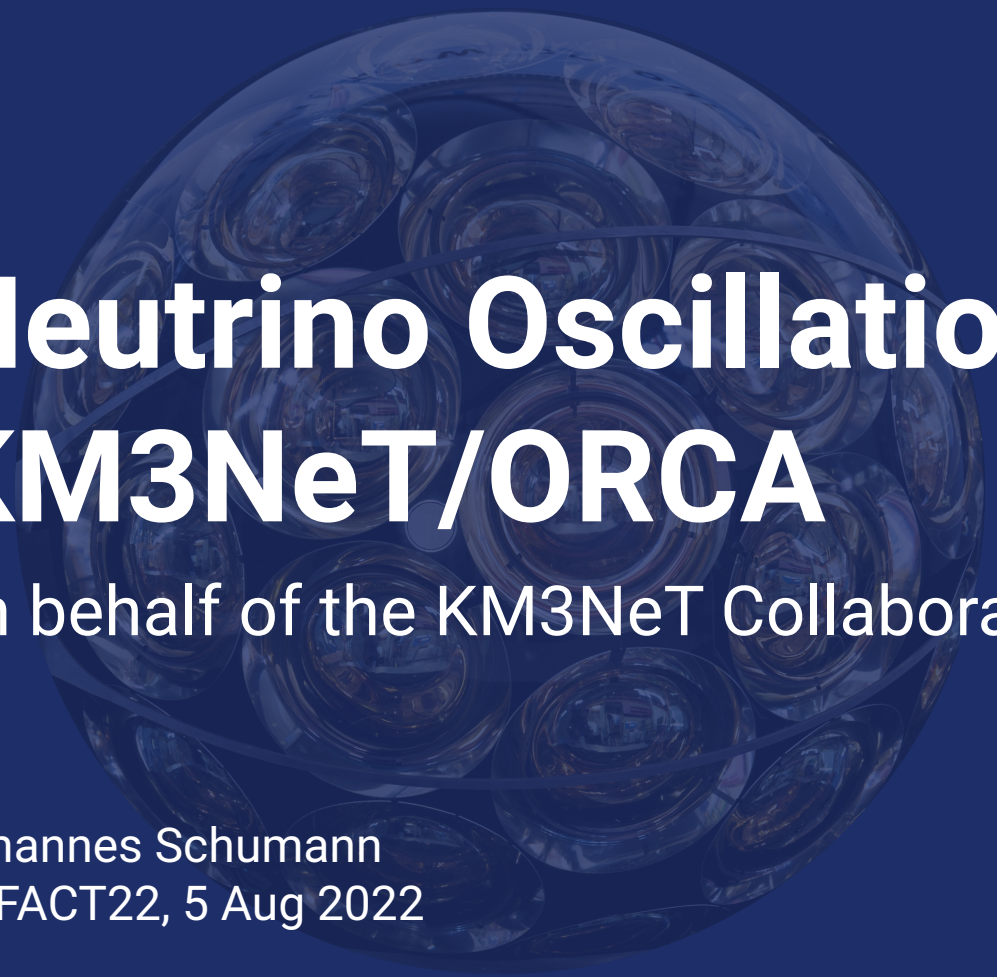
Friedrich-Alexander-Universität
Erlangen-Nürnberg



Neutrino Oscillation Measurement with KM3NeT/ORCA

on behalf of the KM3NeT Collaboration

Johannes Schumann
NuFACT22, 5 Aug 2022

The KM3NeT Collaboration

Collaboration mainly European institutes

- also: Australia, Morocco, South Africa, U.A.E., Algeria and China

Water Cherenkov detectors using sea water as target volume

- 2 detectors sharing 1 optical sensing technology

Oscillation Research with Cosmics in the Abyss (ORCA)

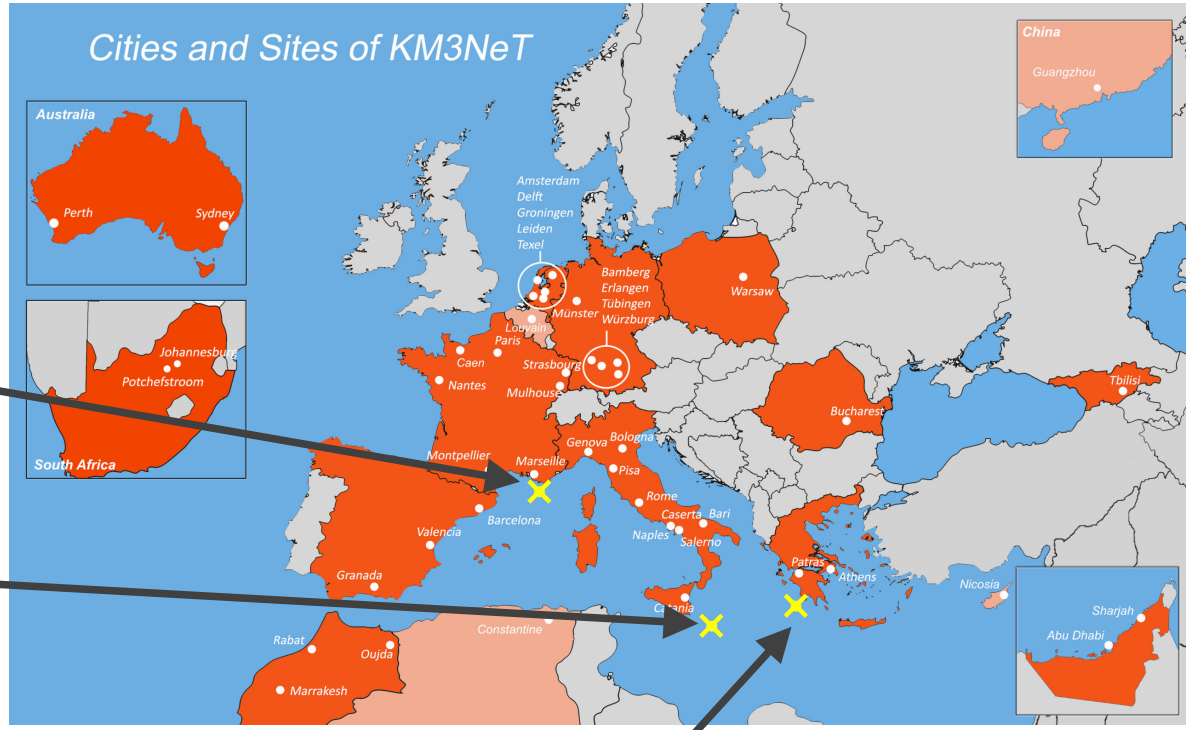
- Dense instrumentation for few GeV atmospheric neutrinos
- Determine neutrino mass hierarchy, oscillation parameters

Astroparticle Research with Cosmics in the Abyss (ARCA)

- sparse instrumentation covering 1km^3 instrumented volume for TeV-PeV cosmic neutrinos
- High-energetic astrophysical neutrino sources, diffuse flux

KM3NeT succeeding ANTARES

- data taking period: 2008 - 2022



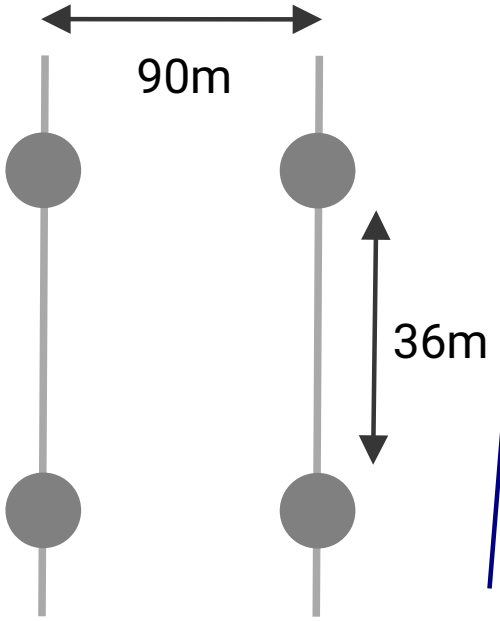
Possible location for 3rd detector site off the Greek coast

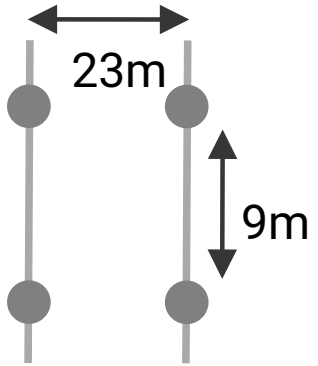
The KM3NeT Detector Sites

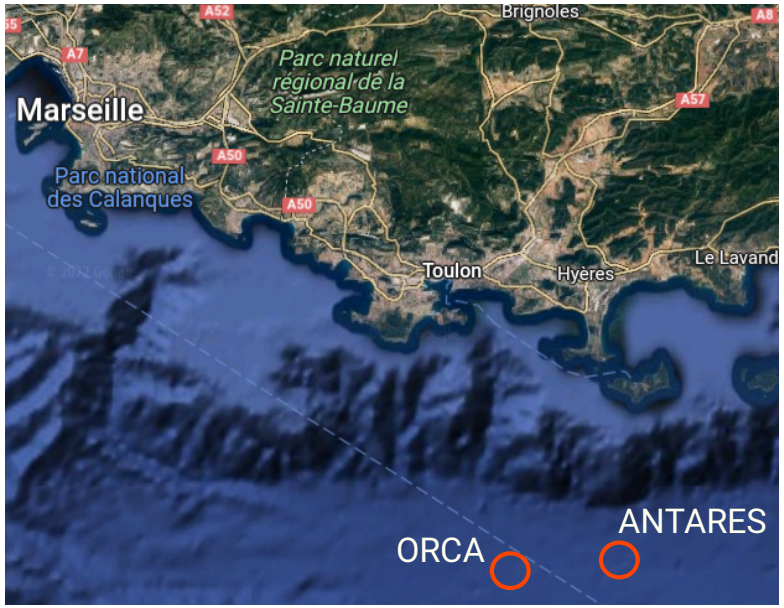
Building Block =
115 strings

ARCA

- Final configuration: 2x Building Blocks, 128340 PMTs
- Positioned ~120km off Sicily at 3500m sea depth
- 19 strings deployed (6.3%)





