Particle detectors

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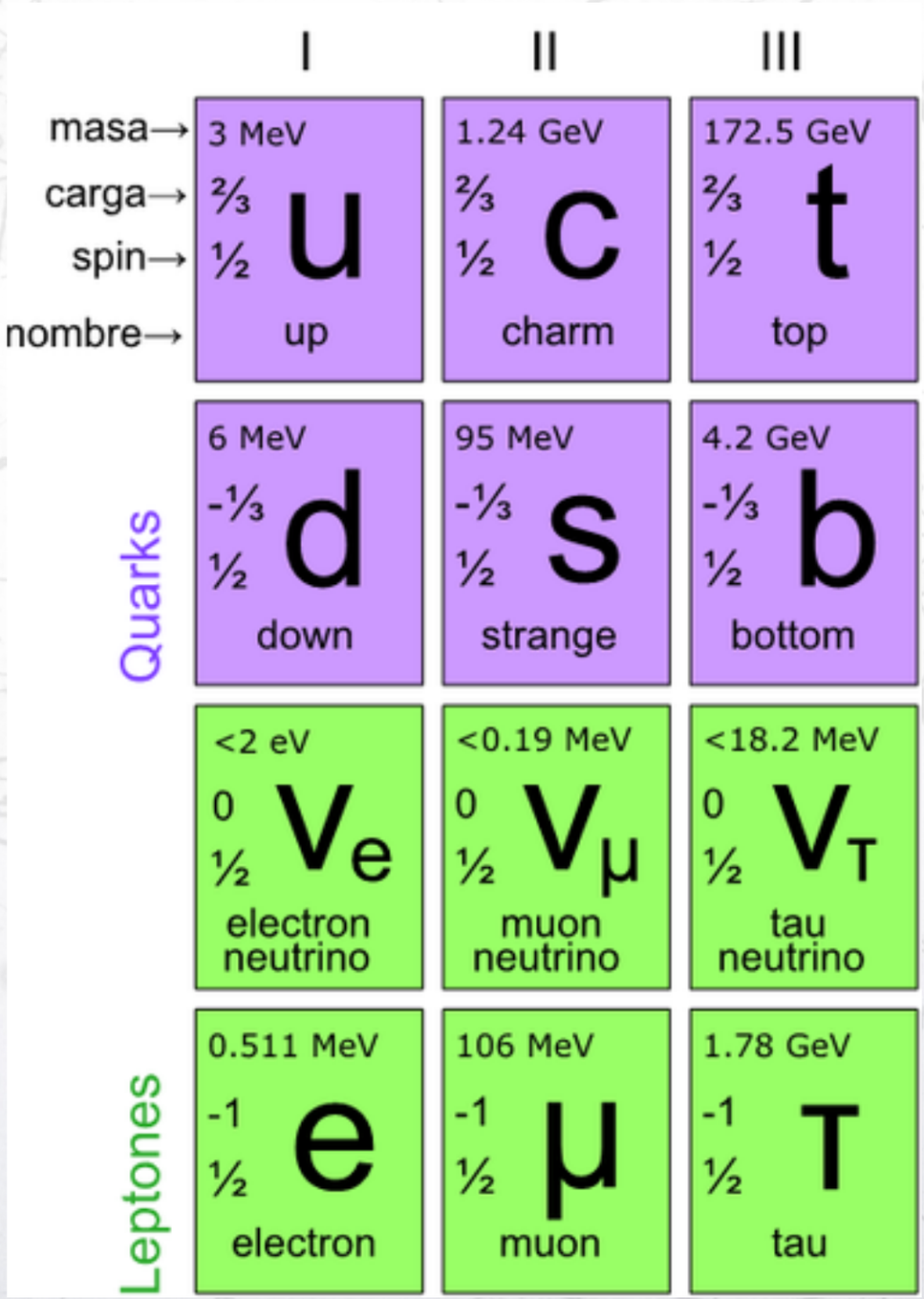
Particles

- Elementary particles are grouped in 3 families.

- Each family is a copy of the previous one with more mass!.

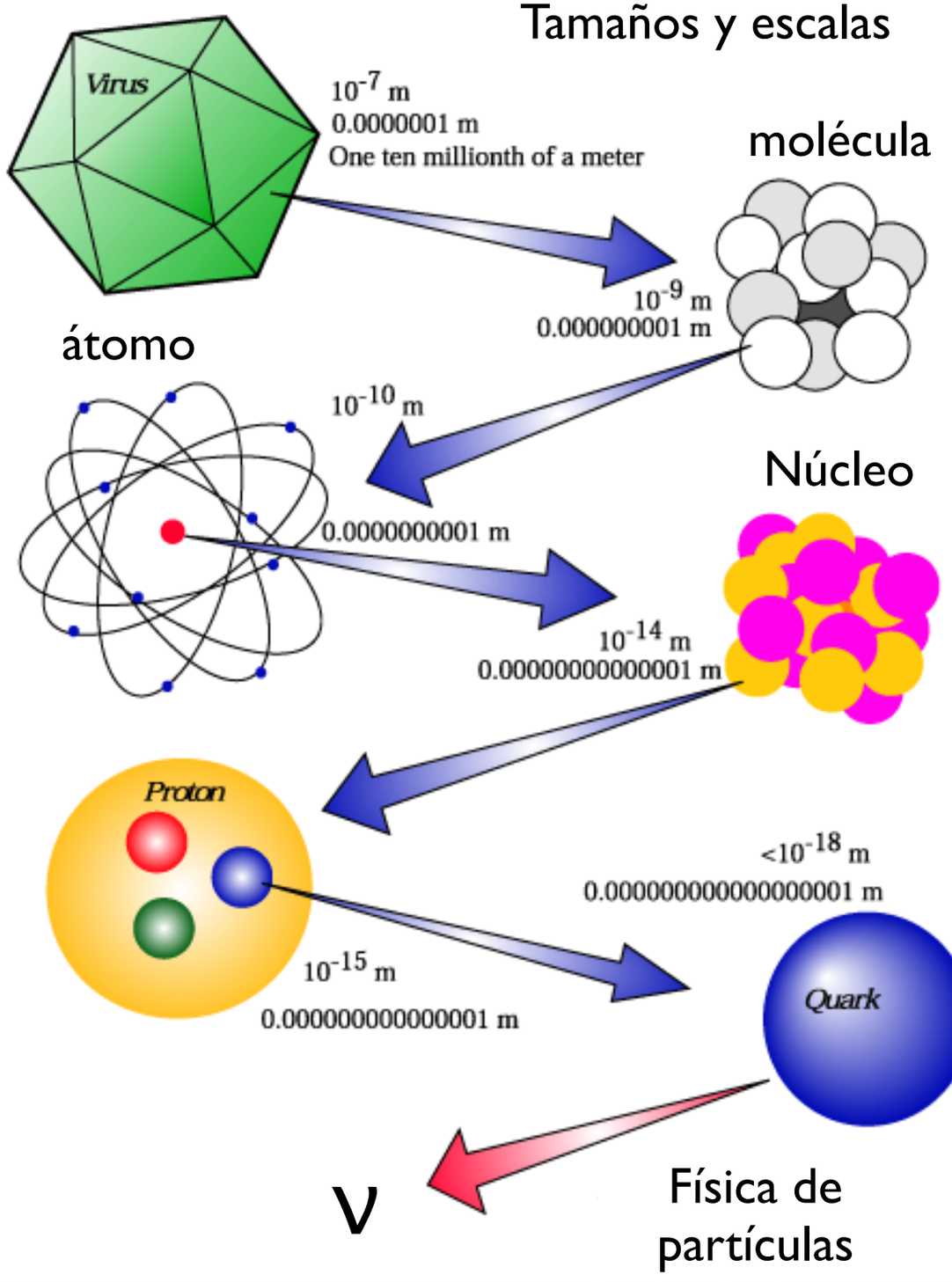
- Lowest mass family constitutes ordinary matter (protons, neutrons and electrons).



Matter

Energía

Tamaños y escalas

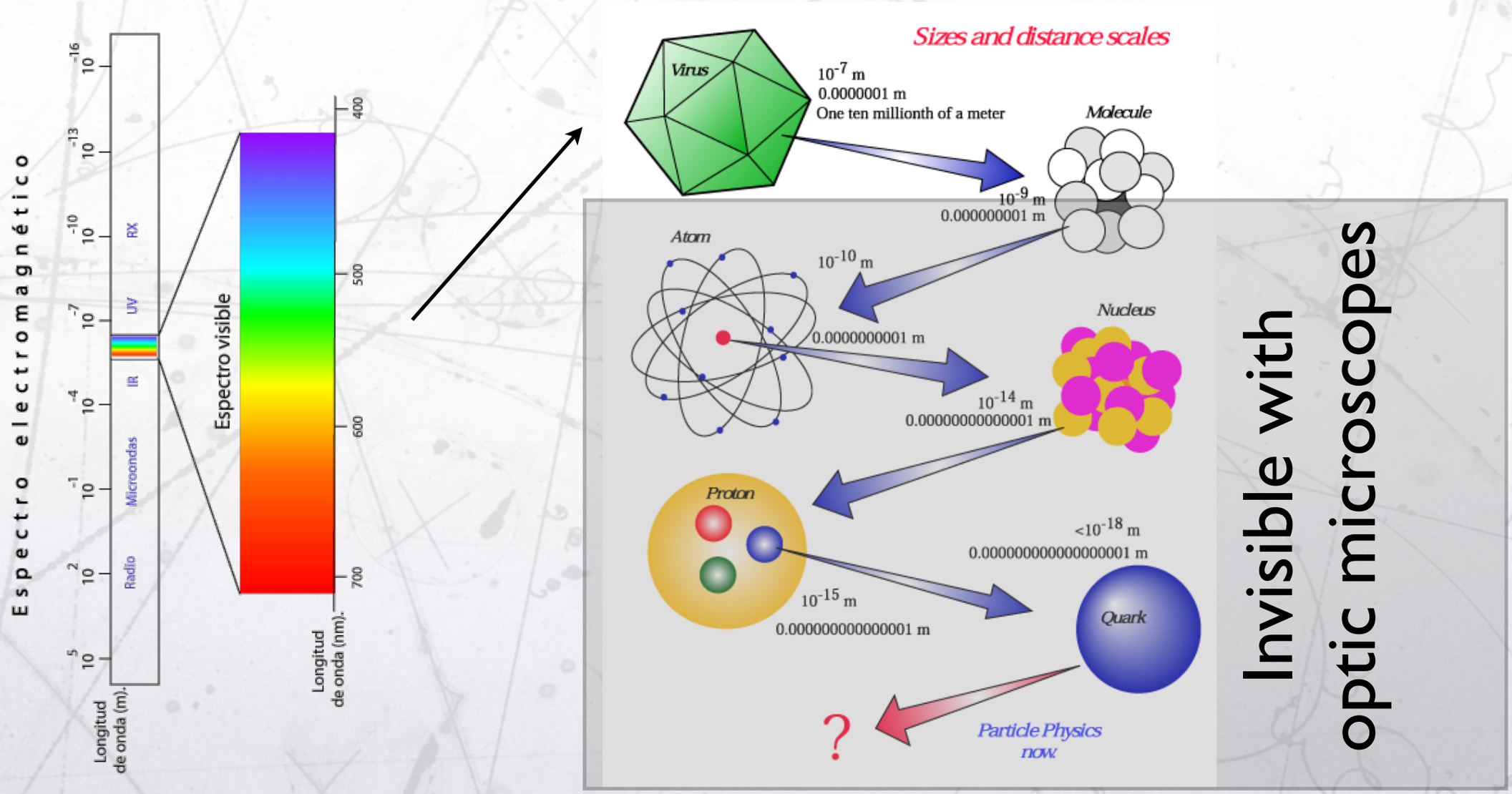


Física de partículas

tamaño

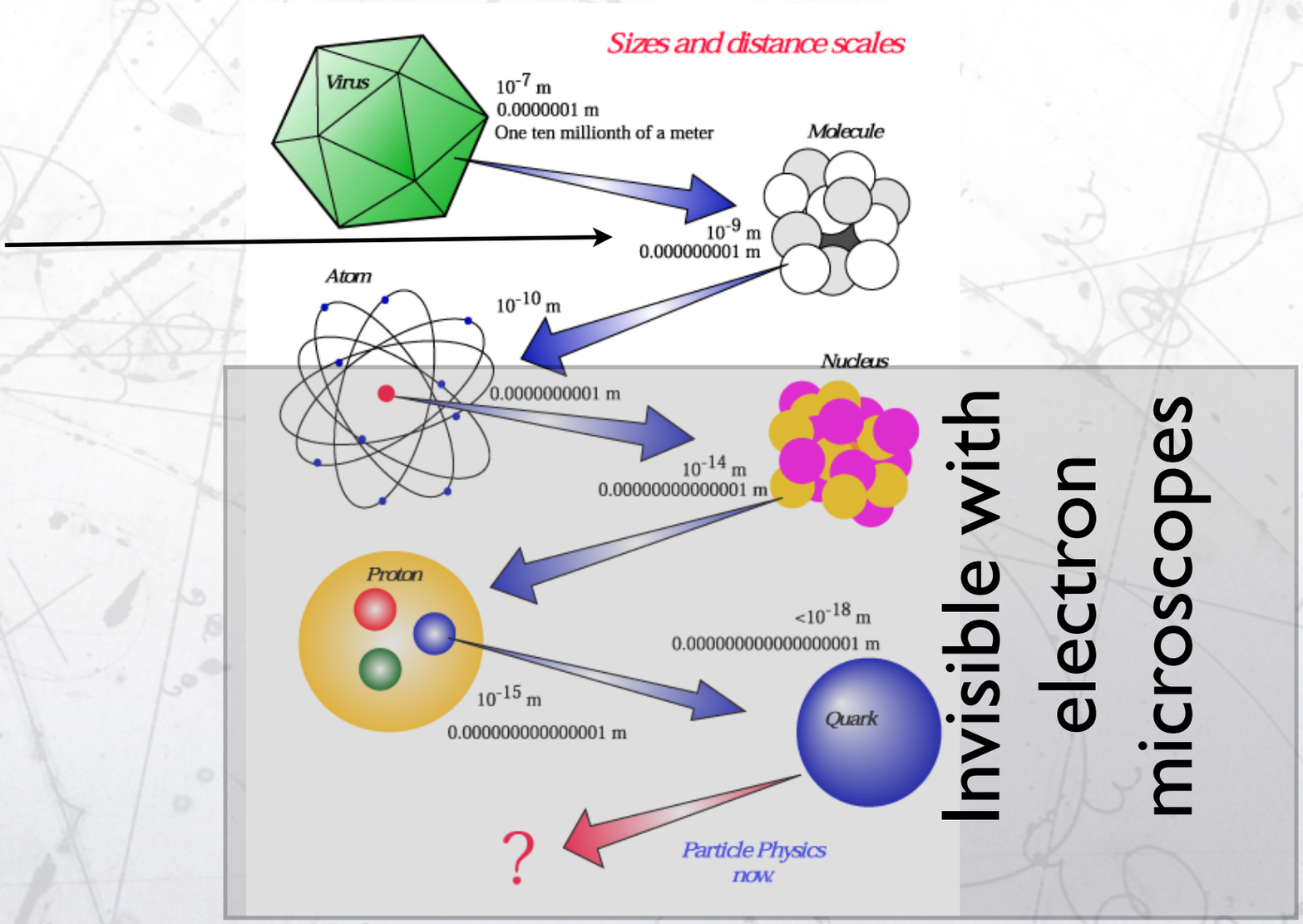
Microscopes ?

- Microscopes allow to "see" objects with the size of the order (or larger) than the light wavelength.



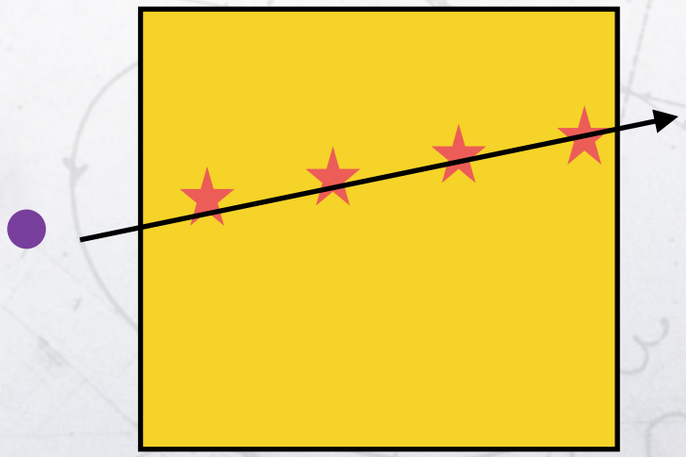
Microscopes ?

