Master Project opportunities in experimental neutrino physics

Paul de Jong, paul.de.jong@nikhef.nl

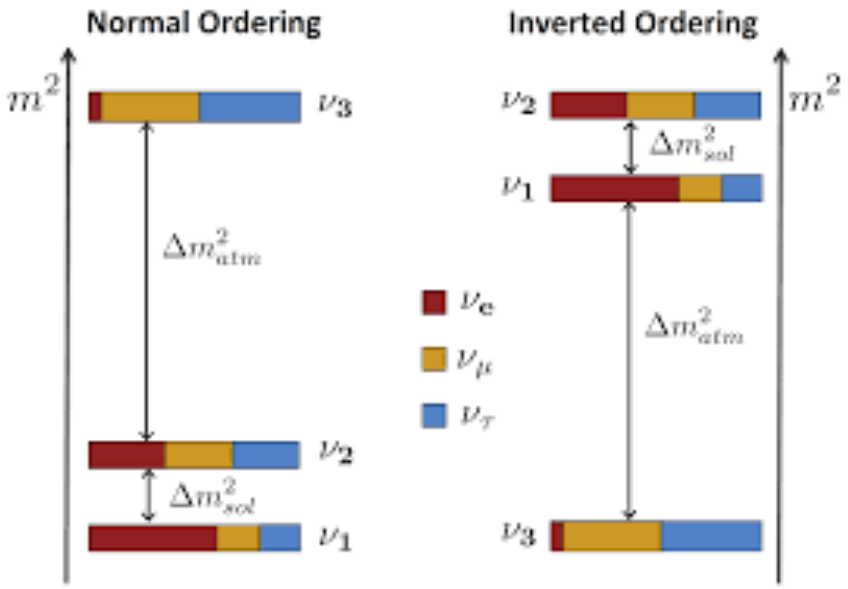
Neutrino properties

In SM: neutrinos strictly massless

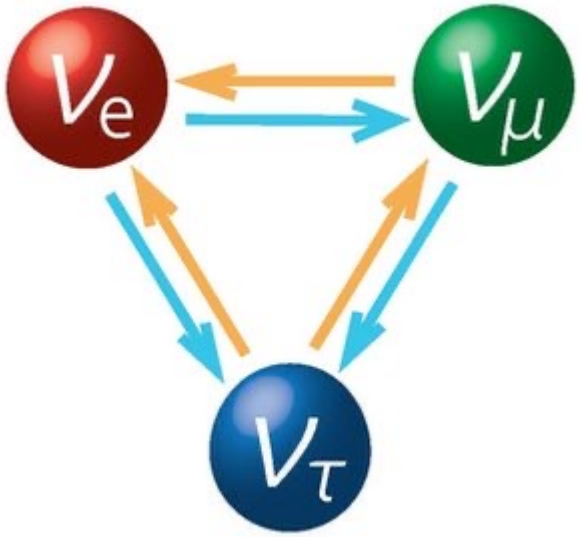
only left-chiral states = left-helicity states participate in interactions

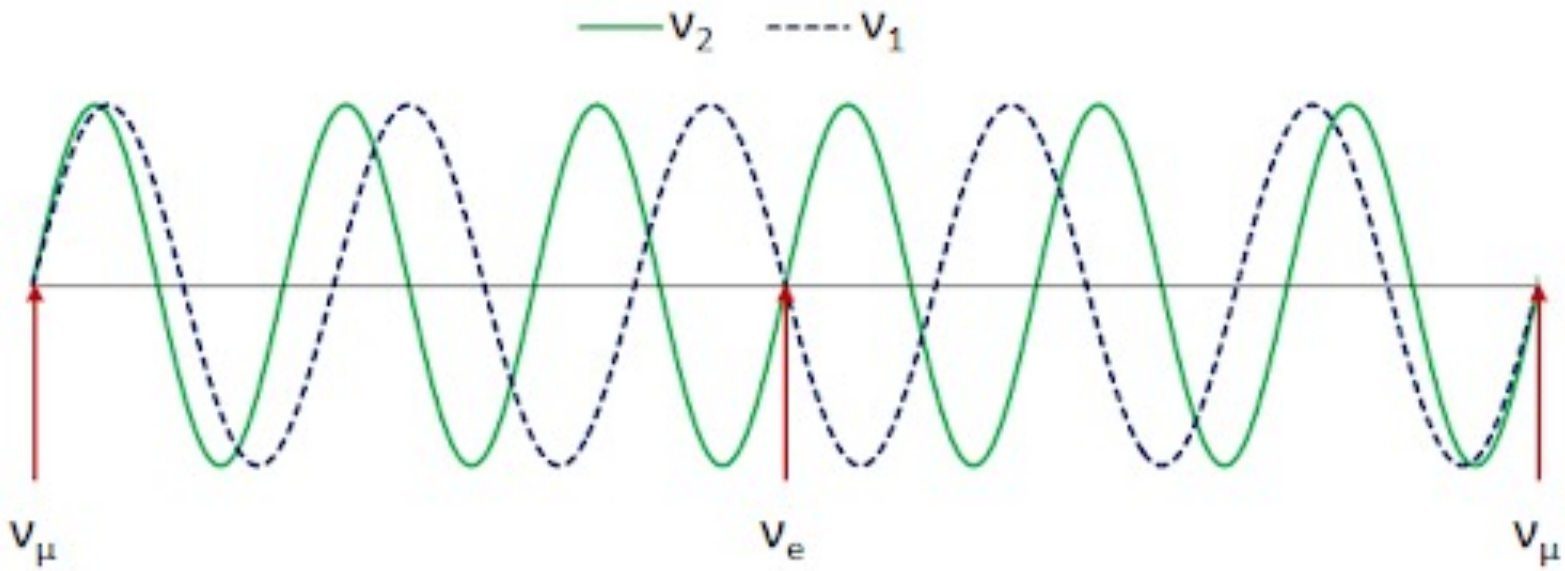
But: we now know that neutrinos have a very small, but non-zero mass.

