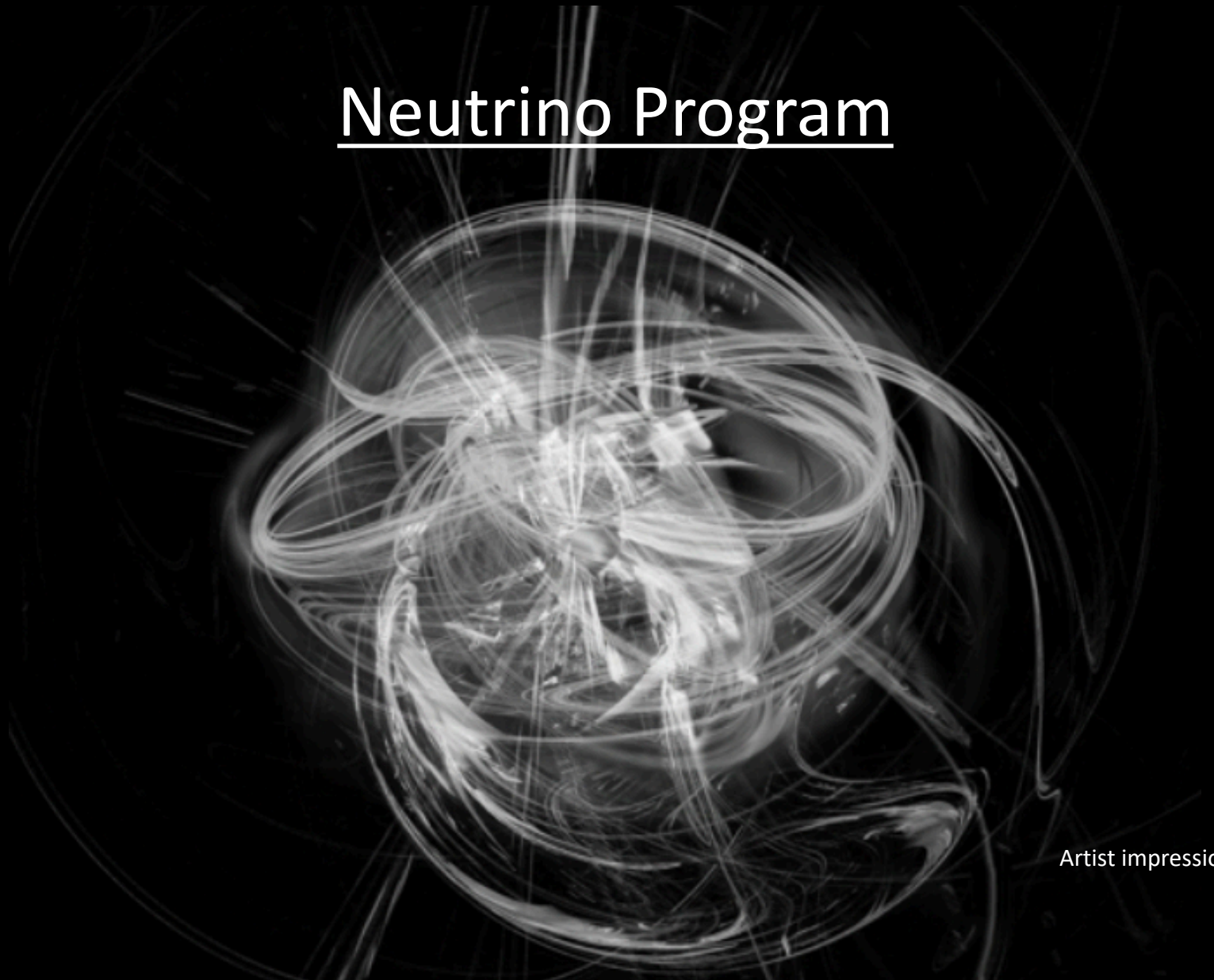
Neutrino Program



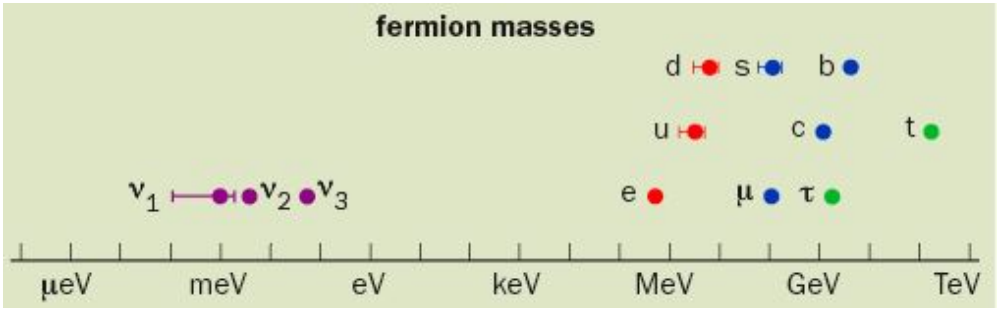
Artist impression of a neutrino

From MeV to ZeV (μeV to MeV covered by Patrick)

