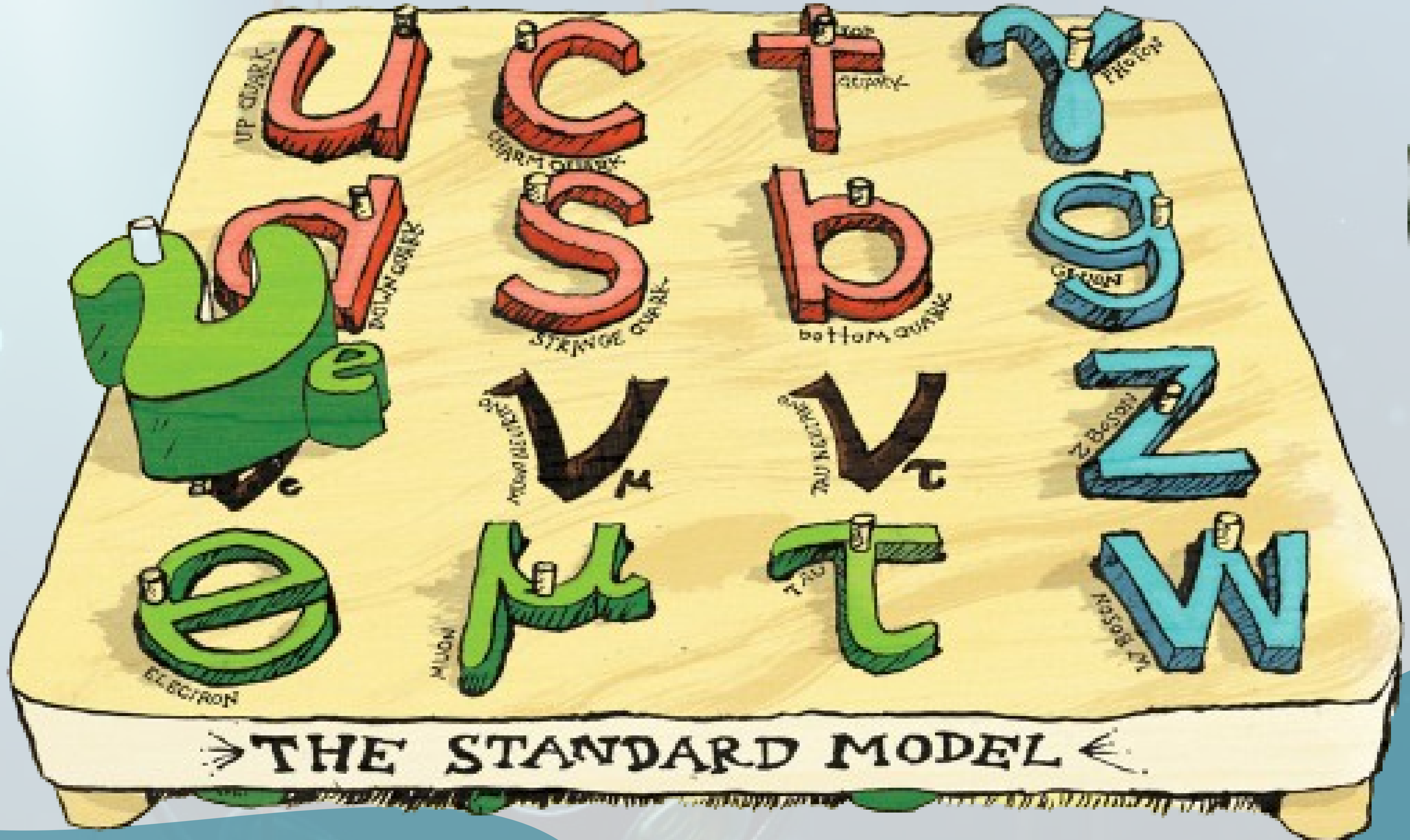
Measuring neutrino oscillations in the deep sea

CDD - Paris

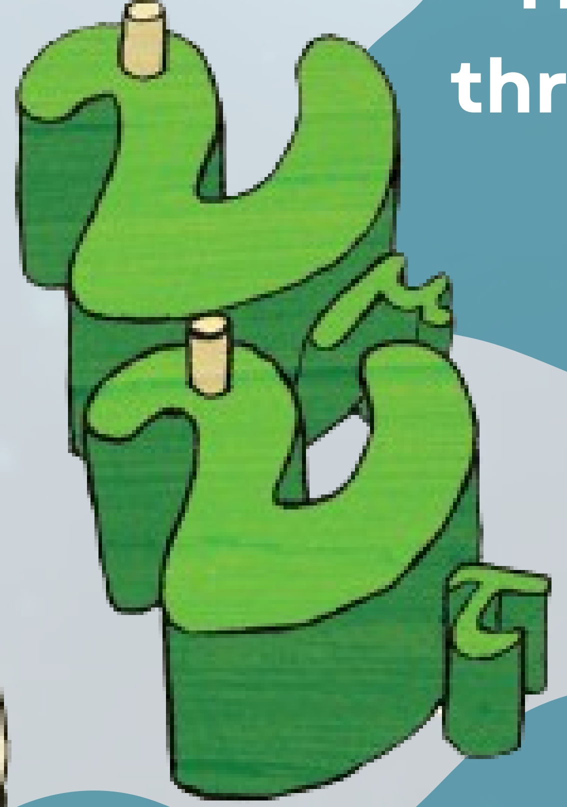
29/03/2024

Santiago Peña Martínez

Neutrinos as fundamental particles



Credits: Symmetry Magazine



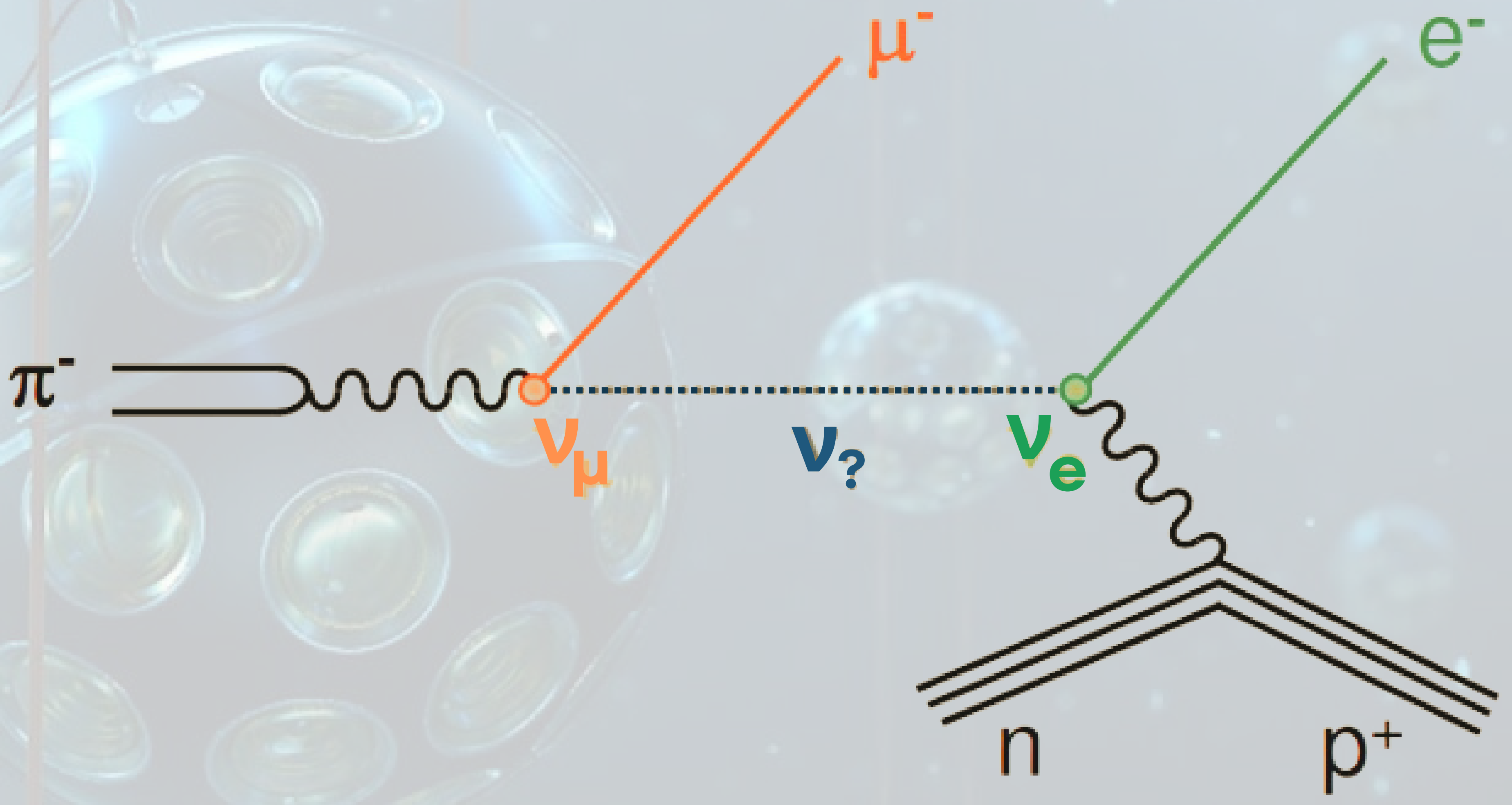
They come in three "flavours":

ν_e ν_μ ν_τ

They are the only particles that have been measured which cannot be fully explained with the Standard Model theoretical framework.

They are very weakly interacting particles produced in different processes involving their heavier counterparts, the leptons.