- *tiny mass: suggests influence of new physics*
- *large mixing between mass- and flavour-states*
- *masses unknown; ordering of mass-states unknown*
- *its own antiparticle? (Majorana fermion)*
- *CP-violation? If yes: leptogenesis?*
- *sterile neutrinos?*



Neutrino oscillations



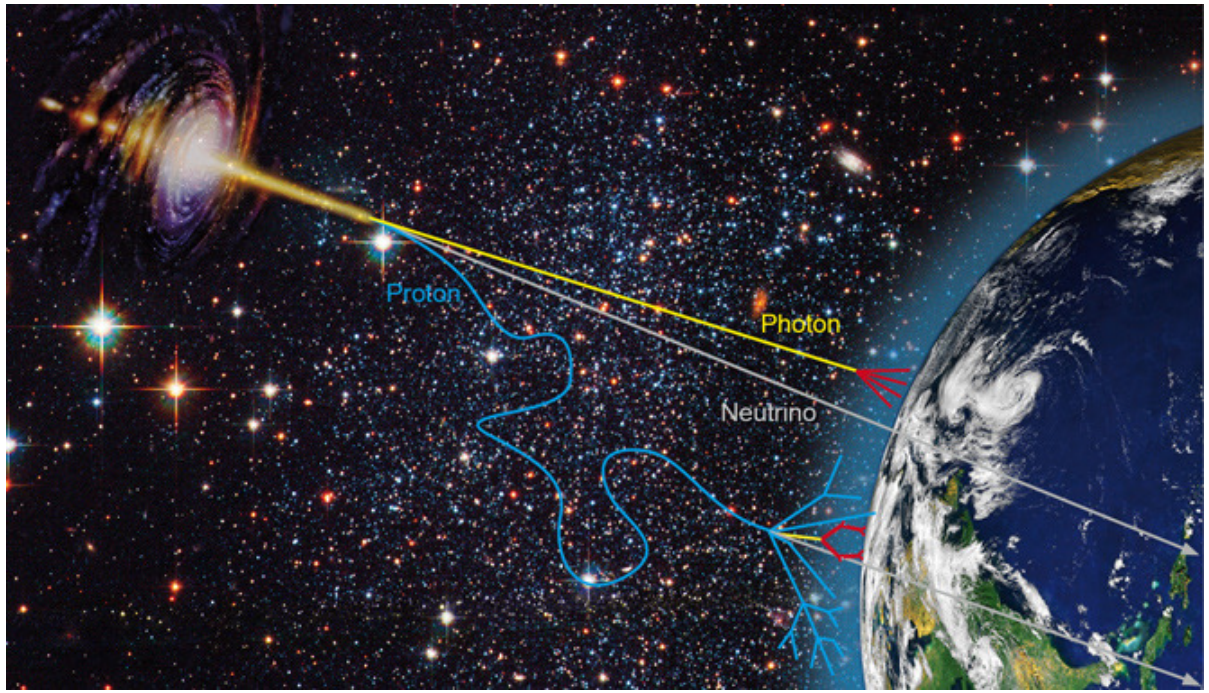


Large mixing of mass- and flavour eigenstates (PMNS matrix)
Flavour-eigenstate decomposes in multiple mass-eigenstates, run out-of-phase.
At time $t > t_0$: results in different composition of flavour-eigenstates: transformation.

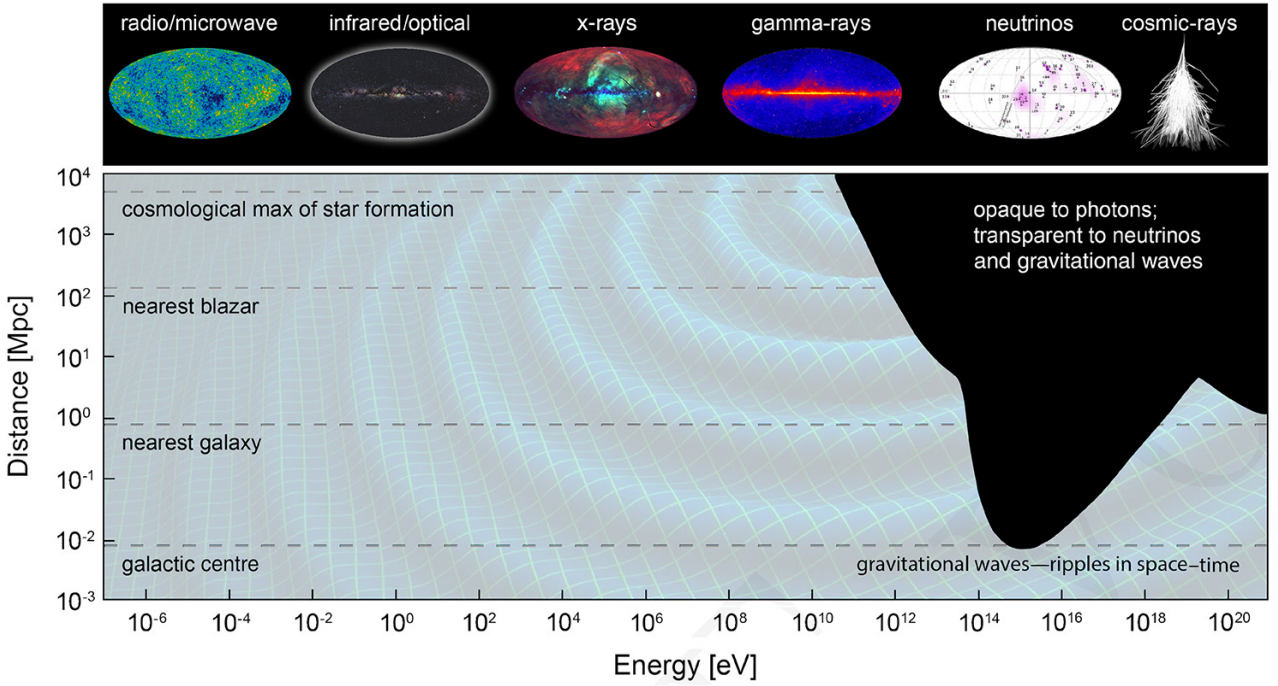
Measurements: mixing parameters, mass-differences, mass-ordering, CP-violation

Neutrinos as a tool

Messengers of extreme processes in the Universe

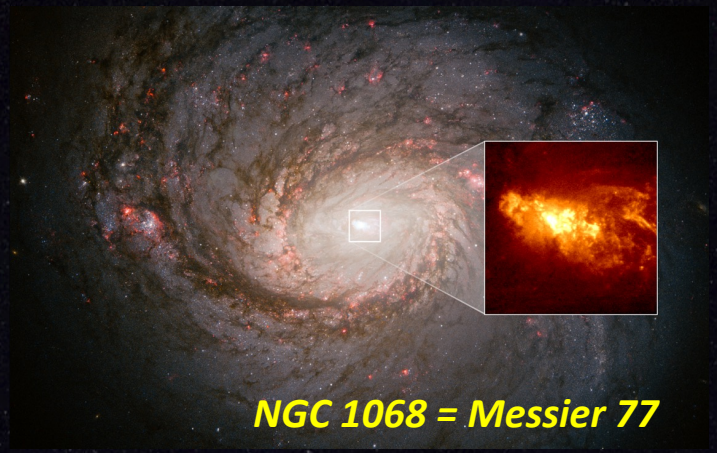


No absorption, no deflection



Whereas γ-rays above 100 TeV are absorbed

Origin of cosmic rays, hadronic accelerators?



