L'esperimento KM3NeT

A caccia di neutrini in fondo al mare

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Outline

- Brief introduction to neutrinos and their habits

- Neutrino astrophysics and astronomy
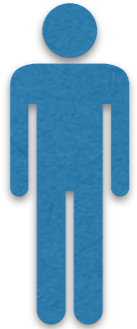
- Detection principles

- The KM3NeT detector

Brief introduction to neutrinos and their habits

What is the mean free path?

- Suppose you are on a walk in the street in your city (and suppose that there is no COVID-19)

- Suppose you want to go from point A and point B
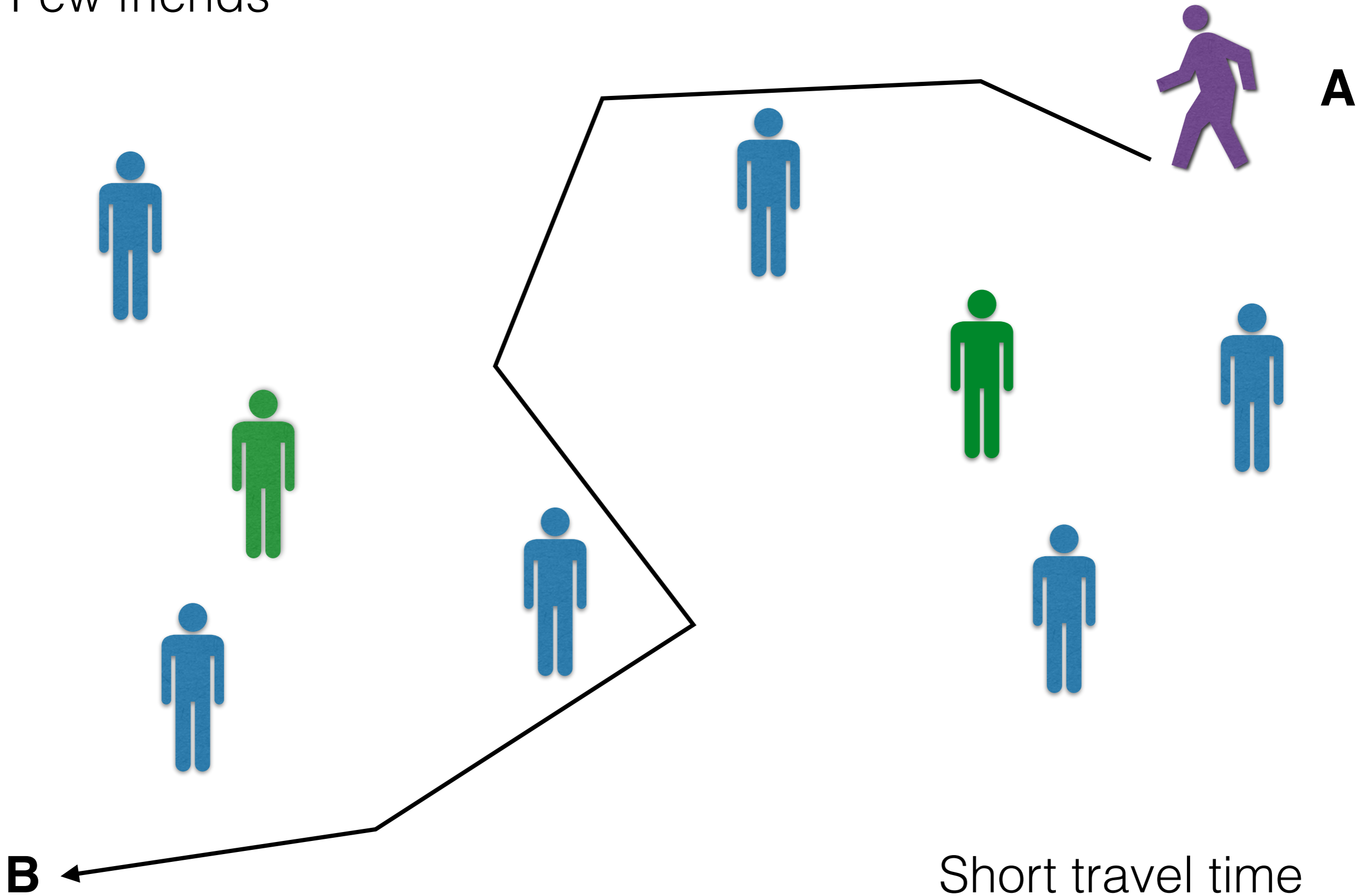
- For how long will you walk?
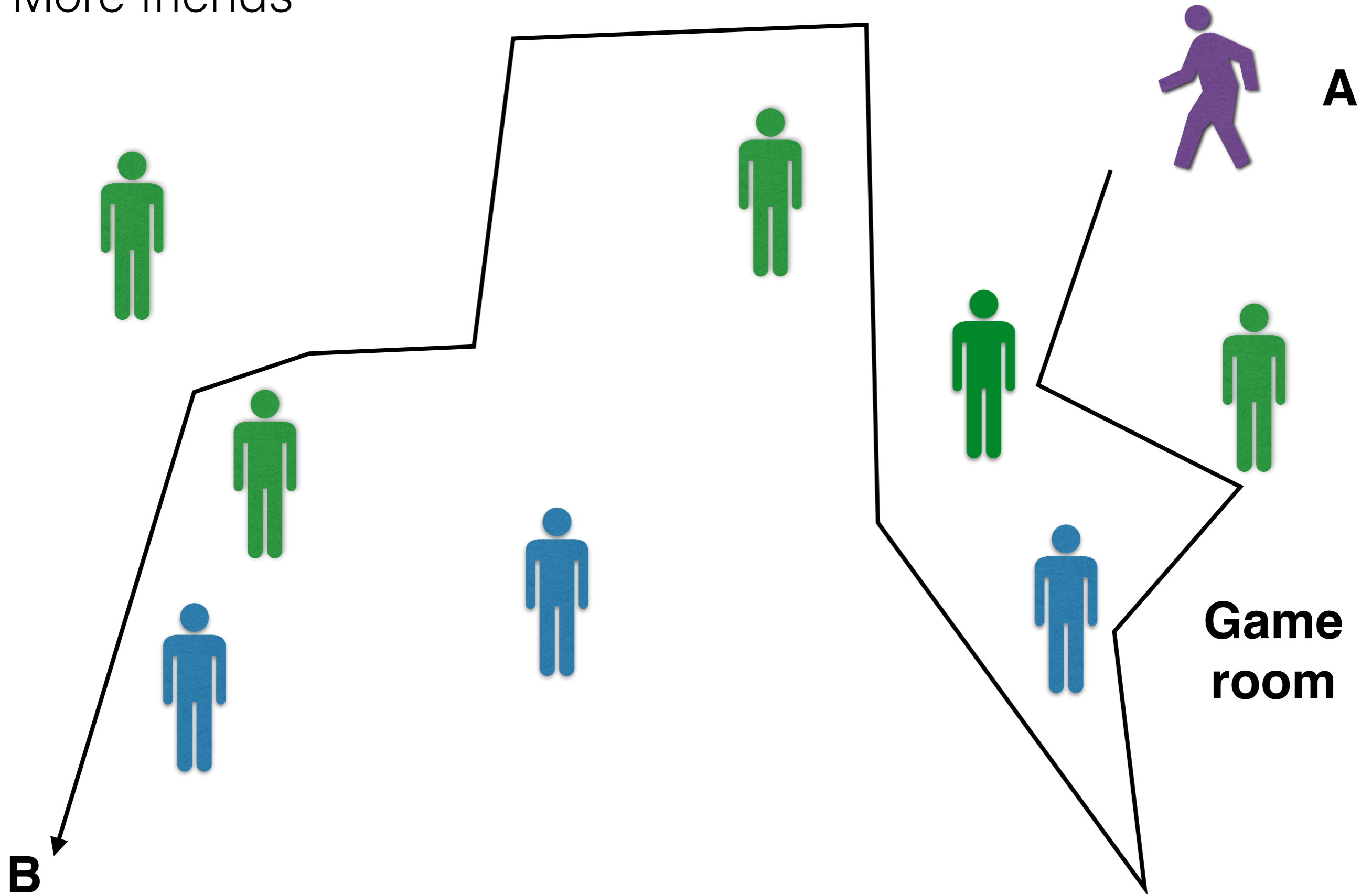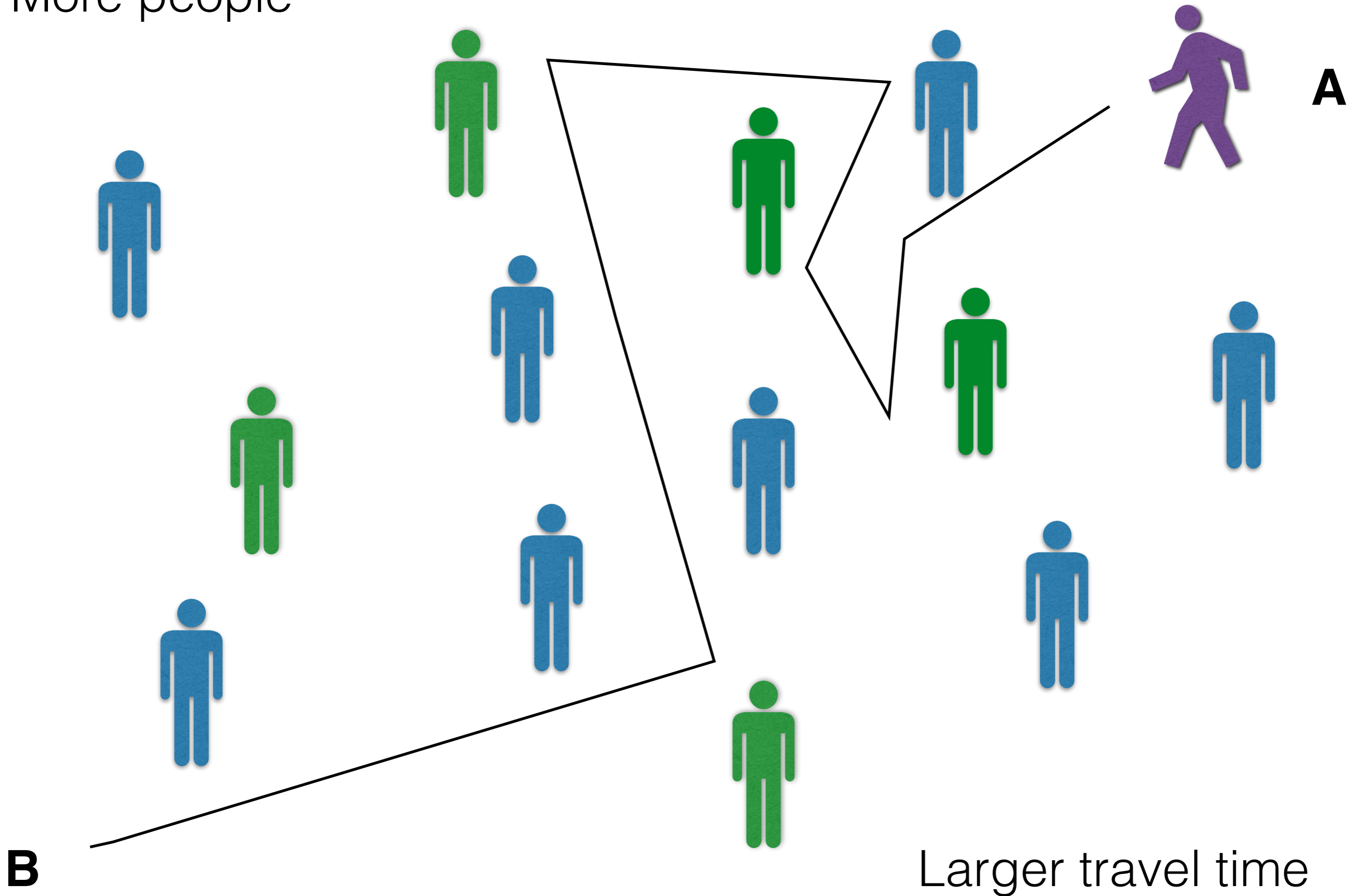
The hypothetical situation