- Electron microscopes could resolve objects between 1 and 20 nanometers. (1nm = 0.000000001 m)



How to detect smaller particles?

- The experimental method is intrinsically different from a microscope:
  - Fundamental particles are normally moving.
  - During their movement they traverse matter.
  - The matter properties are altered by the particle.
  - We detect this change.



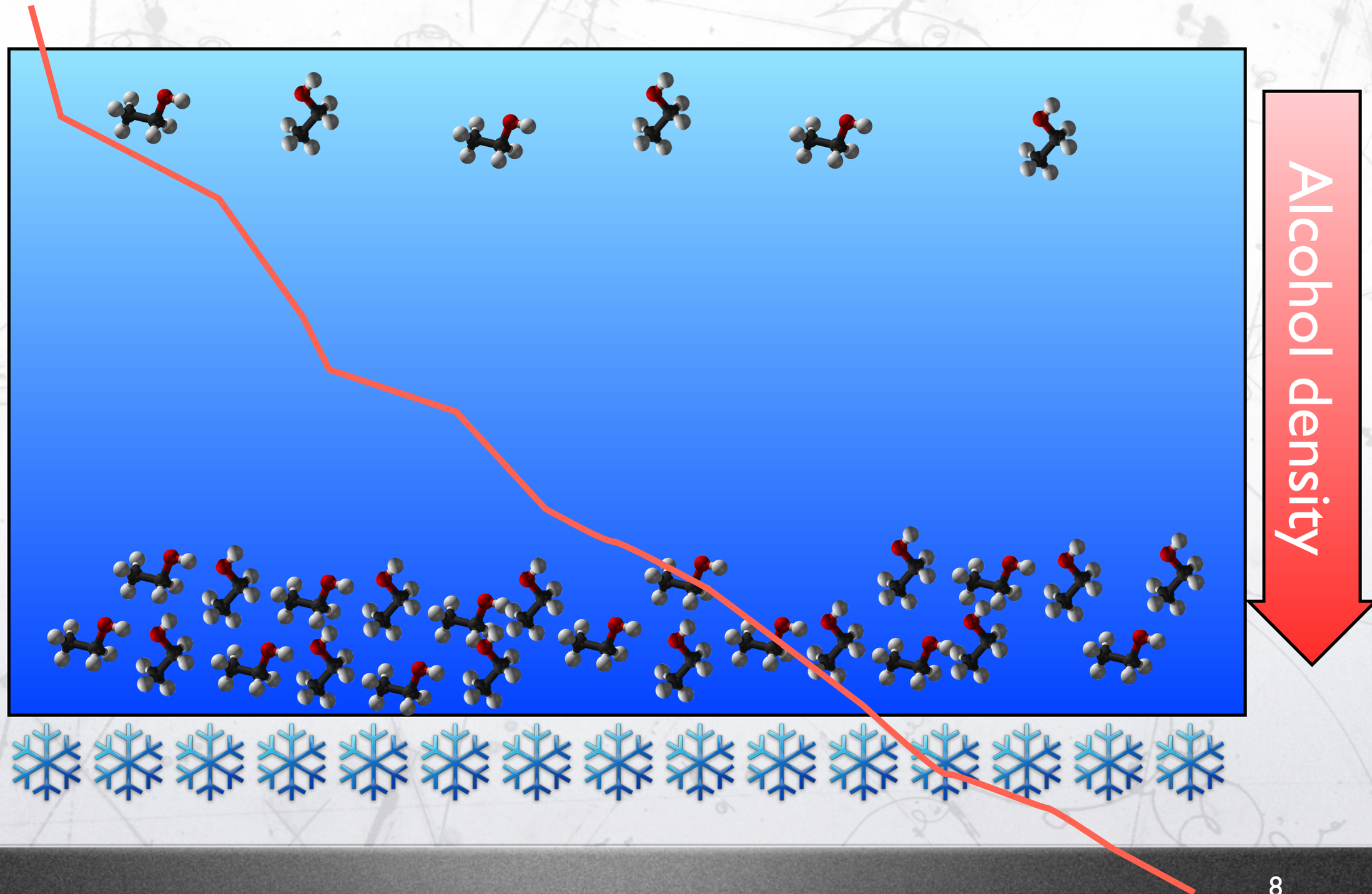
What will happen if the particle is at rest ?

Basic example

Cloud chamber

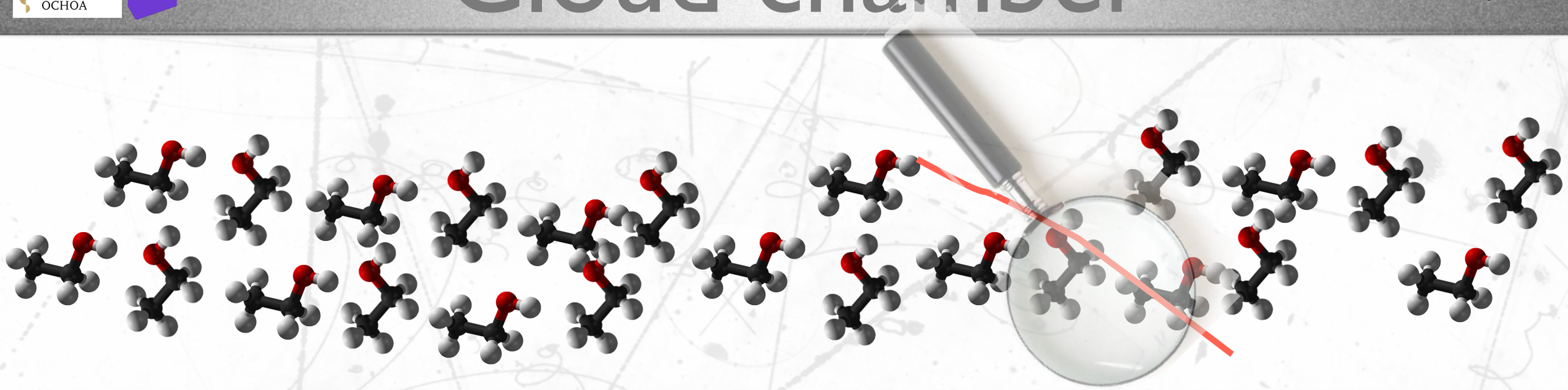
Cloud Chamber

Alcohol vapour

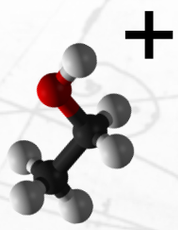


Alcohol almost in liquid state.

Cloud chamber



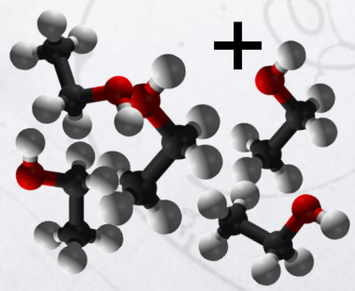
The particle ionize the alcohol molecules (takes out one electron)



electron

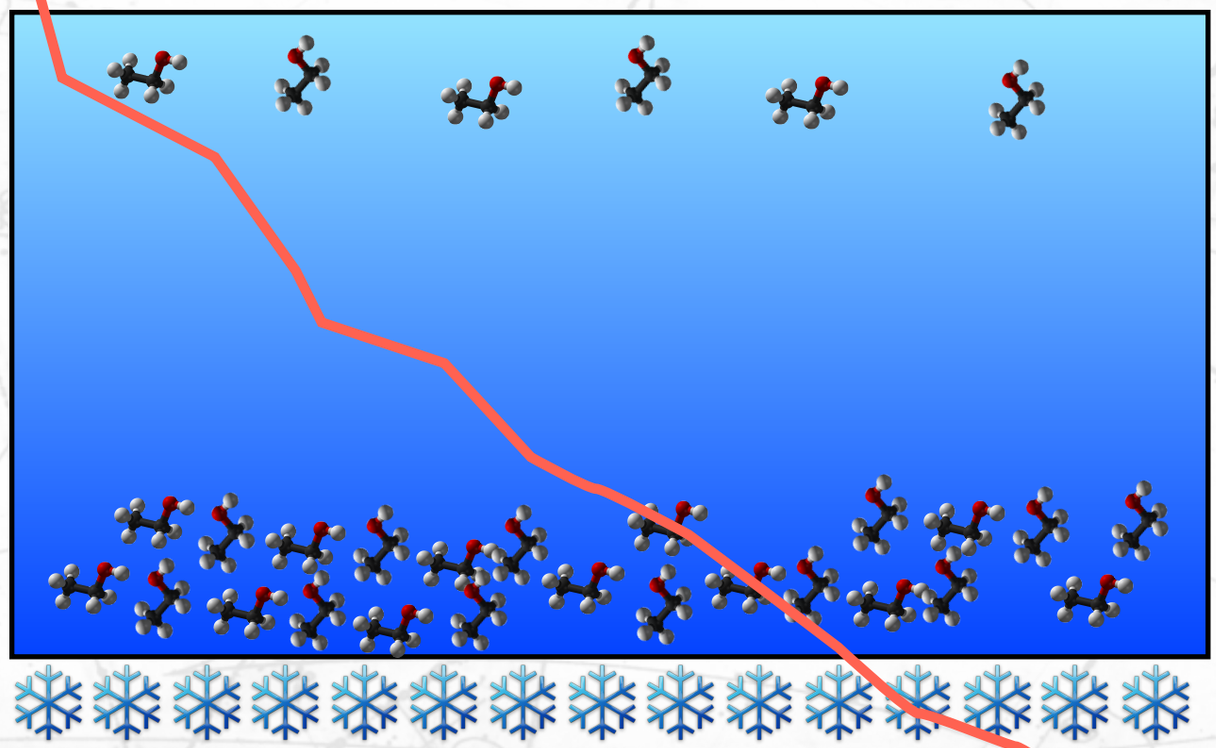
Ion

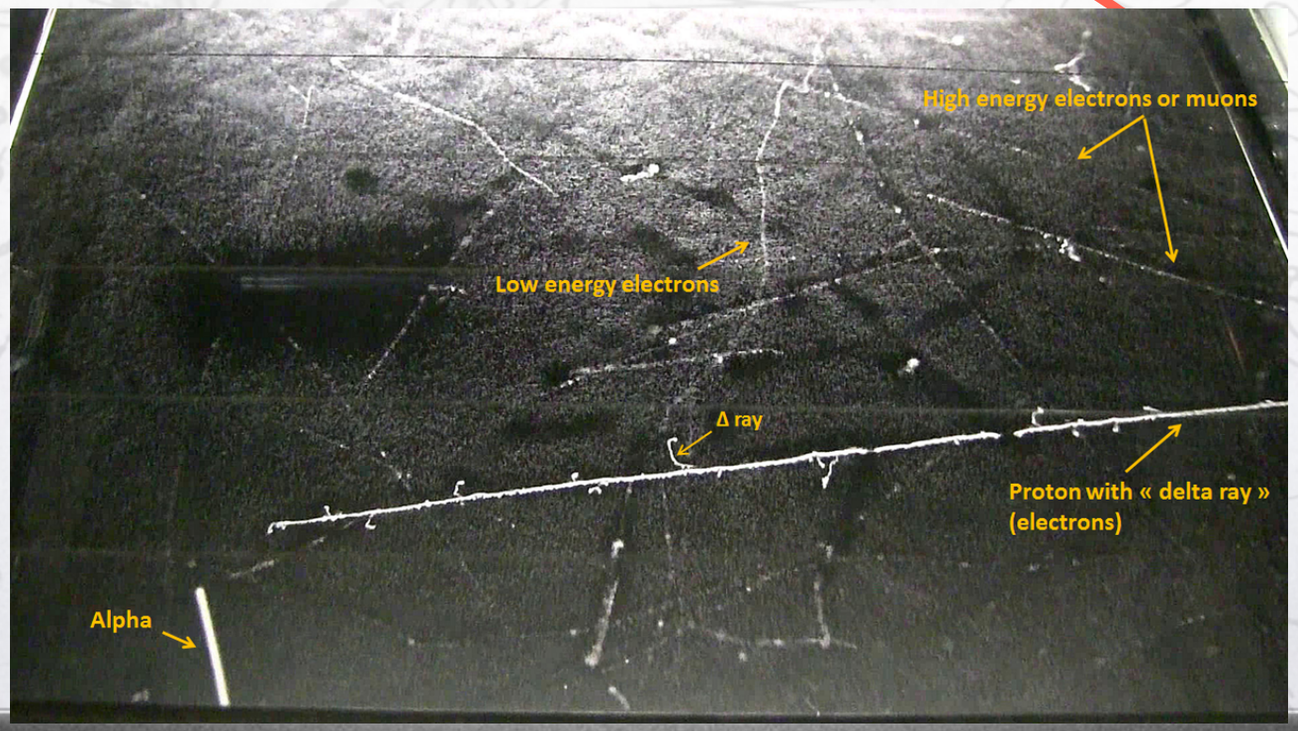
Around the ion other alcohol modules gather and make drops.



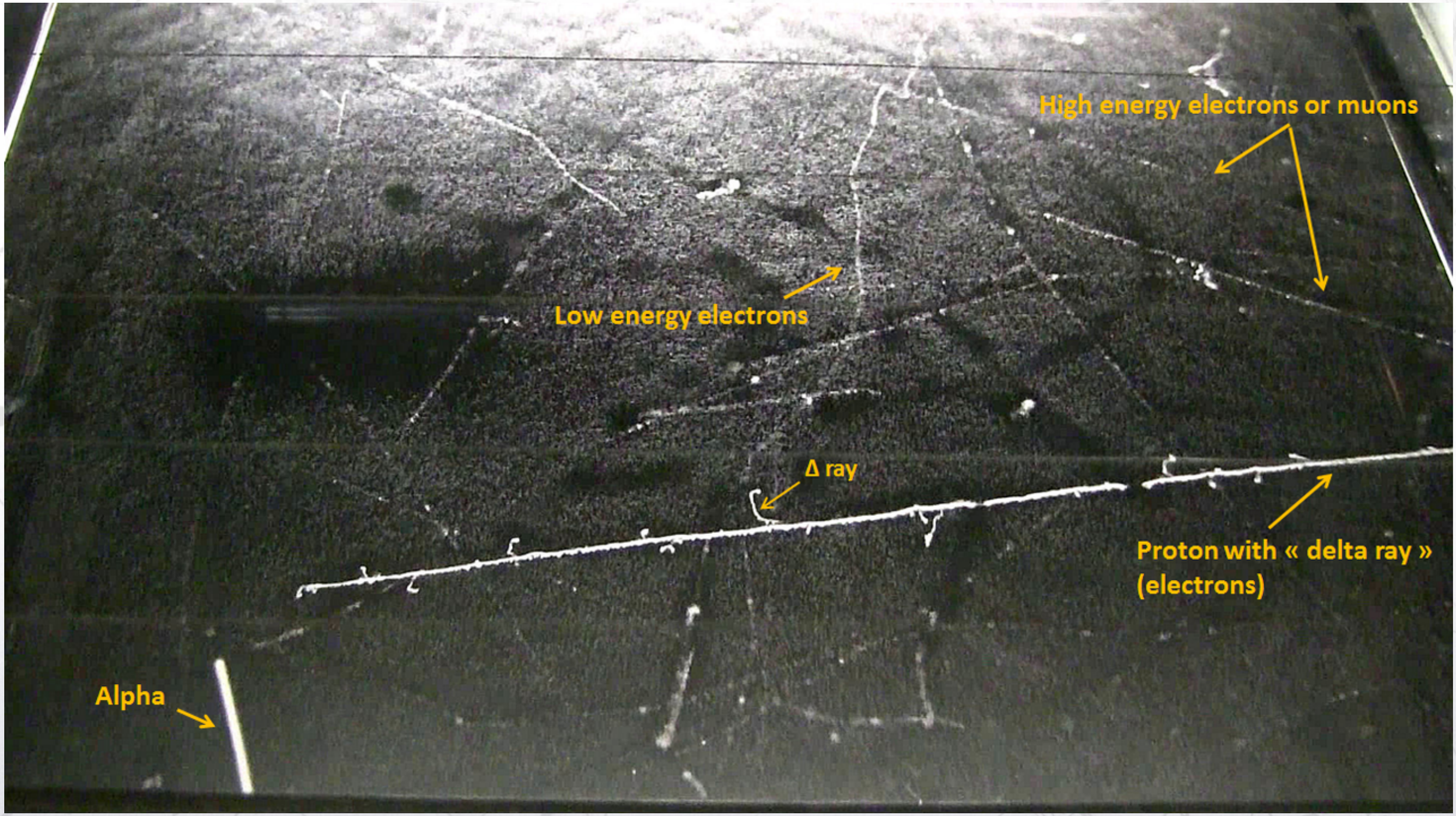
Cloud Chamber

An intense light source makes the drops apparent to the human eye.