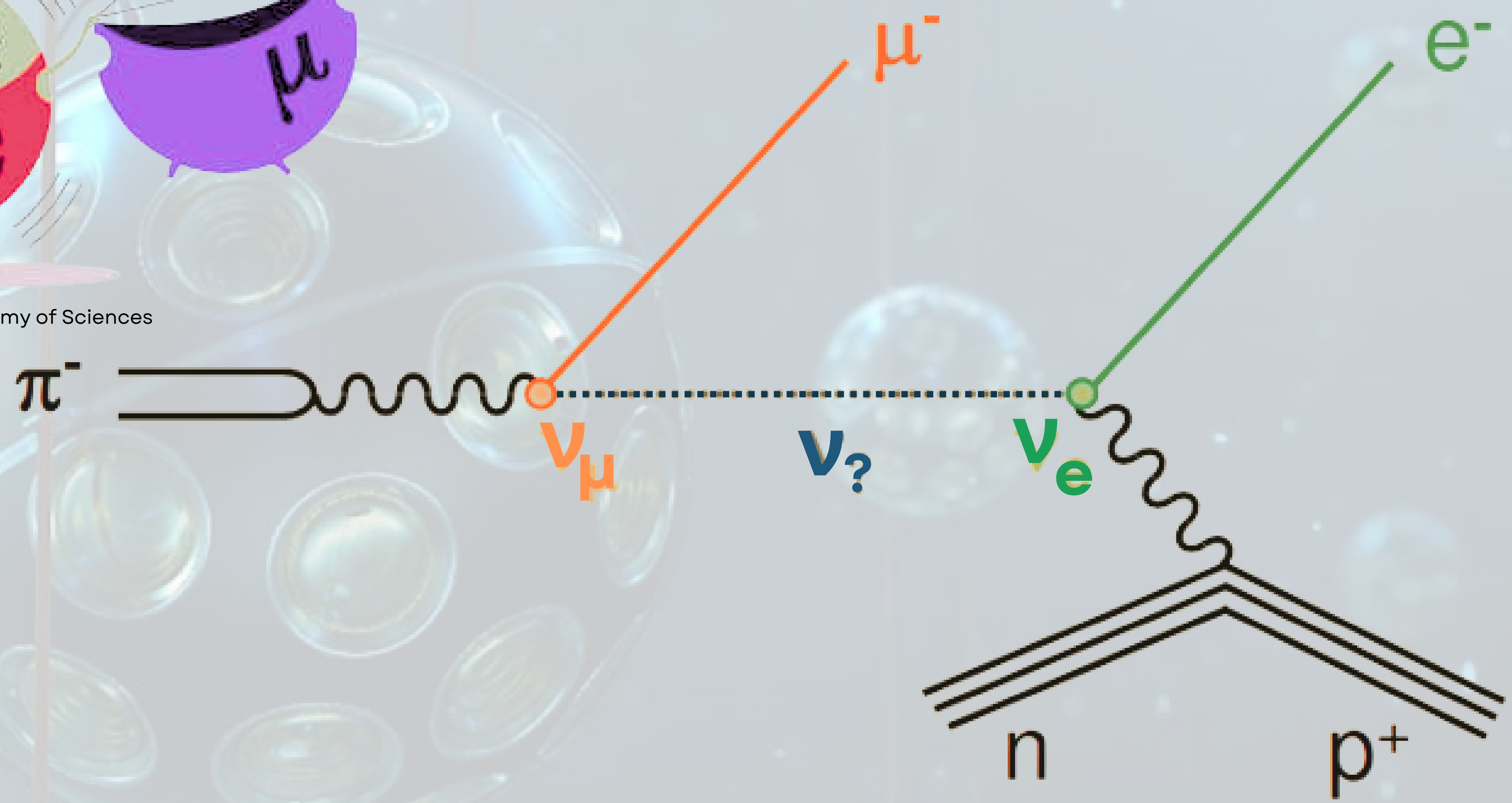
Neutrino Oscillations in a nutshell



Credits: João Coelho

Neutrino Oscillations in a nutshell

Credits: Johan Jarnestad/The Royal Swedish Academy of Sciences



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Neutrino Oscillations in a nutshell

Flavour mixing

- Neutrinos come in three flavours. This is the base where neutrinos interact.
- If we instead look at the neutrinos propagating in space they are studied in the mass basis.
- These two bases are not the same. One is a rotation of the other.

$$\begin{bmatrix} \nu_{\mathrm{e}} \\ \nu_{\mu} \\ \nu_{\tau} \end{bmatrix} = \begin{bmatrix} U_{\mathrm{e}1} & U_{\mathrm{e}2} & U_{\mathrm{e}3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

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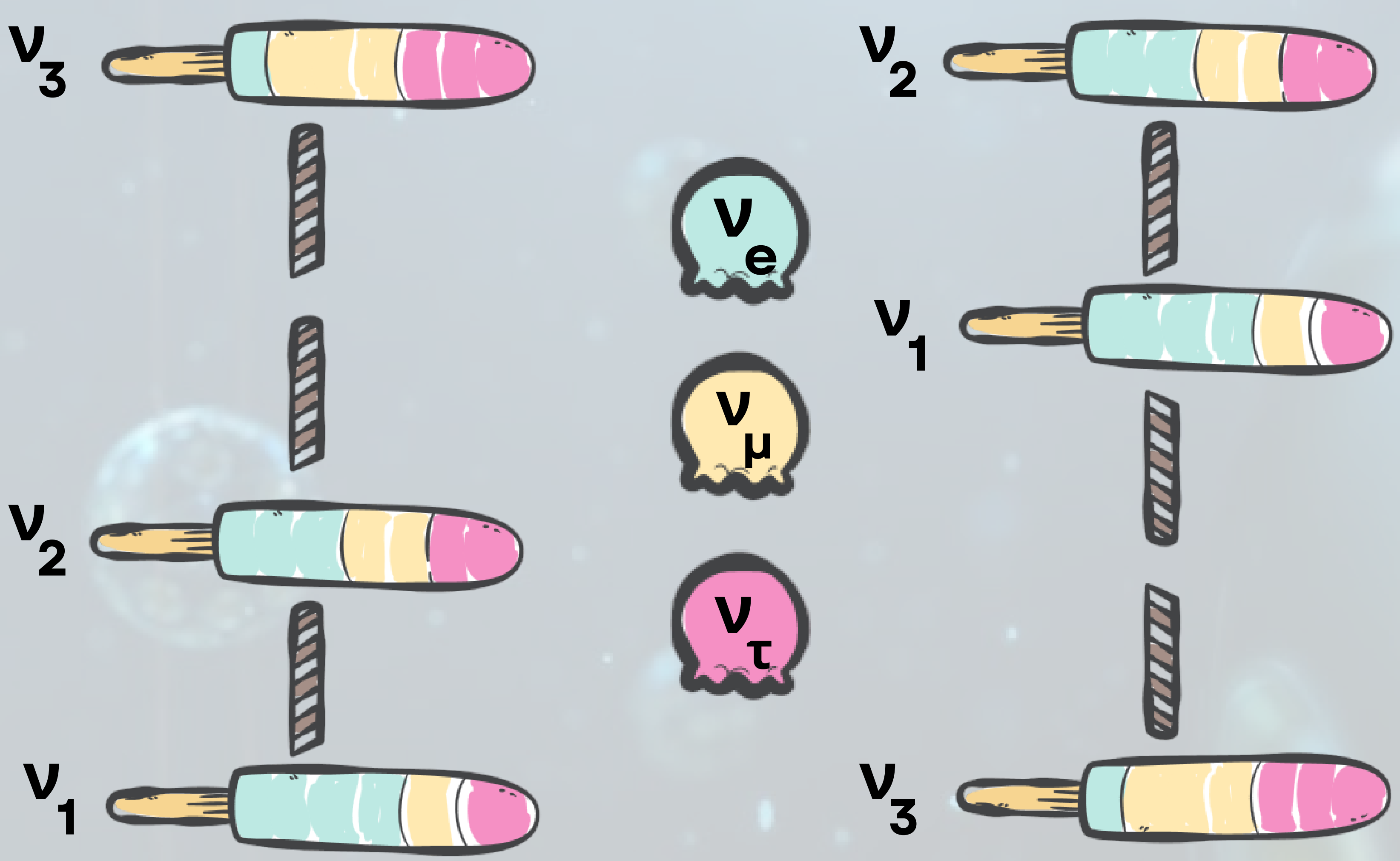
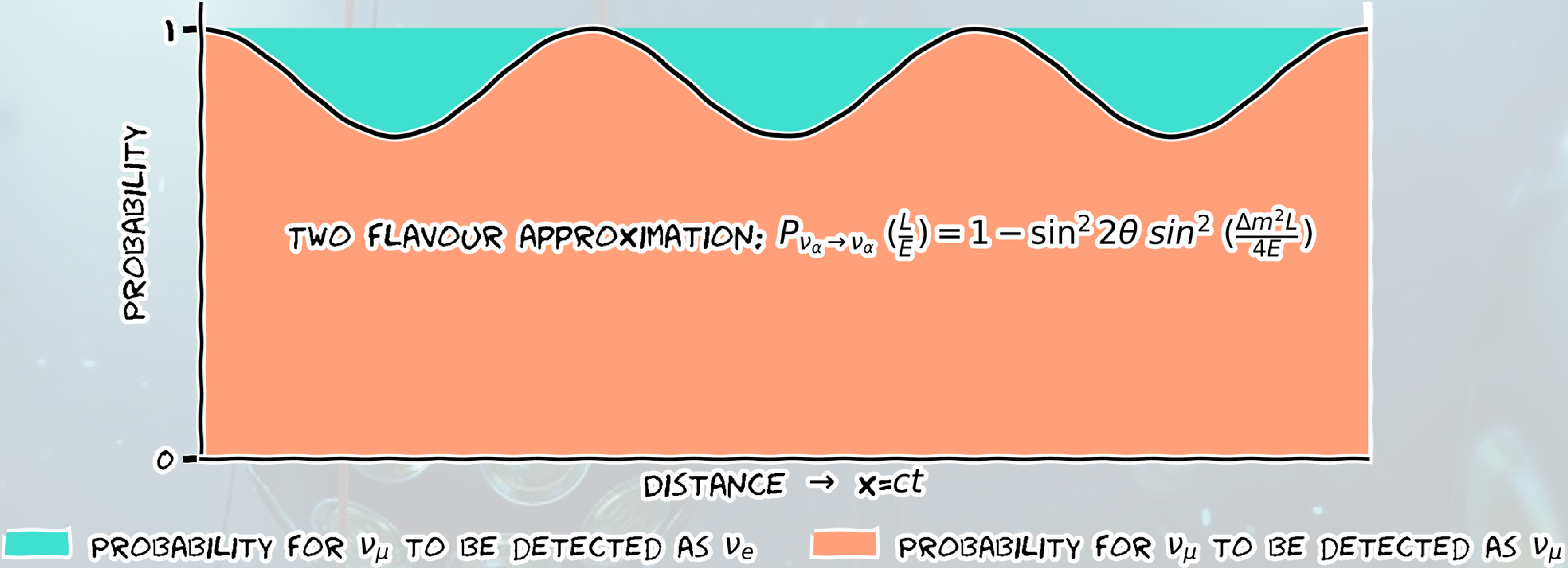
Ice-cream flavour mixing



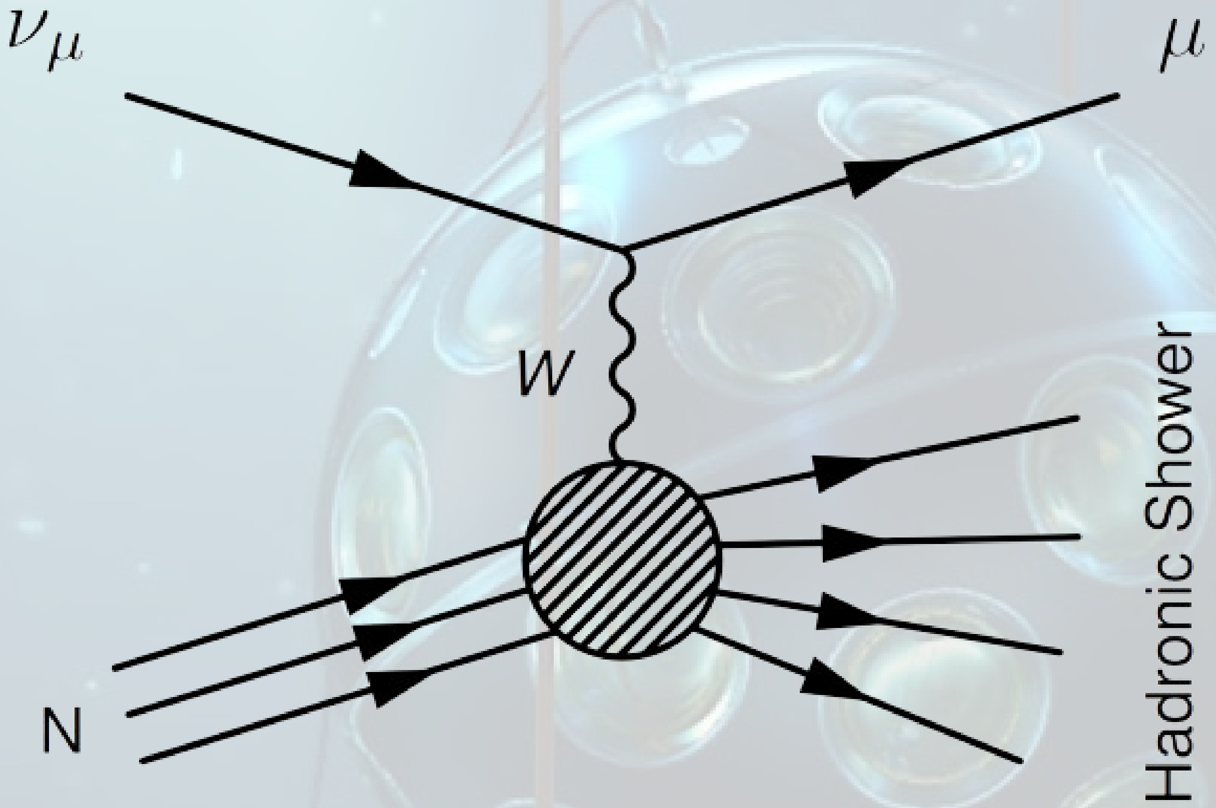
Credits: Kaja Vidovic and Miha Muskinja

Neutrino Oscillations in a nutshell



Interactions with matter

Neutrinos may eventually find a target to interact with. The interaction will produce secondary particles.



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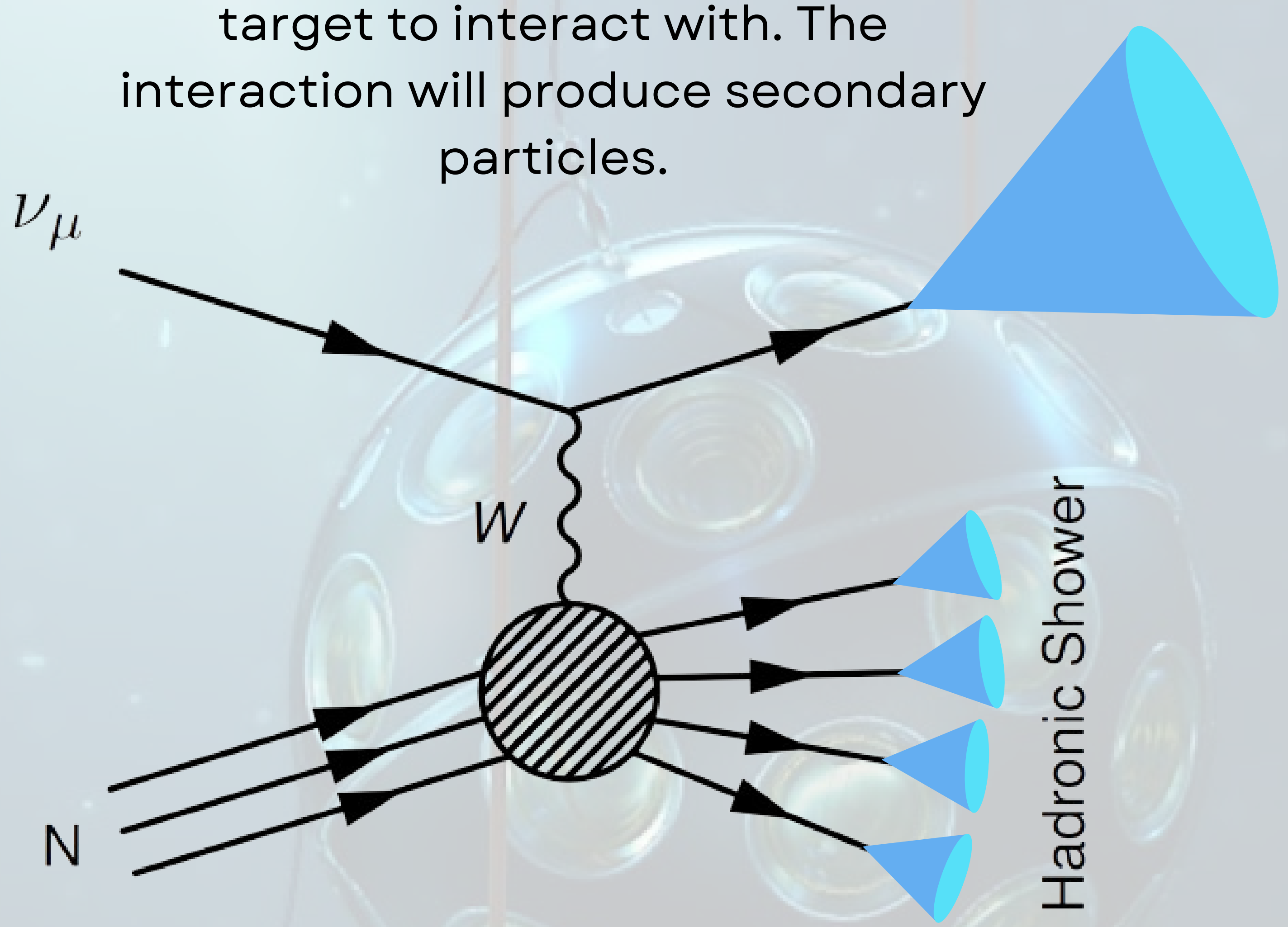
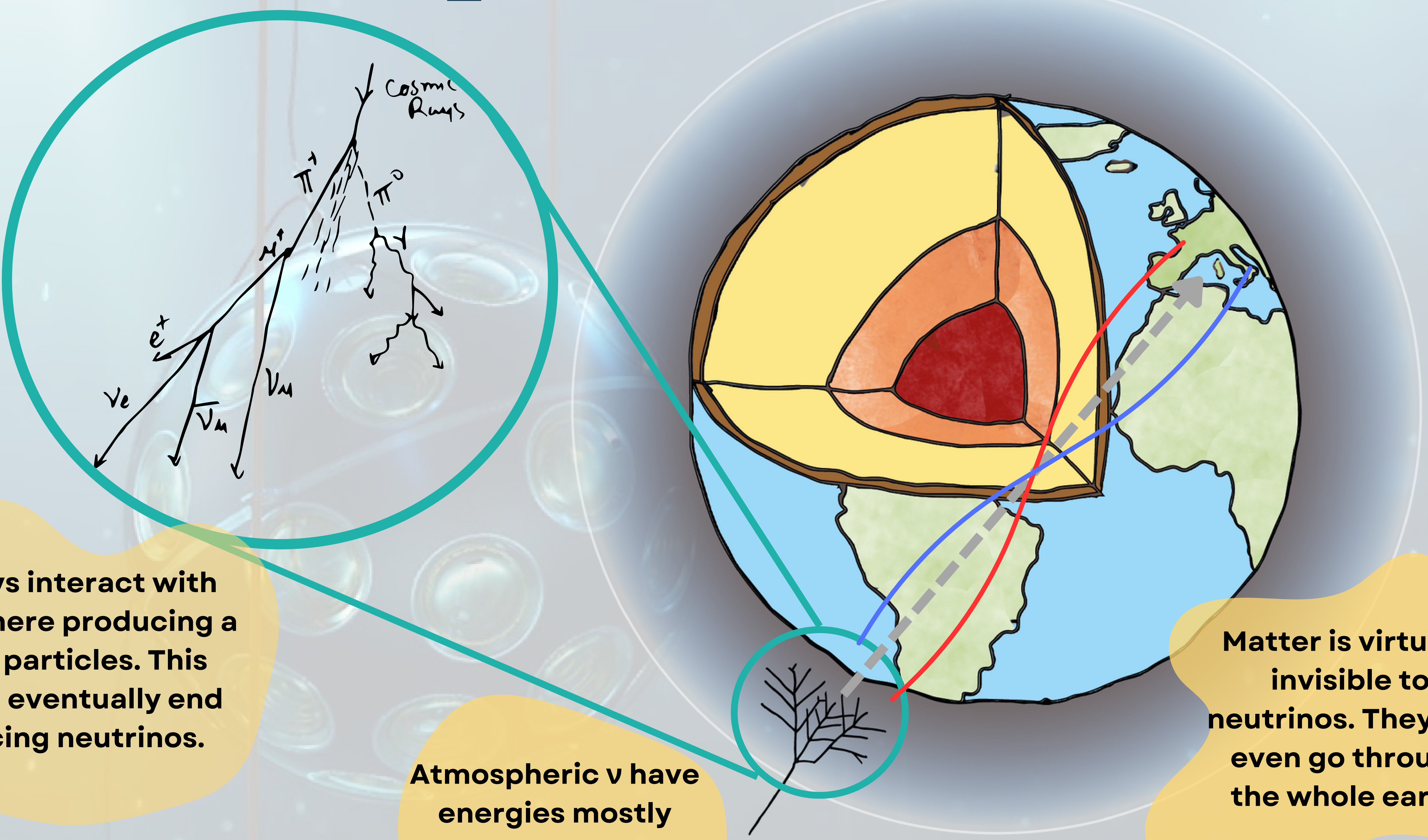


- On a transparent medium, secondary particles can travel faster than the speed of light in the medium.
- This produces radiation in the shape of photons. This is called the Cerenkov effect. Sort of a sonic boom but with light instead of sound.

- Gives an idea on how to build an experiment that uses this as a detection method.
- Big volume of transparent medium. Maybe a lake, the sea or even a glacier. (Spoiler alert: there are detectors at all of these sites.)

Atmospheric neutrinos

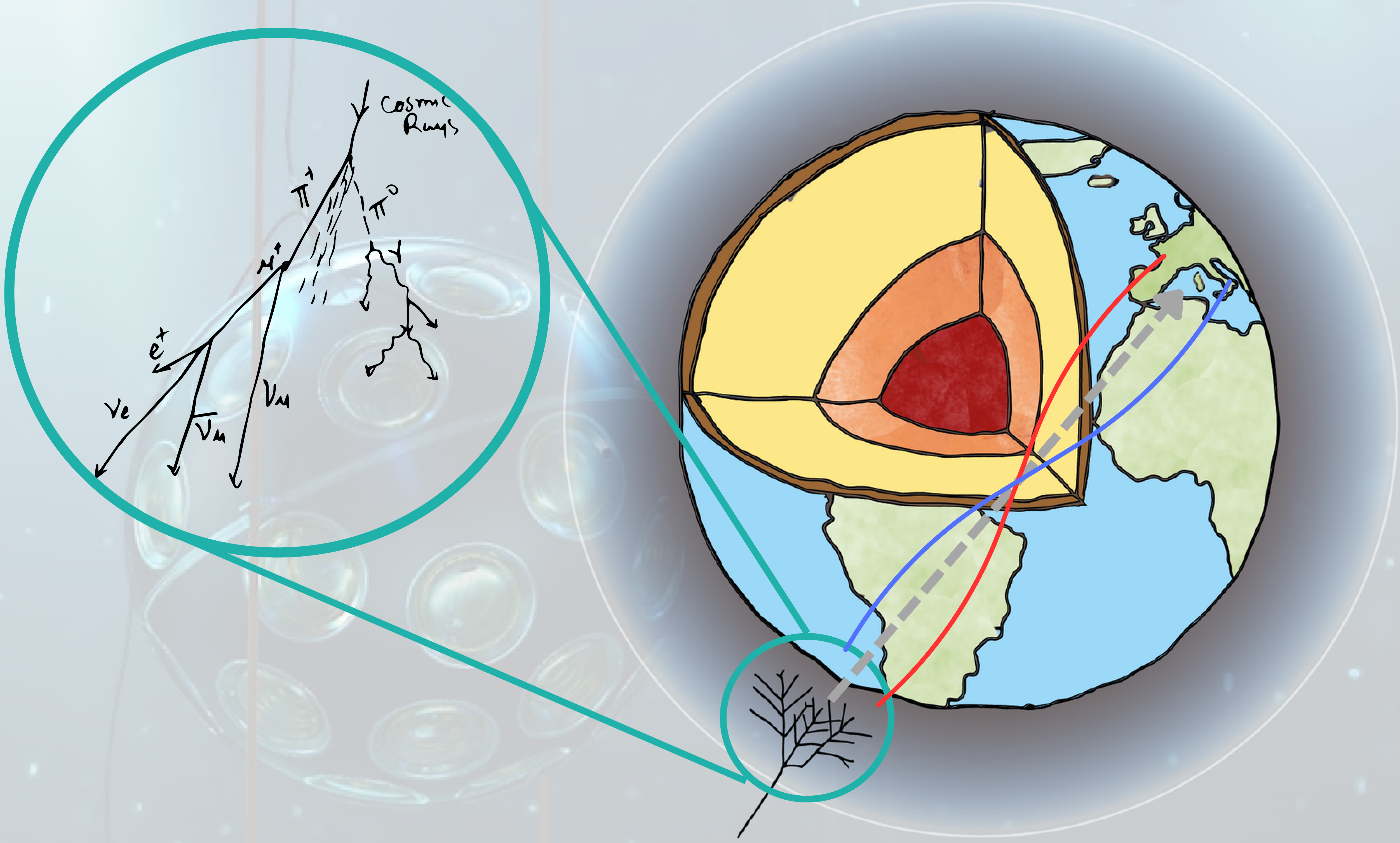


Cosmic rays interact with the atmosphere producing a shower of particles. This shower will eventually end up producing neutrinos.

Atmospheric ν have energies mostly around 1 to 100 GeV

Matter is virtually invisible to neutrinos. They can even go through the whole earth!

How to detect atmospheric neutrinos?



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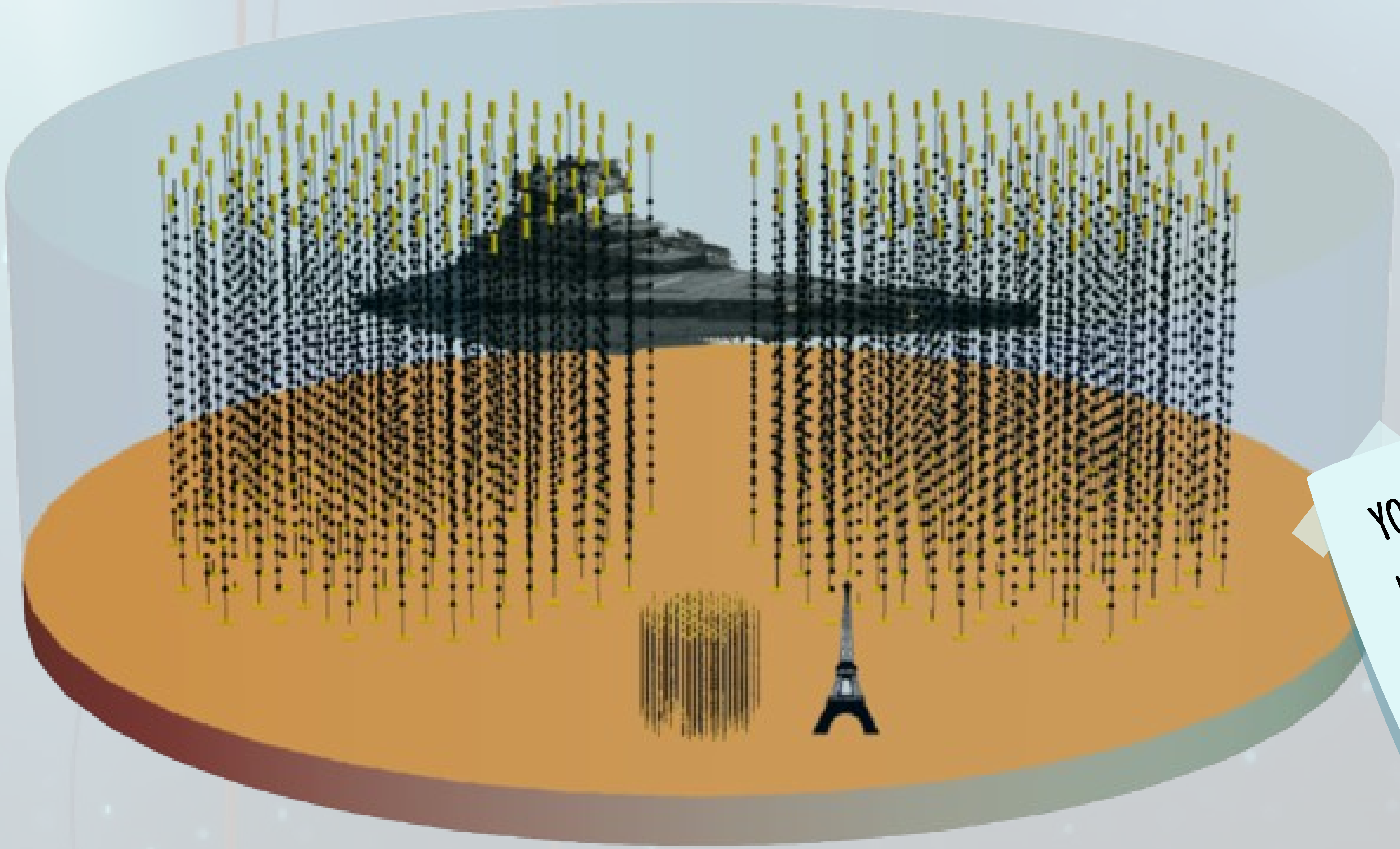
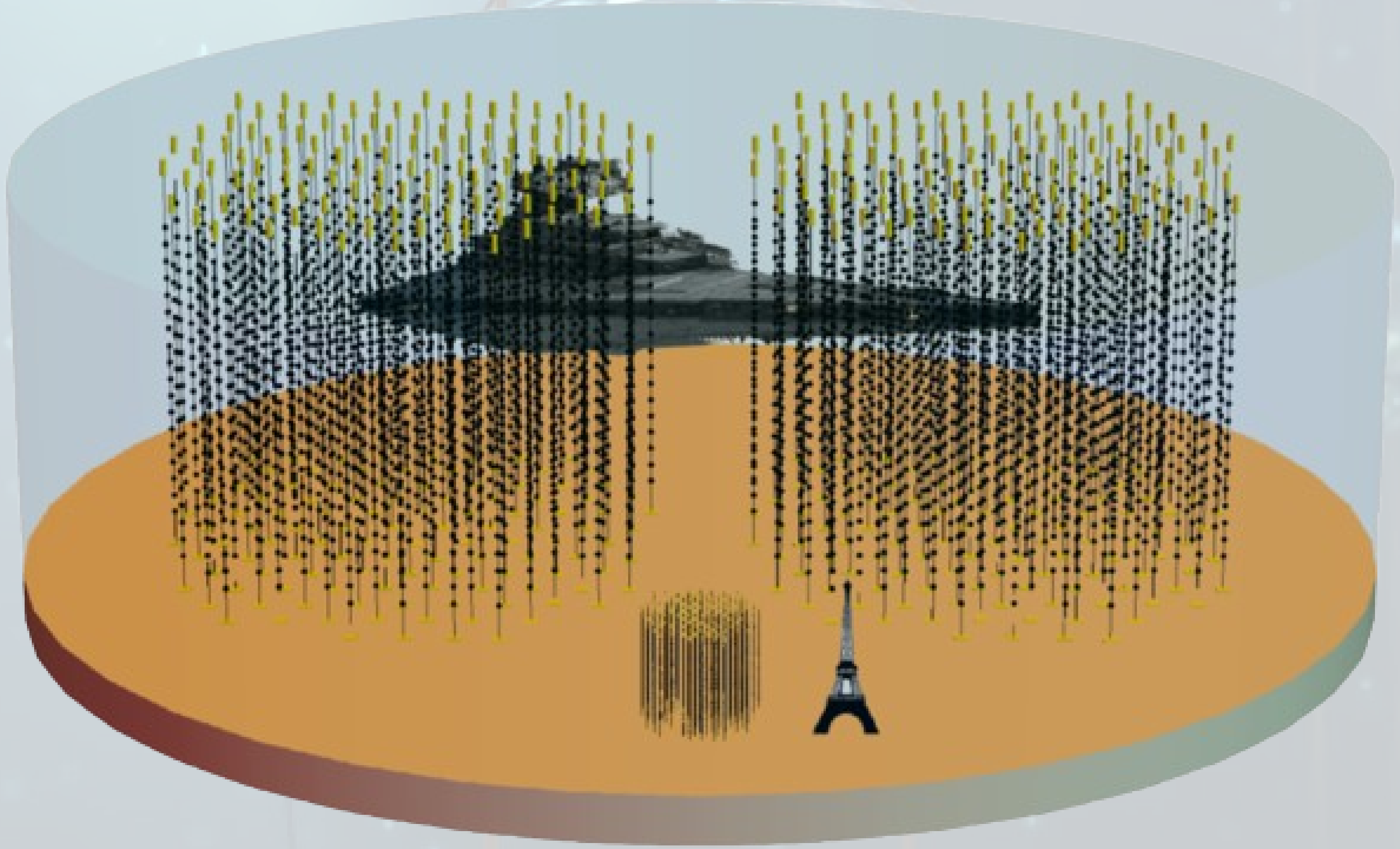


YOU "JUST" NEED A HIGH RESOLUTION DETECTOR ON A BIG TRANSPARENT MEDIUM.

KM3NeT enters the game

- Detector under construction located at the bottom of the Mediterranean sea.
- Two sites for differerent types of physics goals.
- Same technology. Glass sphere with photomultiplier tubes to detect single photons from Cherenkov radiation.



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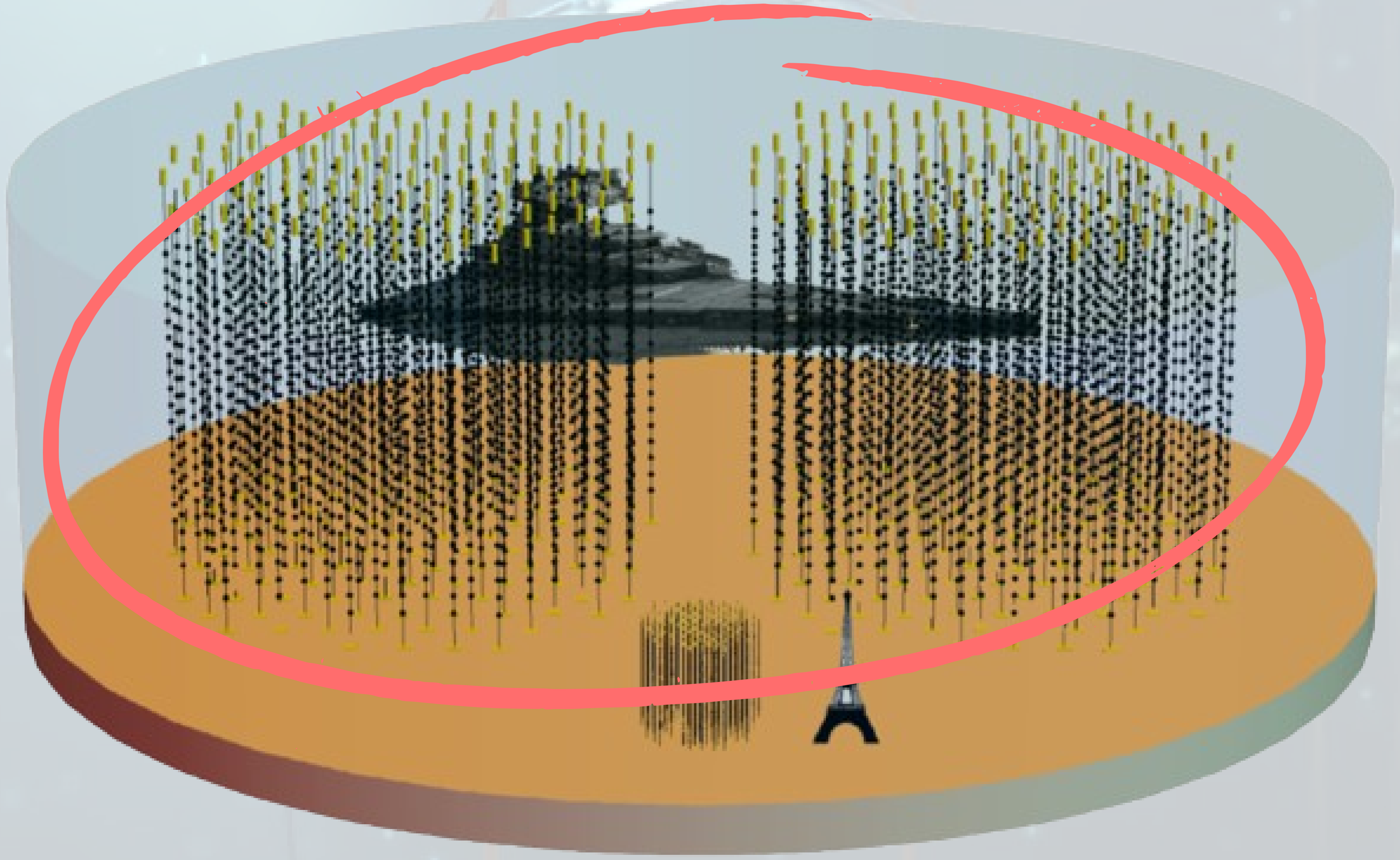

ARCA DETECTOR

- Wide size to detect astrophysical neutrinos.
- Aim to do astronomy with neutrinos with very high energy.

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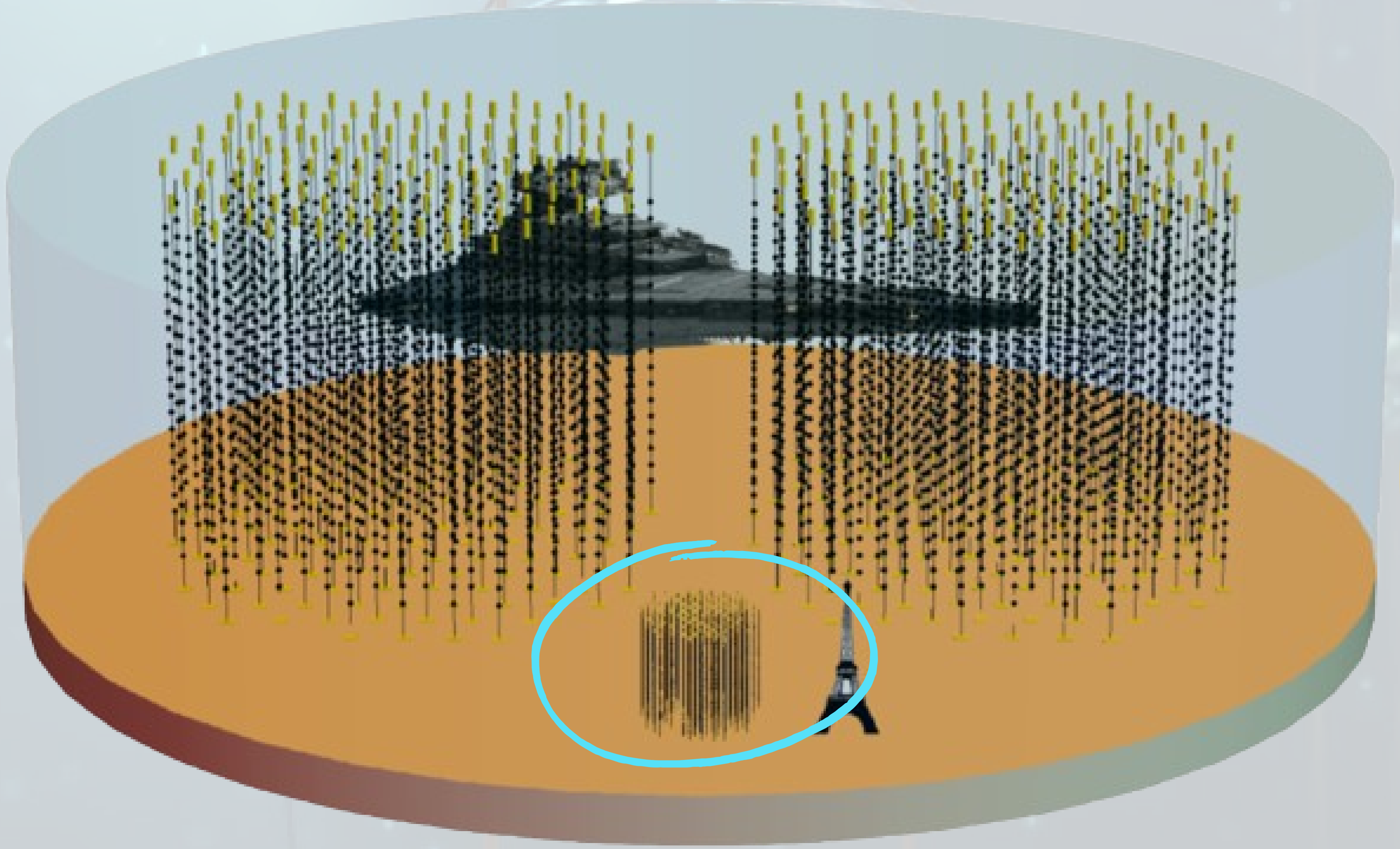
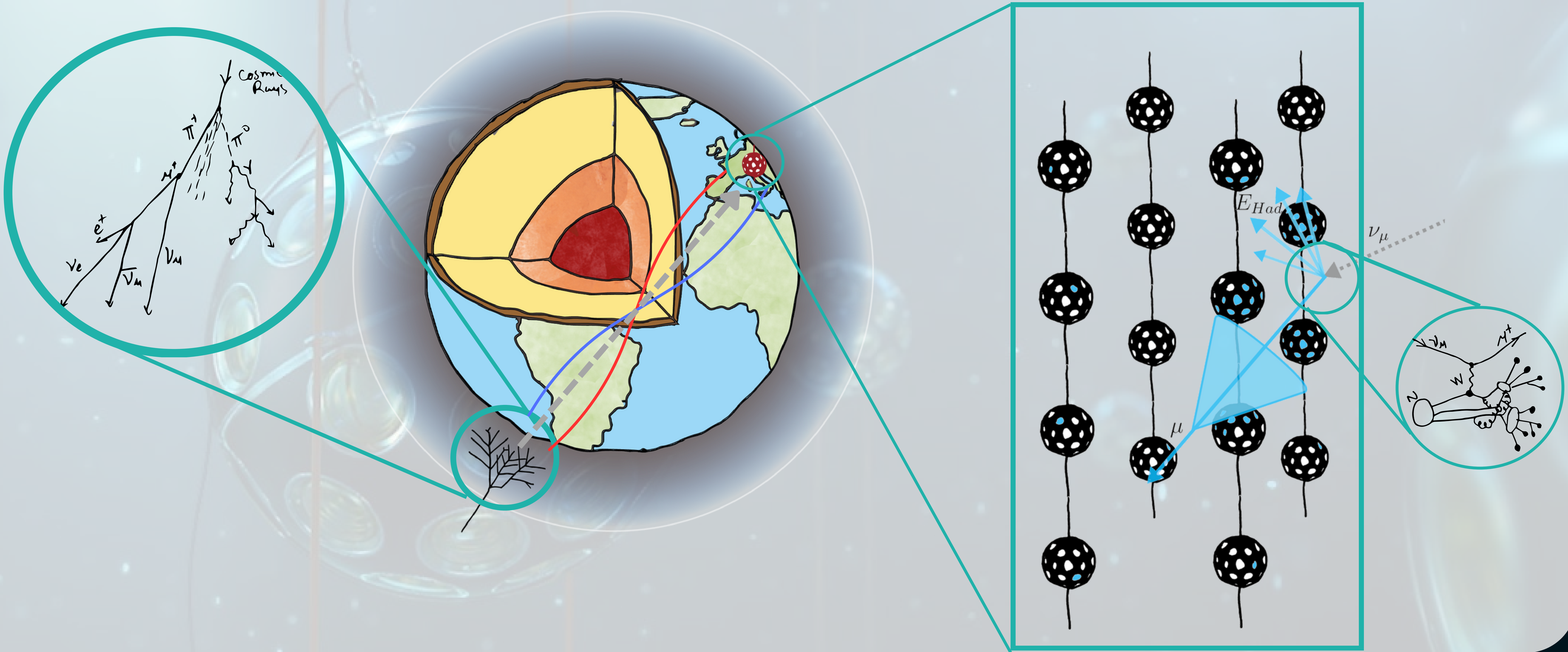


ORCA DETECTOR

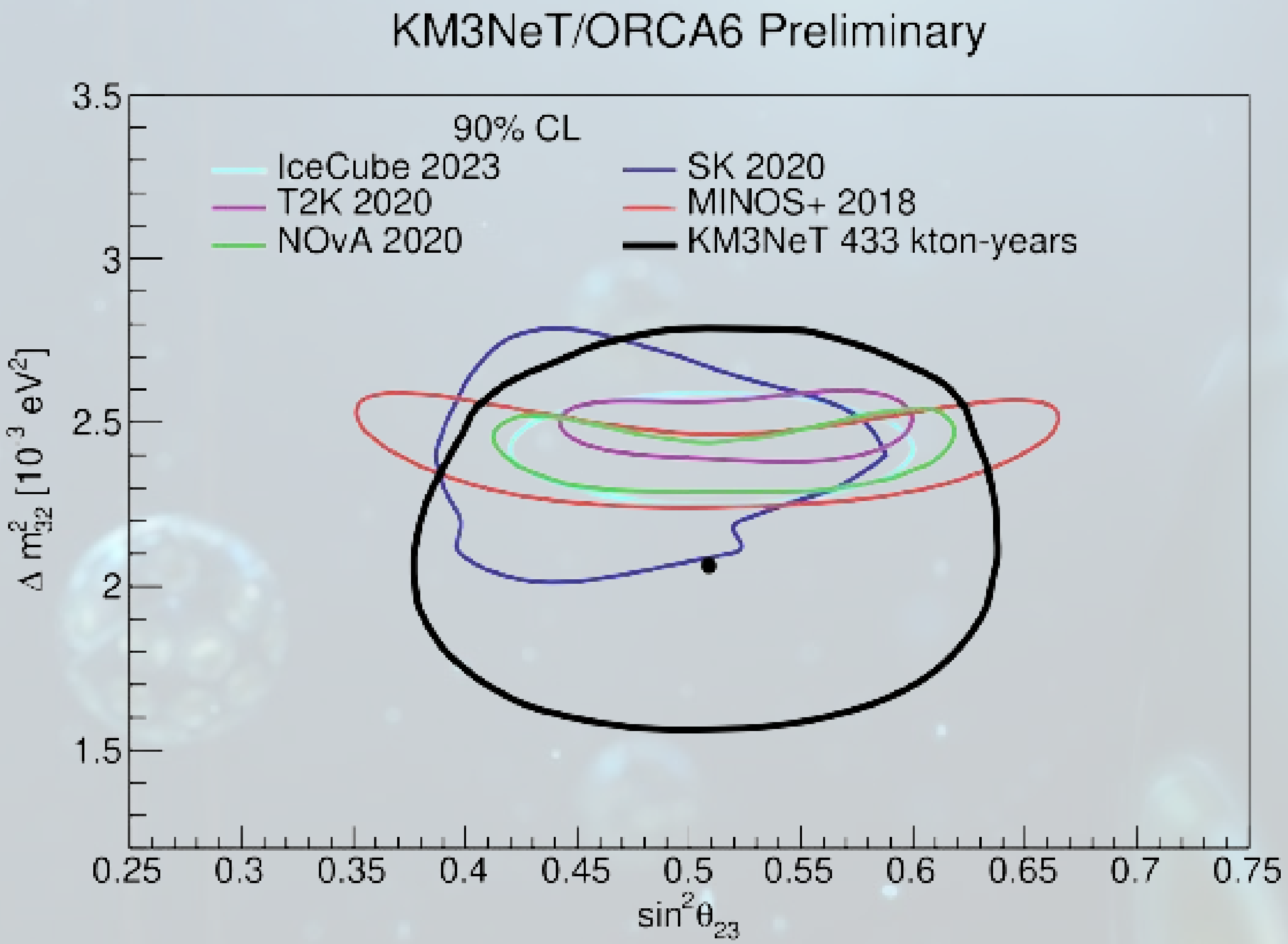
- Dense detector aimed to study neutrino oscillations.
- In particular the main goal is to determine the NMO and measure oscillation parameters.

Detecting atmospheric neutrinos with KM3NeT/ORCA



Recent results on oscillations

- Modular design of the experiment allows to collect data without waiting to be fully constructed.
- Analysed data from a detector 5% of what will be the final detector configuration.
- Results already start to be competitive with other experiments.
- Exposure of 433 kton-years.



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Conclusions and next steps

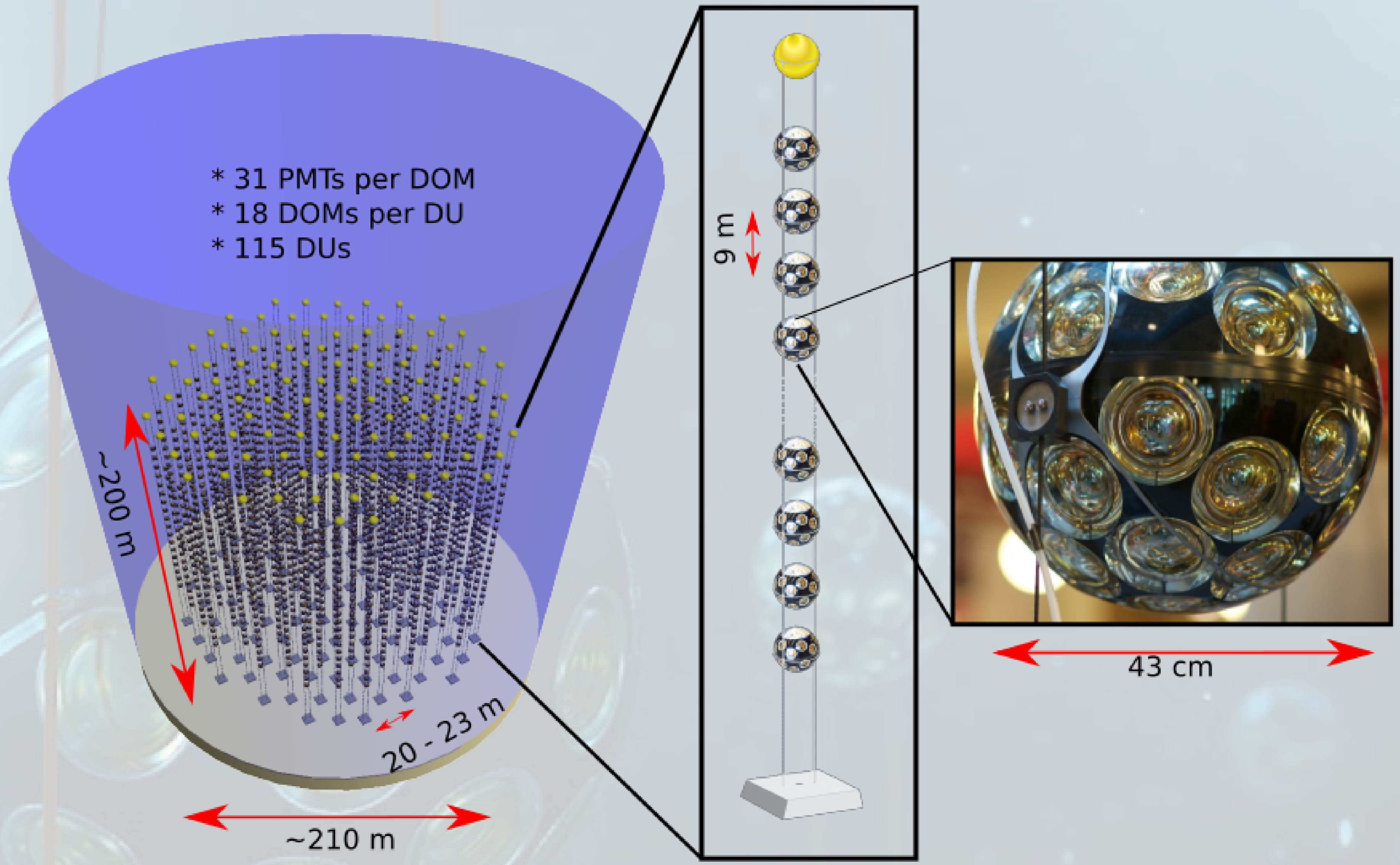
- Experiment under construction with first successful data analyses. Thanks to modular design.
- Recent results start to be competitive with other experiments.
- Lots of interesting physics waiting to be explored using neutrinos. KM3NeT allows to probe models beyond the standard model of particle physics.

FOR THIS SUMMER, I AM CURRENTLY DOING THE ANALYSIS FOR TWICE AS MUCH EXPOSURE

STAY TUNNED FOR MORE!

Backup

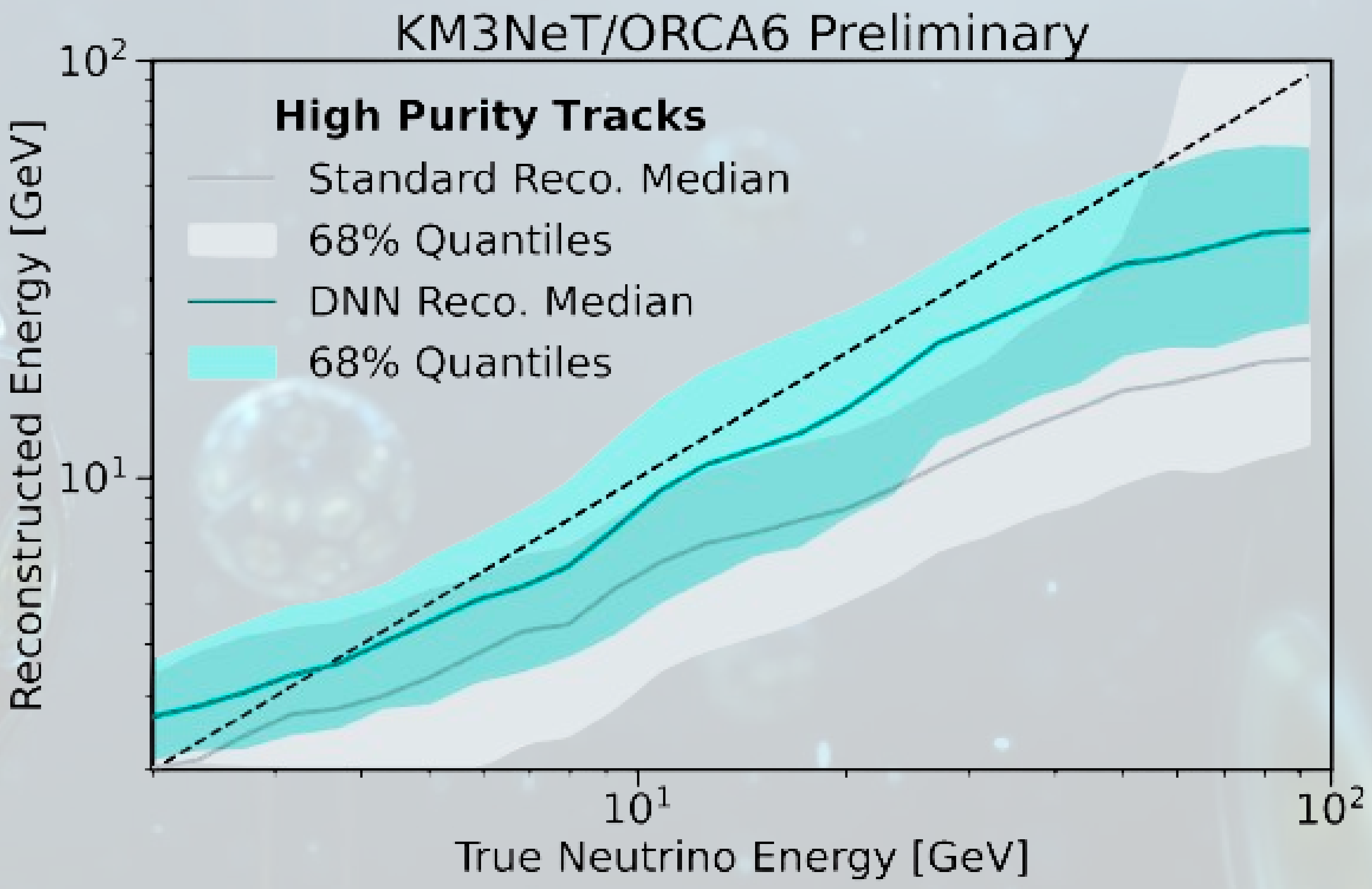
Details of KM3NeT/ORCA



PMT: Photomultiplier Tube, DOM: Digital Optical Module, DU: Detection Unit (string of DOMs)

ML studies to improve energy reconstruction.

- Deep Neural Network to improve reconstructed energy of interacting neutrino.
- High level variables as input to neural network with skip connections architecture.



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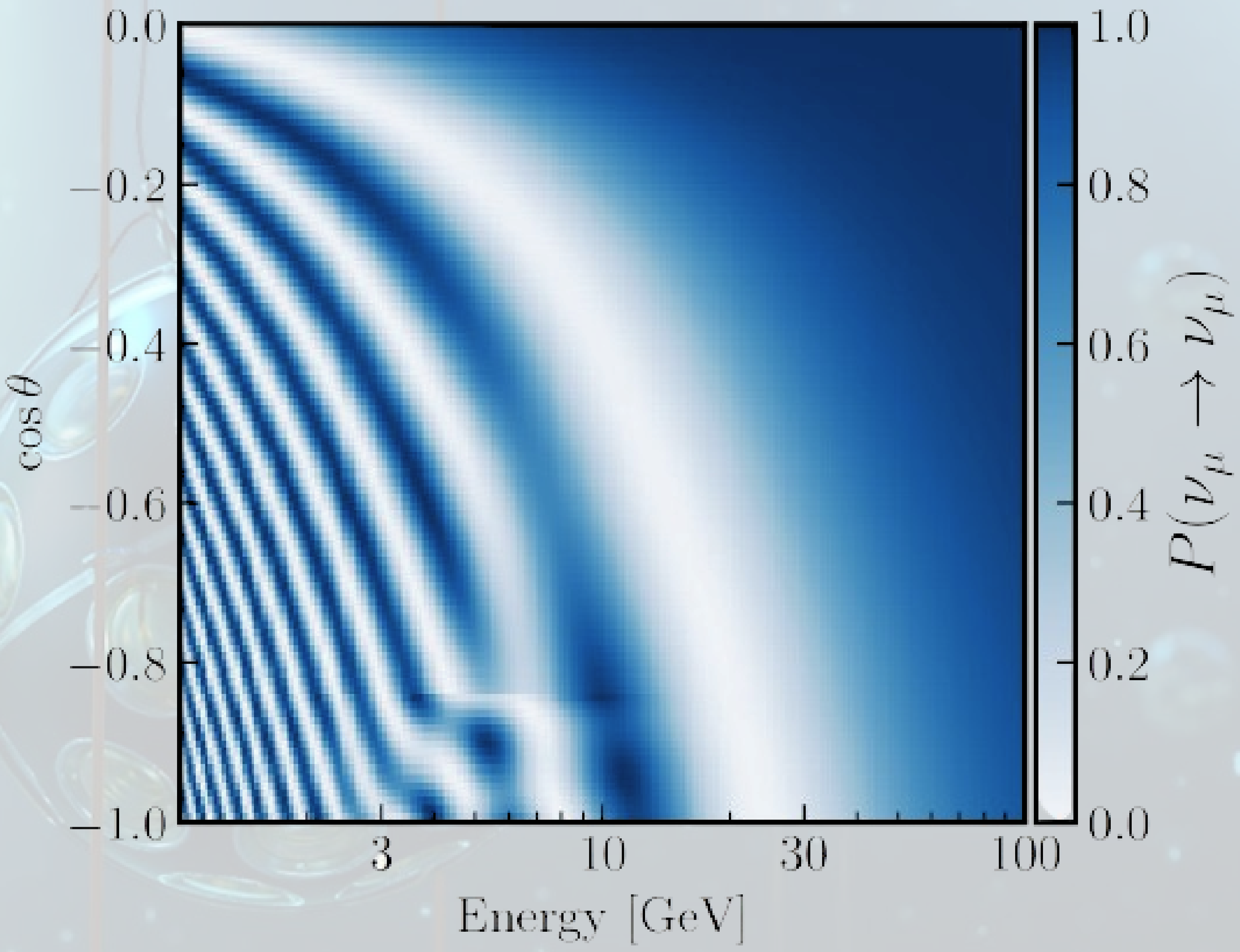
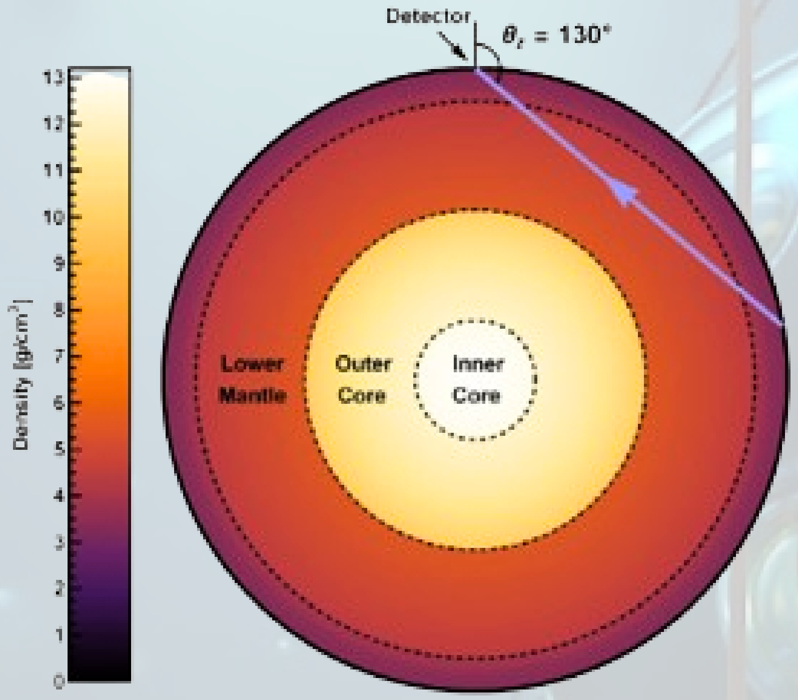
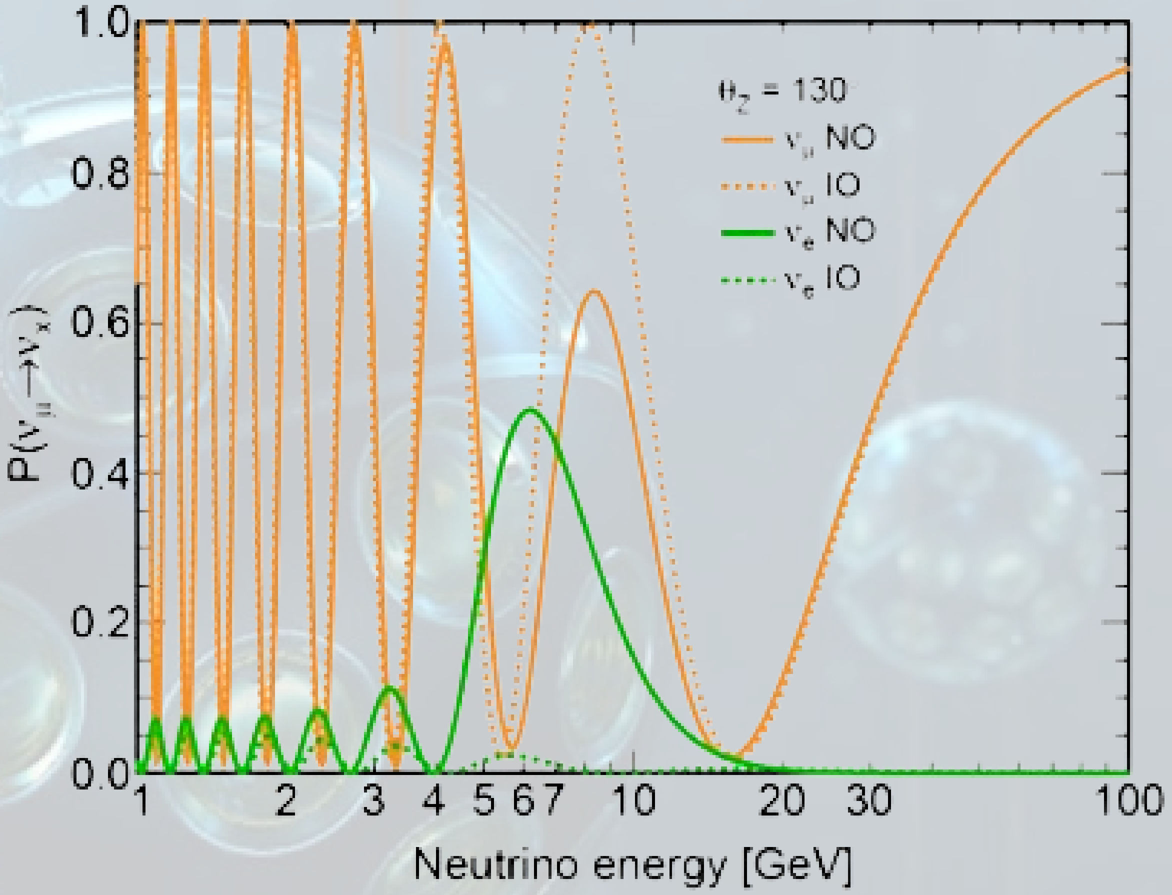
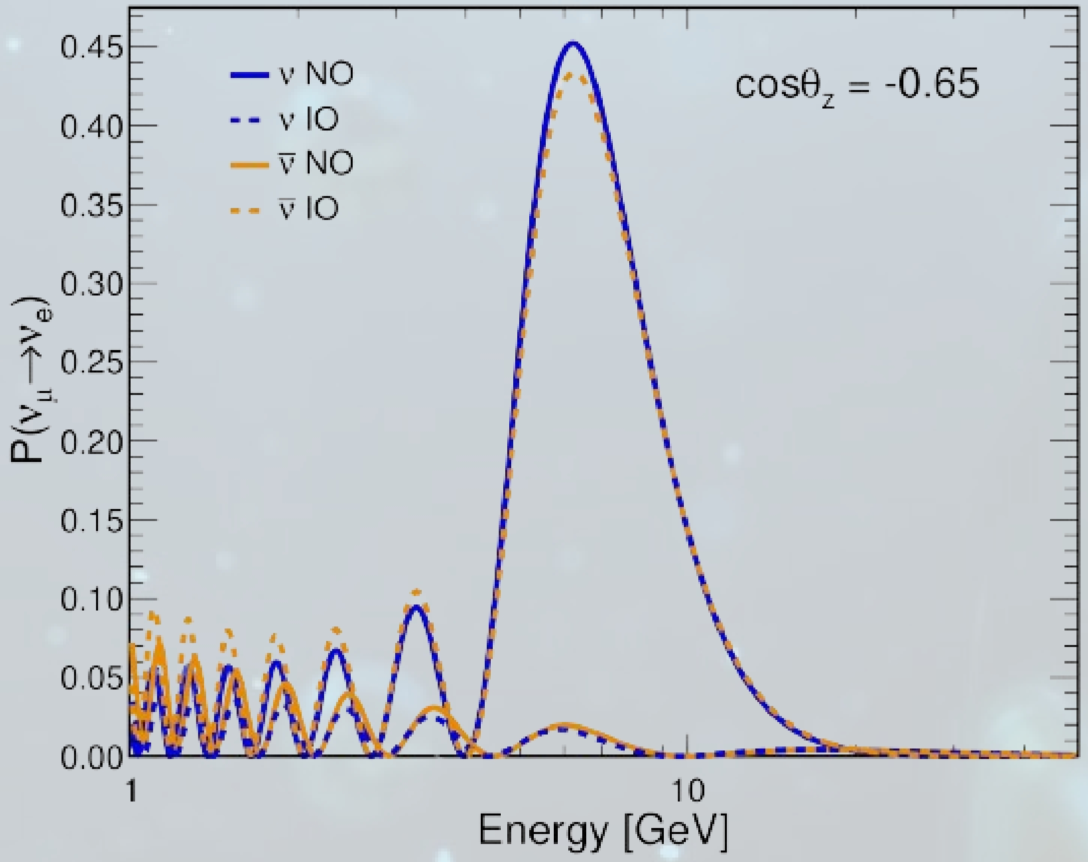
In reality we look at oscillations in 2D



Measuring the mass ordering using matter effects







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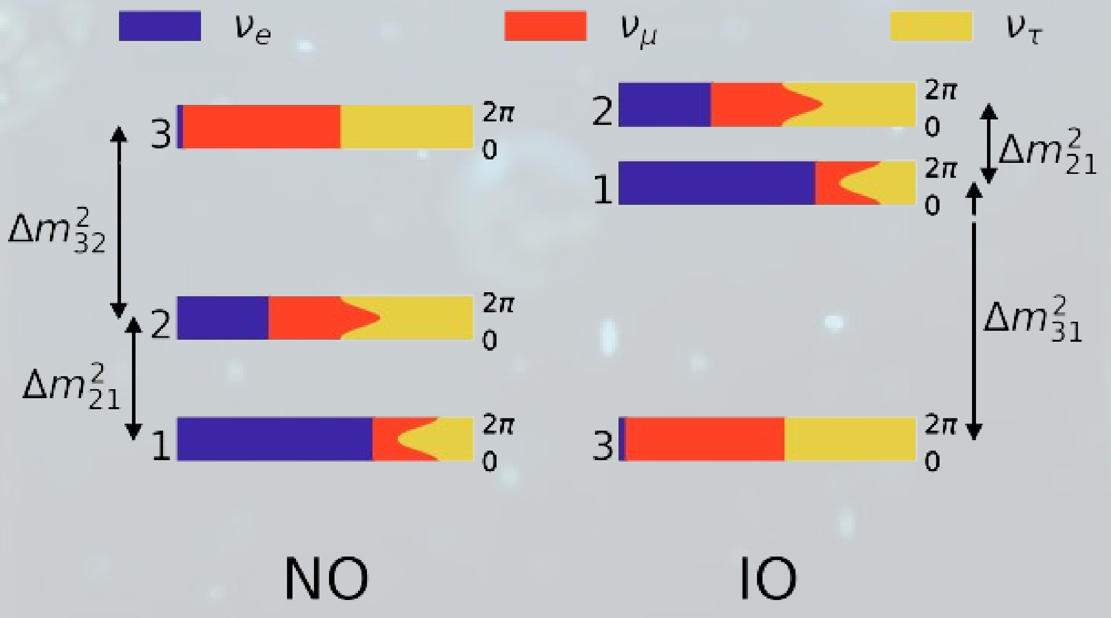
Neutrino oscillations

- A consequence of this mismatch of flavor and mass eigenstates is neutrino oscillations.
- Observing oscillation implies that neutrinos must have non-zero, and different masses
- Quantum superposition of mass eigenstates lead to changes in probability of detection

- Absolute mass scale is not directly accessible
- Has been established that m2 > m1 ✓
- We don't know yet whether m3 is largest or smallest (NMO)



https://globalfit.astroparticles.es/2018/07/03/neutrino-mass-ordering/