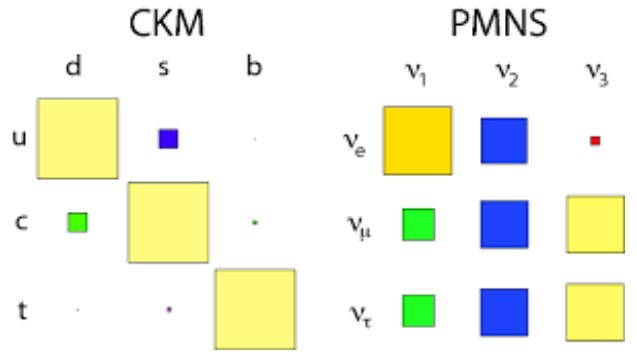
The discovery of neutrino oscillations is the most solid evidence for physics beyond the original formulation of the Standard Model.

It is possible to “repair” the Standard Model by introducing a coupling to the Higgs field, but:

Very small masses: Yukawa coupling $<10^{-12}$?



Neutrino mixing ≠ Quark mixing



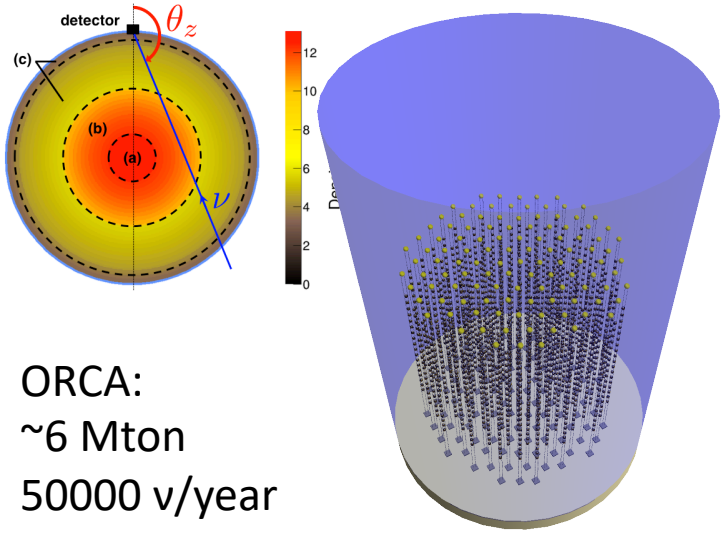
Alternative attractive solutions involving (as of yet unproven) Majorana character of neutrinos exist.

Neutrino mass ordering (123 or 312) still not unambiguously determined.
CP-violation in neutrinos: opens possibility of leptogenesis.
Sterile neutrinos: experimentally still a very confusing picture.

Neutrinos are an excellent gateway towards new physics beyond the SM.

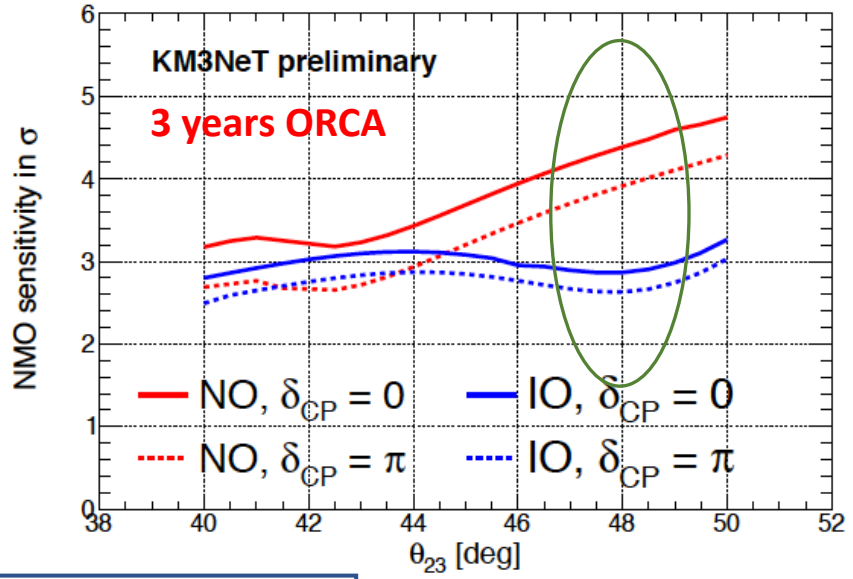
Neutrino oscillation program at Nikhef: KM3NeT, DUNE