Cloud chamber



Cloud chamber

- The cloud chamber is not a toy detector.
- Key discoveries in the history of physics were achieved with a cloud chamber:
  - The positron and the existence of antimatter.
  - The muon and the cosmic rays.
  - The pion.
- Nowadays it is rarely used except for a “bubble chamber” that is similar and it has an excellent spacial resolution.

Detecting particles nowadays

Modern methods

- Cloud chamber is sloooow (~second)
  - Modern experiments like LHC require to mesure events happening every 25 nanosecons.
    - 1 nanosecond is 10^{-9} seconds !
- Cloud chambers requires a complex data processing using pictures:
  - boring, slow, complex and expensive.
- In the information society we want all the information in a computer:
  - How ?

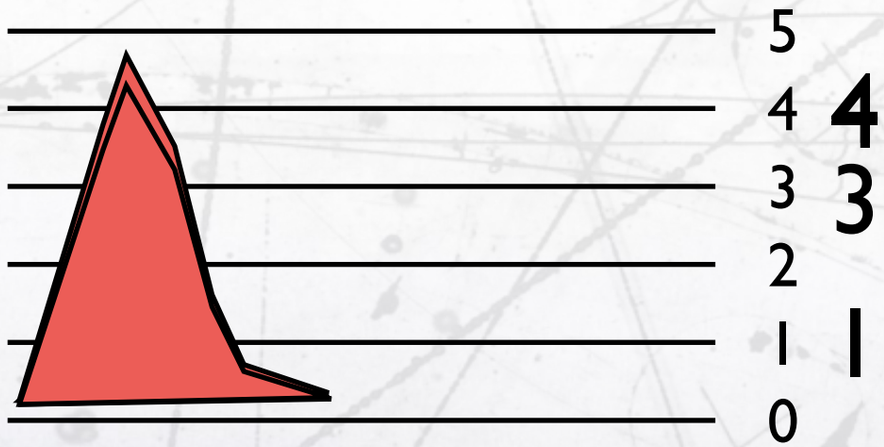
Can we see with out bare eyes signals of 10^{-9} seconds?

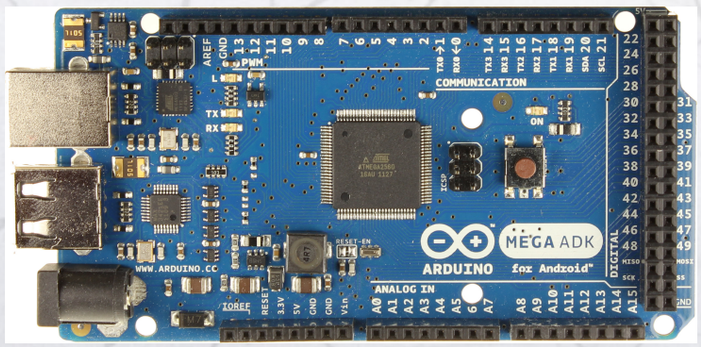
Modern methods

- A computer (like our brain) works on electric pulses.
- If we produce electric pulses with the particles we can transform it into a number using an:
  - "Analog to Digital Convertor" (ADC)
- We can also measure times as a clock running between two electric pulses
  - "Time to Digital Convertor" (TDC)

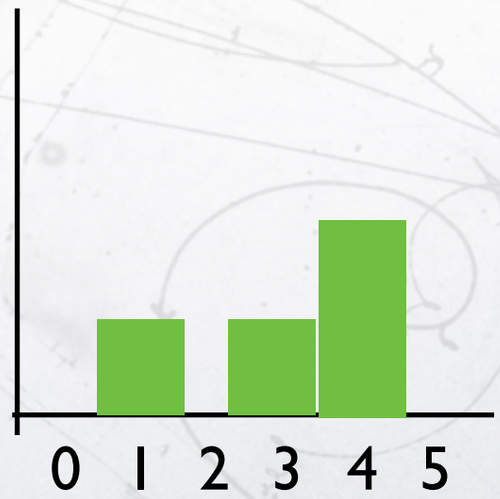
ADC

- The Analog to Digital Converter (ADC) transforms electric pulses into numbers.
- Compares the current with a predefine scale





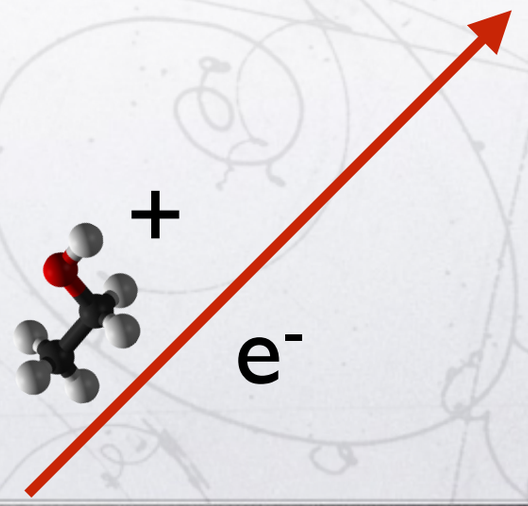
ARDUINO



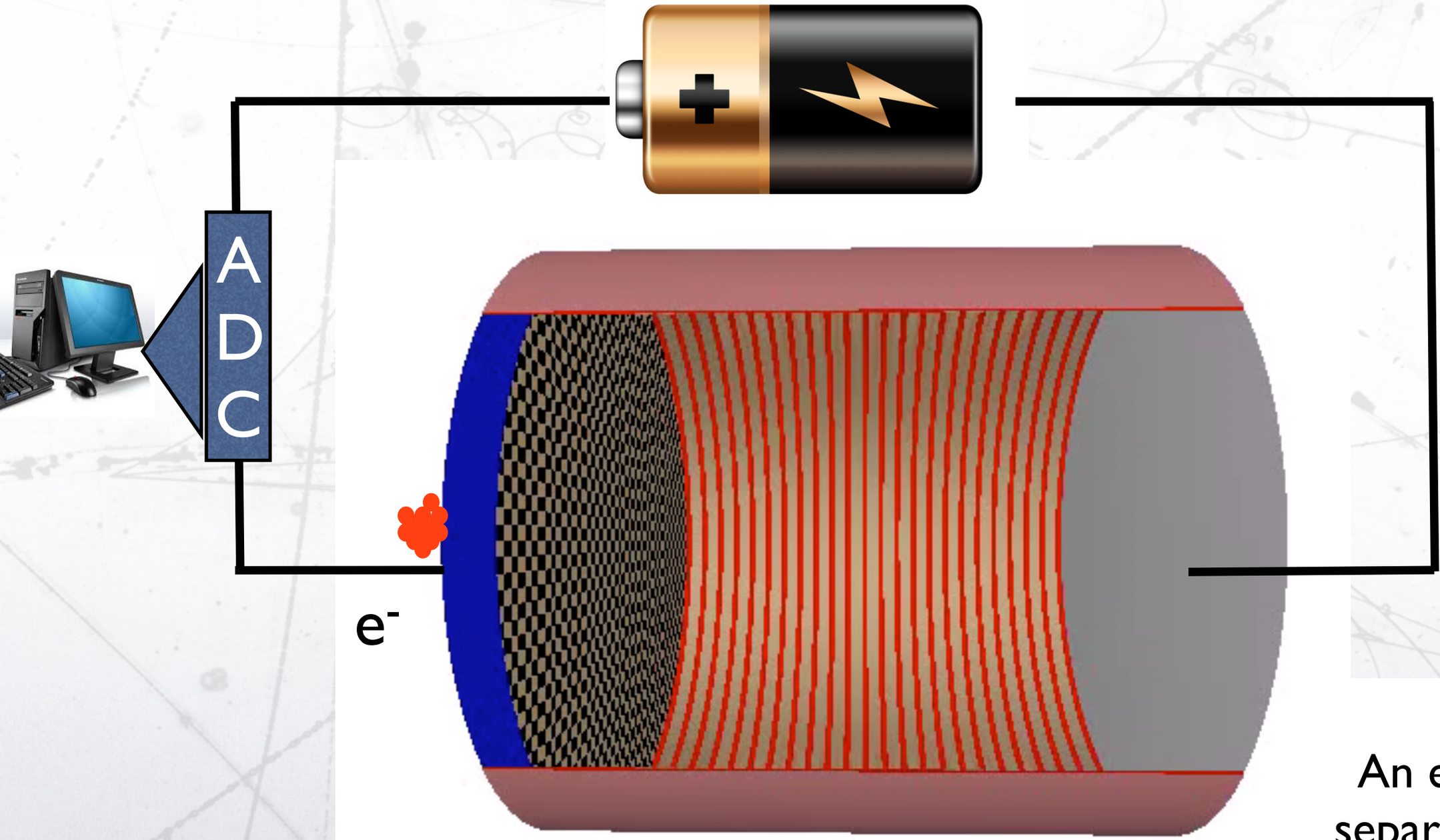
Arduino allows to do this.

Modern methods

- Matter transformations when particle crosses the media has to be transformed in electric pulses !
- An electric pulse is no more than a bunch of electrons moving.
- The cloud chamber was extracting electrons from the alcohol molecules:
  - We have to collect the electrons !



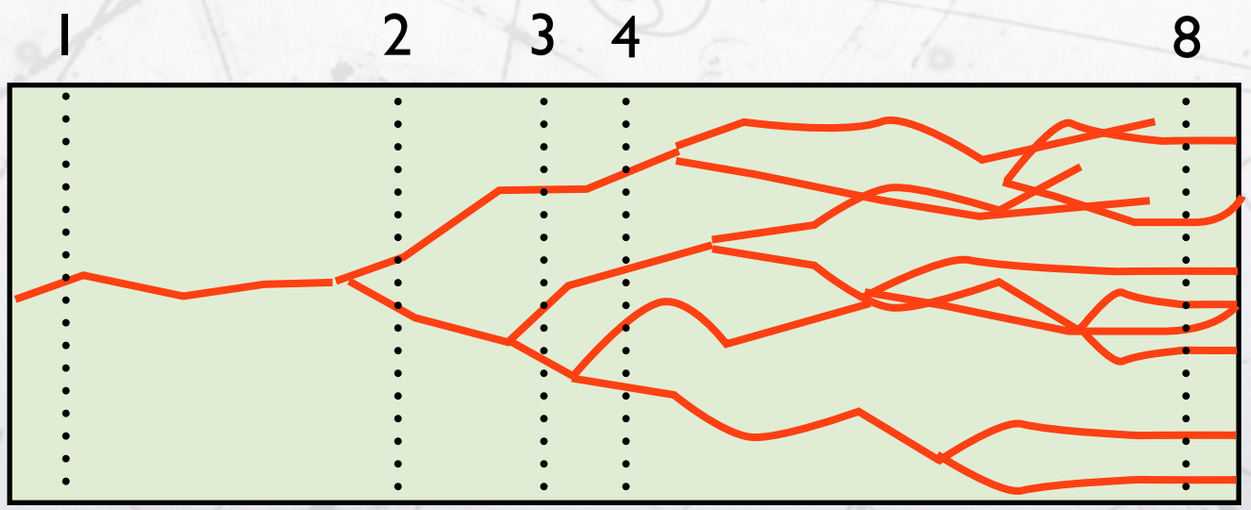
Detecting particles!



An electric field separates charges.

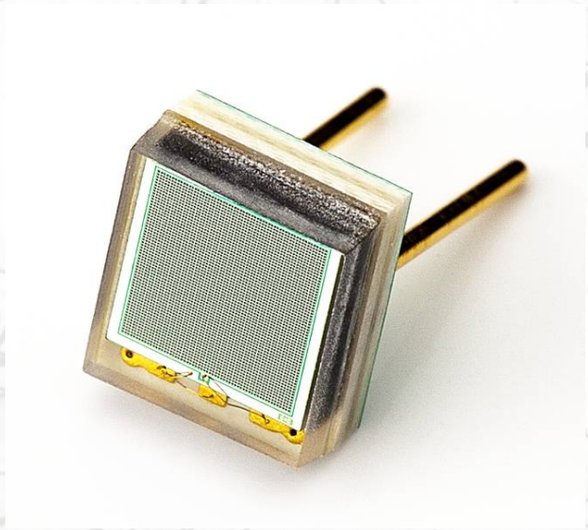
Amplification

- Sometimes the number of electrons extracted is very small to be measured.
- We have to amplify the pulse:
  - Electrons are accelerated.
  - Electron extract more from the media.
  - and so on….



Amplification

photomultipliers

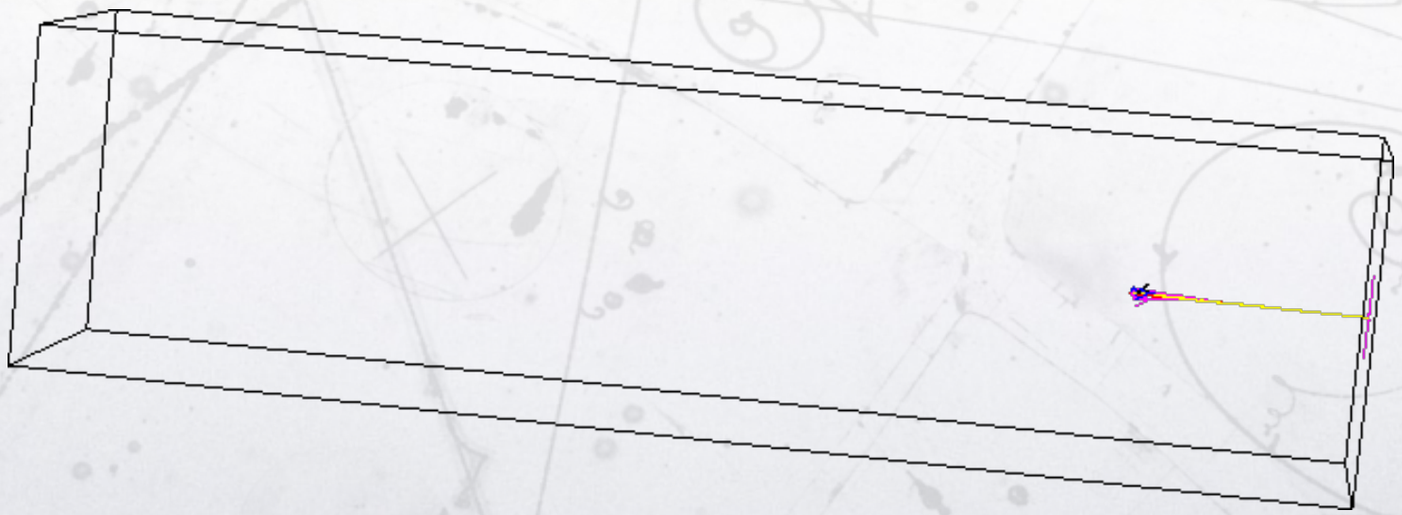


Silicon multipliers.

Gas amplification.

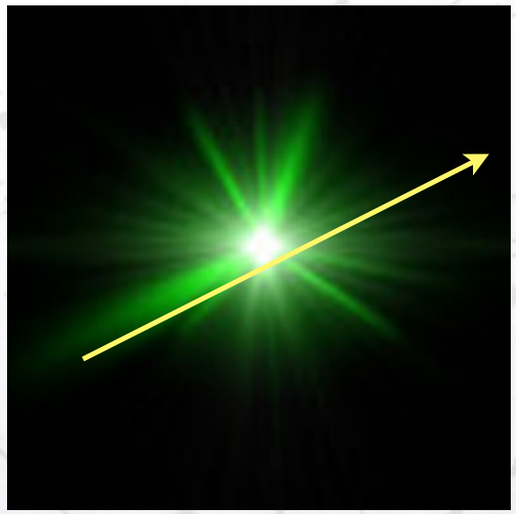
How to detect particles?

