KM3NeT/ORCA: overview, first result and future prospects

32nd Rencontres de Blois 2021

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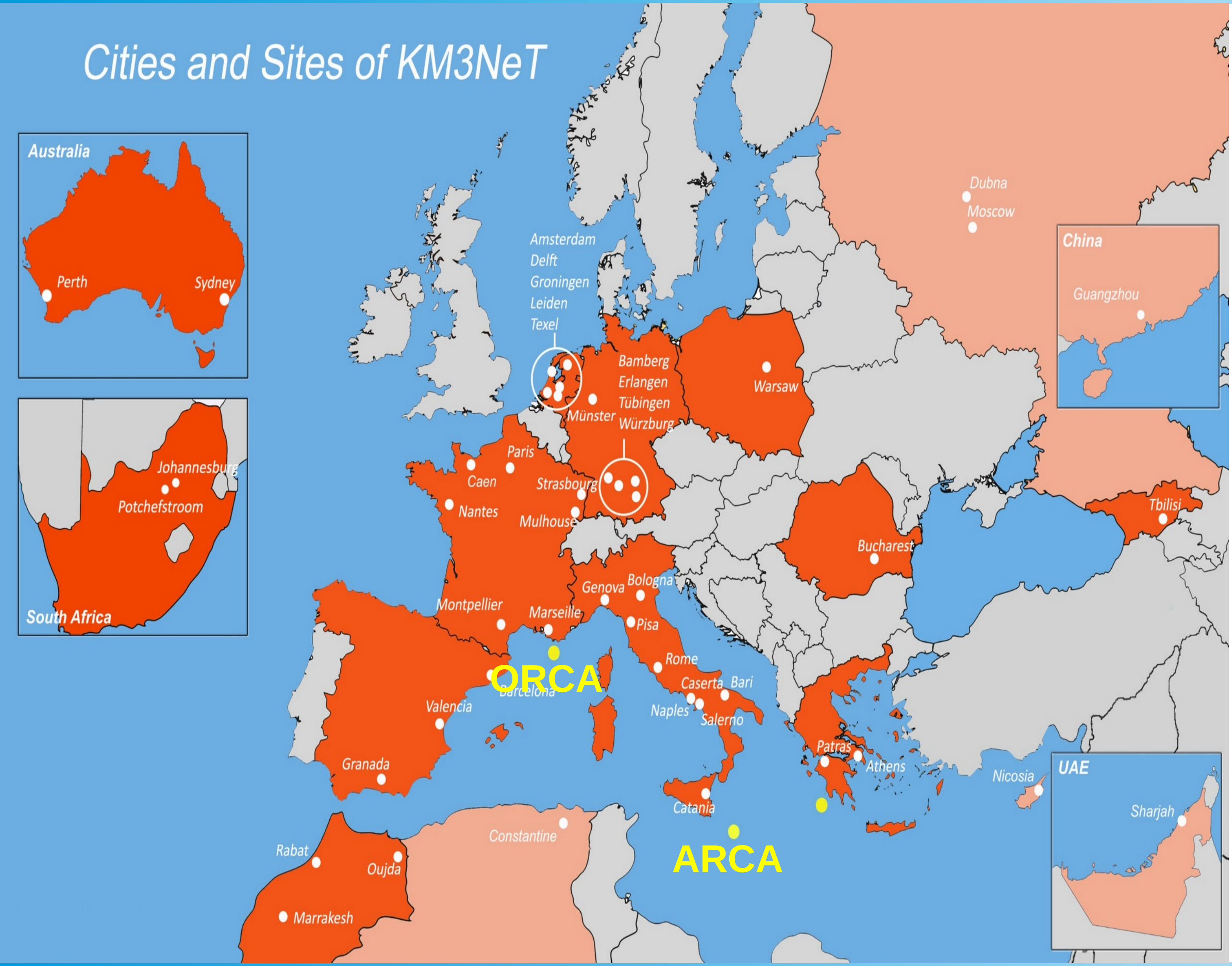
Presentation Outline

1) KM3NeT project – infrastructure and collaboration
2) Current status of the KM3NeT/ORCA detector
3) Physics goals of KM3NeT/ORCA
4) Expected sensitivities and first results
5) Summary and outlook

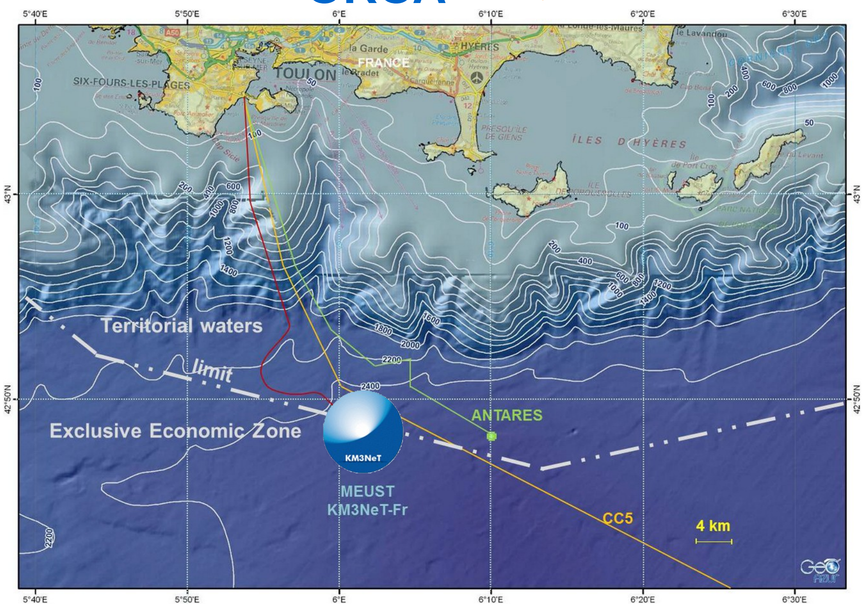
KM3NeT Collaboration



- 55 groups
- 16 countries
- 4 continents
- 2 detectors

KM3NeT Project

ORCA



Source: Atmospheric neutrinos
Neutrino energy: threshold of ~3 GeV
Location: 40 km off-shore Toulon (France)
Eff. Mass: 7 Mton

ARCA

Source: Astrophysical neutrinos
Neutrino energy: up to PeV scale
Location: 100 km from Sicily (Italy)
Eff. Mass: 2x500 Mton

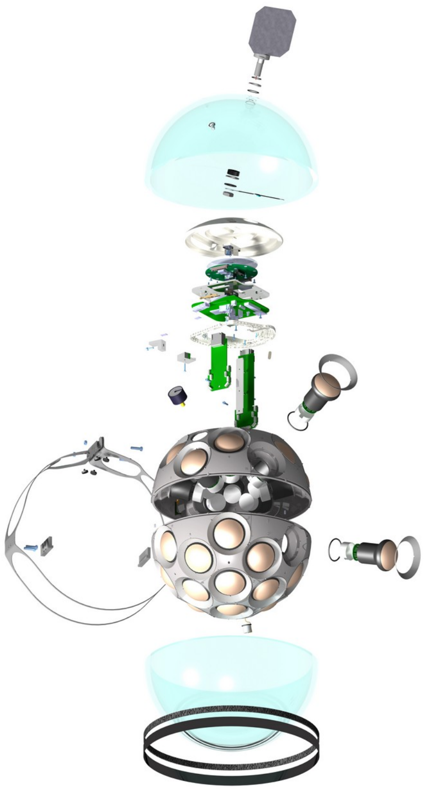
Same technology!

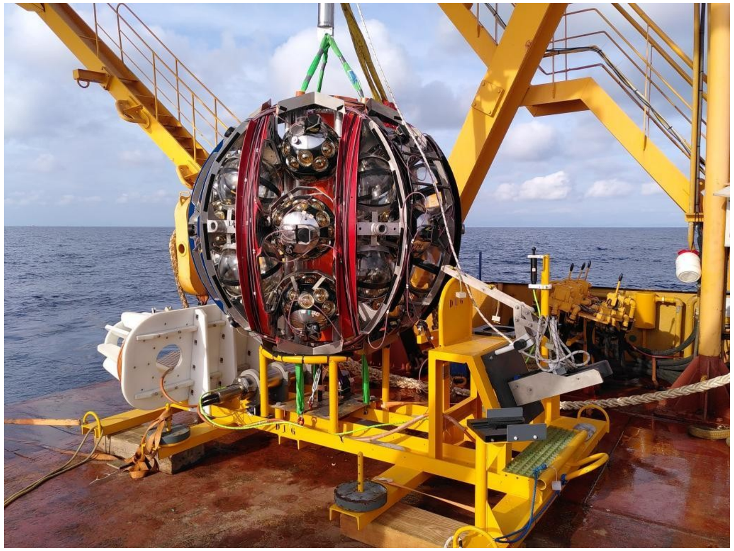
KM3NeT Letter of Intent, arXiv: 1601.07459, DOI: 10.1088/0954-3899/43/8/084001, Journal of Physics G: Nuclear and Particle Physics, 43 (8), 084001, 2016

Detector Technology

Digital Optical Module (DOM):

- 31 Photomultipliers (PMTs) 3” Hamamatsu, R12199-02
- Almost full solid angle coverage
- Piezo and LED nanobeacons devices for calibration

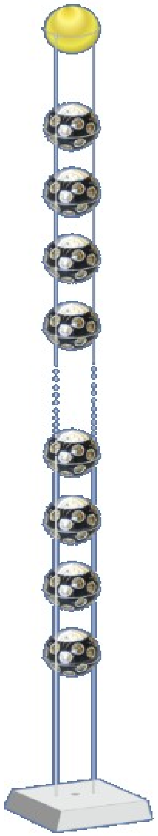




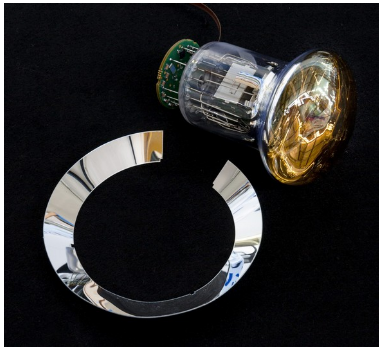
Launcher of Optical Modules (LOM)

- self-unrolling / ROV operation
- reusable

Detection Unit (DU):



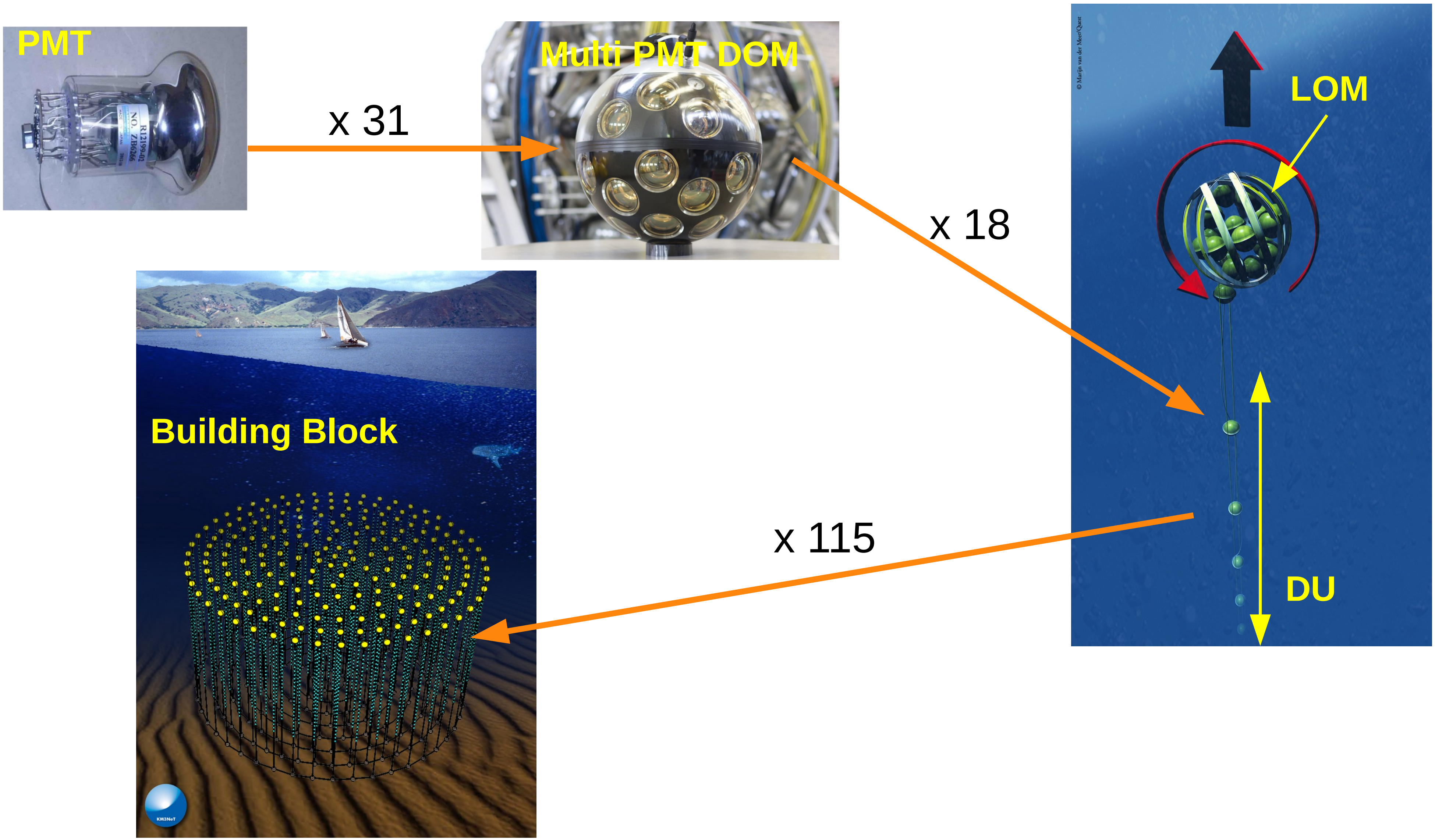
- Vertical string
- 18 DOMs
- Anchored to the sea bottom



PMT with reflector ring

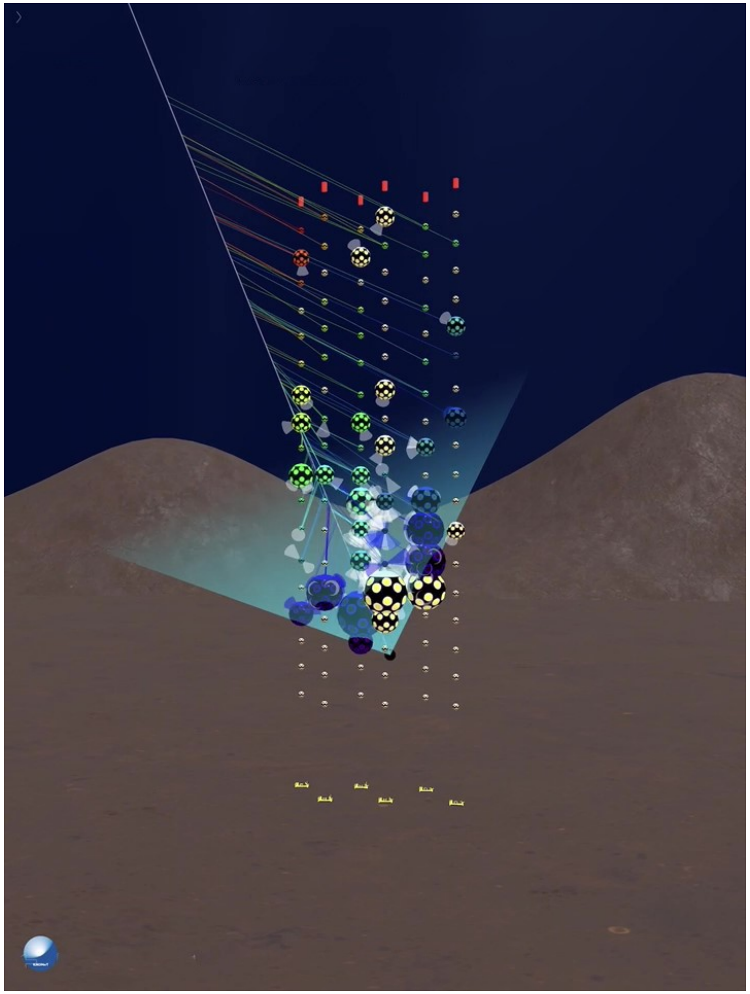
Deep sea tests of a prototype of the KM3NeT digital optical module, DOI: 10.1140/epjc/s10052-014-3056-3
Architecture and performance of the KM3NeT front-end firmware, DOI: 10.1117/1.JATIS.7.1.016001
Deep-sea deployment of the KM3NeT neutrino telescope detection units by self-unrolling, DOI: 10.1088/1748-0221/15/11/P11027

Detector Components



Detection principle

- Charged products of neutrino interactions produce Cherenkov light while travelling through sea water
- Time and charge information from the PMTs together with the DOMs position allow to reconstruct the initial direction and particle energy
- Huge detector volume is required for a sufficient interaction rate and accurate detection of high energy particles (especially muons!)

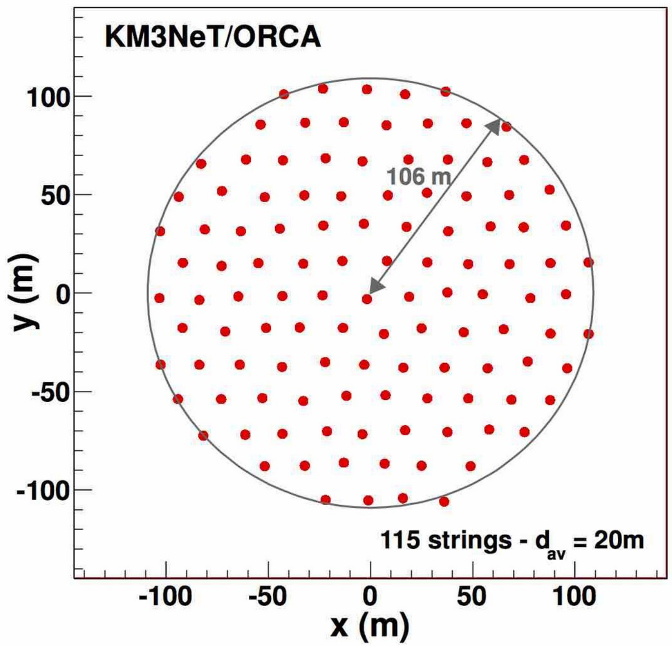


Visualization of the ORCA6 response to a down going muon

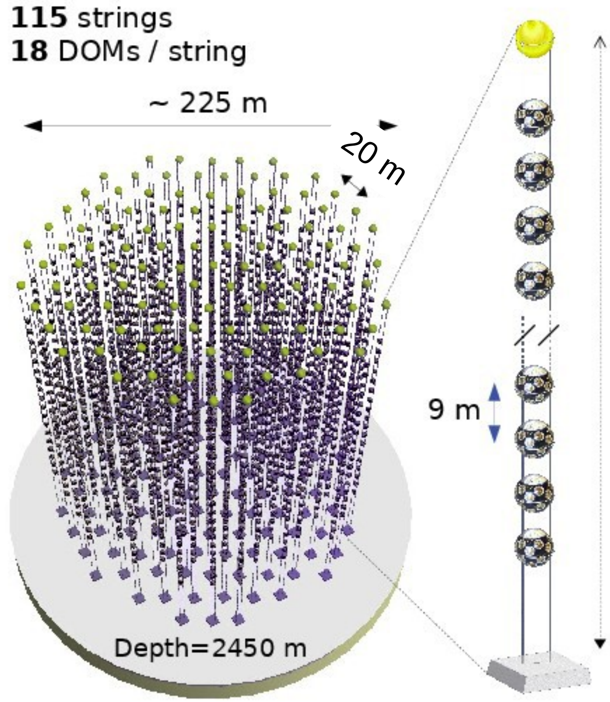
KM3NeT/ORCA Detector

Oscillations Reserch with Cosmis in the Abyss

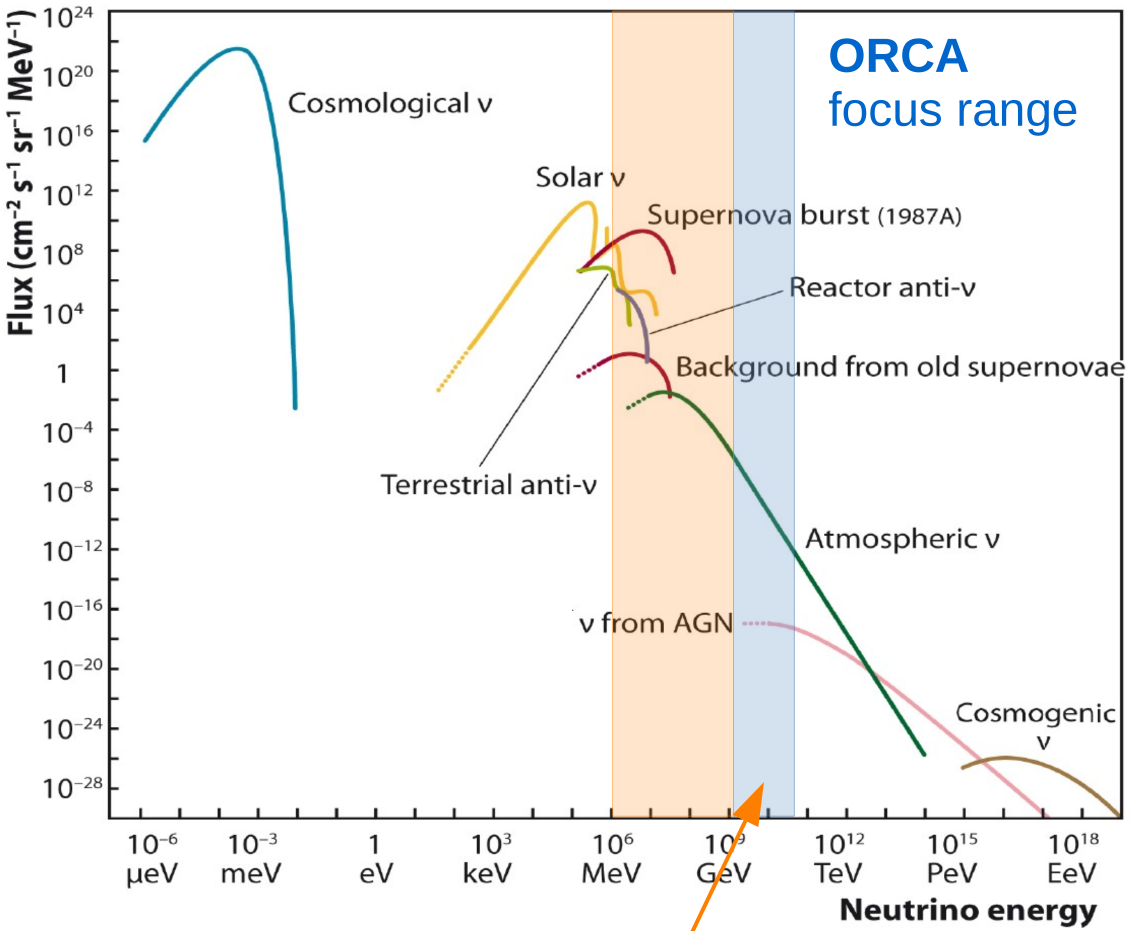
Single block with effective mass of almost 7 Mton of sea water



- Strings and DOMs are densely spaced to provide energy detection threshold of the order of a few GeV
- Layout optimized for neutrino energies in range ~5 – 60 GeV

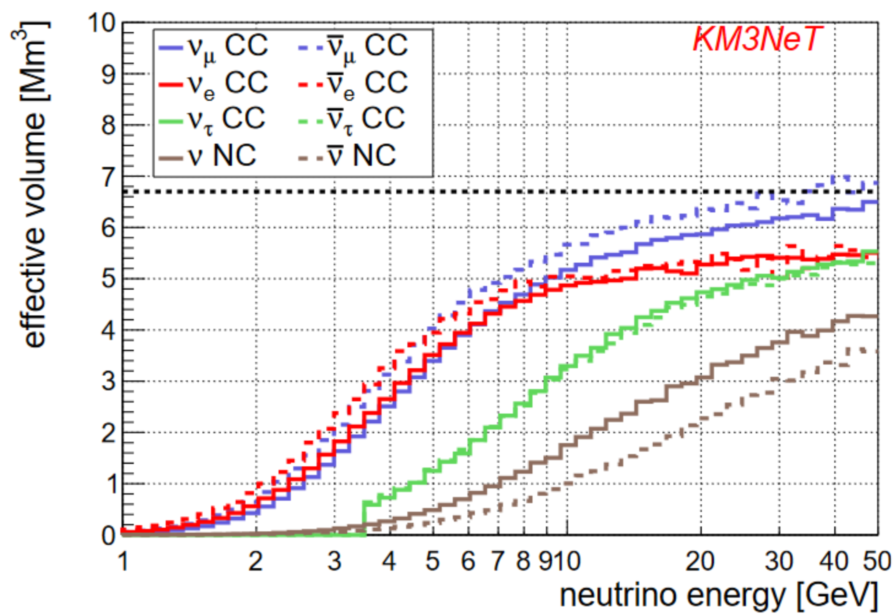


ORCA energy range



This talk!

Up-going reconstructed events



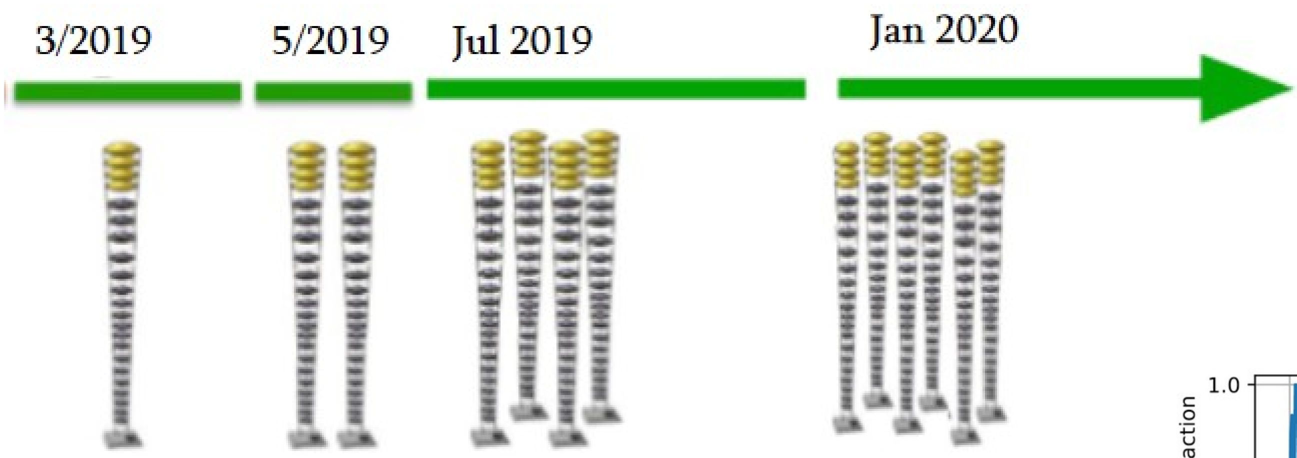
Not mentioned in this presentation:

- Supernova observation potential

DOI: 10.1140/epjc/s10052-021-09187-5

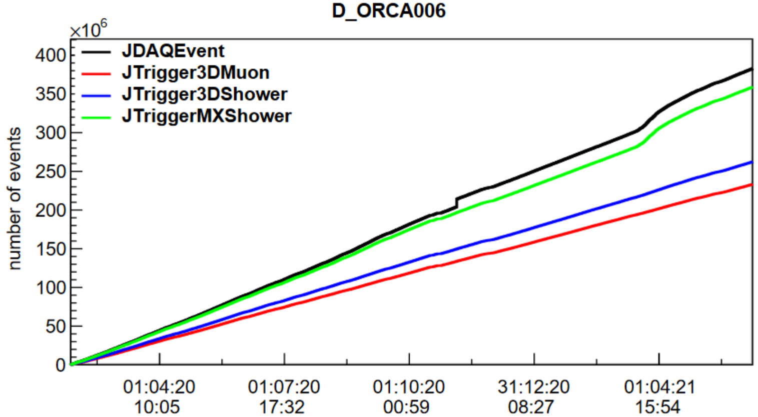
-Potential for GeV neutrino astronomy

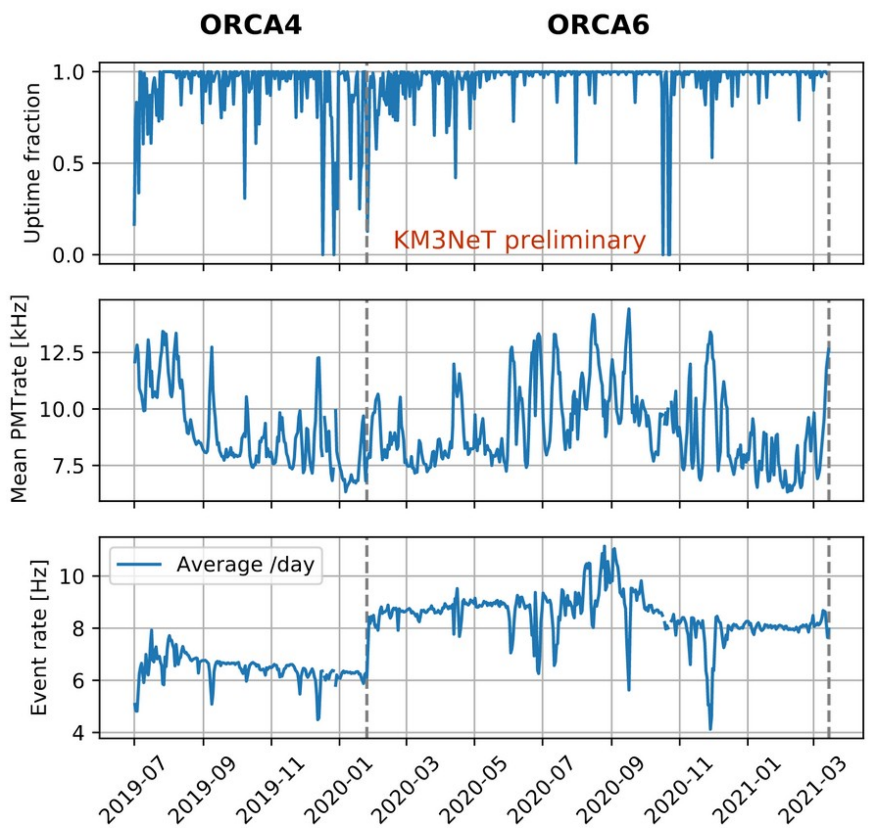
Detector status



7 more lines ready for deployment

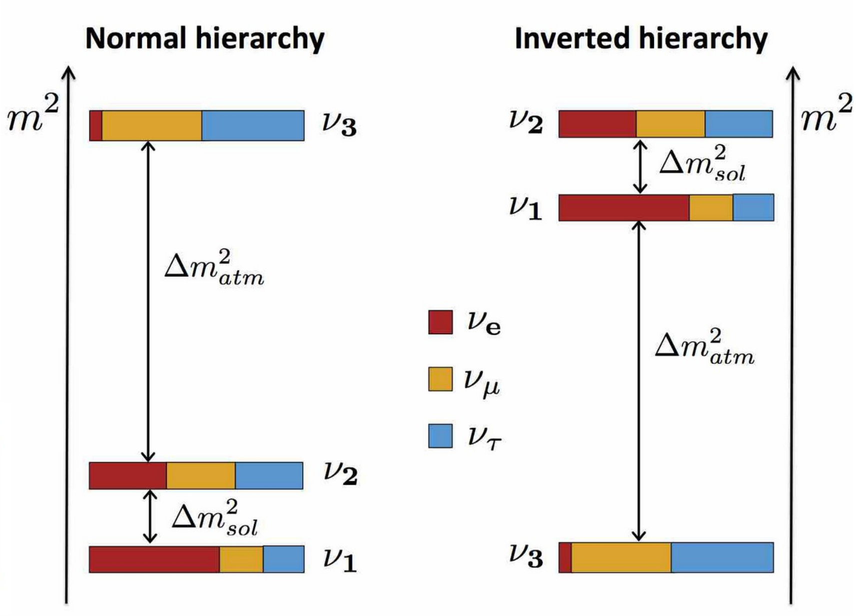
- Since 27 January 2020, the ORCA detector is taking data with 6 DUs.
- Average data taking efficiency ~97 %





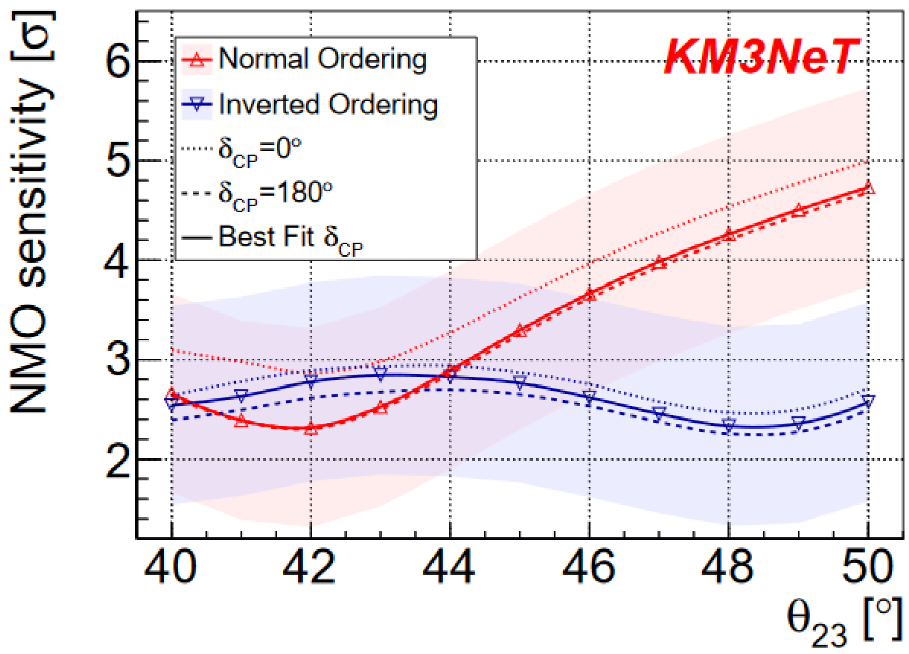
Research with KM3NeT/ORCA

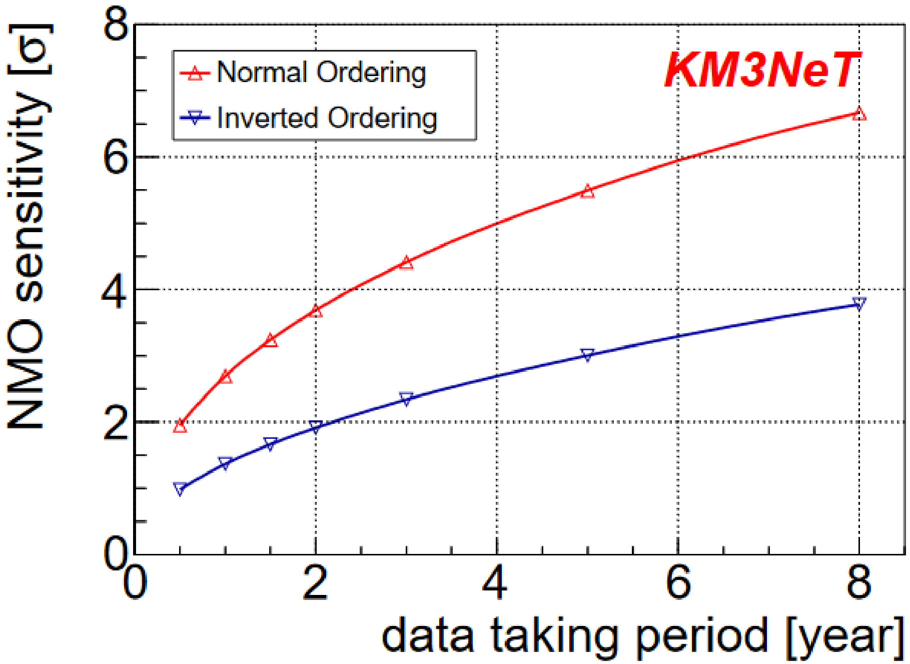
- Resolving neutrino mass ordering
- Physics beyond standard model (neutrino non-standard interactions (NSI), sterile neutrinos, neutrino decay, etc.)
- Standard oscillation parameters
- Earth tomography
- Protvino to ORCA (P2O)
- Supernova observation



$$H_{eff} = \frac{1}{2E} U_{PMNS} \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{bmatrix} U^{\dagger}_{PMNS} + V_{CC} \begin{bmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{bmatrix}$$

Neutrino Mass Ordering





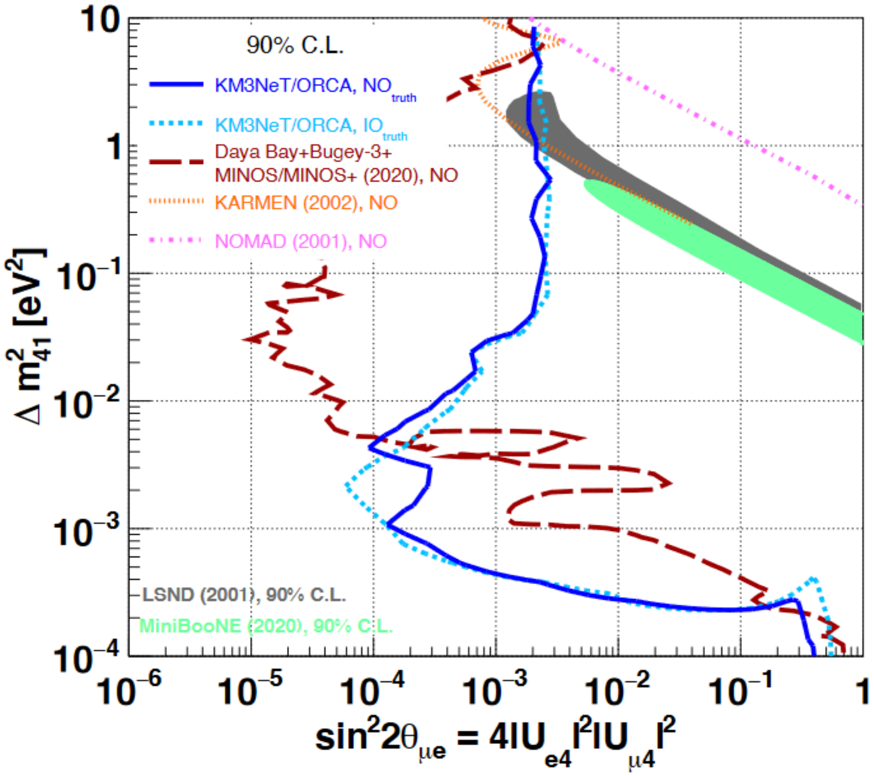
Sensitivity of ORCA115 to NMO after 3 years of data taking

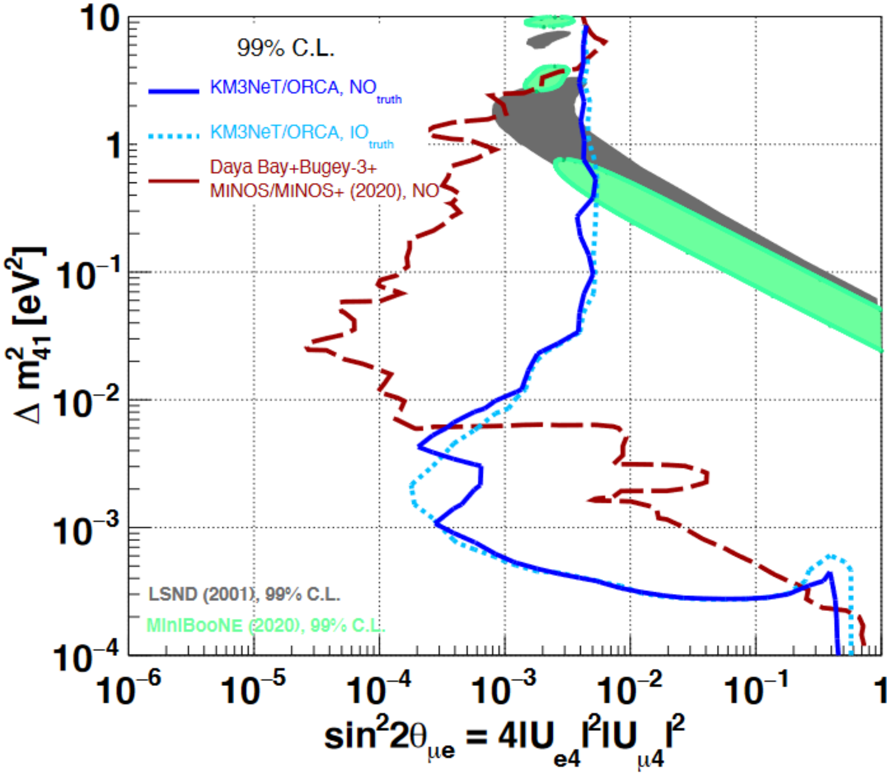
Sensitivity of ORCA115 NMO as a function of operation time

Check out also a combined analysis ORCA and JUNO, arXiv:2108.06293

Determining the Neutrino Mass Ordering and Oscillation Parameters with KM3NeT/ORCA, arXiv:2103.09885, submitted to EPJ-C

Sterile neutrinos



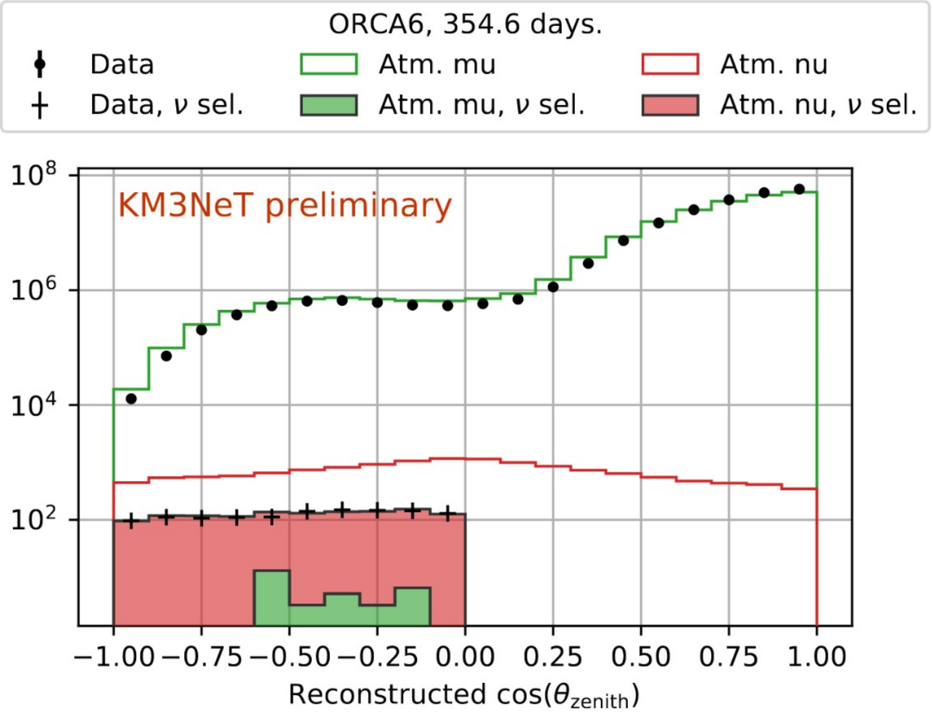


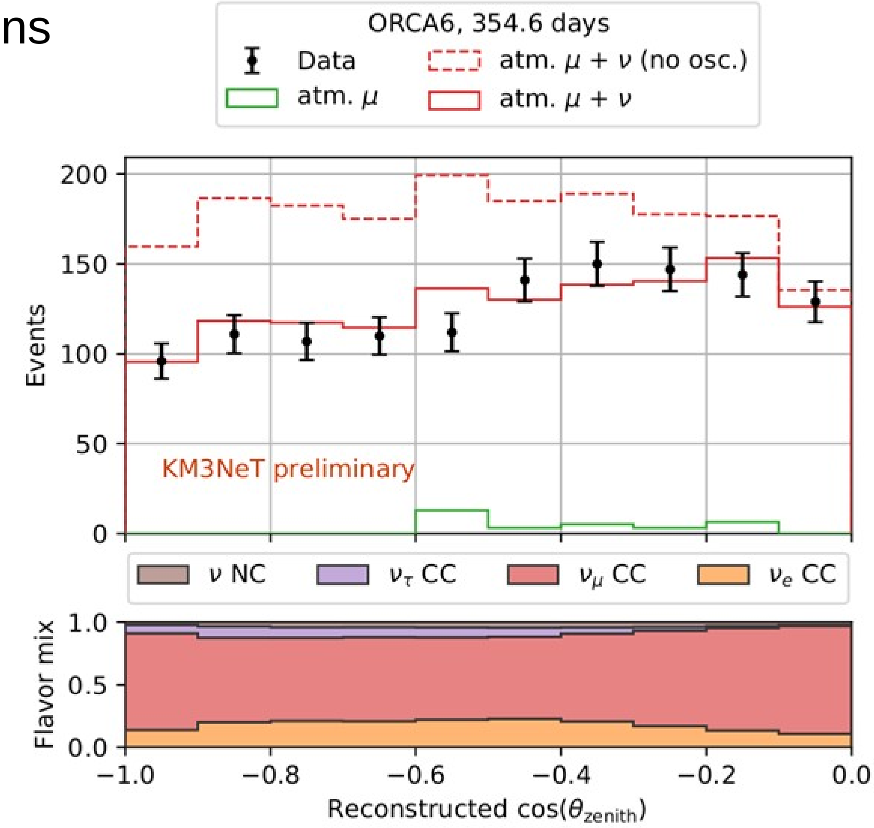
90% (left) and 99% C.L. (right) KM3NeT/ORCA sensitivity to the mixing parameter $|U_{\mu e}|^2$ after 3 years of data taking with the full detector.

Sensitivity to light sterile neutrino mixing parameters with KM3NeT/ORCA, arXiv:2107.00344, submitted to JHEP

First data with ORCA6

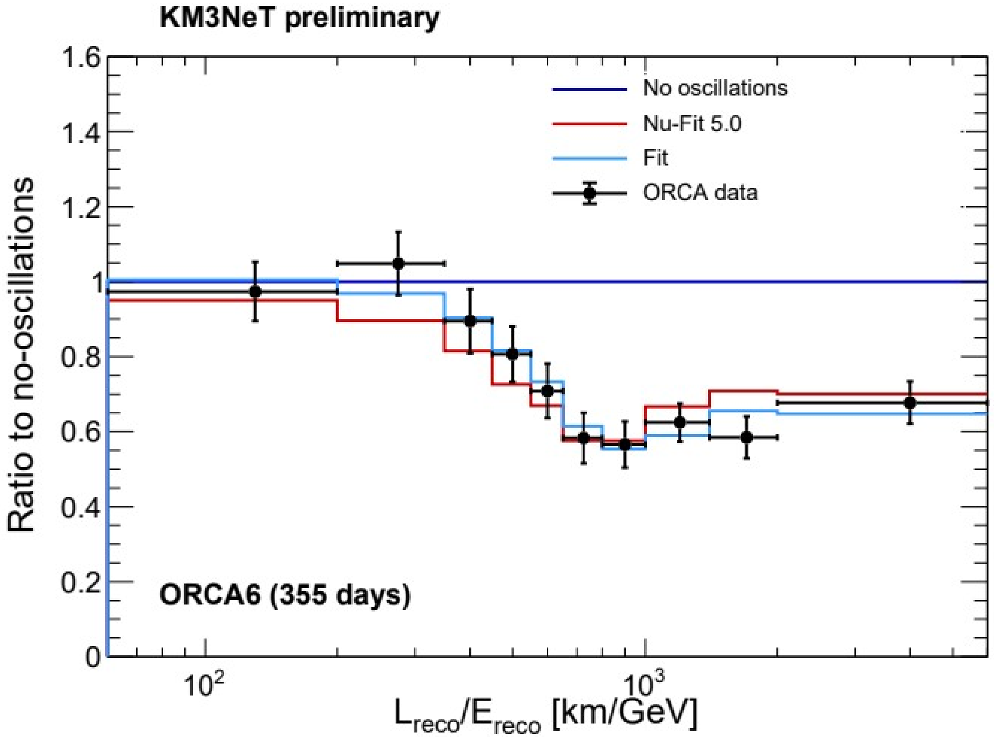
Reconstructed zenith angular distributions

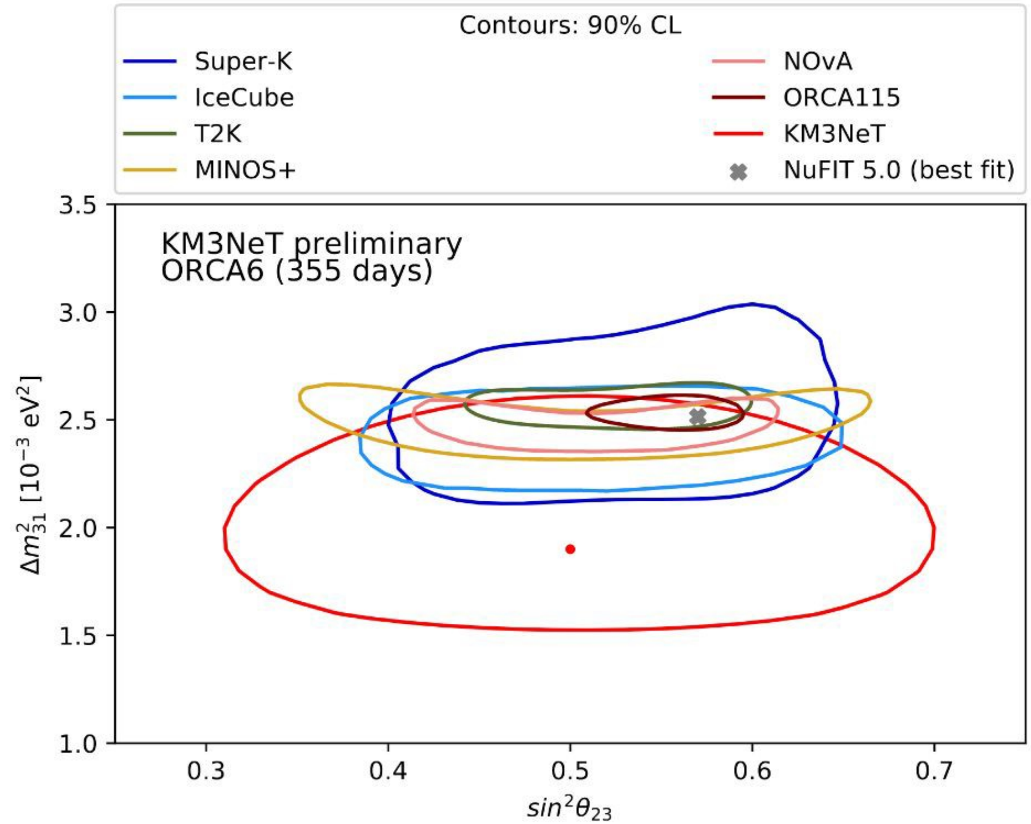




Event selection:
- 1237 neutrino candidates
- very low muon background

First data with ORCA6

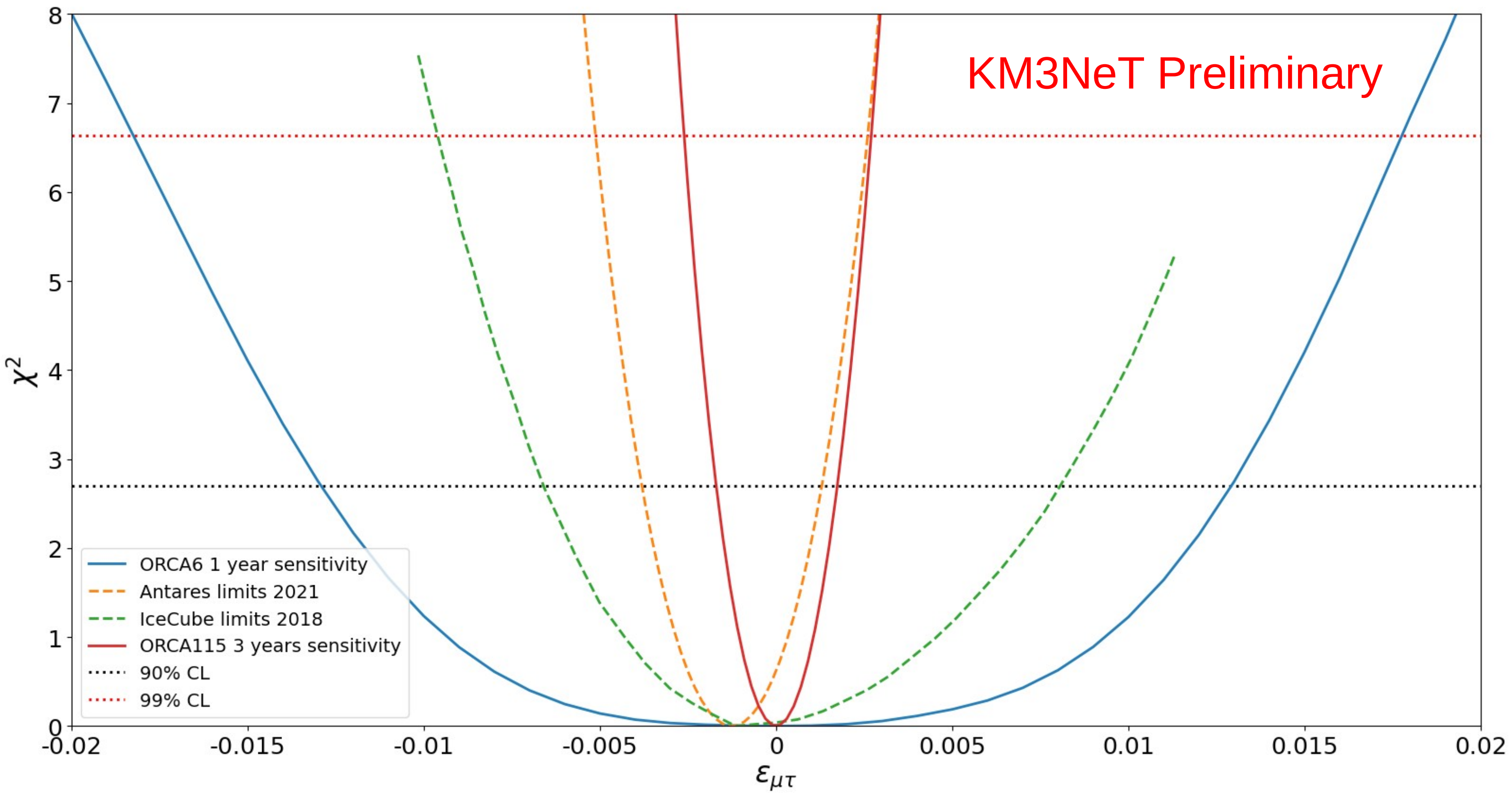




- No oscillations rejected at 5.9σ level
- Final fit performed in 2D! Reco energy and cos(zenith).
- Best fit values: $\Delta m^2_{31} = 1.95^{+0.24}_{-0.22}$, $\sin^2(\theta_{23}) = 0.5 \pm 0.1$

NuFit 5.0 (http://www.nu-fit.org) - global fit of three-flavour neutrino oscillations; arXiv: 2007.14792

Non Standard Interactions (NSI) with ORCA6



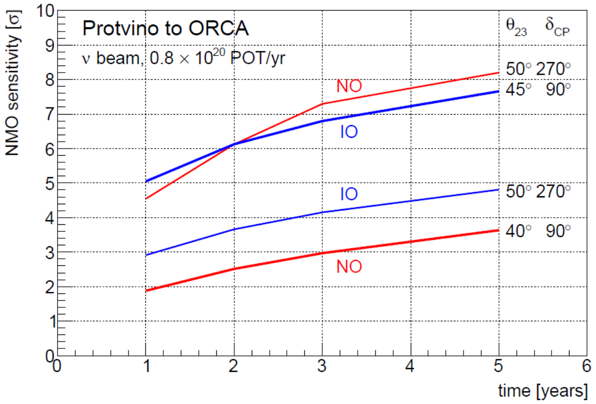
Work in progress!

ORCA6 NSI unblinding coming soon

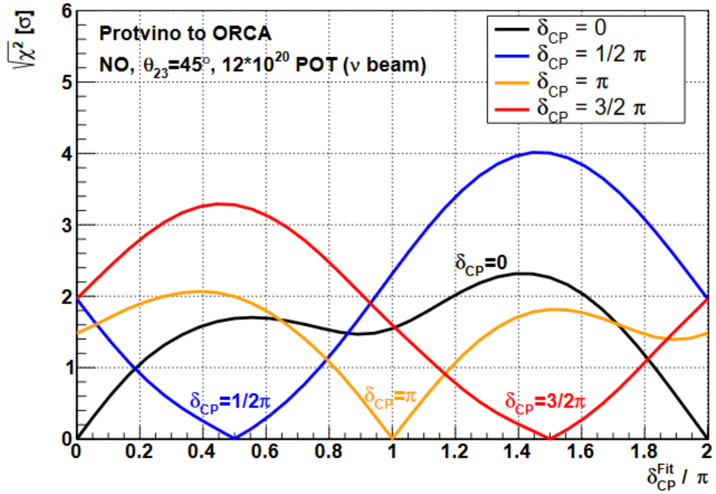
- Same event selection as for the standard analysis (ORCA6)
- Sensitivity from the current 1 year ORCA data set already at the order of magnitude of current results
- Full ORCA115 has potential to improve the current NSI limits

P2O: Protvino to ORCA

- Future project to use ORCA for detection of accelerator neutrinos from Protvino
- NMO sensitivity improvement
- Potential for δ_{CP} measurement



Sensitivity of P2O to neutrino mass ordering as a function of the accumulated exposure time with the 90 kW beam



Sensitivity to exclude certain values of the CP phase δ_{CP} in the P2O experiment after 3 years of running with a 450 kW beam (positive beam polarity)

Letter of Interest for a Neutrino Beam from Protvino to KM3NeT/ORCA, DOI: 10.1140/epjc/s10052-019-7259-5

Summary

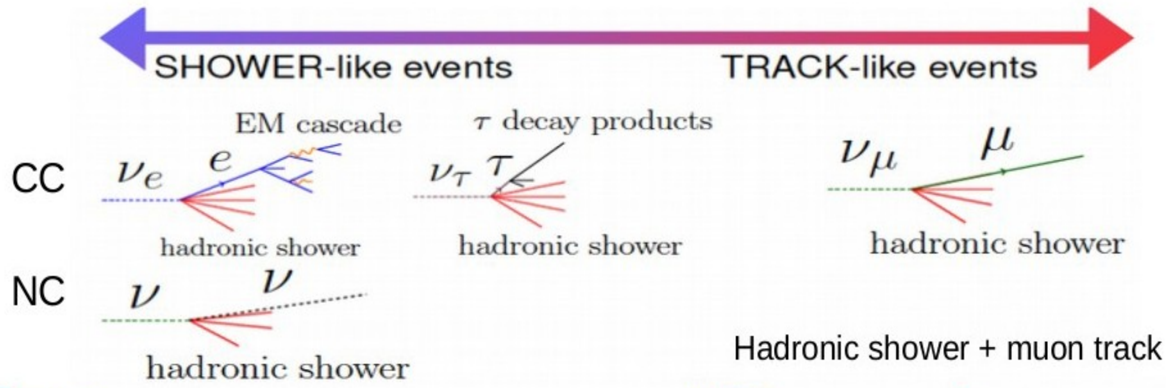
- KM3NeT/ORCA is already capable of probing neutrino oscillations.
- More lines to be deployed soon.
- Neutrino Mass Ordering measurement at 5σ level possible by the end of this decade.
- Once finished, KM3NeT/ORCA will provide world-leading sensitivities for a wide variety of Beyond Standard Model phenomena. Measurements in progress!
- First standard oscillations measurement released:

$$\Delta m^2_{31} = 1.95^{+0.24}_{-0.22}, \quad \sin^2(\theta_{23}) = 0.5 \pm 0.1$$

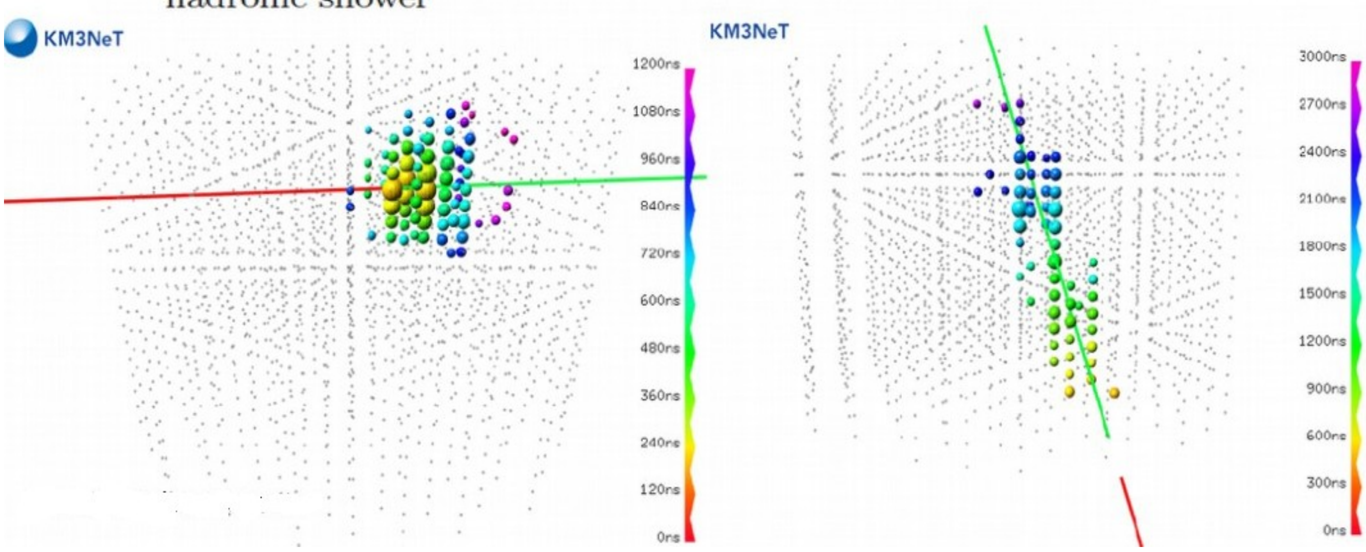
Backup slides

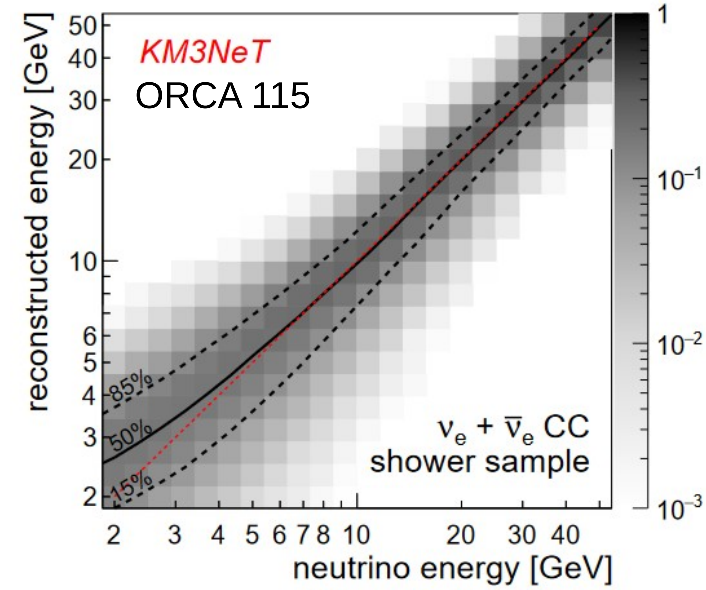
Event topology

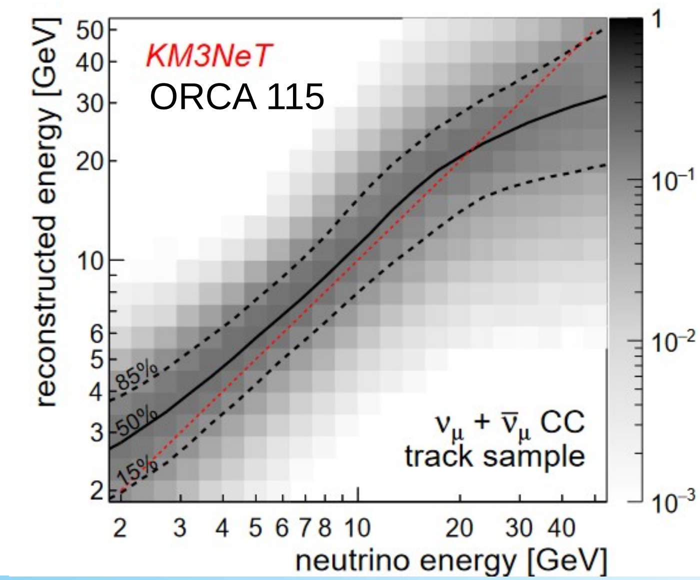
Event type classified with BDT(Boosted Decision Trees)



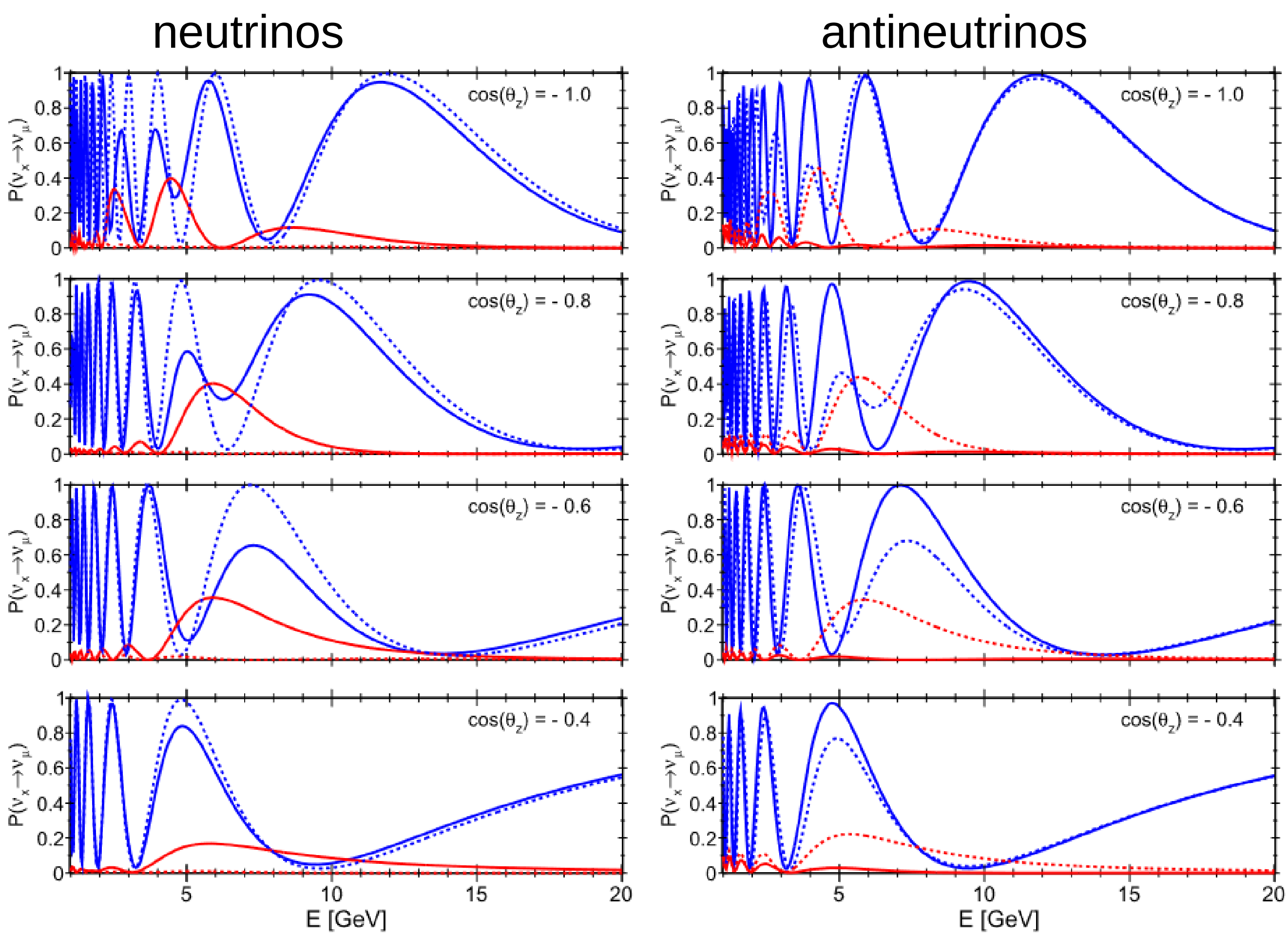
Hadronic shower + muon track





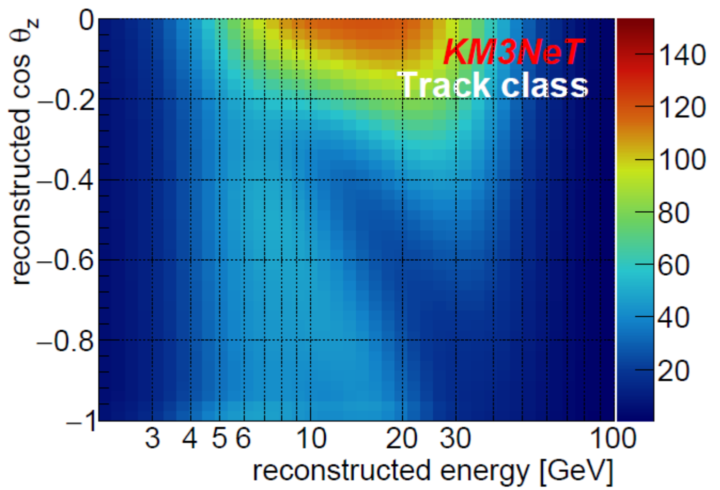


NMO oscillations measurement



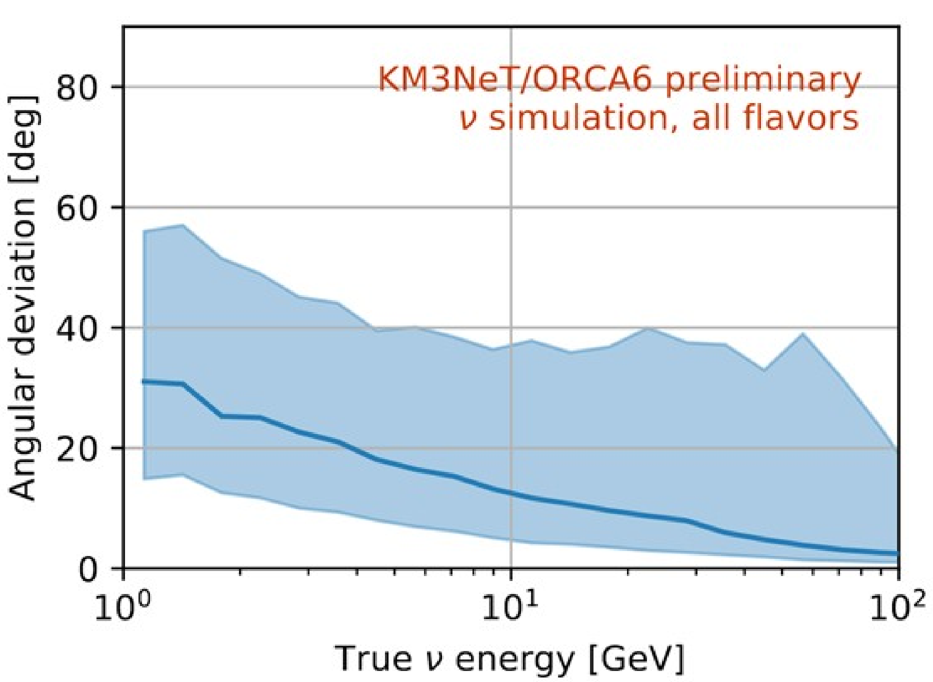
Oscillation probabilities $\nu_\mu \rightarrow \nu_\mu$(blue lines) and $\nu_e \rightarrow \nu_\mu$ (red) as a function of the neutrino energy for several values of the zenith angle. The solid (dashed) lines are for NH (IH).

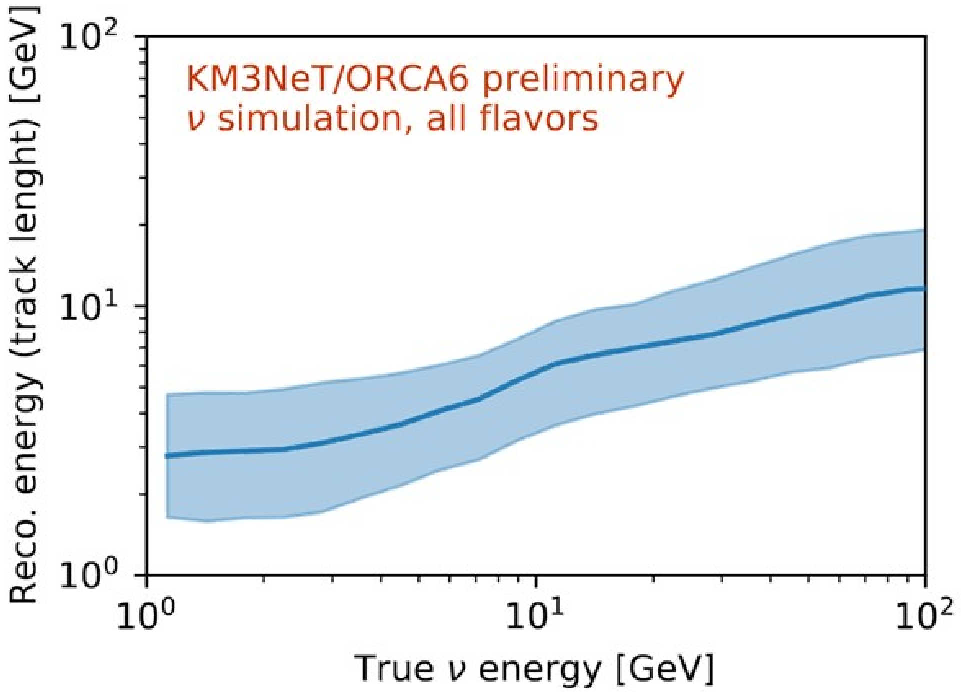
- For a fit, reconstructed energy and direction are mapped into a 2D histogram
- Oscillation model + detector response + flux + cross section= prediction for event rates in the detector



Expected event distributions for NO after 3 years of data taking for events classified as track

Resolution of ORCA6





- Energy resolution limited by the detector size
- Saturation driven by the MIP dE/dx of a muon

Non Standard Interactions (NSI)

NSI are a subset of possible interactions not present in the Standard Model that involve left-chiral neutrinos and left and right-chiral fermions. Neutral current NSI would influence the neutrino propagation through the Earth according to an effective Hamiltonian:

$$H_{eff} = \frac{1}{2E} U_{PMNS} \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{bmatrix} U^\dagger_{PMNS} + V_{CC} \begin{bmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{bmatrix}$$

$$\epsilon_{\alpha\beta} = \cancel{\epsilon^{eC}_{\alpha\beta}} + \cancel{\frac{n_u}{n_e}\epsilon^{uC}_{\alpha\beta}} + \frac{n_d}{n_e}\epsilon^{dC}_{\alpha\beta},$$

For simplicity interaction on fermions other than d-quarks neglected, the results can be easily rescaled assuming a very good approximation n_d / n_e ~ 3 for average Earth matter

Acknowledgements

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