KM3NeT Masterclass

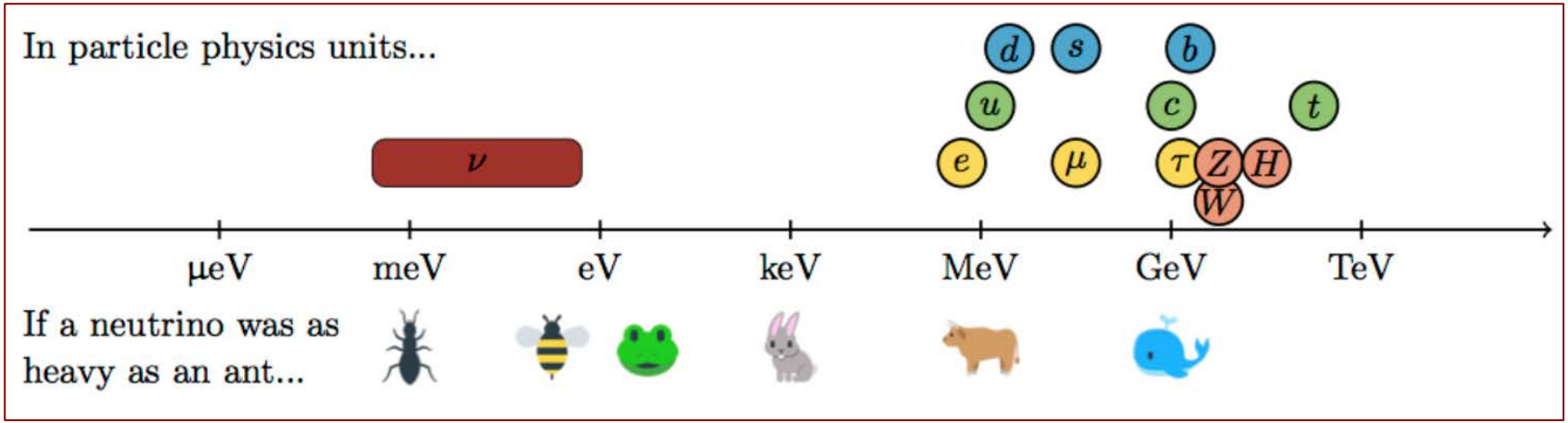
PART I: Introduction to Neutrinos

Neutrinos are special: size and mass

Although neutrinos are among the most abundant particles in the Universe, we are only just beginning to understand them…

They are the lightest elementary particles of matter that we know. In fact, they are so light that we don't know their exact mass!!!

For example: if an electron had the mass of a cow, a neutrino would be as light as an ant.



Neutrinos are special: flavours and forces

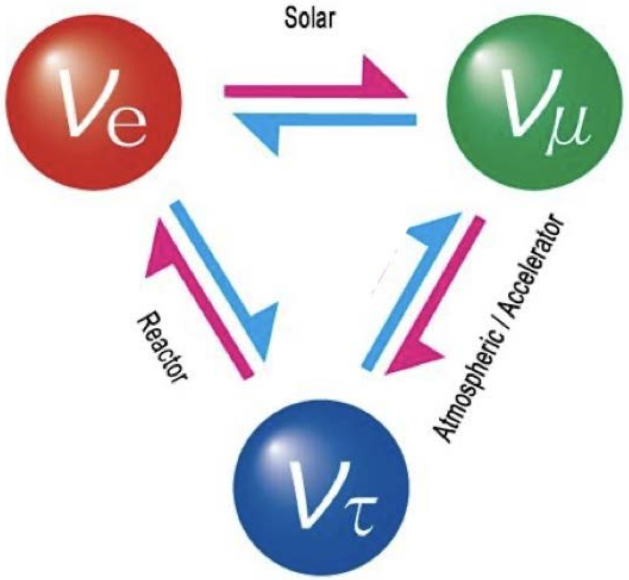
Neutrinos are the particles that interact most rarely in the Standard Model, only through the weak force.

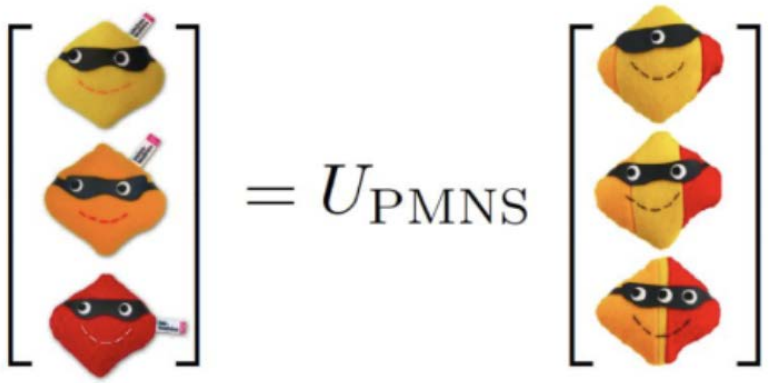
There are three different types of neutrinos, which physicists call flavours.





Neutrinos can change flavour!



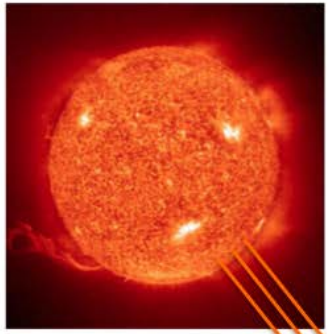


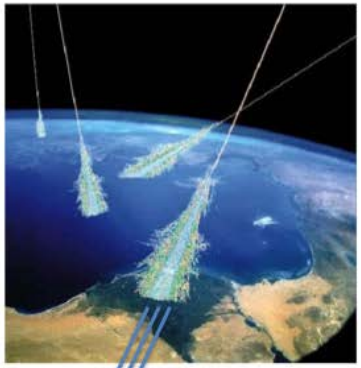
“Neutrinos do not have a single identity”:

Flavour states (v_e, v_μ, v_τ) are superpositions of mass eigenstates, which allows neutrinos to change type while traveling.

This is called neutrino oscillations!

Neutrinos are evervwhere



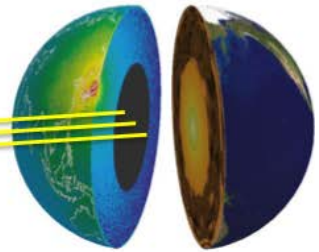


Sun: 5×10^{12}/second

Atmosphere: ~20/second







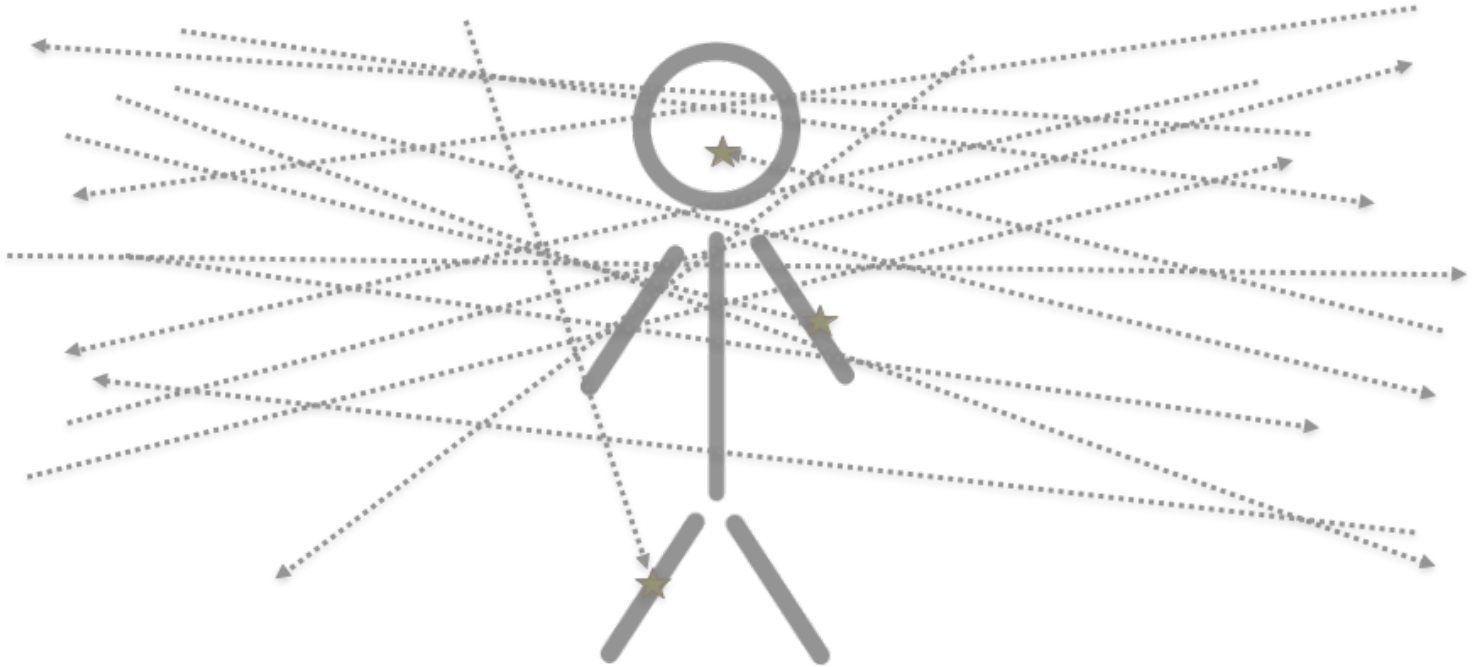
Even bananas emit neutrinos.

