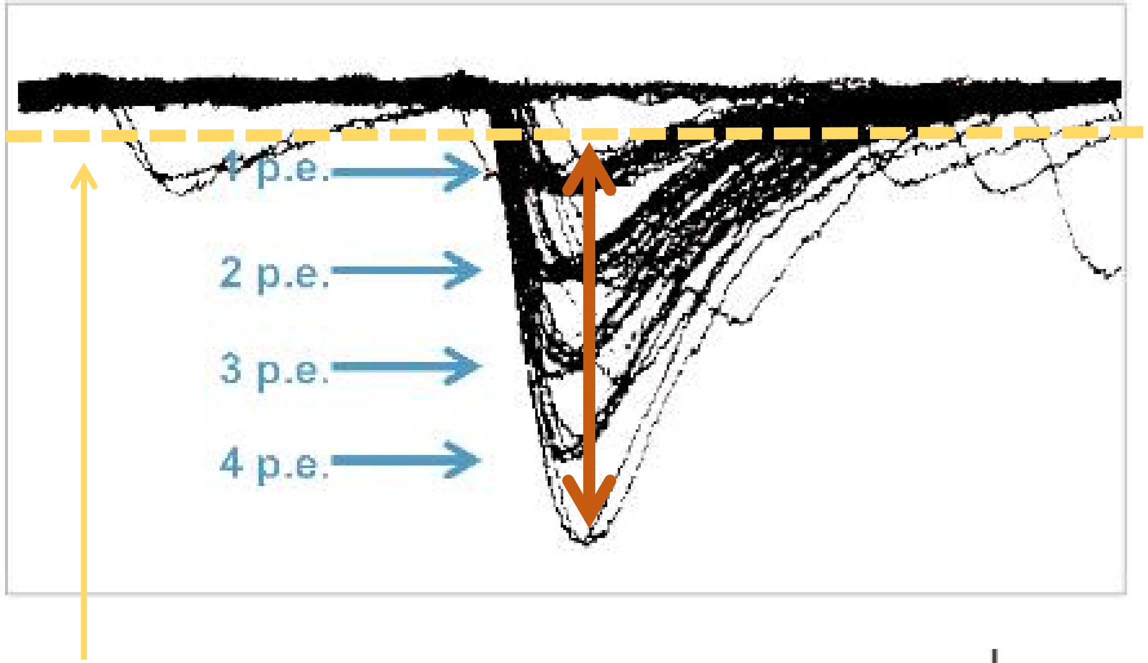




The 2 SiPM signals are **amplified** and **compared** with a reference **threshold**.

A **digital LVDS signal** is provided by the FE electronics **per each analog signal** from the SiPM (single SiPM or coincidence can be selected).

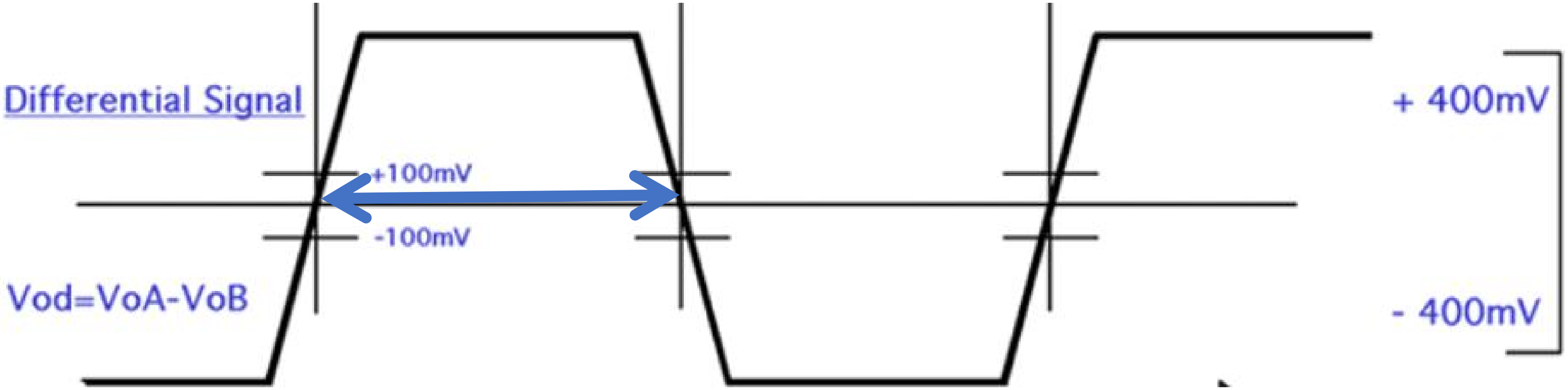
The Front-End electronics



threshol
d

The **higher the analog** signal

the **wider the digital** signal



The FE first calibration

The scintillator + FE
yields **false signals**
(not related with particles)
it's called **NOISE**.