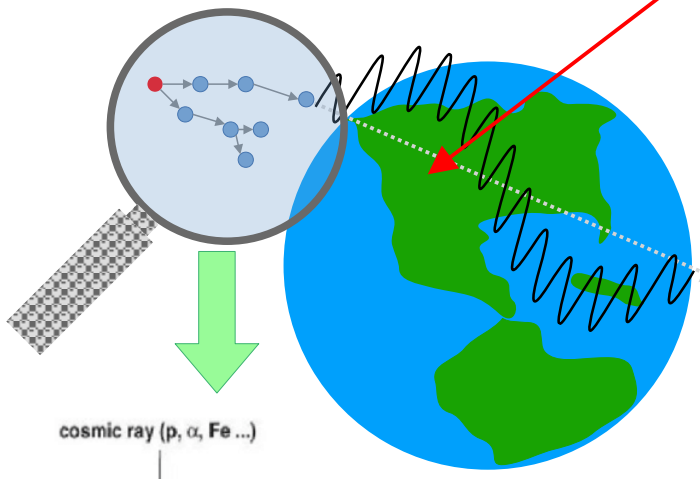


ORCA

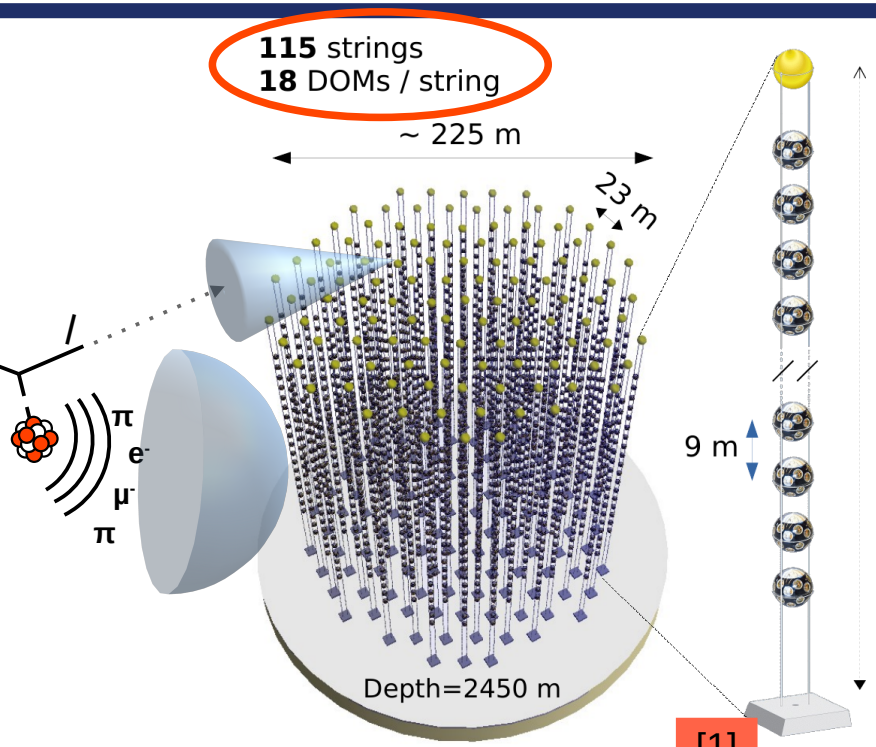
- Final configuration: 1x Building Block, 64170 PMTs
- 11 strings deployed (9.6%)
- Close to the former ANTARES site about 40km off southern french coast near Toulon
- Sea floor depth of the ORCA site ~2450m

KM3NeT/ORCA in a nutshell

You are here



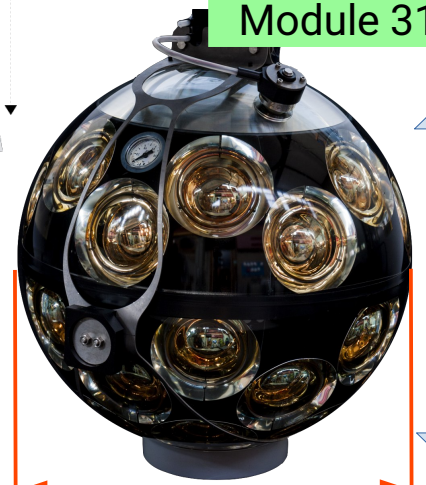
[2]



[1]

Artist Impression of KM3NeT/ORCA

Digital Optical Module 31x3” PMTs



Resolution:

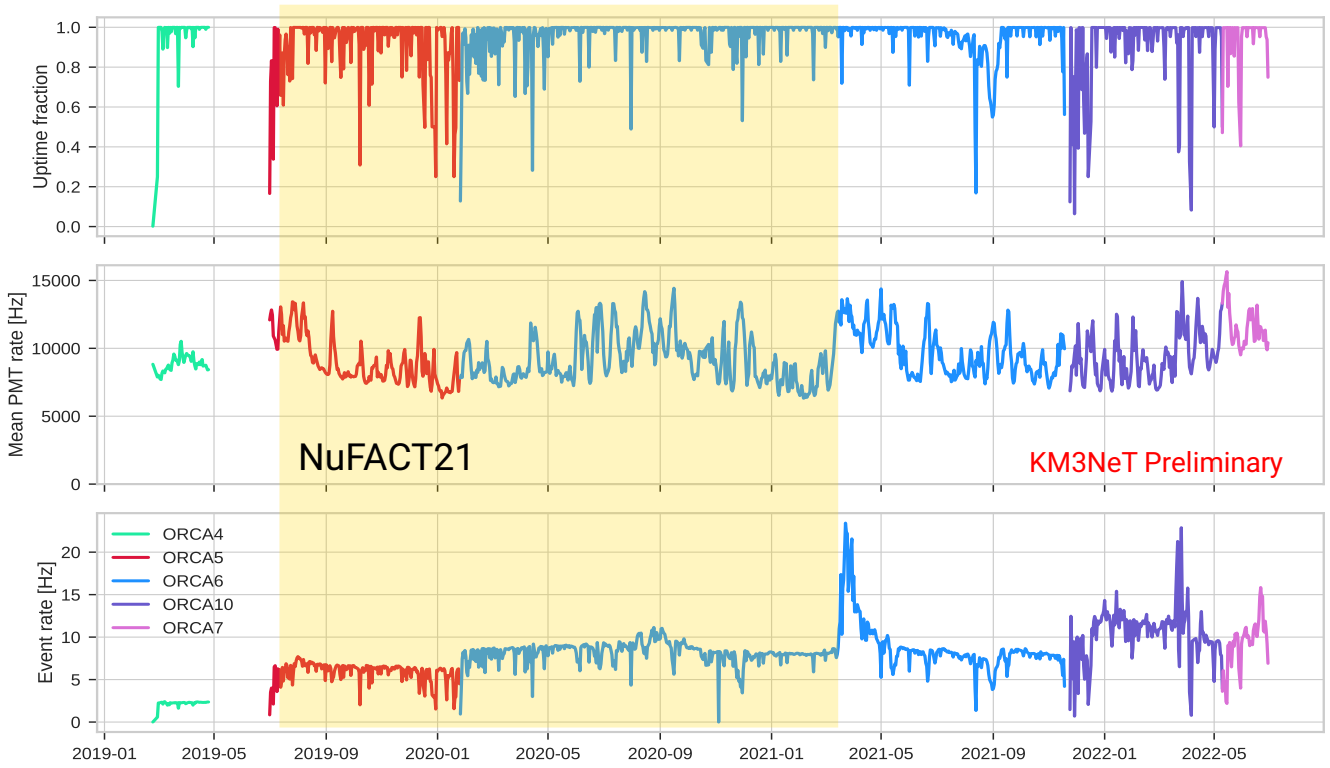
- nano second timing
- ~O(10cm) spatial calibration precision

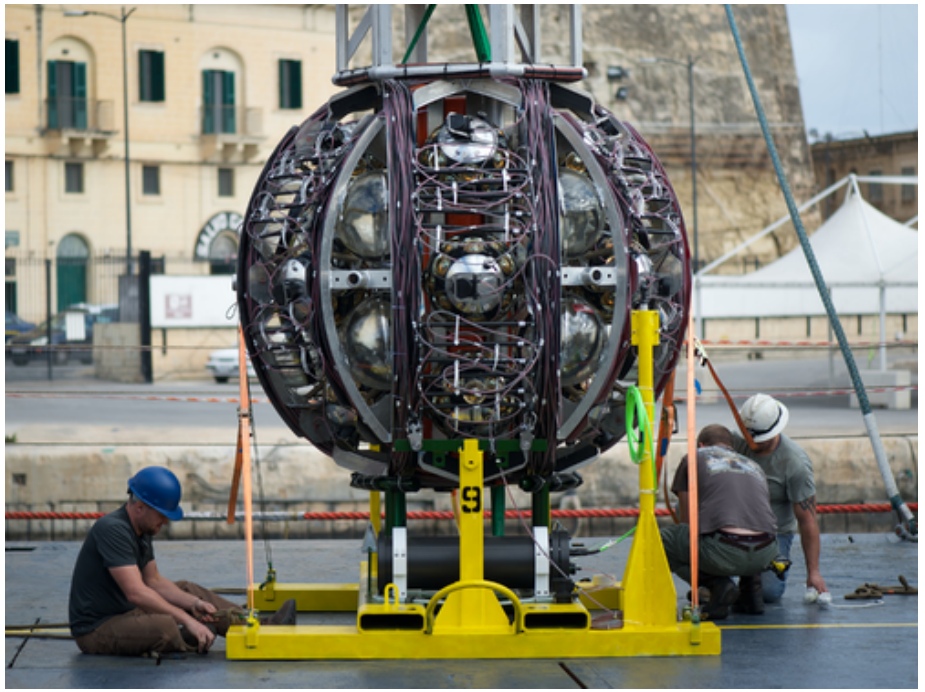
KM3NeT/ORCA current status

Detector Timeline (ORCA)

- Last NuFACT: 6 strings running
- Now: 11 strings deployed → currently 7 running

Some numbers:





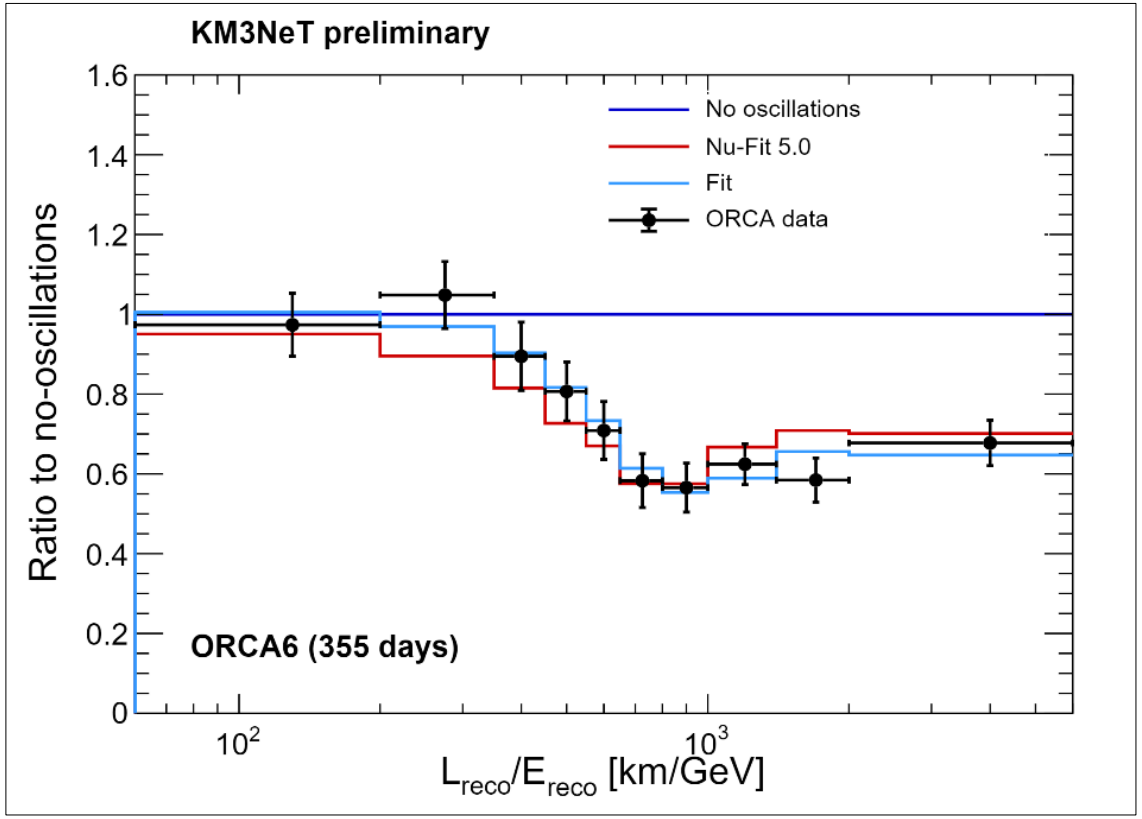
DU furled and ready for the deployment

KM3NeT/ORCA6 Measurement

Oscillation measurement

- Dataset contains 355 days with 6 ORCA strings
- Compared model:
  - Atmospheric flux model → HKKM14
  - Oscillation parameters: → NO & NuFit 5.0 values
- Oscillation pattern matches the prediction very well
- Analysis parameters:

Parameter	Treatment Free/Fixed/Prior
θ_{12} [deg]	Fixed
θ_{13} [deg]	Fixed
θ_{23} [deg]	Free
Δm^2_{31} [10^{-3} GeV^2]	Free
Δm^2_{21} [10^{-5} GeV^2]	Fixed
δ_{CP} [deg]	Fixed
Normalisation	Free
Spectral index	Prior: 10%
$n_{\nu_{up}}/n_{\nu_{horiz}}$	Prior: 7%
$n_{\nu_\mu}/n_{\nu_{\bar{\mu}}}$	Prior: 10%
$n_{\nu_e}/n_{\nu_{\bar{e}}}$	Prior: 10%
n_{ν_μ}/n_{ν_e}	Prior: 3%
n^{NC}	Prior: 10%
n^{CC}_τ	Prior: 20%
Energy scale	Prior: 10%



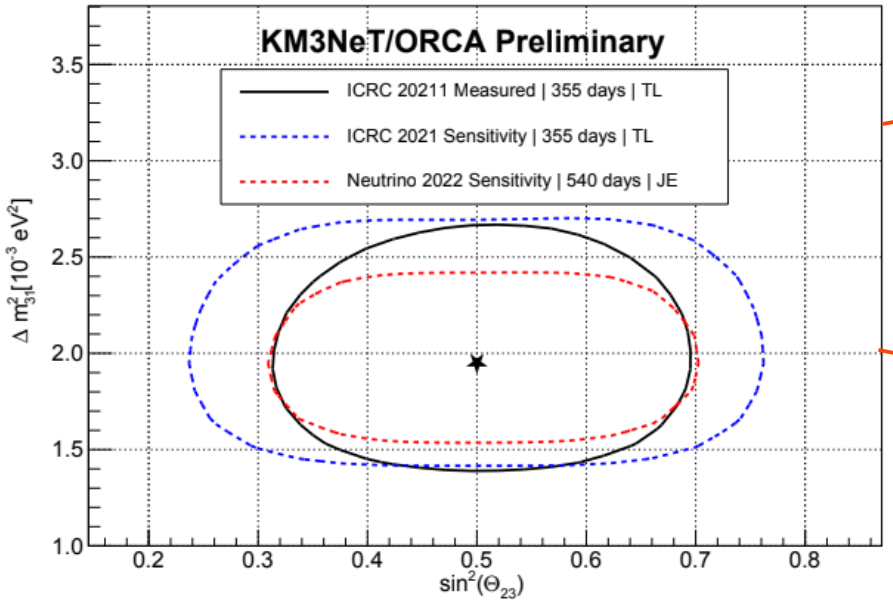
[4]

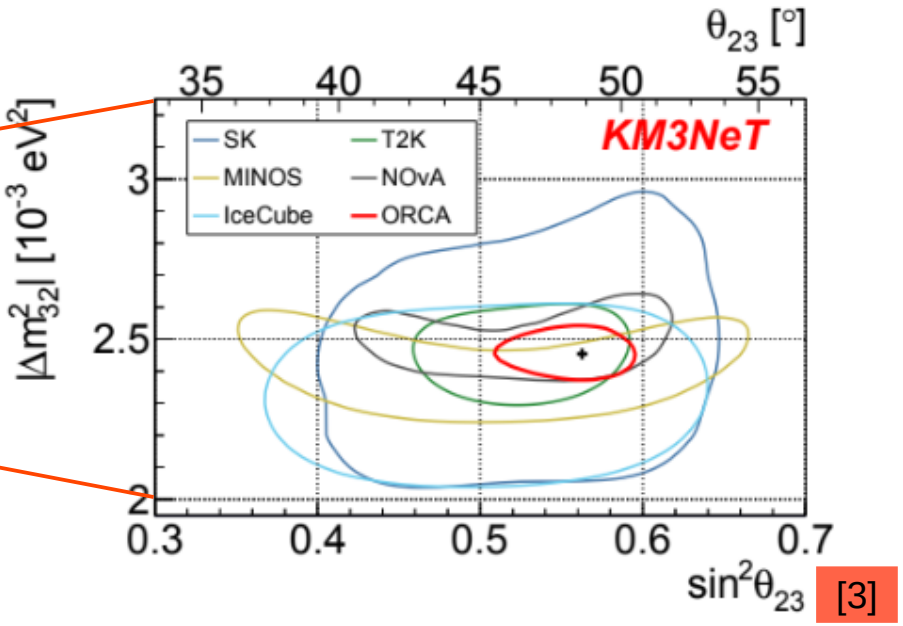
Oscillation Parameter Sensitivity

Updated oscillation parameter measurement with 6 strings

- Livetime increased from 355 days to 540 days
- Improved selection & particle identification
  → together: Sample increased by factor 4
- (Unblinding & Measurement update about to come)

ORCA115 Prediction



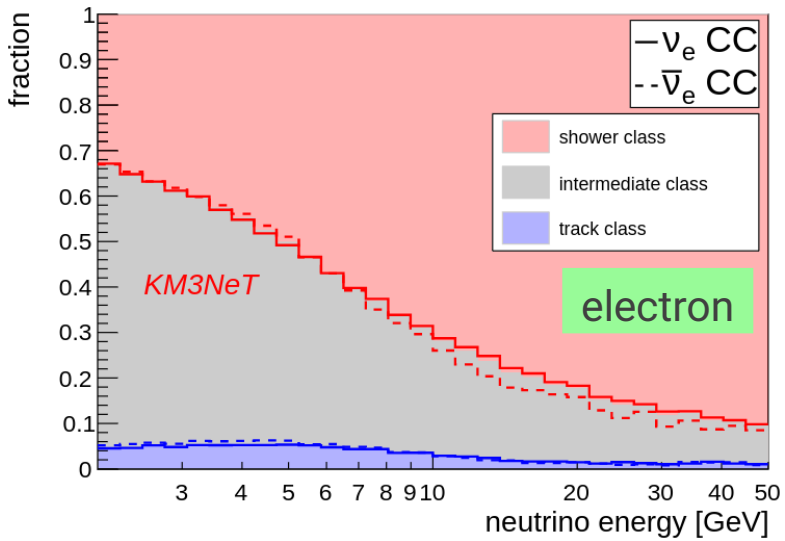


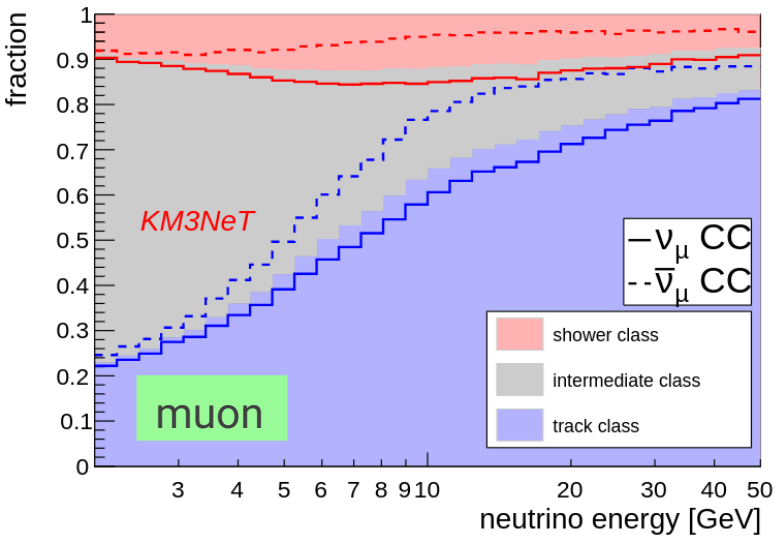
[3]

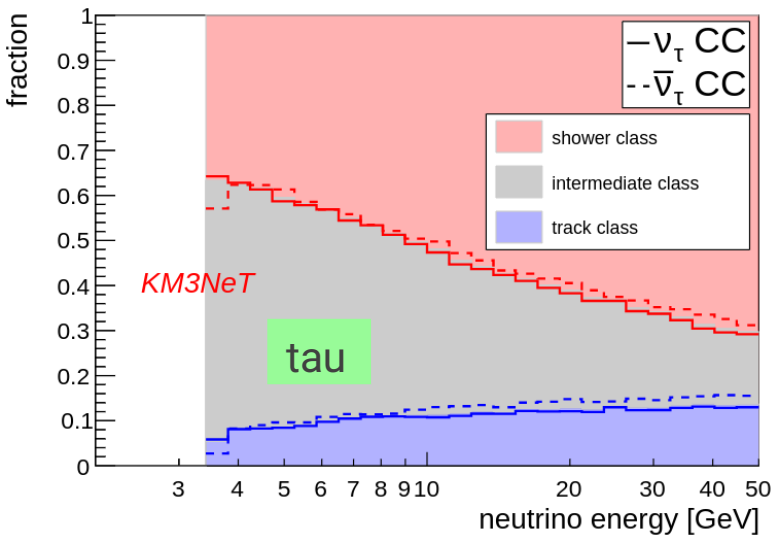
Reconstruction & Particle Identification

Triggered events are reconstructed with different algorithms

- Reconstruction algorithms differ in the event geometry hypothesis, i.e. track and shower
- Events are classified by multiple features using random decision forests (RDF):
  Features: likelihood, reconstructed energy & direction, number of triggered hits, etc.
- ν / μ classification → muon score
- noise classification → noise score
- track/shower classification → track / intermediate / shower







[3]

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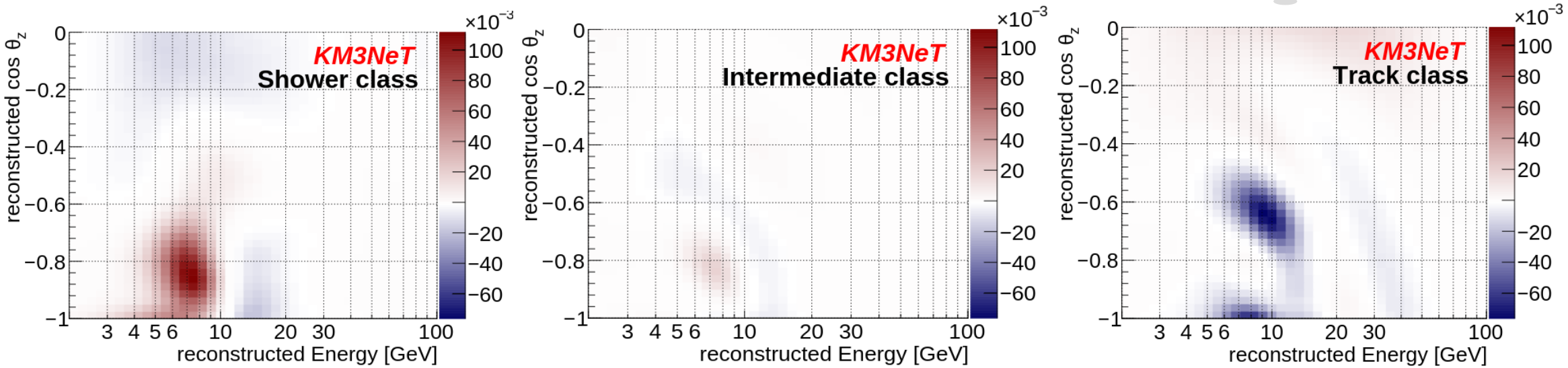
$(N_{NO}\text{-}N_{IO})$
$|N_{NO}\text{-}N_{IO}|/N_{NO}$