For a surface of 10x10 cm^2

Earth: ~10^9/second

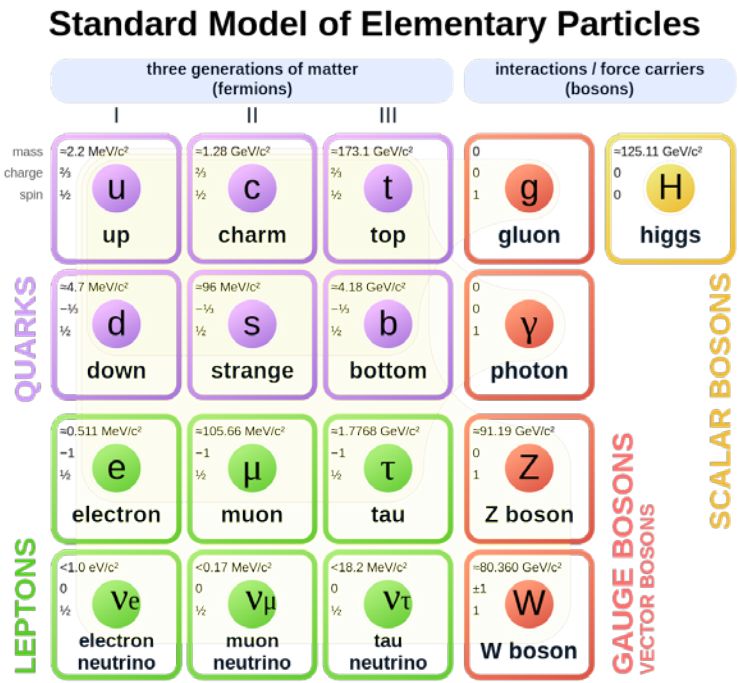
But still…

they barely interact with anything.



Trillions pass through your body every second, yet they leave no trace.

Elementary Particles

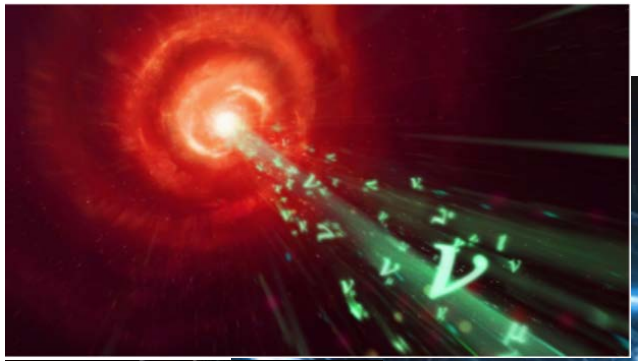


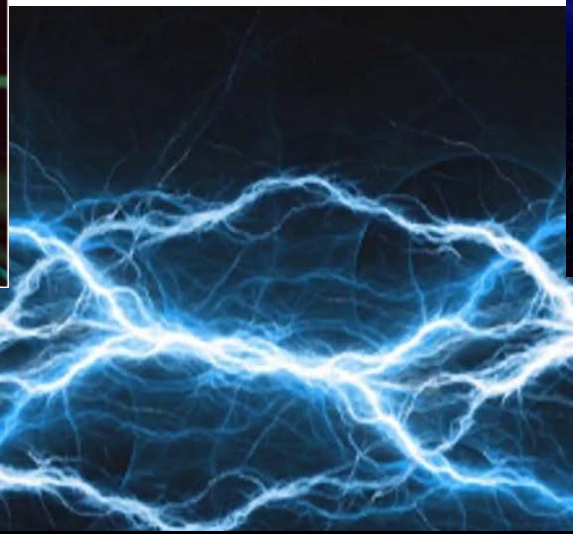
Properties of neutrinos:

- No electric charge
- Very small mass, very fast
- Three flavours…
- …each associated with a charged particle of the same flavour (e, μ, τ)…
- …with the possibility to *oscillate* (i.e., change flavour)
- They interact very rarely with matter

Neutrinos are special...

Neutrinos have no charge… they barely interact with anything.









Scientists can't use electric or magnetic forces to capture them.

Can we detect Neutrinos?

How can you detect something that leaves *almost* no trace and barely (weakly) interacts with matter?

We have to think smarter to detect them.



That’s the challenge for today!

Why neutrinos?



Why are scientists so interested in detecting neutrinos?

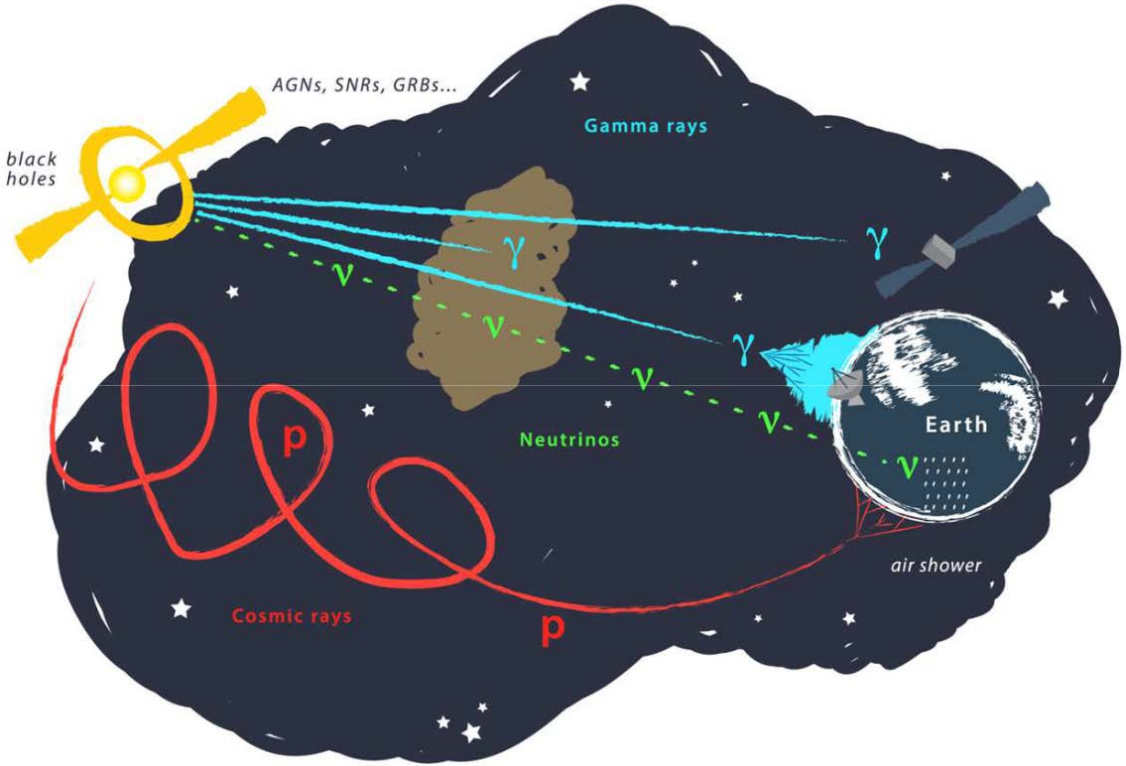
Remember: Neutrinos are like ghosts in the Universe… they can pass through almost anything…

PART II: Introduction to Neutrino ASTRONOMY

How do we observe the universe?



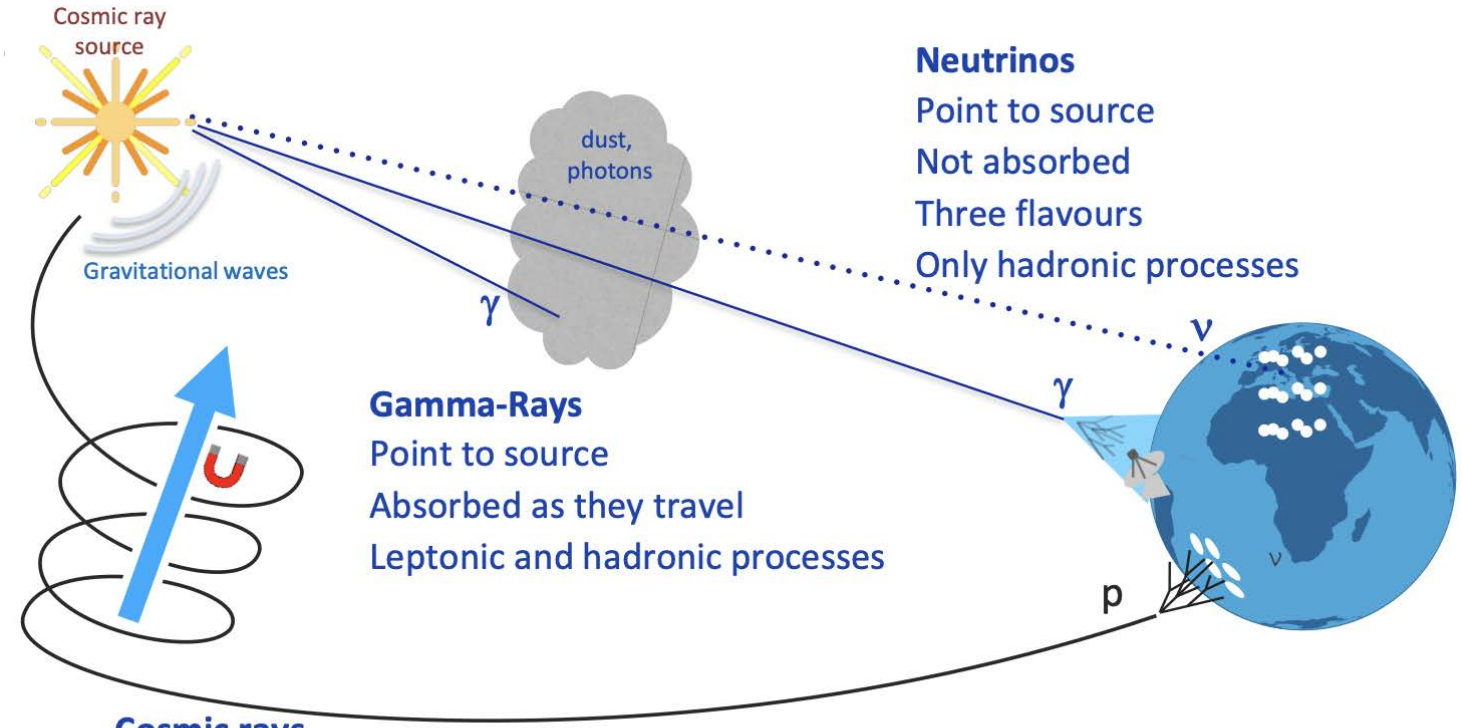
Why neutrinos?