Blazars?
Tidal disruption events?
Radio galaxies?

Two experimental facilities:

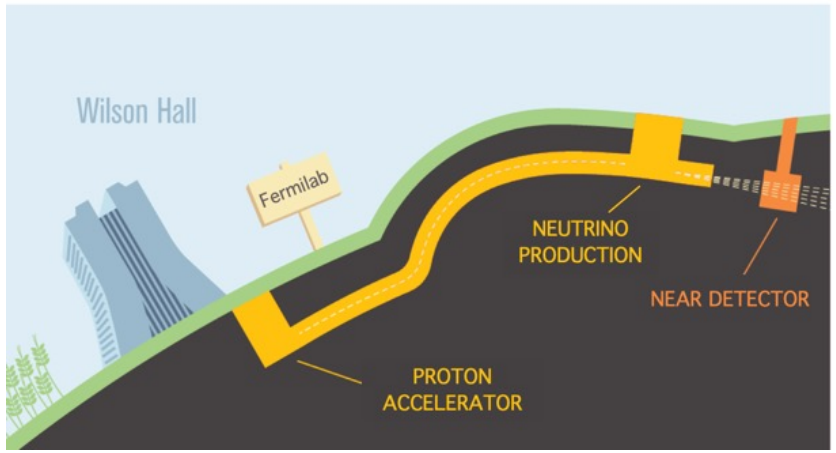
DUNE

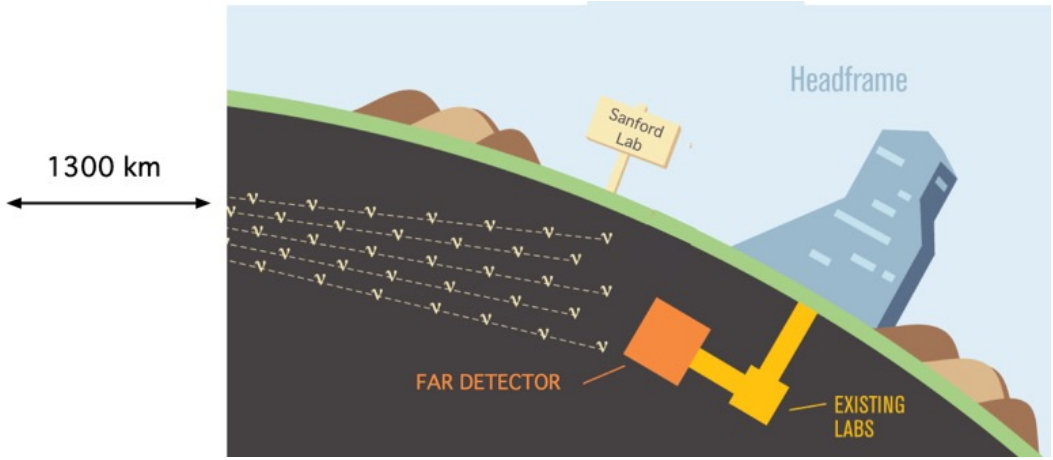
KM3NeT

+ preparations for an acoustic neutrino detector

(+ neutrinoless double beta decay in KamLAND,
cosmic neutrino background in Ptolemy: part of Nikhef Dark Matter group)

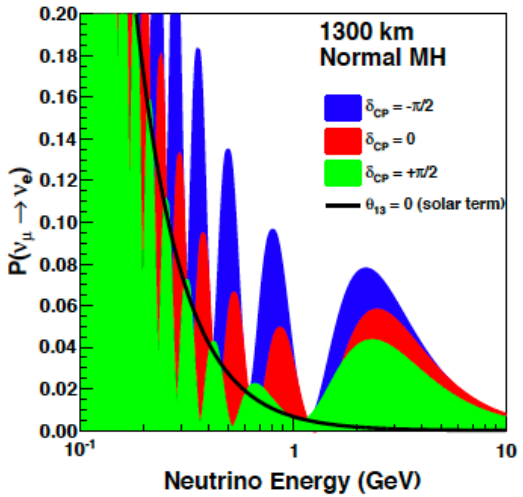
Deep Underground Neutrino Experiment (DUNE)

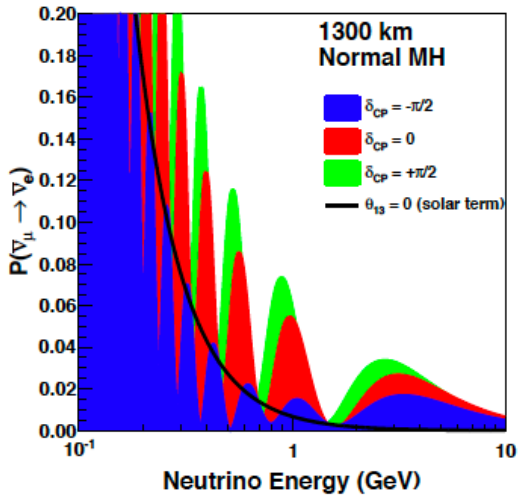




World's most powerful ν_μ or $\bar{\nu}_\mu$ beam from Fermilab (Chicago) to SURF (South Dakota), 1300 km

Oscillations:



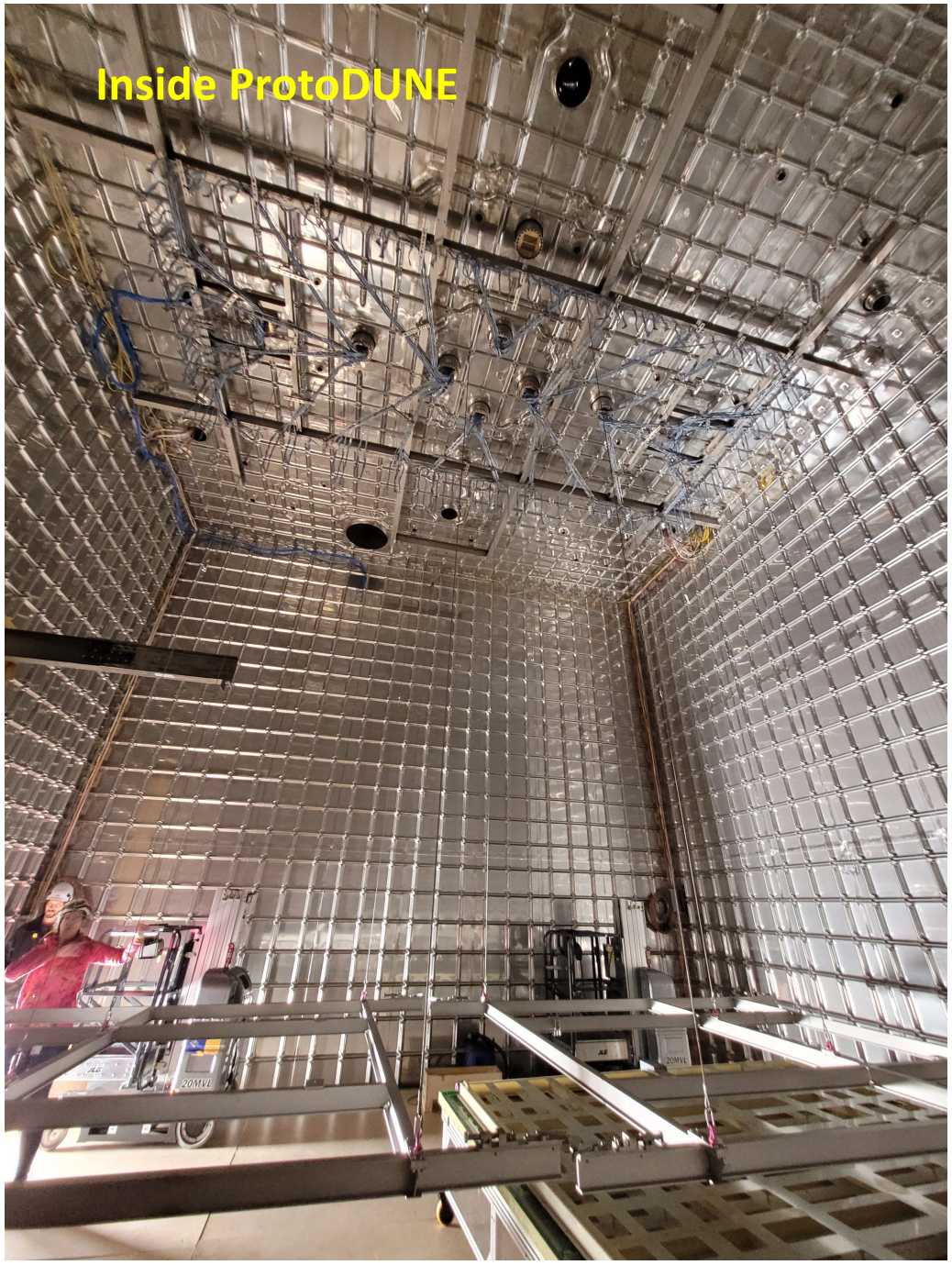


Far detector: liquid argon TPC
4 x 17 kton target mass
1500 m underground

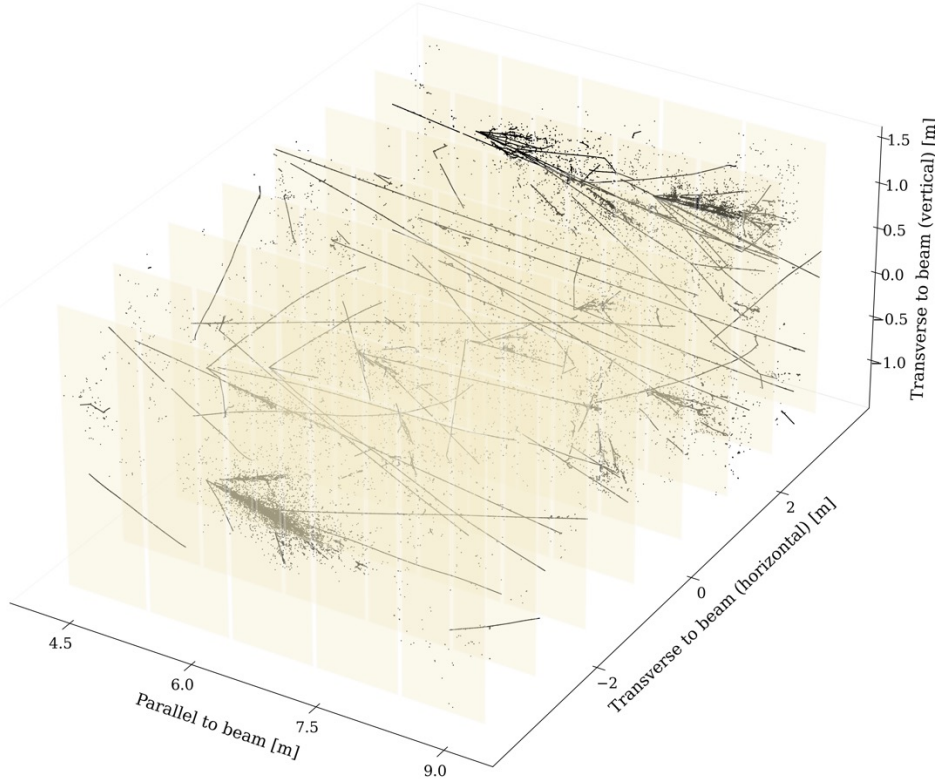
Goal: measure CP-violation


1500 m deep in South Dakota


CERN North Area


Inside ProtoDUNE

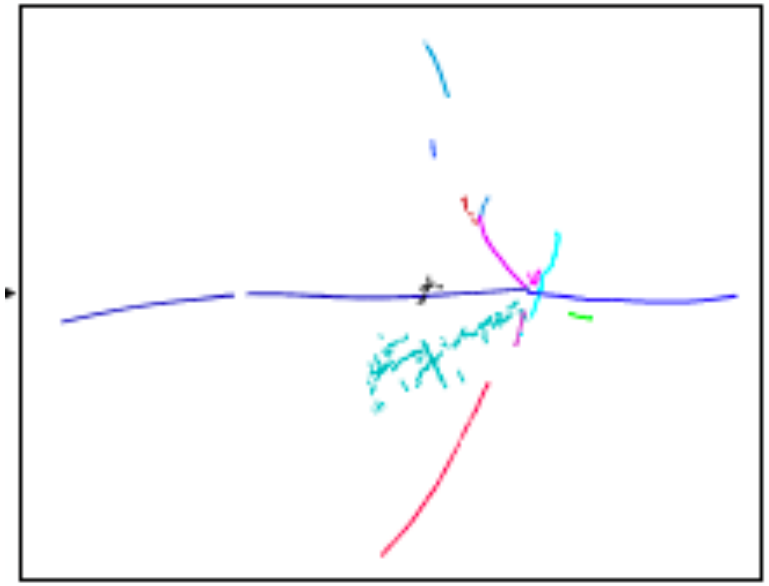
Very important for DUNE: Near Detector



More than 10 neutrino interactions per second, never seen before!

Nikhef: scintillation light detection, event reconstruction

Master projects in DUNE:



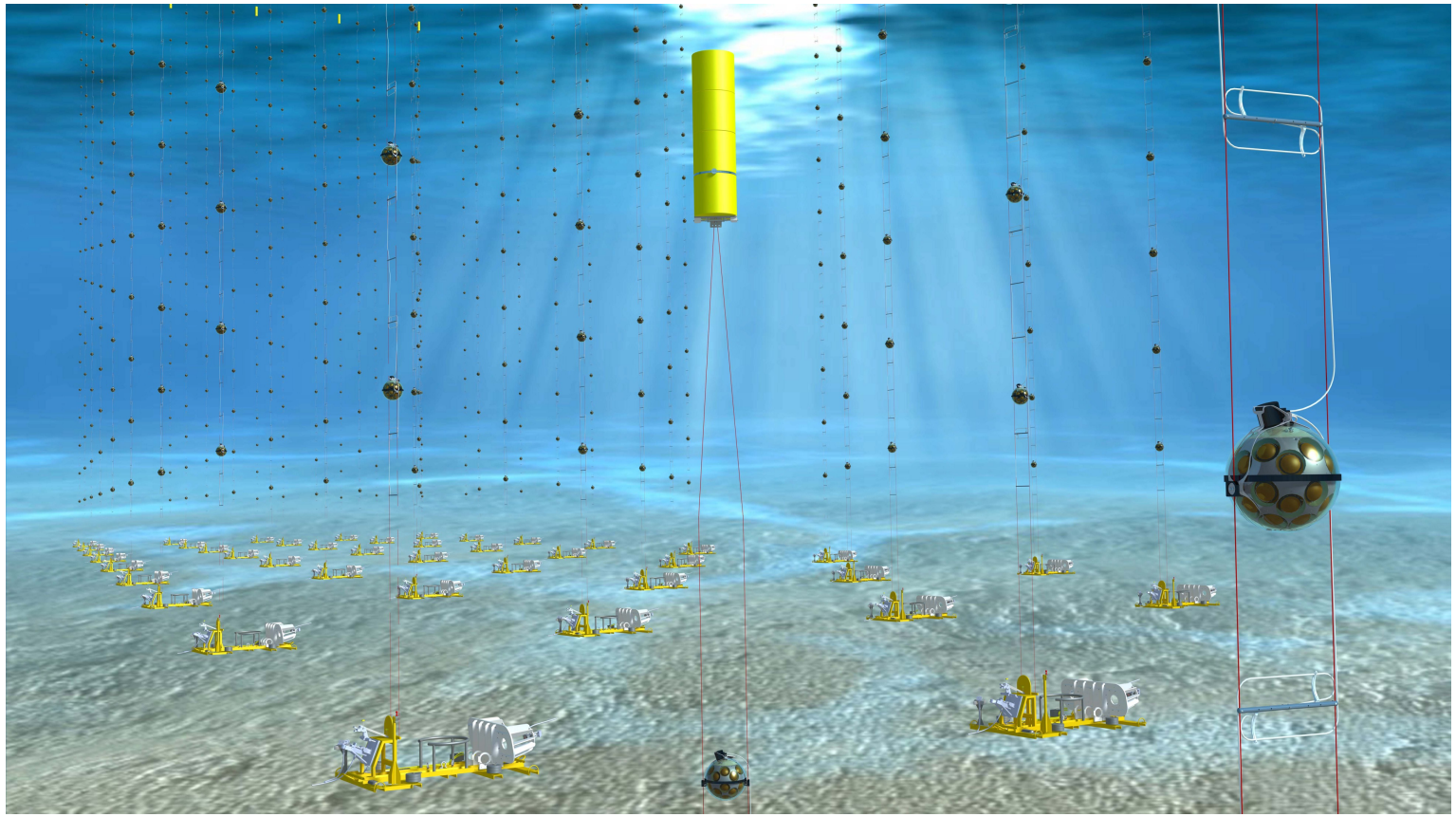
with simulated data: *event reconstruction in a liquid argon TPC*
event classification with machine learning
improving oscillation fits
scintillation light detection in near detector

with actual data from a prototype TPC: CERN beam data analysis
Near-detector prototype (Fermilab)

in the Nikhef lab: scintillation light detection in liquid argon

and probably more…

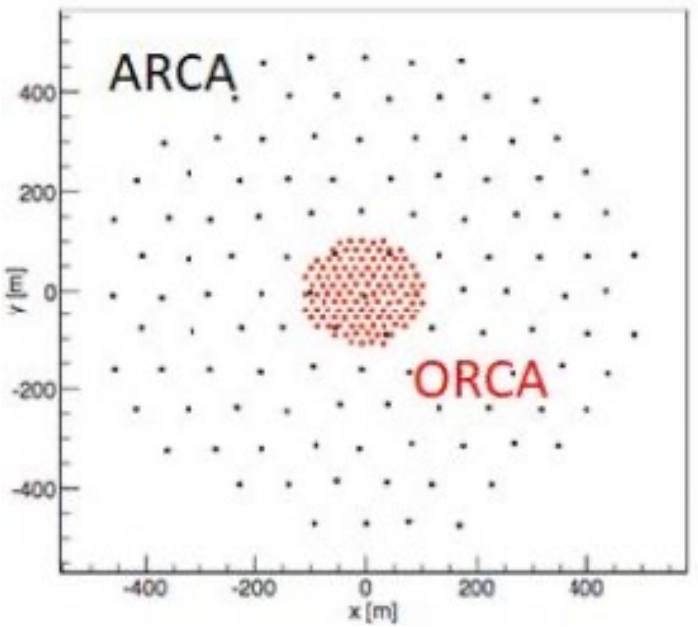
KM³ Neutrino Telescope (KM3NeT):



Building blocks:

ORCA, Toulon, France

ARCA, Sicily, Italy



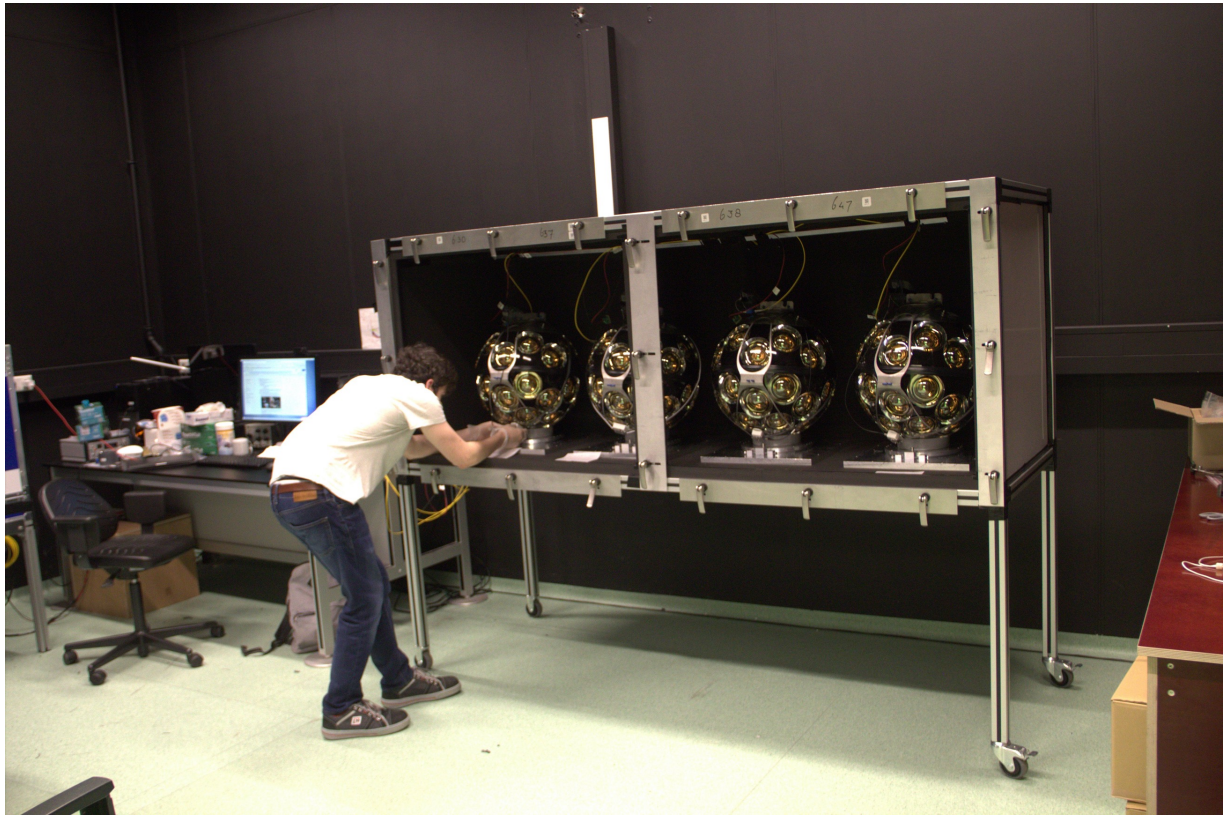
3D array of light-sensitive detectors on the bottom of the Mediterranean

Detect Cherenkov light from relativistic charged particles.
If from neutrino interaction: reconstruct neutrino direction and energy

ORCA: oscillation physics
ARCA: cosmic neutrinos

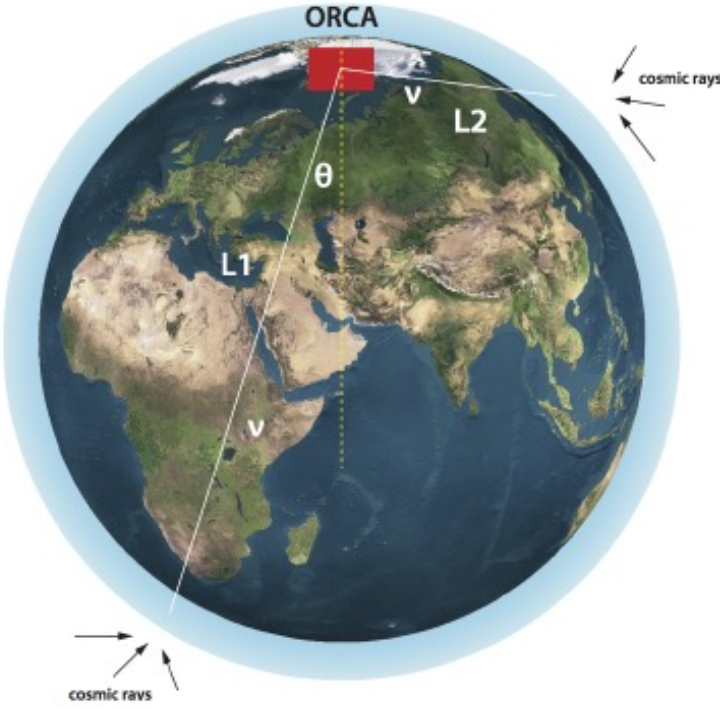
@Nikhef

18 DOMs form a detection line



Functional test at Nikhef

Oscillation physics with atmospheric neutrinos in ORCA

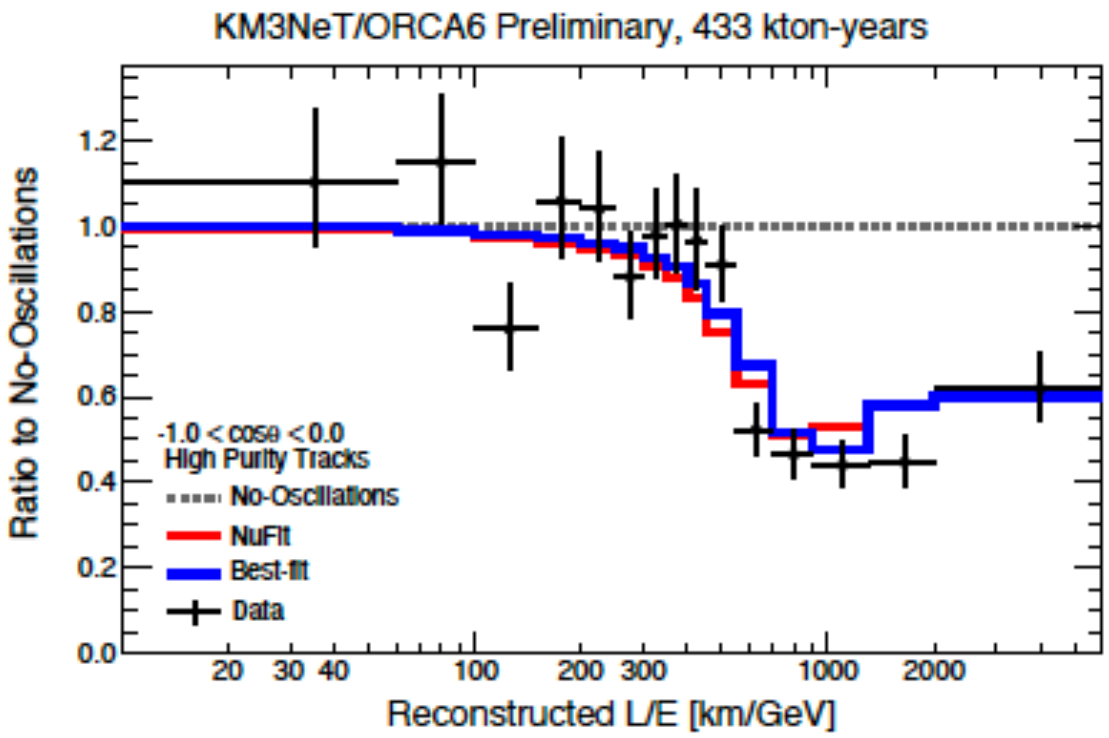


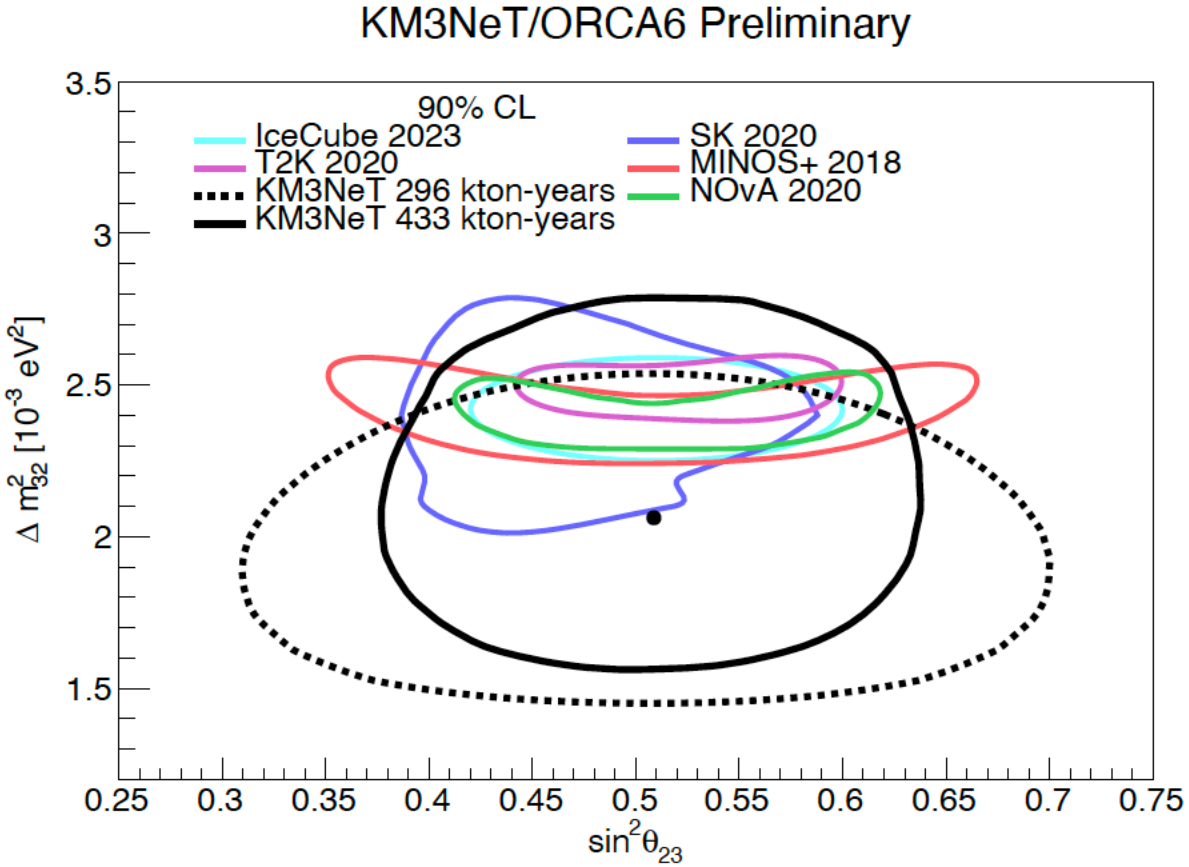
neutrinos from cosmic ray interactions in the atmosphere
angle in detector gives information on oscillation length
need to separate electron- from muon-neutrinos
most interesting energies: 3-100 GeV

18 lines taking data now, ~10 more in 2024.

Possible projects: *oscillation analysis (and improvements) with the first data*
first tau-neutrino observations and flux measurements
search for exotic signatures (heavy neutrinos, monopoles,…)
event identification and machine learning

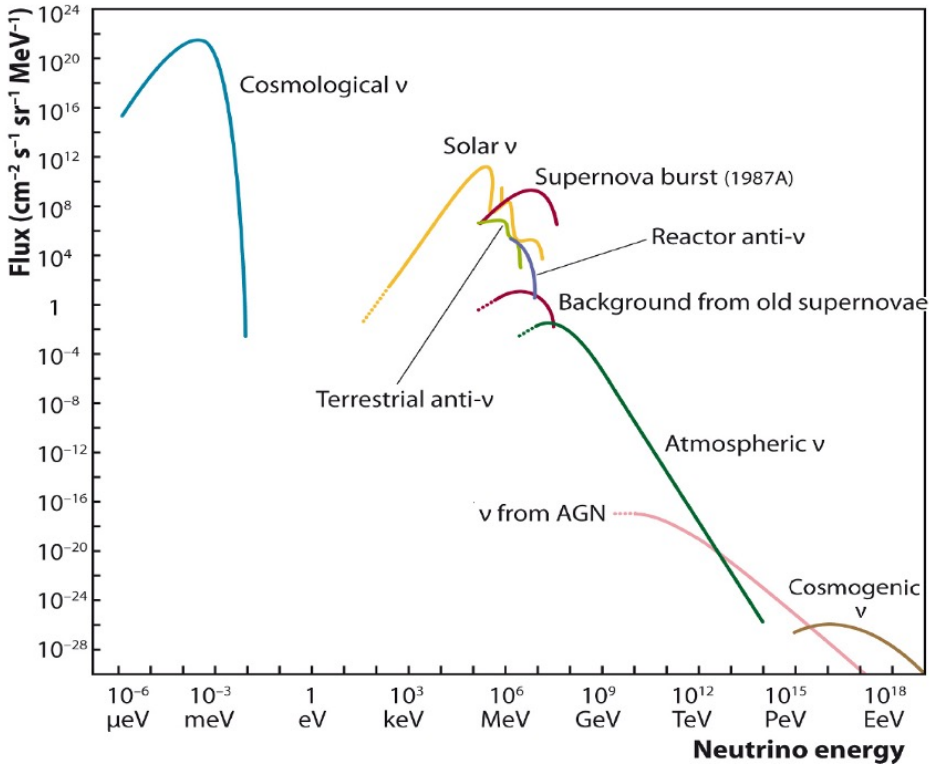
Result of 2023, just 6 lines:





Soon, θ_{23} will be dominated by neutrino telescopes, like KM3NeT
First step towards measuring neutrino mass ordering!

Cosmic neutrino hunting with ARCA



Flux above 10 TeV dominated by cosmic neutrinos
First detections have been done by IceCube
Advantage of KM3NeT: better pointing resolution: sources

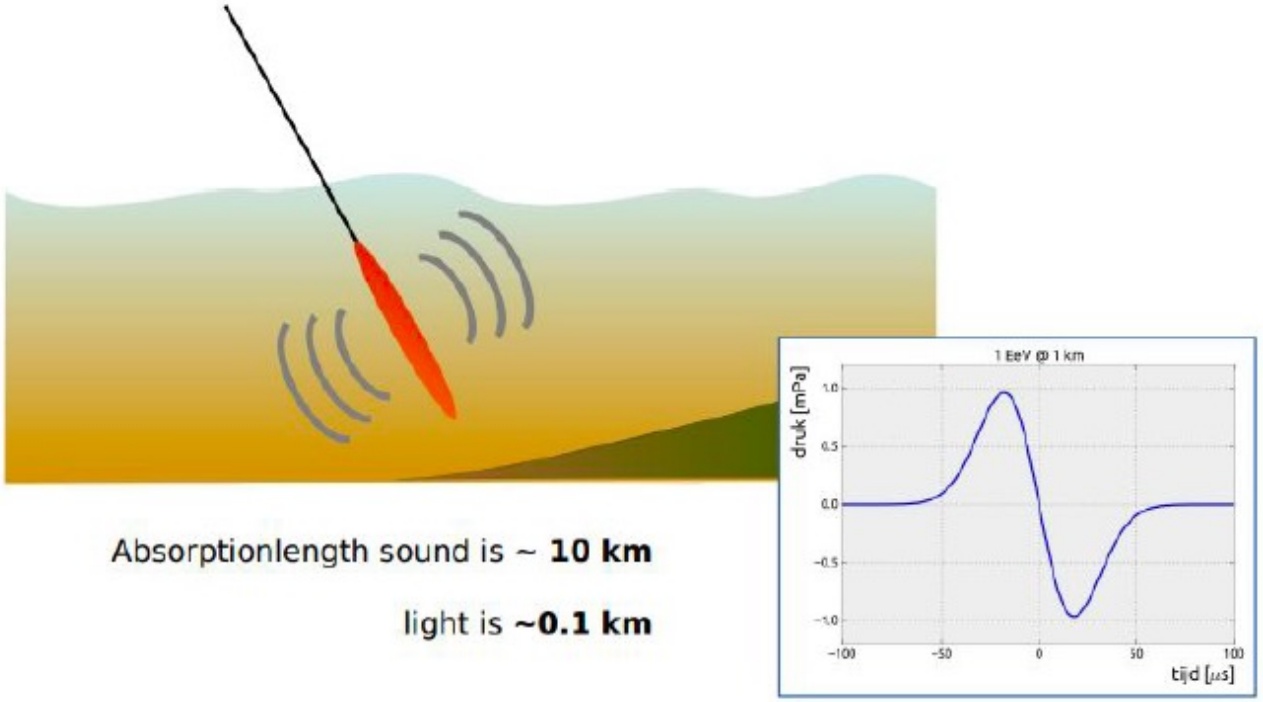
28 lines operational, 10 more before end of 2024

Projects: diffuse flux; galactic plane flux
source searches with catalogs or transients
search for neutrinos from dark matter annihilation

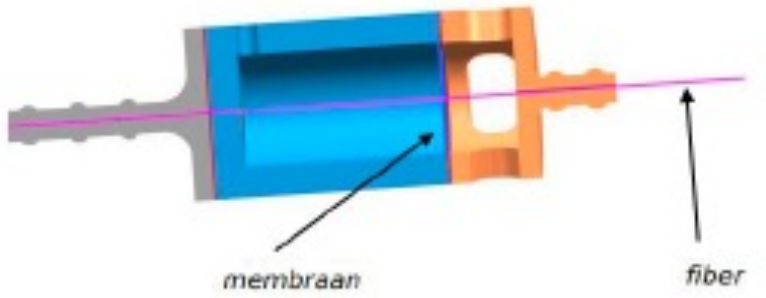
Also the use of ANTARES data is possible. Preliminary: interesting correlation with radio blazars.

Acoustic detection:

Ultra-high energy neutrinos ($E > 10^{18}$ eV) leave an acoustic pulse in water



Under development: optical fiber hydrophones



Backgrounds: random noise
man-made noise
sea mammals!

Projects: neutrino signal modelling, data filtering, signal/background separation

Even more projects:

Ronald Bruijn: cosmic ray physics at the bottom of the sea

> *Cosmic ray muons at the bottom of the sea are a background for oscillation physics*
> *but they are a probe of ultra-high energy cosmic particle interactions in our atmosphere.*
>
> *Projects: data analysis, hardware construction of a scintillation detector*

Overview:

https://wiki.nikhef.nl/education/Master_Projects

In general:

Projects are at Nikhef, you will be part of the Nikhef neutrino physics group

Supervisors: Ronald Bruijn, Paul de Jong, Aart Heijboer, Dorothea Samtleben,
Maarten de Jong, Daan van Eijk, Mieke Bouwhuis, Ernst-Jan Buis (TNO)
+ postdocs, PhD-students
(+DUNE: Patrick Decowski, Tina Pollmann, PhD-students)

Required knowledge/skills: nothing in particular
basic SM/neutrino physics helps
be OK with programming (C++/root, Python)


You’re welcome!