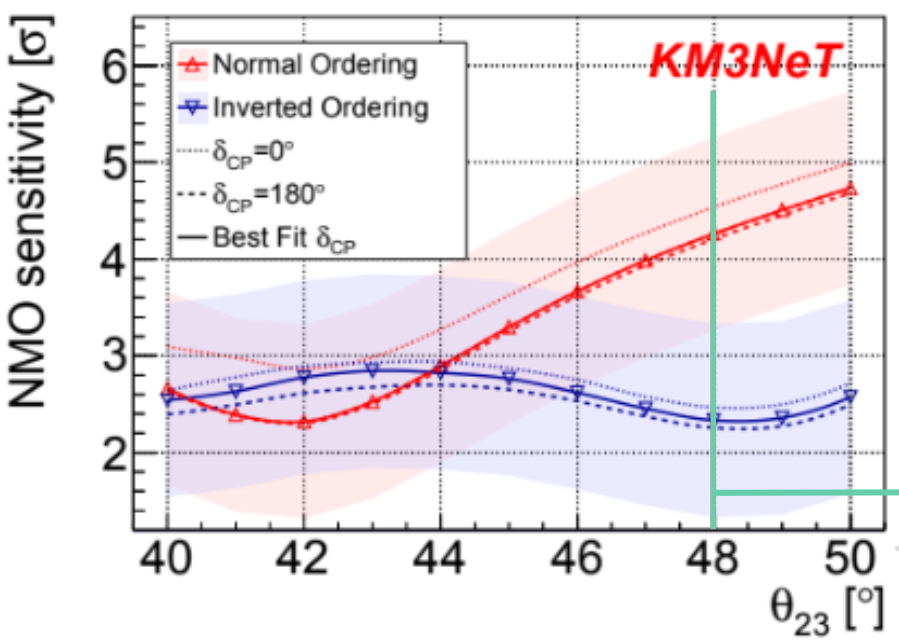


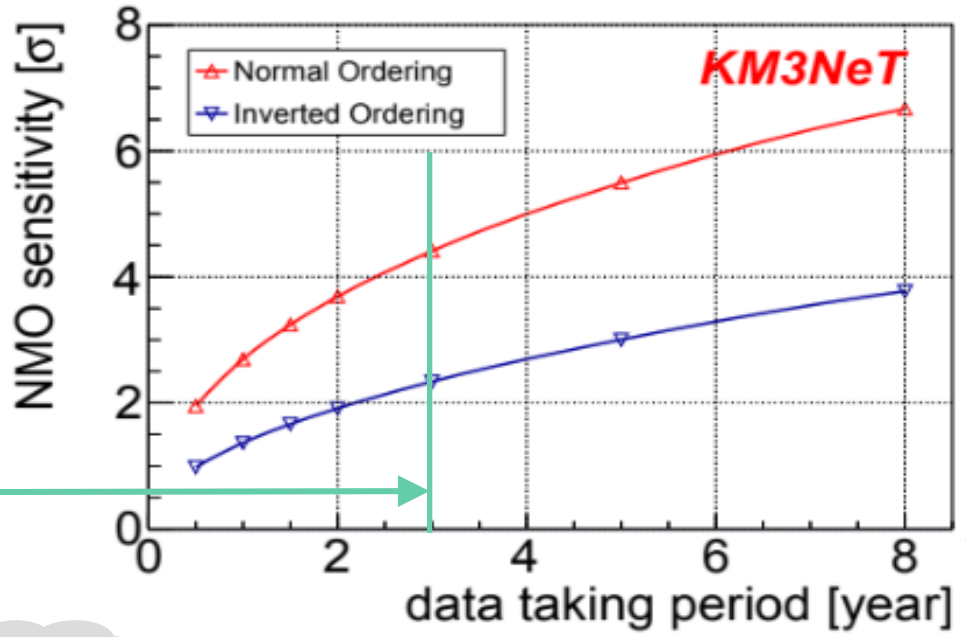
[3]

KM3NeT/ORCA full detector estimated sensitivity

ORCA Mass Ordering Sensitivity

- assumed data taking time: 3 years





3yrs

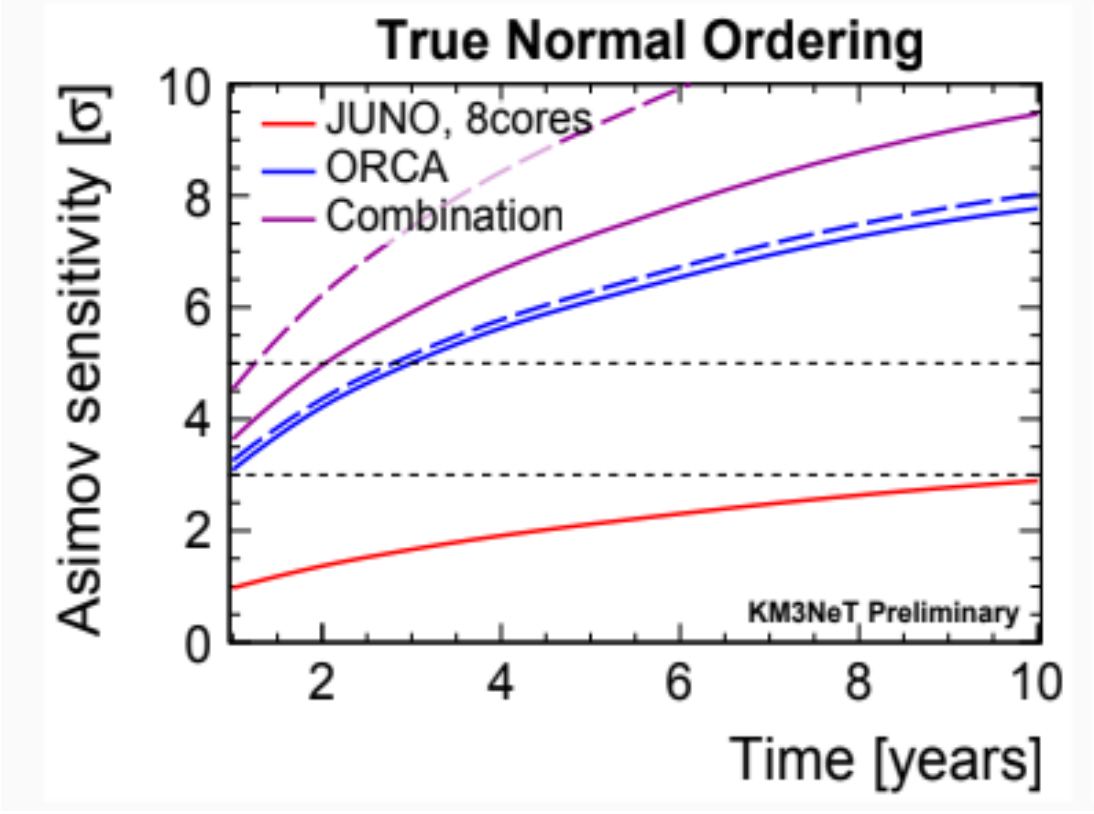
@ θ_{23}= 48°

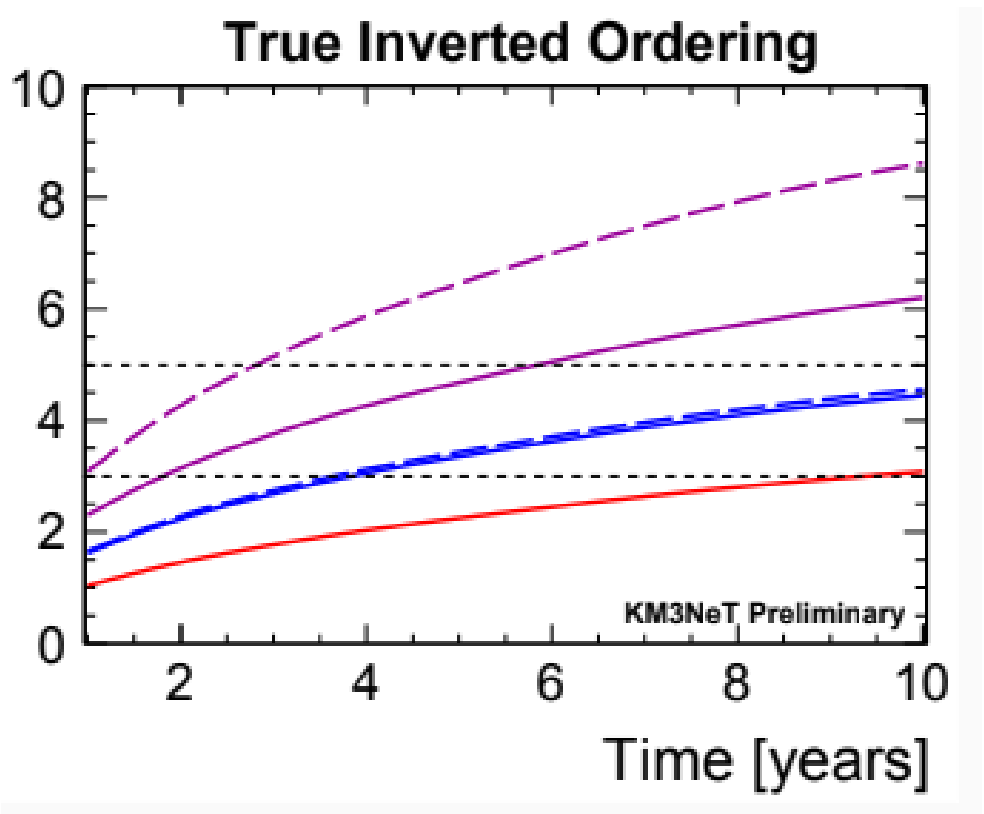
[3]

NMH sensitivity combined with JUNO

Massive increase of sensistivity by combining ORCA & JUNO

- Analysis approach: Δm_{31} disagrement on wrong NMO hypothesis
- Sensitivity boost compared to full ORCA only: 4σ → 6σ @3yrs, normal ordering and Θ_{23} = 48°





[5]

KM3NeT/ORCA Sterile Neutrinos

4th Sterile Flavour Properties

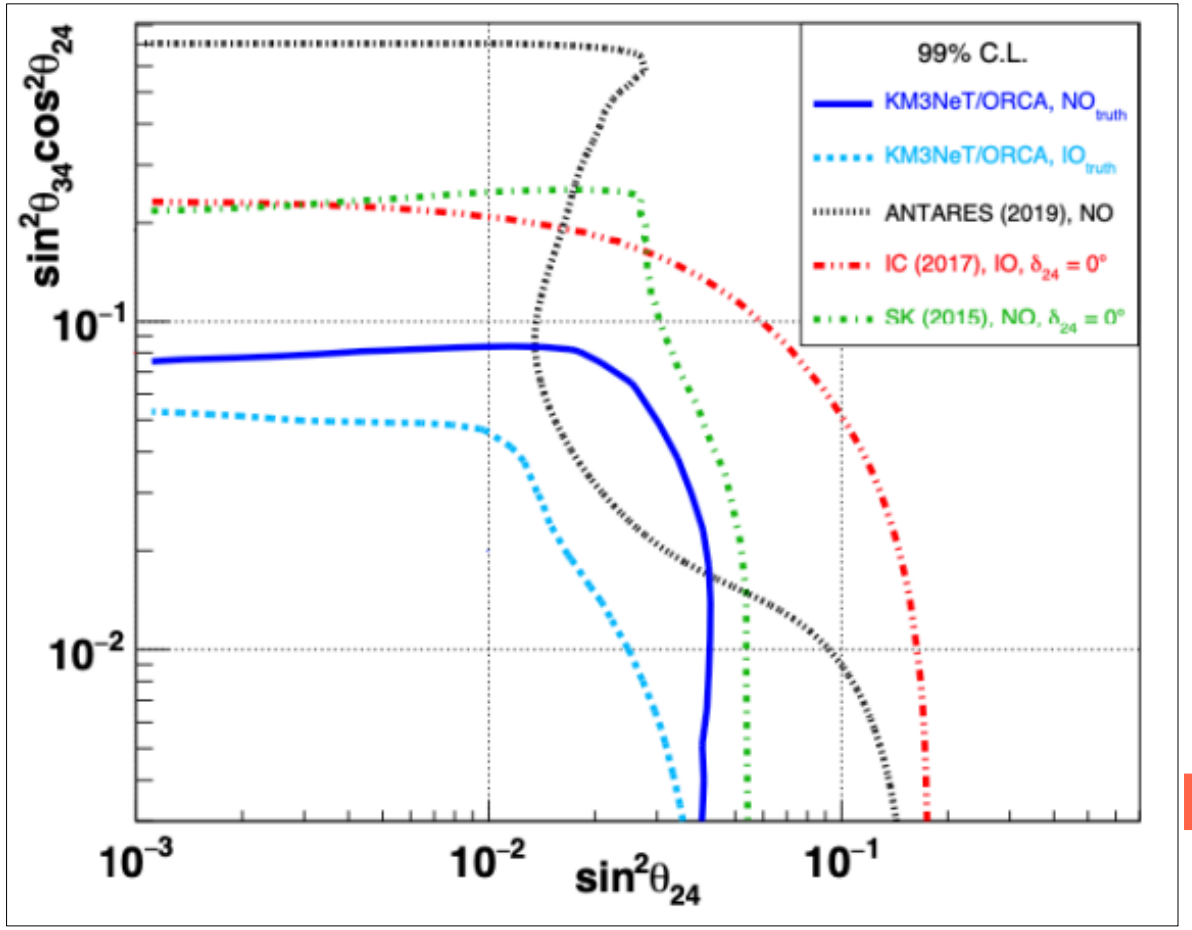
- 4 neutrino flavour yields:
  - **3** additional **mixing angles**
  - **2** additional **phases**
  - **(1** additional **mass)**

