EPIC 2

School of Programming for Scientific Research 2

11-14 October 2022

A rare event search
In neutrino physics

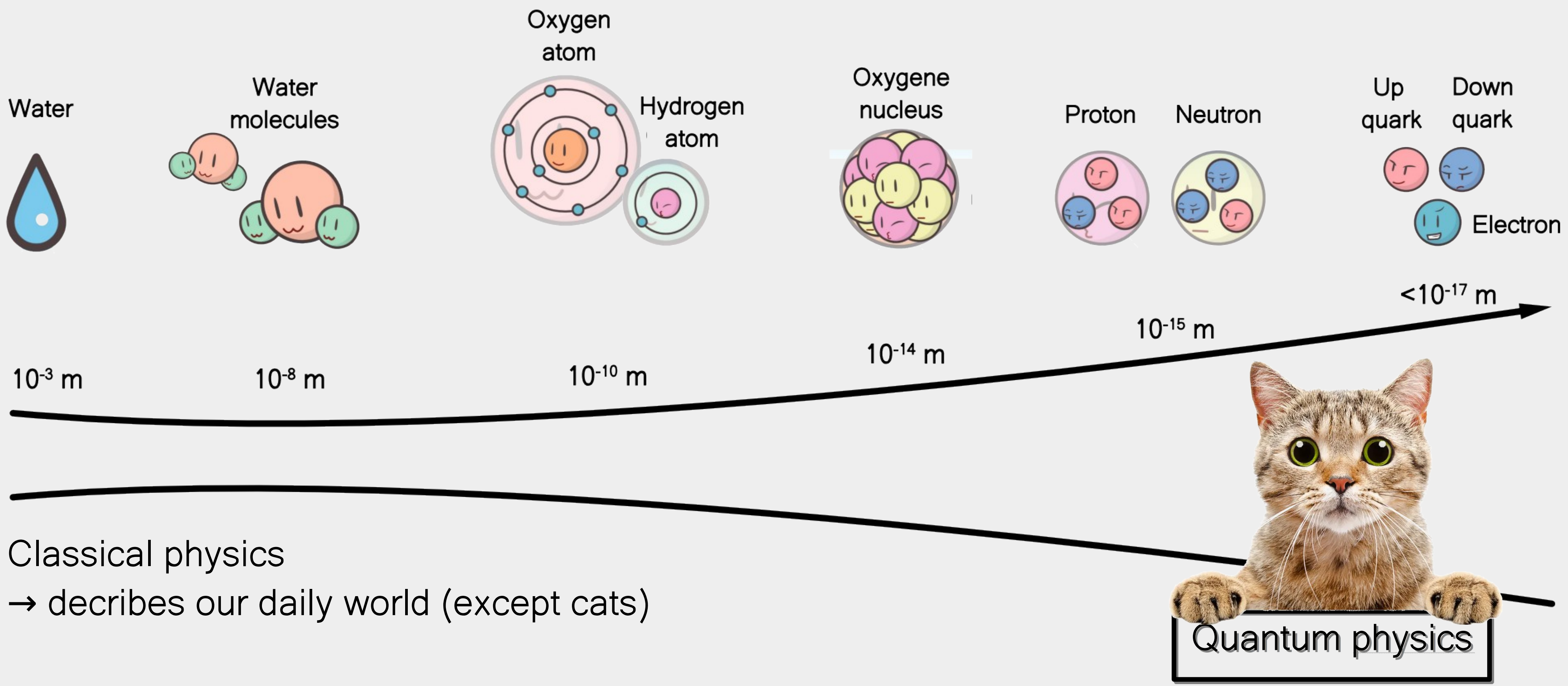
Cloe Girard-Carillo

A rare event search in neutrino physics

- Particle physics introduction
- Zoom on neutrino physics
- SuperNEMO: a detector for rare event searches
- Introduction to data aquisition and analysis

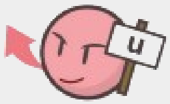
What are we composed of?

Zooming inside matter...



Different types of matter: the Standard Model of particle physics

« Daily » matter: what we deal in our everyday life



Different types of matter: the Standard Model of particle physics

« Daily » matter: what we deal in our everyday life

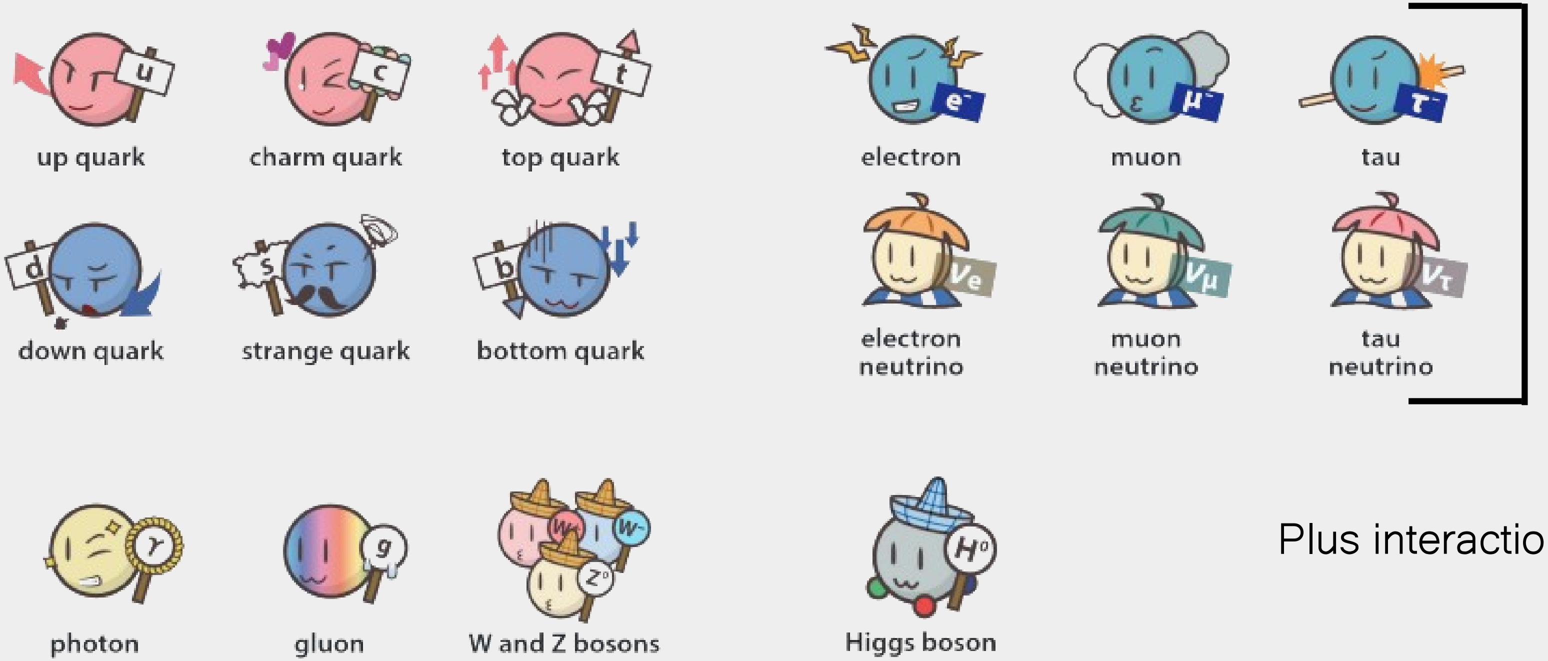
And all sorts of elementary particles…

+ antimatter

Different types of matter: the Standard Model of particle physics

« Daily » matter: what we deal in our everyday life

And all sorts of elementary particles…



+ antimatter

Plus interactions!