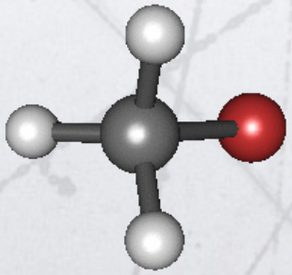
- This detection occur only for electrically charged particles:
  - We detect the particle charge!
- Neutral particles cannot be detected unless they interact and and convert in charged particles.



How to detect particles?

- Some times, the energy of the particle is not enough to extract electrons from atoms (hard) or molecules (easier).
- In this case, the particle can excite the molecule or atom.
- The molecule or atom de-excite emitting light.





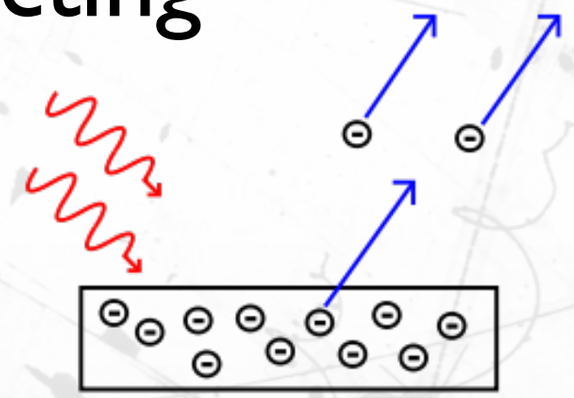
Aurora Borealis is produced by electrons from the sun that excites atmospheric molecules

Light

- Particles crossing matter can produce different types of light:
  - scintillator (Aurora Boreal)
  - Cerenkov (blue light in nuclear reactors).
- Light emitted from a particle crossing media with different index of refraction.

Detecting light?

- Light detection is achieved by extracting electrons from matter:
  - Photoelectric effect.

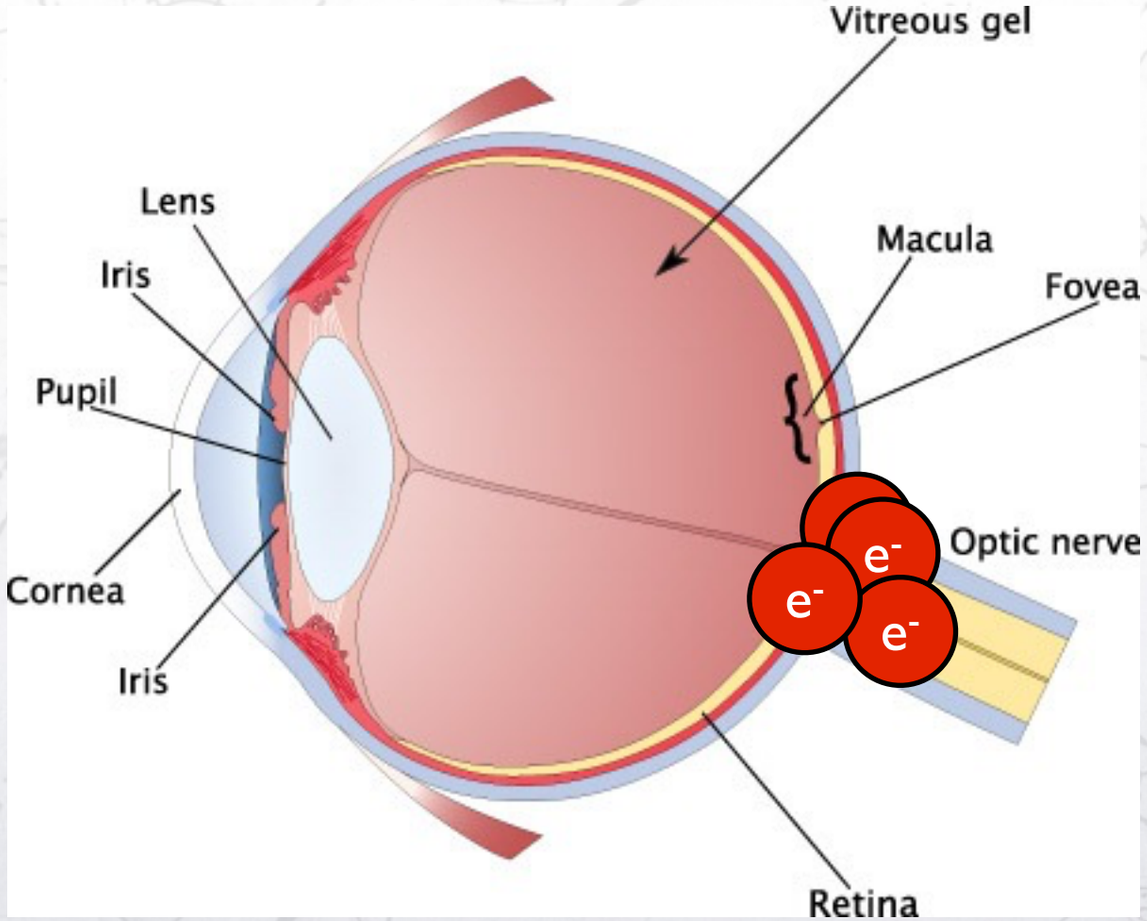


- Once the electrons are extracted from the media we can form electric pulses and measure them.

Fotón → electrón → ADC

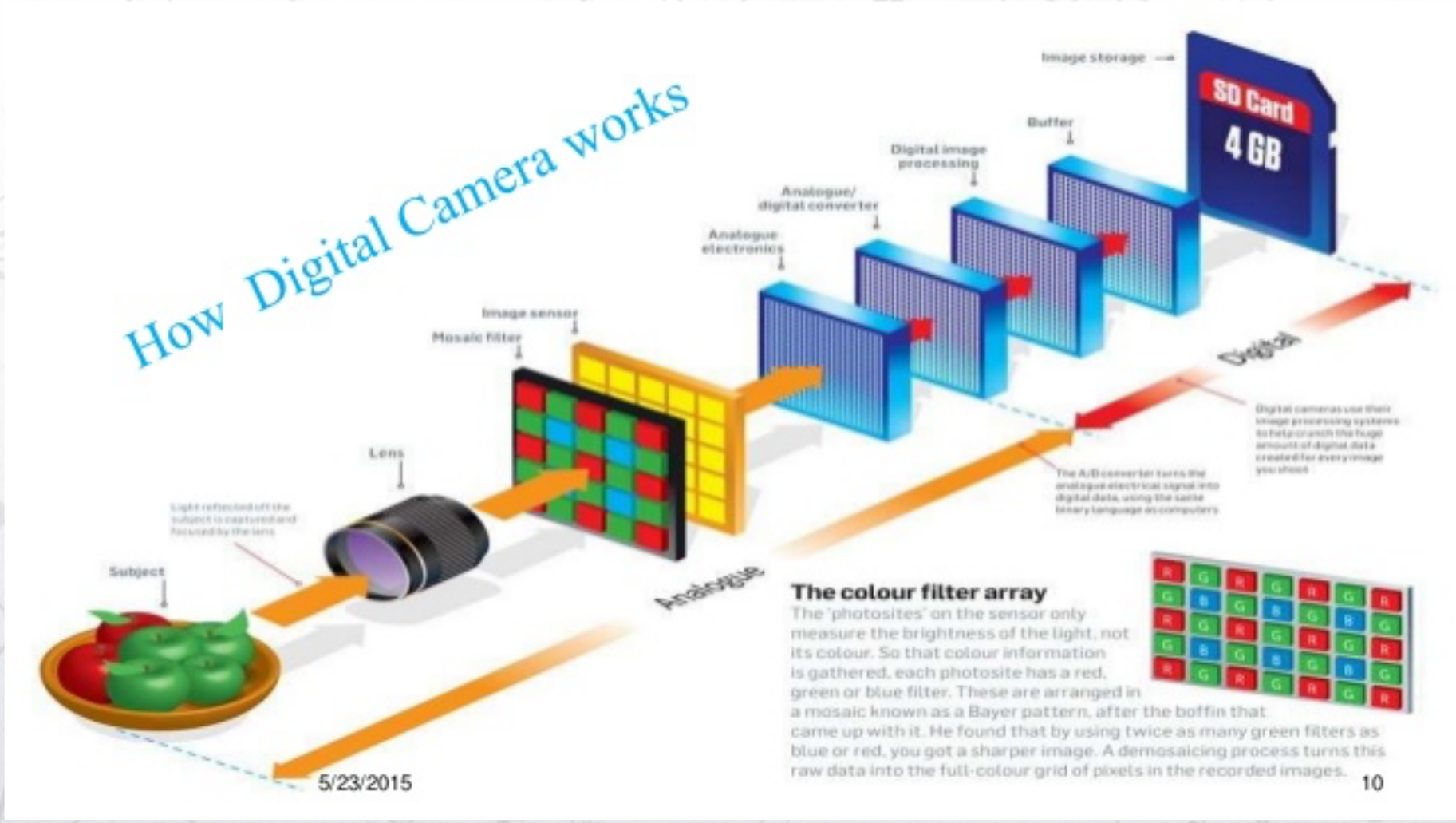
Detecting light?

- Human eye transform light (photons) into tiny electric currents transmitted across neutron synapsis.



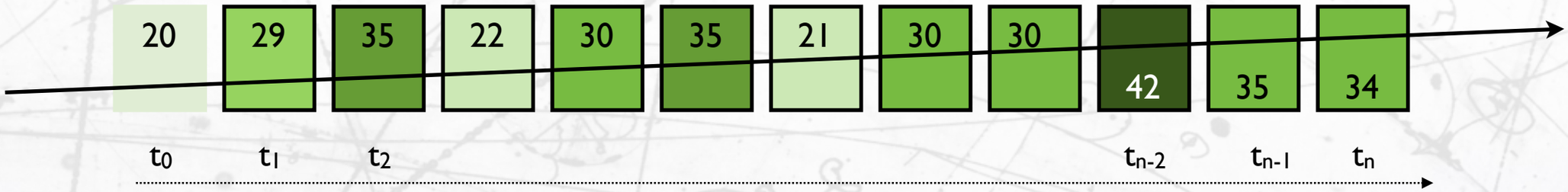
Detecting light?

- Also your digital camera uses the same method.



Measurements

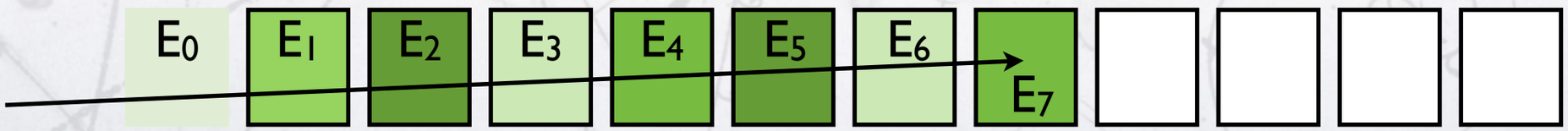
- We measure the amount of electrons and photons emites during the interaction. This is proportional to the energy deposited by the particle.
- If we segment the detector:



- We can measure the time when the particle crossed a pixel (velocity).
- We can measure the amount of energy deposited at each pixel.

Measurements

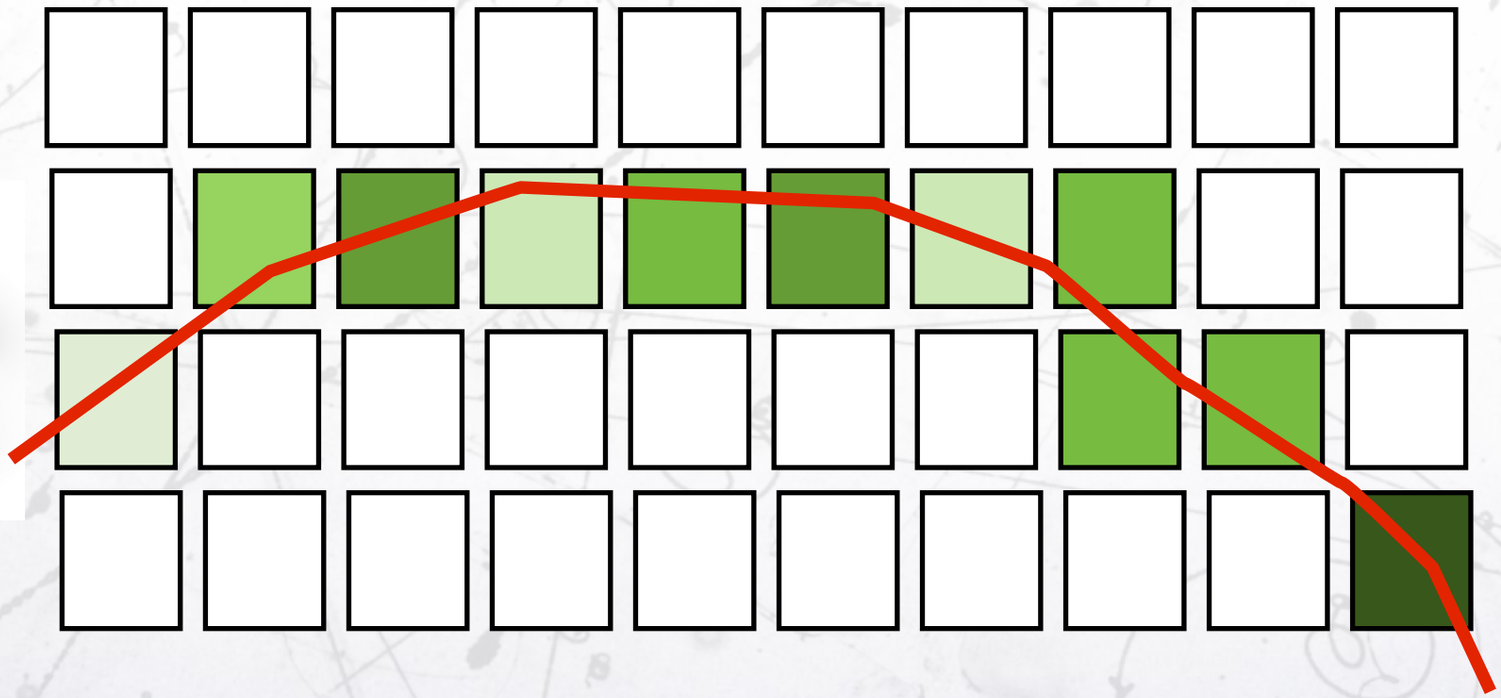
- A particle can loose all its energy and stop.
  - The length of the trajectory is an estimation of the particle's energy.
  - We can also measure the total energy deposited in the detector (calorimetry) which is proportional to the kinetic energy of the particle.



$$E = E_0 + E_1 + E_2 + \ldots.$$

Measurements

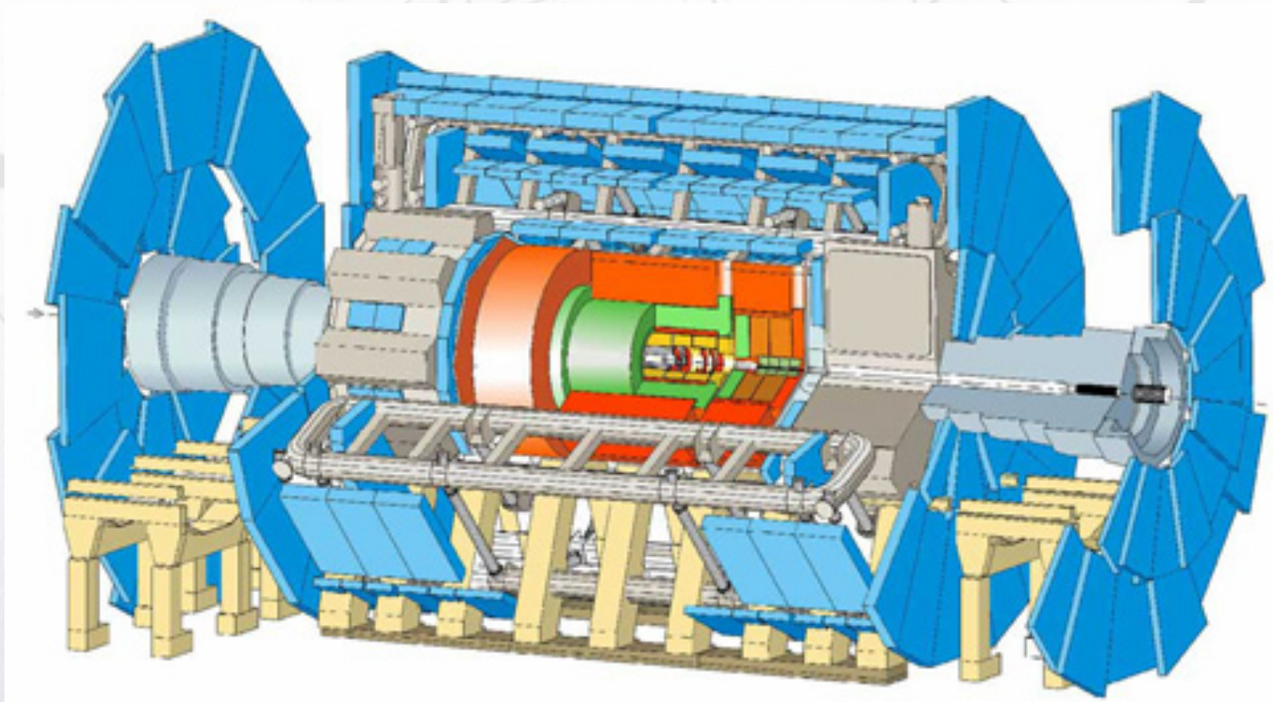
- If the detector is immersed in a magnet.
- The particle trajectory curves