Given sensitivitiy for large Δm_{41} limit

- assumed data taking time 3 years

Free phase δ_{24} worsens the sensitivity

- here phase for IC and SK is assumed to be $\delta_{24} = 0°$

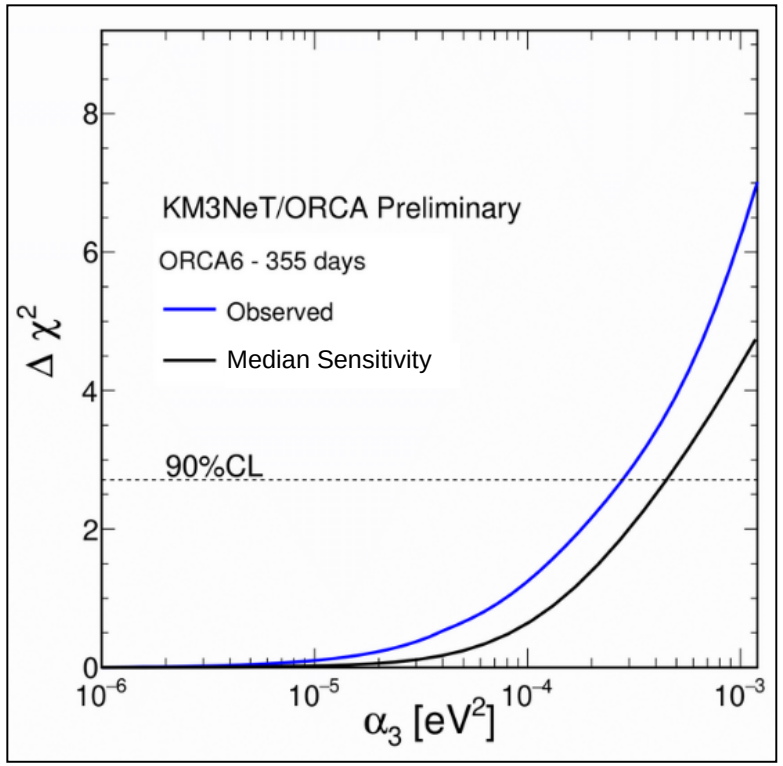


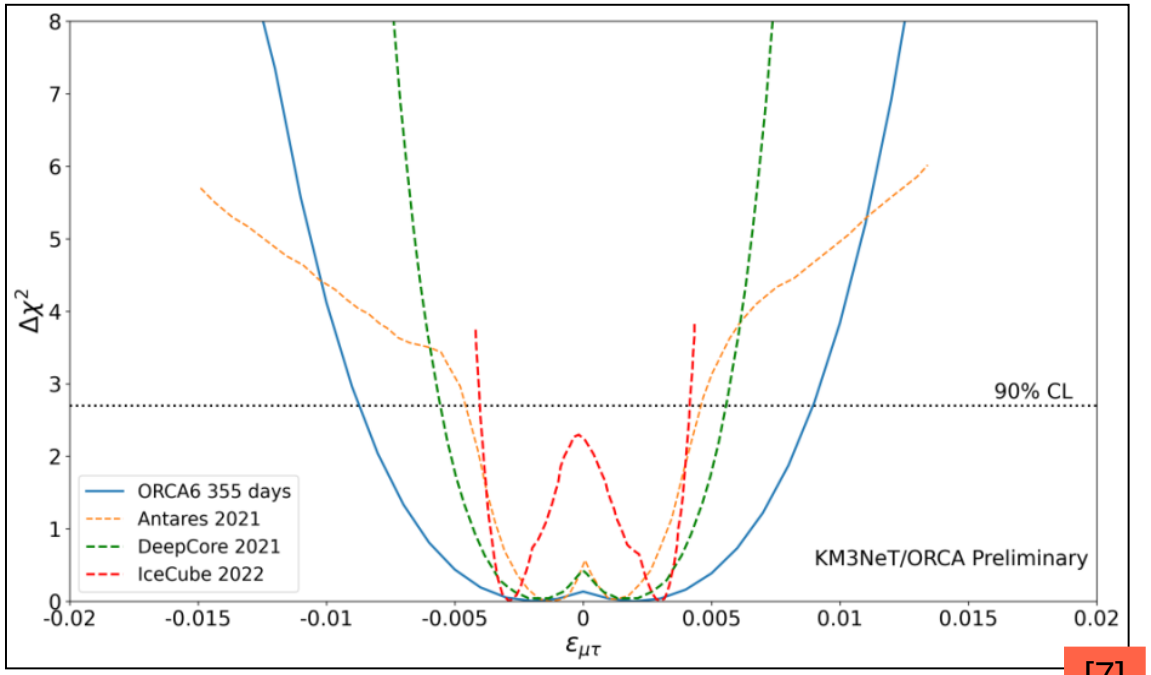
[6]

Non Standard Interactions & Neutrino Decay

Constraining non-standard interactions

- 1 year sensitivity about to be competitive to other experiments
- ORCA prediction for 355 days livetime in 6 string configuration





[7]

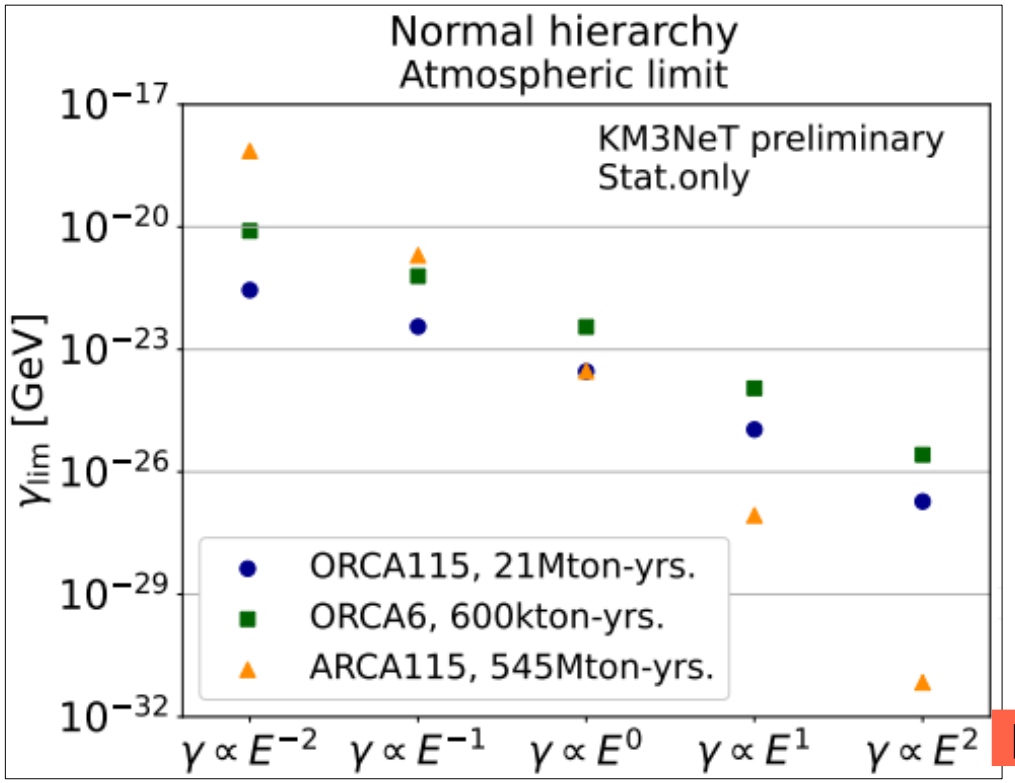
Neutrino decay / livetime

- Proof of principle
- Full ORCA detector will be world-leading

Neutrino Decoherence

Preliminary sensitivities

- Constraints on a wide range of power law indices, i.e. [-2, 2]
- ORCA dominates negative indices → lower energies more relevant
- ARCA dominates positives indices → vice versa as higher energies are more relevant

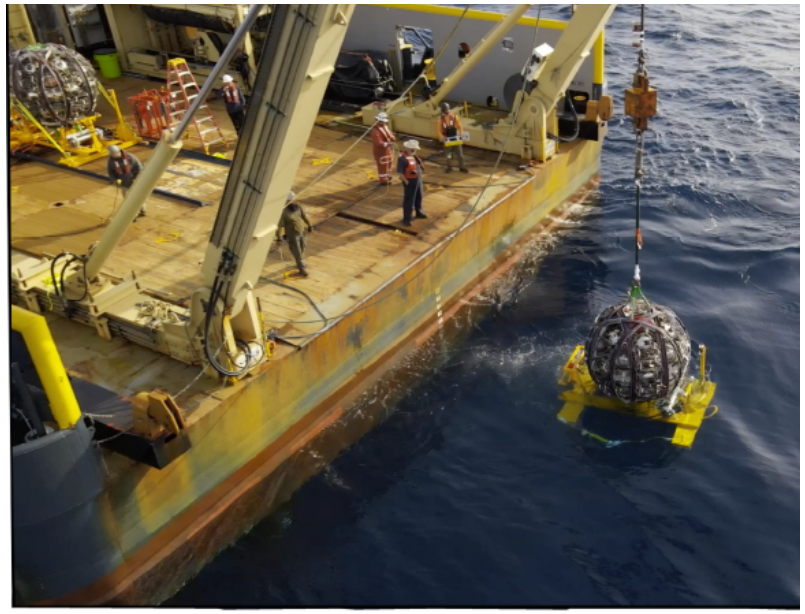


[8]

Summary

ORCA Detector Status

- First oscillation results already obtained
  → e.g. NSI already competitive
- Data taking is on-going while detector is growing (currently 11 strings deployed)
- Refinement of the data analysis causes sample size growth larger than livetime growth



Perspectives

- Upon completion KM3NeT/ORCA will be one of the leading experiments with respect to NMH & oscillation parameter measurement with atmospheric neutrinos
- Construction ramping up on the way to the full detector

Thank You!