The Standard Model of particle physics

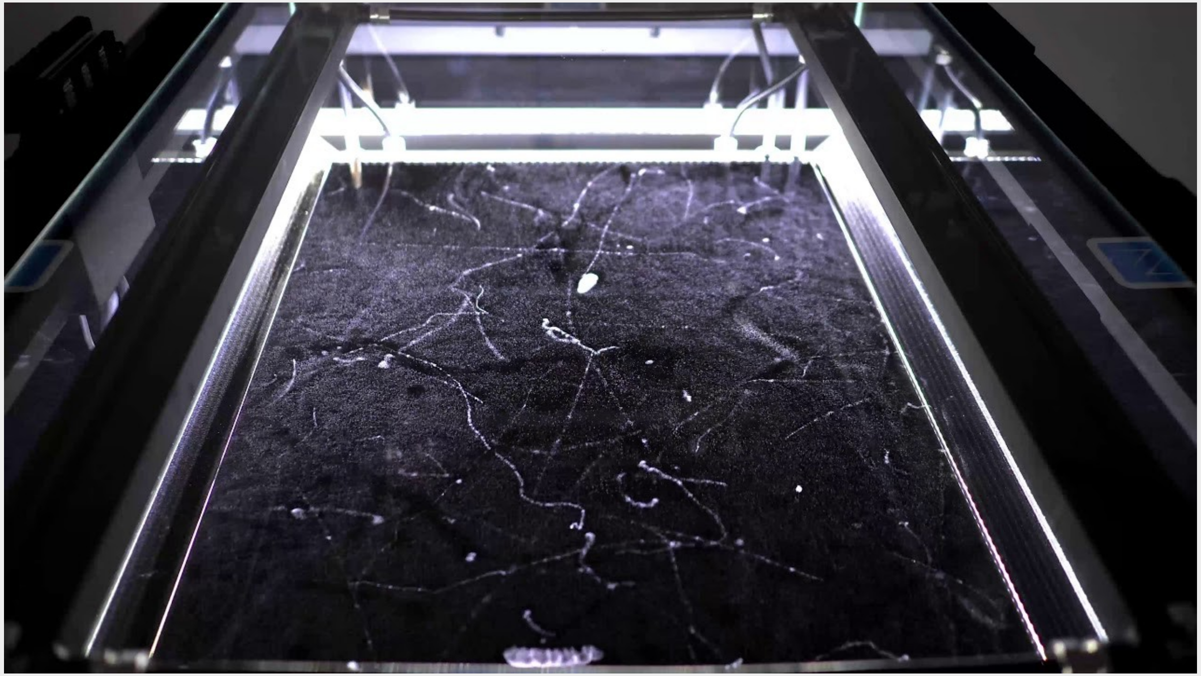
Detecting particles

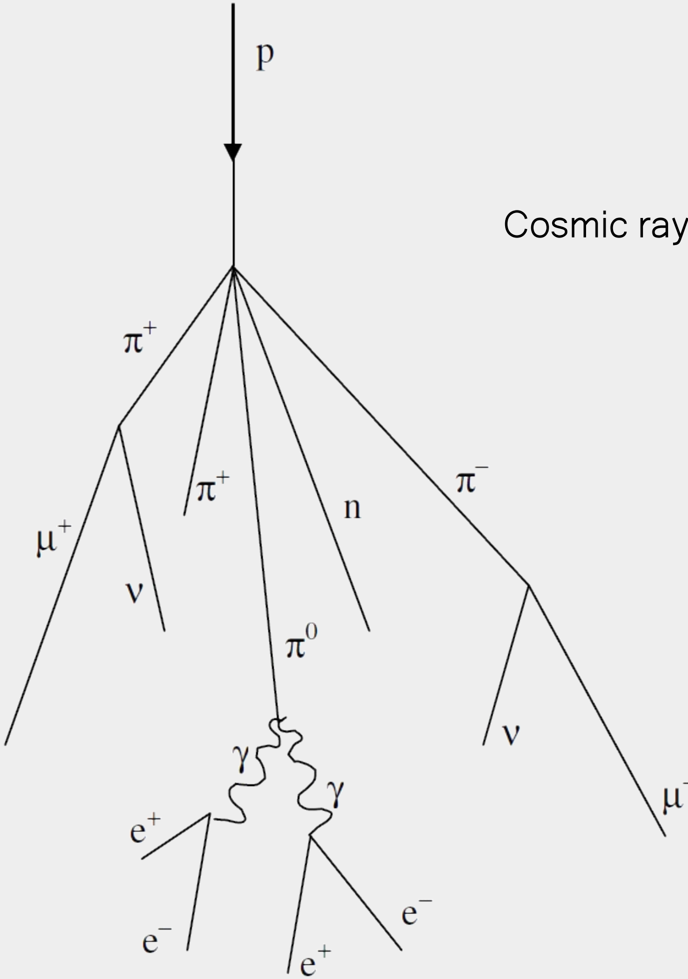
How do we recognise particles from one another ?

→ the way they interact with us

Some are easier to observe than others...

Cloud chamber





Cosmic rays

Discovery of neutrinos : a bit of history

Predicted

H.Becquerel (1896)

Discovery of radioactivity: **β decay**

Only electron observed

Non conservation of total energy

W.Pauli (1930)

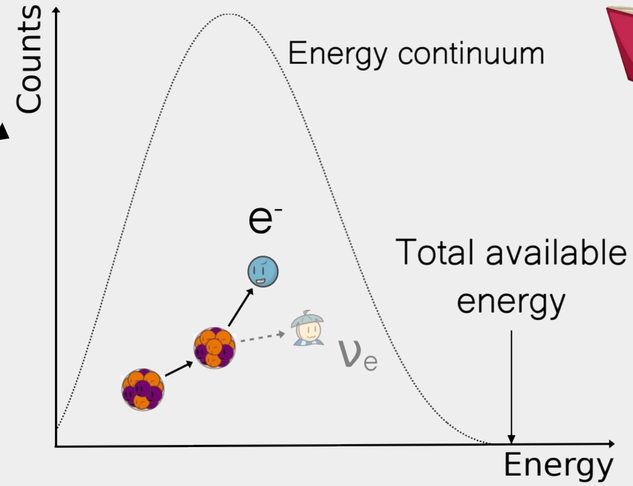
Solution to conserve total energy

“**Neutrino**”: small interaction probability, neutral, spin 1/2, small or null mass

E.Fermi (1934)