The **threshold are adjusted** in order to have a **counting rate** per SiPM **higher than the expected** particle rate.

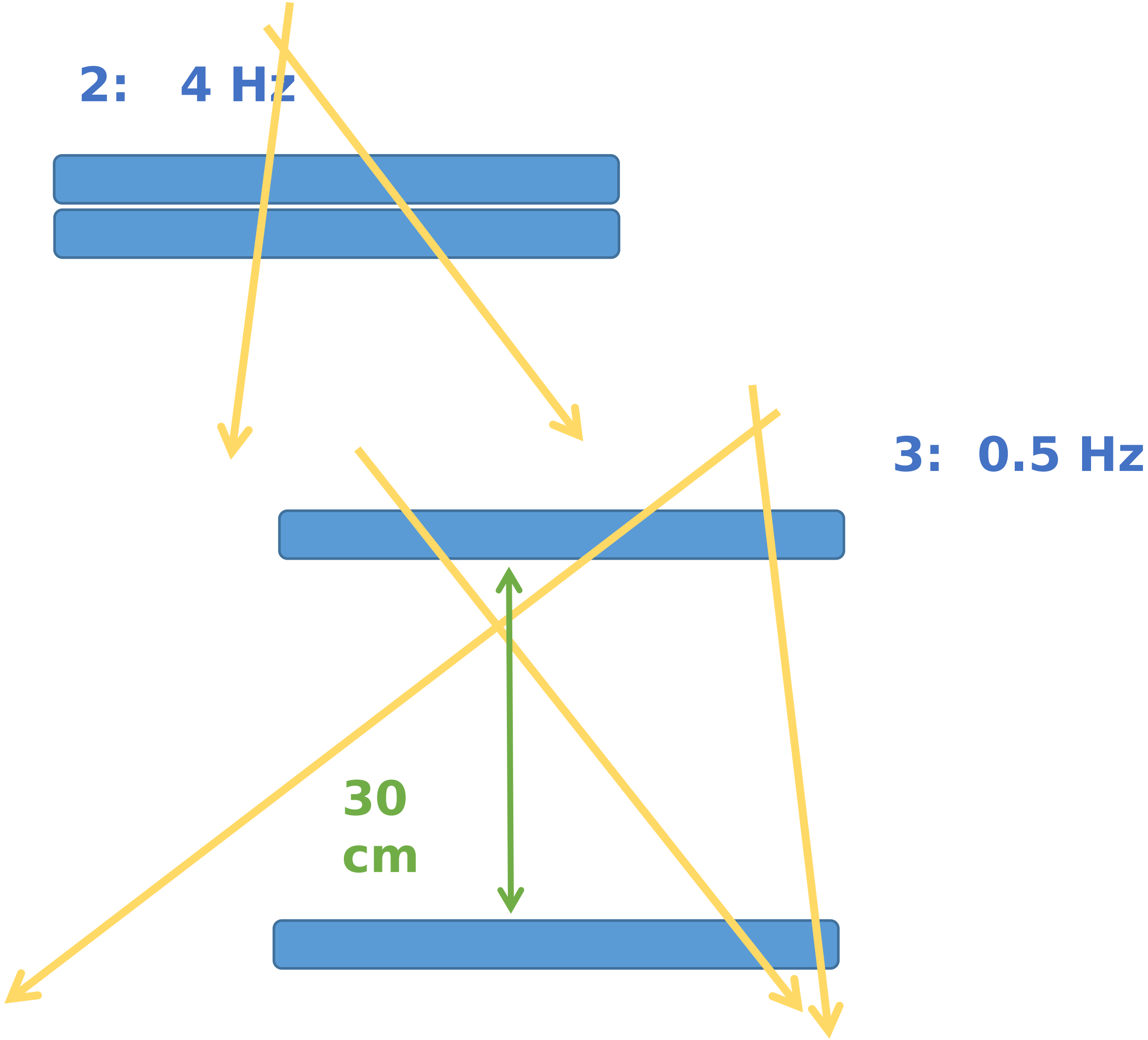
$$\nu_{exp} \sim 170\ \mu/(s\ m^2) \cdot (0.15\ m)^2 \sim 3.8\ \mu/s$$