References

[1] A. V. Akindinov and others, “Letter of Interest for a Neutrino Beam from Protvino to KM3NeT/ORCA”, Eur. Phys. J. C, vol. 79, no. 9, p. 758, 2019, doi: 10.1140/epjc/s10052-019-7259-5.

[2] A. López-Oramas, Multi-year Campaign of the Gamma-Ray Binary LS I +61◦ 303 and Search for VHE Emission from Gamma-Ray Binary Candidates with the MAGIC Telescopes. 2015. doi: 10.13140/RG.2.1.4140.4969.

[3] S. Aiello and others, “Determining the neutrino mass ordering and oscillation parameters with KM3NeT/ORCA”, Eur. Phys. J. C, vol. 82, no. 1, p. 26, 2022, doi: 10.1140/epjc/s10052-021-09893-0.

[4] L. Nauta and others, “First neutrino oscillation measurement in KM3NeT/ORCA”, PoS, vol. ICRC2021, p. 1123, 2021, doi: 10.22323/1.395.1123.

[5] N. Chau, J. P. Athayde Marcondes de André, V. Van Elewyck, A. Kouchner, L. Kalousis, and M. Dracos, “Neutrino mass ordering determination through combined analysis with JUNO and KM3NeT/ORCA”, JINST, vol. 16, no. 11, p. C11007, 2021, doi: 10.1088/1748-0221/16/11/C11007.

[6] S. Aiello and others, “Sensitivity to light sterile neutrino mixing parameters with KM3NeT/ORCA”, JHEP, vol. 10, p. 180, 2021, doi: 10.1007/JHEP10(2021)180.

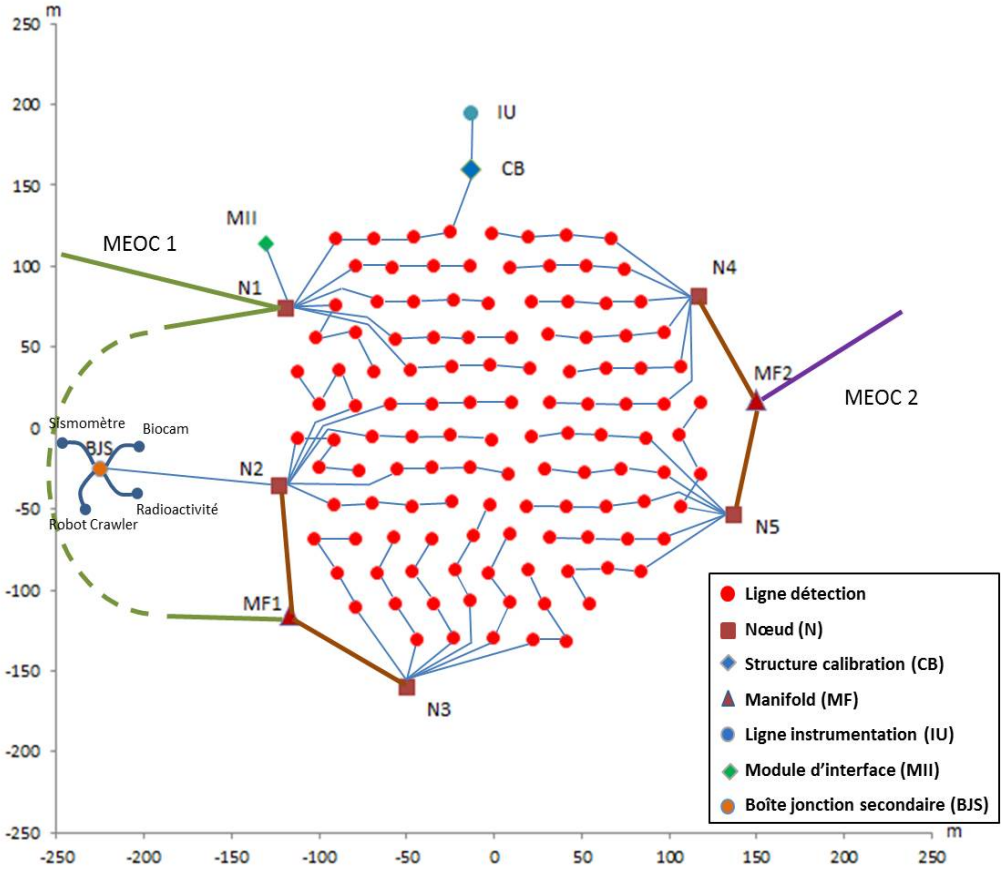
[7] J. Manczak, “First limits on neutrino non-standard interactions with KM3NeT/ORCA6.” Zenodo, 2022. doi: 10.5281/zenodo.6785232.

[8] Lessing, N. (2022). Sensitivity to quantum decoherence in neutrinooscillations with KM3NeT [Masterthesis]. Friedrich-Alexander-Universität Erlangen-Nürnberg.