Neutrinos as Cosmic Messengers:

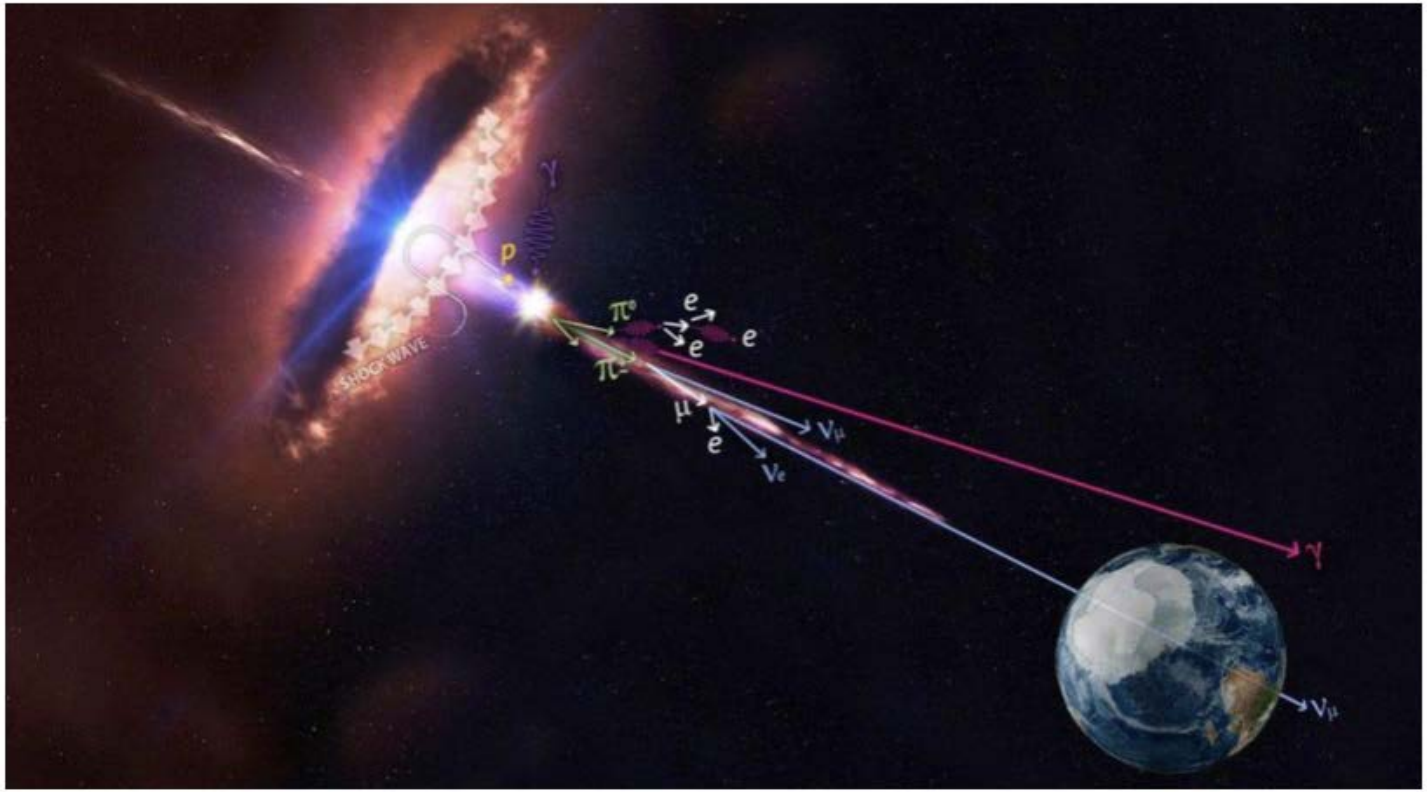
- They travel in **straight lines**
- Practically, they are **not absorbed by the interstellar medium**
- They can **reveal information about processes in astrophysical sources** that light or cosmic rays cannot reveal.

Neutrinos and multimessenger

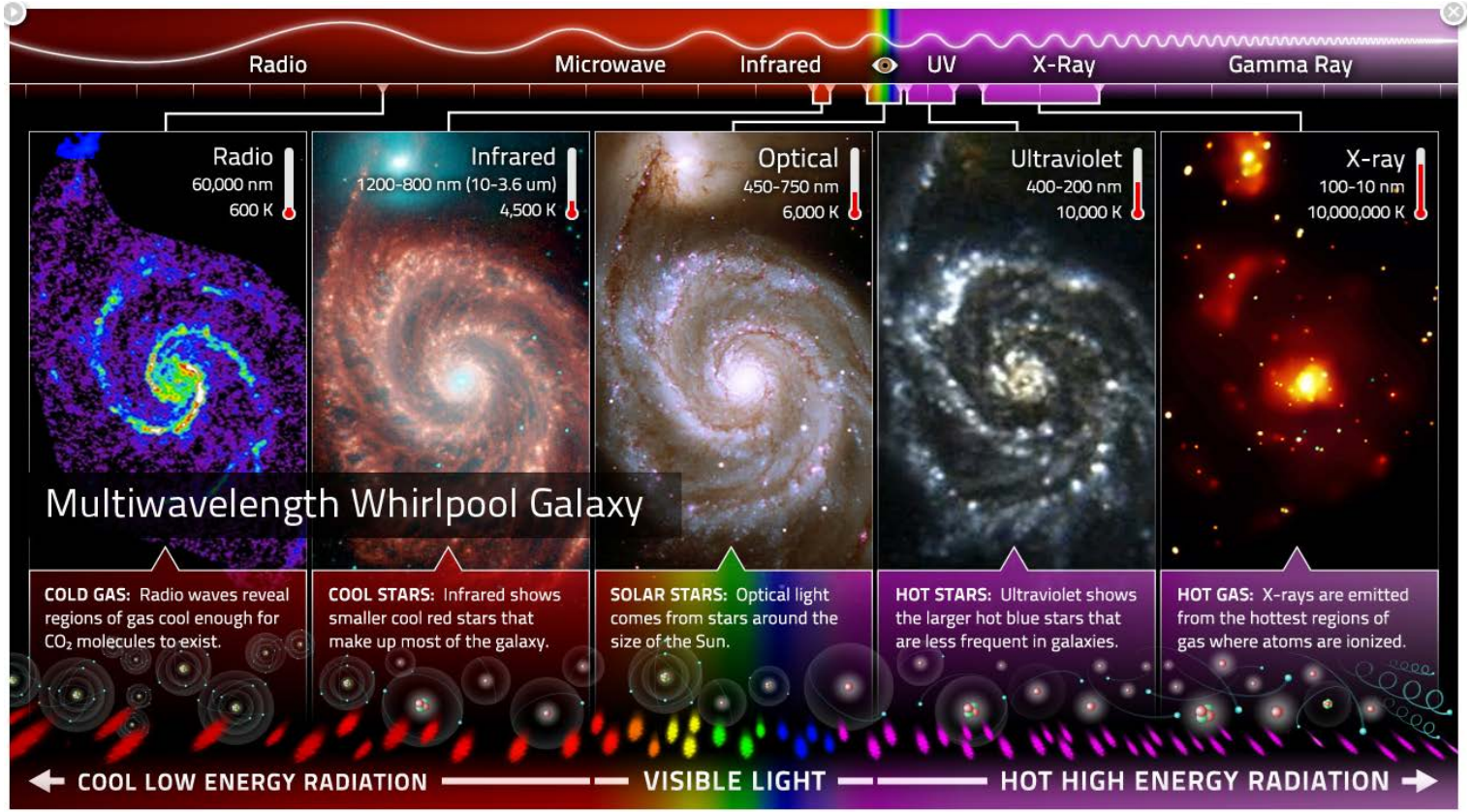


Multi-messenger astronomy: combining different signals to study extreme astrophysical phenomena. Each one brings one piece of the puzzle.