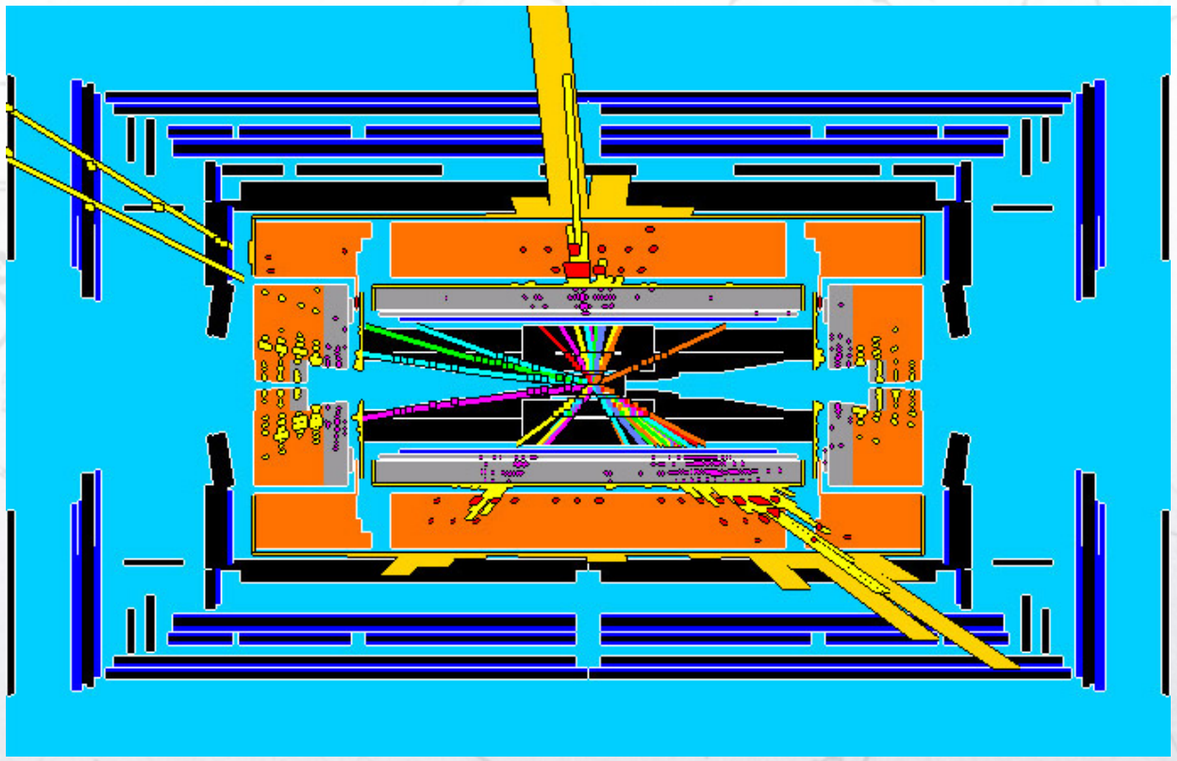


- The curvature is proportional to the particle's momentum (mass x velocity).

Same principle as an electric motor.

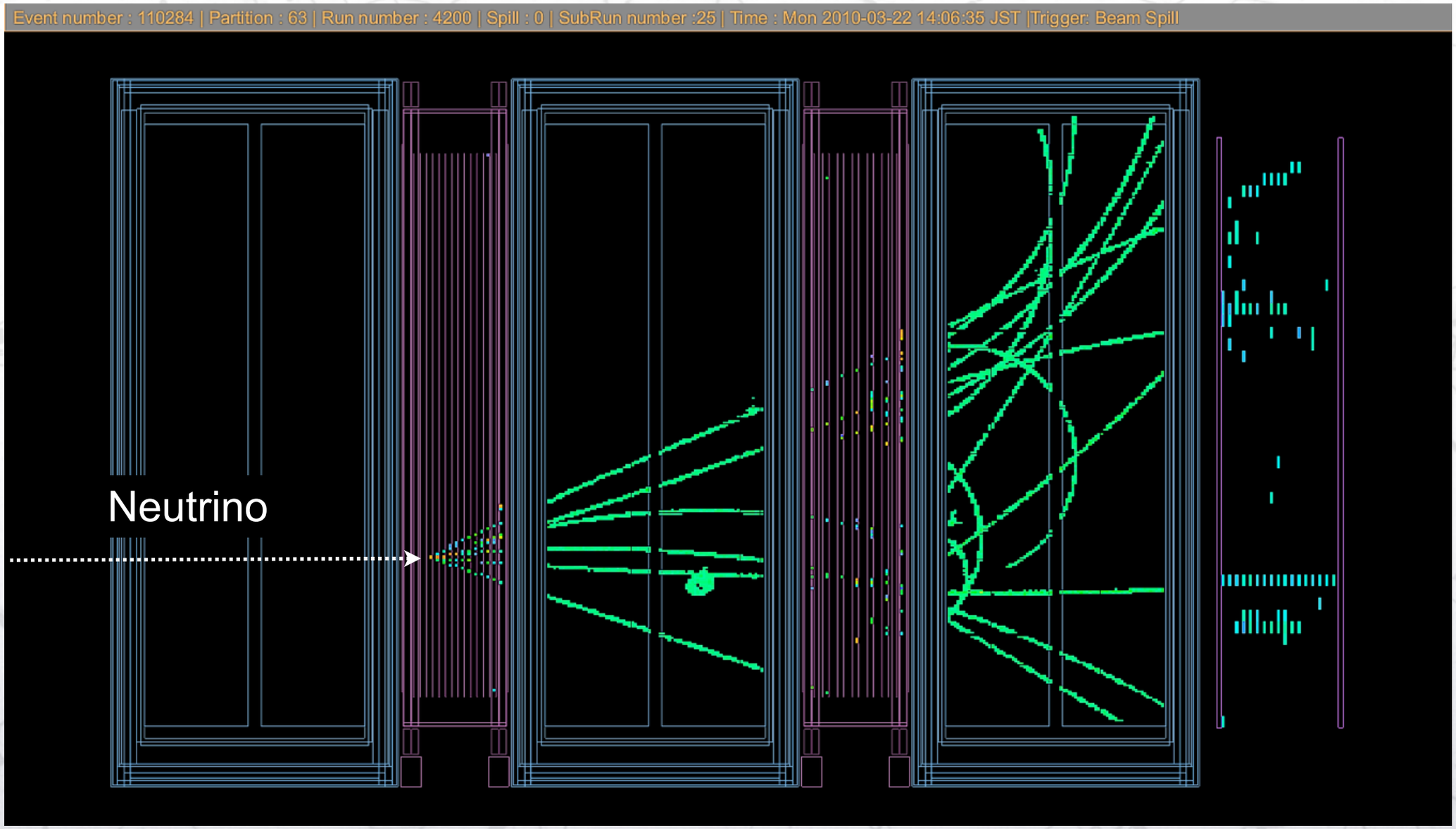
- Big particle detectors (ATLAS in LHC) is composed of millions of small detectors measuring different properties: energy, curvature, start and end position, time of flight, …





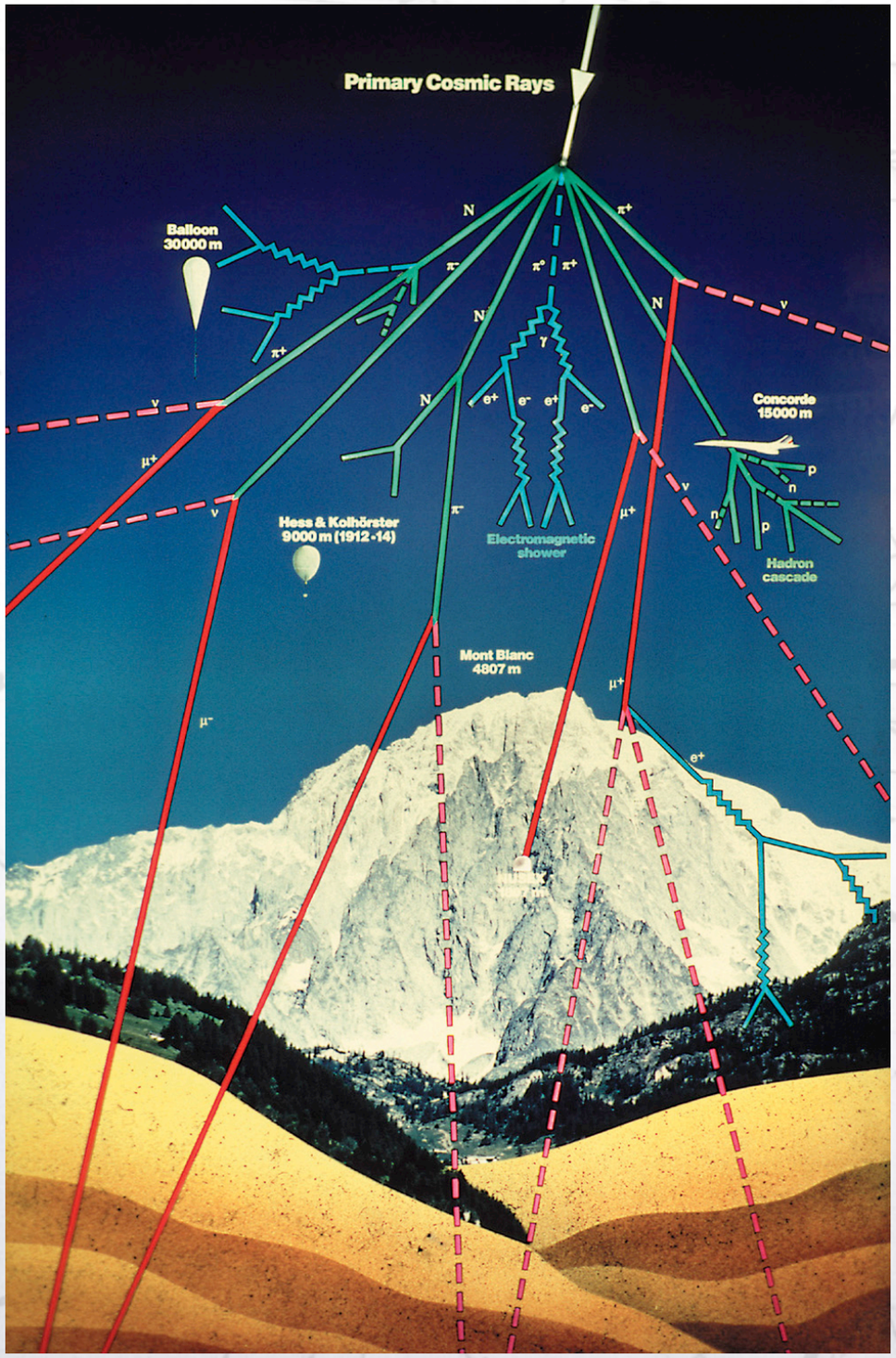
Neutrinos in T2K

My experiment!



Cosmic rays!

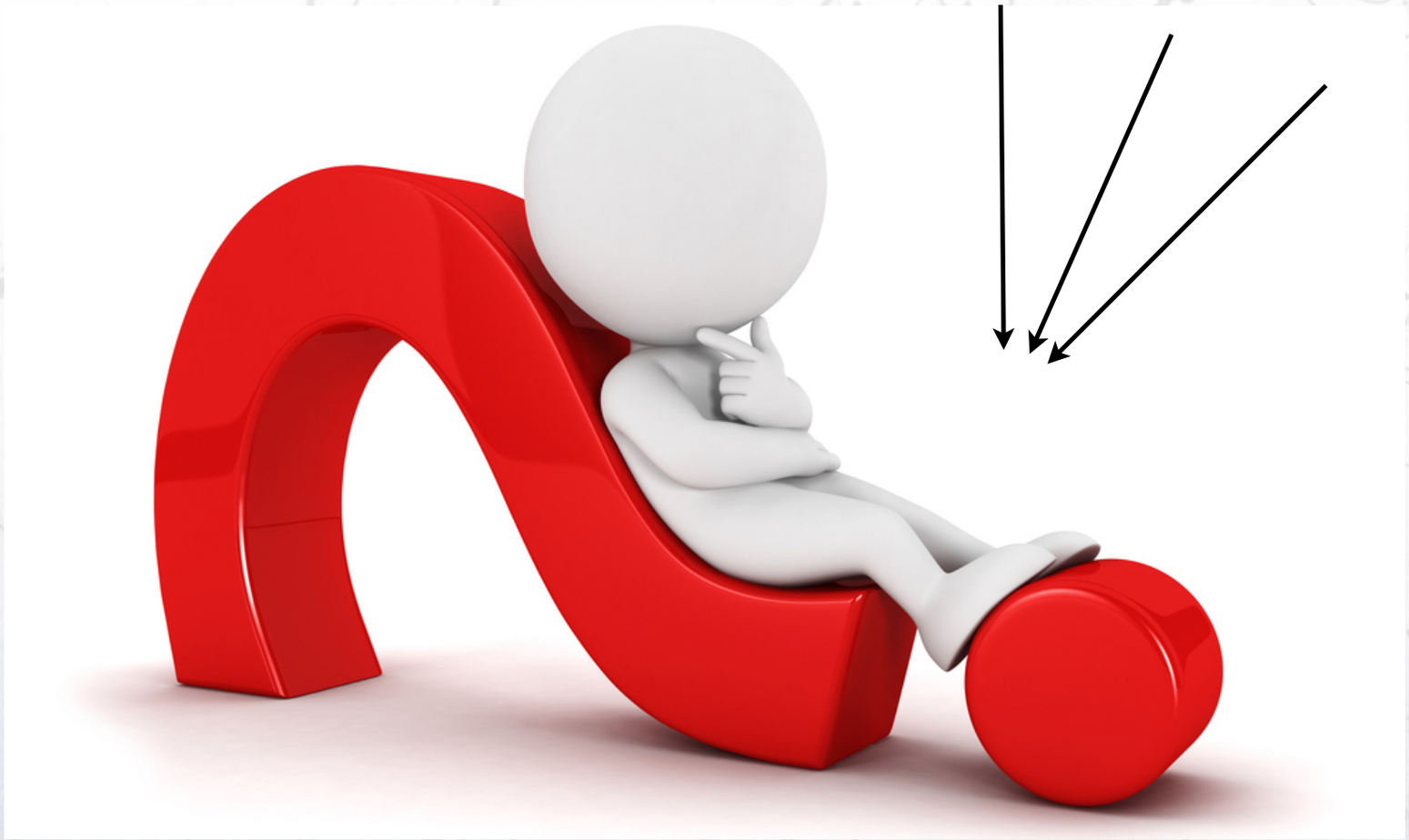
Cosmic rays



- Cosmic rays are subatomic particles produced in the atmosphere during the interaction of energetic particles coming from outside the earth.
- They have so much energy, they collide with atoms in the atmosphere and produce a shower of particles.
- Many of them reach earth surface where we can measure them.
- These particles are normally muons:
  - muons are electrons with 200 times the electron mass.

Cosmic rays

- Are the cosmic rays isotropes or they come predominately from one direction?