KM3NeT: ORCA: atmospheric neutrinos, few GeV to few tens of GeV (ARCA: cosmic neutrinos)
Oscillation physics, sterile neutrinos, non-standard interactions,…

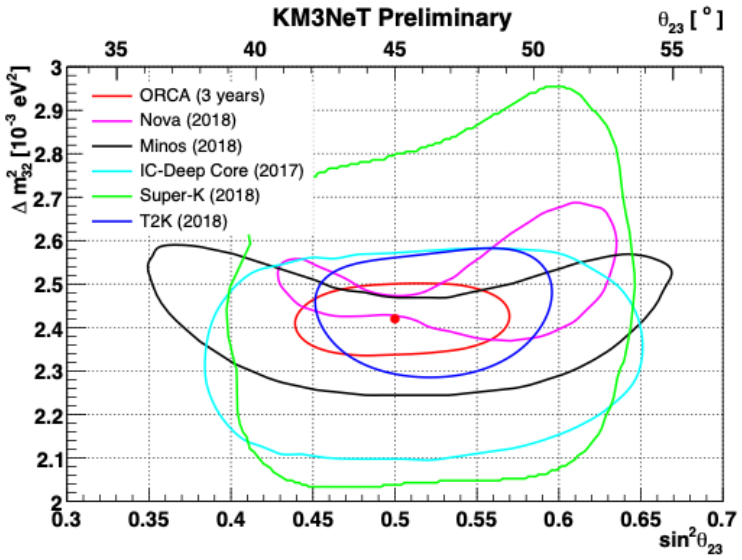


ORCA:
~6 Mton
50000 ν/year

Neutrino mass ordering sensitivity

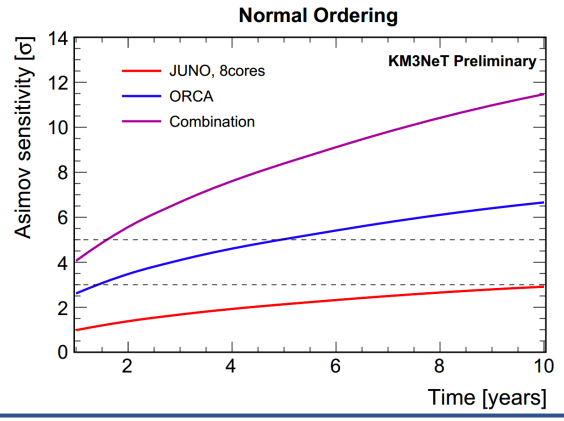


Oscillation parameters



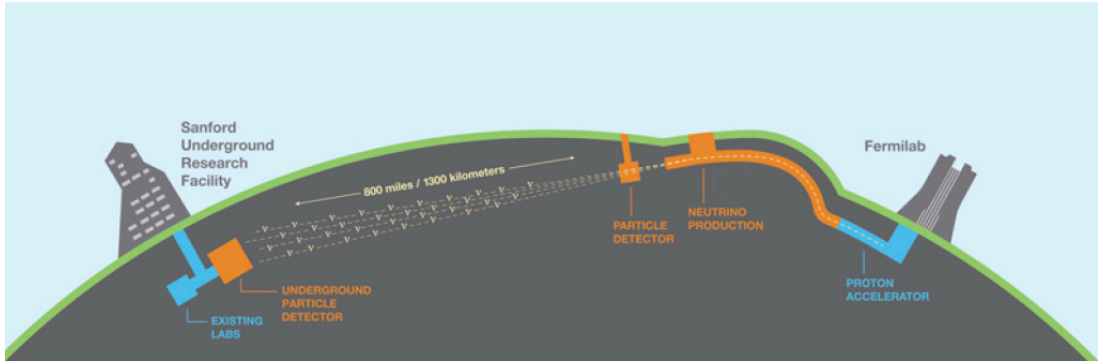
Data analysis together with JUNO increases sensitivity

Fitting Δm^2_{31} with the wrong mass ordering hypothesis leads to tensions JUNO-KM3NeT



Option: beam from Protvino to ORCA, access to CP-violation
EoI submitted

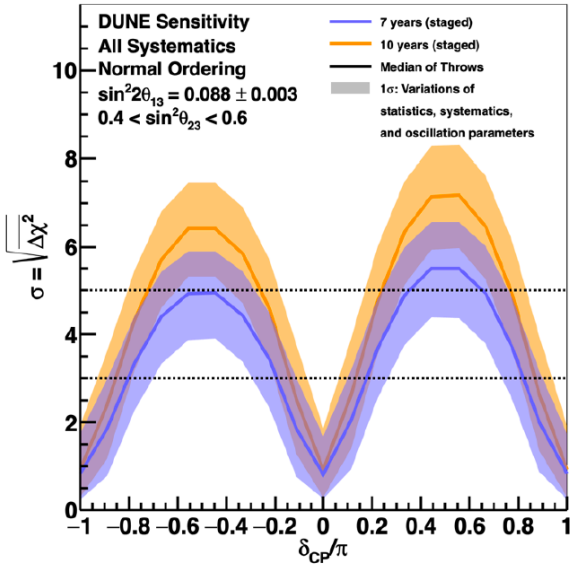
Oscillation physics: Deep Underground Neutrino Experiment (DUNE)



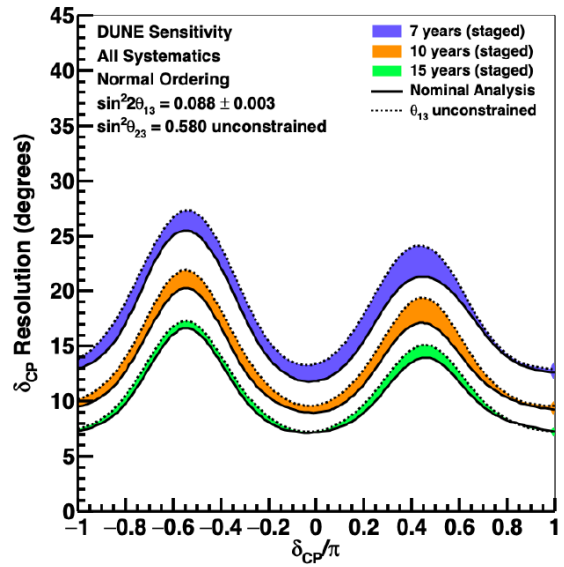
Wideband ν beam from 1.0-2.4 MW p beam at FNAL
Baseline 1285 km, relevant E_ν a few GeV
Far detector: 4 x 10 kton LAr TPC, 1500 m underground
First module 2026, beam 2029?
Near detector: various technologies, large event sample

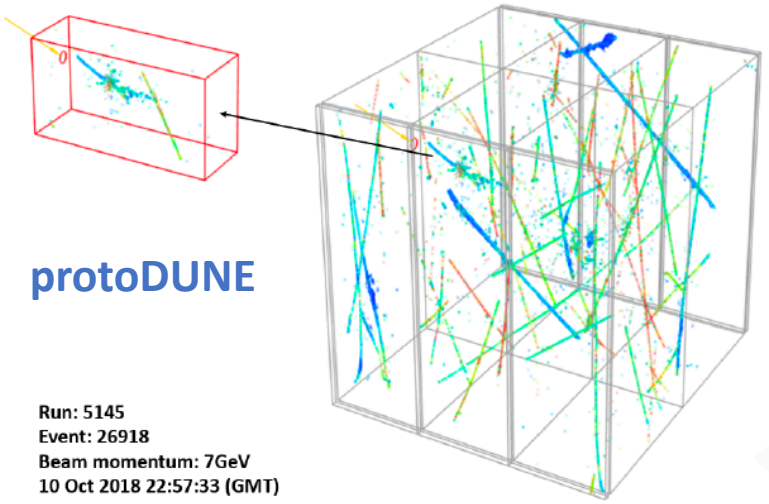
Very challenging, but rewarding experiment: full spectrum of oscillation physics

CP violation sensitivity



δ_{CP} resolution





Nikhef: DAQ, computing, event classification, ProtoDUNE single phase

ProtoDUNE at CERN: data taken 2018, analysis in progress
ProtoDUNE II at CERN 2022- even closer to real DUNE