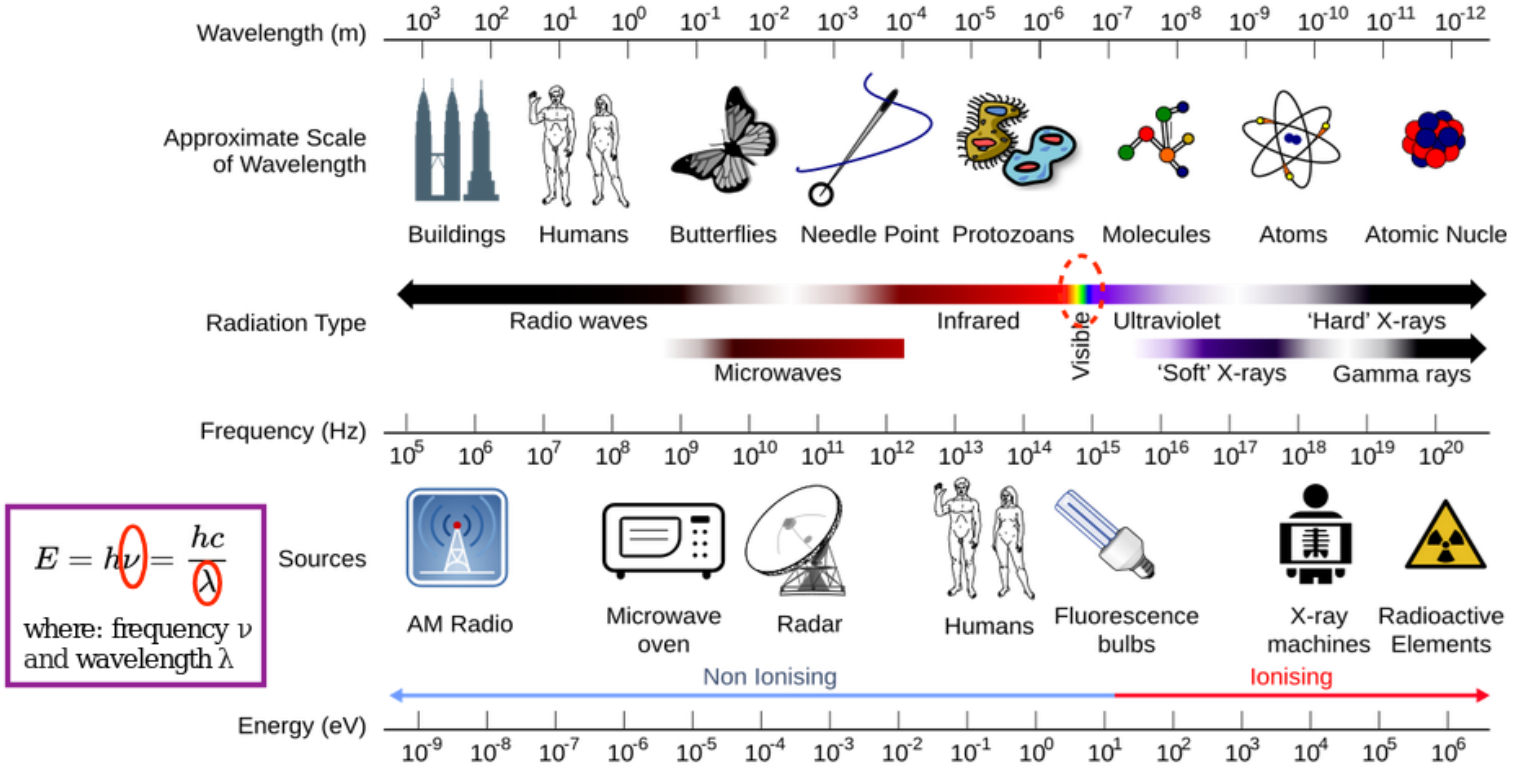
High-energy neutrino astronomy



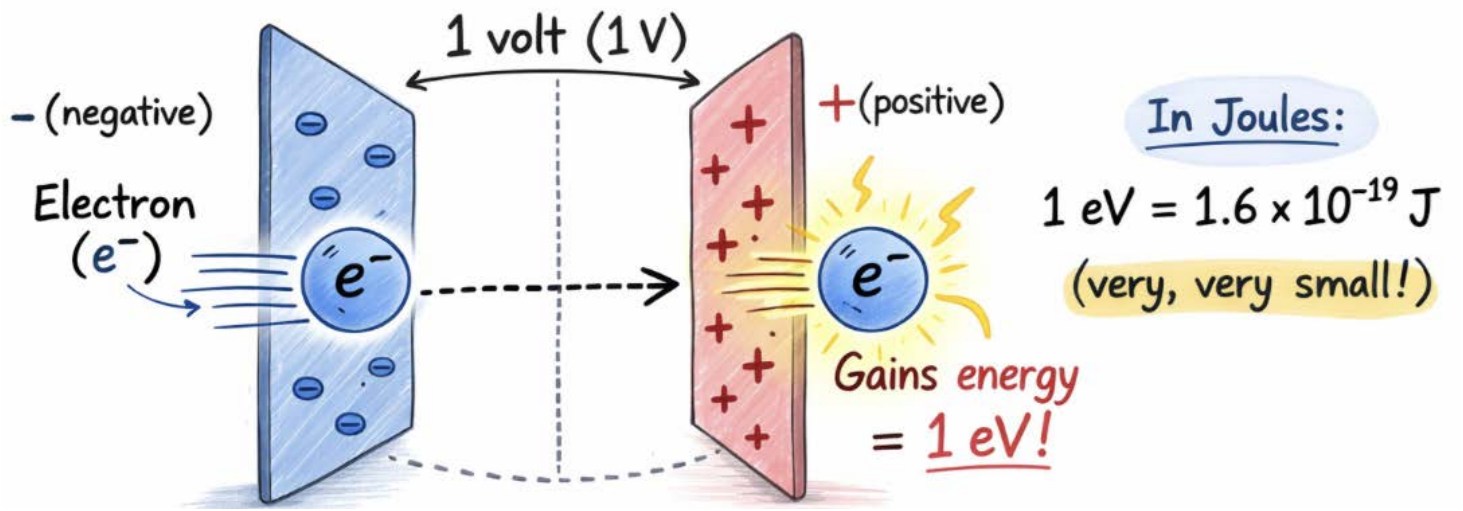
THE UNIVERSE AT DIFFERENT WAVELENGTHS



Energy and Wavelength Ranges



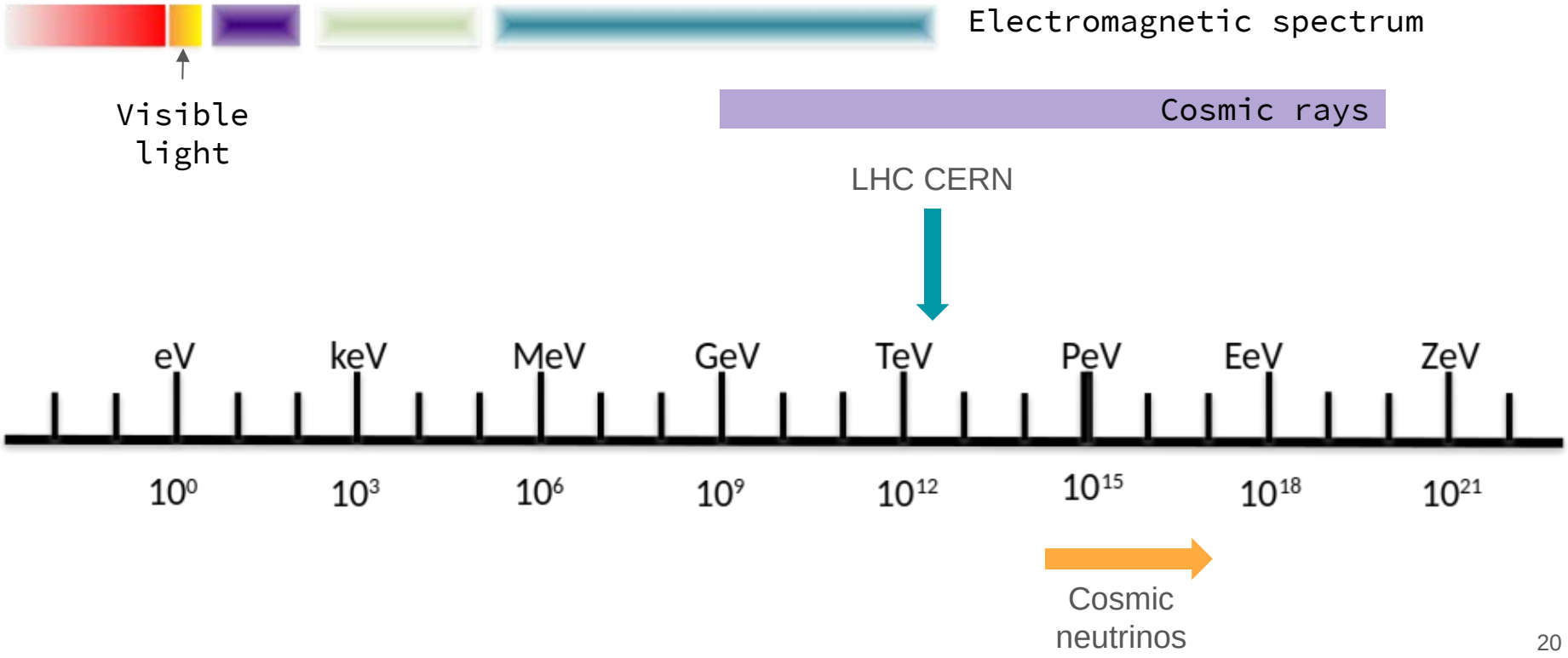
What is the electronvolt ?