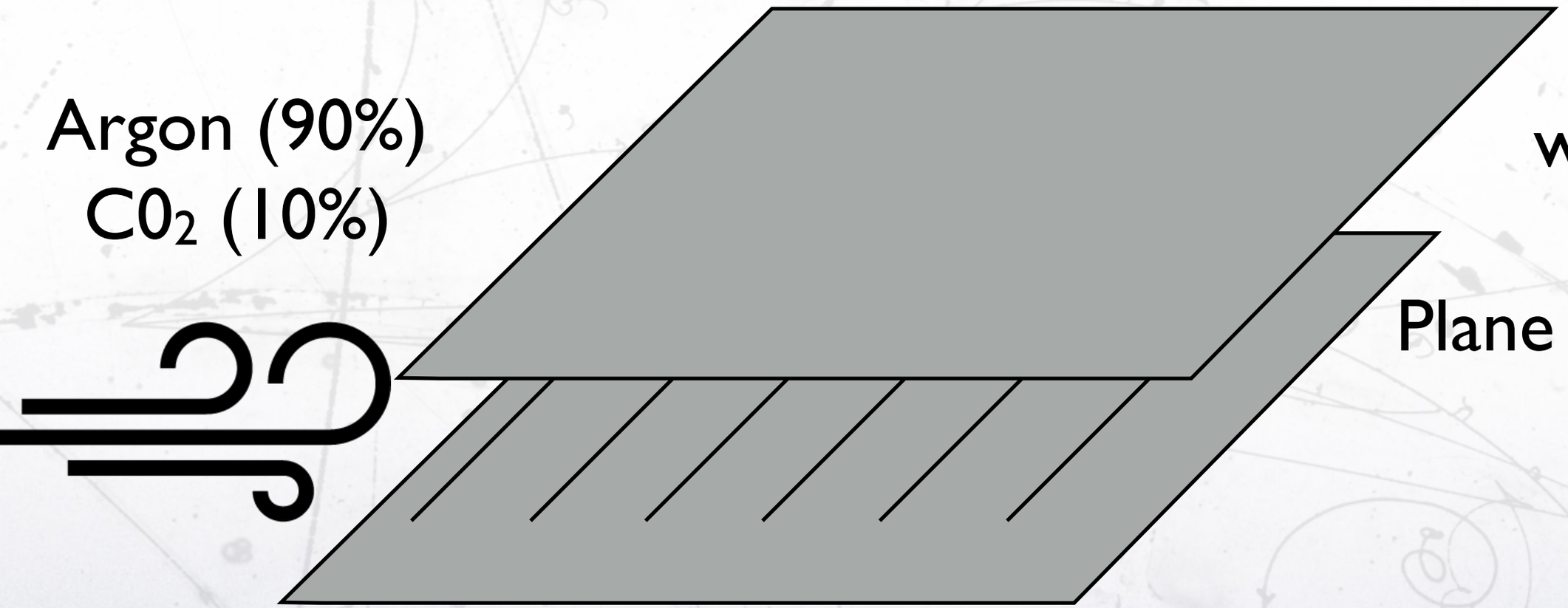
You will build a device to detect cosmic rays and answer this question.

Basics of our detector

Basic principle

Plane @ 2500V

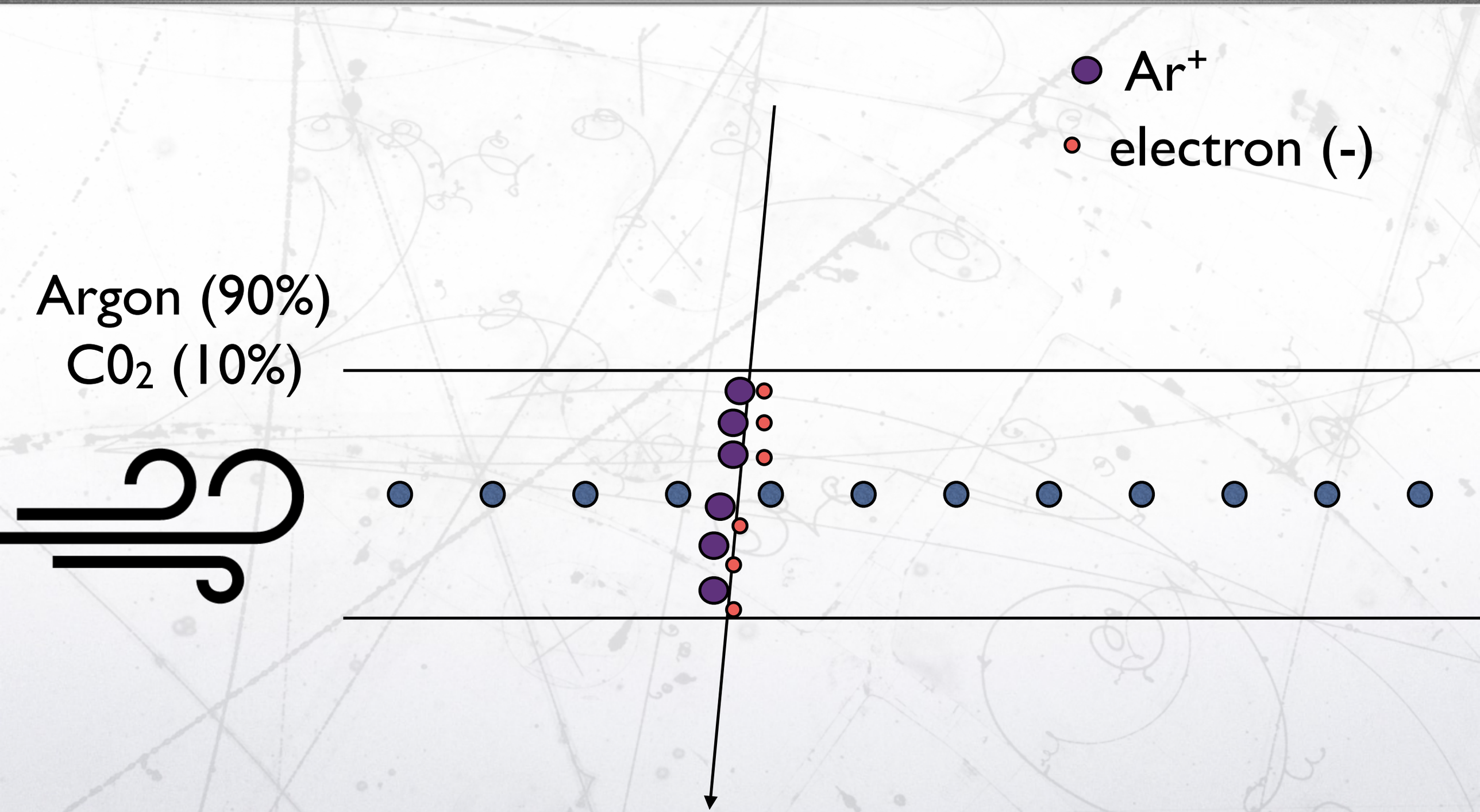
Argon (90%)
$C0_2$ (10%)



wires @ 0V

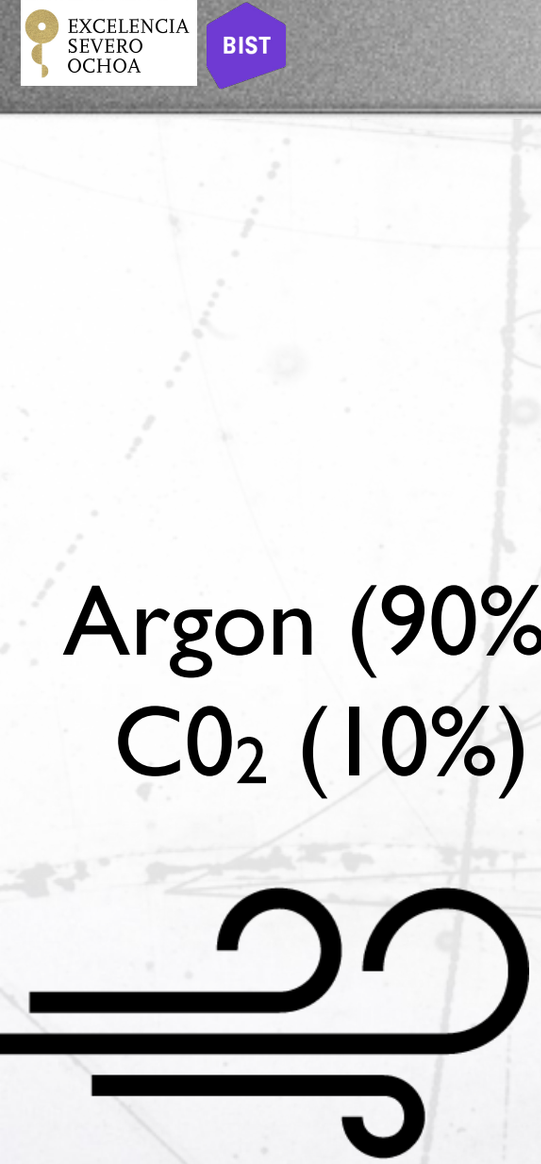
Plane @ 2500V

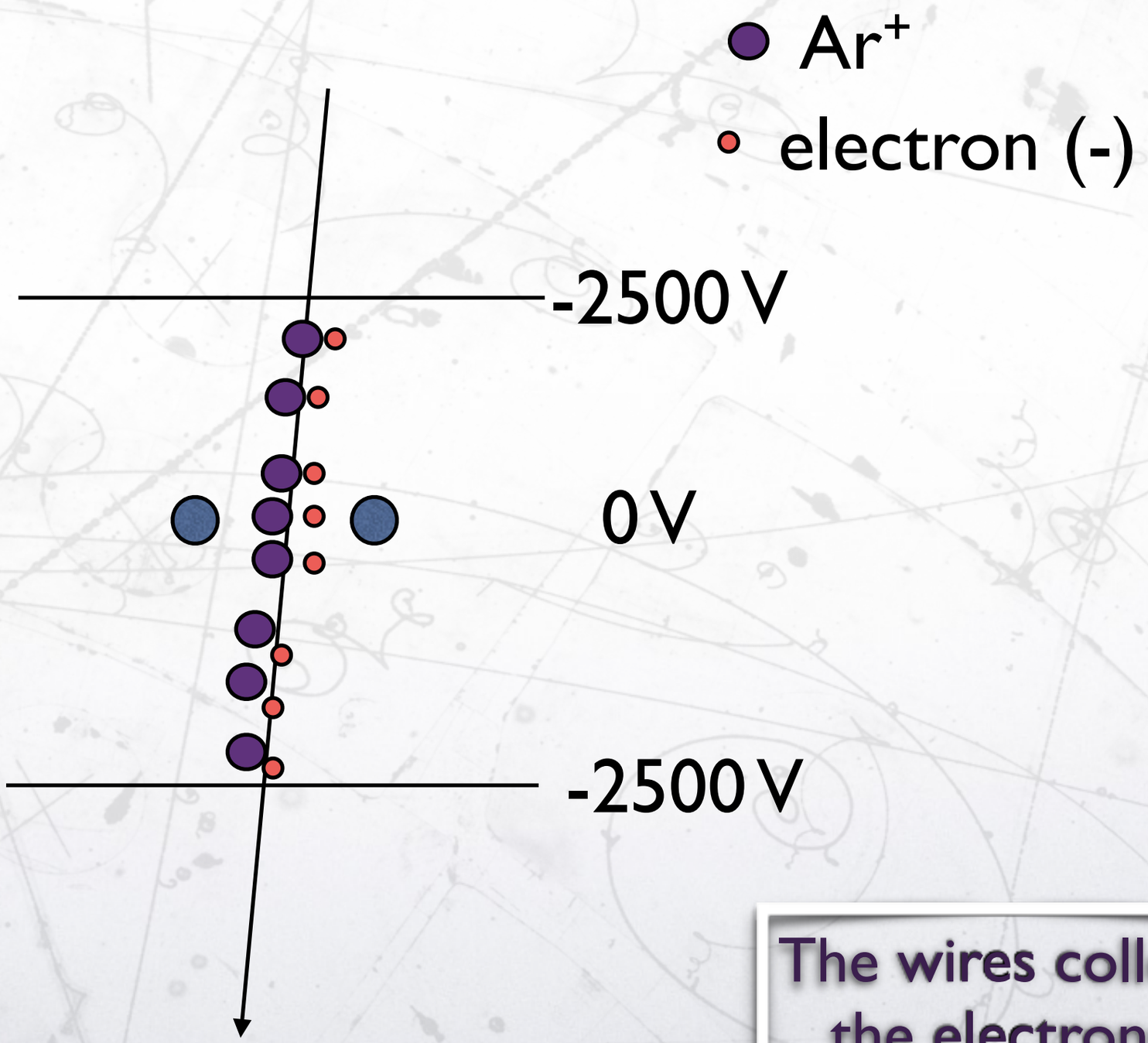
Basic principle



Basic principle

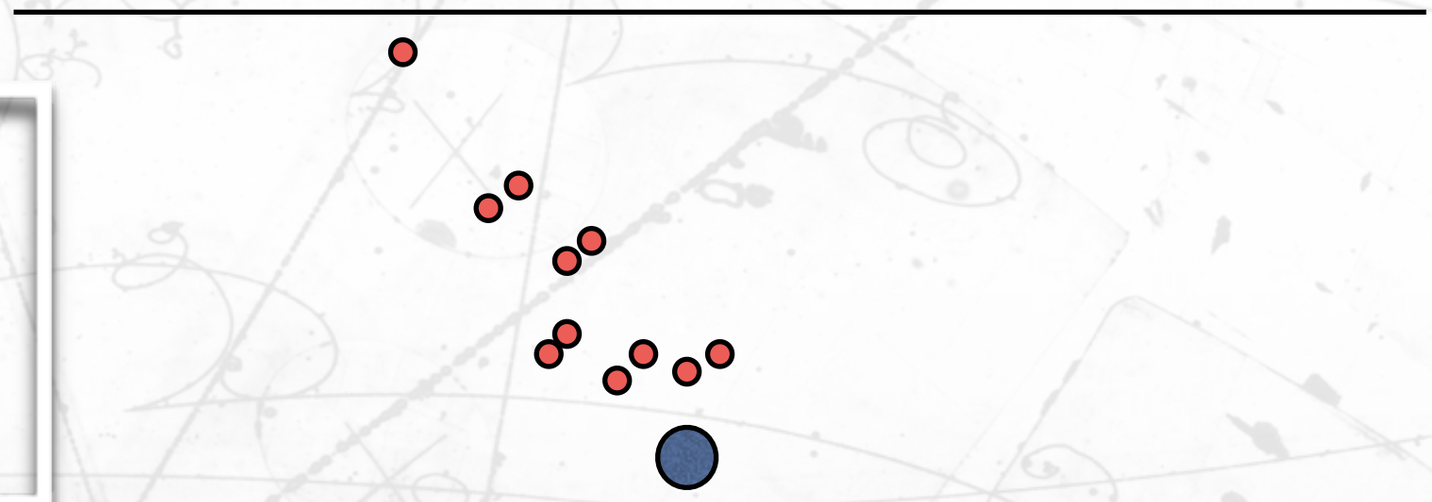
Argon (90%)
CO_2 (10%)





The wires collect the electrons

Basic principle



In the electric field the electrons are accelerated

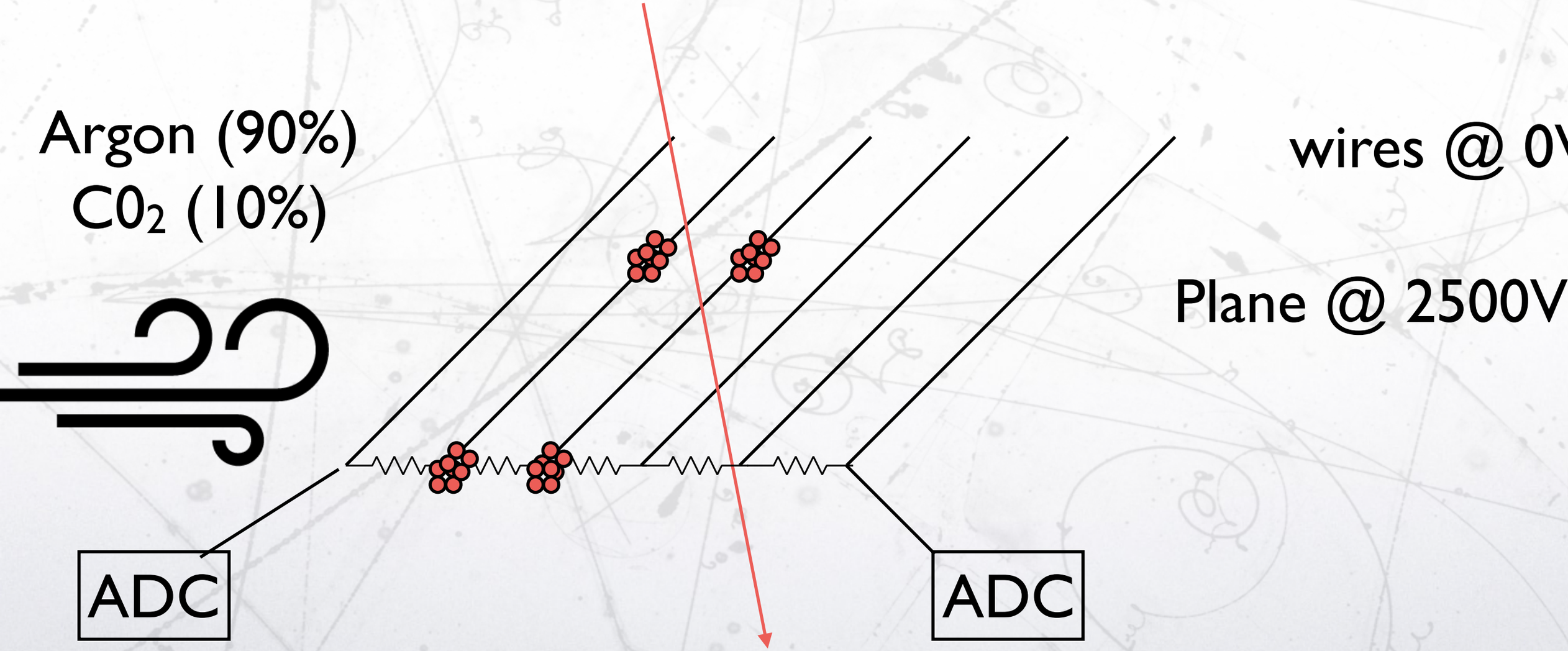
They extract more electrons in the gas

which also extract more electrons

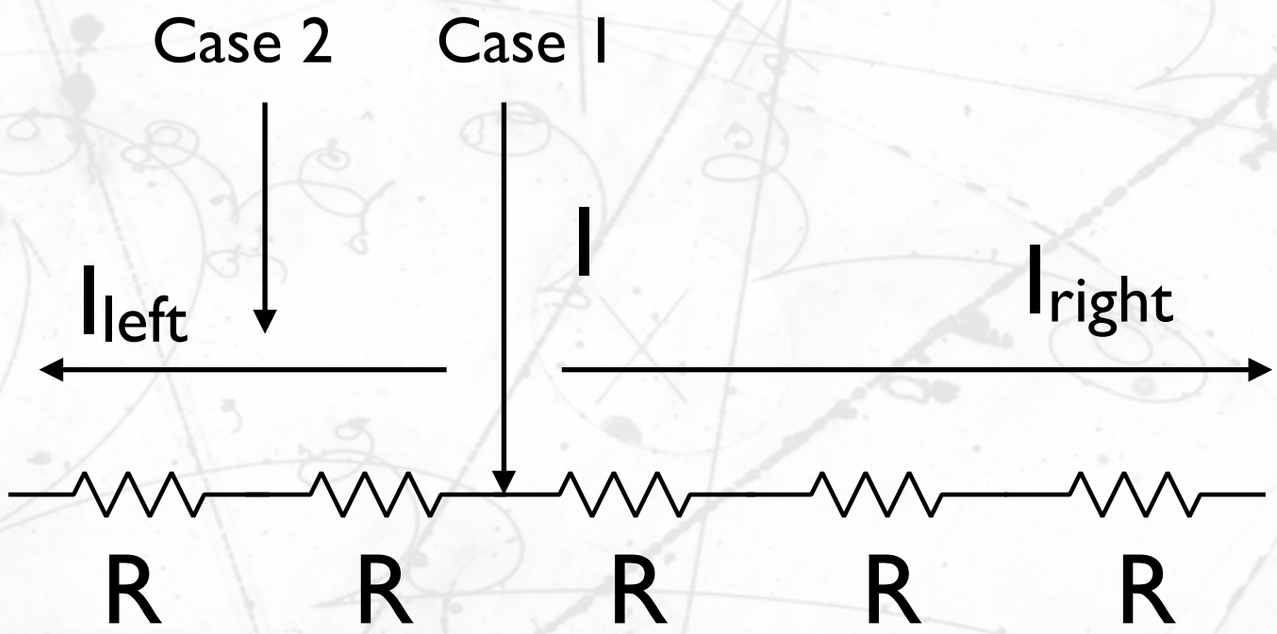
The wire collects more electrons than the original one. Amplification

Basic principle

Argon (90%)
CO_2 (10%)



Basic principle



I is the electric current: number of electrons/ unit time.

Charge conservation: $I = I_{left} + I_{right}$

Ohms law:

$V = IR$

Case 1

$V = I_{left}\ 2R = I_{right}\ 3R$

$I_{left} = 3/2\ I_{right}$

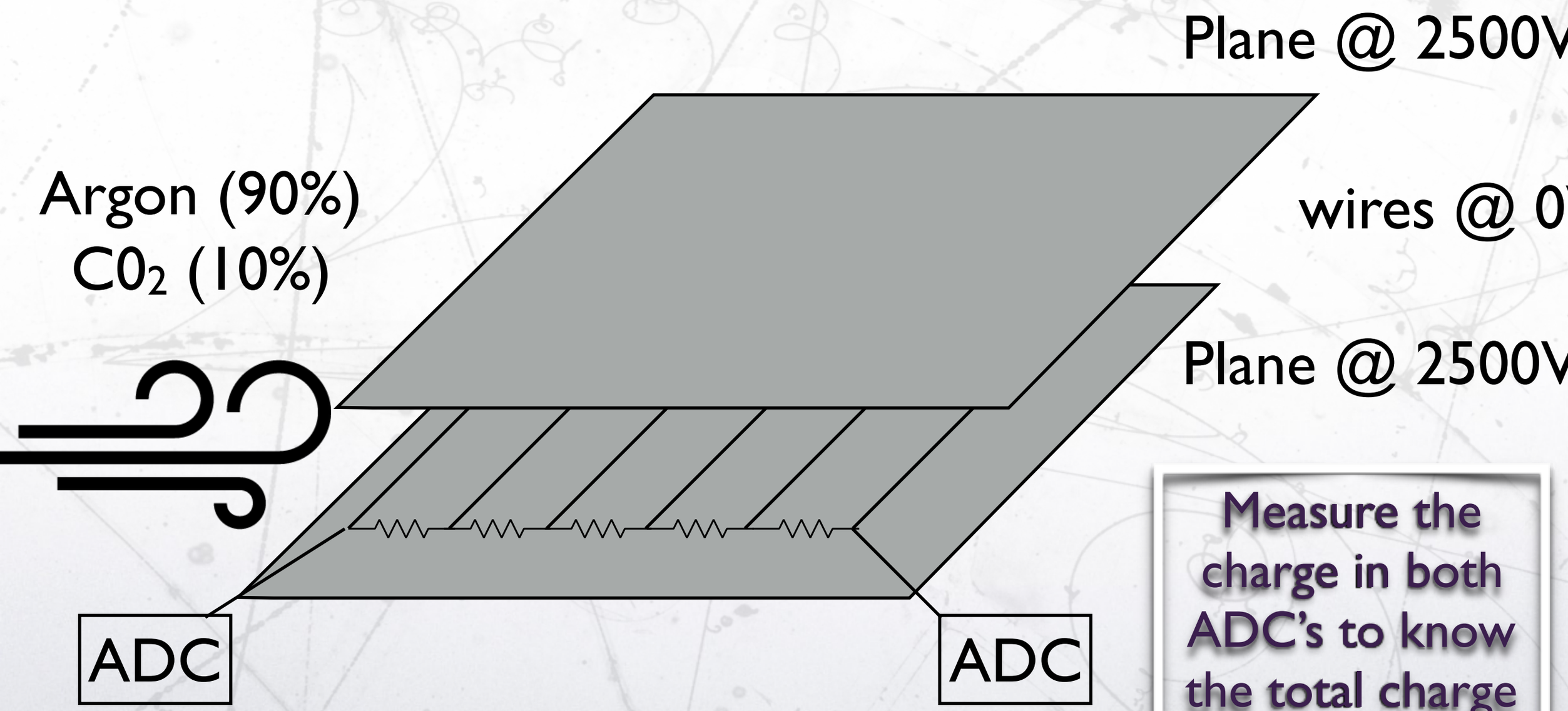
Case 2

$V = I_{left}\ 1R = I_{right}\ 4R$

$I_{left} = 4\ I_{right}$

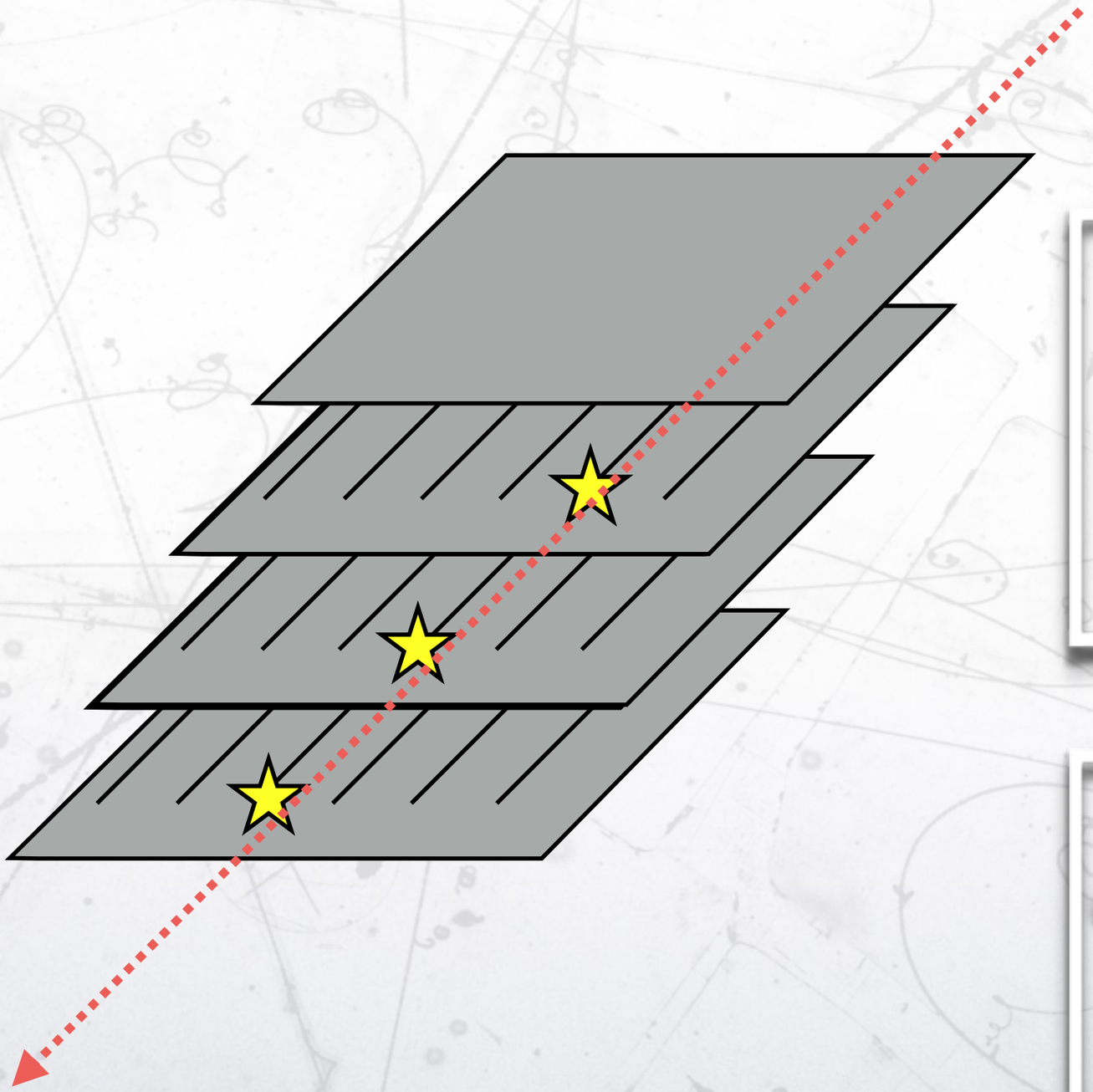
The ratio between I_{right} and I_{left} tells the wire that collected the charge.

Basic principle



Measure the charge in both ADC's to know the total charge and the position

Basic principle



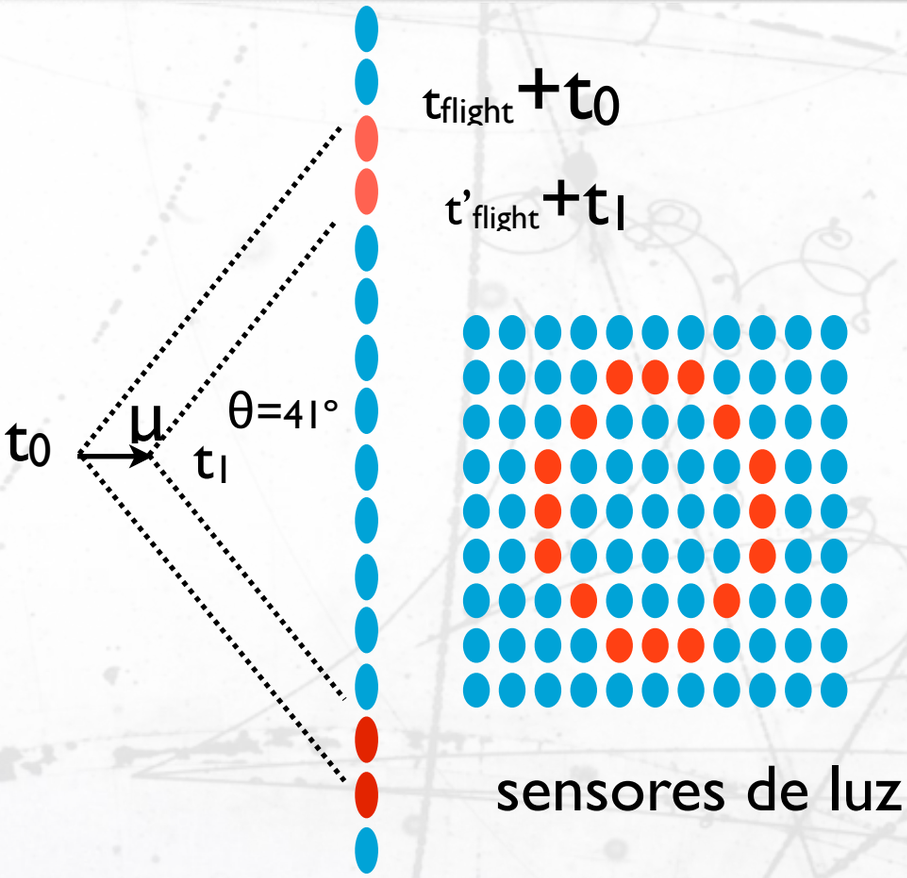
With more than one plane, we can determine the direction of the track.

With two orientations (x,y) we get the 3D direction.

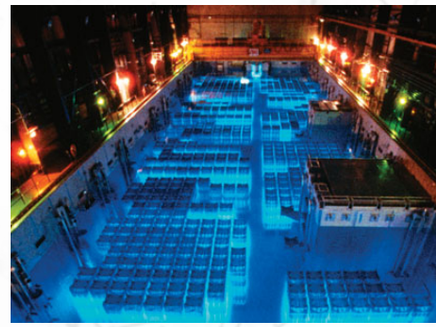
Are you ready ?

Support slides

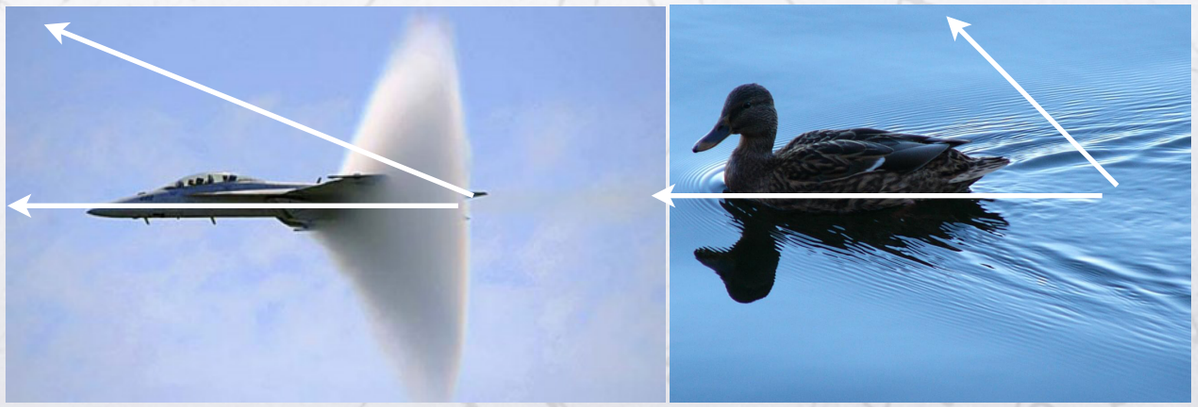
Cerenkov y grandes detectores



- Cuando una partícula cargada electricamente viaja en un medio material más rápido que la luz en el medio emite una luz azulada.
- En agua la luz va en una dirección de 45° respecto de la partícula y se puede medir su dirección.

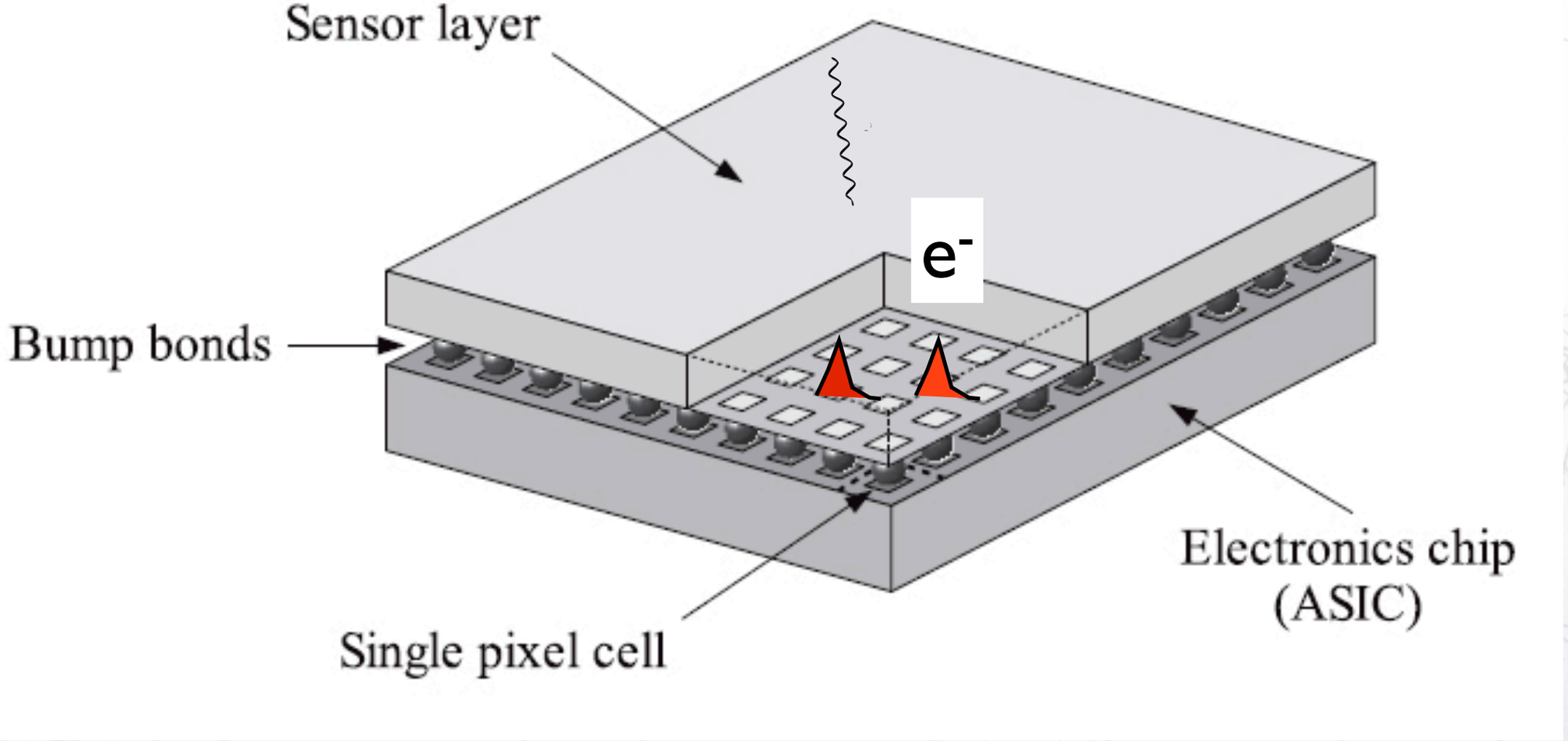


- Las ondas de choque se producen en otros ámbitos de la física.



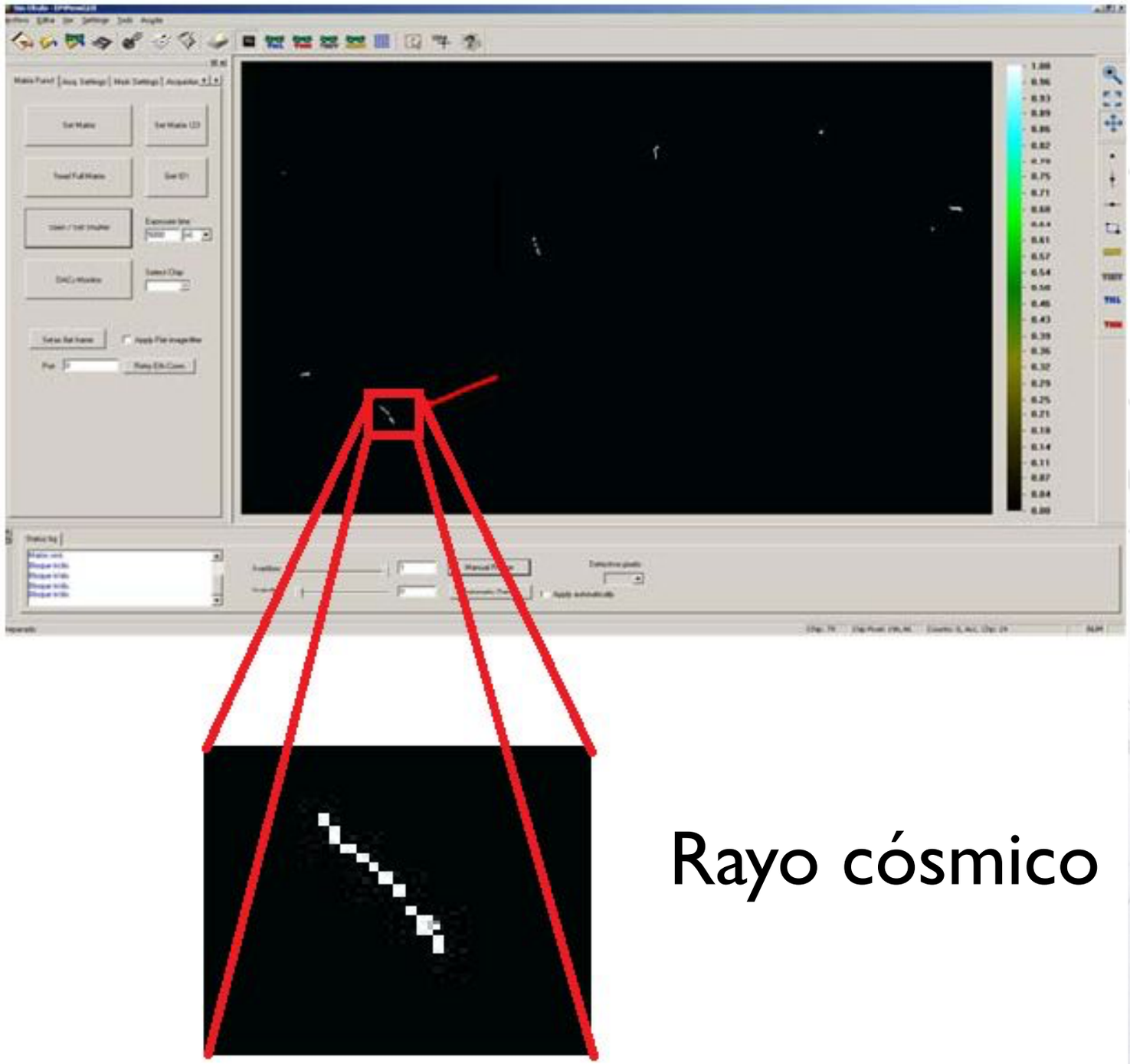
Hoy en el laboratorio veréis uno de ellos

fotón, partícula



Podemos medir la energía en cada pixel y/o el tiempo en el que ocurrió.

MediPix



Rayo cósmico

Rayos cósmicos

- ¿Cómo medir la dirección de los rayos cósmicos?

Det 1

¿Síncrono?

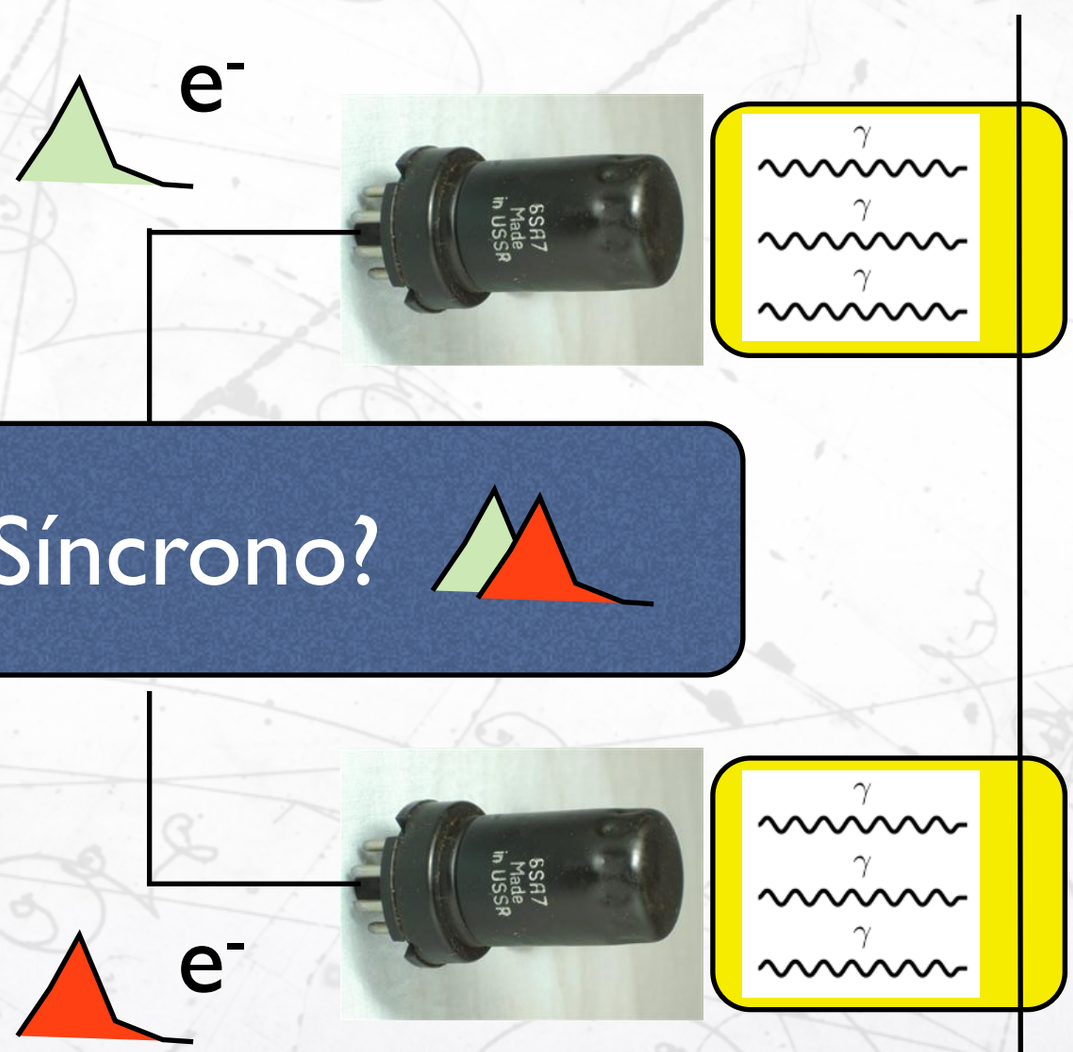
Det 2

θ_1 θ_2 θ_3

θ_1	N_1
θ_2	N_2
θ_3	N_3

Coincidencias

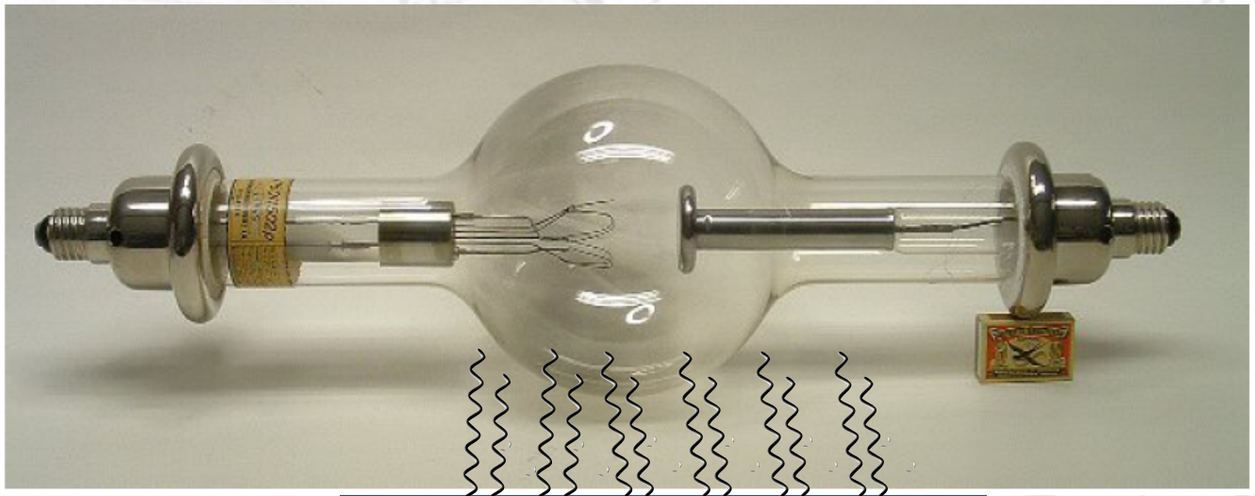
Cada coinciencia contamos una unidad.

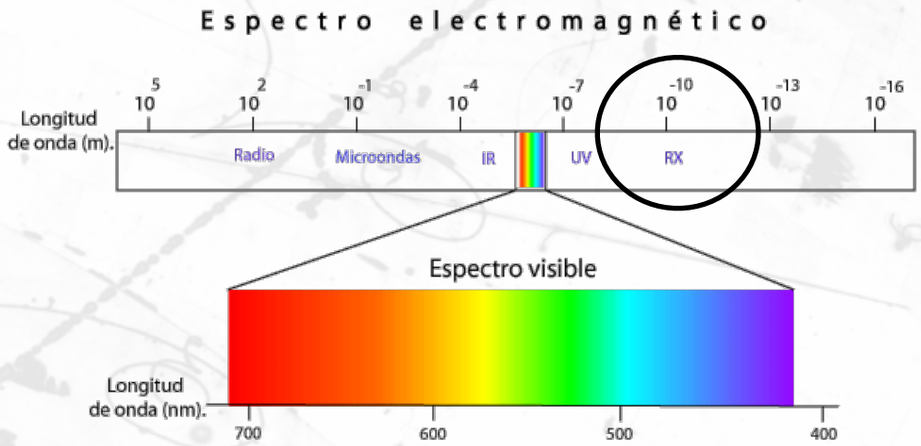


Como la distancia es pequeña las señales deben de llegar con < 10^{-9} segundos de retraso

Hoy veremos 10^{-9} s en el laboratorio

Maquinas Rayos X





Los rayos X son absorbidos por los tejidos de la mano dependiendo de su densidad.