Effective theory

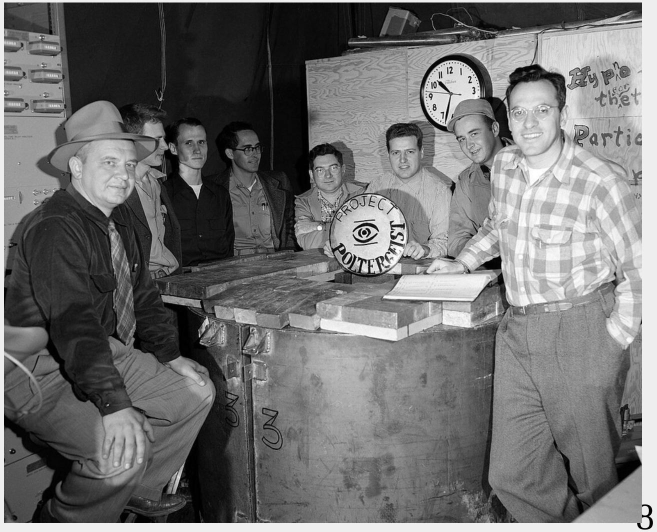
Foundation stone of **weak interaction**



Observed

C.Cowan & F.Reines (1956)

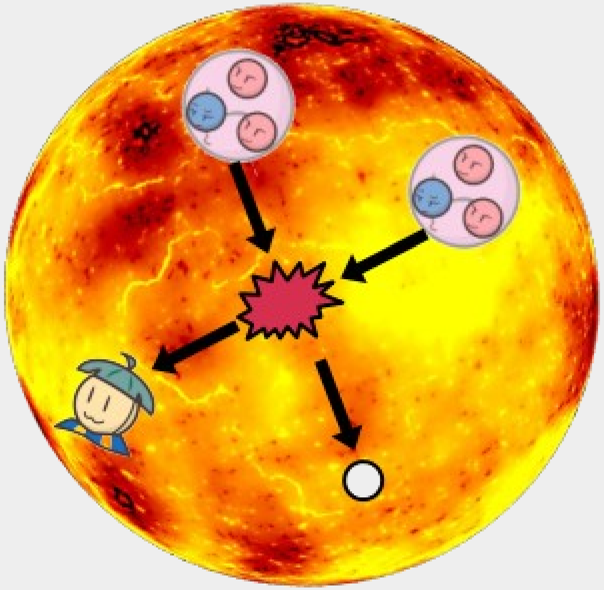
Experimental dicovery



Where are neutrino produced ?

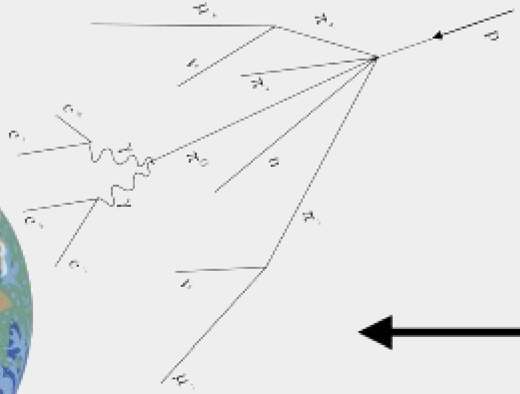
Plenty of sources (on earth, solar system, galaxy and beyond...)

Solar



Geoneutrinos
Reactor
Accelerator

Atmospheric

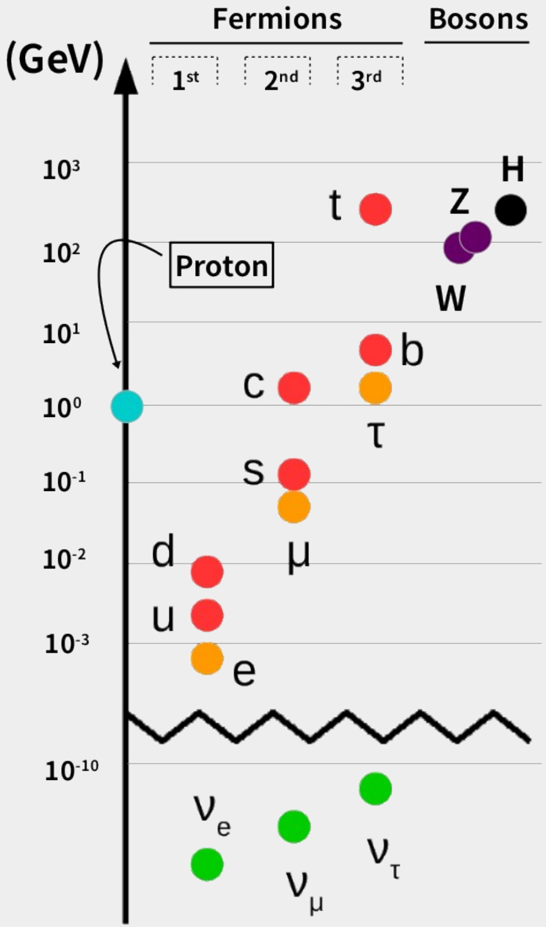


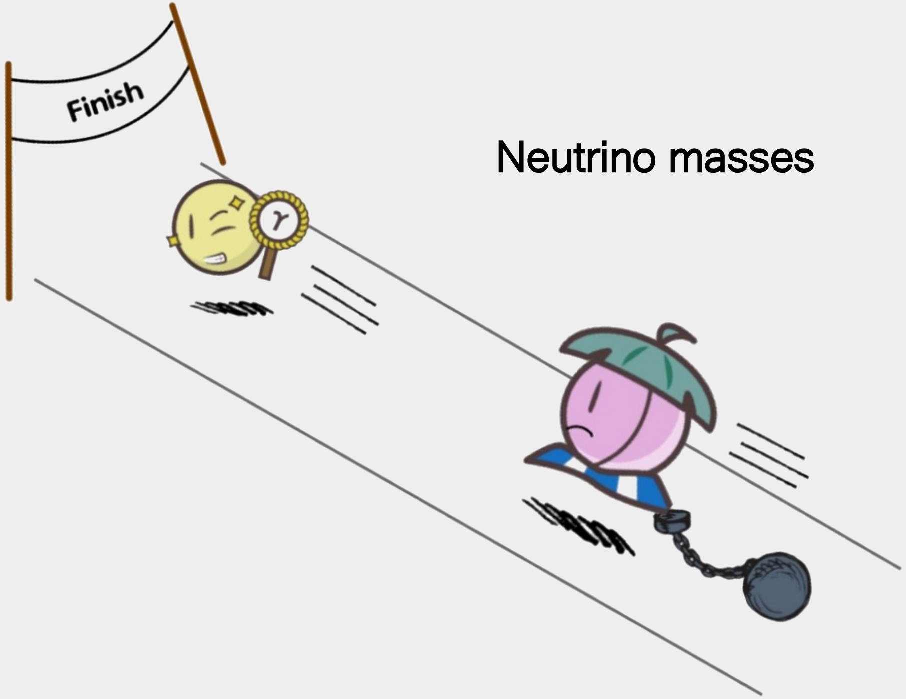
Cosmic
Relic (Big Bang) → next talk

Neutrino detectors are adapted to the neutrino source they aim to detect (neutrino energy...)