A

B

Few friends

A

B ←

Short travel time

More friends

A

Game
room

B

Larger travel time
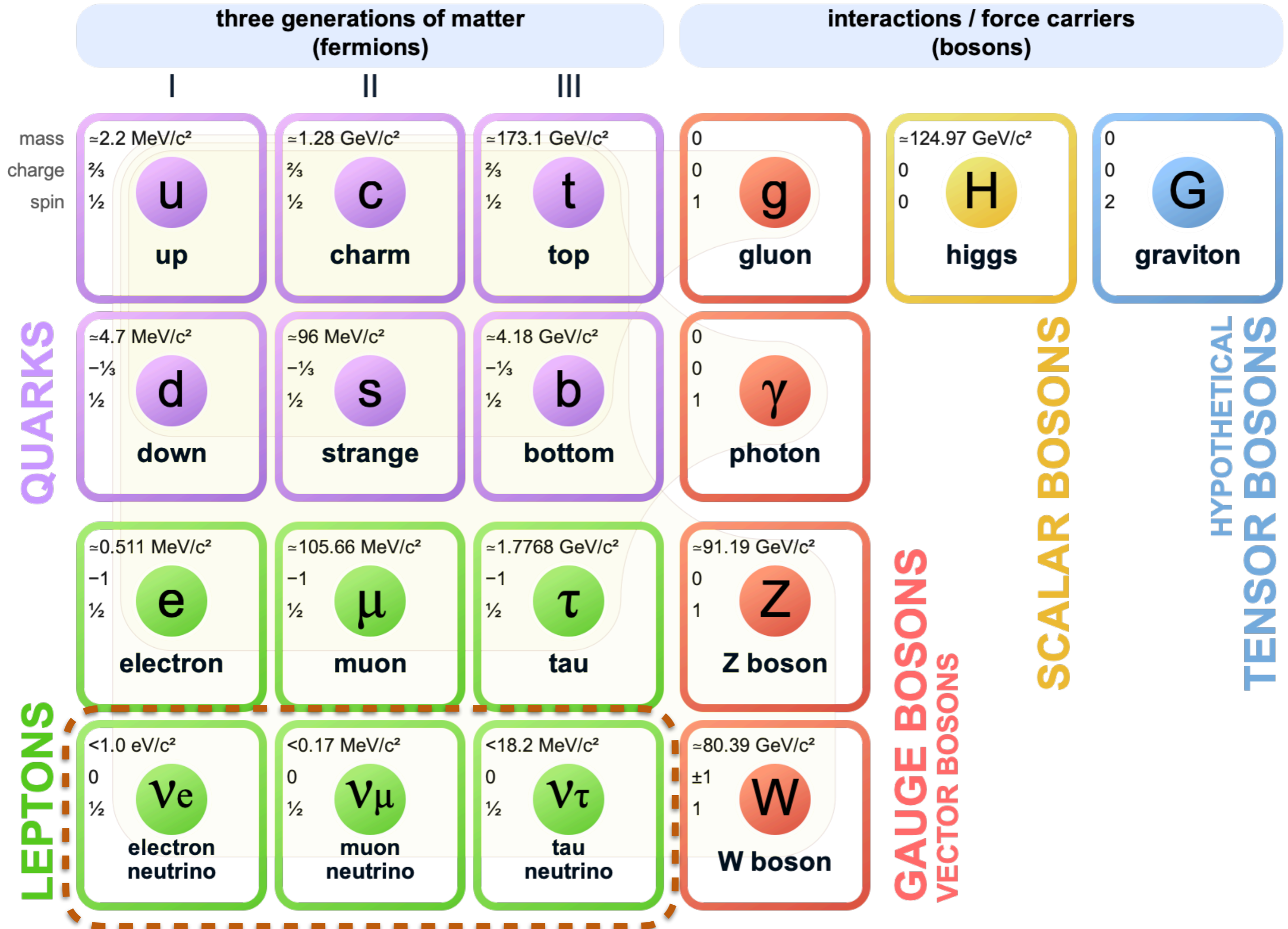
More people

A

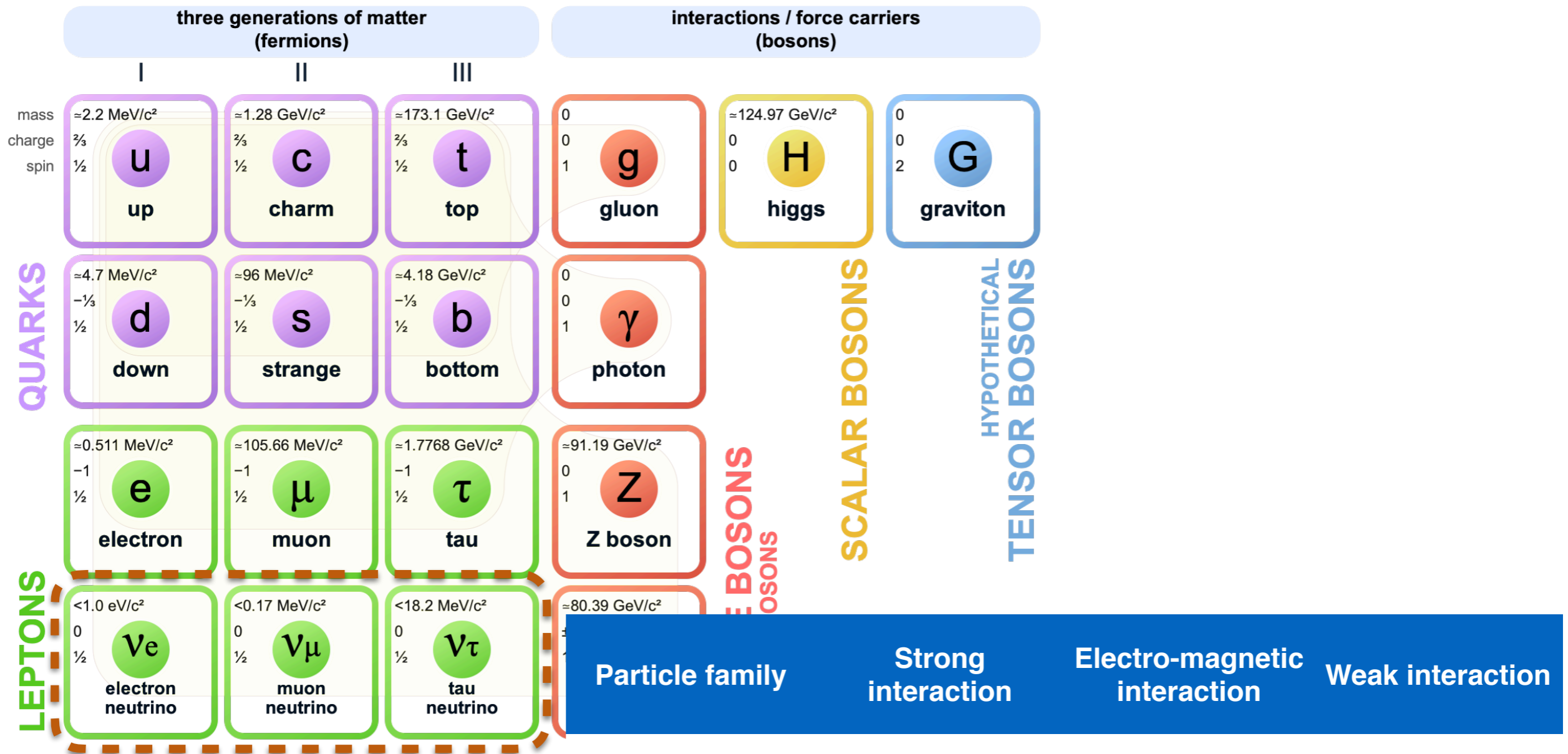**B**   Larger travel time

- The mean free path is the average space a particle travels between two interactions

    - Depends on the density of the medium (number of people in the streets)

    - Depends on how "strong" is the ability of the particle to interact with the particles of the medium (fraction of friends in the population)

Standard Model of Elementary Particles and Gravity

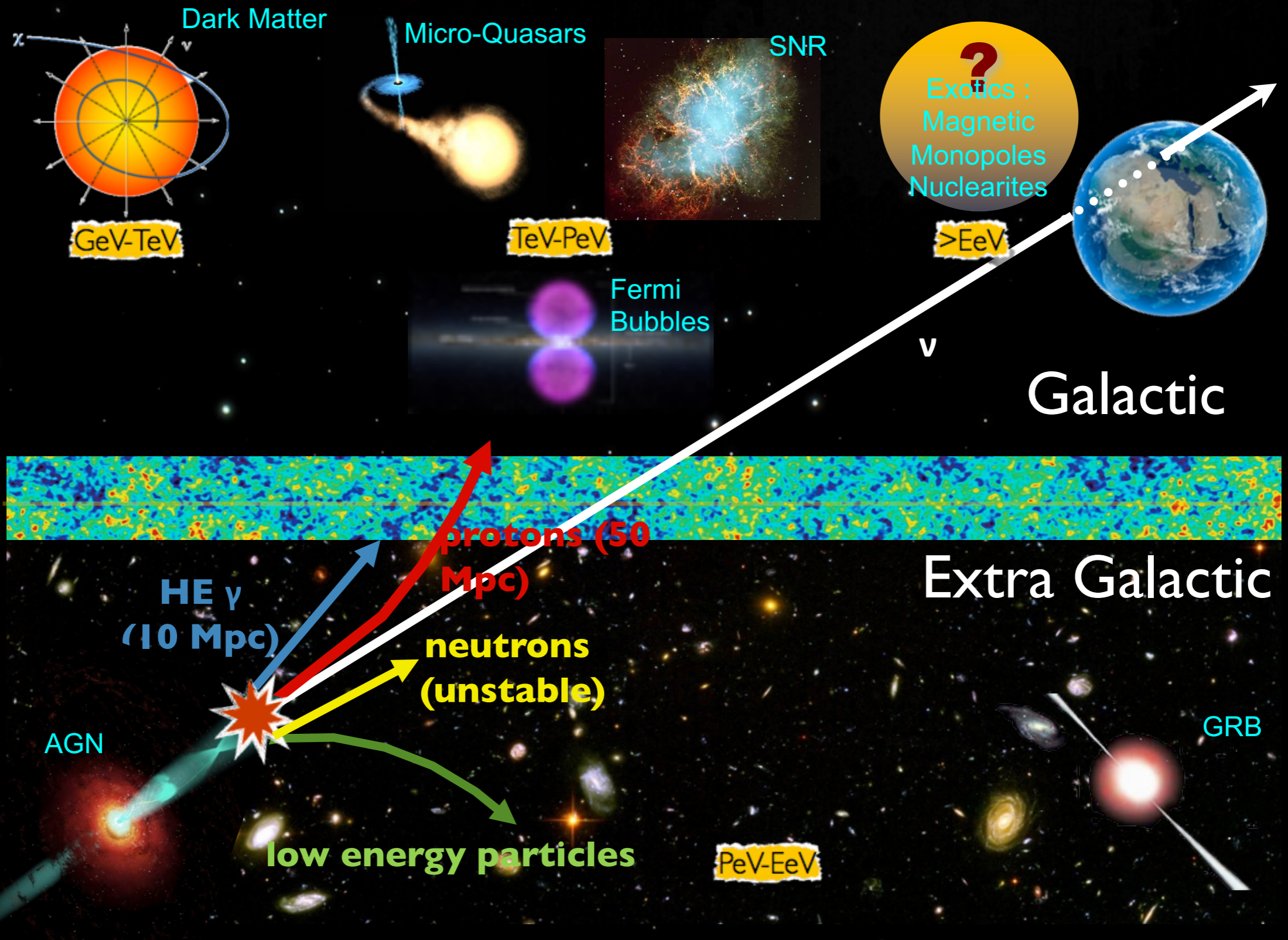# Standard Model of Elementary Particles and Gravity

three generations of matter
(fermions)

interactions / force carriers
(bosons)

I   II   III

mass
charge
spin

QUARKS

≈2.2 MeV/c²
⅔
½
u
up

≈1.28 GeV/c²
⅔
½
c
charm

≈173.1 GeV/c²
⅔
½
t
top

0
0
1
g
gluon

≈124.97 GeV/c²
0
0
H
higgs

0
0
2
G
graviton

≈4.7 MeV/c²
−⅓
½
d
down

≈96 MeV/c²
−⅓
½
s
strange

≈4.18 GeV/c²
−⅓
½
b
bottom

0
0
1
γ
photon

≈0.511 MeV/c²
−1
½
e
electron

≈105.66 MeV/c²
−1
½
μ
muon

≈1.7768 GeV/c²
−1
½
τ
tau

≈91.19 GeV/c²
0
1
Z
Z boson

LEPTONS

<1.0 eV/c²
0
½
νe
electron
neutrino

<0.17 MeV/c²
0
½
νμ
muon
neutrino

<18.2 MeV/c²
0
½
ντ
tau
neutrino

≈80.39 GeV/c²

SCALAR BOSONS

HYPOTHETICAL TENSOR BOSONS

Particle family	Strong interaction	Electro-magnetic interaction	Weak interaction
Quarks	x	x	x
Charged leptons (e.g. electron)		x	x
Neutrinos			x

the mean free path of a 1MeV electron neutrino in lead is around 1 light year! **A**
(~30 light years in Iron!)

B
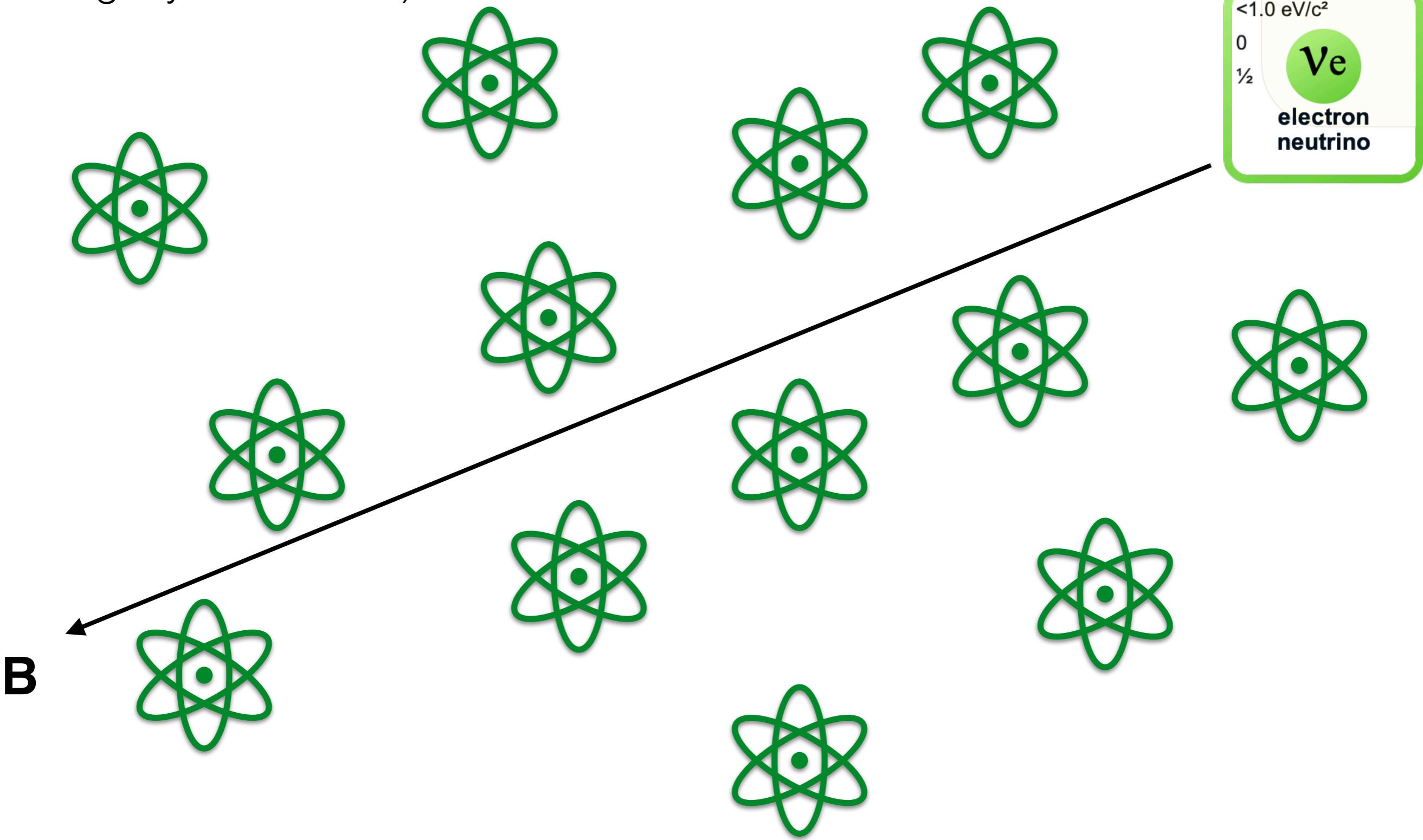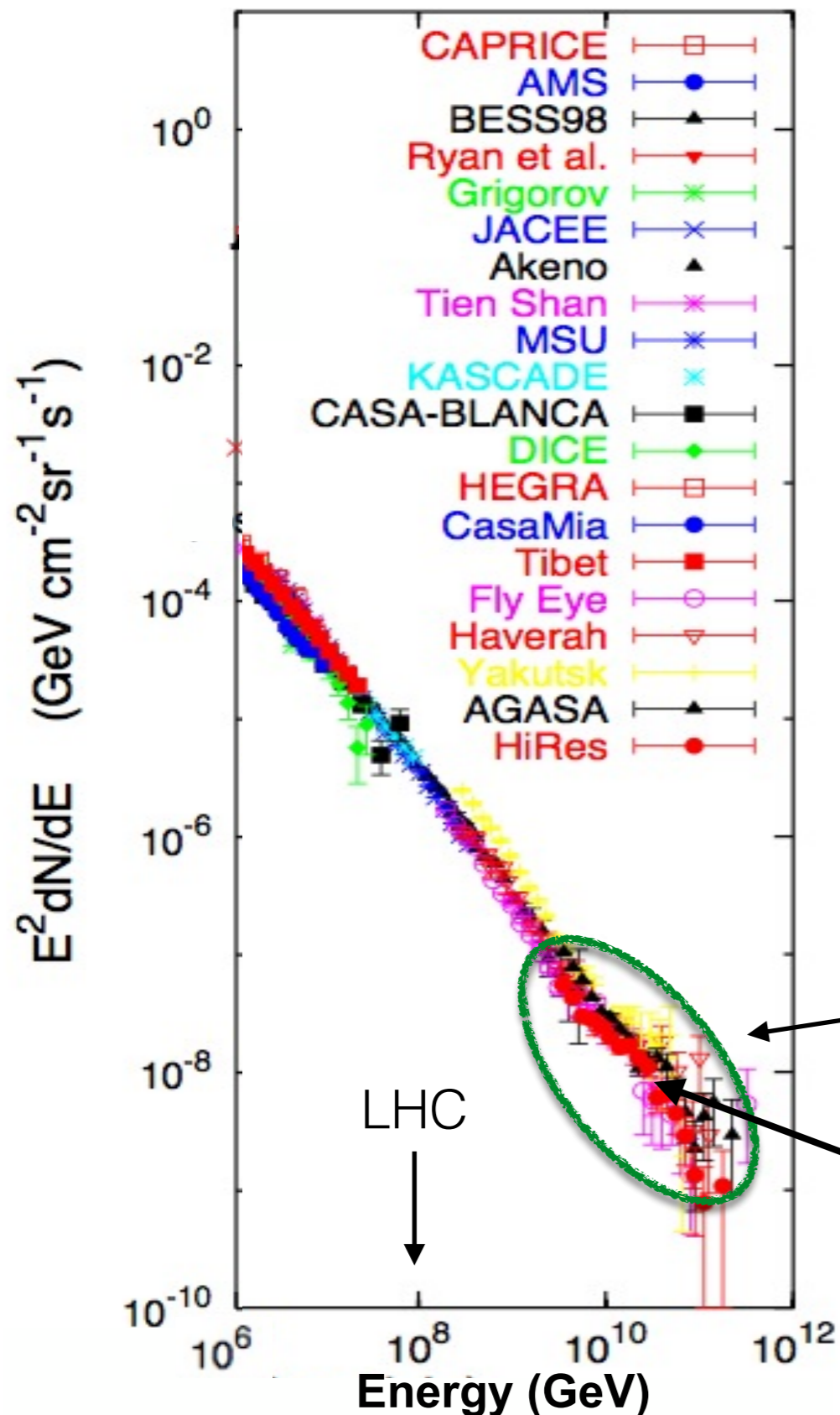
Neutrinos are among the most asocial known particles!

Neutrino astrophysics and astronomy

Cosmic-rays accelerator candidates

Dark Matter

Micro-Quasars

SNR

Exotics : Magnetic Monopoles Nuclearites

GeV-TeV

TeV-PeV

>EeV

Fermi Bubbles

ν

Galactic

protons (50 Mpc)

HE γ (10 Mpc)

Extra Galactic

neutrons (unstable)

AGN

GRB

low energy particles

PeV-EeV

Cosmic spectrum

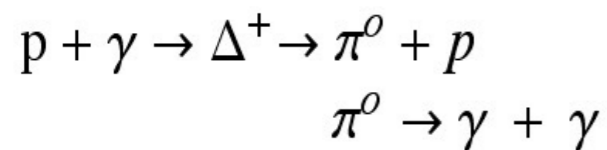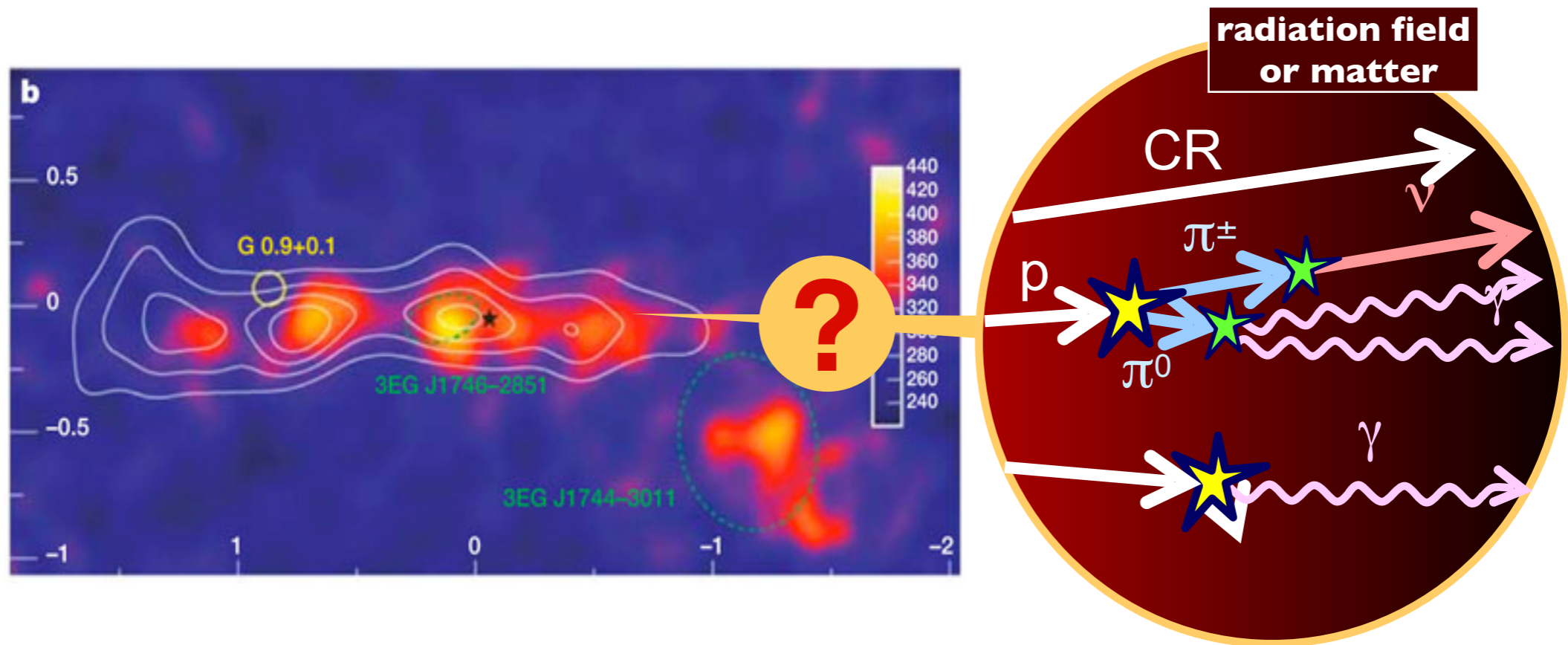Flux => number of particles per time unit per surface unit

Measured cosmic ray flux as a function of the particle energy

The flux (fortunately!) rapidly decreases with energy

Most interesting region: ultra high energy!

1 particle/km² /century!!!!

15

Connection between cosmic rays and neutrinos

radiation field or matter

CR

ν

p

π±

π⁰

γ

γ

?

$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^o + p$$
$$\pi^o \rightarrow \gamma + \gamma$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow \pi^+ + n$$
$$\pi^+ \rightarrow \nu_\mu + \mu^+$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
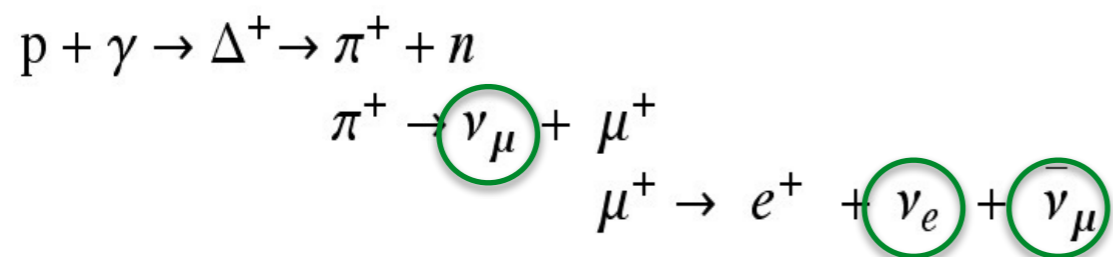
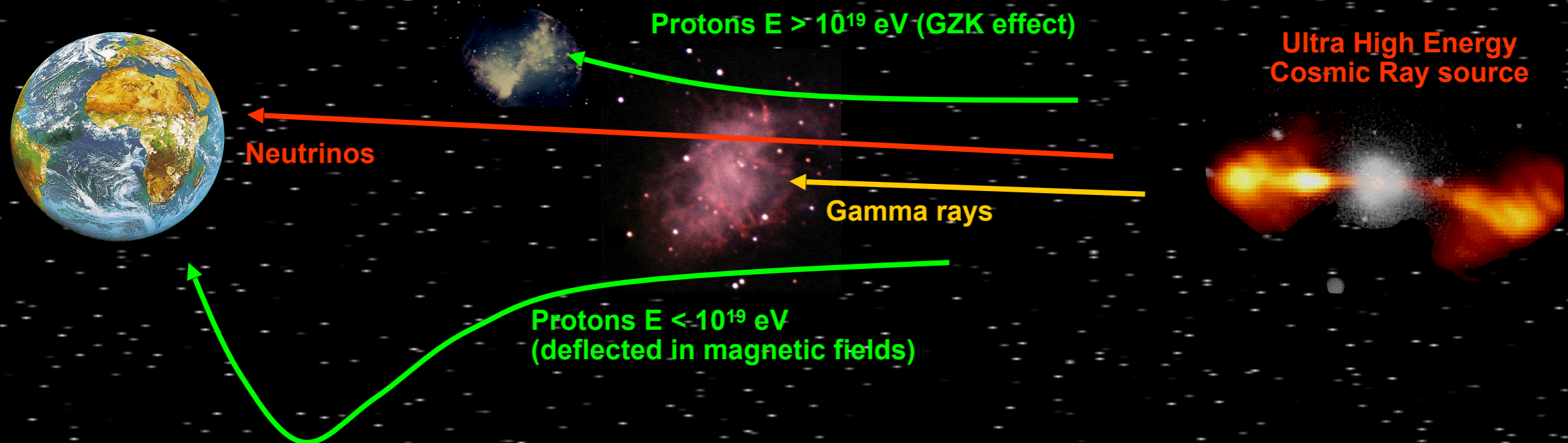A cosmic accelerator for high-energy protons and nuclei is also a source of high-energy photons and neutrinos!

Why neutrino astronomy?

Within the ultra-high-energy cosmic-rays context, neutrinos are the only long-lived particles that can propagate through the Universe without interacting and unaffected by magnetic fields, thus preserving information about the emitting source.
Using HE neutrinos as a probe, instead of protons and photons, we have:

- the extension of the observable astronomic horizon;
- the possibility of an astronomic measurement (pointing the source);
- the possibility to discover far sources, which are optically hidden by other objects.

Protons E > 10^{19} eV (GZK effect)

Ultra High Energy
Cosmic Ray source

Neutrinos

Gamma rays

Protons E < 10^{19} eV
(deflected in magnetic fields)

Detection principle

How to detect a neutrino?

- Step 1: wait the neutrino to interact with matter

- Step 2: detect (all) the (charged) particles produced in the interaction

The Cherenkov effect

- A charged particle, travelling in a medium at a speed higher than the speed of light in the medium, emits light!

- You may think this effect as the electromagnetic equivalent of the sonic barrier infringement
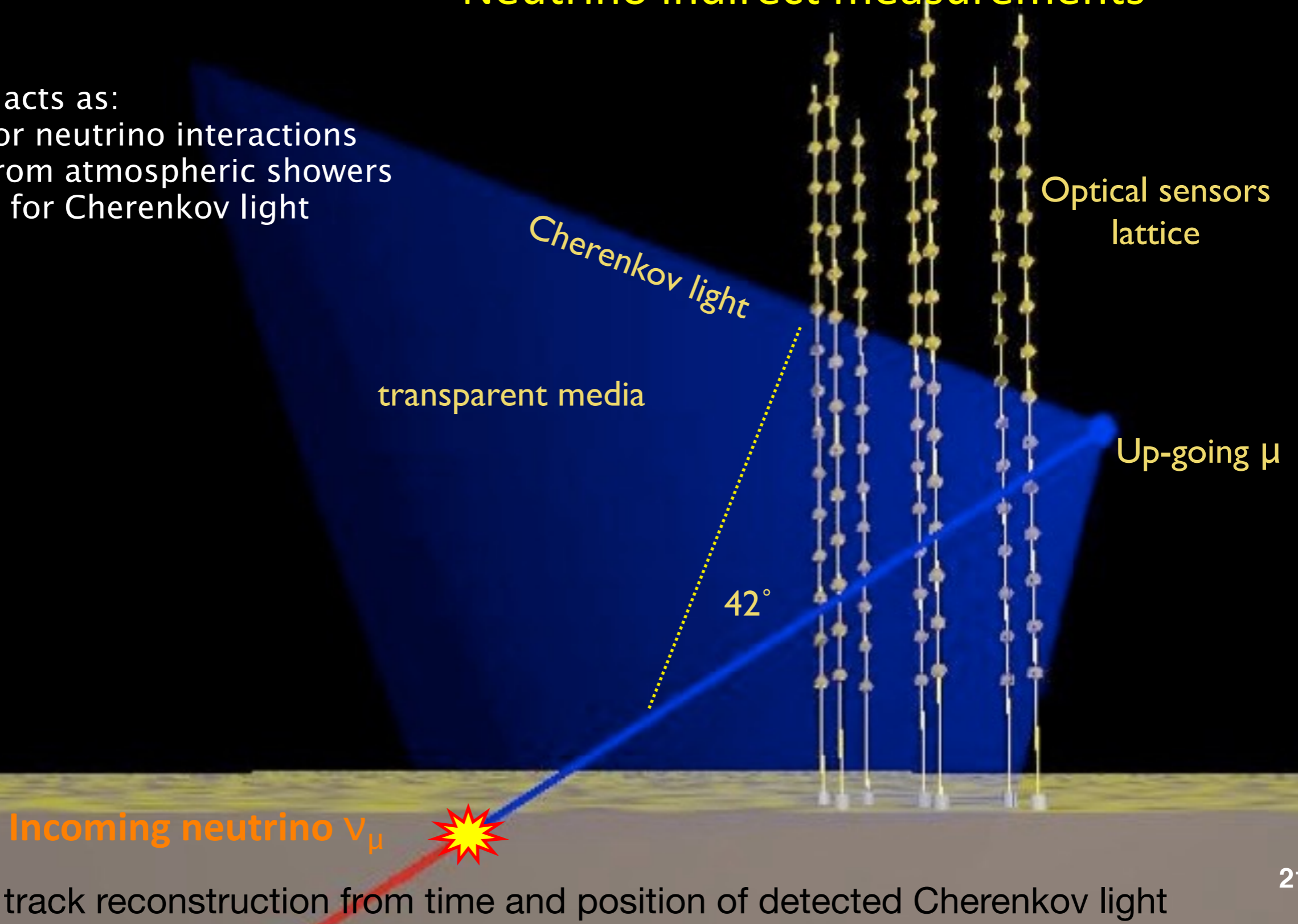
Underwater Cherenkov detection technique

Neutrino indirect measurements

sea water acts as:
- target for neutrino interactions
- shield from atmospheric showers
- radiator for Cherenkov light

Cherenkov light

Optical sensors lattice

transparent media

Up-going μ

42°

Incoming neutrino ν_μ

track reconstruction from time and position of detected Cherenkov light

The KM3NeT detector

KM3 Neutrino Telescope

KM3NeT is a network of neutrino detectors being built by the KM3NeT Collaboration in the Mediterranean Sea.
- **ORCA** = Oscillation Research with Cosmics in the Abyss —> neutrino **mass hierarchy**
- **ARCA** = Astroparticle Research with Cosmics in the Abyss —> neutrino **astronomy**
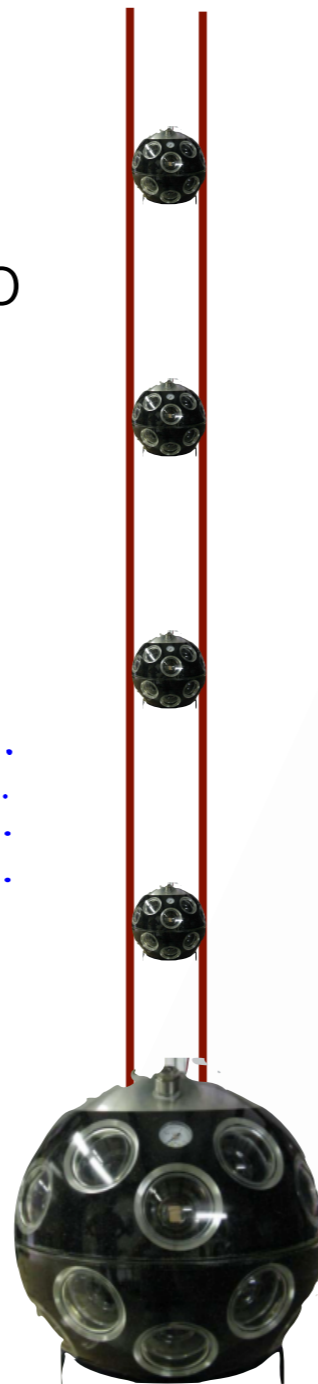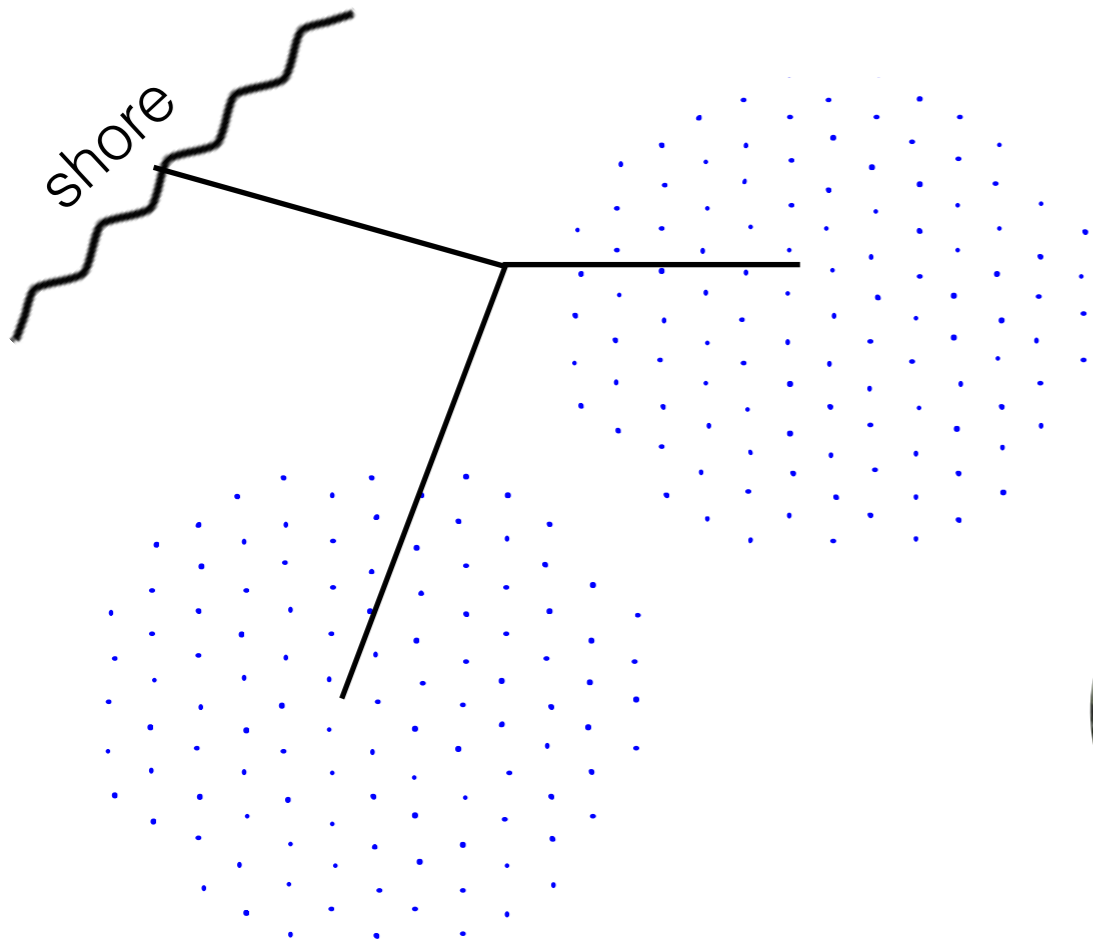

ORCA
2500m bsl
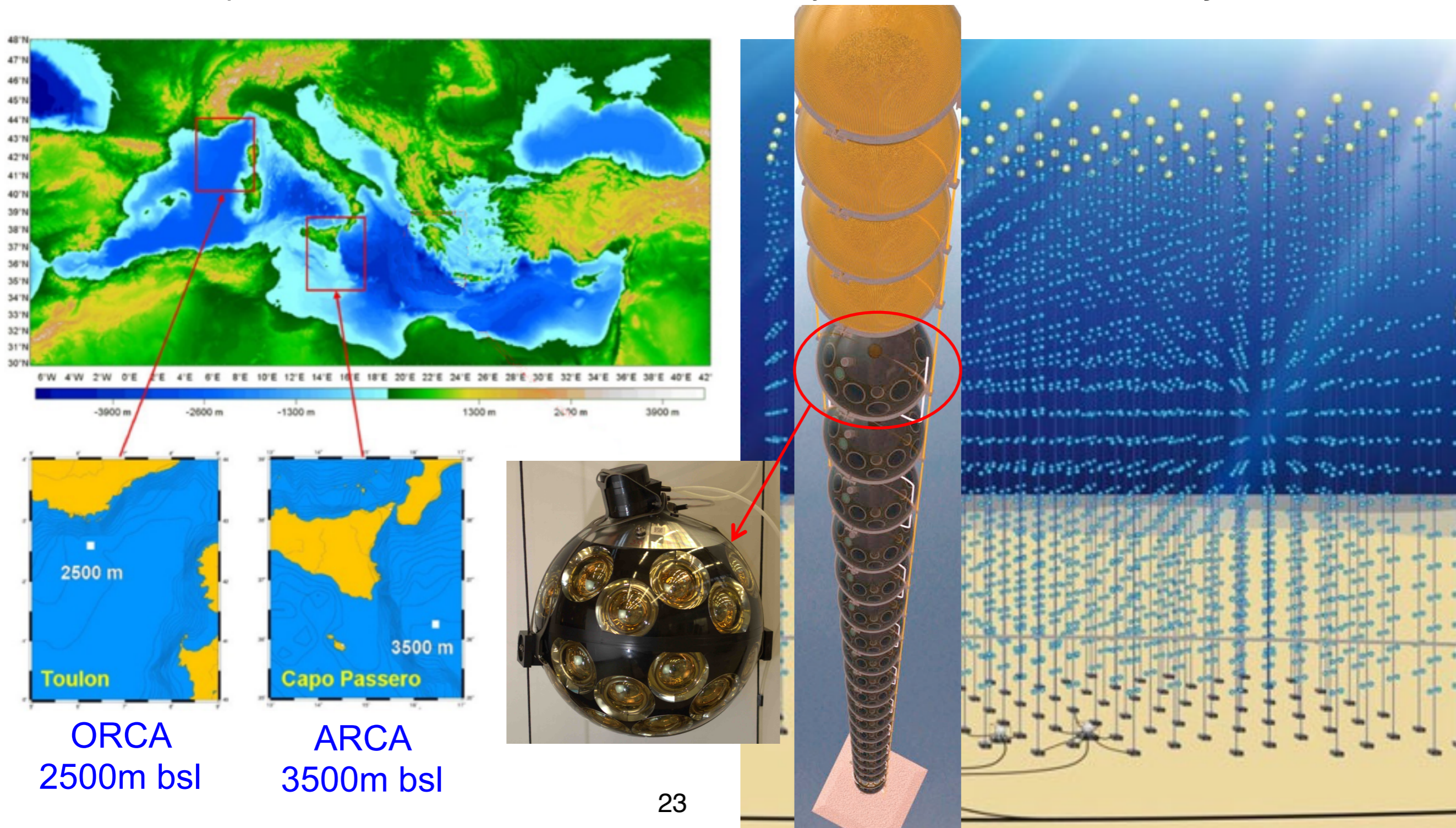
ARCA
3500m bsl

KM3NeT: one experiment, two sites

The common element is the Detection Unit (DU): vertical structure hosting 18 Digital Optical Modules (DOMs) each one equipped with 31 3" PMTs.
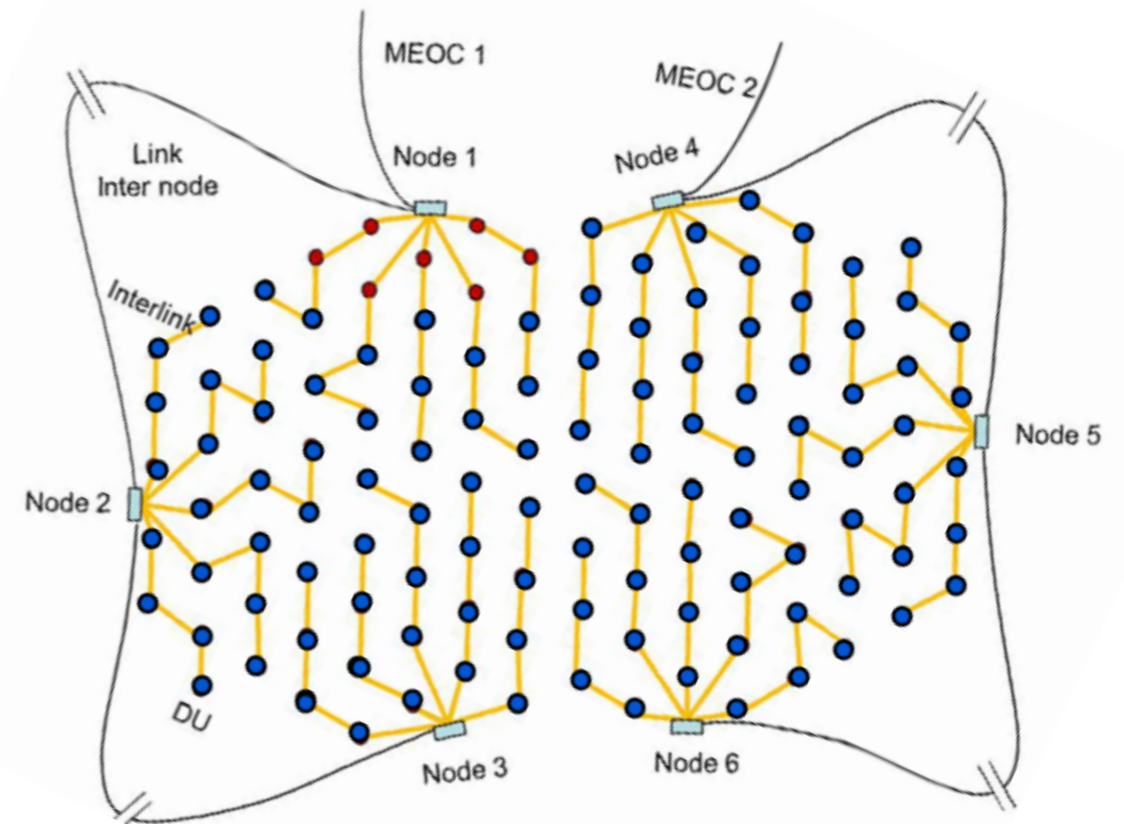
Astronomy **R**esearch with **C**osmics in the **A**byss (**ARCA**)

2 x 115 strings in the Capo Passero site
vertical spacing: 36 metres

Oscillation **R**esearch with **C**osmics in the **A**byss (**ORCA**)

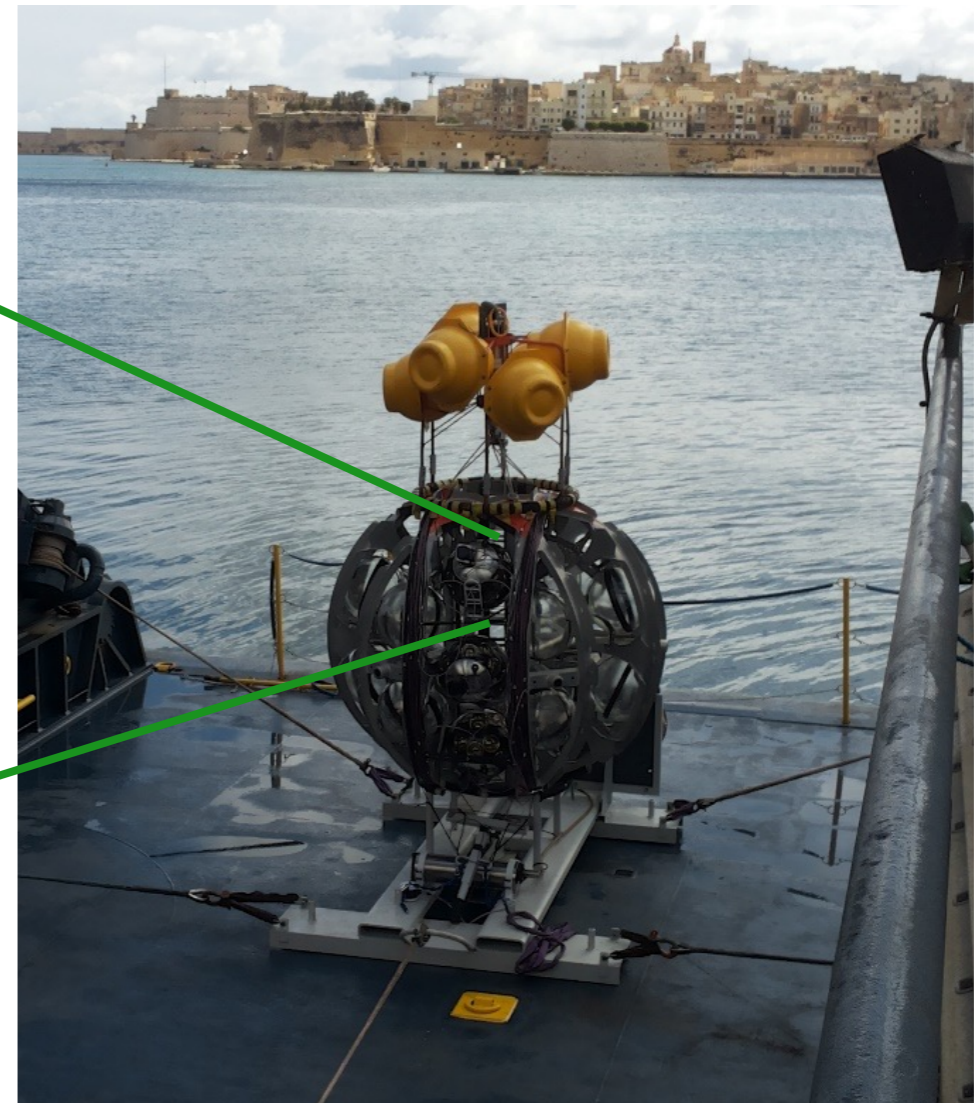115 strings in the Toulon site
vertical spacing: ~6 metres

KM3NeT: digital optical module

- Optical module:
  - 31 x 3" PMTs
  - "looks" in all directions
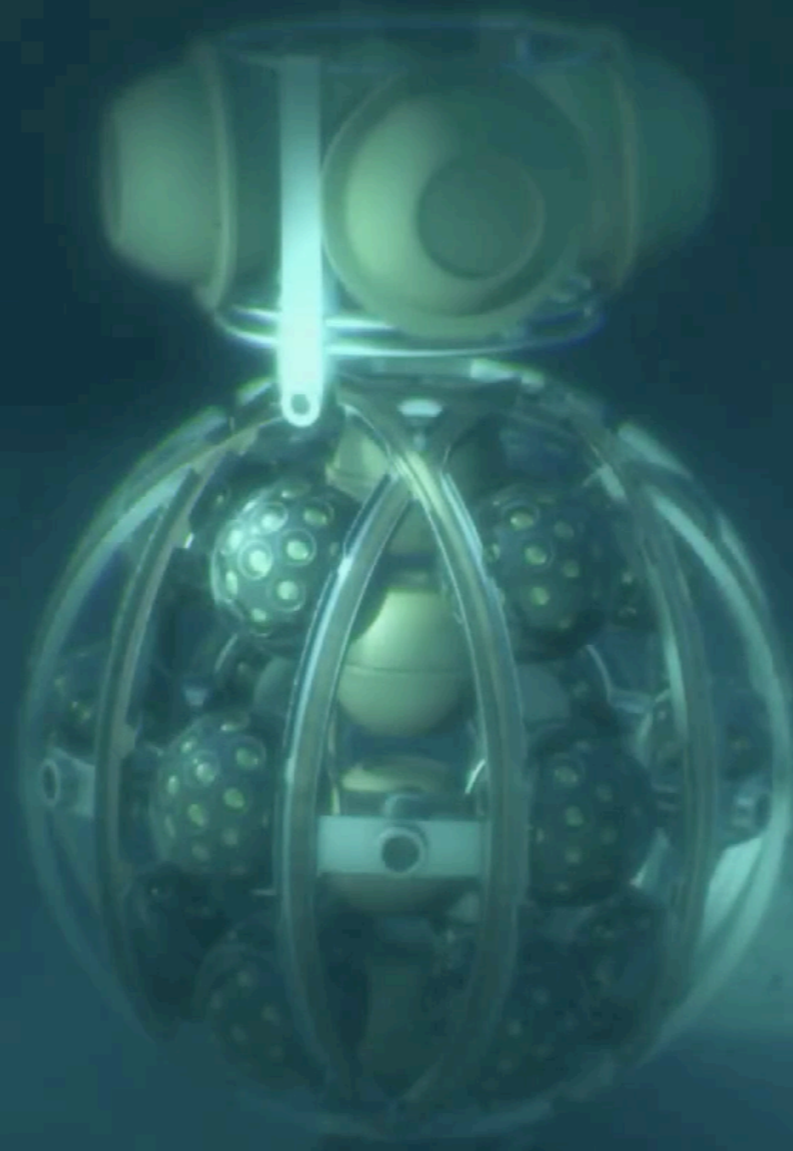 - directional resolution
  - optimised to look downward

~43cm

- Launcher vehicle:
  - rapid deployment
  - autonomous unfurling
  - recoverable

# Installation on the sea bed

https://youtu.be/crLCpt2CXDw

All-data-to-shore approach

- KM3NeT leverages a very new and peculiar technique of data taking called all-data-to-shore.

- Each DOM acts as a node of a computer network using the same technology that connects houses to the Internet via optical fibres. This allows:

  1. remote control of each single DOM independently

  2. the distribution of a common time reference (a clock) that synchronises all parts of the detector at a **sub-nanoseconds** level

  3. send **all collected light signals** to the on-shore computing facility

Multi-messenger studies

- *Multi-messenger* means studying the same event with multiple probes.
- Combining data from multiple observatories allows better understanding of investigated phenomena.
- Multiple observations reduce the systematics of the discovery
- Search for a space-time correlation between HE nu and e-m emissions (γ-rays, X, radio, optical), UHECR or Gravitational Waves.
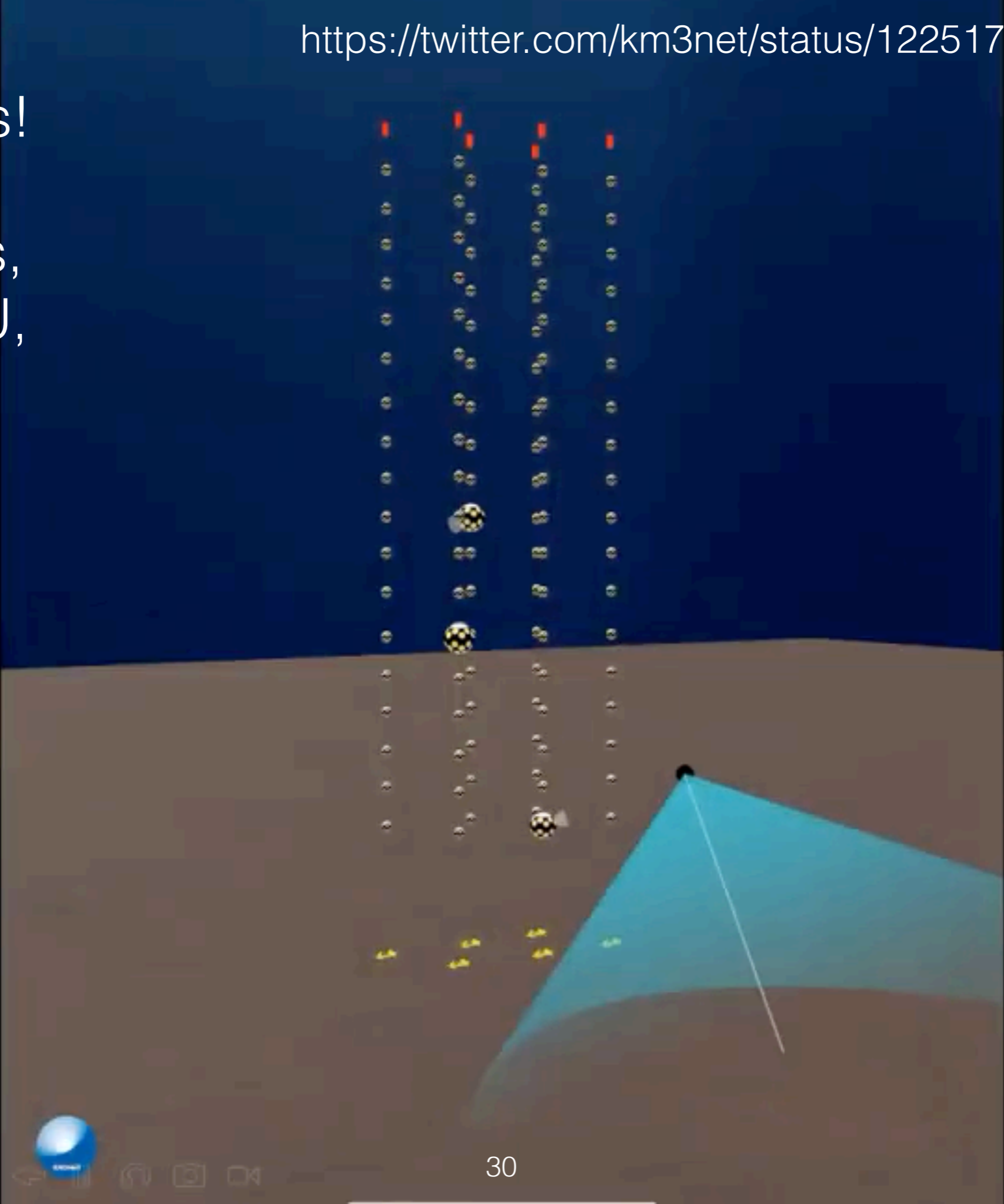
Quick alert triggered by neutrino detection —> follow-up by other observatories.
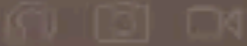
Simulated events (full detector)
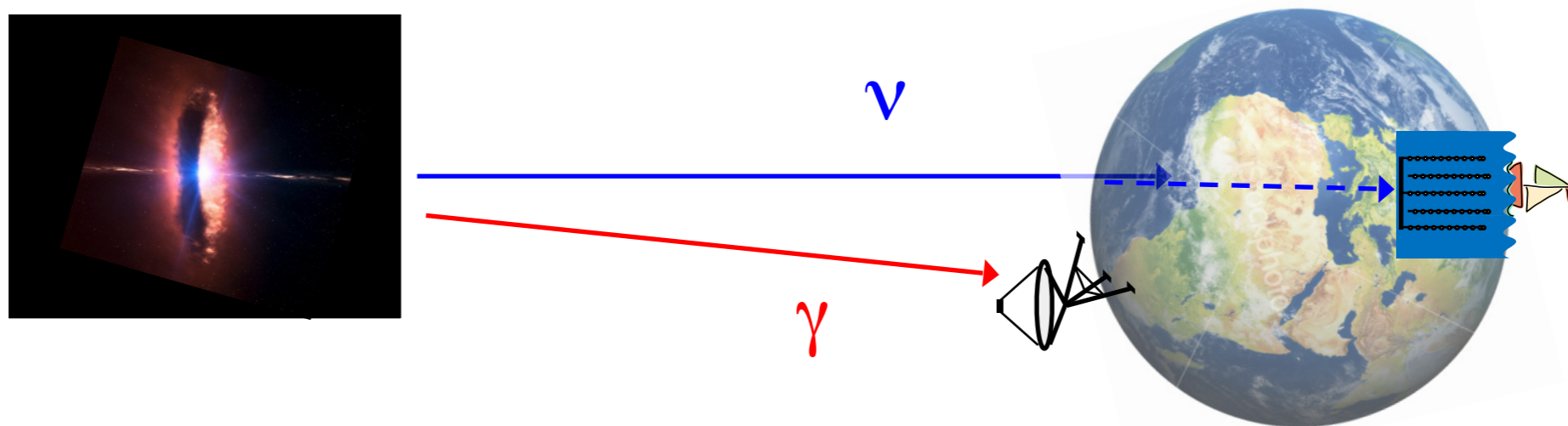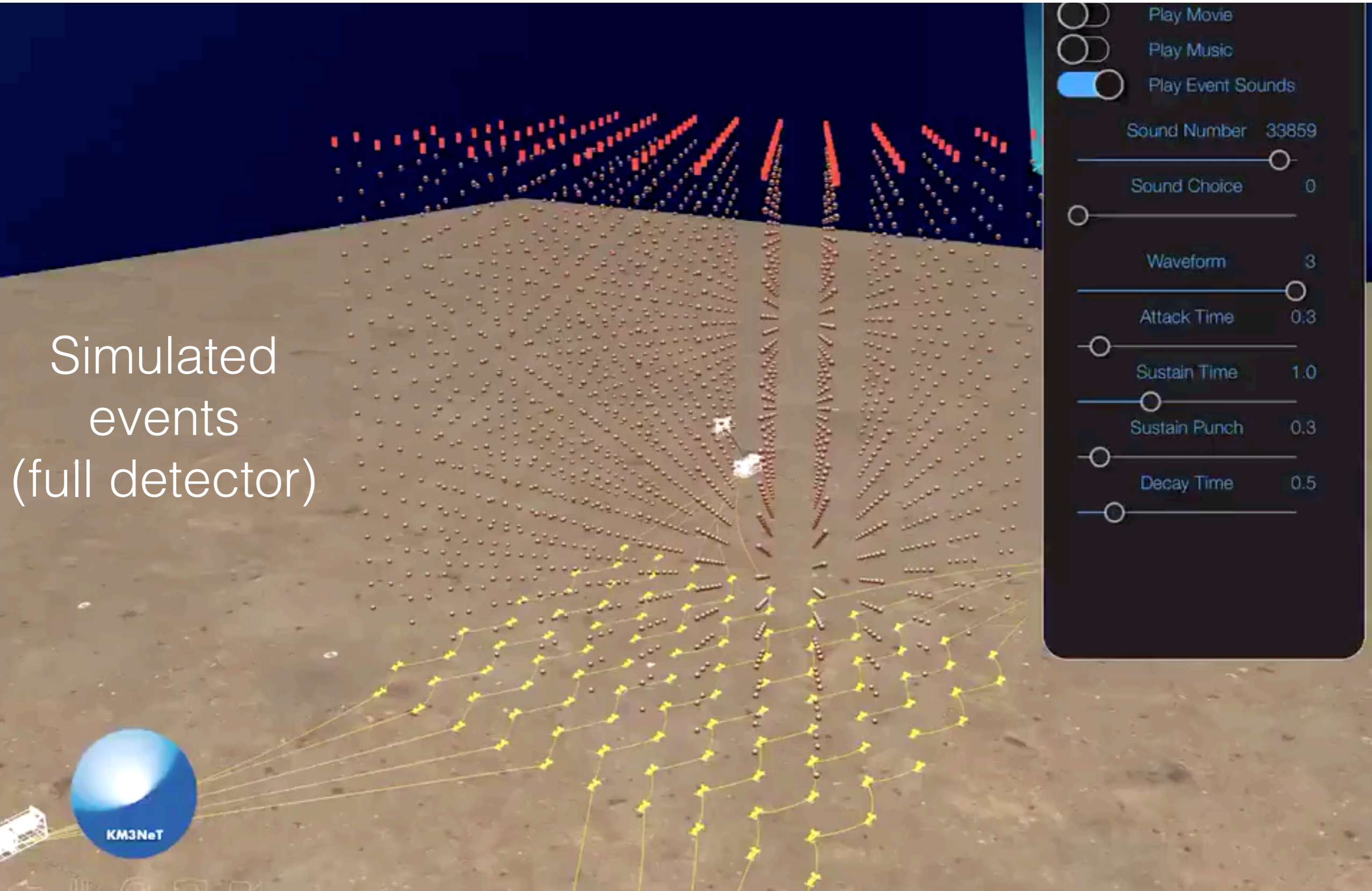
Credit P. Coyle

Real events! Neutrino candidates, ORCA-6DU, February 2020

Credit P. Coyle

Conclusions

- KM3NeT is and will be a network of **enormous** neutrino detector to win the **challenges** of:

  - discovering high-energy cosmic ray sources

  - unveil the CR acceleration mystery

  - do fundamental physics studies in the neutrino sector

- Is already taking data while it's being built!

Thank you for your attention