Mount Rushmore
Main shaft
Shaft above DUNE
Lead, South Dakota

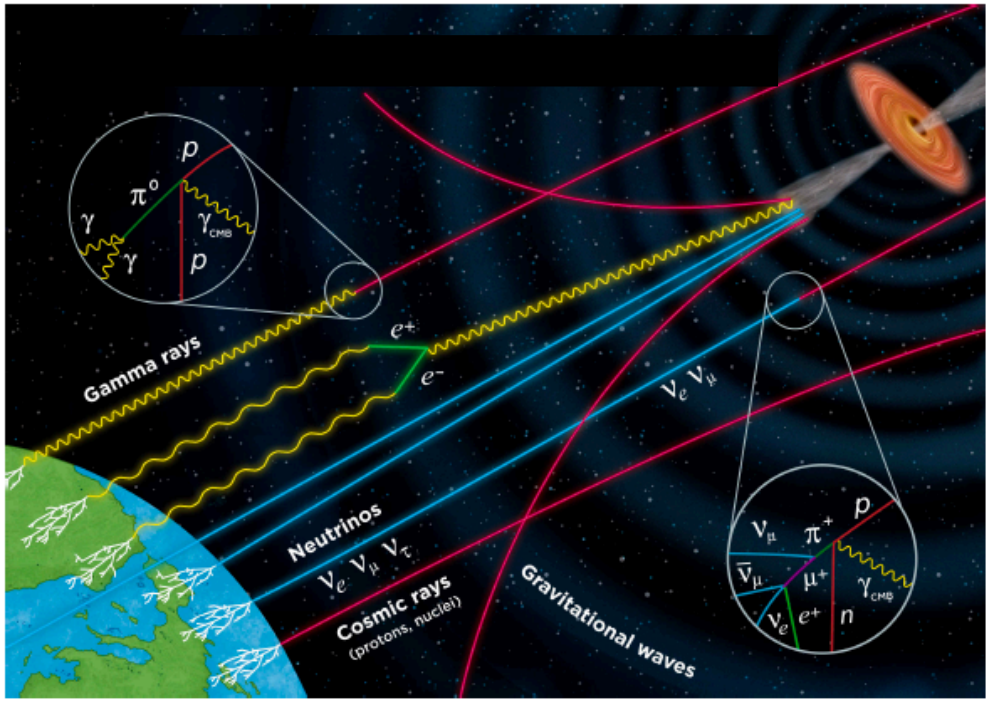
Cosmic neutrinos

Diffuse cosmic flux, and point-sources
Sources: CR acceleration, DM annihilation

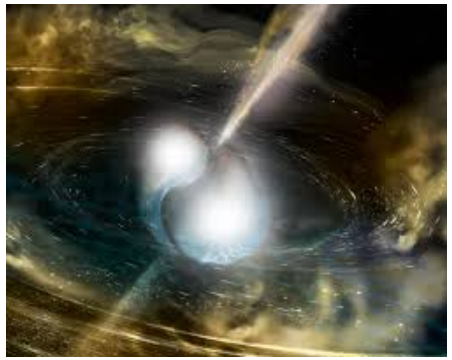
Galactic sources: supernovae, SN remnants,
pulsar wind nebulae, X-ray binaries,…

Extragalactic sources: active galactic nuclei, compact
binary mergers, gamma ray bursts,
tidal disruption events,…

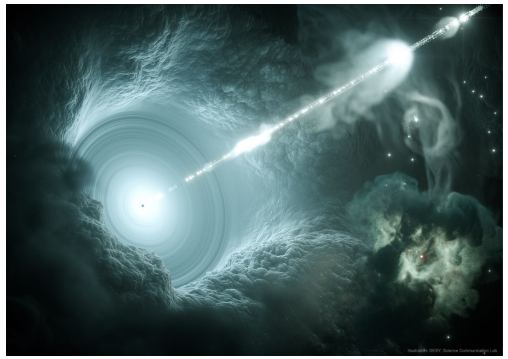
Cosmogenic neutrinos: from UHECR-γ interactions



source: GRAND



Binary neutron star merger



Blazar

Point-sources still need unambiguous identification
Measure energy spectrum, correlate with γ-rays
Multimessenger astrophysics, also transients
Neutrino-nucleon cross section at UHE (in atmosphere/water)
Flavour composition
Lorentz violation studies
New neutral heavy leptons

BSM physics

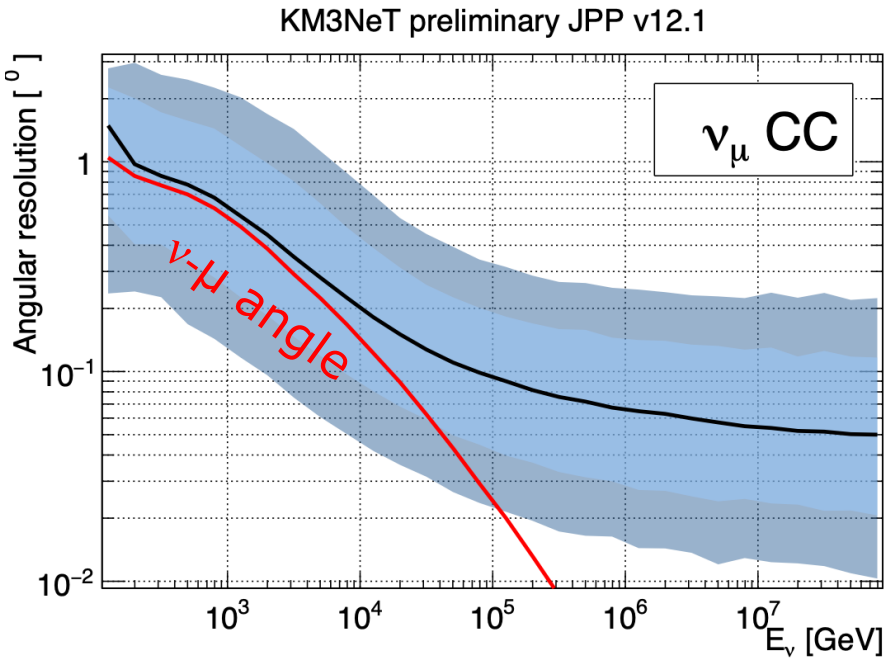
Cosmic neutrinos as a tool, but also a probe of BSM physics at Ultra High Energies/in extreme environments