Some questions about neutrino properties

Mass hierarchy





Neutrino masses

Neutrinos are massive: Dirac or Majorana particles?

First logic guess: Dirac particles

As other fermions: Higgs mechanism generates neutrino masses

Need to **extend the SM** with new particle (right-handed - chirality - neutrino)

Another proposition: Majorana particles

Origin of neutrino masses different from those of charged fermions ?

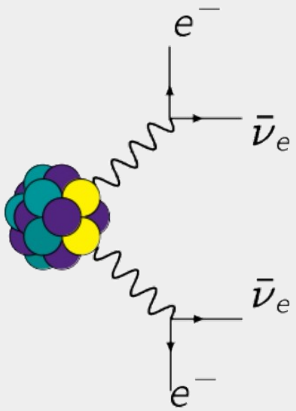
Some rules are broken
Would explain **smallness** of neutrino masses

We need to go *beyond* the Standard Model

Probe: Neutrinoless double beta decay ($0\nu\beta\beta$)

Probe the neutrino nature with neutrinoless double beta decay

2νββ



Simple β energetically impossible

2 simultaneous neutron decay

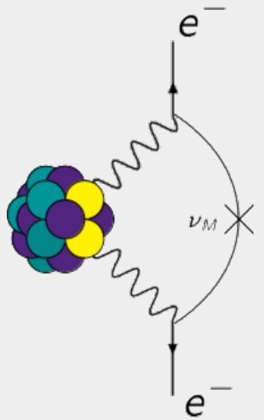
Allowed in SM

Rarest nuclear decay observed:

$T_{1/2}^{2\nu\beta\beta} \sim 10^{18} - 10^{21}$ years

Majorana particle

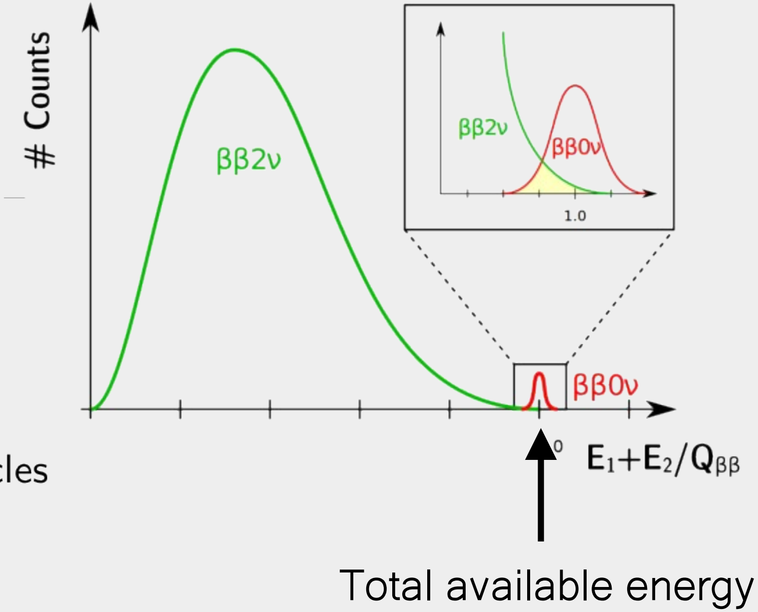
0νββ



Forbidden in SM

Only if neutrinos = Majorana particles

$T_{1/2}^{0\nu\beta\beta} > 10^{24} - 10^{26}$ years

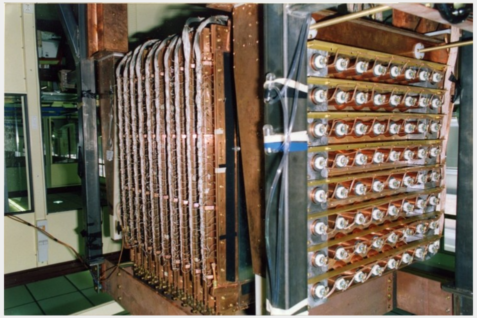


Observe $0\nu\beta\beta$ to probe Majorana nature of neutrino

Semiconductors, bolometers, time projection chambers, liquid scintillators, **tracking calorimeters**

Prototypes (1989-1997)

NEMO(1)

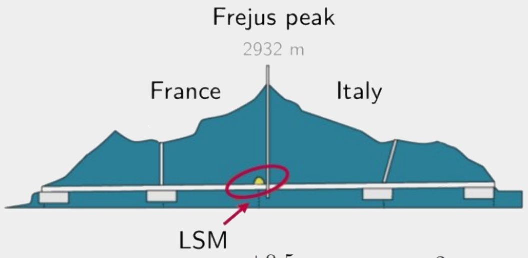


NEMO2

NEMO3

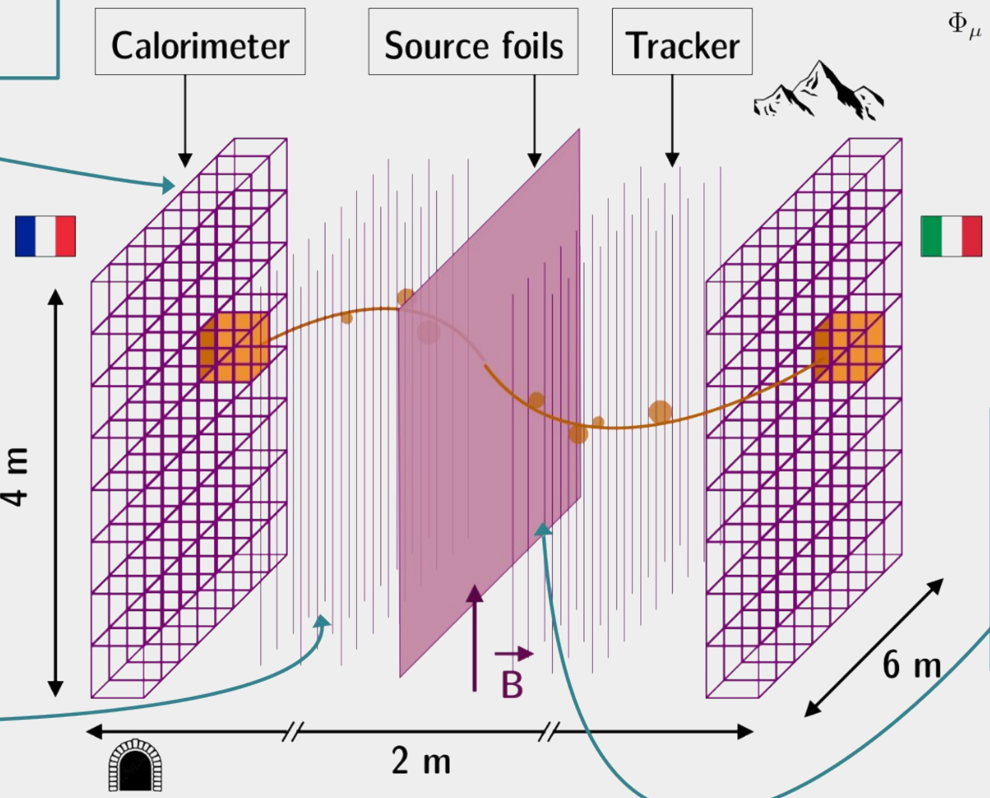
...SuperNEMO!!

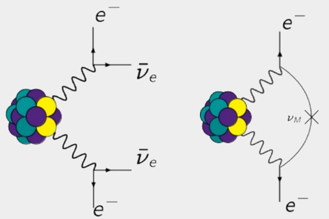
The SuperNEMO demonstrator: an open view



$$\Phi_\mu = (5.4 \pm 0.2^{+0.5}_{-0.9})\ \mathrm{muons/m^2/d}$$

Segmented in optical modules
Measure individual particles' energies and times of flight



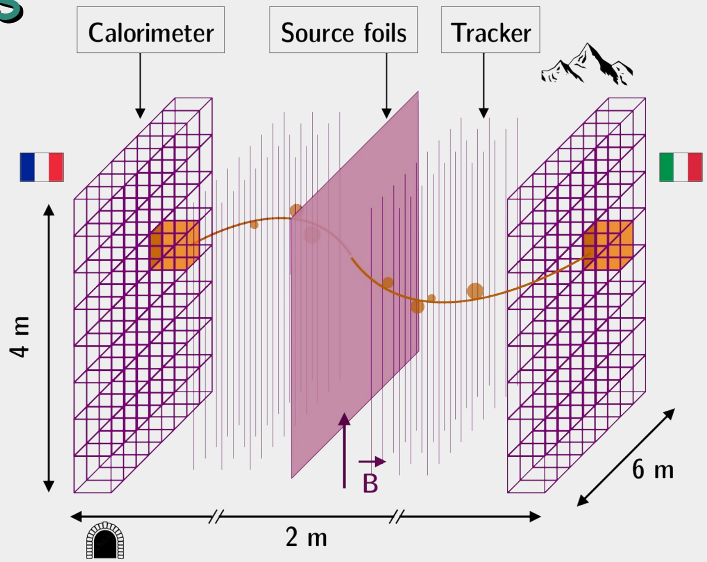


25 G from copper coil
Bend charged particles trajectories

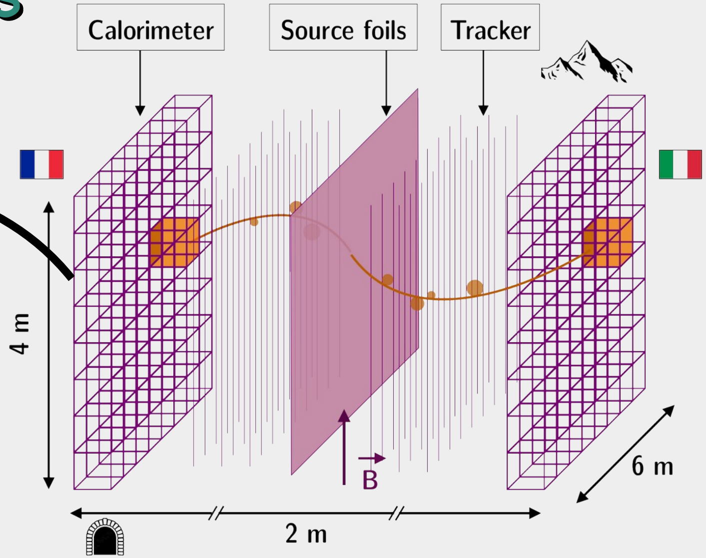
Wire chamber
Particles' track reconstruction and identification

ββ isotope
~100 μm thickness for the electrons to escape from it

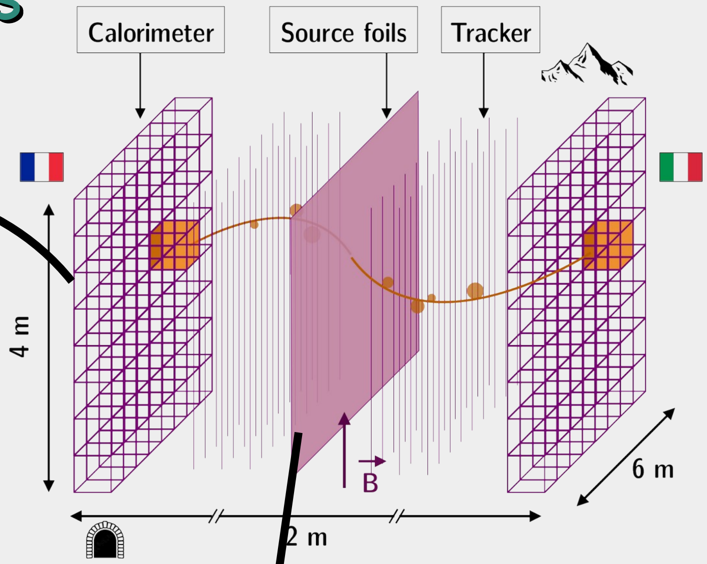
The SuperNEMO demonstrator: a few pictures