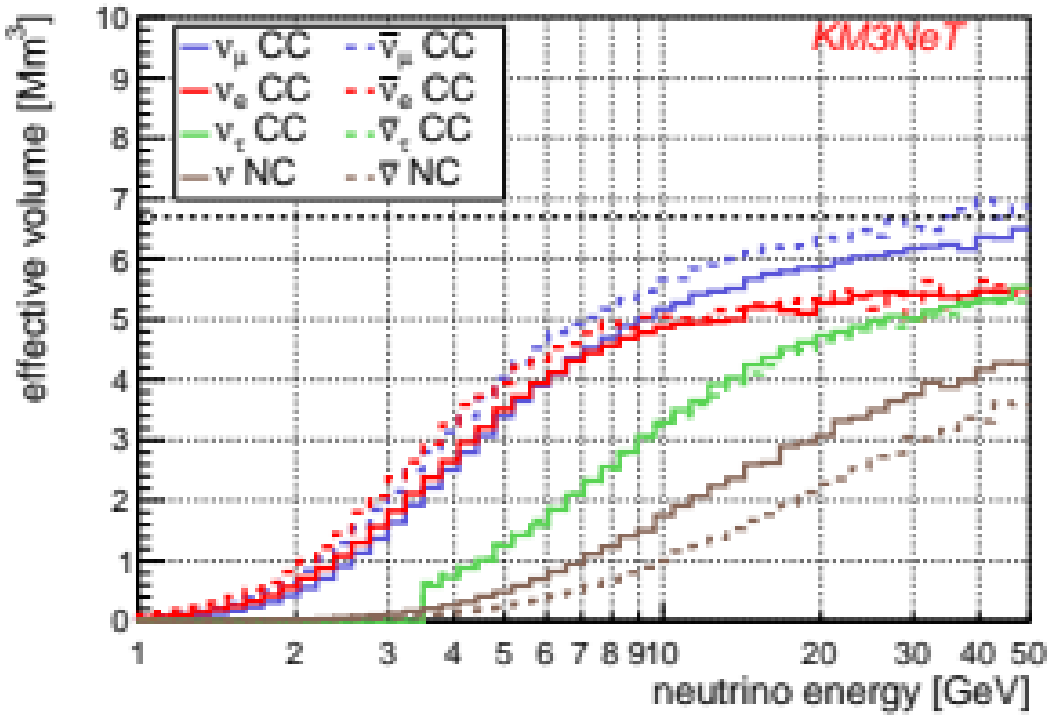
Backup

KM3NeT/ORCA Details

Planed ORCA layout and components

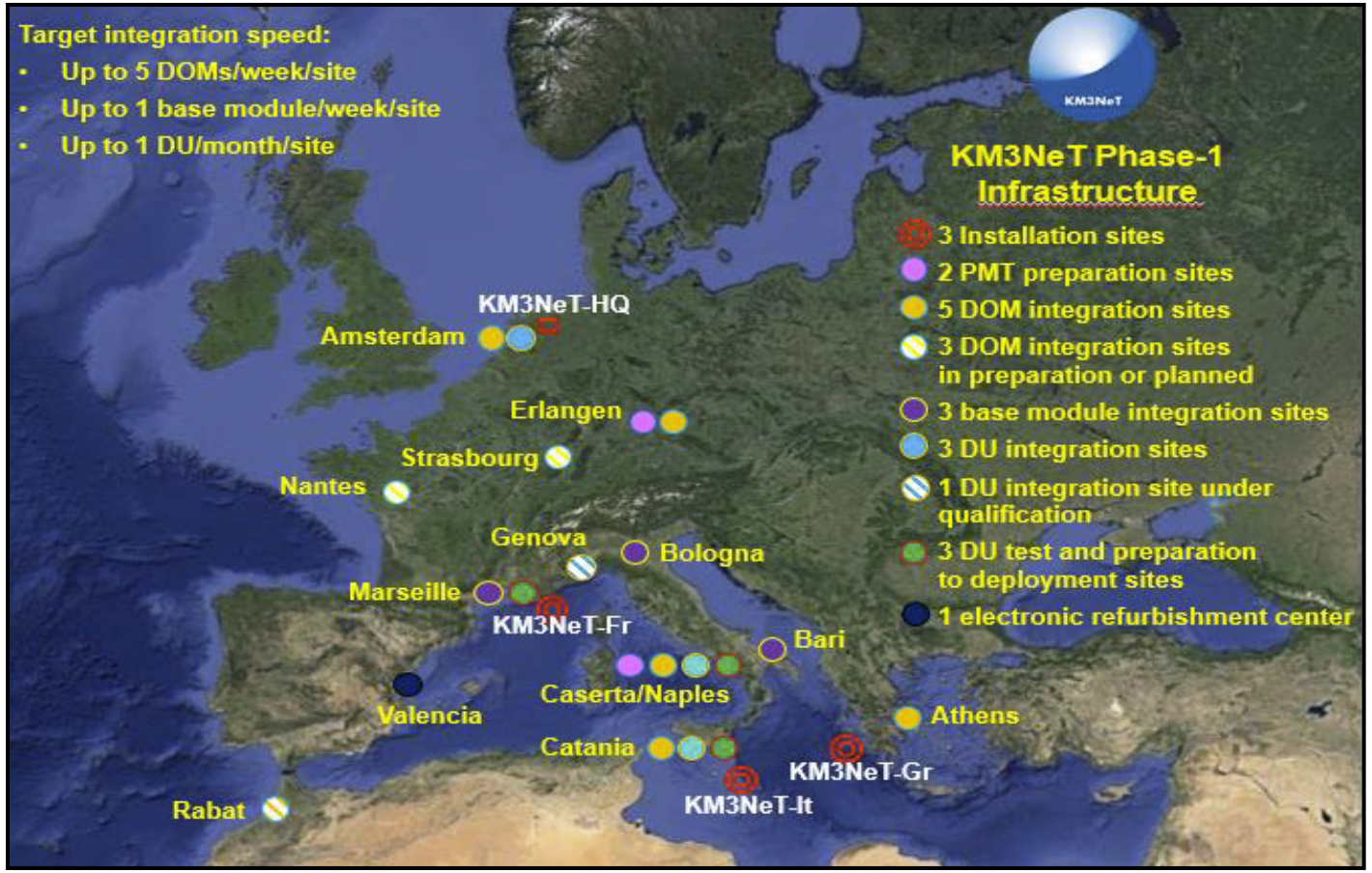


Estimated effective Volume



KM3NeT Infrastructure

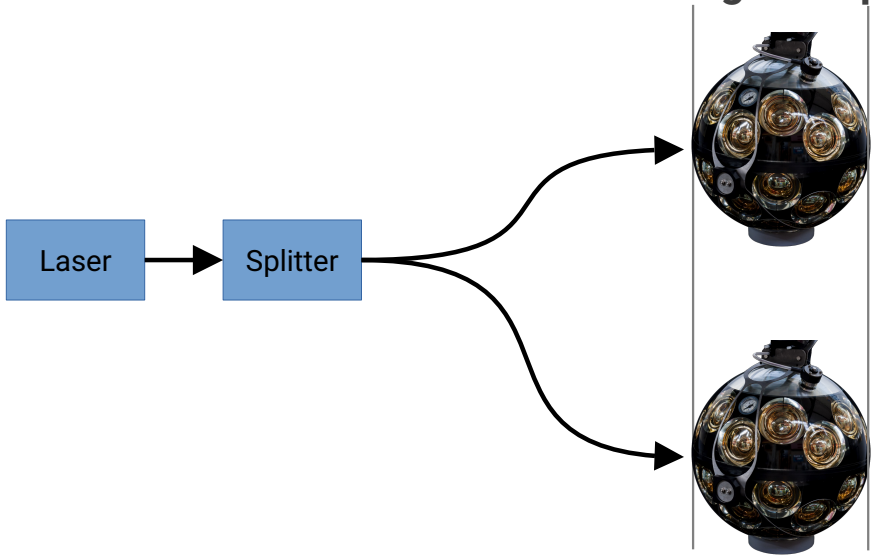
Infrastructure and production sites



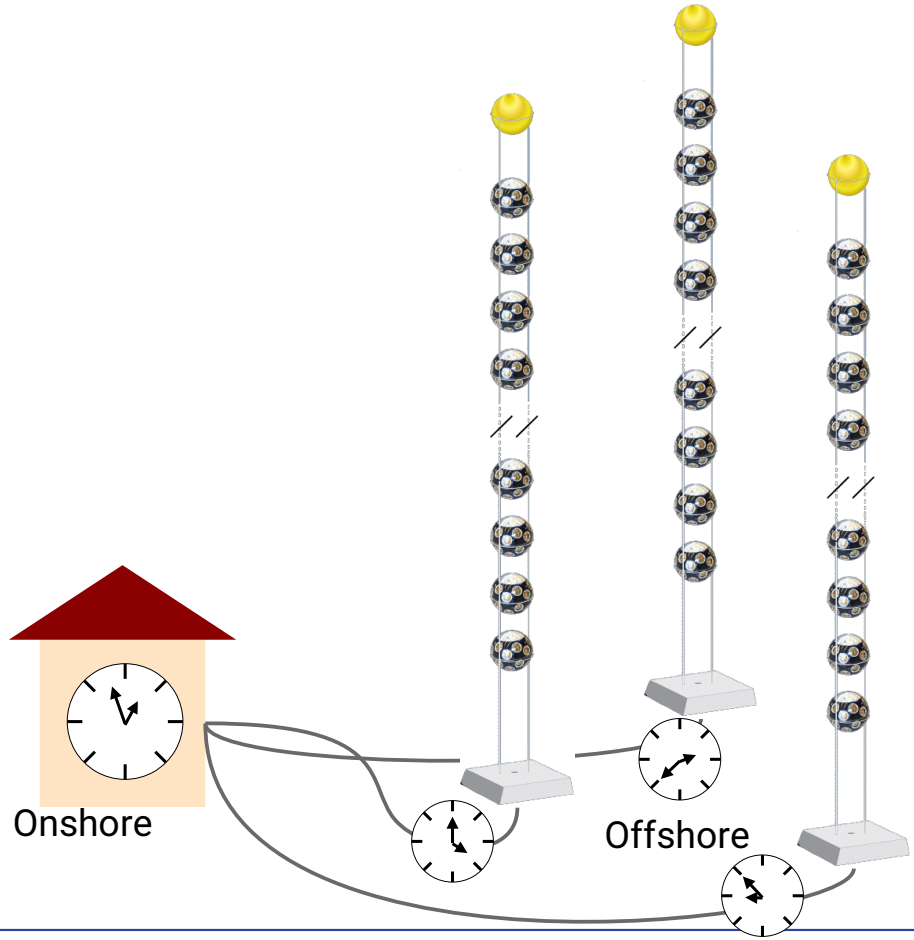
KM3NeT/ORCA time calibration

Inter PMT calibration → Insitu using Potassium 40

Inter DOM calibration → On-shore using laser pulses

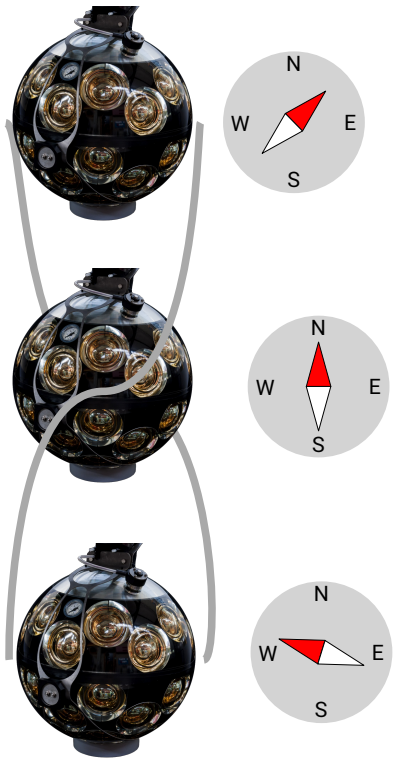


Inter string calibration →Synchronisation with network master clock

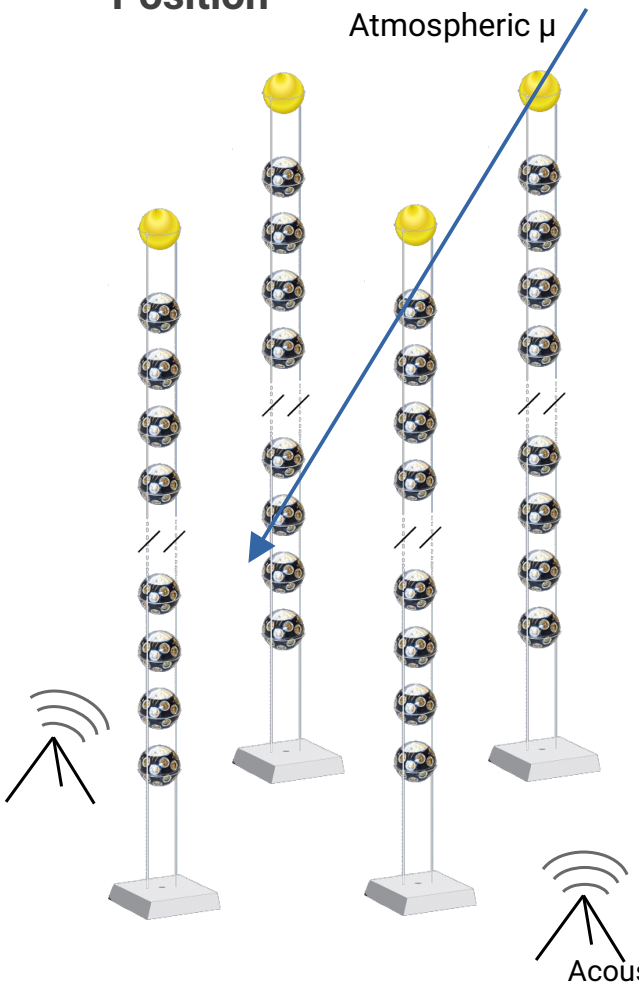


KM3NeT/ORCA position calibration

Orientation

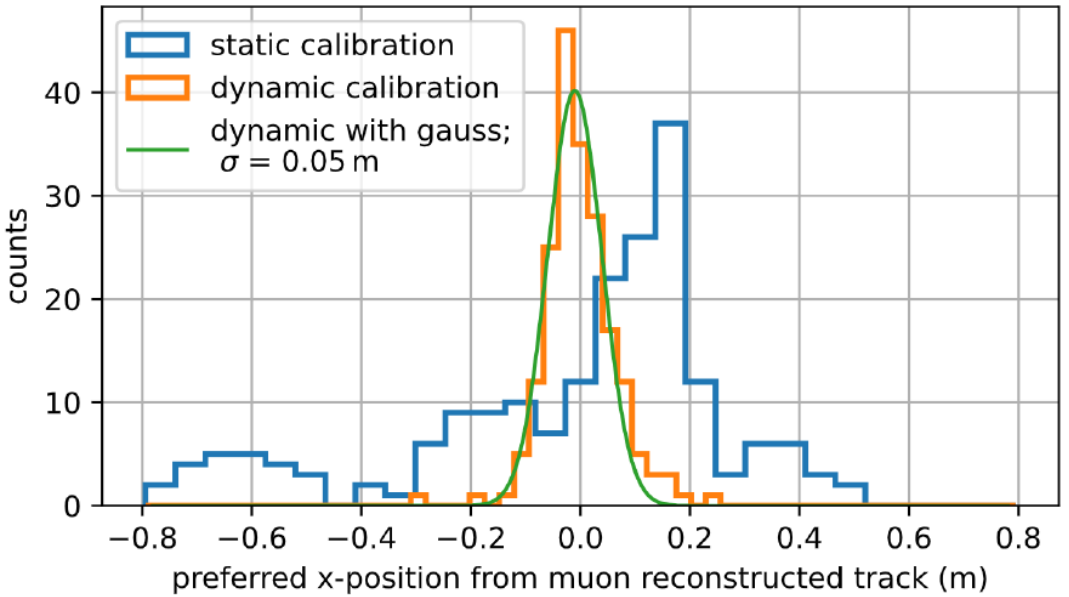


Position



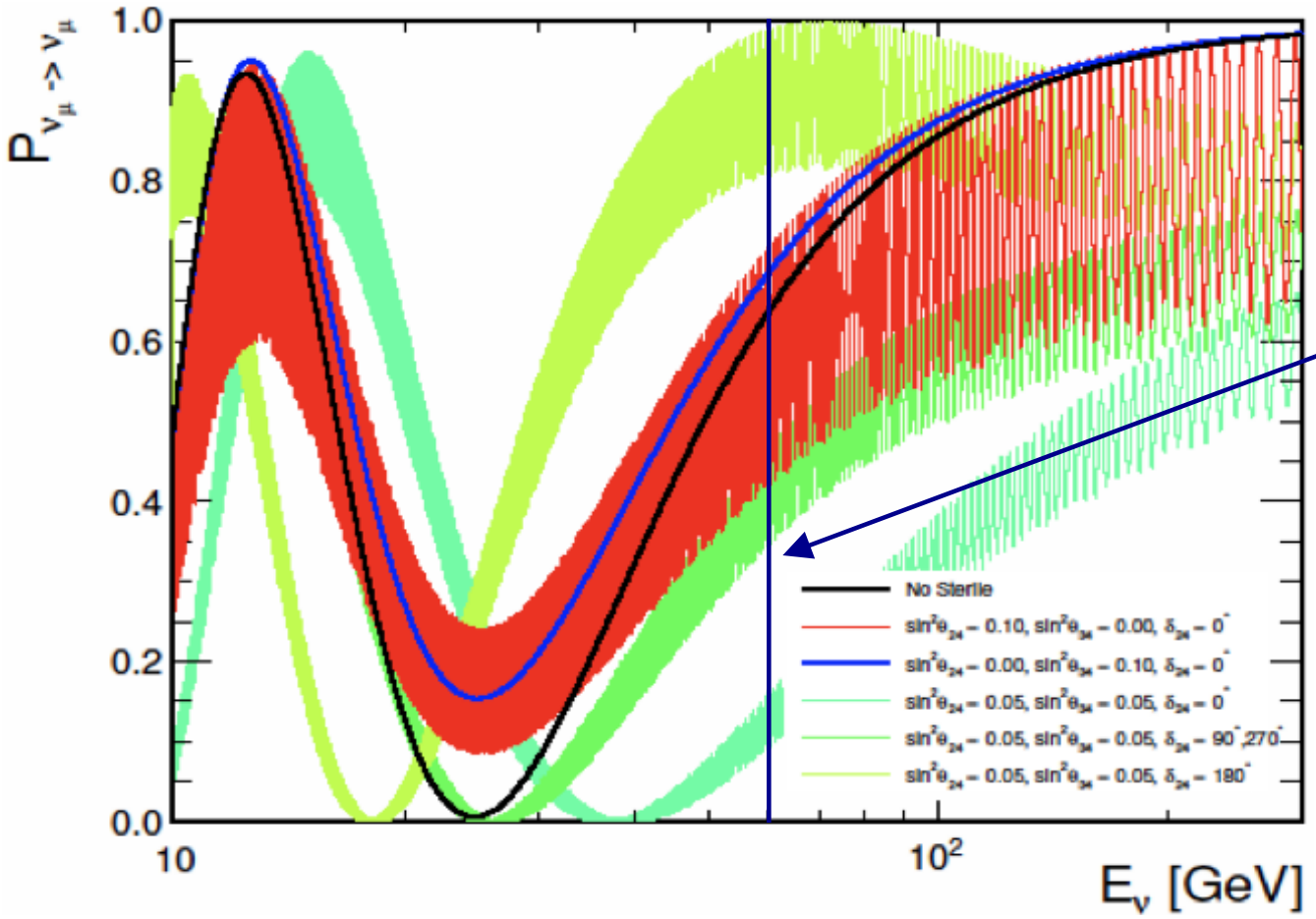
Calibration result:

- Calibrate with a acoustic calibration and check muon reconstruction time residuals



Sterile oscillation pattern

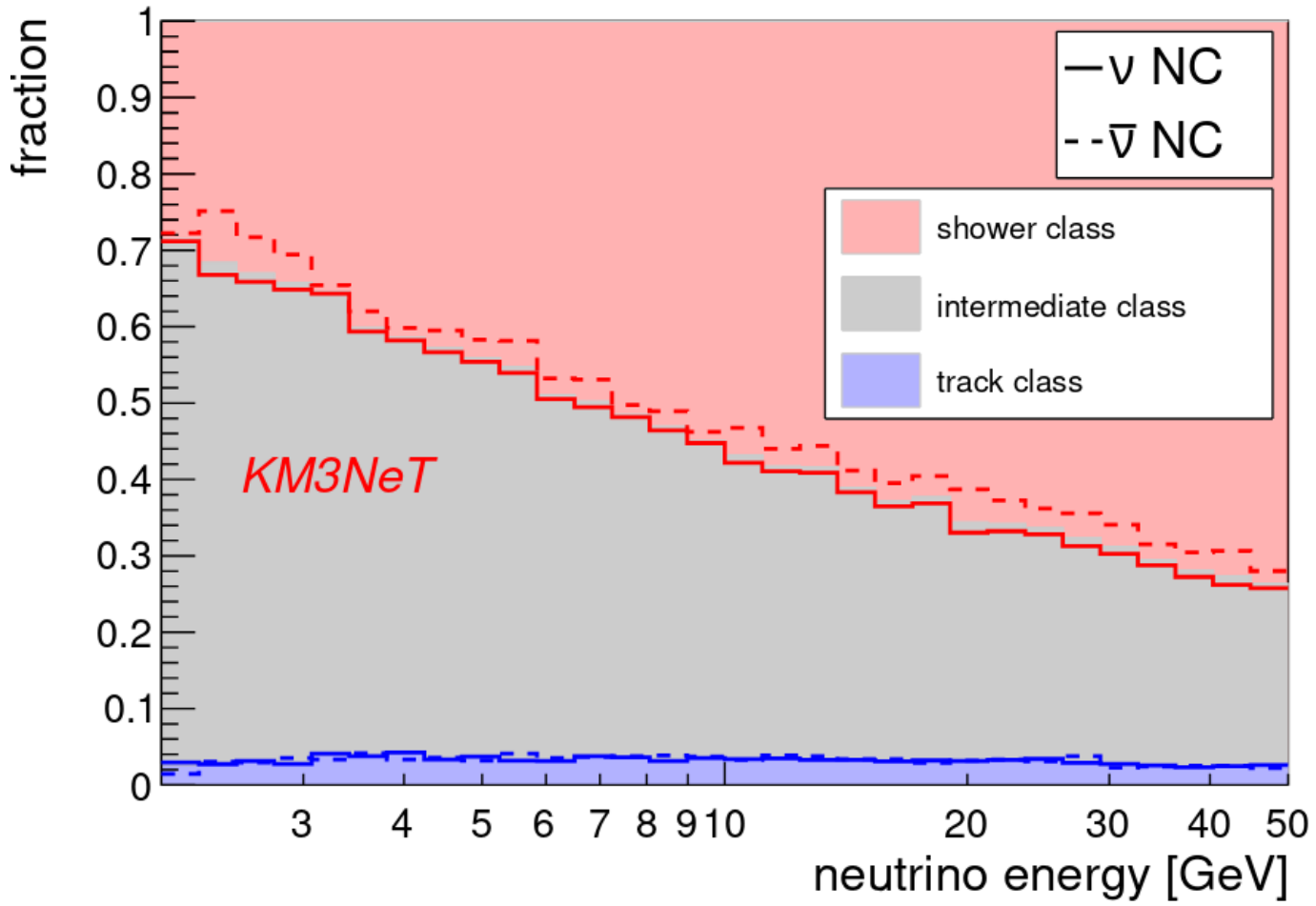
Oscillation probability P(μ→μ):



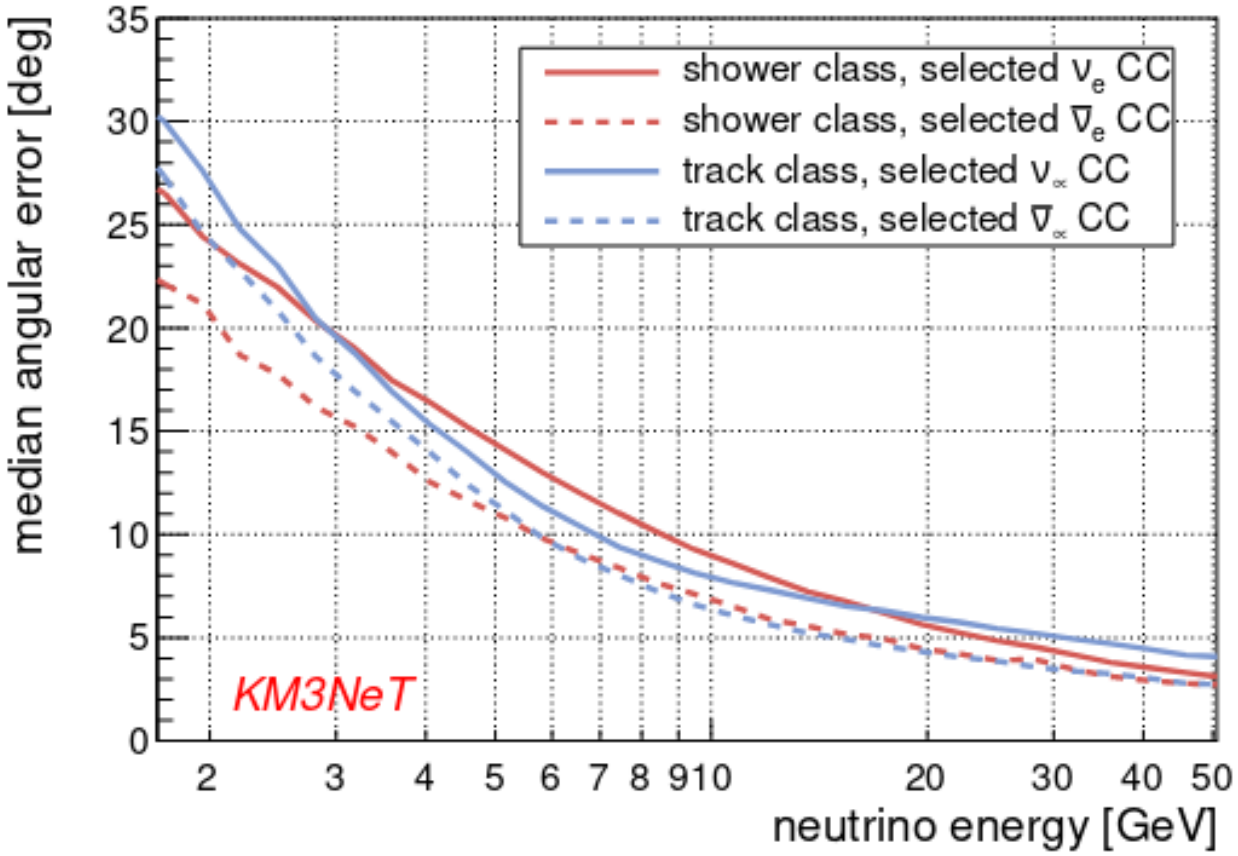
ANTARES Sensitivity:

- IceCube dataset only up to ~60GeV while ANTARES dataset contains up to over 100 GeV
- ANATRES sensitivity decreases if dataset is limited to the IceCube used energy range

NC Particle Identification

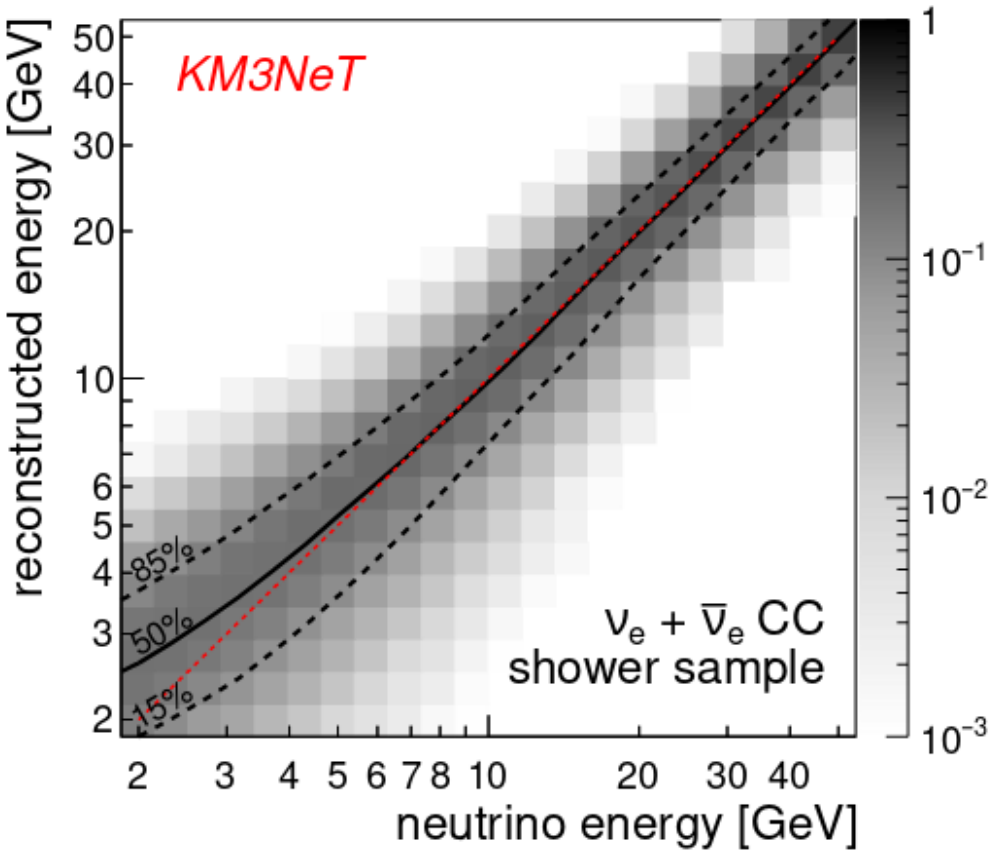


Direction Reconstruction



Energy Reconstruction

Shower:



Track: