Atmospheric neutrino oscillation studies with KM3NeT/ORCA

Valentin Pestel,
On behalf of the KM3NeT Collaboration
ICHEP 2022, Bologna, Italy
09/07/2022

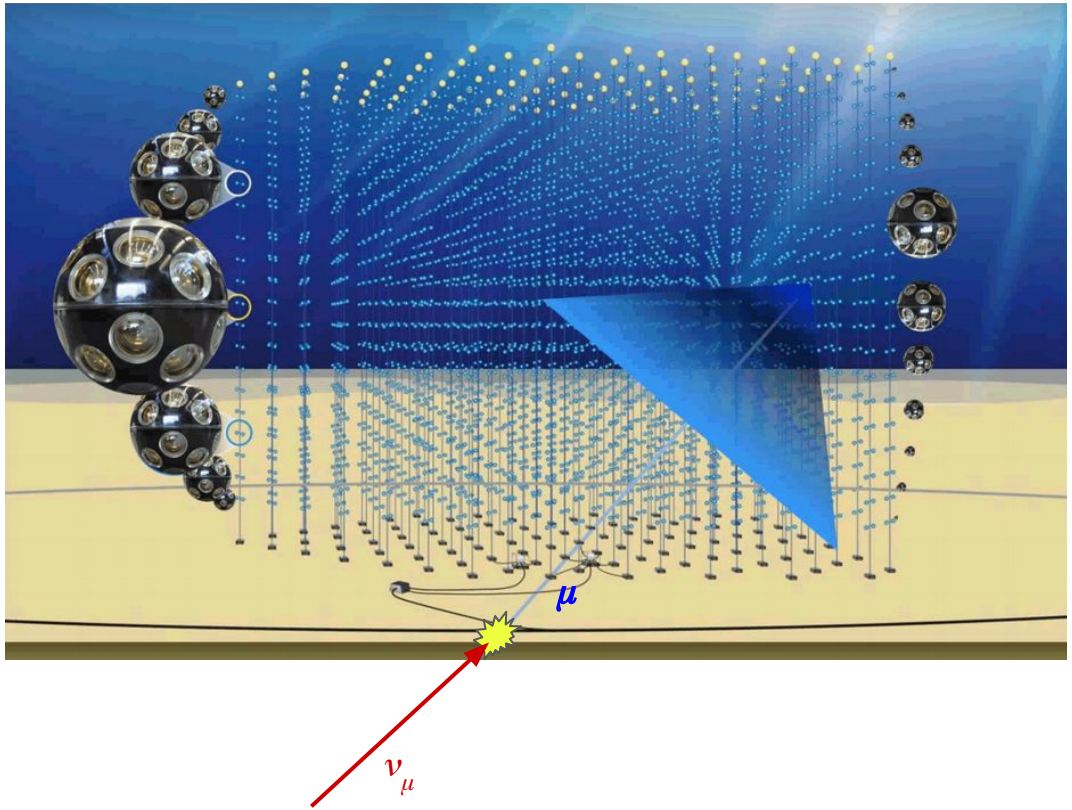
KM3NeT principle

Use large sea water volume as detection volume

- Neutrino interaction produces charged secondary(ies), inducing Cherenkov radiation

Need for a (very) large array of photosensors

- Story started in Mediterranean Sea with ANTARES, in operation with 0.1km^3 from 2008 to 2022



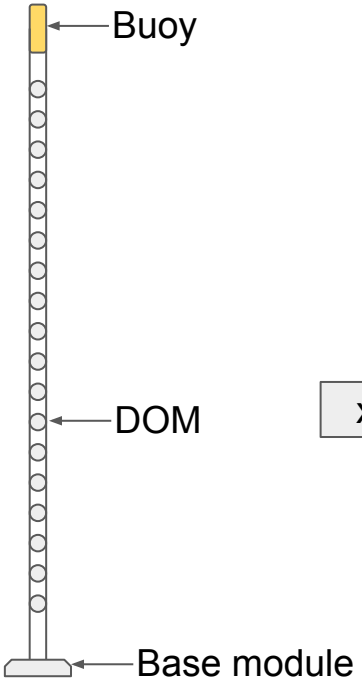
KM3NeT technology

Digital Optical Module (DOM)

- 31x3” PMTs
- ns timing
- ~10cm spatial positioning

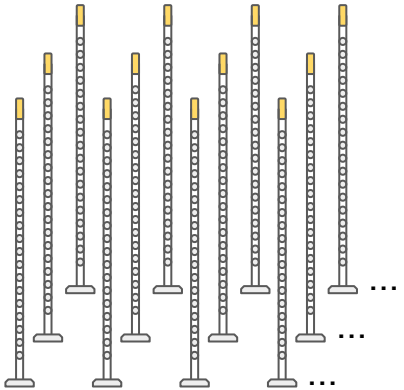
x18

Detection Unit (DU)



x115

Building Block (BB)



KM3NeT detectors

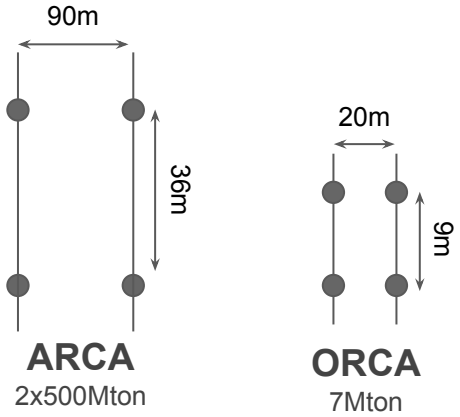
1 collaboration, 1 technology , 2 detectors

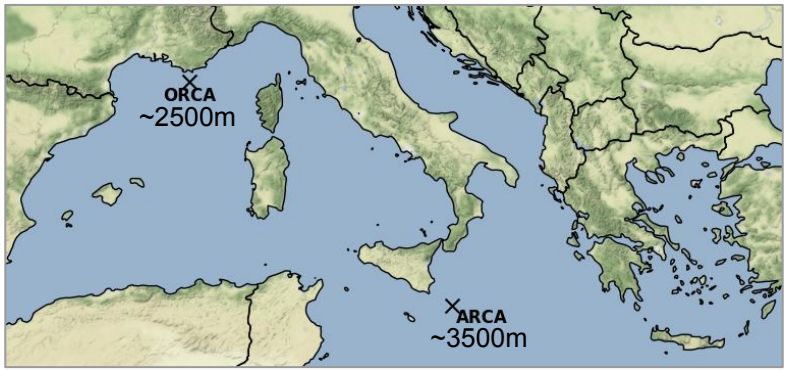
ARCA (2xBB, 128340 PMTs)**:**

- Large array, optimized for [1TeV:10PeV]
- Neutrino astronomy
  - ➢ Point source observation, diffuse flux

ORCA (1xBB, 64170 PMTs)**:**

- Dense array optimized for [1GeV:100GeV]
- Atmospheric neutrino oscillation
- GeV neutrino astronomy

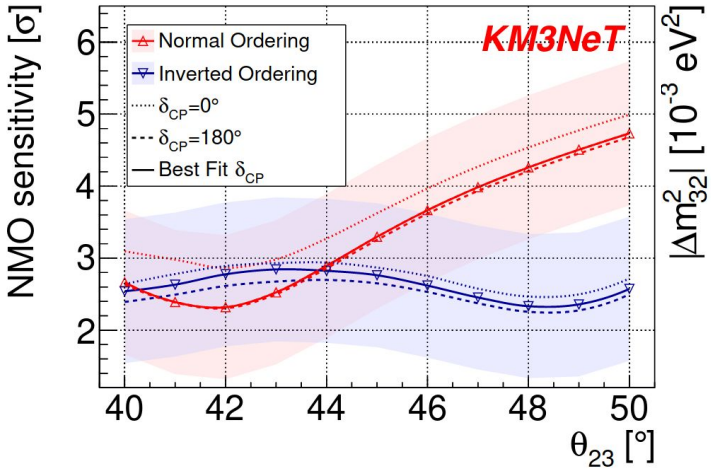


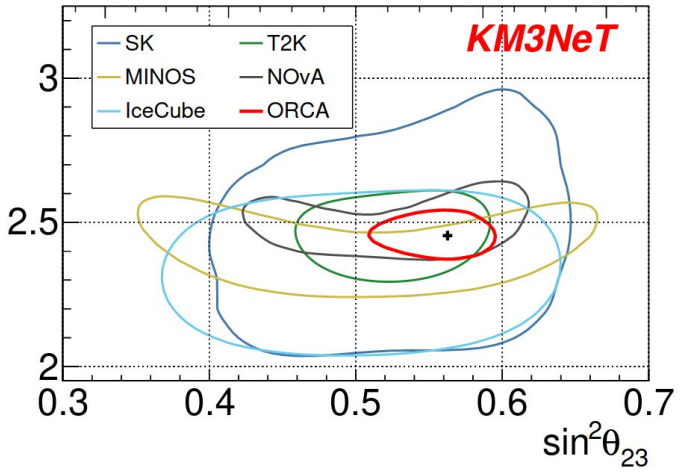


ORCA expected sensitivity

Competitive sensitivity to Δm^2_{32}, θ_{23} and Neutrino Mass Ordering (NMO)

- Reliable low energy neutrinos detection (<10 GeV) and track-cascade separation capability
- Also sensitive to PMNS matrix unitarity, sterile neutrinos, low energy astrophysical neutrinos, neutrino earth-tomography studies ...





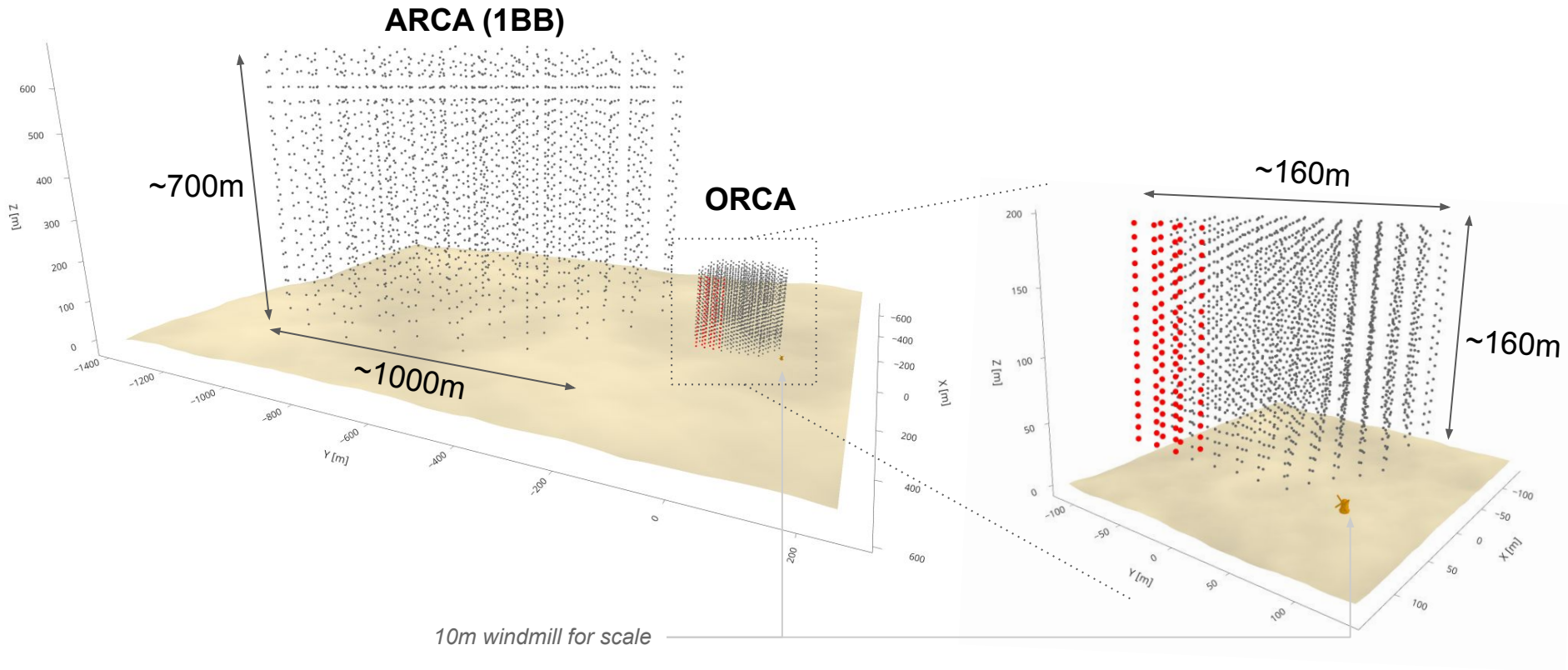
Expected results for 3 years exposure, full detector.

"Determining the Neutrino Mass Ordering and Oscillation Parameters with KM3NeT/ORCA", 2022
doi.org/10.1140/epjc/s10052-021-09893-0

"Combined sensitivity of JUNO and KM3NeT/ORCA to the neutrino mass ordering" arXiv:2108.06293

Also relevant for probing BSM physics models.
See next talk by V. Carretero **"Searches for neutrino physics beyond the standard model with KM3NeT/ORCA6"**

ARCA/ORCA Detector size



KM3NeT/ORCA6 configuration

Stable data-taking since mid 2019

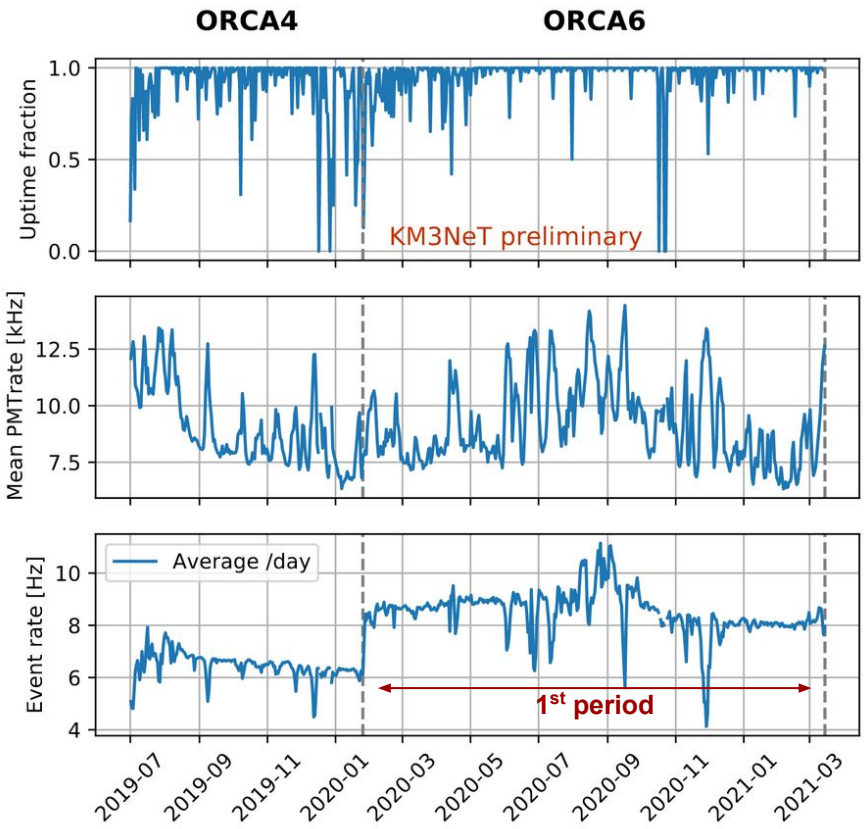
- 4 DUs, then 6DUs in January 2020
- Efficient data taking
  - ~91% in 2019
  - ~99% in 2021

Very efficient trigger algorithm

- Good event rate stability
- Resilient against background fluctuations
  - Uses coincidences between PMTs and DOMs

This contribution focus on ORCA6 1st period

- 96% uptime, 92% passing run selection
- 354.6 days exposure after selection

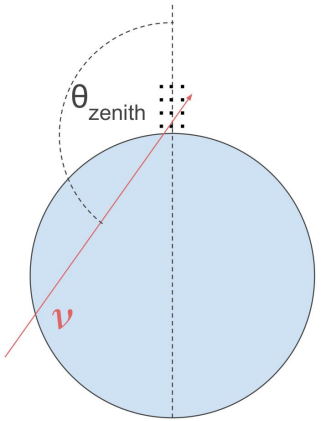


Look into the data : ORCA6

Everything reconstructed as a track

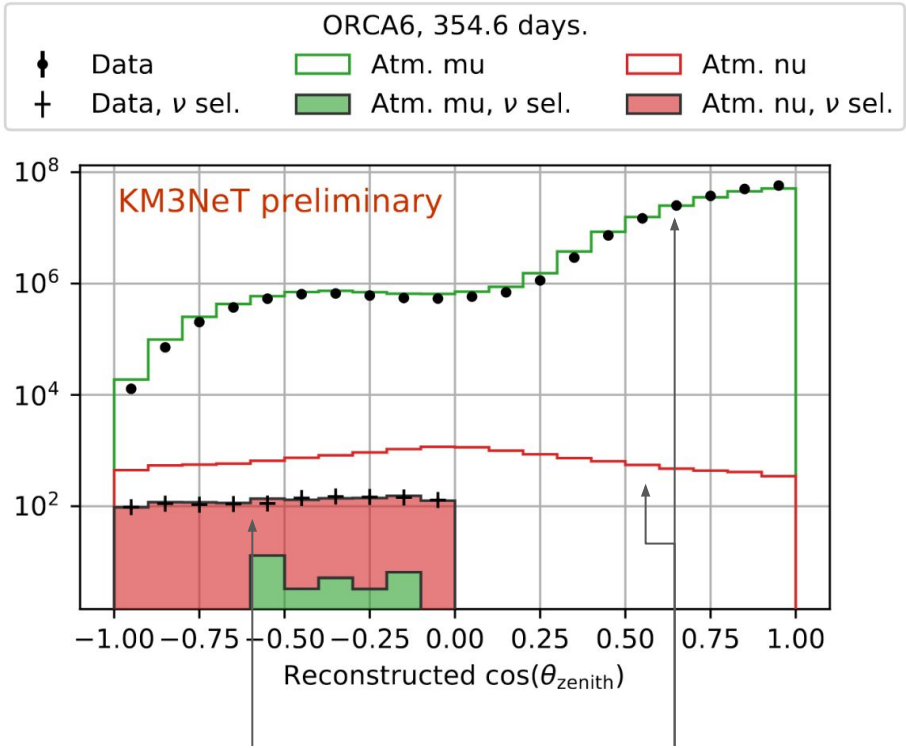
- (Atm)muons MC produced with MUPAGE
  - Flux verified against HEMAS full CR-shower simulation
- Neutrino MC produced with gSeaGen
  - KM3NeT-GENIE code
  - NuFit 5.0 N.O.

Atmospheric muons are the main background



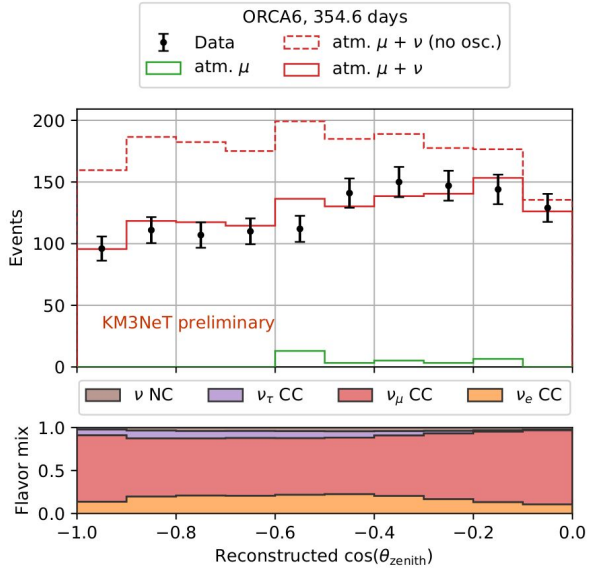
Neutrino selection

- Only up-going events
- Reconstruction quality
- Track start point contained in 60m radius
  - Detection mass of about ~1.5Mton



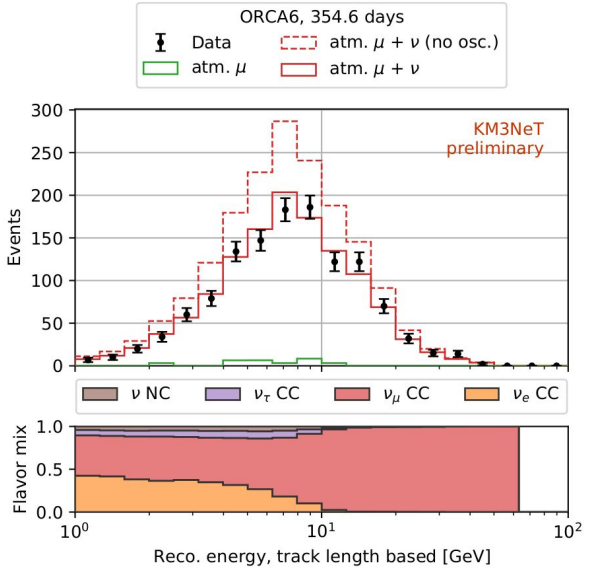
Zenith angle distribution

1237 neutrino candidates in 354.6 days, only few muons expected, S/B ~ 40, signal dominated by ν_μ



cos(θ) directly linked to neutrino path L

Larger oscillations effect for small cos(θ)



Energy based on reconstructed track length, limited by detector size

Neutrino oscillation pattern

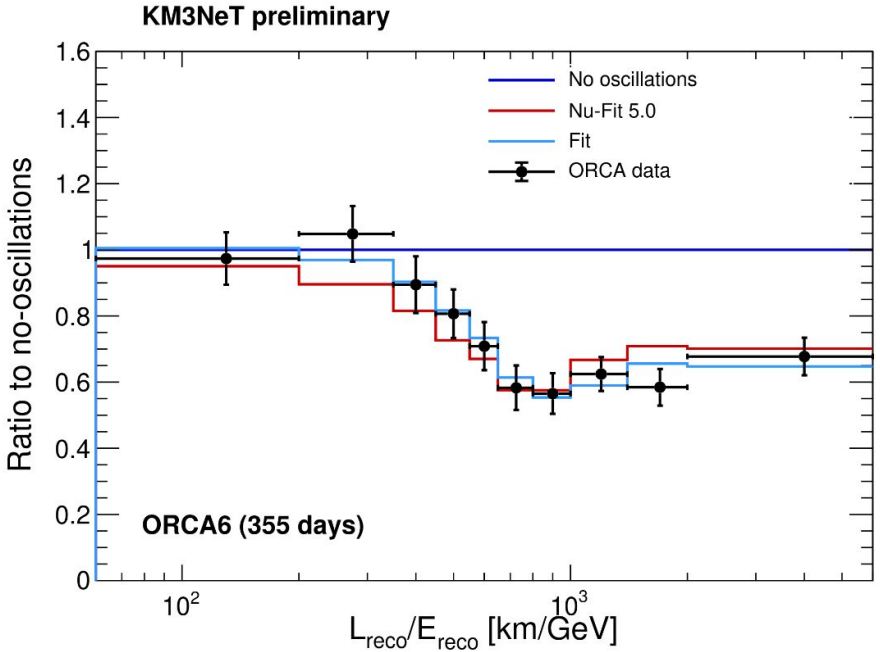
Very clear oscillation pattern

- HKKM14 atmospheric flux model
- NuFit 5.0 assuming normal ordering
- Fit performed on 2D binned dataset
  - Energy vs zenith angle

Systematics included in the fit

- Flux
- Cross-section
- Overall normalization
- Detector systematics

Strong oscillation signal, with only 6 DU



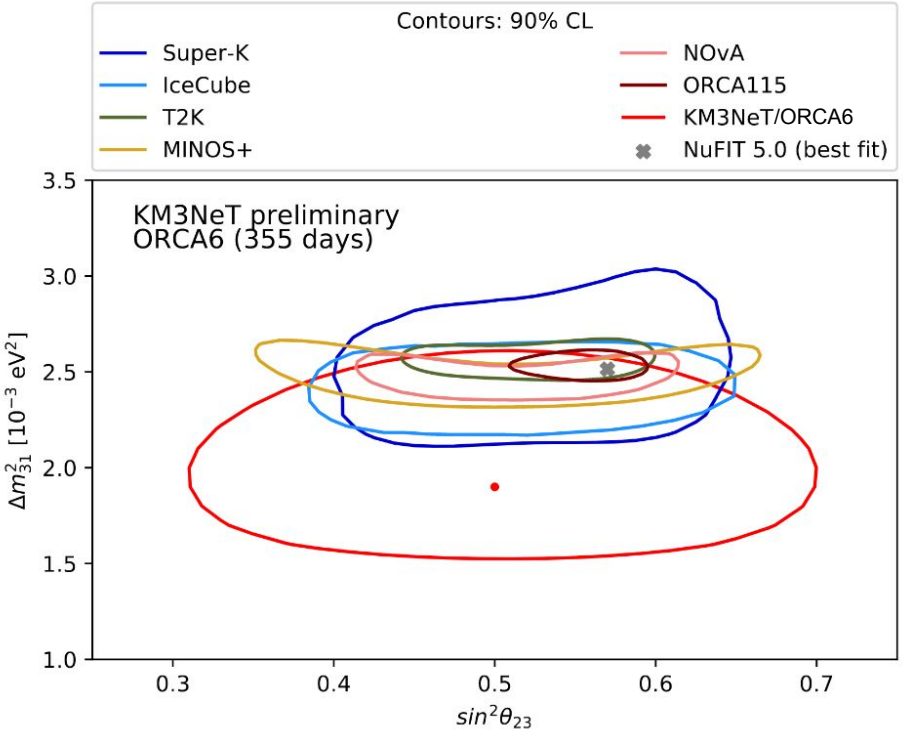
Sensitivity to neutrino oscillations

Data has a preference to oscillation of 5.9σ

- NuFit 5.0 best fit within 90% C.L.
- Outperform ANTARES oscillation results, based on 10 years https://doi.org/10.1007/JHEP06(2019)113
- ORCA6 in shape to be competitive with other experiments

Lot of improvement foreseen for ORCA115

- Dedicated shower channel, PID
- 30% energy resolution

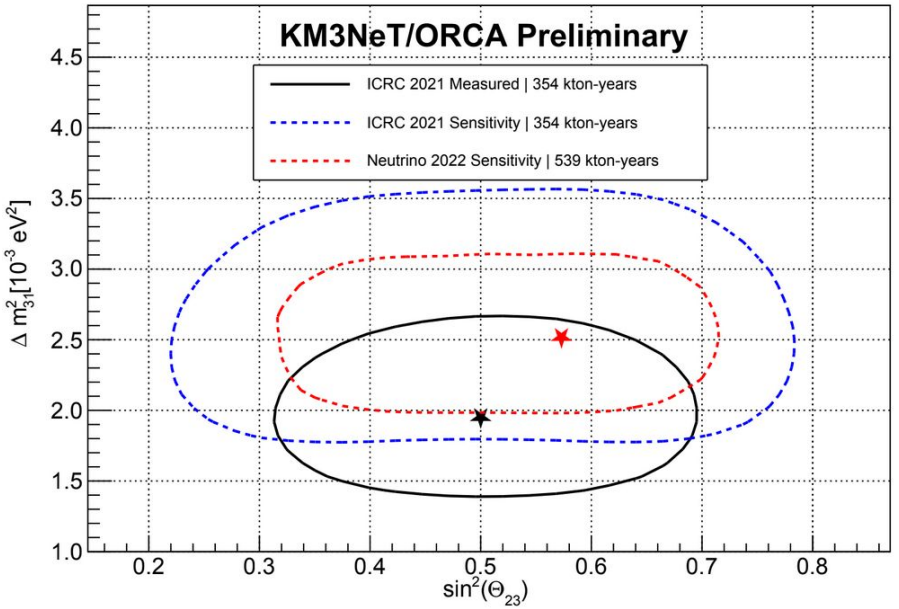


Short term improvement

Definitive ORCA6 analysis on-going:

- Larger dataset (+50%)
- Introduction of shower reconstruction
- Shower/Track PID
- Improved fitting methodology

Major sensitivity improvement



Summary

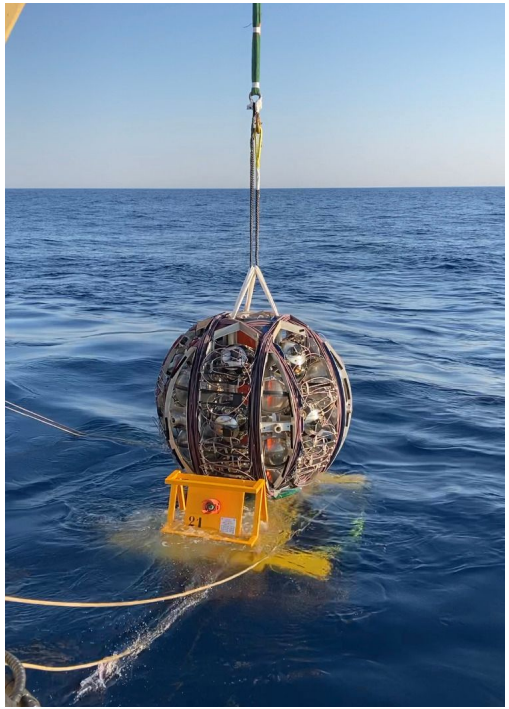
ORCA6 first neutrino oscillations analysis

- ORCA ready for oscillation physics !
- Oscillation favored at 5.9σ with only 5% of photosensors
- Limited by statistic and energy resolution
  - Will improve with the detector growing
  - Track/shower discrimination to be included soon
- Improved result to be released in the coming months

KM3NeT ORCA and ARCA DU mass production underway

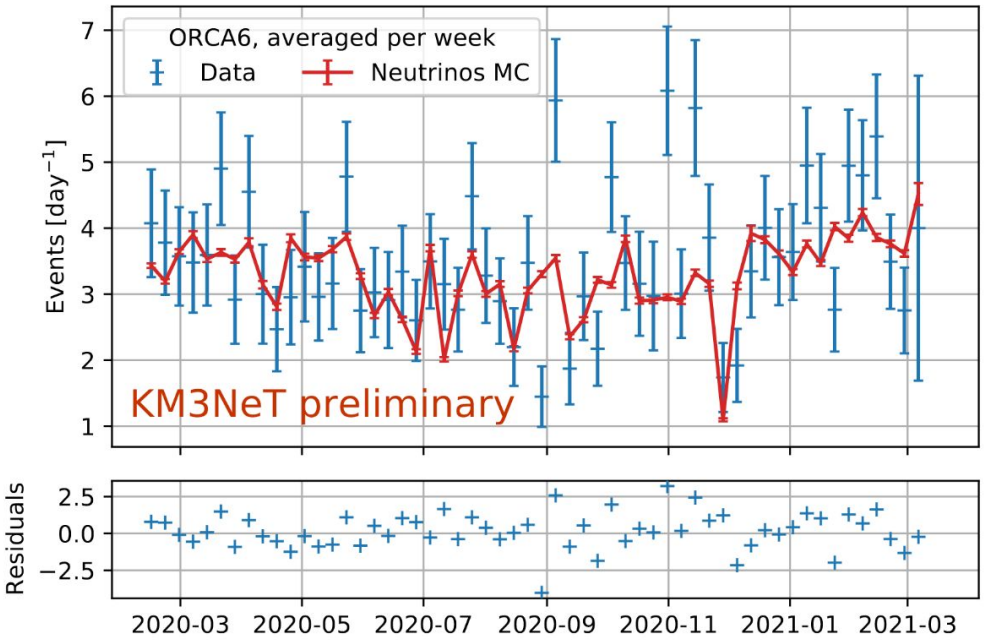
- Detectors will grow at an accelerated pace
- Next deployments to come this year

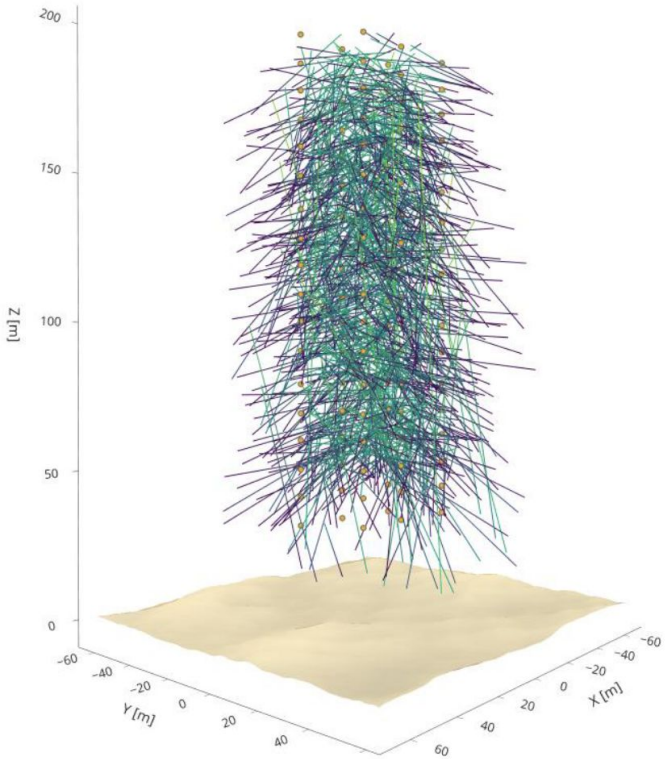
Thank you !



DU being deployed, last ARCA deployment, 13/06/2022

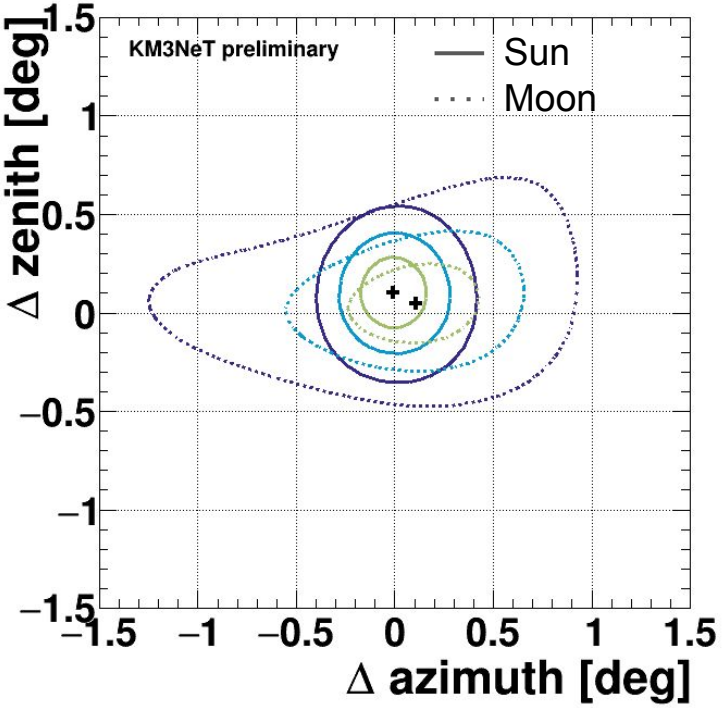
Selection rate and time stability

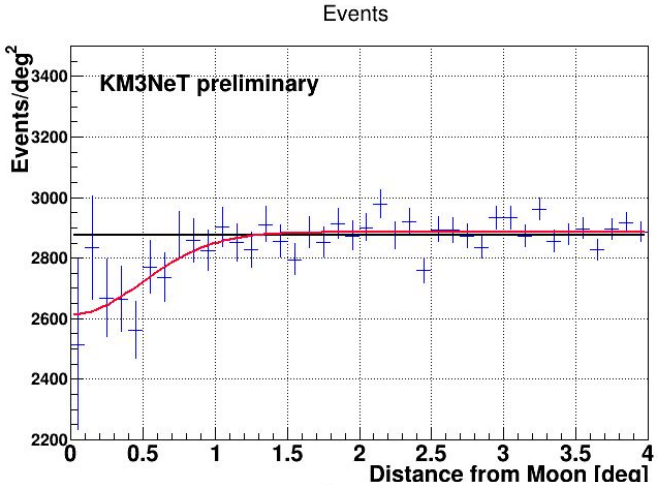


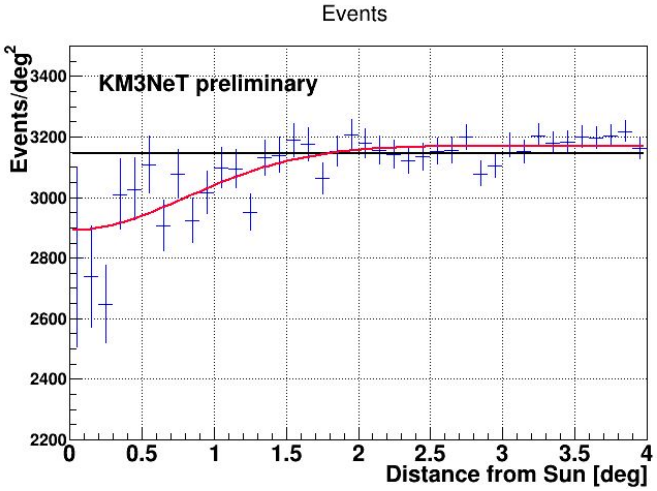


Neutrino candidates in ORCA6 analysis

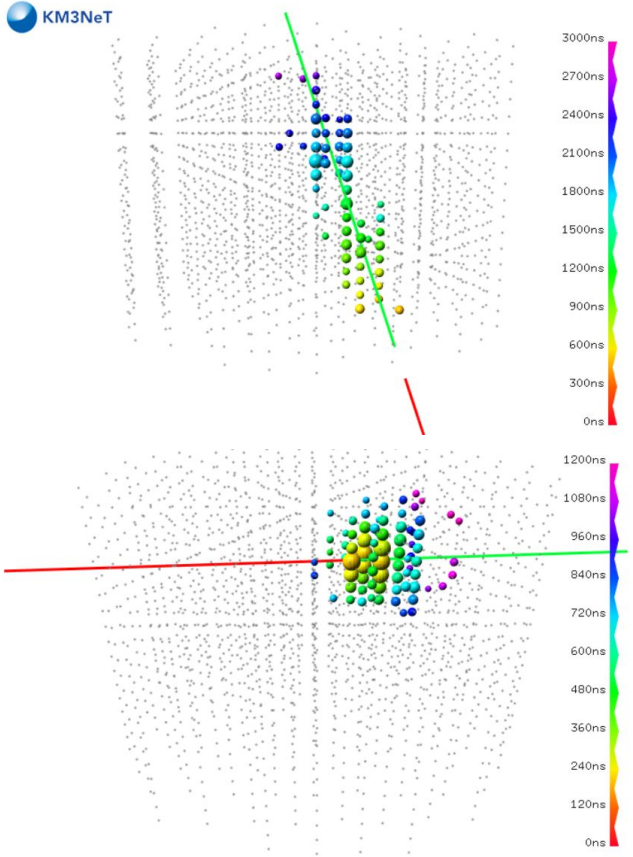
Track reco performance: Sun and moon shadow analysis

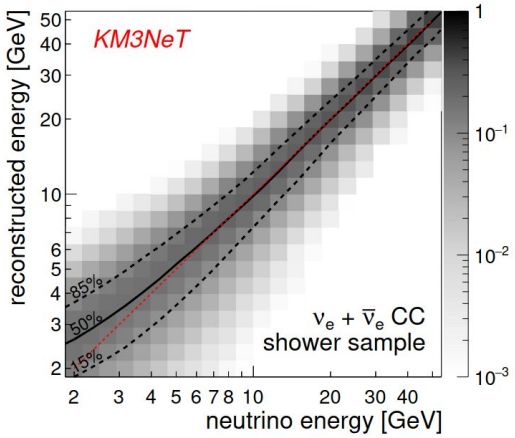


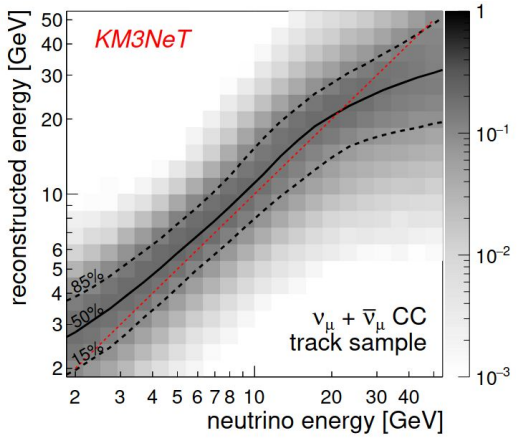




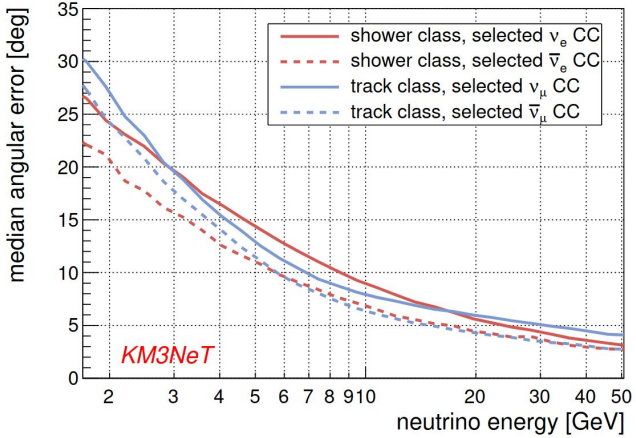
Track & shower topologies (full detector)



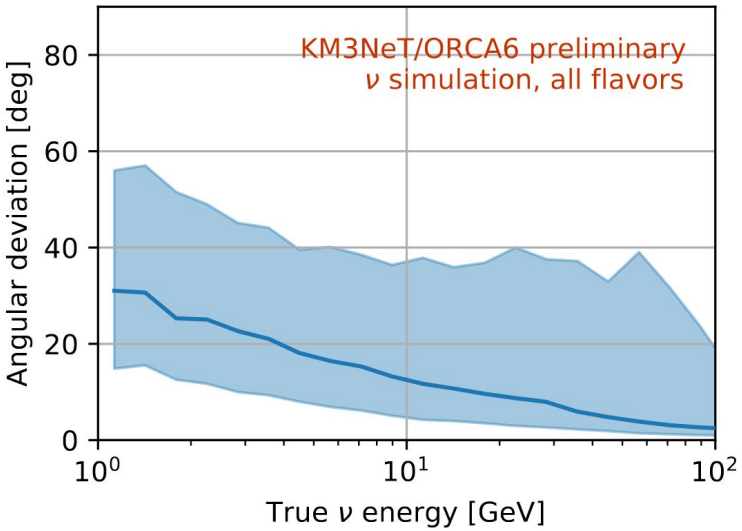


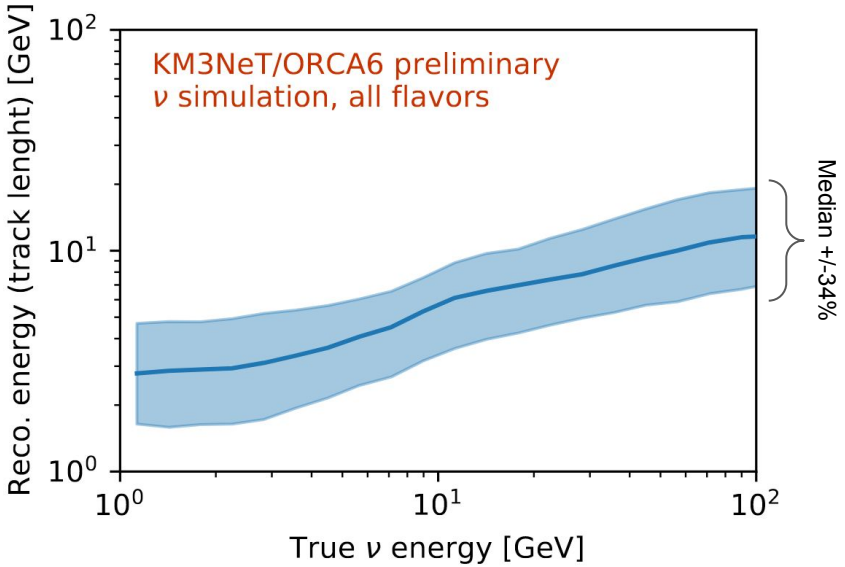


arXiv:2108.06293



Resolution ORCA6





Angular and (especially) energy resolution limited by the small detector size and mixed track/shower topologies. Will greatly improve in the future.

ORCA6

Neutrino fit systematics uncertainties

Parameter	Treatment	Fit value
Δm^2_{31} [10^{-3} eV^2]	Free	$1.95^{+0.24}_{-0.21}$
θ_{23} [deg]	Free	$45.4^{+5.6}_{-5.7}$
Norm	Free	$0.88^{+0.03}_{-0.11}$
Flux: spectral index	$\mathcal{N}(0, 0.3)$	$0.052^{+0.053}_{-0.010}$
Flux: zenith angle bias	$\mathcal{N}(0, 0.07)$	$0.035^{+0.059}_{-0.060}$
Skew $\mu\overline{\mu}$	$\mathcal{N}(0, 0.1)$	$0.00^{+0.10}_{-0.10}$
Skew $e/\overline{e}$	$\mathcal{N}(0, 0.1)$	$0.00^{+0.10}_{-0.10}$
Skew μe	$\mathcal{N}(0, 0.03)$	$0.00^{+0.03}_{-0.03}$
NC normalization	$\mathcal{N}(1, 0.1)$	$0.99^{+0.10}_{-0.10}$
τ normalization	$\mathcal{N}(1, 0.2)$	$0.97^{+0.20}_{-0.20}$
Energy scale	$\mathcal{N}(0, 0.1)$	$0.00^{+0.03}_{-0.01}$