Experimental facilities: KM3NeT/ARCA

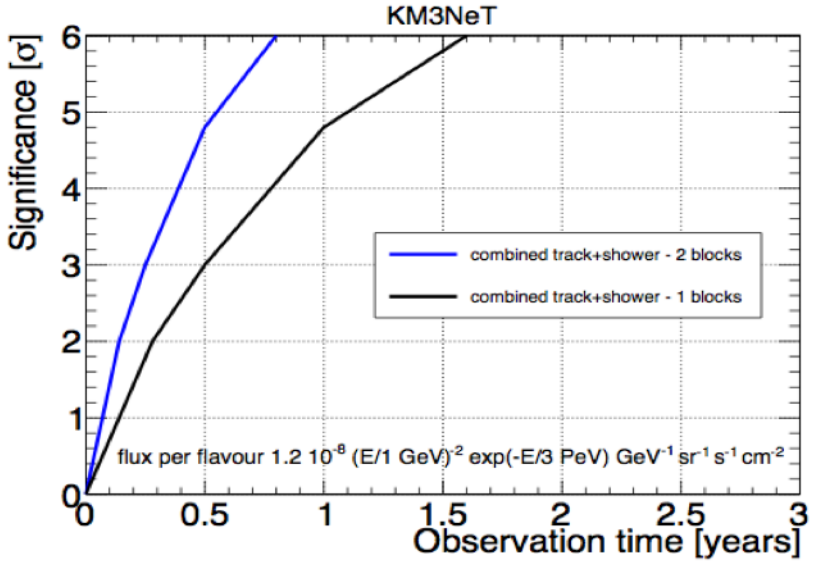
2 building blocks, > 1 km^3

Northern Hemisphere

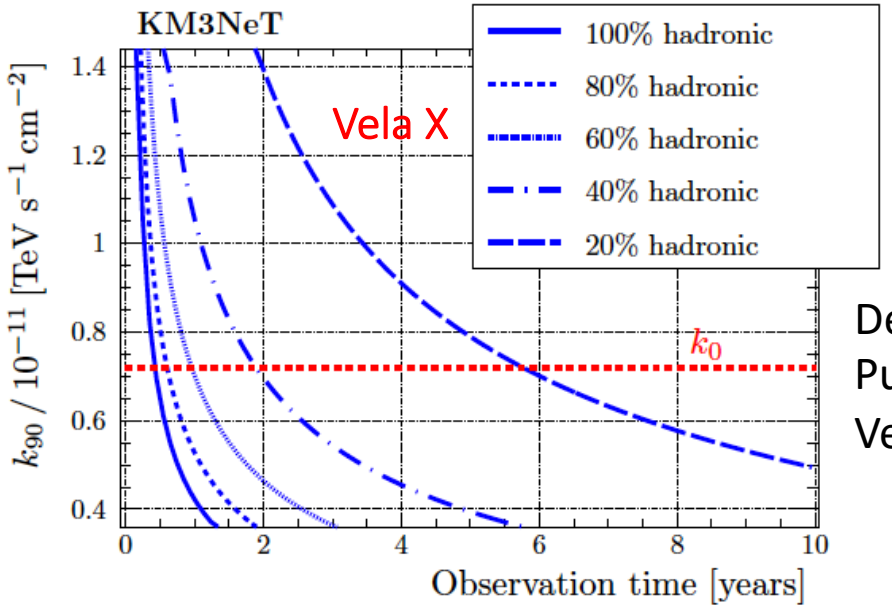
Superior pointing resolution



0.05 degree



Significance of diffuse flux detection

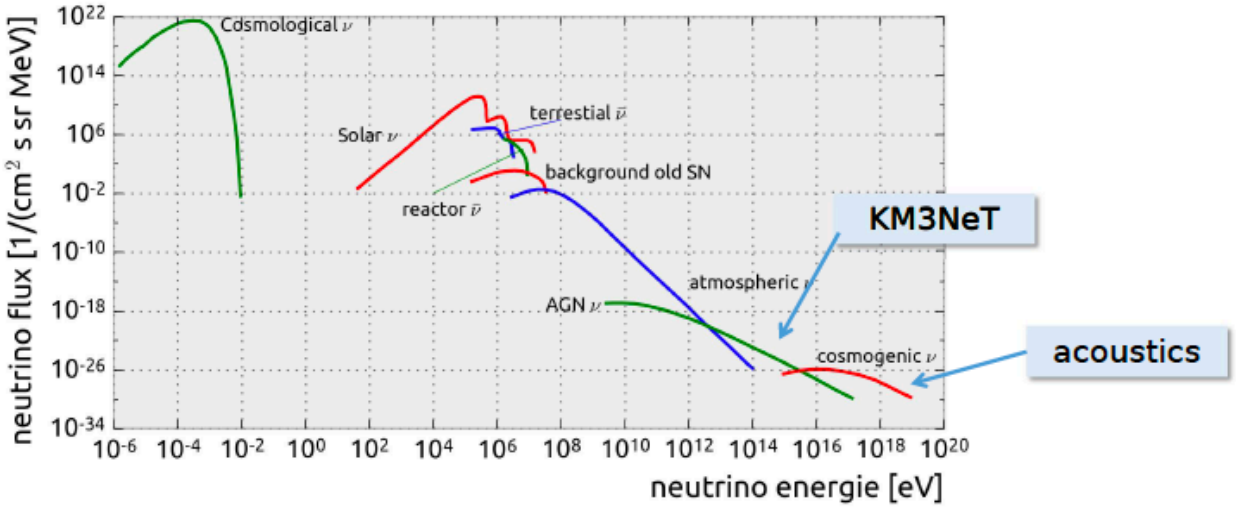


Detection of ν flux Pulsar Wind Nebula Vela-X

Bonus: cosmic ray program in KM3NeT
earth tomography with neutrinos

Experimental facilities for UHE neutrinos: KM3NeT-acoustic / GRAND

KM3NeT-acoustic: detect the sound of UHE (>10^{18} eV) neutrino-induced showers in water

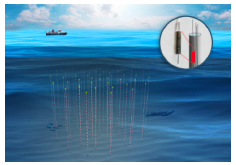


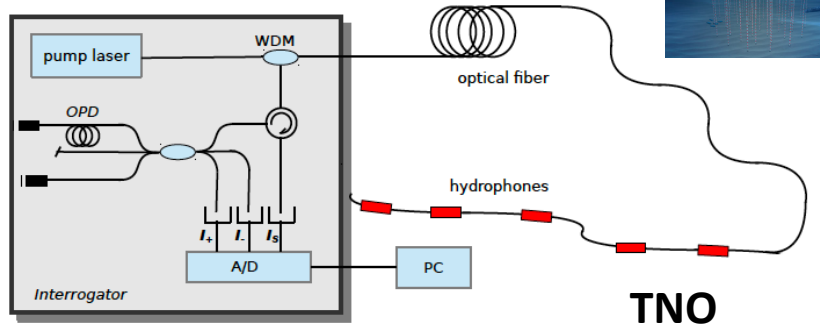
Sources:

- Cosmogenic neutrinos (GZK cutoff)
- Blazars
- Tidal Disruption Events (TDE)

TDE also a source of GW in the LISA band.
GW data analysis techniques apply.

Plan: Proof of concept within KM3NeT2.0 roadmap: up to 2023
Pathfinder infrastructure 10-100 lines up to 2028
Investigate industrial sensor manufacturing.
Beyond 2030: 100 km^3 seawater instrumented, > 1000 lines
(e.g. Pylos KM3NeT site?)



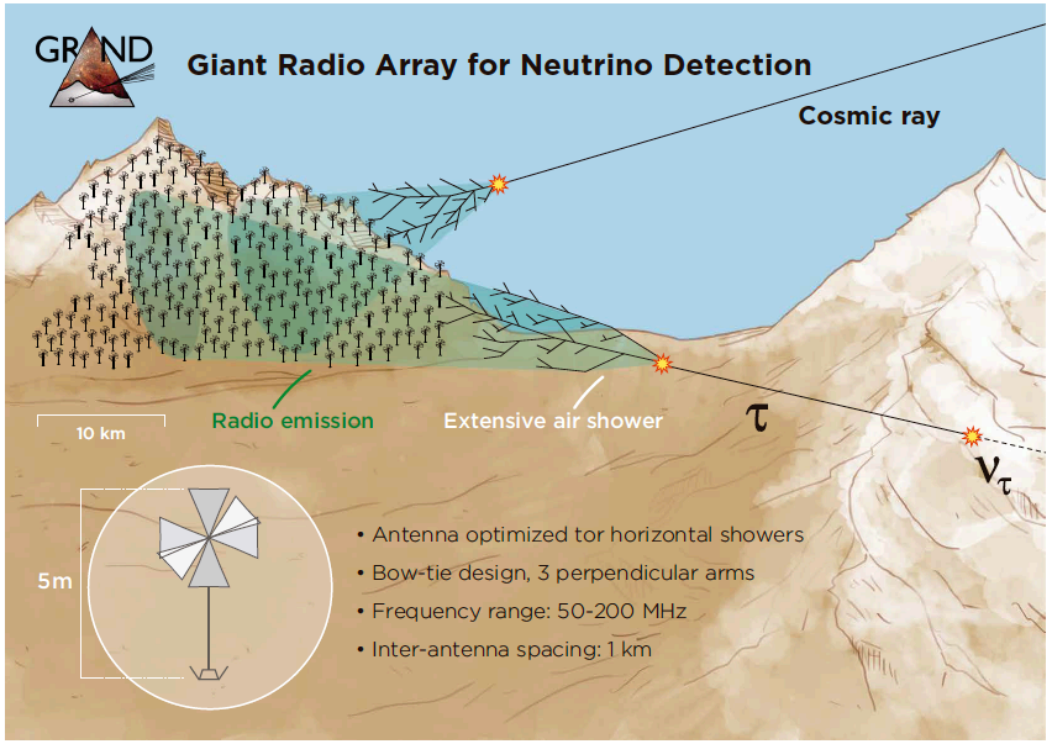


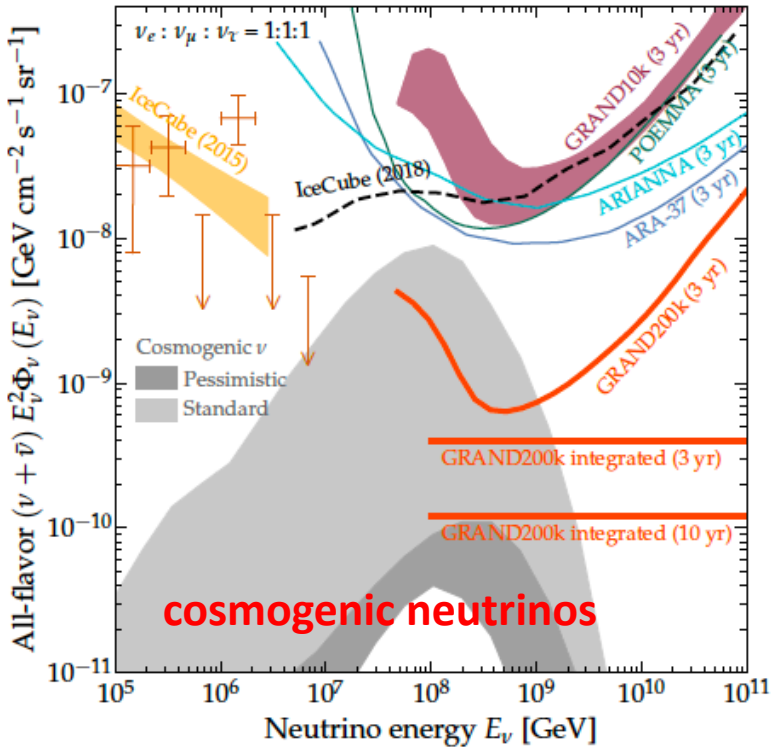
Optical fiber hydrophones

Bonus: multidisciplinary program: sea science, marine biology

Giant Radio Array for Neutrino Detection (GRAND)

Detect UHE neutrinos by measuring neutrino-induced extended air showers with radio antennas

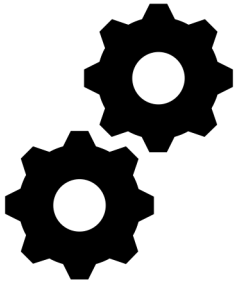




Plan: Proto300 (300 antennas, 300 km^2) 2020-2024 test self-triggering
GRAND10k 2025-203x first neutrinos > 0.1 EeV?
GRAND200k >203x 20 hotspots of 10k antennas, neutrino astronomy > 1 EeV

Sites in China under investigation

Technology



Large area, fast, efficient, cheap single photon detection.

PMT, SiPM, APD,…

Large areas to be covered, poorly – or not at all accessible:

Low-power and low-cost electronics.
High-reliability electronics. Risk analysis.
Accurate timing over large distances, no GPS.
Cheap, reliable mechanics, able to withstand extreme environments.

LAr scintillation light detection: UV photons.

Cheap, sensitive, low-noise hydrophones.

Computing

“Triggerless” running, massive data analysis needs.
Fast, real-time data processing.

Machine learning techniques, already succesful in pattern recognition, event classification.
Inter-group activity at Nikhef?

Open science: be pragmatic, listen to the users.

Need for more use of professional, open source, documented tools, and
less home-made software.
In particular also beneficial for collaboration with astronomy.

Strategy Wishlist

Complete KM3NeT: ORCA 2024, 1st block ARCA 2024, 2nd block 2026?

Strengthen DUNE effort: little manpower/funding so far. Fantastic oscillation experiment!

Develop acoustic neutrino detection program in phases

Build GRAND in phases

Create a multi-messenger effort:

at Nikhef: already big crosstalk XENON-KM3NeT-PAO
nationally: with Gravitational Waves, and with astronomy community (complete EM spectrum)
GW should not overpower other APP efforts

Align and synchronize APP funding agencies.
Facilitate doing experiments in China.