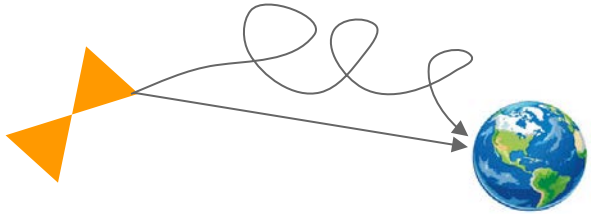
An **electronvolt (eV)** is the kinetic energy gained by an electron accelerating through a potential difference of **1 Volt**.

It is a tiny unit of energy used to measure the energy of **subatomic particles** in physics.

Orders of Magnitude of Energy



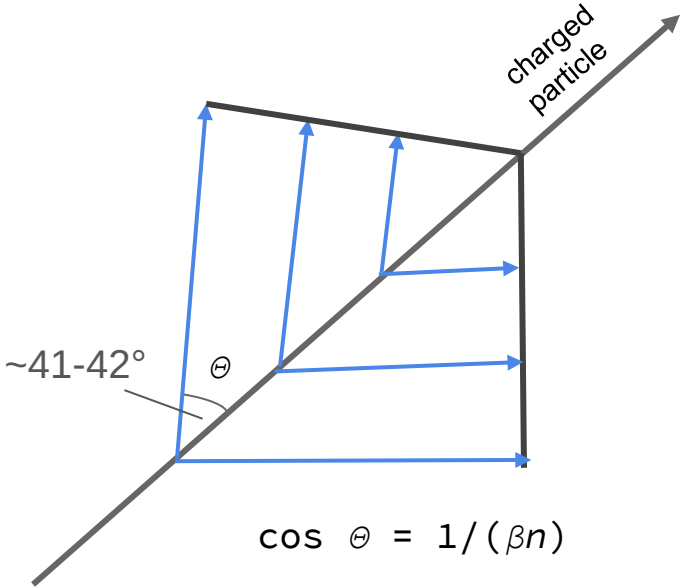
Cosmic messengers

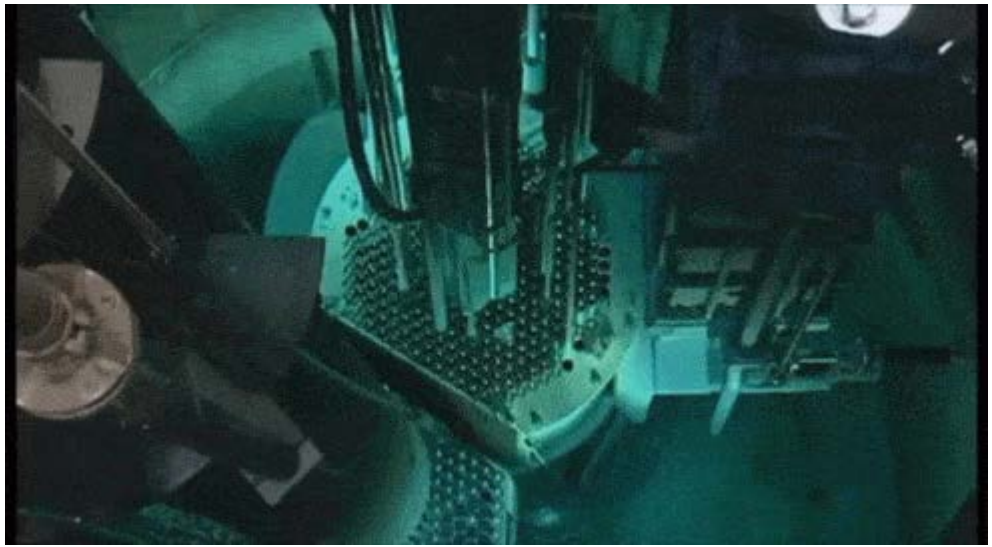


	Electromagnetic Radiation	Cosmic Rays	Neutrinos
Properties	No electric charge	Charged particles, therefore influenced by magnetic fields	No electric charge
Interaction	Absorbed by molecular clouds, …	Interact in the Earth's atmosphere	Not absorbed by interstellar matter
Information	Signature of various phenomena	Evidence of particle acceleration	Provides additional information

THE CHERENKOV EFFECT

A flash of blue light produced when a charged particle travels faster than light in a medium.

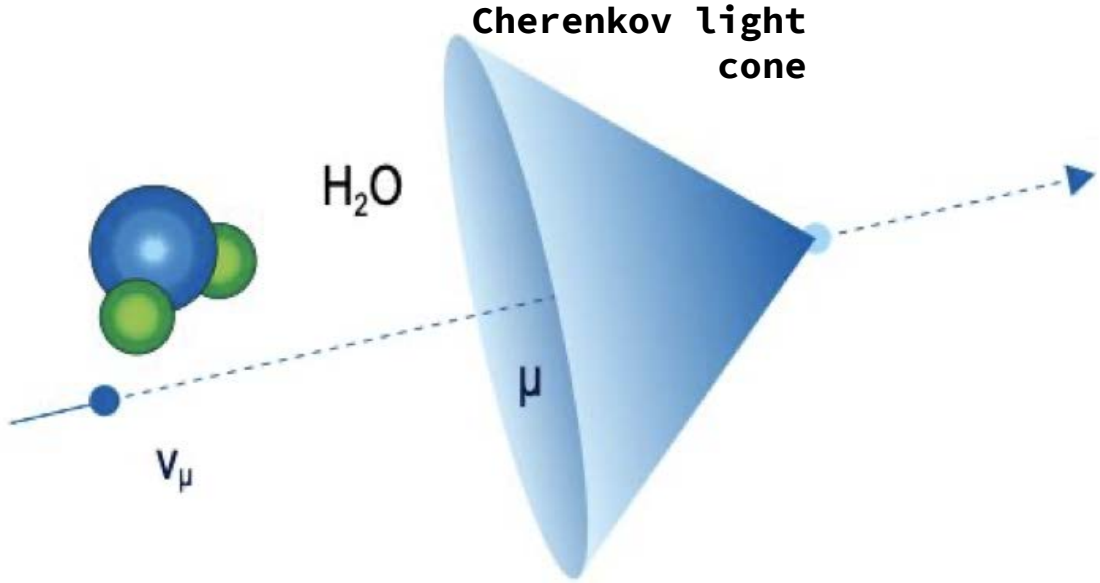




where: ***β*** = speed of particle/speed of light in vacuum, ***n*** = refractive index of the medium

Neutrino detection method

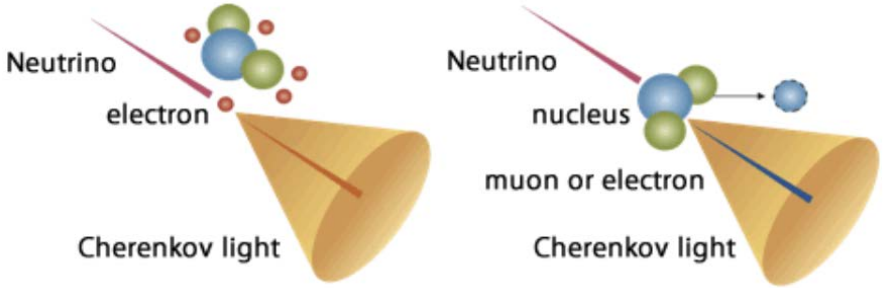
A flash of blue light produced when a charged particle travels faster than light in a medium.

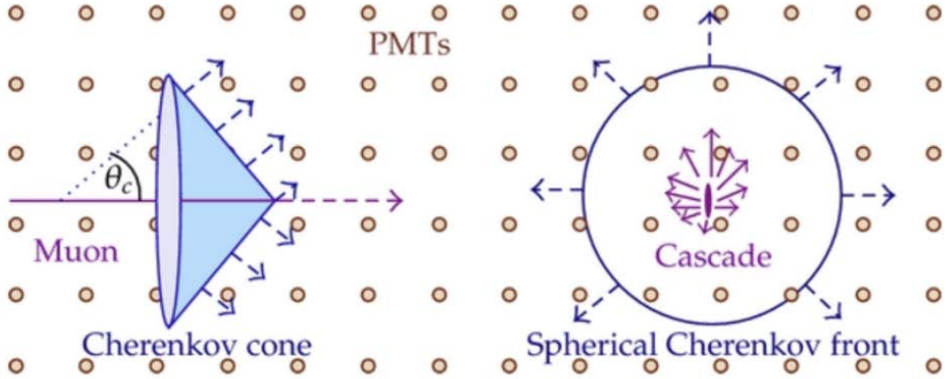


Neutrino interaction in the medium

Neutrino INTERACTIONS AND DETECTION PRINCIPLE

Two types of interactions:
Charged Current (CC) and Neutral Current (NC) interactions



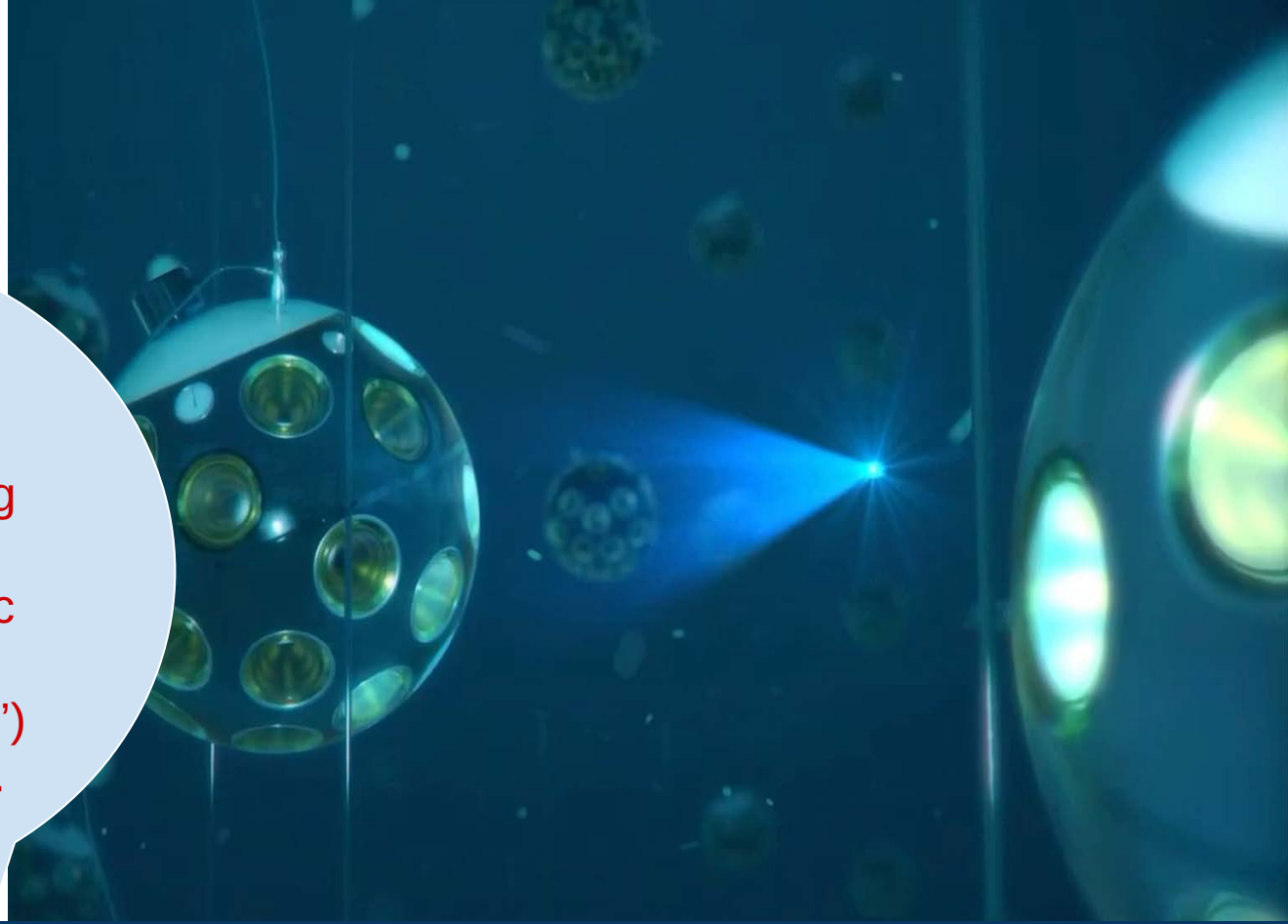


Neutrino Detection:

- Transparent medium
- Detectors are located deep underground or underwater to reject background (atmospheric muons)
- Huge detection volumes

NEUTRINO DETECTION

When a neutrino interacts, it can produce charged particles propagating faster than light in water - characteristic blue light (the ‘Cherenkov radiation’) will then be emitted.

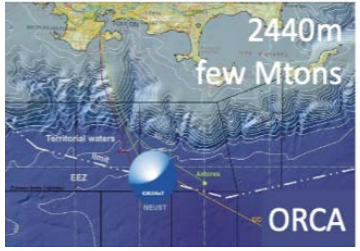


Scientists deploy large-scale deep-sea neutrino detectors equipped with photosensors to detect neutrino-induced signals.

PART III: THE KM3NeT DETECTOR

The KM3NeT detectors: ARCA&ORCA

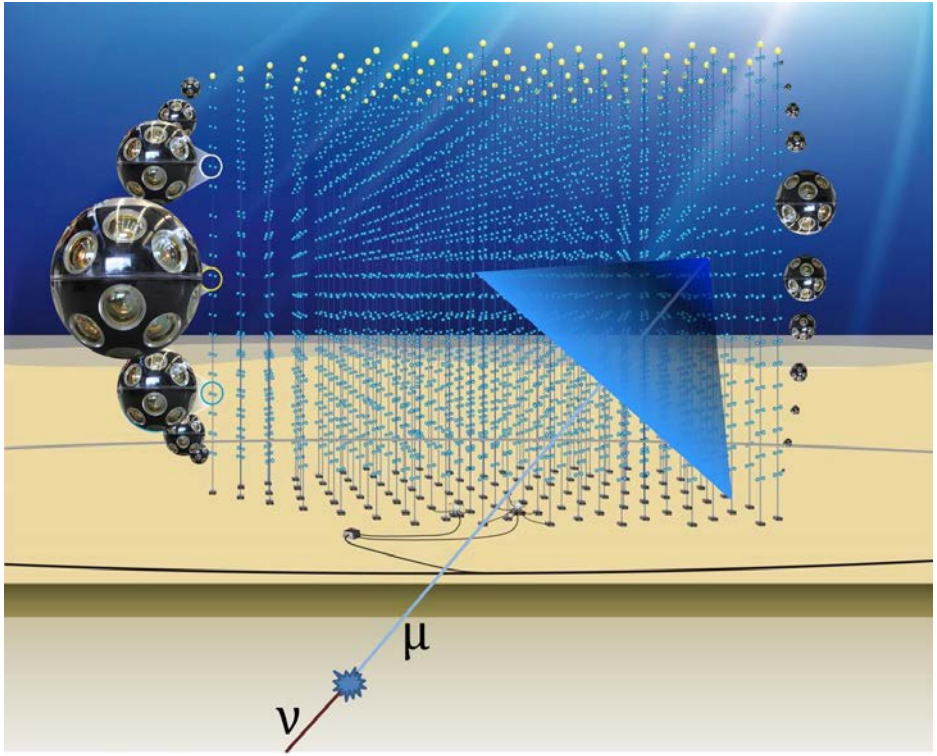




Neutrino Oscillations
Mass Hierarchy



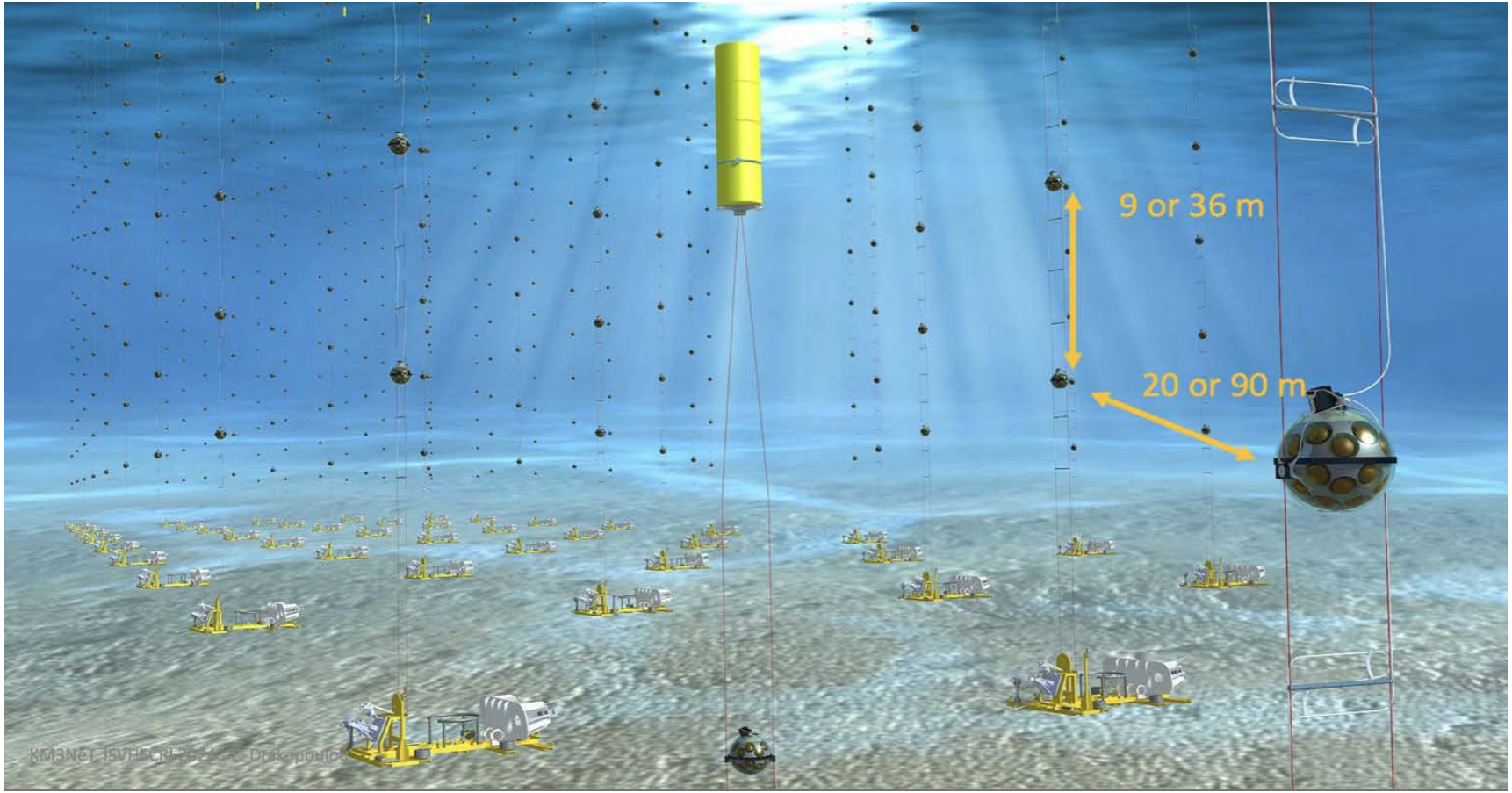
Detection of neutrinos from
astrophysical sources



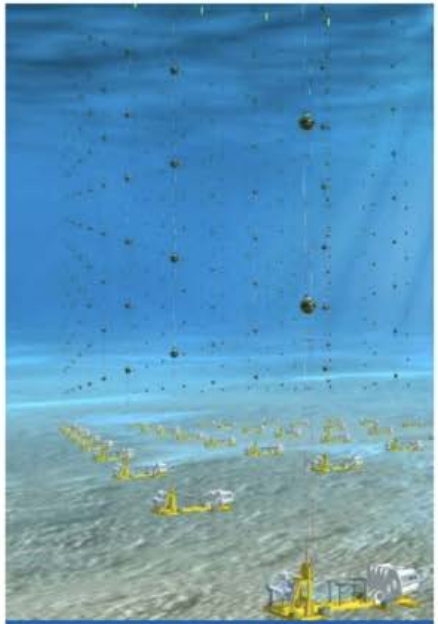
Same technology for ARCA and ORCA



The KM3NeT detectors



The KM3NeT optical modules



1 building block =
115 lines



1 line =
18 optical modules

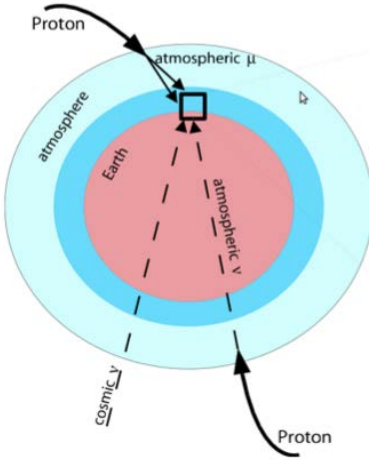


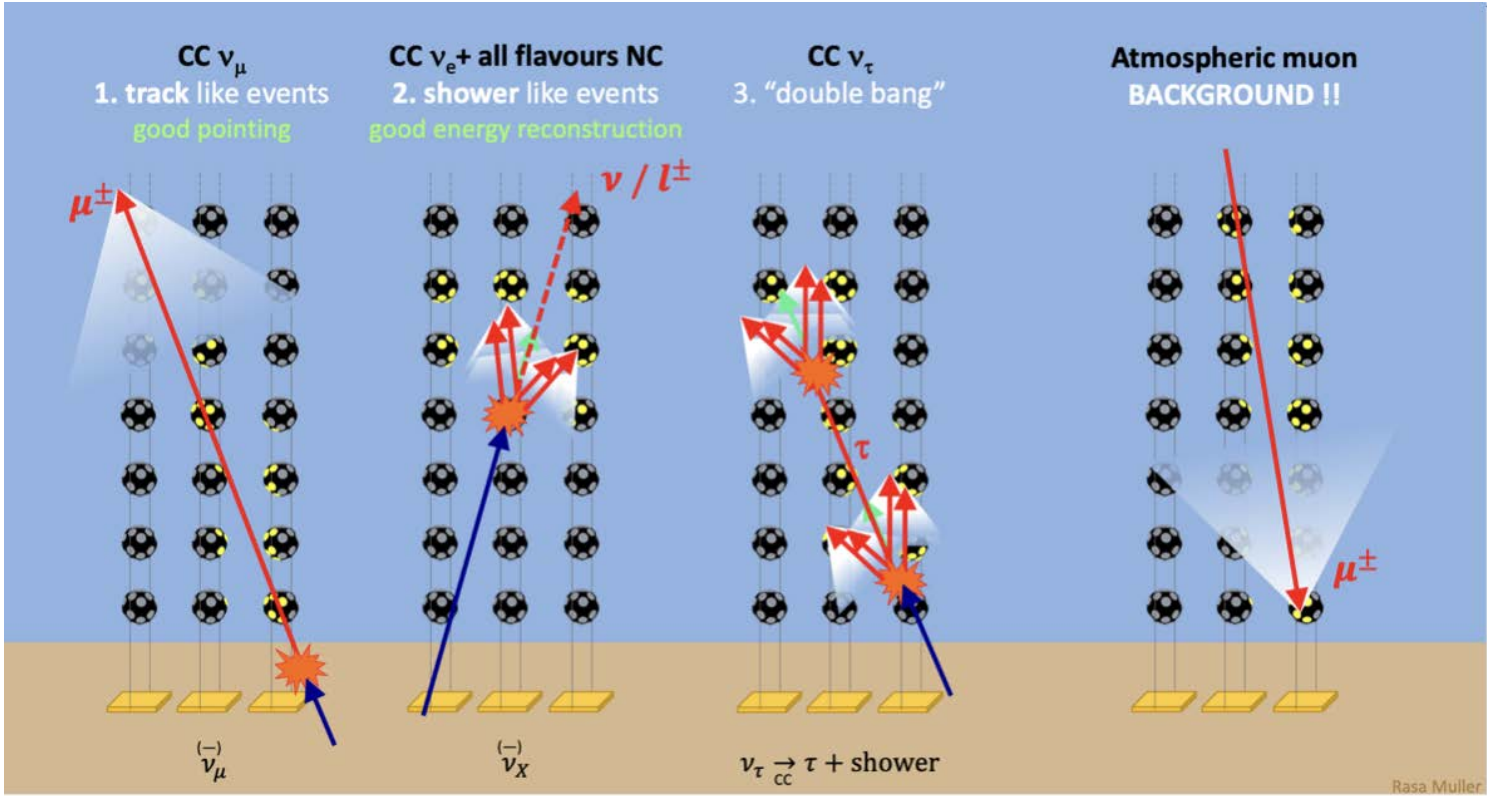
1 optical module =
31 photomultiplier tubes



71 unique components
(in solid or liquid phase)

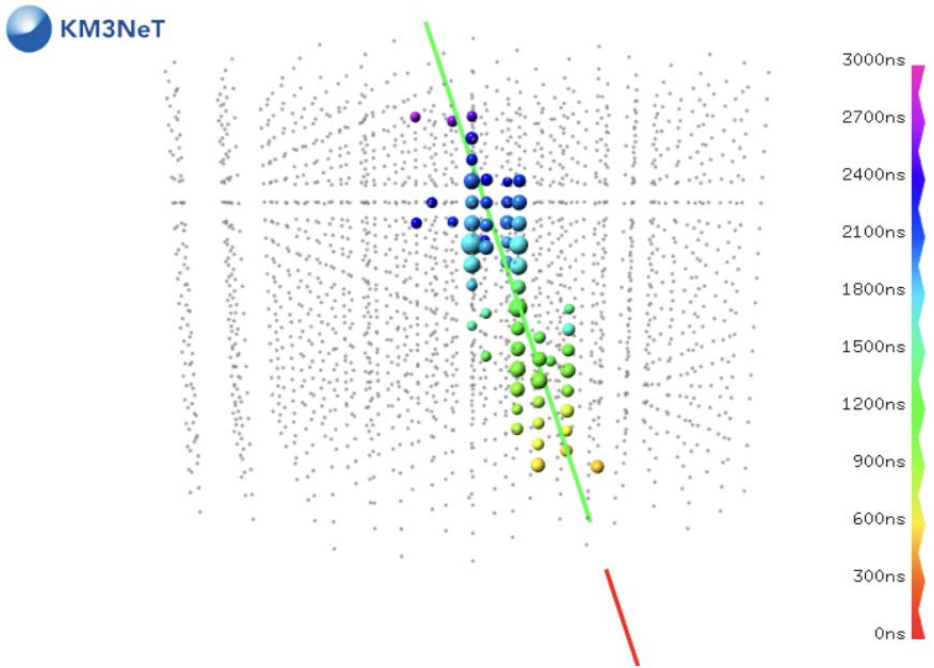
Event signatures



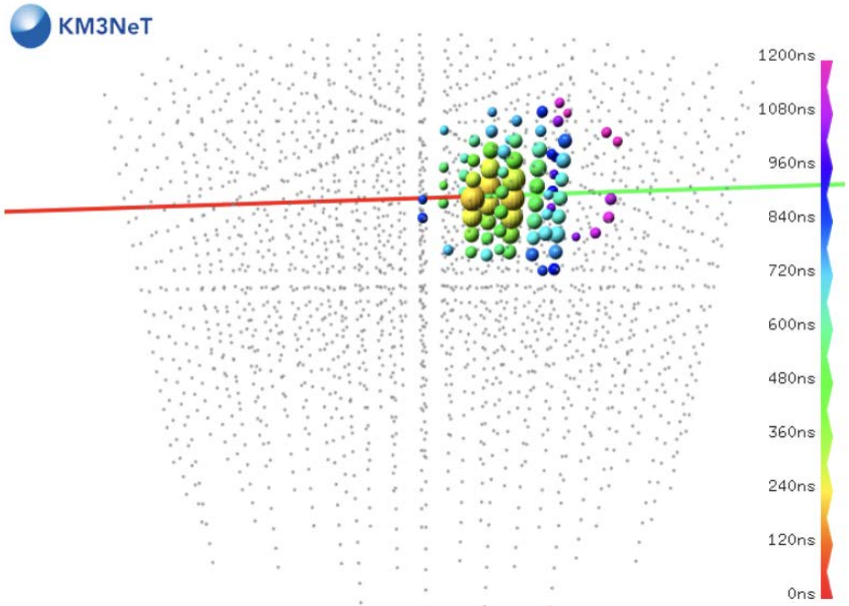


What does a neutrino interaction look like?

Track



Shower

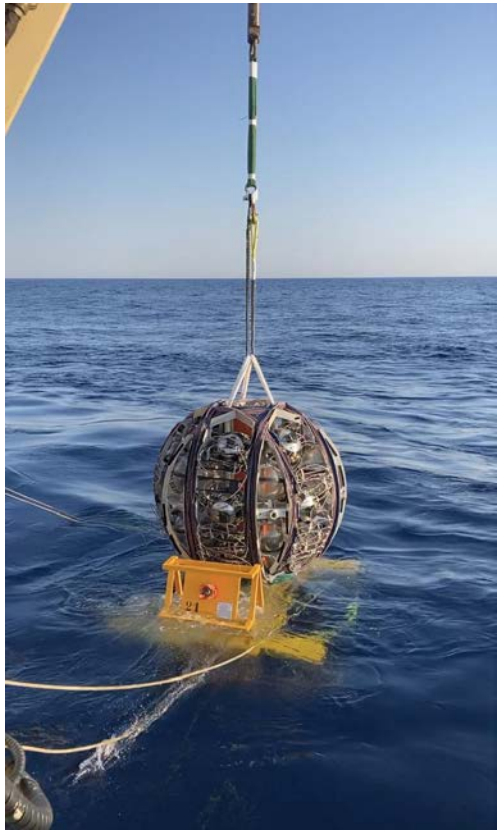


How do we deploy thousands of photosensors on the seabed?

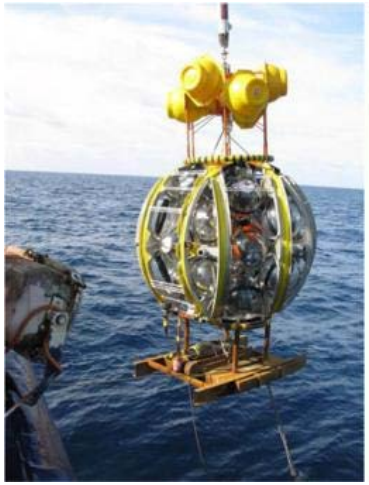




How do we deploy thousands of photosensors on the seabed?



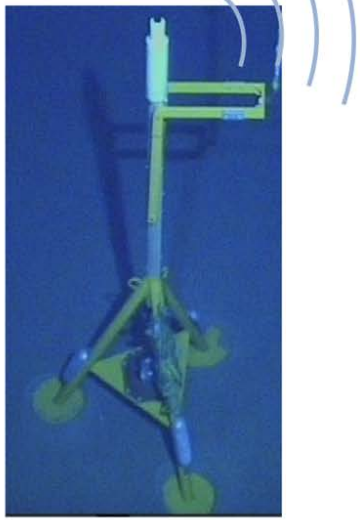


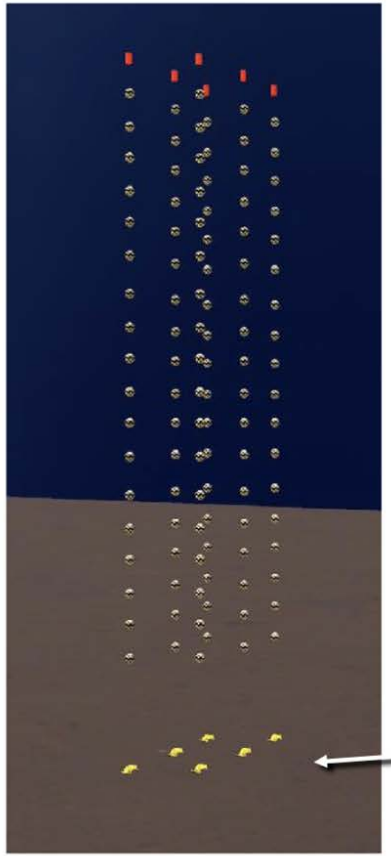




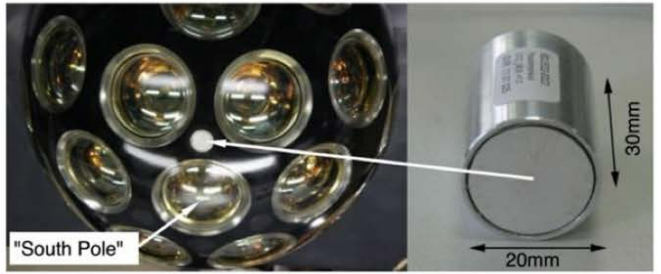
DETECTOR CALIBRATION

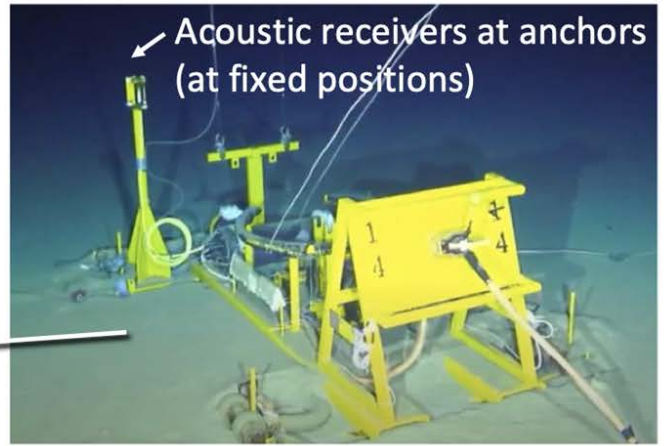
Several acoustic beacons located at fixed positions around detector emit pulse sequences at regular intervals



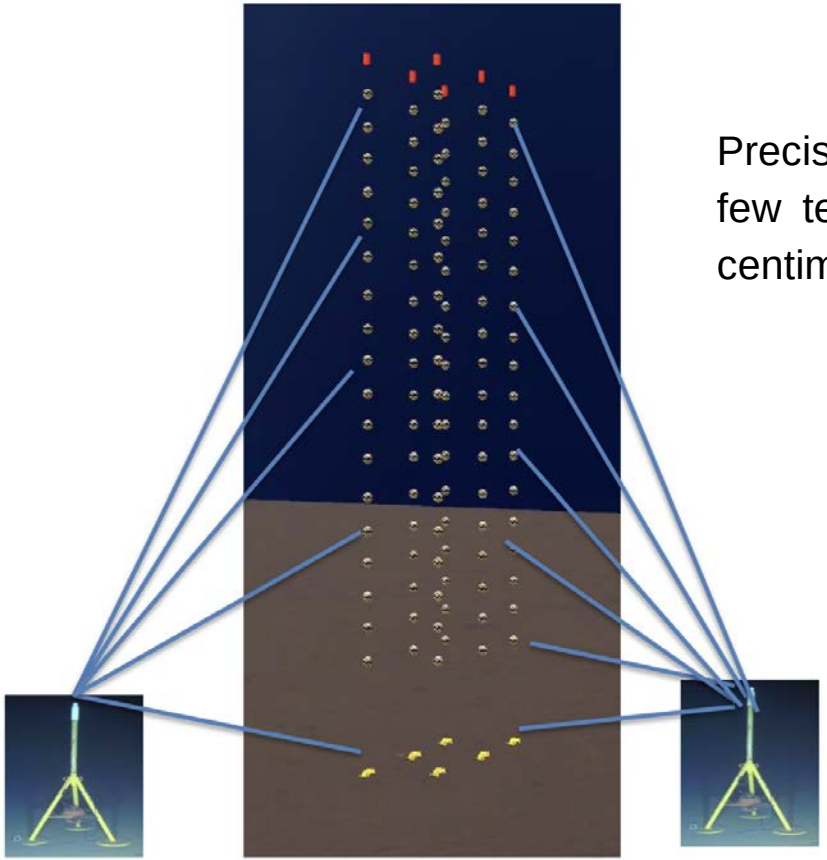


Acoustic receivers in DOMs (swaying in sea currents)



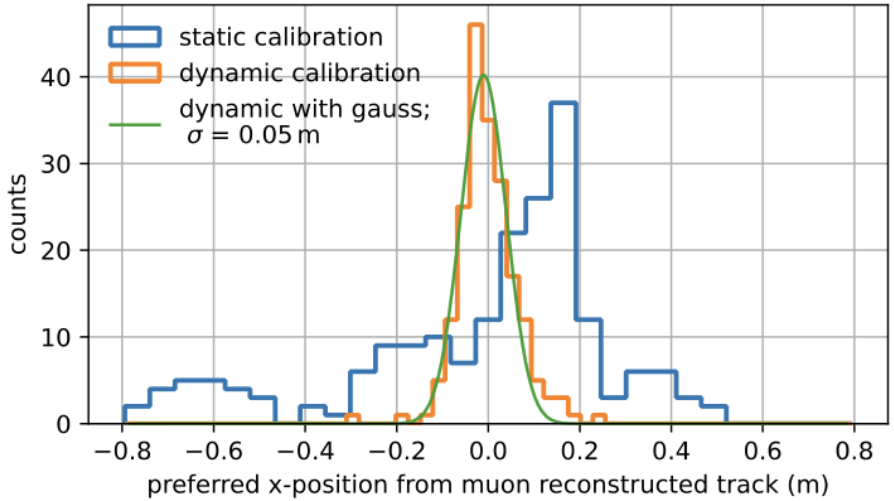


DETECTOR CALIBRATION



Precision of few tens of centimeters

Use of dynamic positions, verified by muon calibration



TRACE OF A REAL NEUTRINO