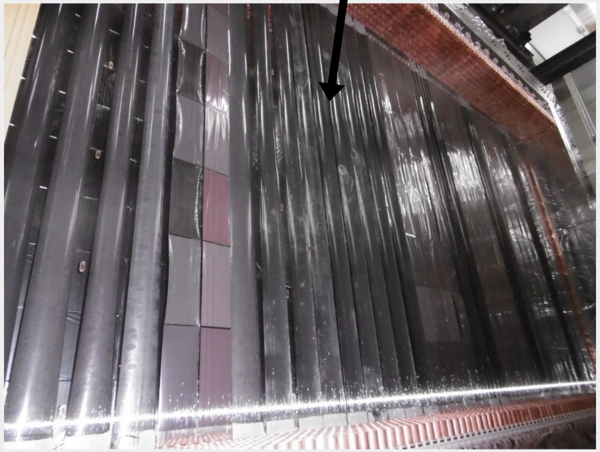


The SuperNEMO demonstrator: a few pictures

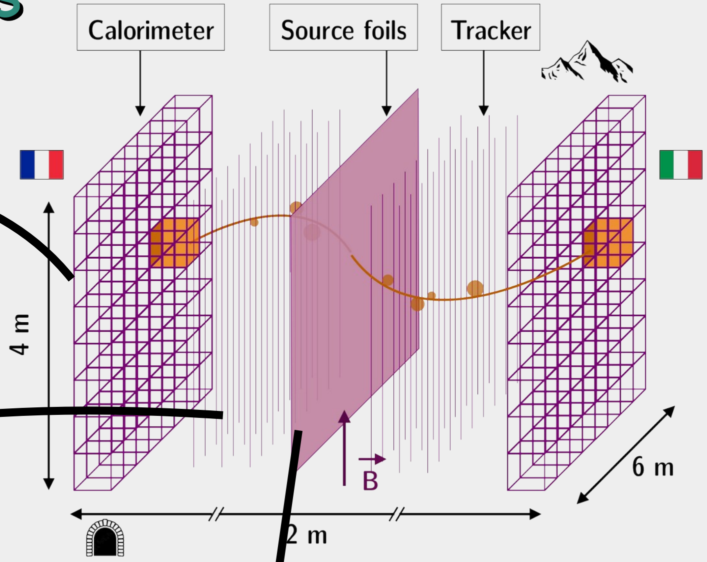


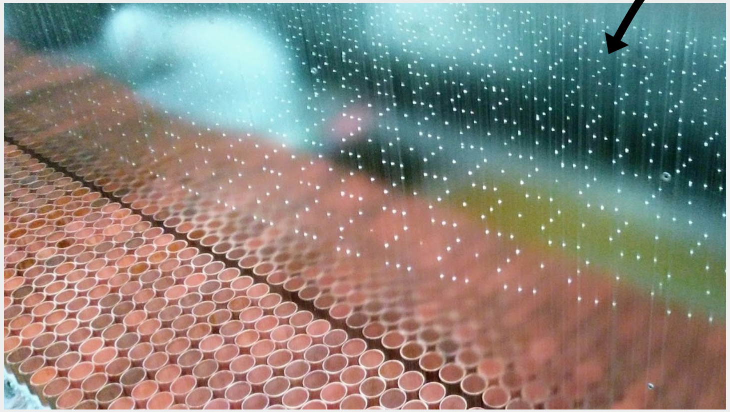
The SuperNEMO demonstrator: a few pictures

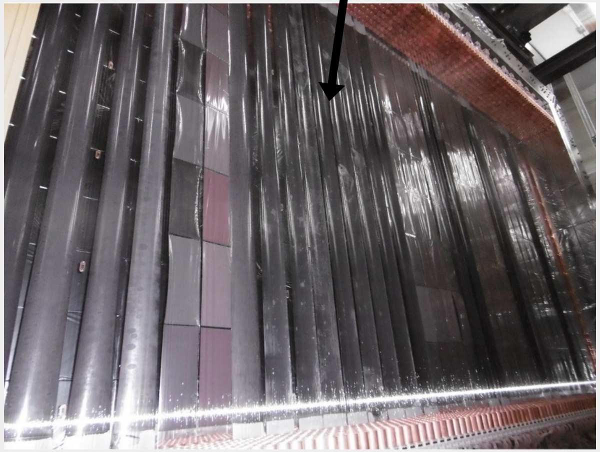




The SuperNEMO demonstrator: a few pictures





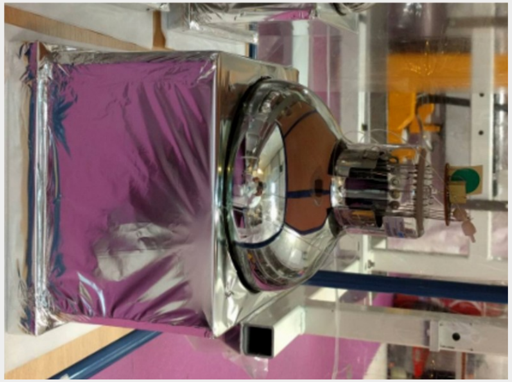


What is a signal? The SN calorimeter example

1- Interaction inside scintillator → Scintillation photons created

2- Multiplication of the scintillation photons inside the photomultiplier

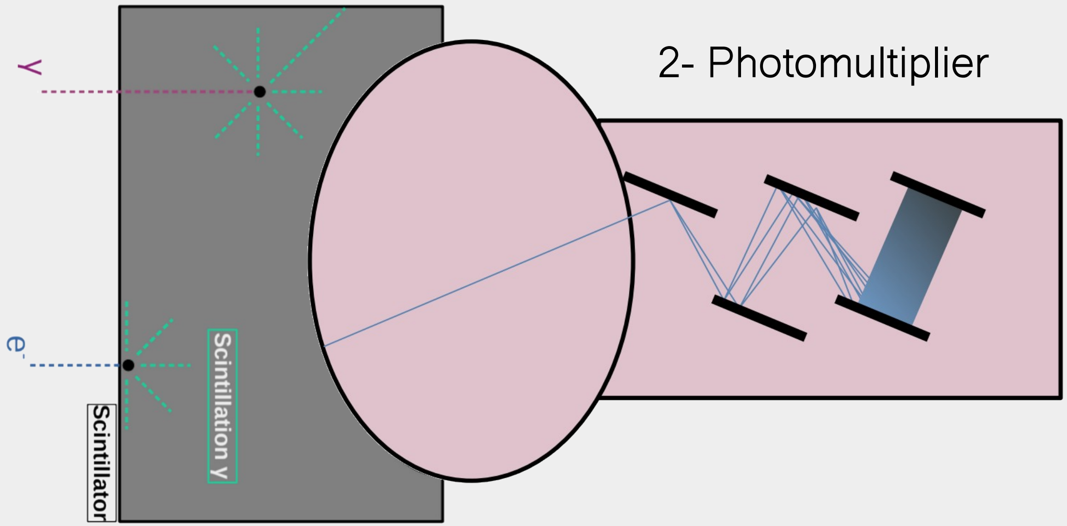
One optical module (x712)



scheme →

1- Scintillator

2- Photomultiplier

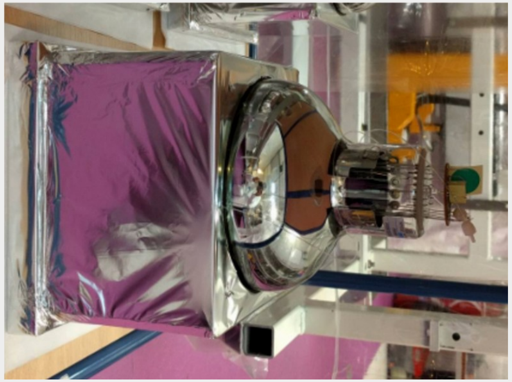


What is a signal? The SN calorimeter example

1- Interaction inside scintillator → Scintillation photons created

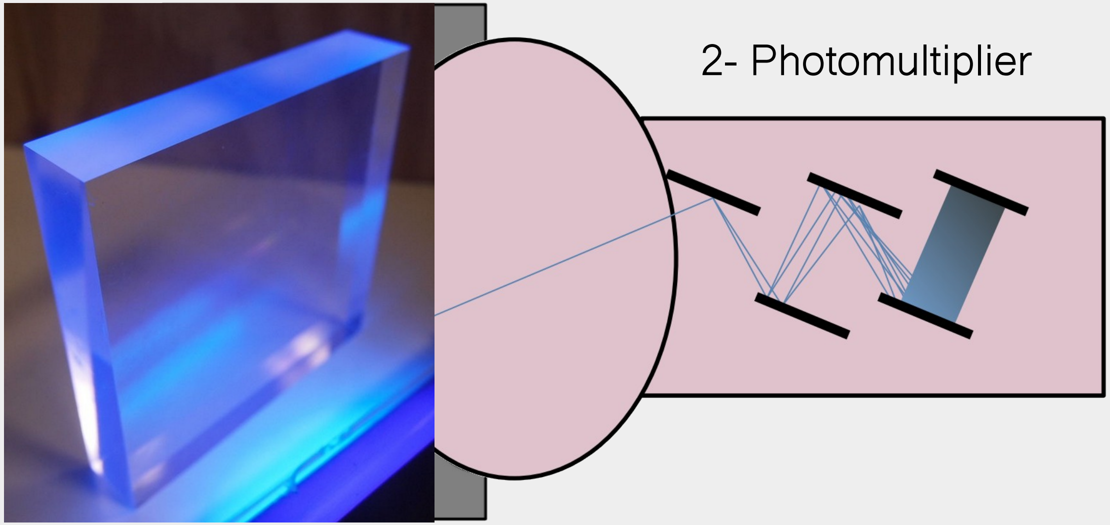
2- Multiplication of the scintillation photons inside the photomultiplier

One optical module (x712)



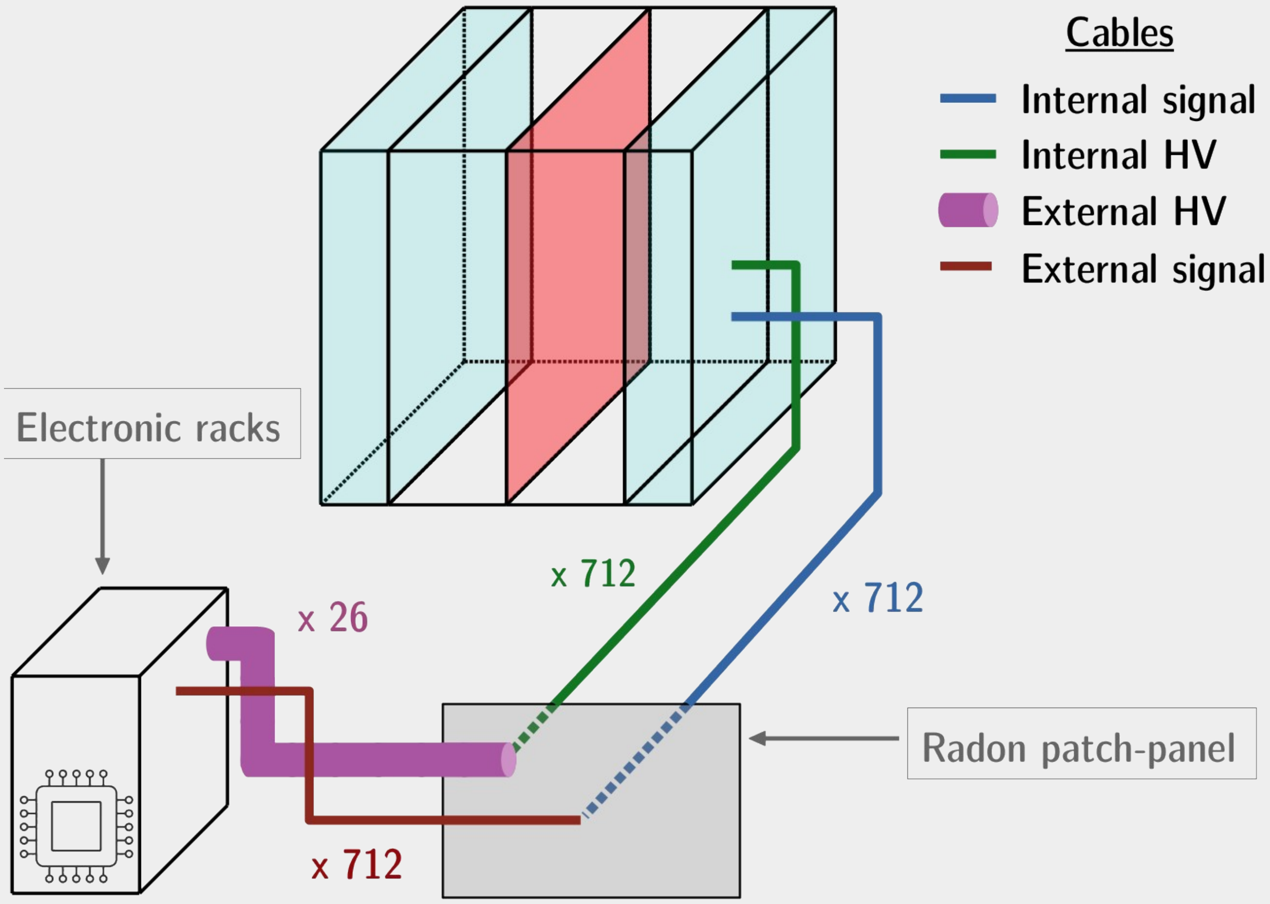
scheme →

1- Scintillator



From particle interaction to signal

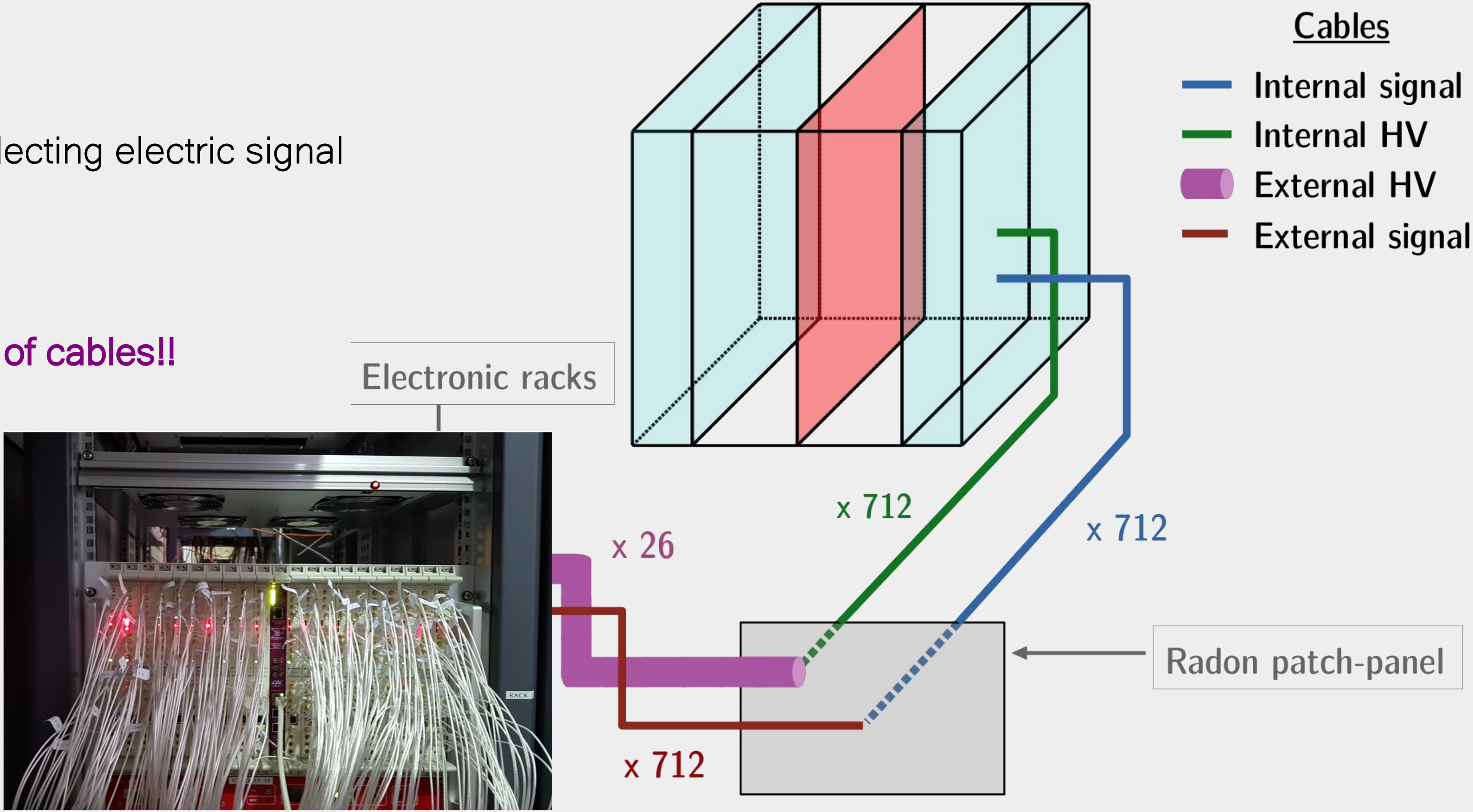
Collecting electric signal



From particle interaction to signal

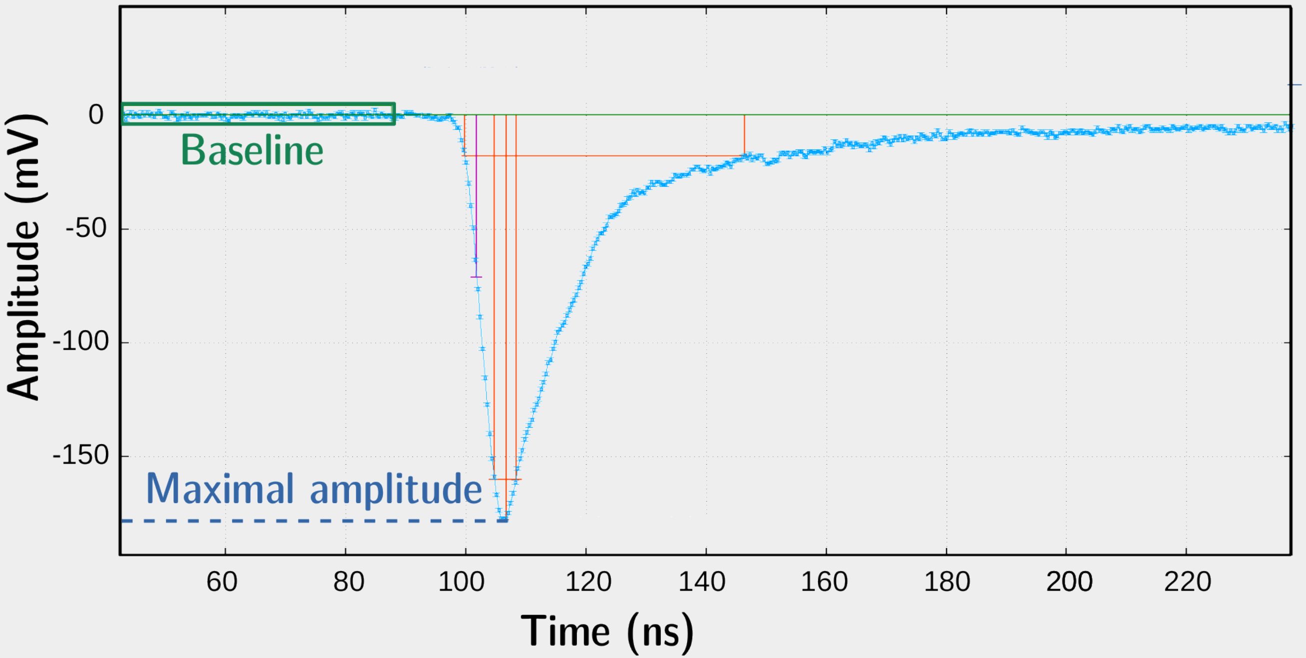
Collecting electric signal

A lot of cables!!



Using the waveform to deduce infromation on the interaction

The shape of the waveform depends entirely on the type of detector

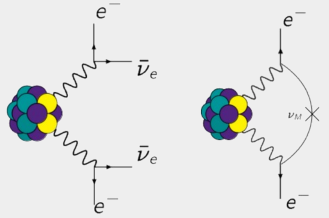


- Energy = deposited charge
- Time arrival of particles

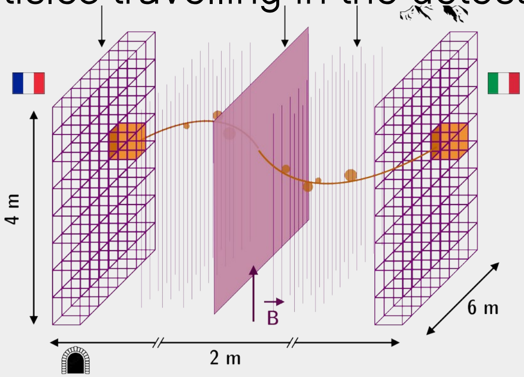
Using complementary information of tracker signal

The complete detection chain

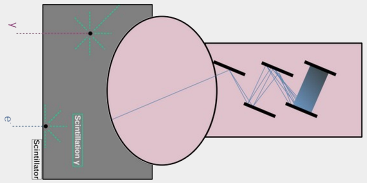
The decay we want to detect



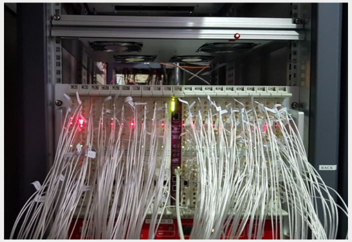
Particles travelling in the detector



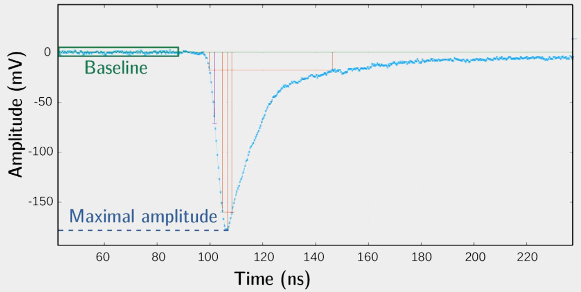
Interaction of particles



Electric signal collection



Information about energy and time



What's next?

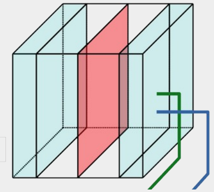
Now what do we do with this information?

Hint: years of data collection → won't do it by hand

Precise simulations of detector
(geometry + material)
Monte-Carlo method

GEANT4
A SIMULATION TOOLKIT

Data acquisition



Reconstruction of the event
Successive algorithms allowing to characterise events

Personal code example

Analysis of simulated or real data

Personal code example


THANK YOU