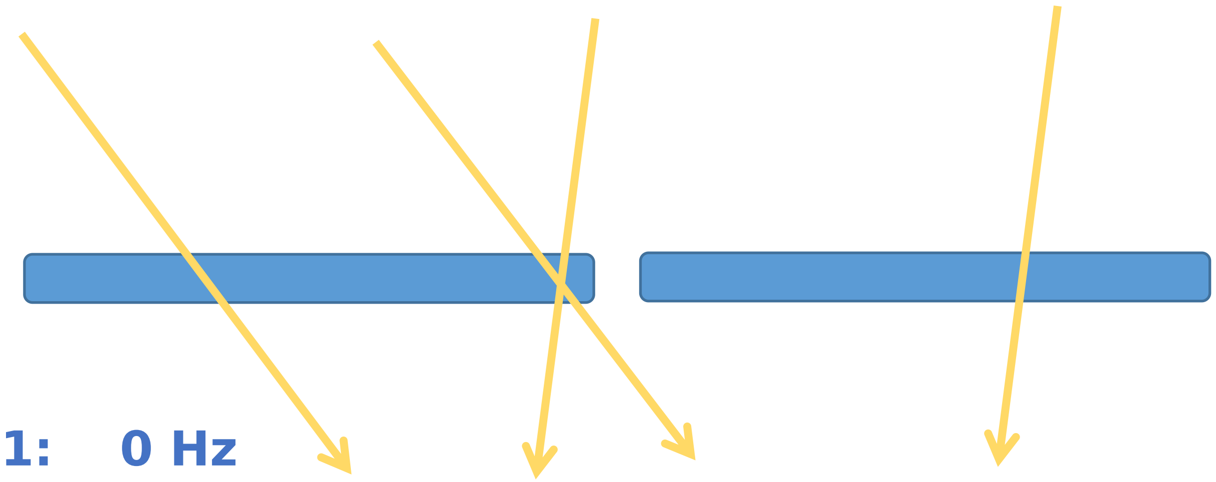
The Coincidence calibration

The 2 scintillators + the coincidence module

have been tested in **3 different configurations**

for the final approval





The CB - how to operate

Powering the CB:

there are **2 power connectors**:

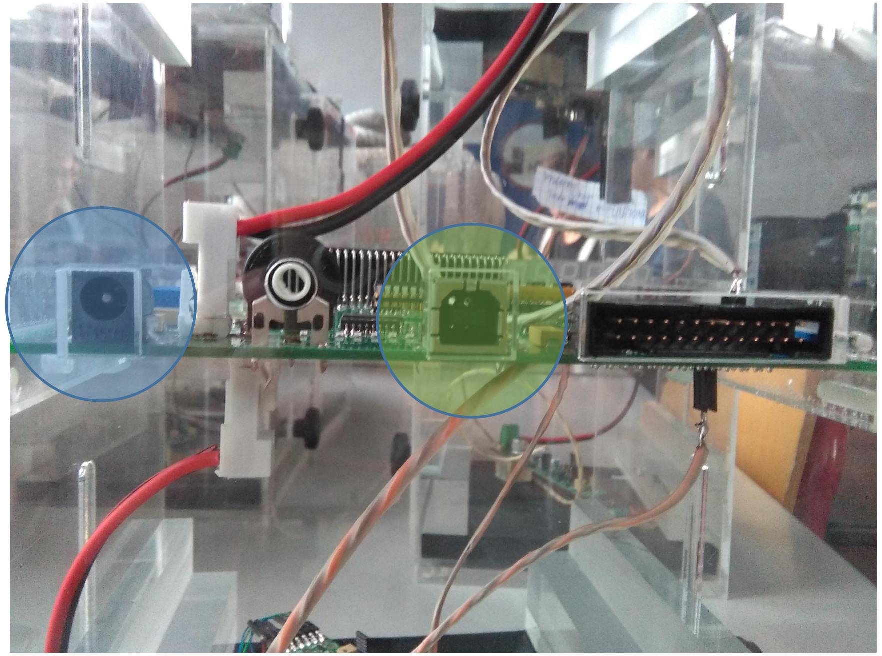
1. jack 5.5 mm

2. USB

both powered at 5 V

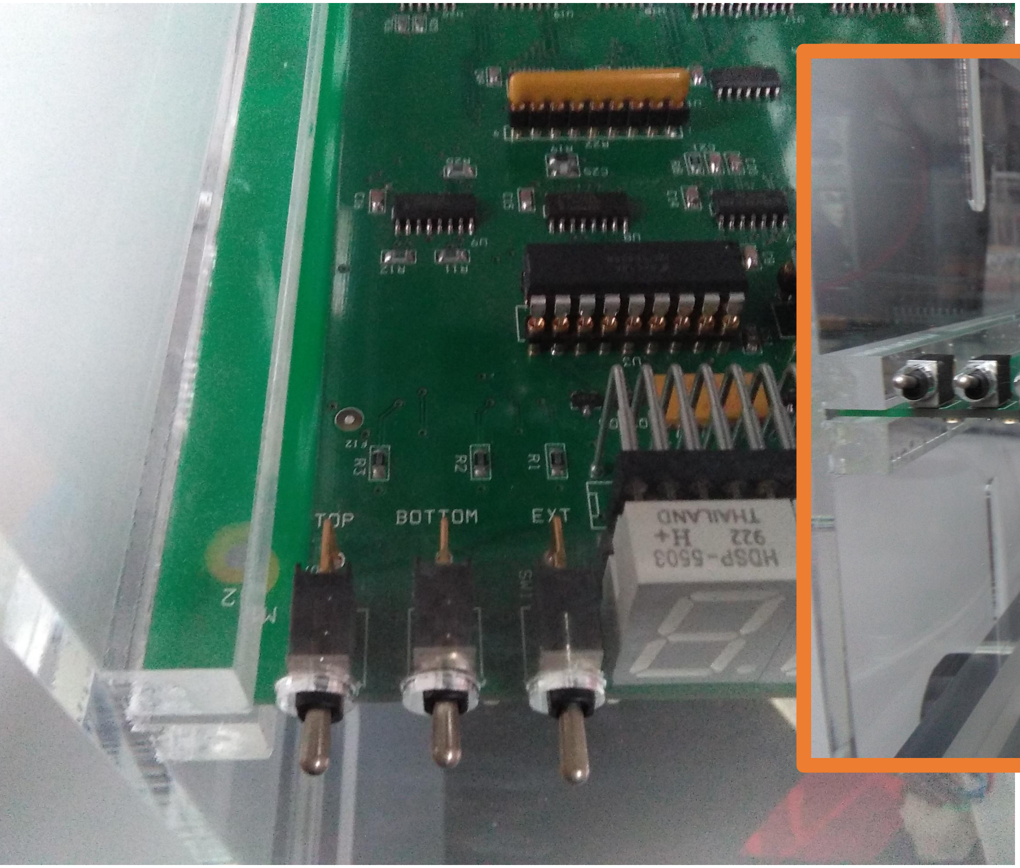
by a power bank

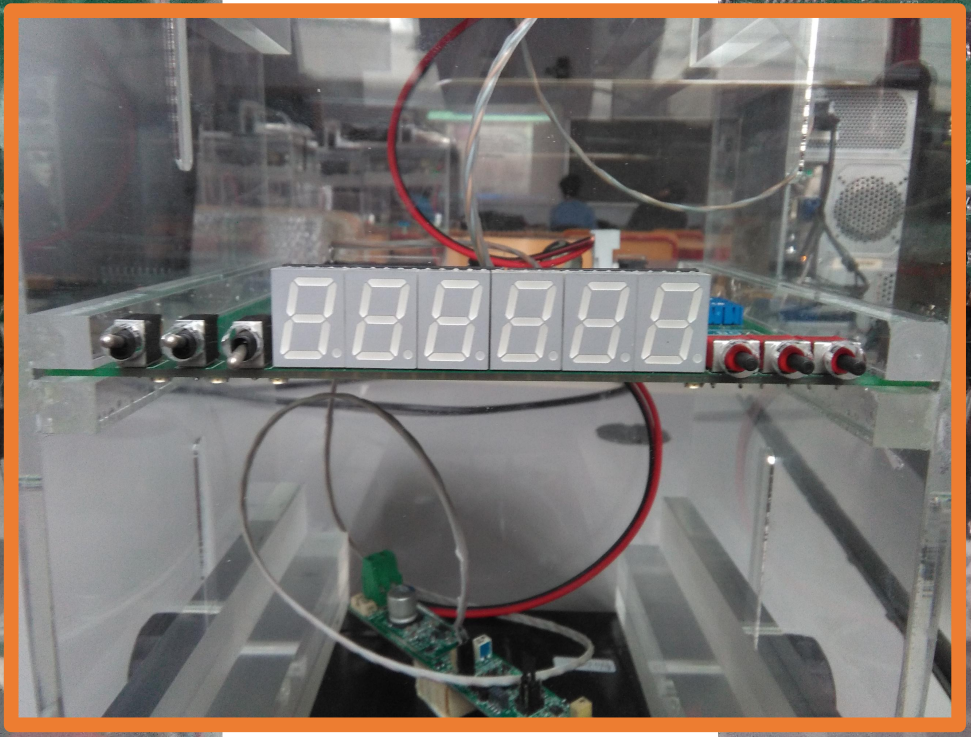
(but you can also use your laptop or the DCDC provided with the CB)

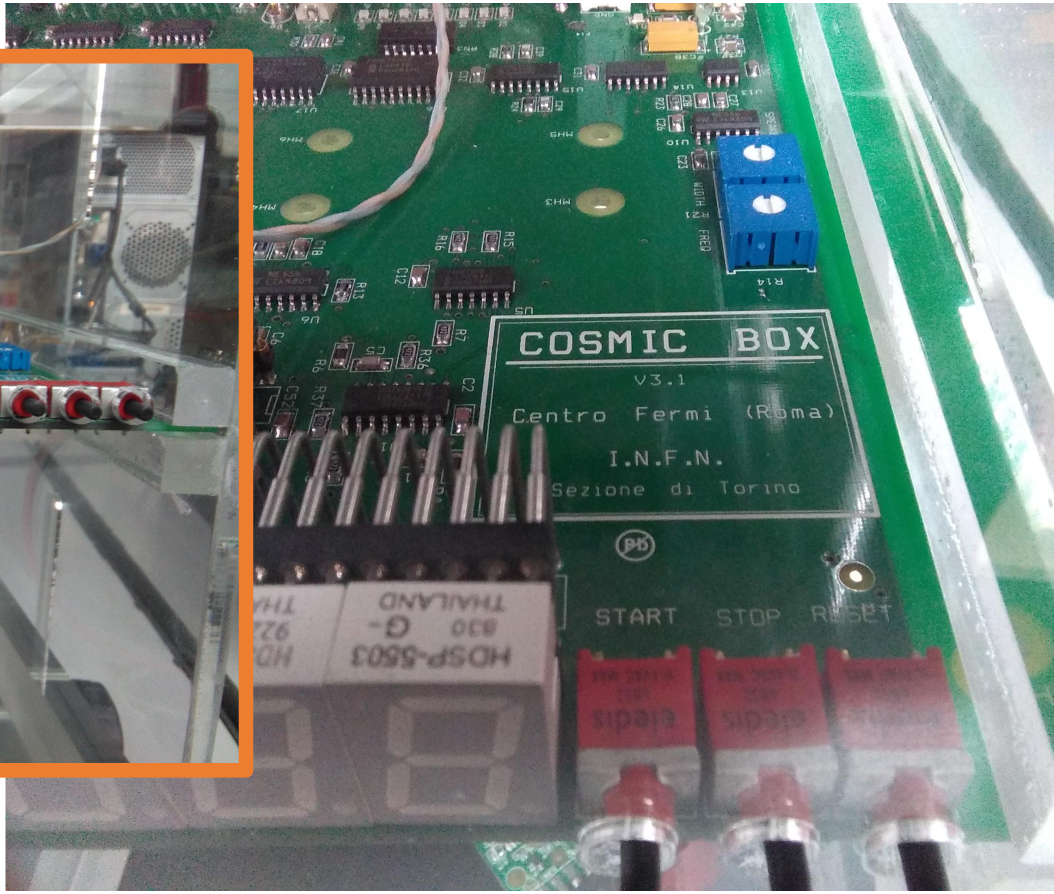


The CB - how to operate

Front buttons and display







Selectors for COINCIDENCE logic (UP means ON)

Start/Stop/Reset the counter

The CB - how to operate

Each CB has

a complete set of signals

available on the rear dual-in line connector:

TOP out signal

BOT out signal

EXT out signal

COINCIDENCE signal

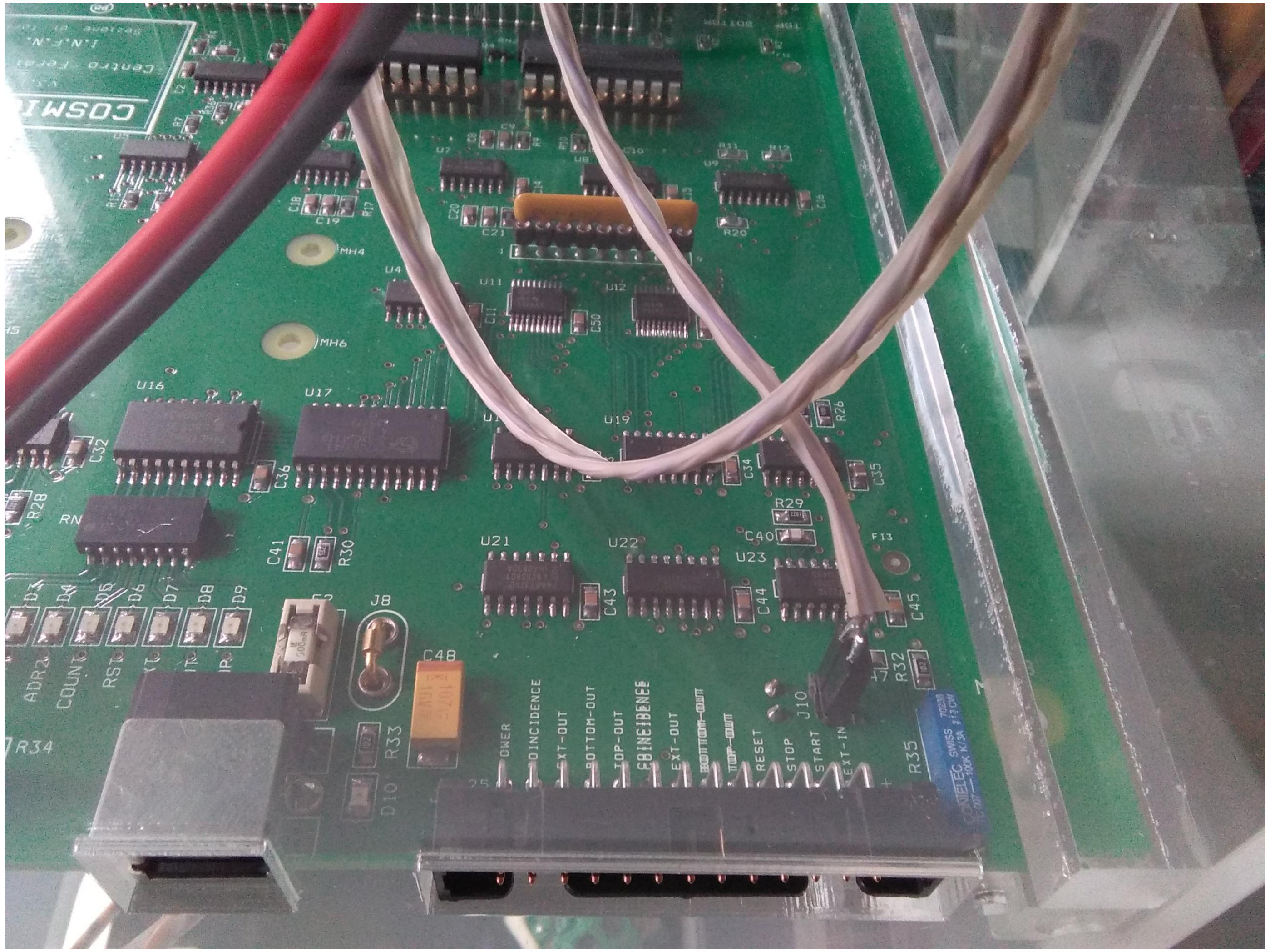
EXT in signal

START

STOP

RESET

thus can be operated by a dedicated PC



The CB - how to operate

The sunlight

The **e.m. waves**

are **NOISE** sources

Before starting the measurement use the **aluminum cover** to protect the CB from external noise

The CB - how to operate

How to **perform a measurement**:

1. find a **flat surface** where laying your CB

2. check the **acceptance** of the CB is **not shadowed** by any side wall

3. **power it**

4. **protect it** with the cover

5. **start** the measurement

take note of:

a. **counts**

b. **start and stop time** (with 5 seconds max uncertainty)

c. pressure (at least 3 measurements during the count)

d. **altitude** (try several measurements with different mobiles using GPS)

Always **take note of all the values**!