

KM3NeT status and outlook

and some recent ORCA neutrino oscillations results

Paul de Jong
Nikhef and University of Amsterdam
on behalf of the KM3NeT Collaboration

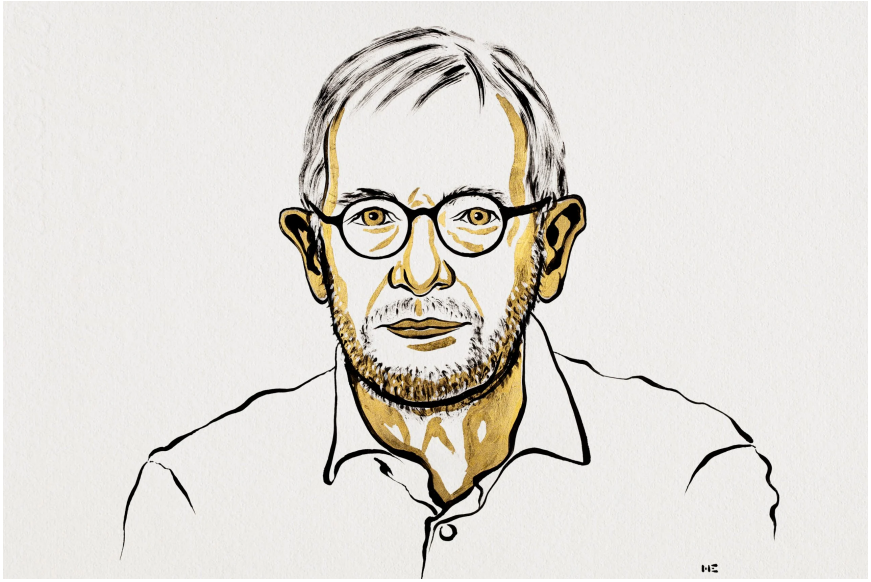

junction box


cable termination frame 3



From the Mediterranean Sea to the South Pole:





Congratulations, Francis Halzen!

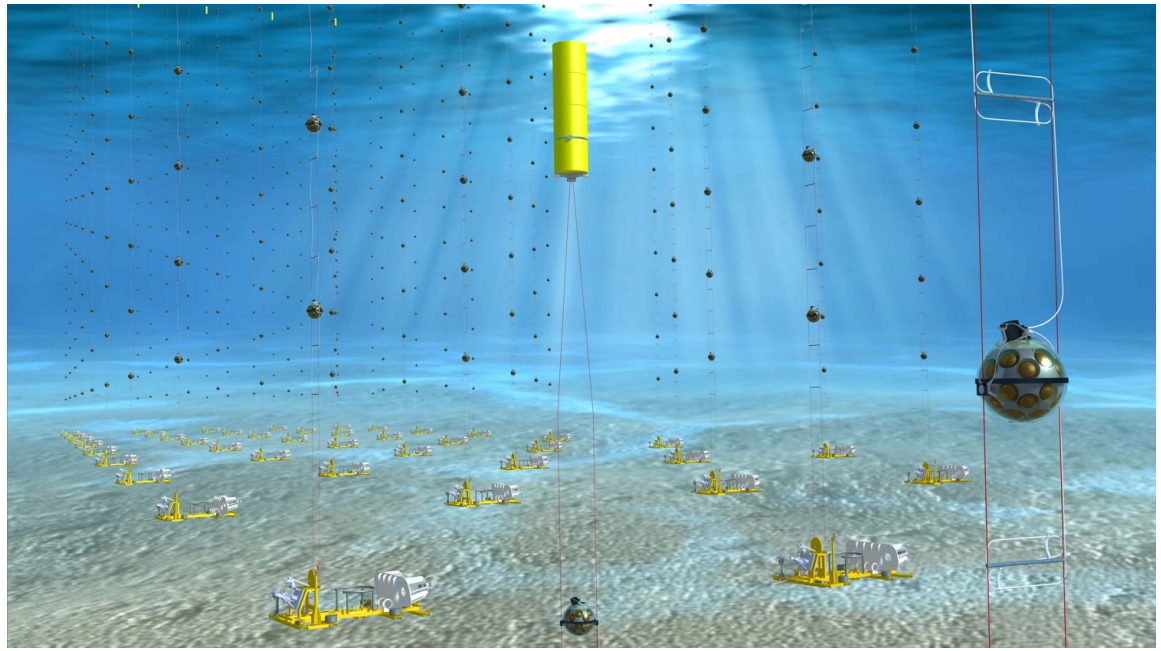
The Nobel Prize in Physics 2026 was awarded to Francis Halzen "for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin."

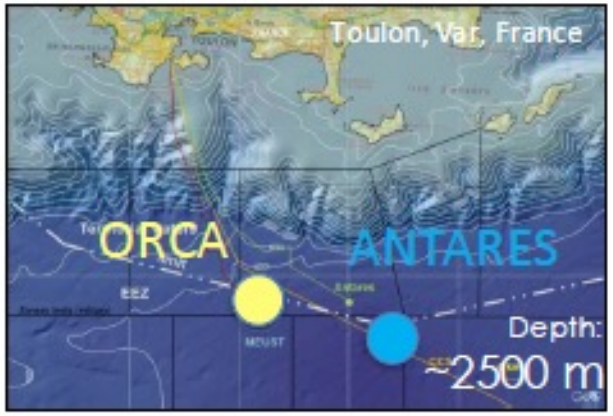
KM3NeT also congratulates the IceCube Collaboration, and looks forward to a further exploration of the neutrino sky in a global partnership.

KM3NeT: research infrastructure in the Mediterranean Sea

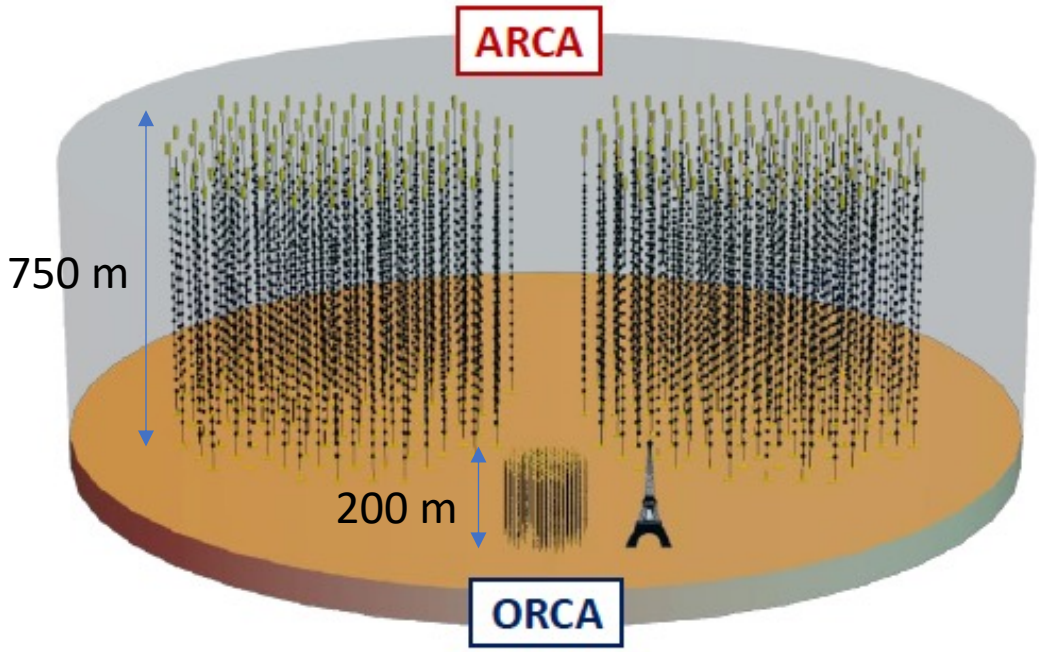
km³ Neutrino Telescope

Two neutrino telescopes + portal for earth/sea sciences and marine biology









ORCA: 108 detection units, dense spacing (20m between lines), 6.5 Mton fiducial mass

ARCA: 198 detection units, sparse layout (90m between lines), 1 Gton (1 km³)

Detector layout: common technology





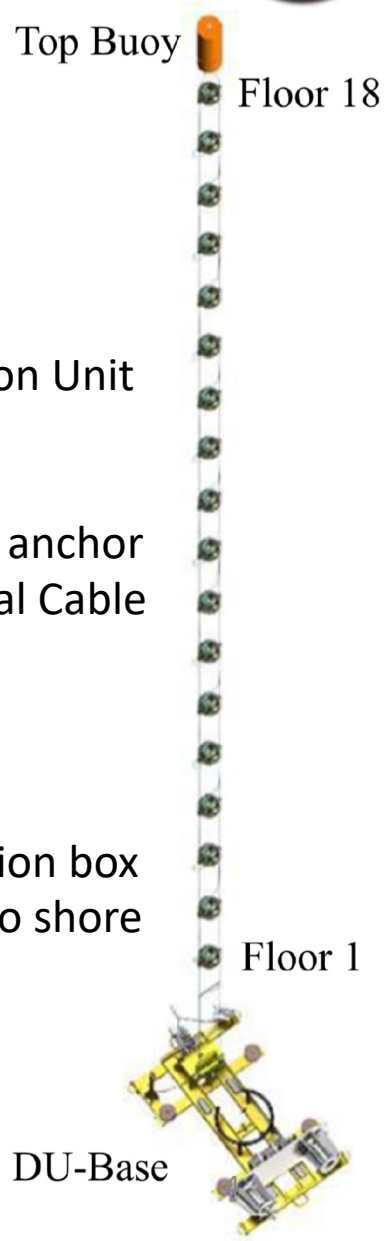
Digital Optical Module
JINST 17 (2022) P07038

31 PMTs per DOM

18 DOMs per Detection Unit

connected to base module on anchor
via Vertical Electro-Optical Cable

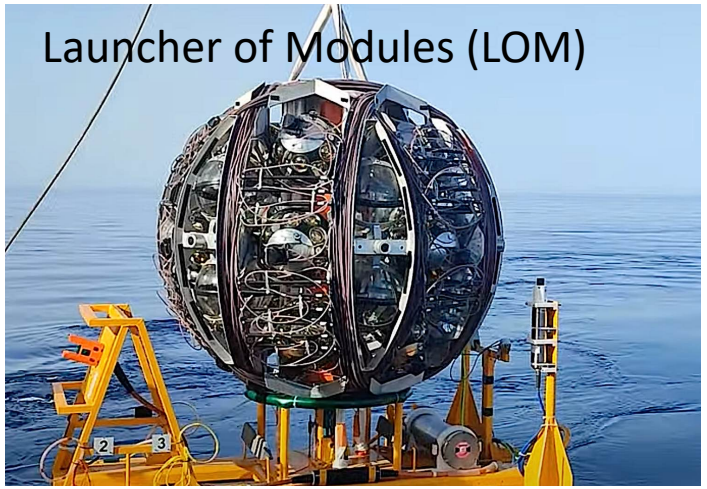
base module connected to junction box
junction box connected to cable to shore



Hamamatsu R14374-02 3-inch PMT
Dark count rate ~ 500 c.p.s.
Transit time spread < 1 ns
Only few afterpulses/delayed pulses
JINST **20** (2025) P07054

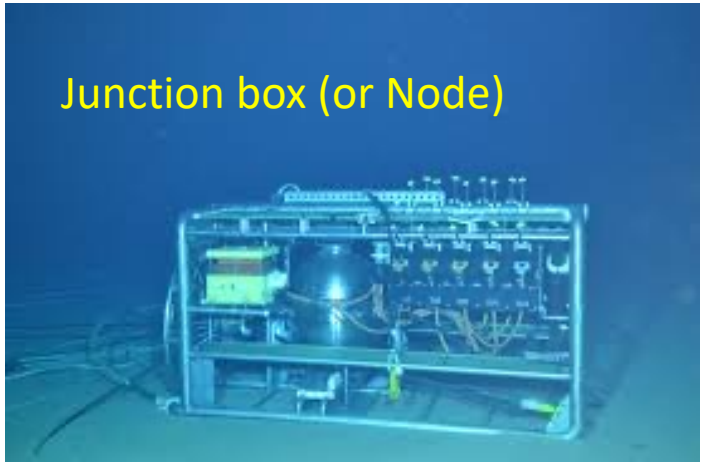
+ piezo sensor,
LED nanobeacon,
accelerometer,
compass

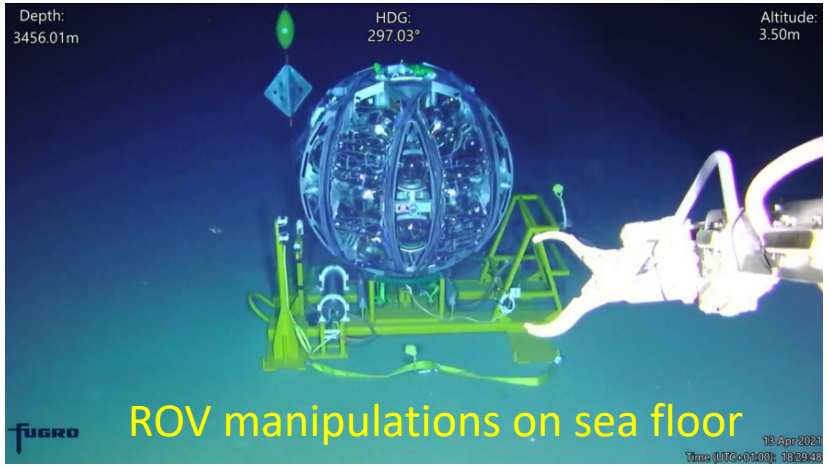
Deployment of Detection Units





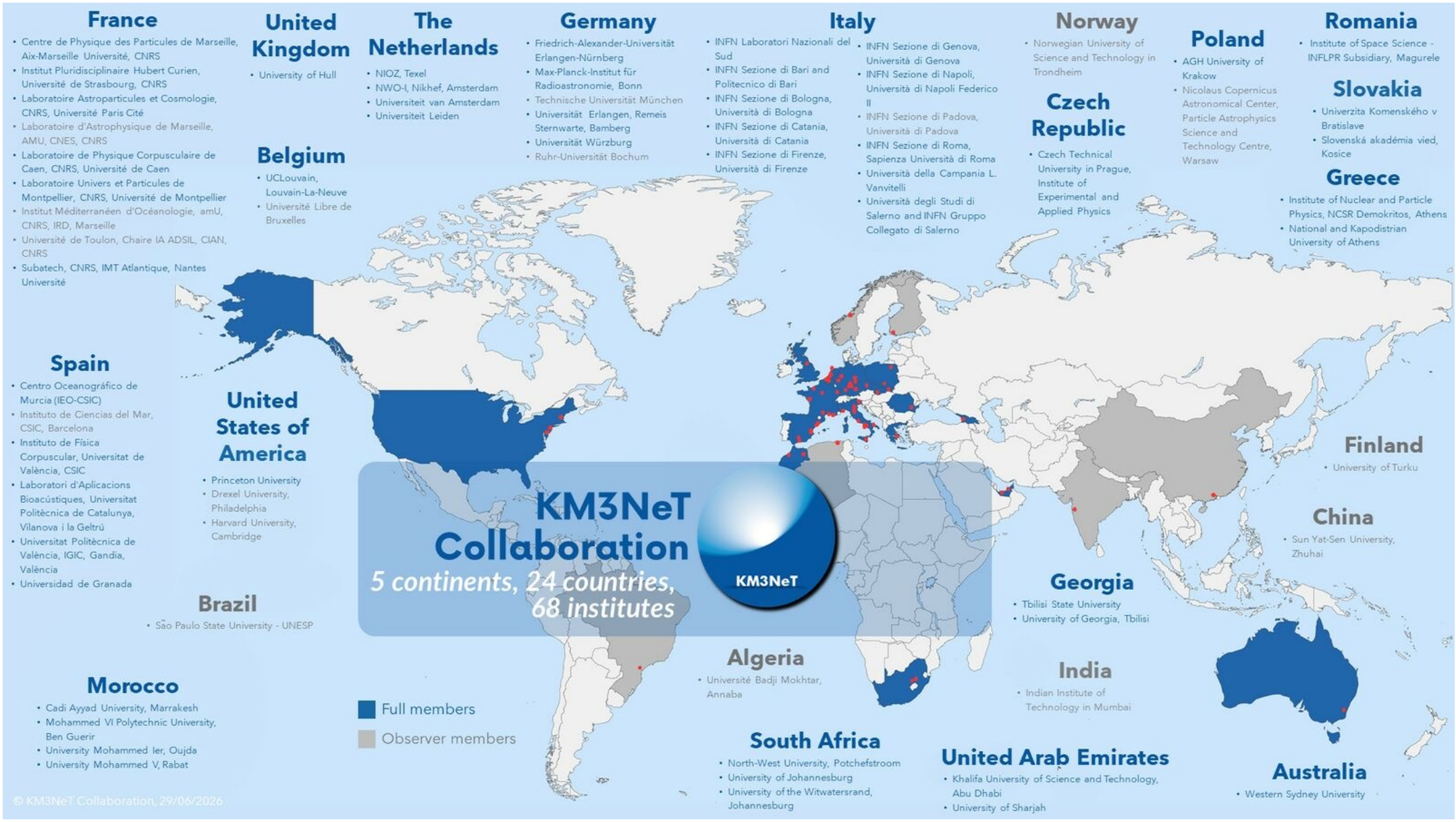






Now performed more than 100 times…

JINST 15 (2020) P11027



Since June 2026, also INAF (Italian National Institute for Astrophysics) is a member of KM3NeT.

KM3NeT integration sites and activities

A distributed European infrastructure supporting detector construction and operations.

Nikhef / Amsterdam
- Pressure tests
- Digital Optical Modules
- Detection Units

Caen
- Detection Units

Nantes
- Digital Optical Modules
- Base Modules (in preparation)

Paris
- Calibration Units

Marseille
- Base Modules
- Detection Units
- Nodes & Junction Boxes

Montpellier
- Base Modules

Valencia
- Electronics & DAQ
- Base Modules

Granada
- Electronics & DAQ

Rabat / Oujda
- Rabat: Digital Optical Modules
- Oujda: Base Modules



Strasbourg
- Digital Optical Modules

ECAP / Erlangen
- Photomultipliers
- Digital Optical Modules

Genova
- Detection Units
- Calibration Units

Bologna
- Base Modules
- Electronics & DAQ

Firenze
- Electronics & DAQ

CAPACITY Lab / Caserta
- Photomultipliers
- Digital Optical Modules
- Base Modules
- Detection Units
- Calibration Units
- European Central Storage

Salerno
- DOMs (in preparation)
- Electronics & DAQ

Bari
- Base Modules
- DUs (in preparation)

Catania / LNS
- LNS: calibration units
- LNS: electronics & DAQ
- LNS: base modules
- LNS: nodes & junction boxes
- LNS: detection units
- Catania: nodes & junction boxes
- Catania: DOMs

Athens
- Digital Optical Modules
- Pressure tests

KM3NeT is organizing for the future

From a collaboration to a long-term European Research Infrastructure: legal entity, strategic recognition, and ESFRI Landmark status.

KM3NeT
Neutrinos for a deeper understanding of the Universe

1 Legal maturity — ESTABLISHED

KM3NeT AISBL

International non-profit entity under Belgian law

Signed in Brussels: **18 June 2025**
Operational from: **January 2026**

- Provides the legal framework for construction, operation, maintenance, scientific exploitation and future decommissioning
- Identified as the most suitable legal framework for KM3NeT-Infradev2

2 European strategic priority — APPEC 2026

APPEC

Astroparticle Physics European Consortium

APPEC Roadmap 2026 (proposed wording)

"APPEC fully prioritizes the KM3NeT collaboration to complete the construction of the large-volume telescope optimized for high-energy neutrino astronomy, ARCA, and the dedicated detector to resolve the neutrino mass hierarchy, ORCA."

- Strong external validation of the scientific and societal relevance
- Clear strategic signal for long-term support

3 ESFRI Landmark — ROADMAP 2026

ESFRI Landmark

Recognized in the ESFRI Roadmap 2026

- Recognizes KM3NeT as a mature European Research Infrastructure
- Confirms implementation progress and institutional readiness
- Increases European visibility and strategic credibility
- Strengthens the framework for long-term operation, sustainability and future upgrades

What the AISBL enables

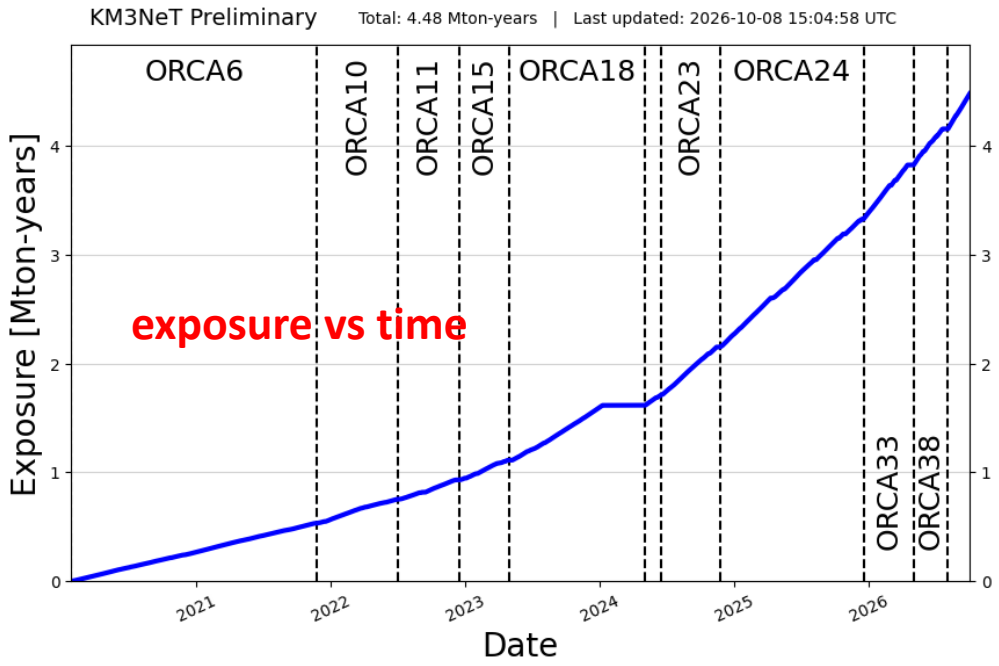
construction | installation | maintenance | scientific operation | governance | future decommissioning

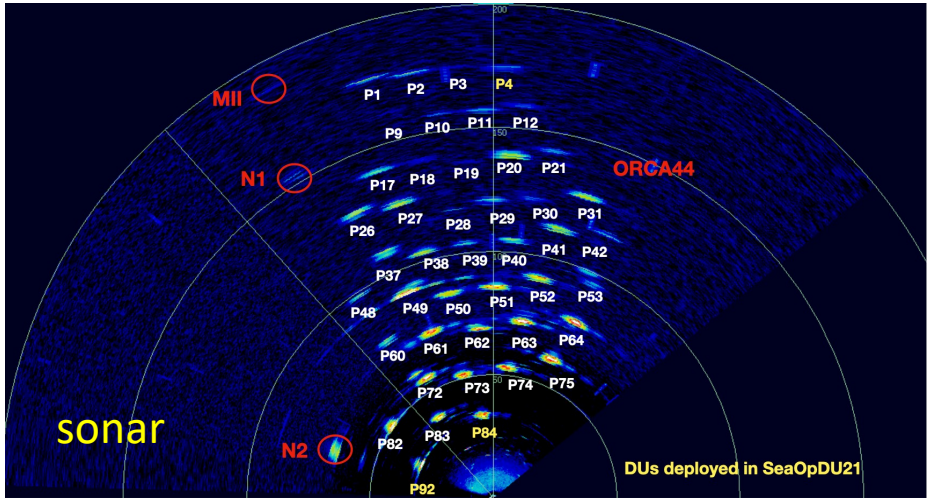
What this means for the future

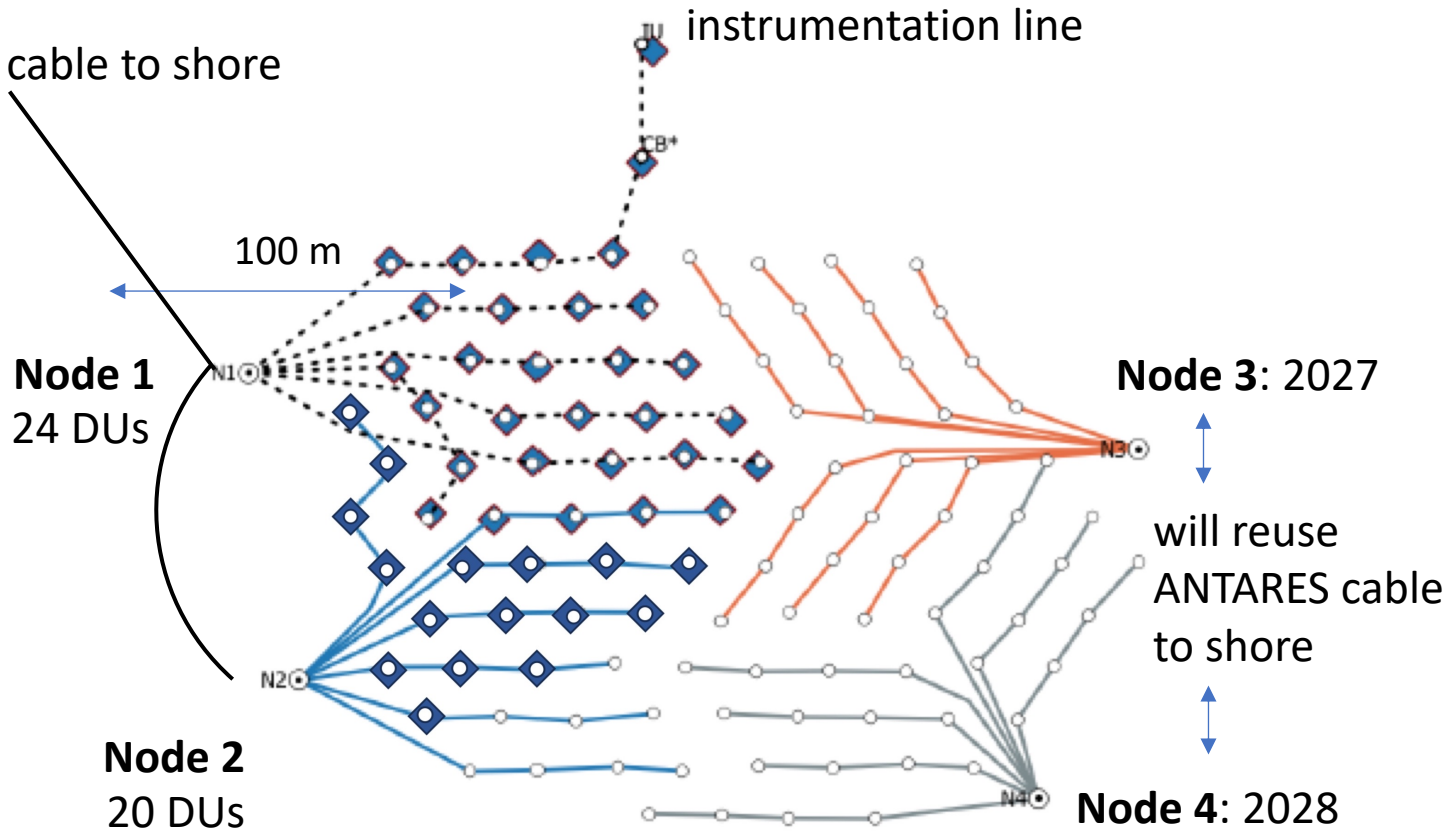
complete ARCA | complete ORCA | deliver leading science | consolidate governance | attract new partners | ensure sustainable long-term operations

Key message: KM3NeT is preparing not only to complete ARCA and ORCA, but to operate as a sustainable European Research Infrastructure: AISBL provides the legal framework, APPEC prioritizes completion, and ESFRI Landmark now recognizes KM3NeT as a mature RI.

KM3NeT/ORCA status and evolution







Latest sea operation October 1-4, 2026.

ORCA is starting to take data with 44 DUs

ORCA Completion Plan

Original layout had 115 DUs on 5 nodes, **new plan has 108 DUs on 4 nodes**.

Saves effort and funds on design of complicated 3-node cable splitter, instead simple commercial solution.

We believe that Nodes 2, 3 and 4 can handle 28 DUs (instead of 24 originally foreseen)

In this plan, we will have 108 DUs in the water at least 6 months earlier than in the 5-node plan, and cheaper.

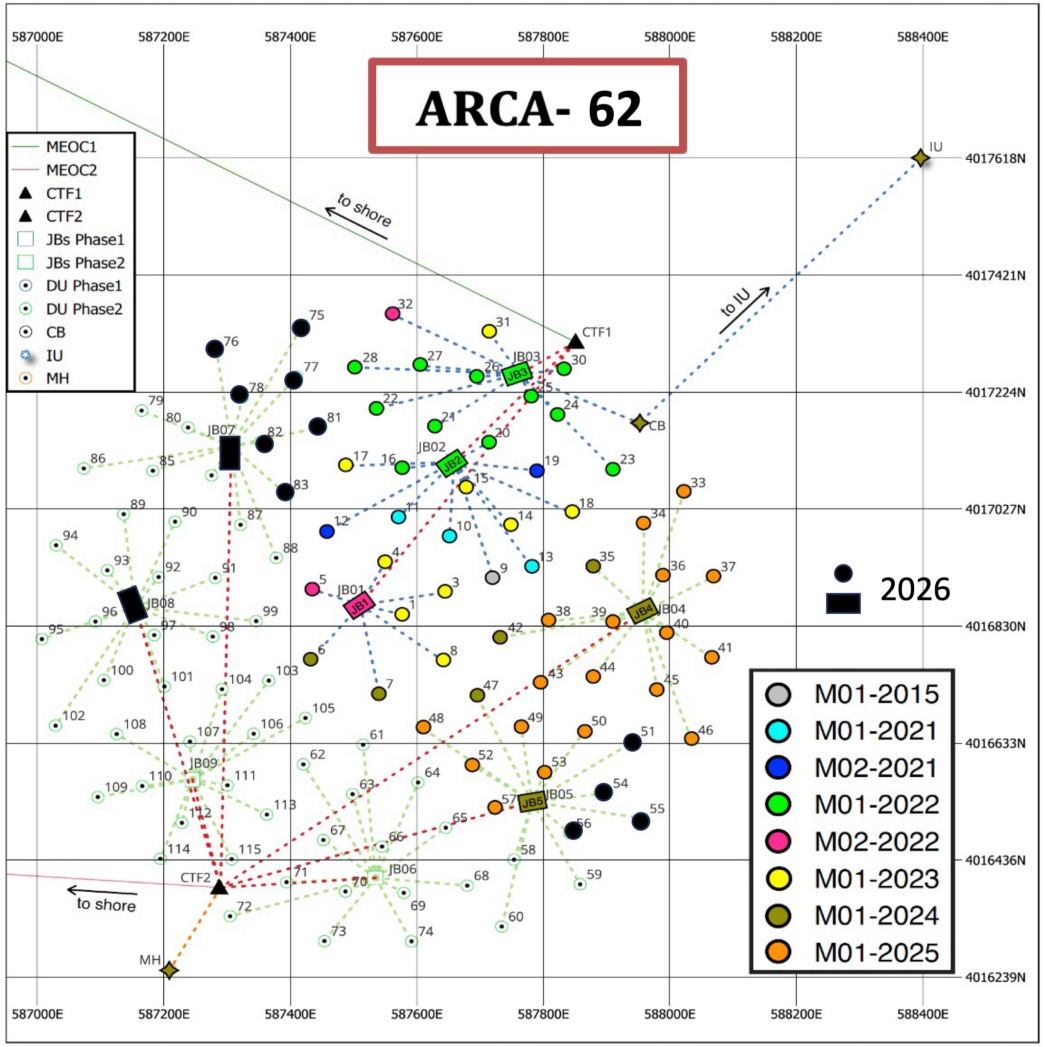
Funding is in the bank for >90 % of the infrastructure.
Remainder are yearly pledged contributions from CNRS.

Final DOM and DU integration by the end of 2029,
final deployment in 2030.





ARCA evolution

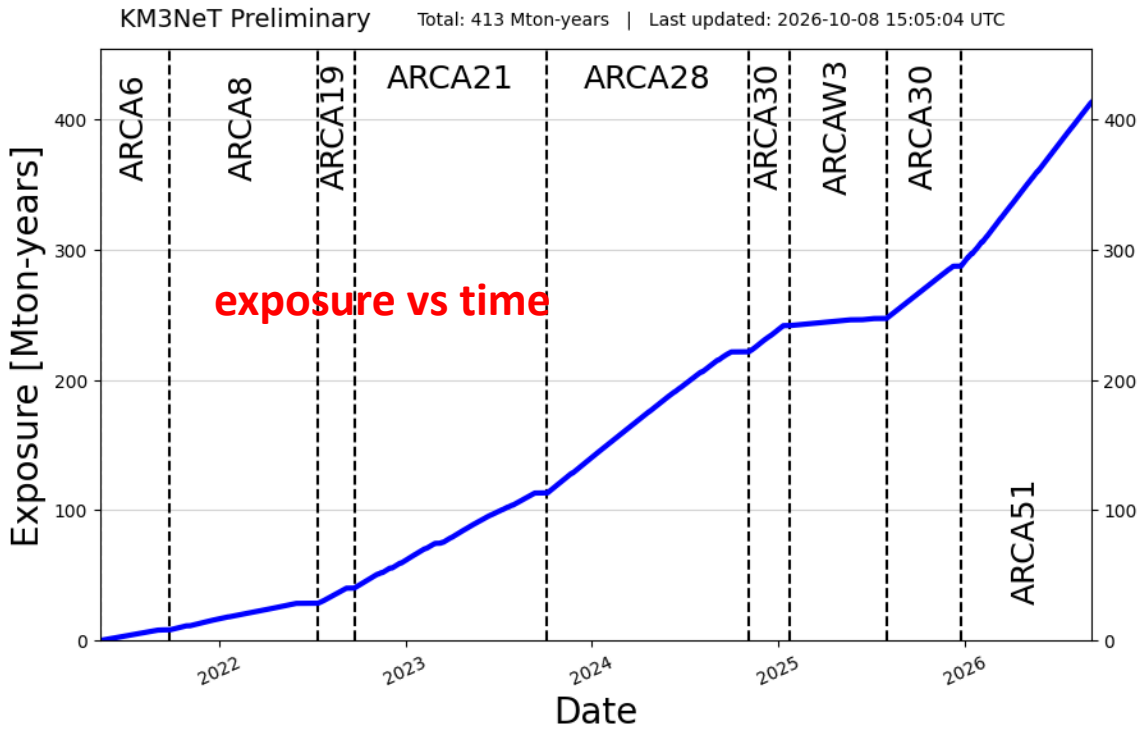


Summer 2026 campaign: ARCA 51 → ARCA 62

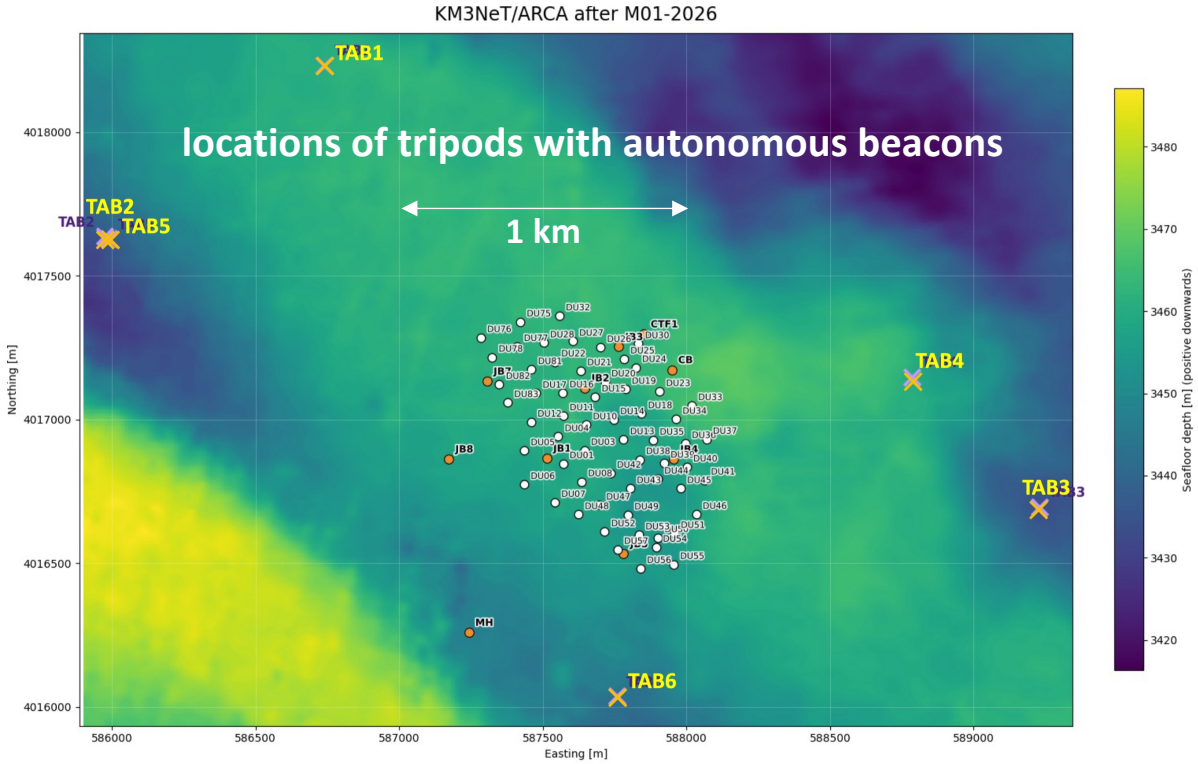
4-20 September, 2026

New boat operator (NextGeo Solutions, Napoli)





ARCA acoustic detector position calibration



Acoustic position calibration: static + dynamic components

where are the anchors?

correction for movements with sea current

Absolute position calibration needs precise locations of TABs (Tripods with Autonomous Beacons)

TAB6 deployed in 2024, TAB1, TAB2, TAB3 in 2025

Precisely located with “box-in” procedure in 2025.

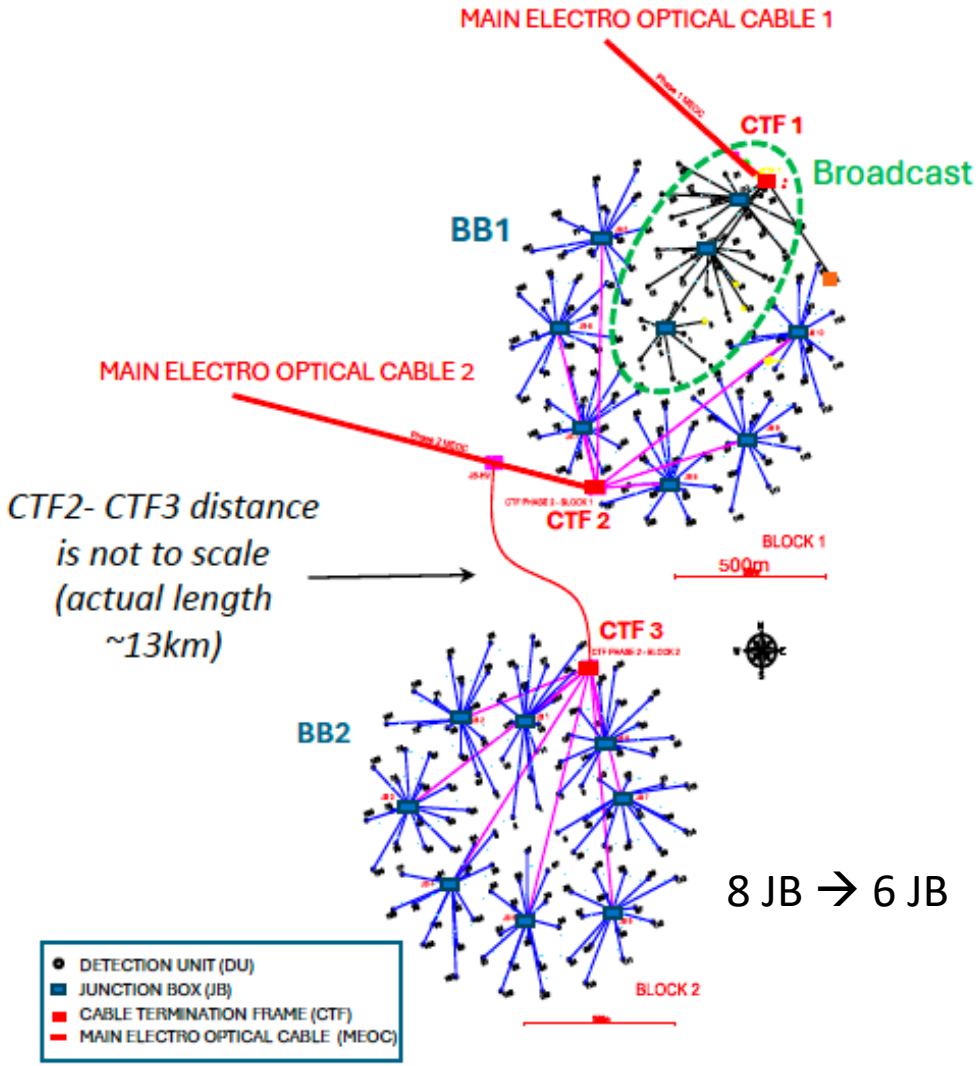
Unfortunately, emissions from TAB2 and TAB3 were not detected by ARCA DOMs (most likely TABs not working).

2026: TAB4 and TAB5 deployed at/close to TAB2/3 sites, and “boxed-in”.
careful quality control, live data taken during deployment: TABs work.

As further backup, we did a relative depth determination of all TABs.

We believe we now have the data to recalibrate the origin of KM3-230213A

ARCA plan to completion



8 JB → 6 JB

For completion of BB1: deploy 2 more junction boxes, 52 DUs.
All funded and under construction, to be deployed 2027, 2028, 2029

CTF3 deployed September 2026: start of BB2!

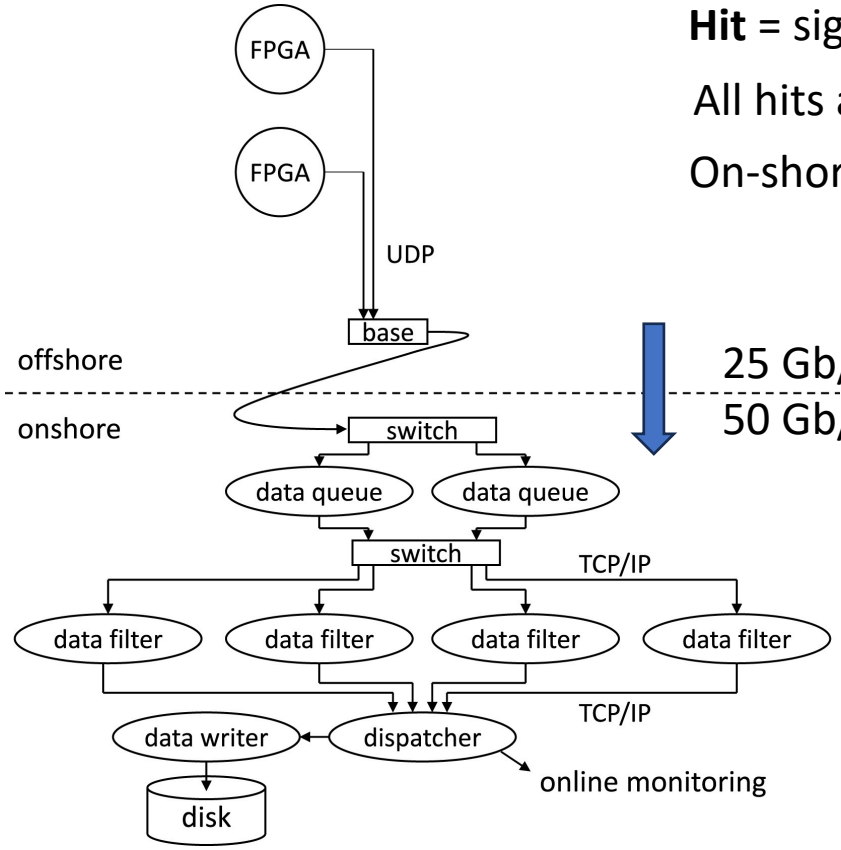
Power distribution system on MEOC2 will only be able to serve 6 junction boxes on CTF3, or 84 DUs.
We plan to complete ARCA with 114 (BB1) + 84 (BB2) = 198 DUs

There is some (but limited) liberty to redesign BB2 layout.

Funding for 3 JBs and 48 DUs still to be acquired.
(But ARCA in total is funded for >80%)

BB2 construction 2029-2032.

Data taking



25 Gb/s ORCA
50 Gb/s ARCA

Hit = signal over threshold: PMT ID + time-at-threshold + time-over-threshold

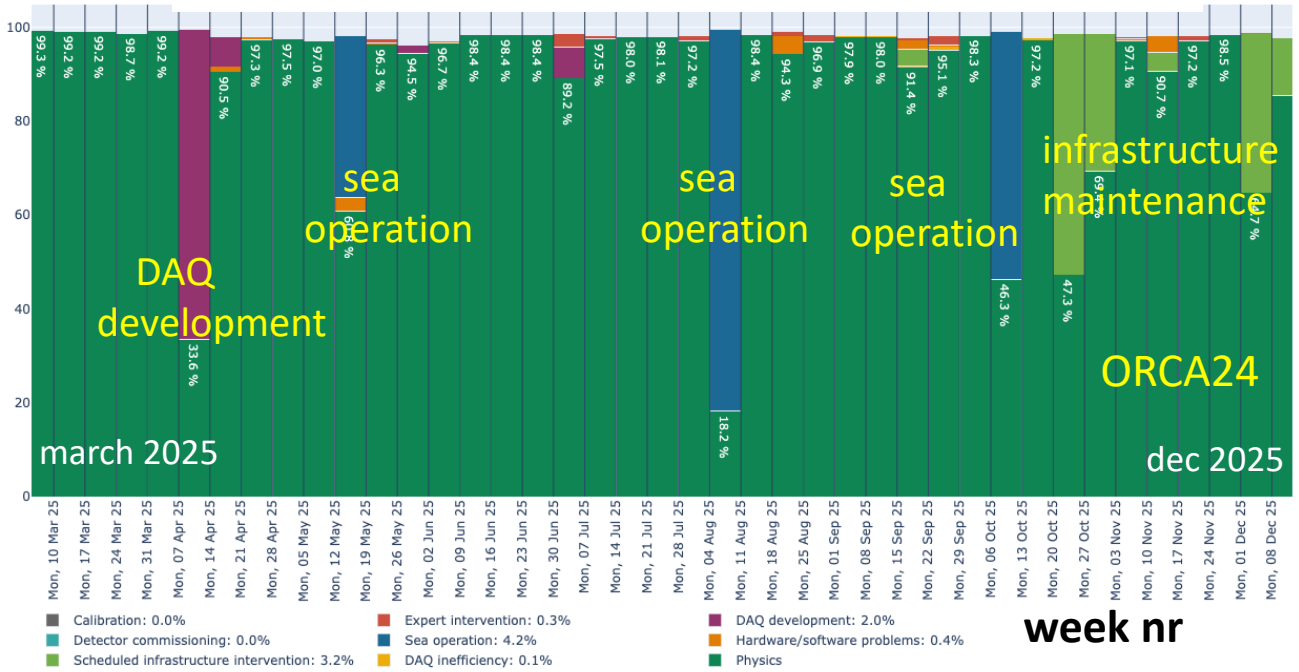
All hits are sent to shore over fibers: ~ 300 kHz per DOM, 250 Mb/s per DU

On-shore data filters trigger on coincidences/causal relations, typically 20-30 Hz

Events – all hits in snapshot of 2.5-10 µs

NIM A1083 (2025) 171097

DAQ efficiency outside planned shutdowns > 95%

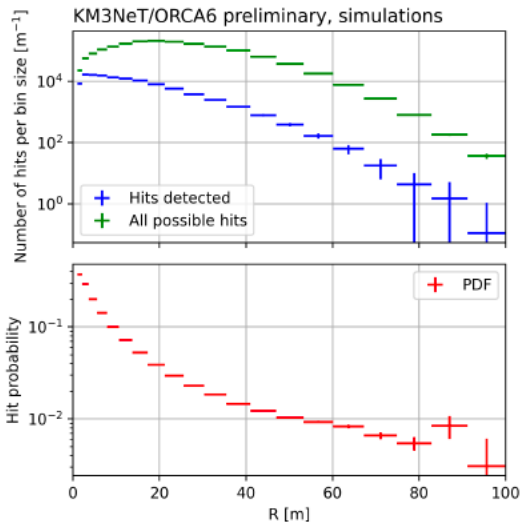


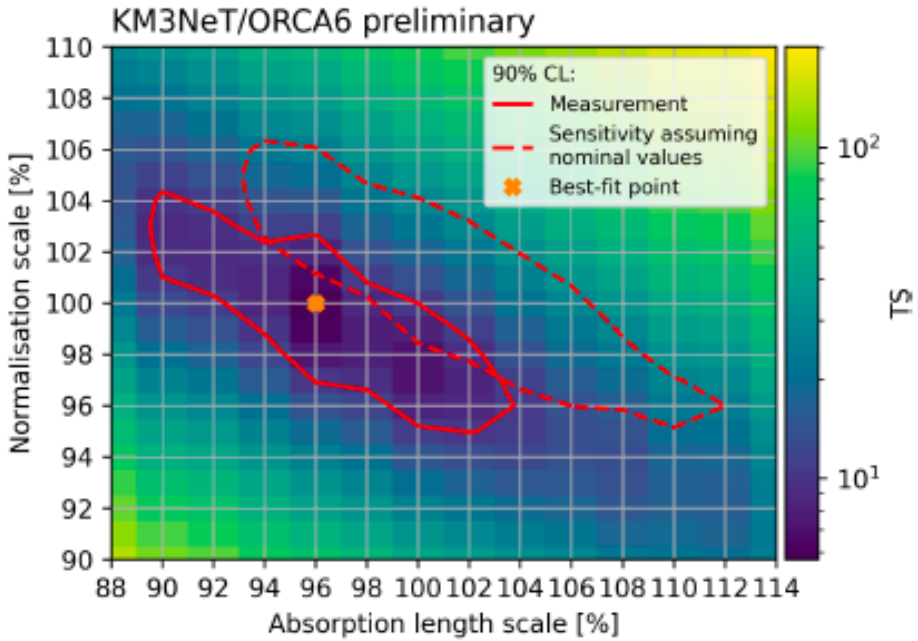
Calibration

Water properties

Stopping atmospheric muons inside ORCA: measurement of water properties.

In-situ: absorption length determined to be within a few percent of values used in sim/reco.





[PoS ICRC2025 (2025) 1158]

Currently updating treatment:

$$\frac{1}{l_{abs}(\lambda)} = \frac{1}{l_{abs,water}(\lambda)} + \frac{1}{l_{abs,particles}}$$

(work in progress)

e.g. Smith & Baker (1981)
typically $l \approx 50\text{m}$

Fit after PMT correction.
typically $l \gg 300\text{m}$

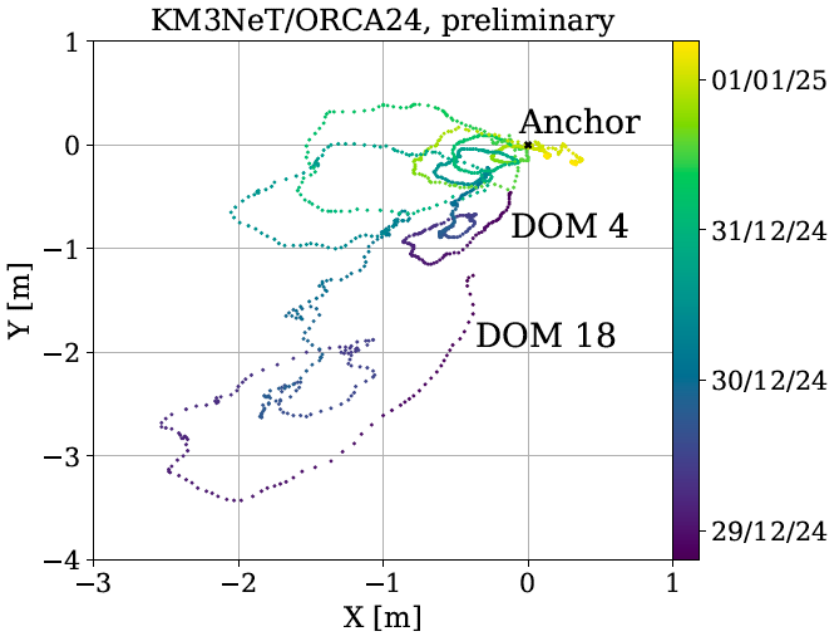
We look forward to POCAM-like device in KM3NeT, as well as a calibration device from Trident.

Calibration

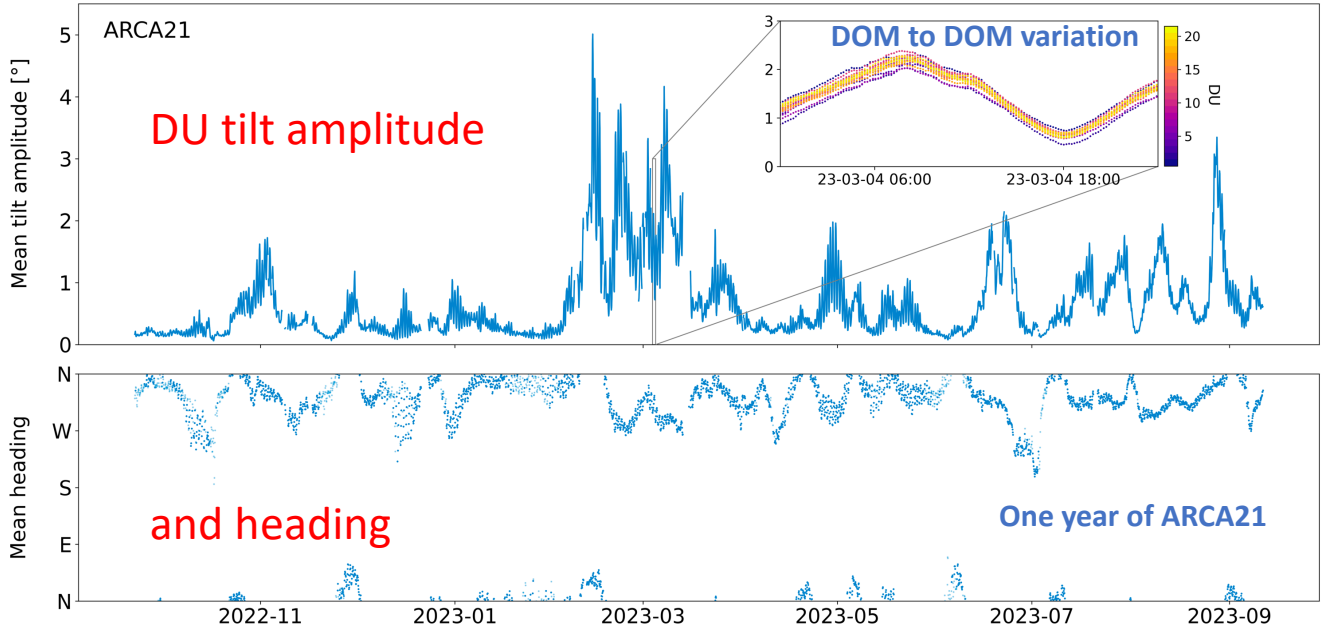
Dynamic positioning by acoustic calibration

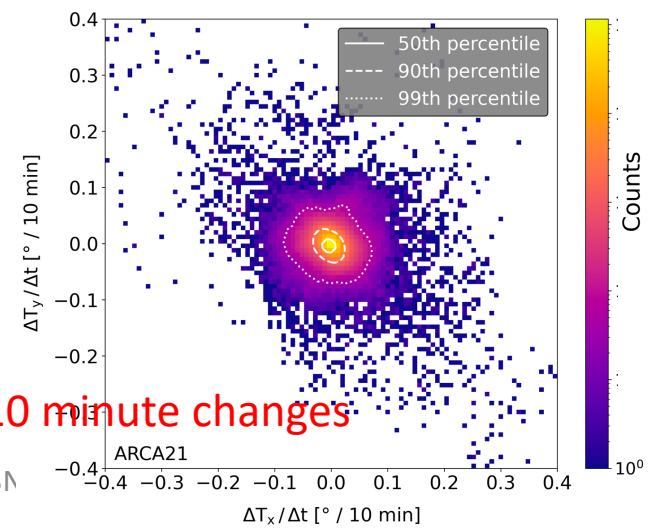
paper in preparation

Time evolution of DOM positions.
Evaluated every 10 minutes.

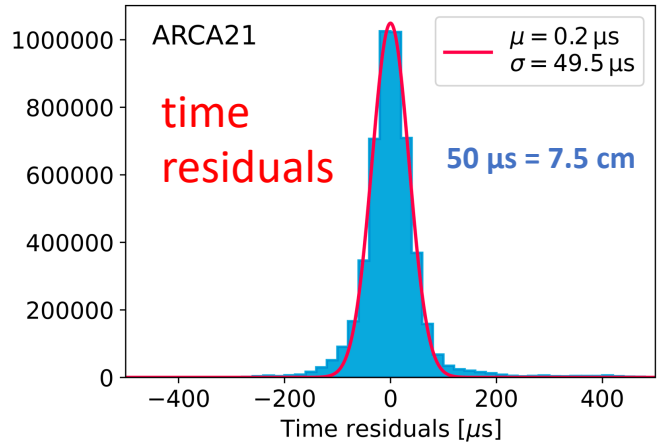


reconstructed DOM movements versus time





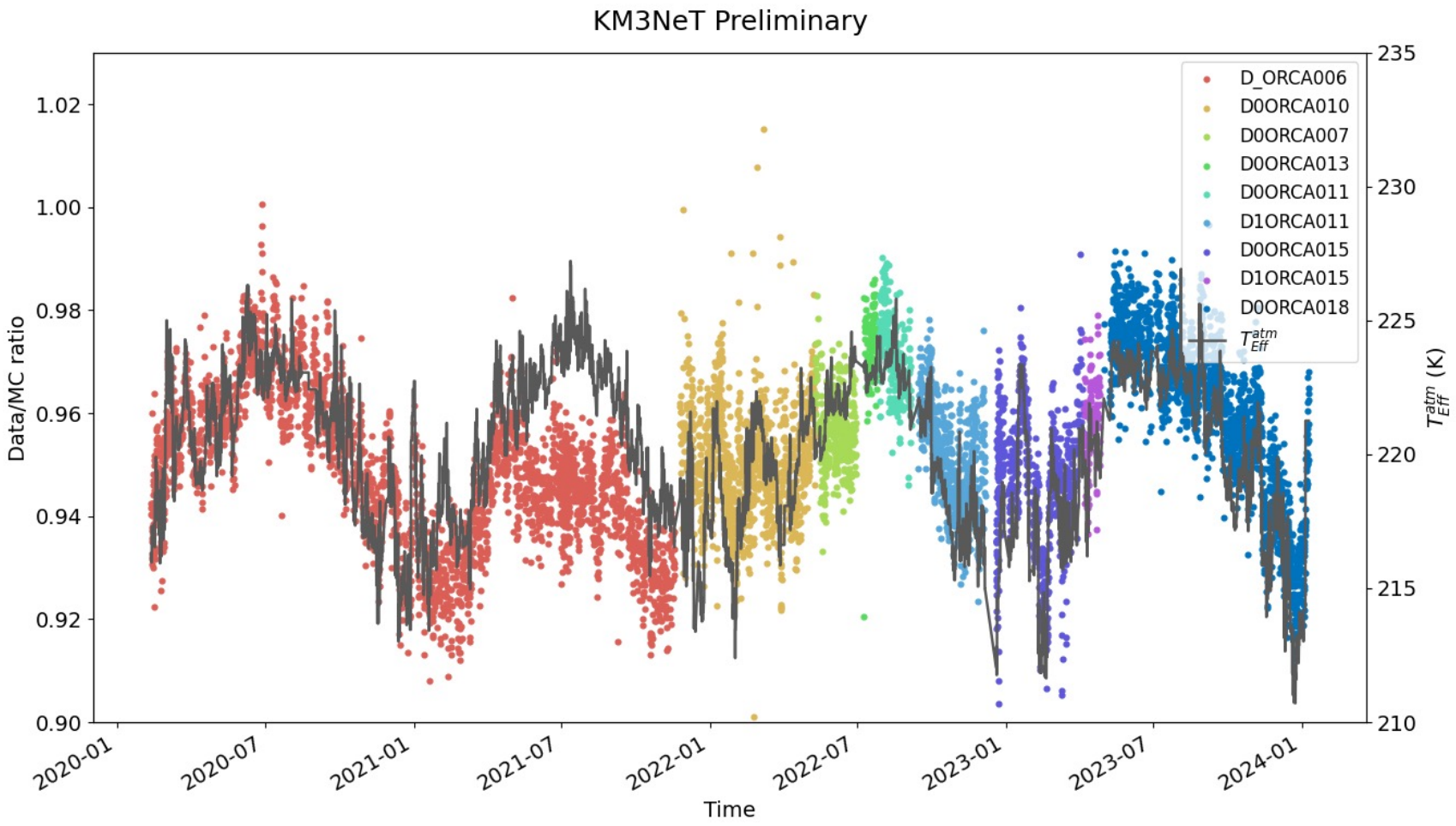
10 minute changes



Cross-check: cosmic ray shadow of sun and moon)

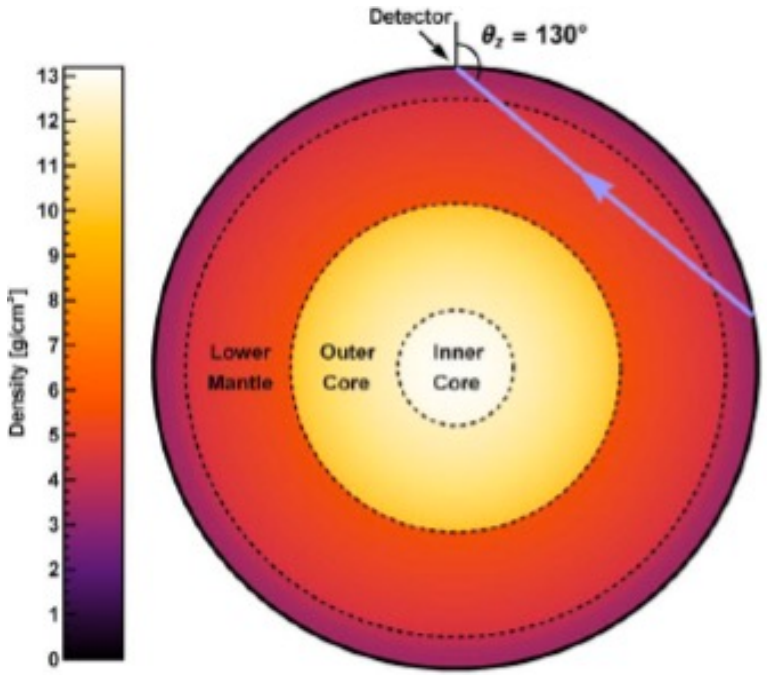
Data/MC muon rates after calibration

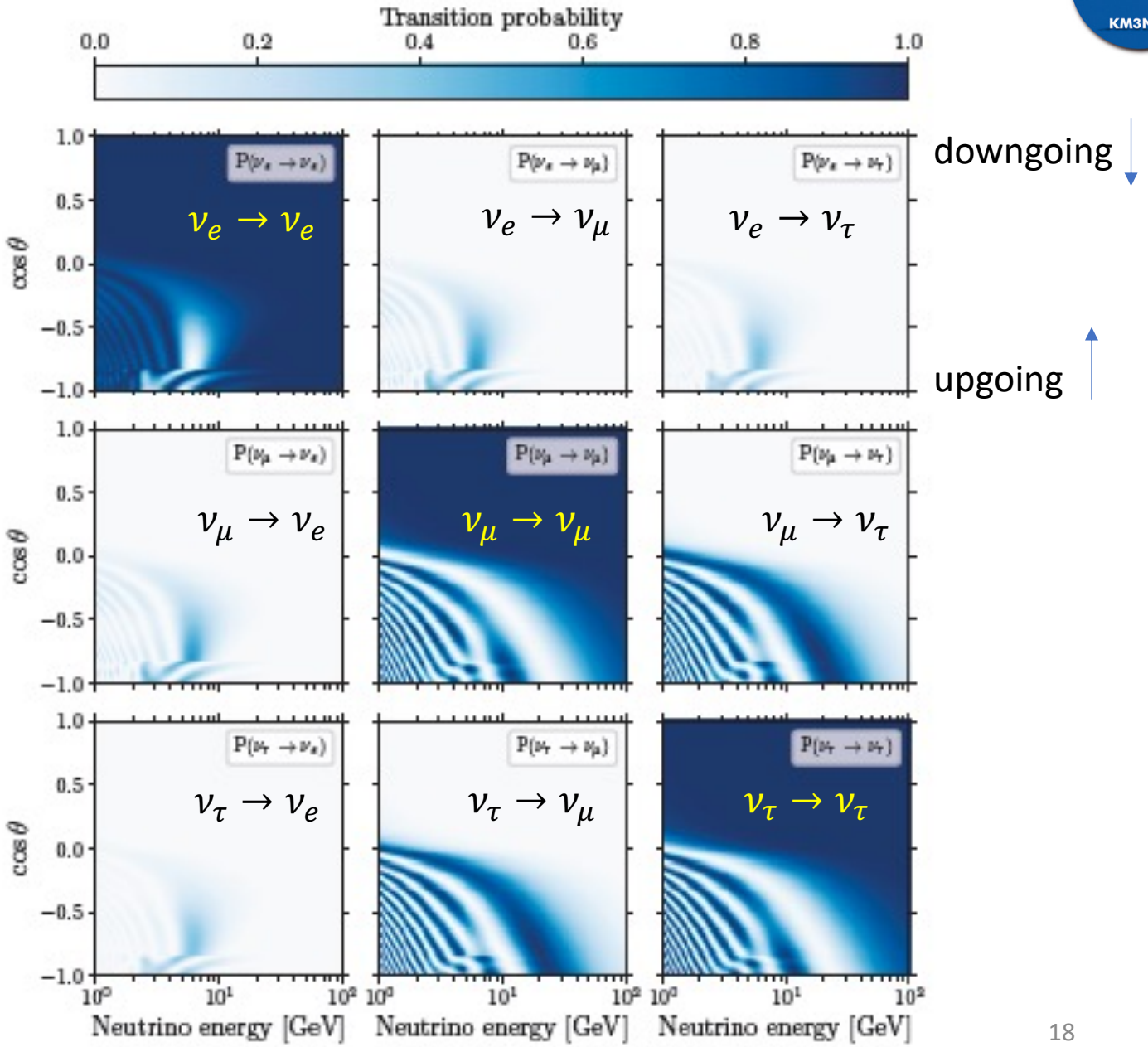
MC has all known detector calibrations implemented, but not the yearly flux changes due to atmospheric temperature variations.



Data/MC ratio follows annual cycle well

Oscillation physics with atmospheric neutrinos

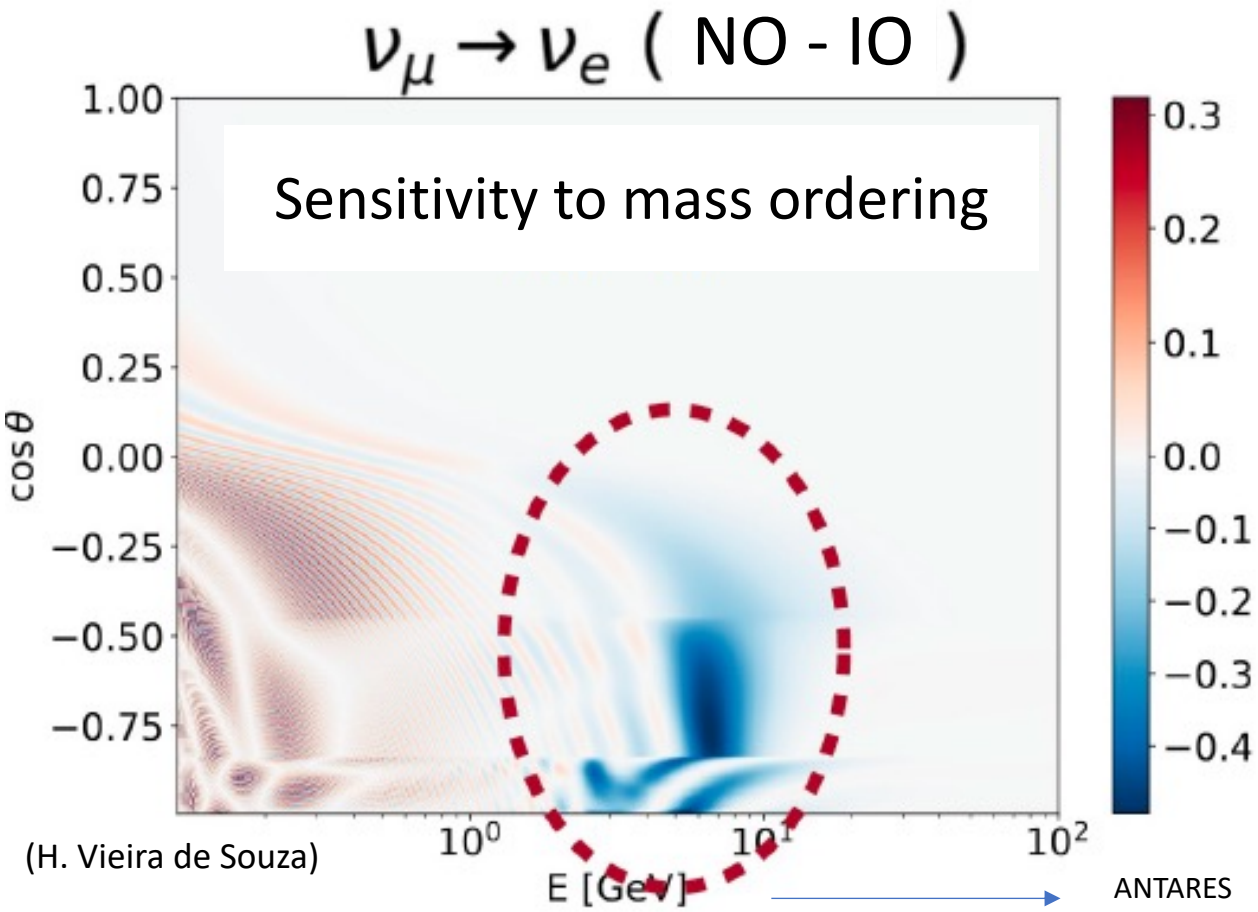




Long baselines: 10-12700 km
Baseline fully correlated with $\cos\theta$

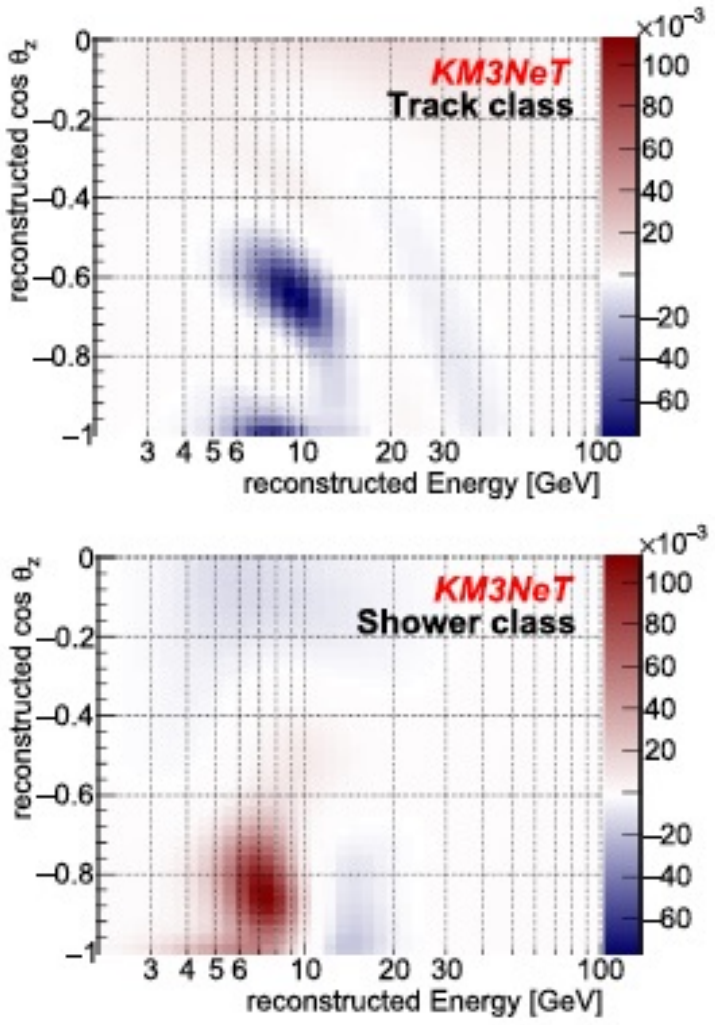
Matter effect: opportunity to measure the neutrino mass ordering

Relevant neutrino energy range (mass ordering)



(H. Vieira de Souza)

where do NO-IO differ?



ANTARES

ICECUBE/DEEPCORE

KM3NeT/ORCA

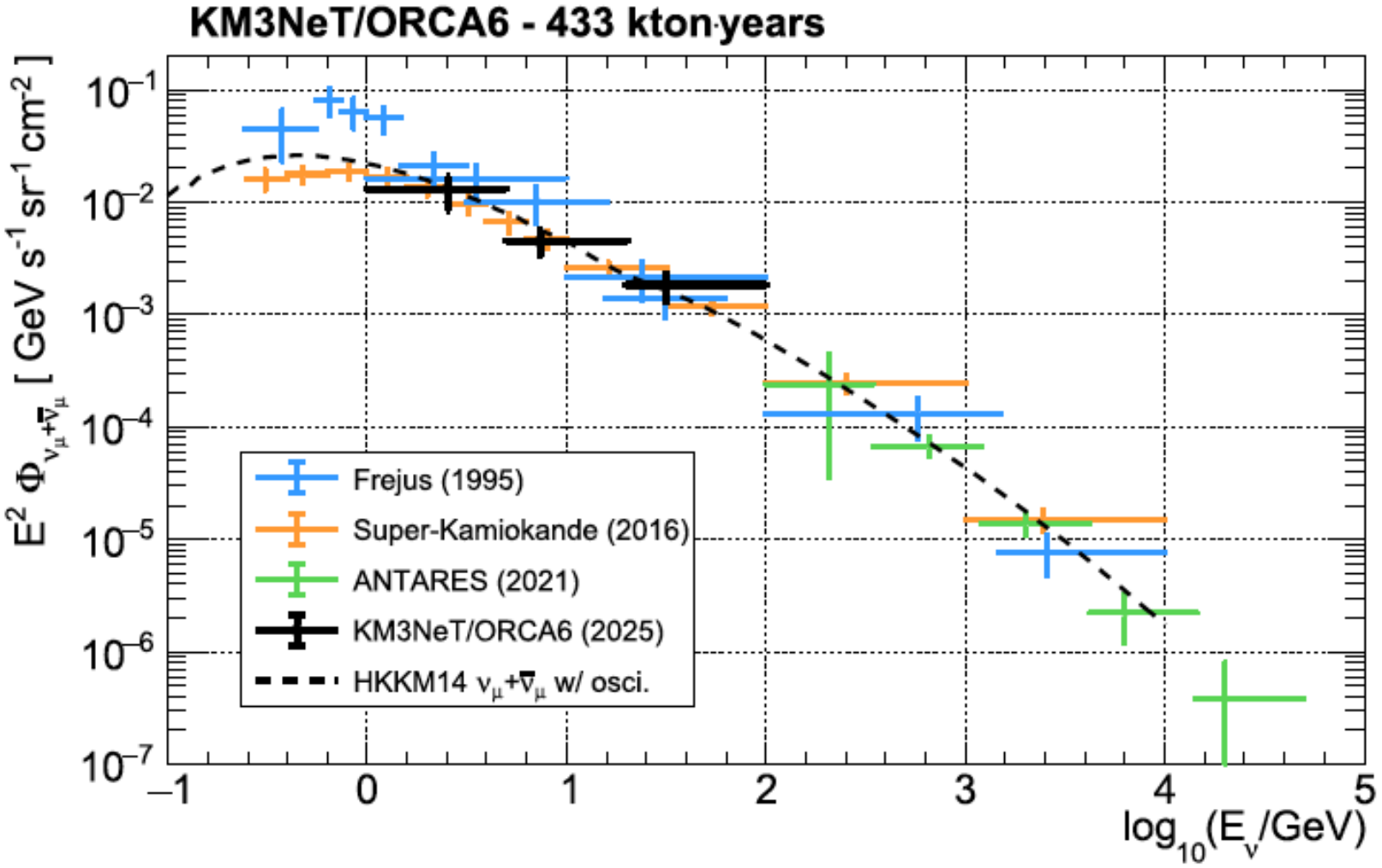
ICECUBE/UPGRADE

SUPER-K/HYPER-K/DUNE

Atmospheric neutrino flux

Measurement of the atmospheric ν_μ flux with six detection units of KM3NeT/ORCA

Eur. Phys. J. C **85** (2025) 871



Measured flux is consistent with Honda HKKM14 model, but error bars still sizable.

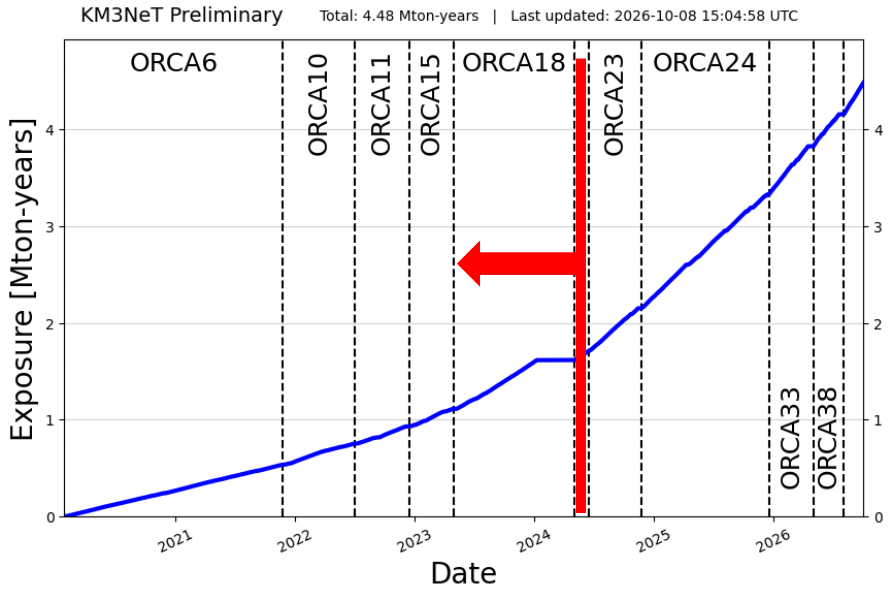
For this ORCA6-18 analysis:

We also tested an alternative flux model, based on DaemonFluxv1 but not tuned for ORCA location, no geomagnetic effects, overshoots at low energies (HybridFlux).
Parameters varied in flux systematics.

New Results Summer 2026

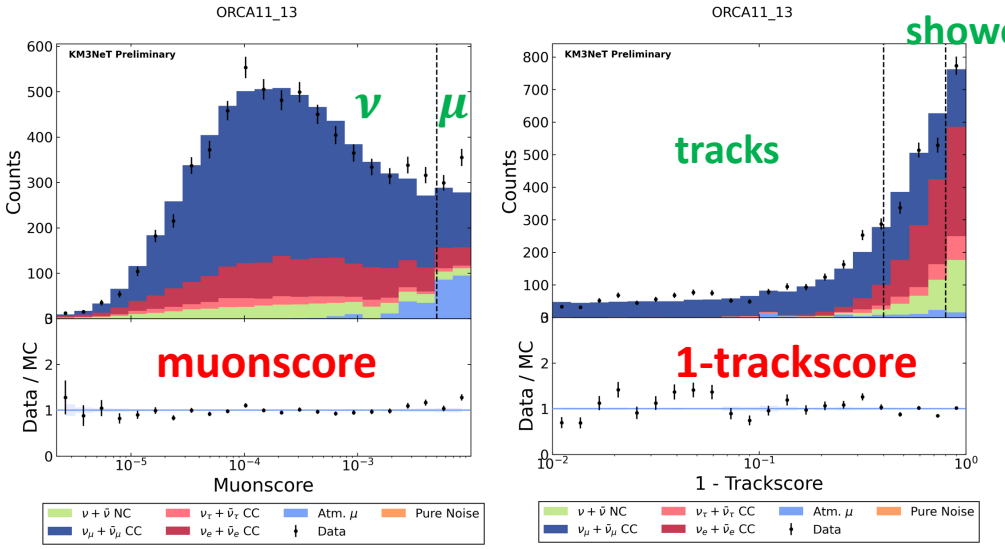
ORCA 6-18 (~4 years data)

- Neutrino oscillations in 3-generation framework
- Tau neutrino production



Selection:

- basic quality criteria
- upgoing events
- noise rejection (random and sparks)
- atmospheric muon rejection (muonscore BDT)
- classification: track/shower/intermediate (BDT)



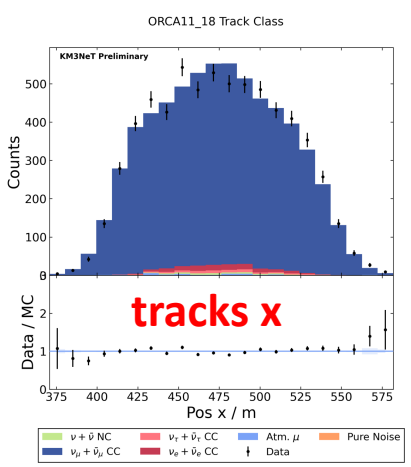
ORCA6-7 and ORCA11-18: exposure 1.4 Mton-years

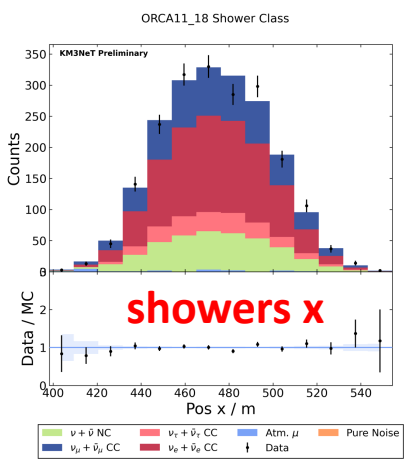
ORCA data selection

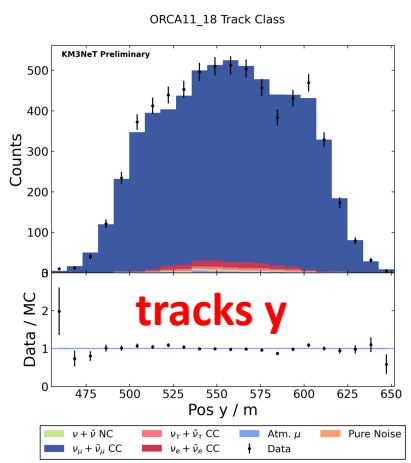
Event Type	ORCA6/7 tracks	ORCA6/7 interm.	ORCA6/7 showers	ORCA11–18 tracks	ORCA11–18 interm.	ORCA11–18 showers
$\nu_e\mathrm{CC} + \bar{\nu}_e\mathrm{CC}$	50	336	682	87	646	911
$\nu_\mu\mathrm{CC} + \bar{\nu}_\mu\mathrm{CC}$	3869	748	493	5641	1151	557
$\nu_\tau\mathrm{CC} + \bar{\nu}_\tau\mathrm{CC}$	36	80	176	53	141	212
$\nu\mathrm{NC} + \bar{\nu}\mathrm{NC}$	19	112	276	31	219	430
atmospheric $\mu + \bar{\mu}$	29	22	30	31	20	21
Total MC	4003	1298	1657	5843	2176	2131
Total Data	4098	1361	1586	6329	2236	2016

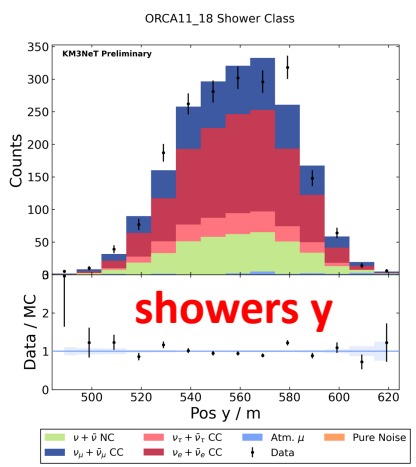
- pre-fit
- Honda flux

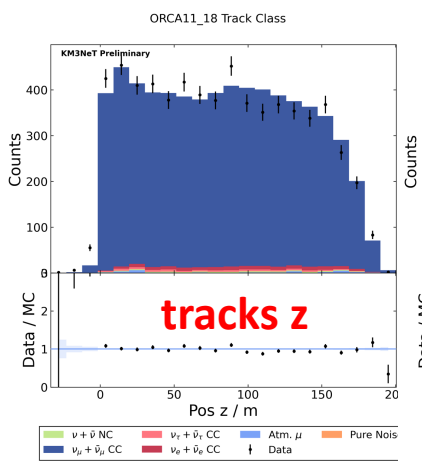
(μ contamination 0.9%)
$\Sigma = 17108$ MC
$\Sigma = 17626$ Data

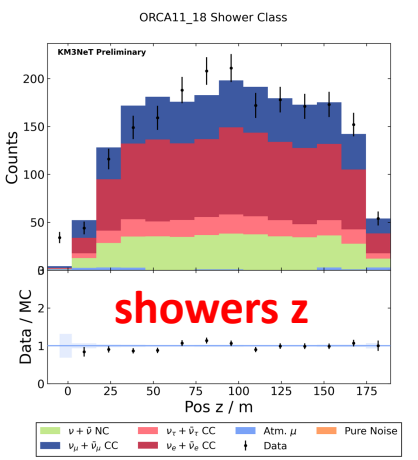






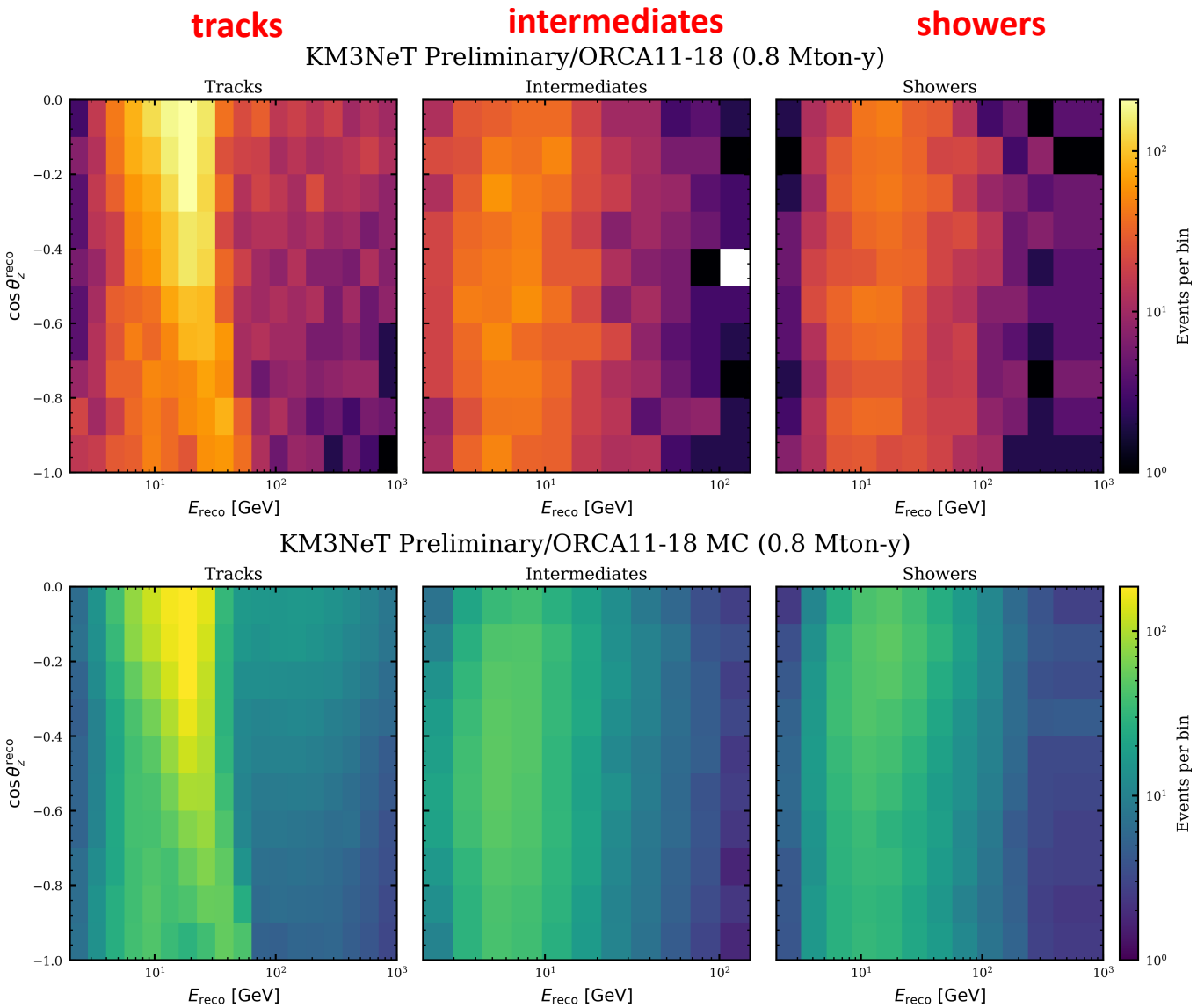






ORCA15-18, physical distributions of events in the detector

Oscillations fit procedure



Oscillations fit is performed on these 2D distributions of $\cos\theta$ versus E

We split the data set in ORCA6-7 and ORCA11-18, with different reponse functions.

Systematics:

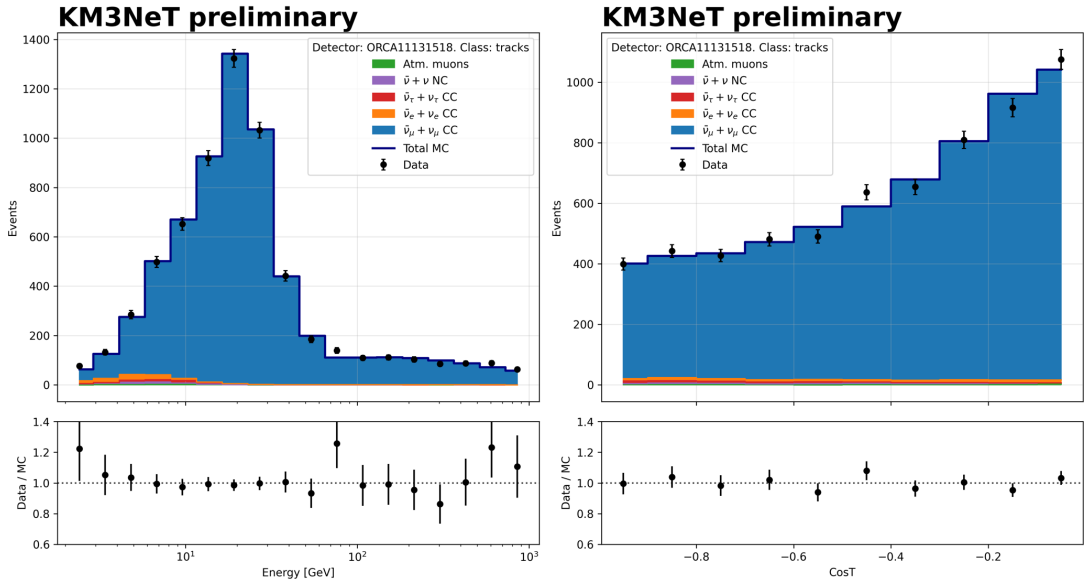
- Flux: HybridFlux parameter variation (also implemented for Honda flux)
- Cross sections: rescale QE, RES, NC, τ
- Detector: trigger efficiency, energy scale (including PMT QE and water properties)

The fit prefers the Honda flux over the HybridFlux by $\Delta\chi^2 = 3.6$

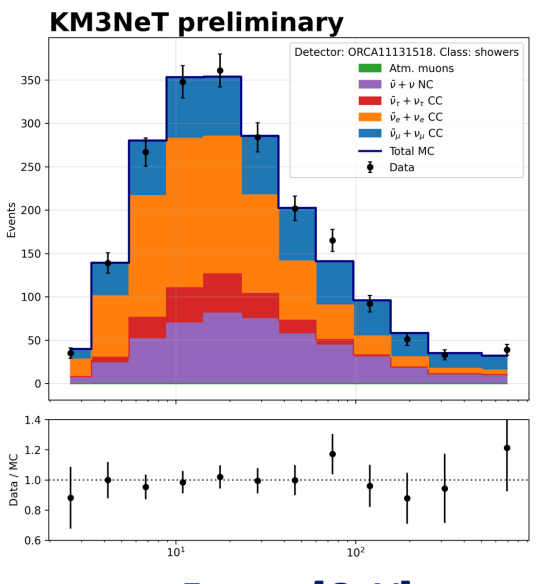
Results are quoted with the Honda flux.

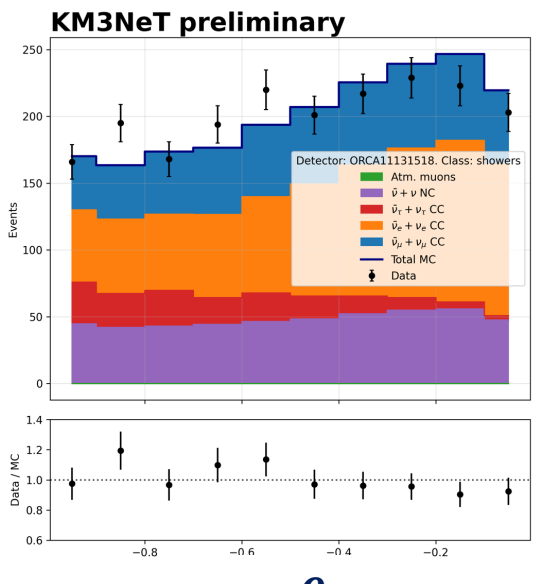
Post-fit data

Tracks



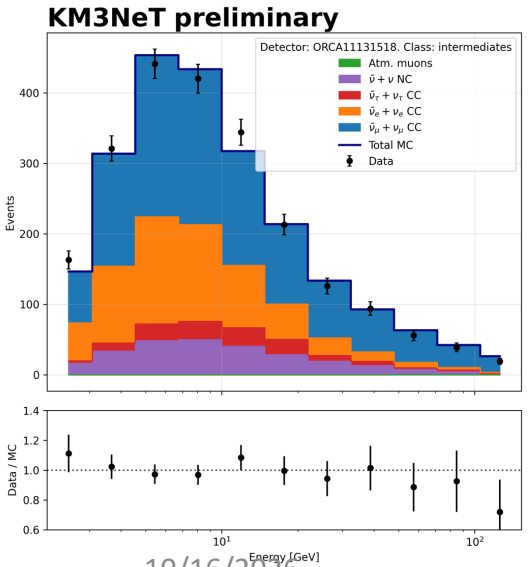
Showers

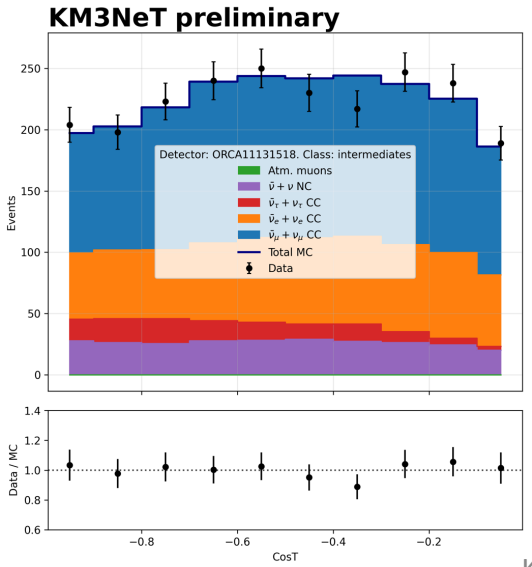




Energy [GeV] $\cos\theta$

Intermediates

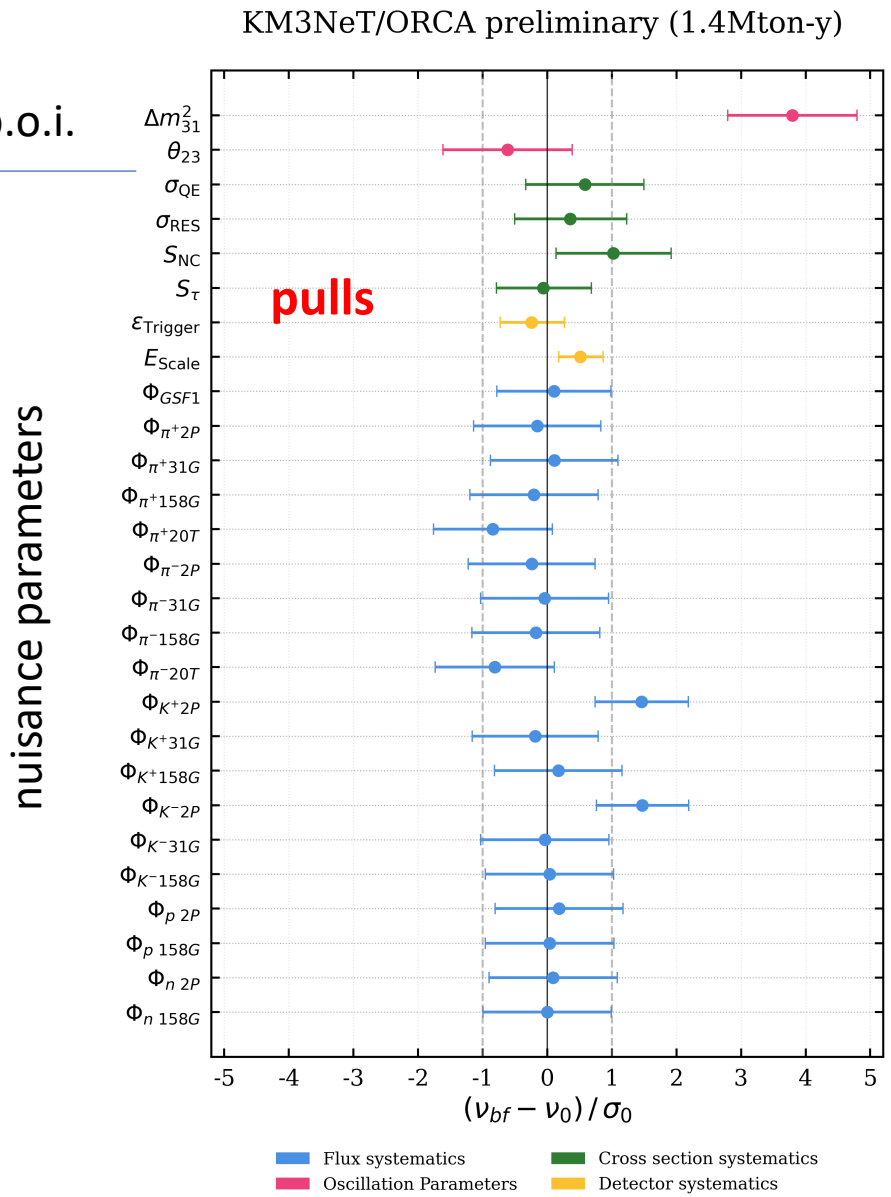




ORCA 11-18

Post-fit Energy and $\cos\theta$ distributions for tracks, showers, and intermediates

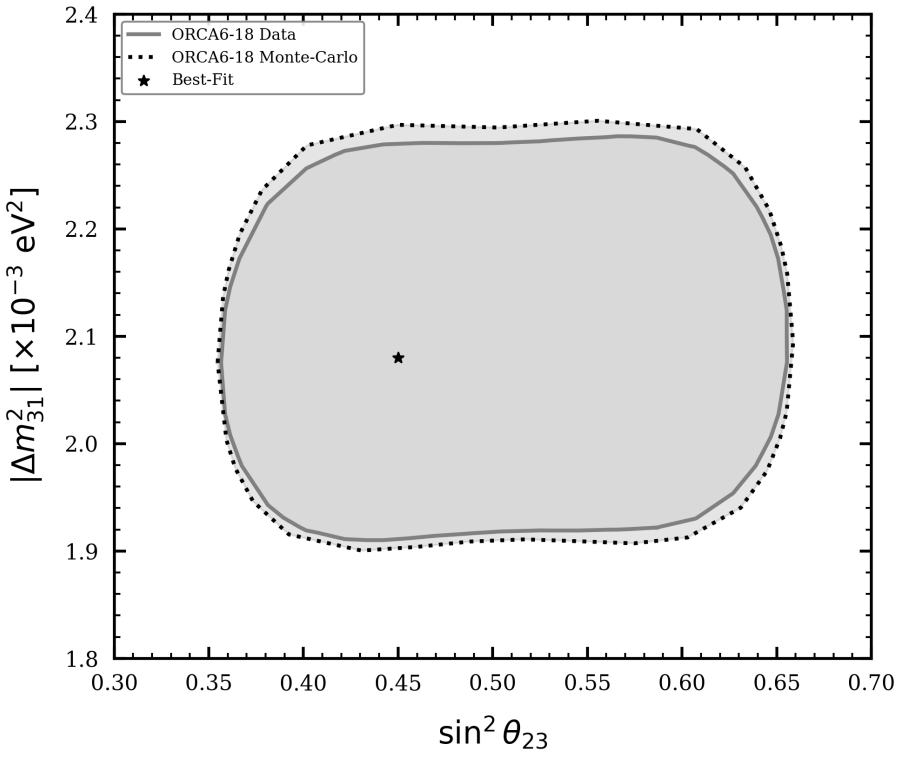
ORCA6-18 oscillations fit result, 1.4 Mton-year



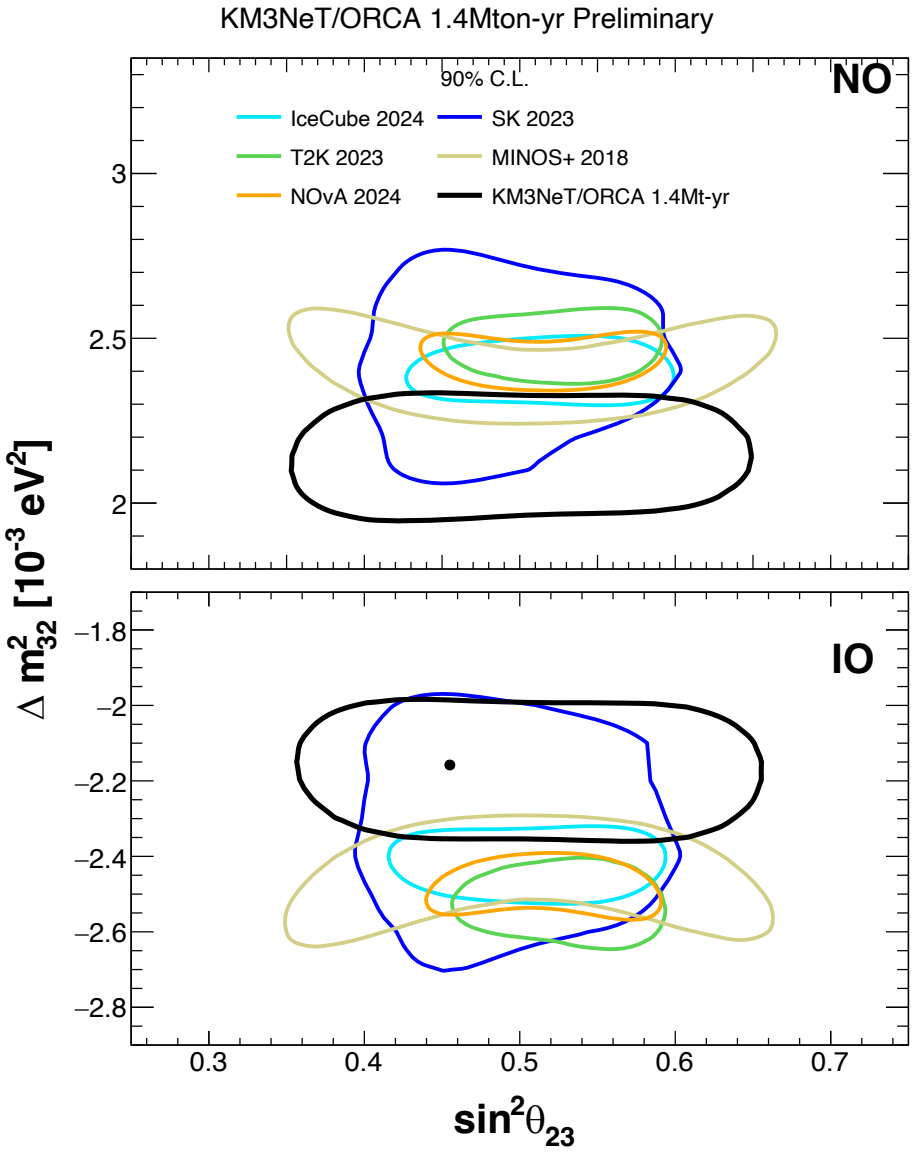
No large pulls in nuisance parameters.

Largest pull in Δm^2_{31}

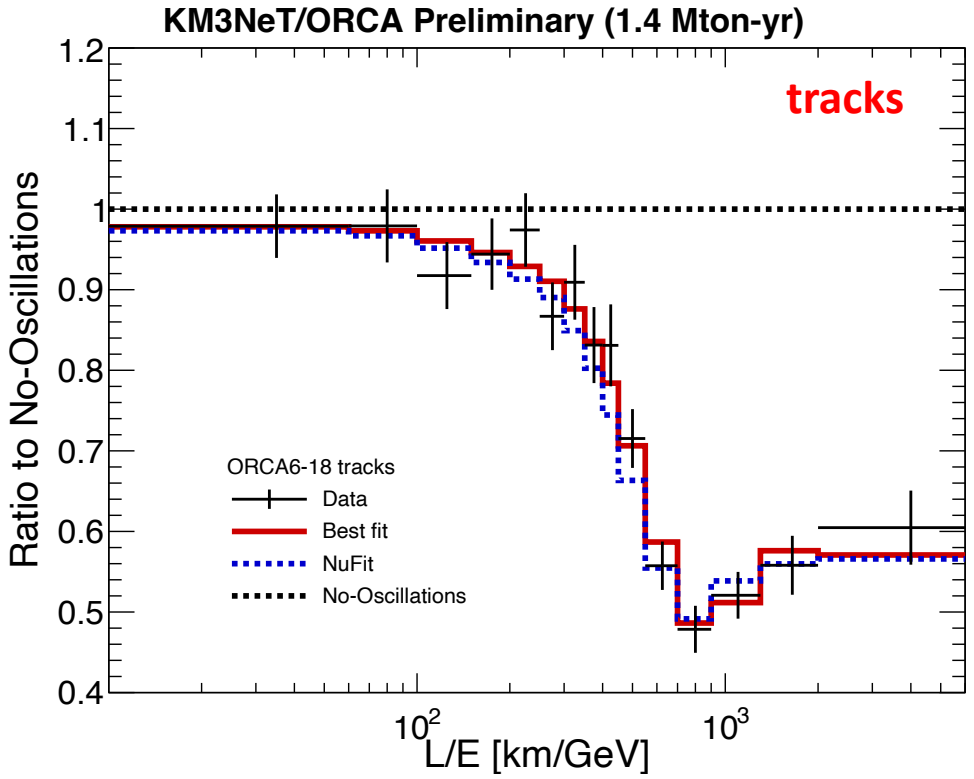
90% CL contour in data is on top of expectation



ORCA6-18 oscillations fit result, 1.4 Mton-year



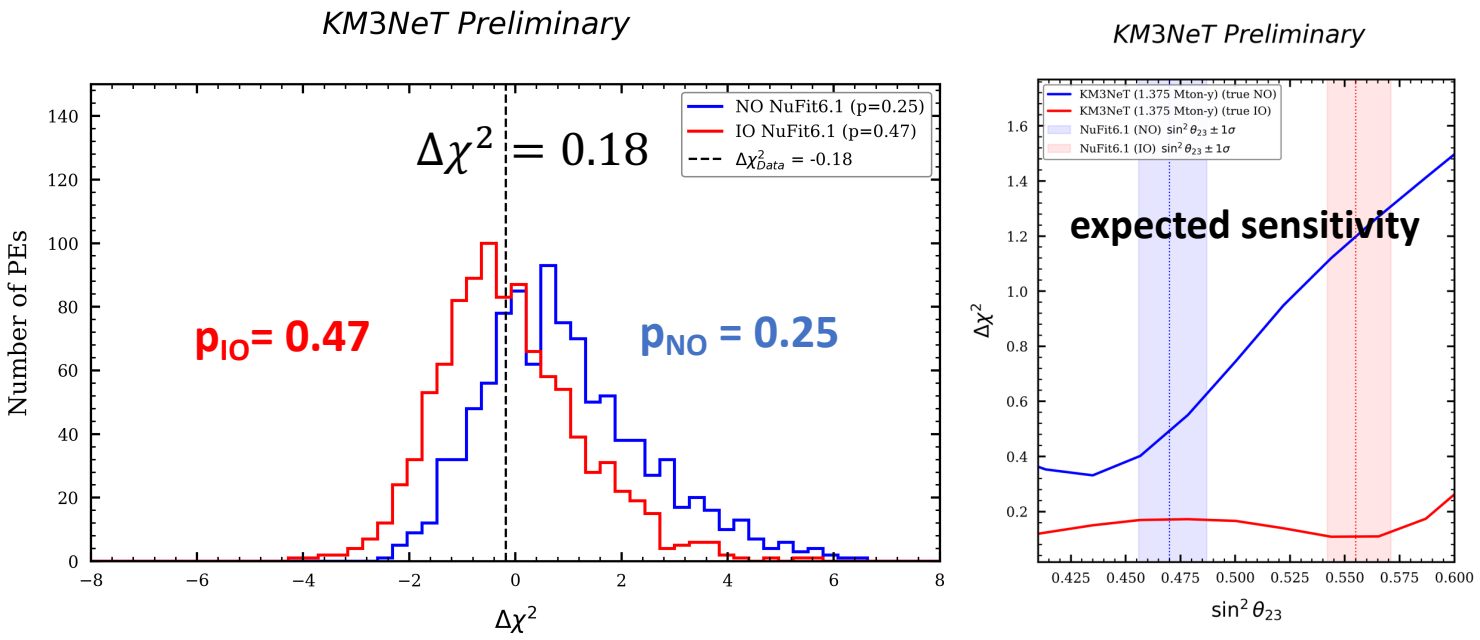
$\sin^2\theta_{23} = 0.45^{+0.16}_{-0.05}, \Delta m^2_{31} = (-2.08^{+0.08}_{-0.09}) \cdot 10^{-3}$ eV²



In the long term, neutrino telescopes have excellent sensitivity to θ_{23}

ORCA6-18 oscillations fit result, 1.4 Mton-year

Neutrino Mass Ordering (Normal = NO, Inverted = IO)



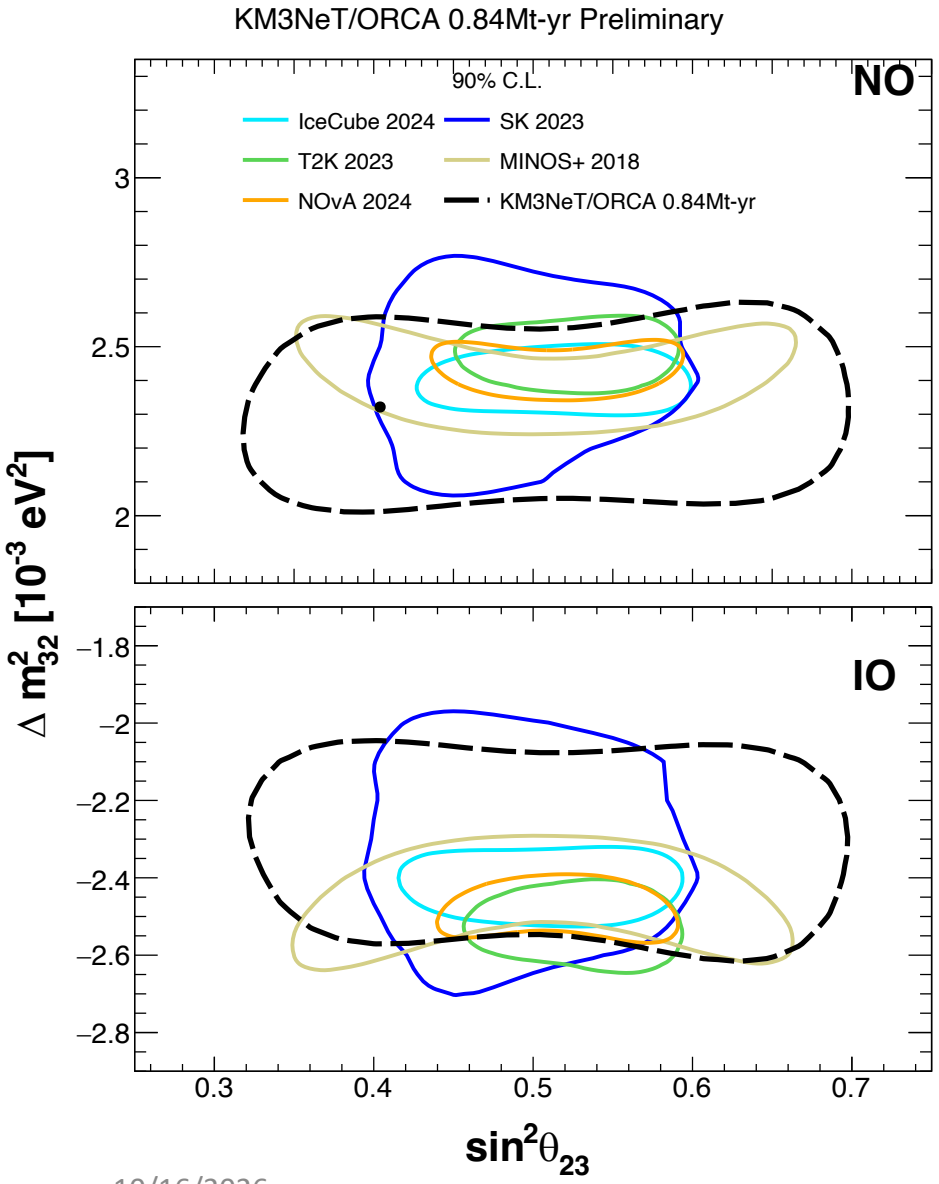
However, with external input from reactor expts. (Daya Bay and JUNO, **preliminary**):

$$\chi^2_{IO} - \chi^2_{NO} \approx 4.7$$

(preference for NO)

Slight preference for the IO, not statistically significant (as expected)

New data of ORCA11-18 only



In this analysis, ORCA6 data was reanalysed as part of the ORCA6-18 sample, with re-optimised selection criteria.

Results are consistent with earlier ORCA6 publication.

J. High Energ. Phys. **2024**, 206 (2024)

We also fit new data ORCA11-18, 0.84 Mton-year, alone

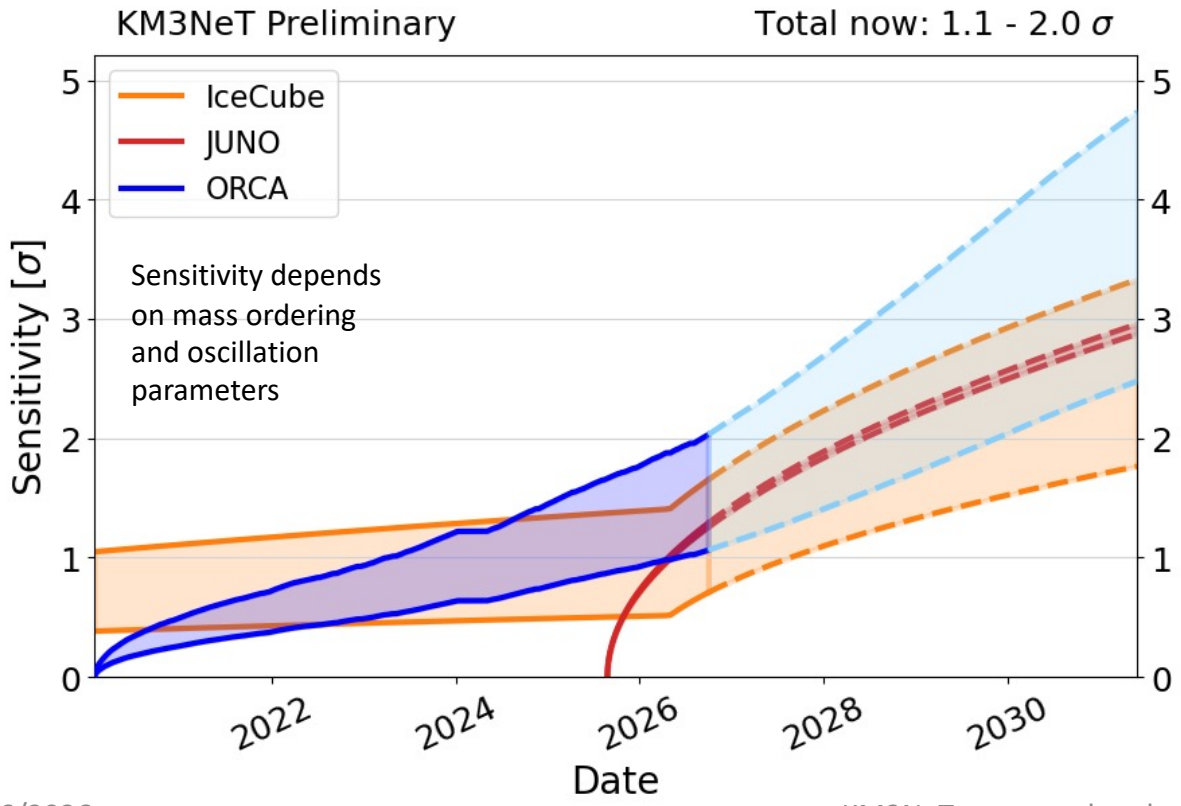
Within uncertainties, ORCA6-7 and ORCA11-18 are statistically consistent.

ORCA11-18 alone prefers somewhat higher Δm^2_{32} than ORCA6-7, and prefers NO over IO

Outlook to growing ORCA detector

ORCA keeps growing, from 44 DUs now, to 52 DUs (node 2 filled, 2027), to 80 DUs (node 3 filled, 2028/2029), to 108 DUs (node 4 filled, 2030)
(roughly: 2.5 Mton → 3.1 Mton → 4.8 Mton → 6.5 Mton)

Sensitivity to mass ordering with realistic detector growth:



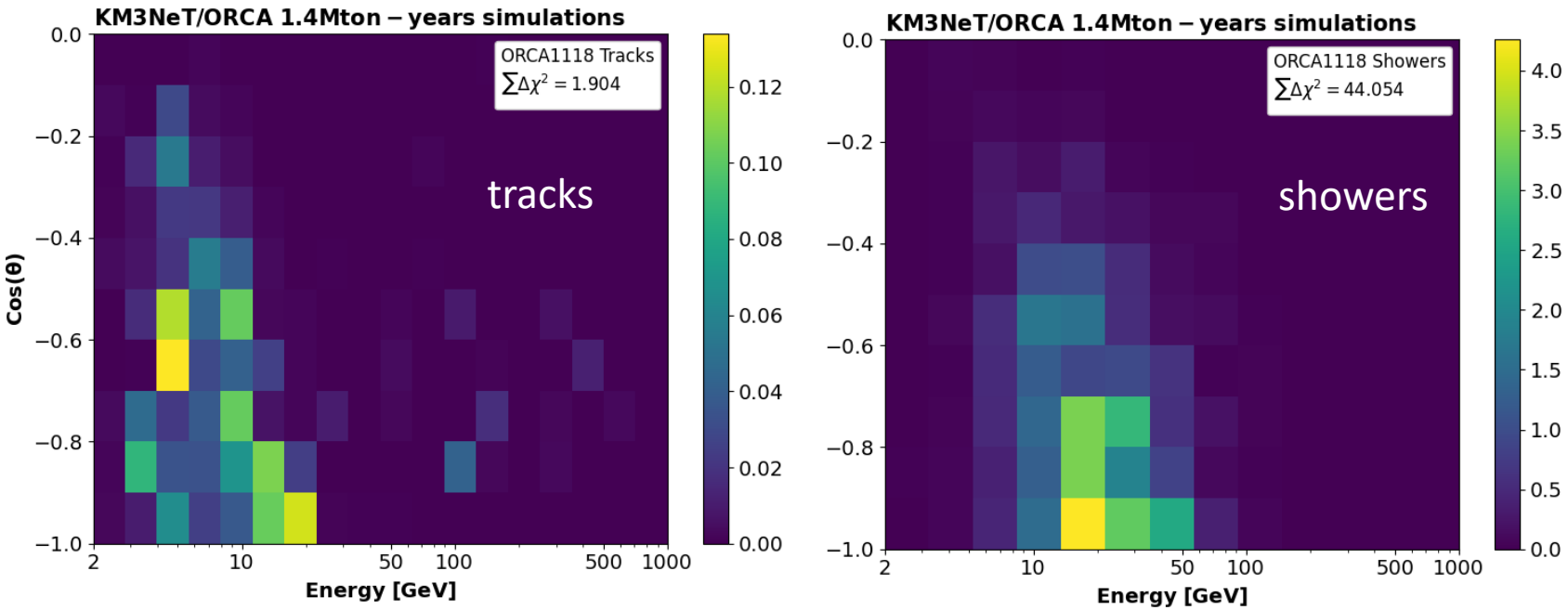
By the end of 2030 ORCA should have collected an exposure of 20 Mton-yr, corresponding to some 250000 neutrinos.

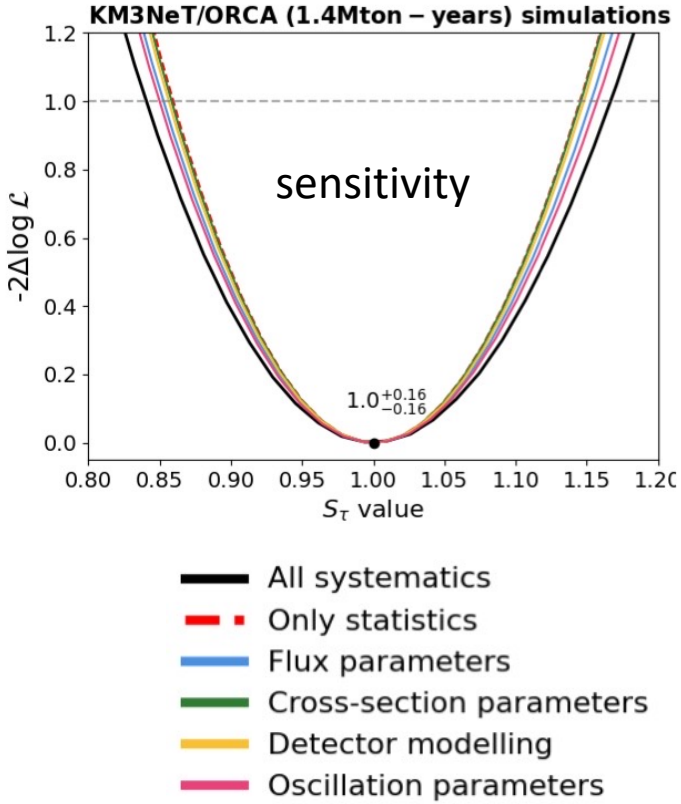
Still aim to improve reconstruction and classification at energies of 2-10 GeV.

Tau neutrino appearance

Tau neutrinos mostly originate from oscillations of muon neutrinos.
We leave the tau neutrino normalisation S_τ free in the fit.
Tau neutrinos are best visible in the shower sample.

Simulations: where does S_τ sensitivity come from?

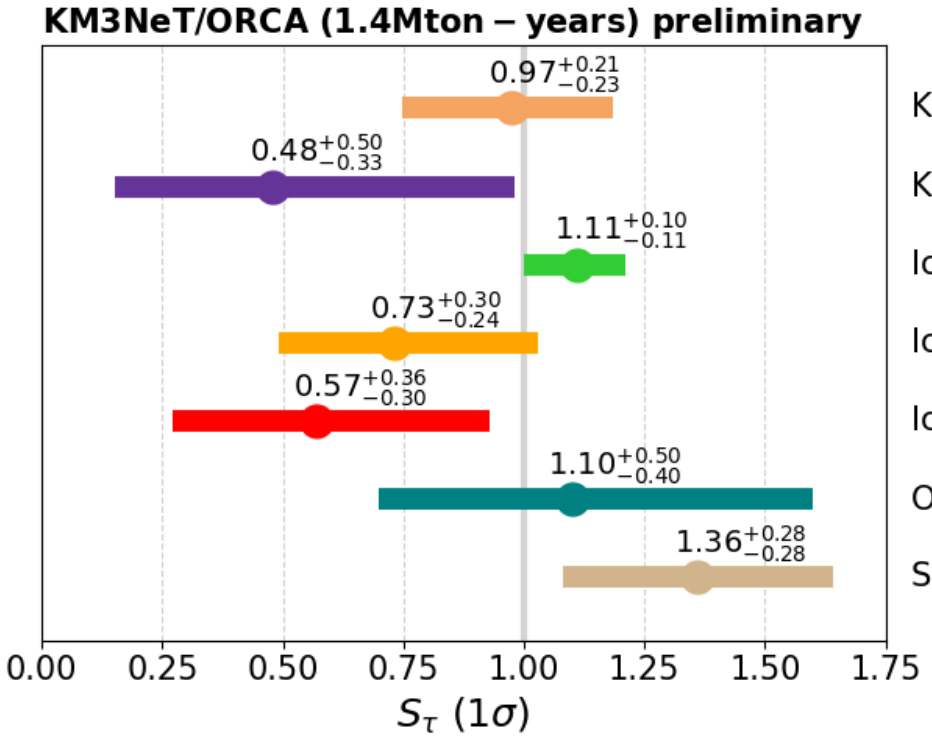


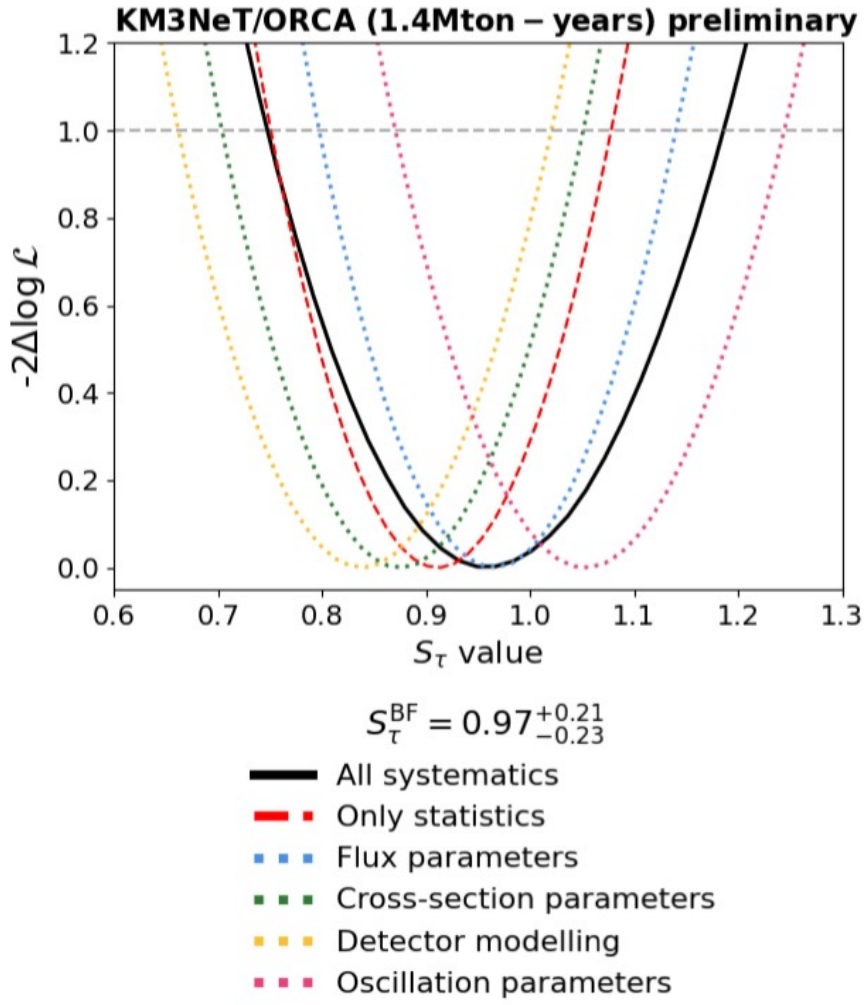


Tau neutrino appearance

Result: $S_\tau = 0.97^{+0.21}_{-0.23}$

$N_\tau = 680 \pm 150$



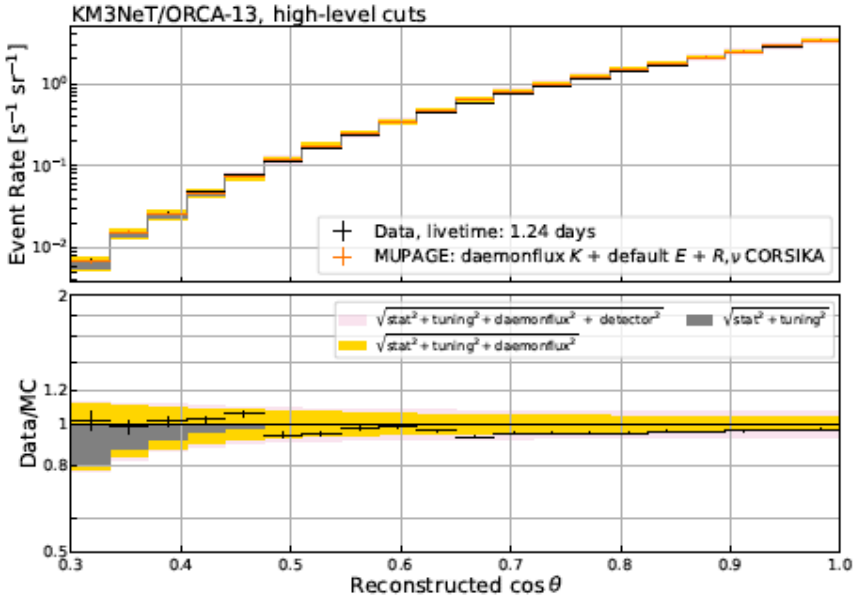


NMO Combination, flux

Good cooperation between IceCube and KM3NeT to come to a “neutrino telescope” NMO combination.
A major gain in sensitivity is then achieved by a combination with JUNO, also being prepared.

Common systematics to be studied: cross sections, flux.

Flux: our ORCA **neutrino data** was not well described by “Hybridflux” (based on Daemonfluxv1, but not available for ORCA site, and no geomagnetic effects included).



Good news: updated Daemonflux seems to describe our cosmic **muon data** much better. (Here shown for ORCA, but also for ARCA)

paper in preparation

Summary and conclusions

KM3NeT provides an infrastructure at two locations in the Mediterranean Sea
for neutrino physics and astronomy, for earth and sea sciences and marine biology.

KM3NeT is maturing (e.g. ESFRI Landmark status), and growing, with a plan to completion.

KM3NeT/ORCA is currently a 2.5 Mton water Cherenkov neutrino detector for atmospheric neutrinos with energies above 2 GeV, and will grow to 6.5 Mton in 2030.

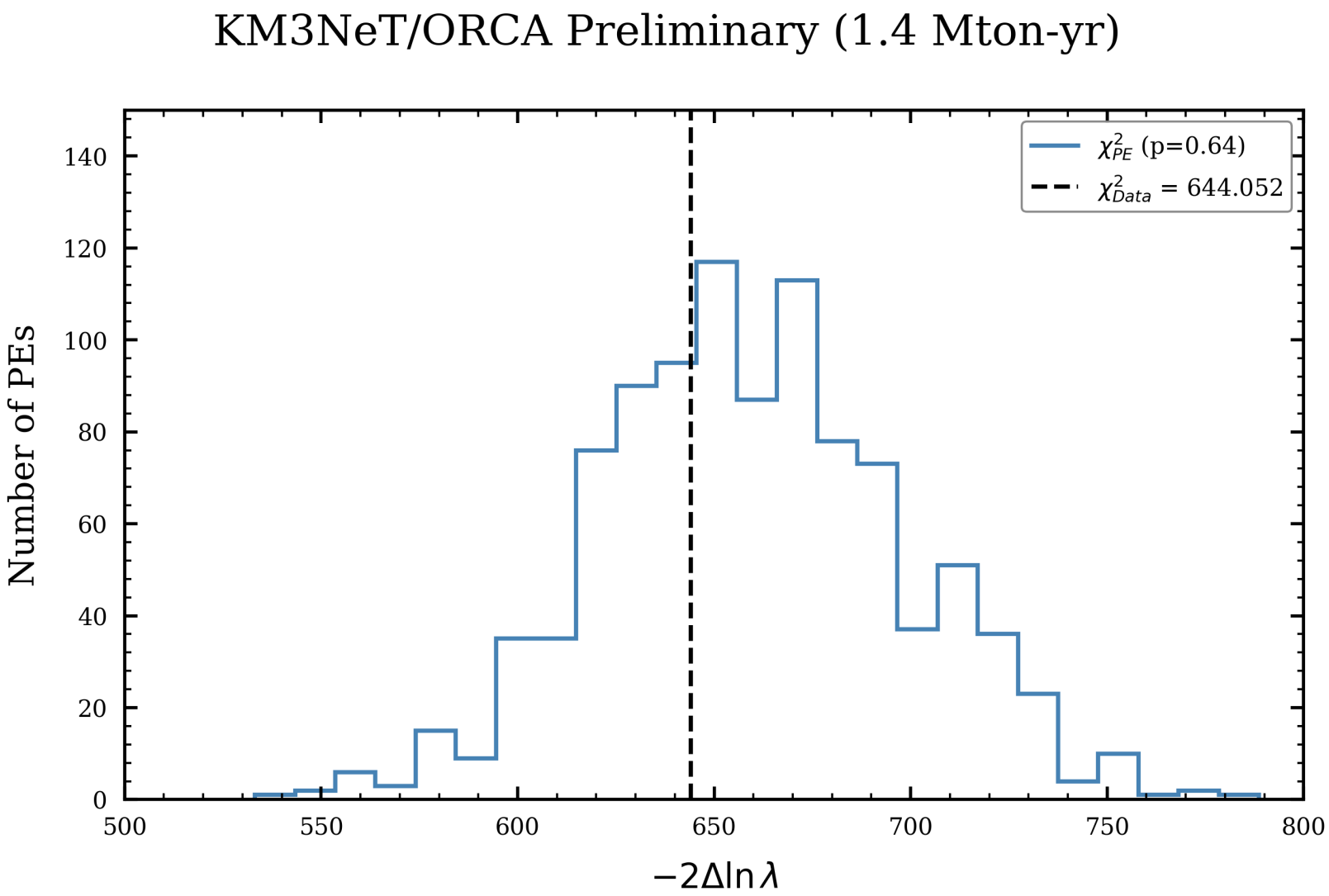
With the data of ORCA 6-18 (1.4 Mton-year exposure) we measure:

- $\sin^2\theta_{23} = 0.45^{+0.16}_{-0.05}, \Delta m^2_{31} = (-2.08^{+0.08}_{-0.09}) \cdot 10^{-3}$ eV^2
- ORCA alone: a small preference for Inverted Ordering; significance as expected for this exposure
- tau neutrino production, with scale factor $S_\tau = 0.97^{+0.21}_{-0.23}$

The outlook for oscillation physics with ORCA is excellent.
We look forward to further collaborate with IceCube/JUNO.

Backup Slides

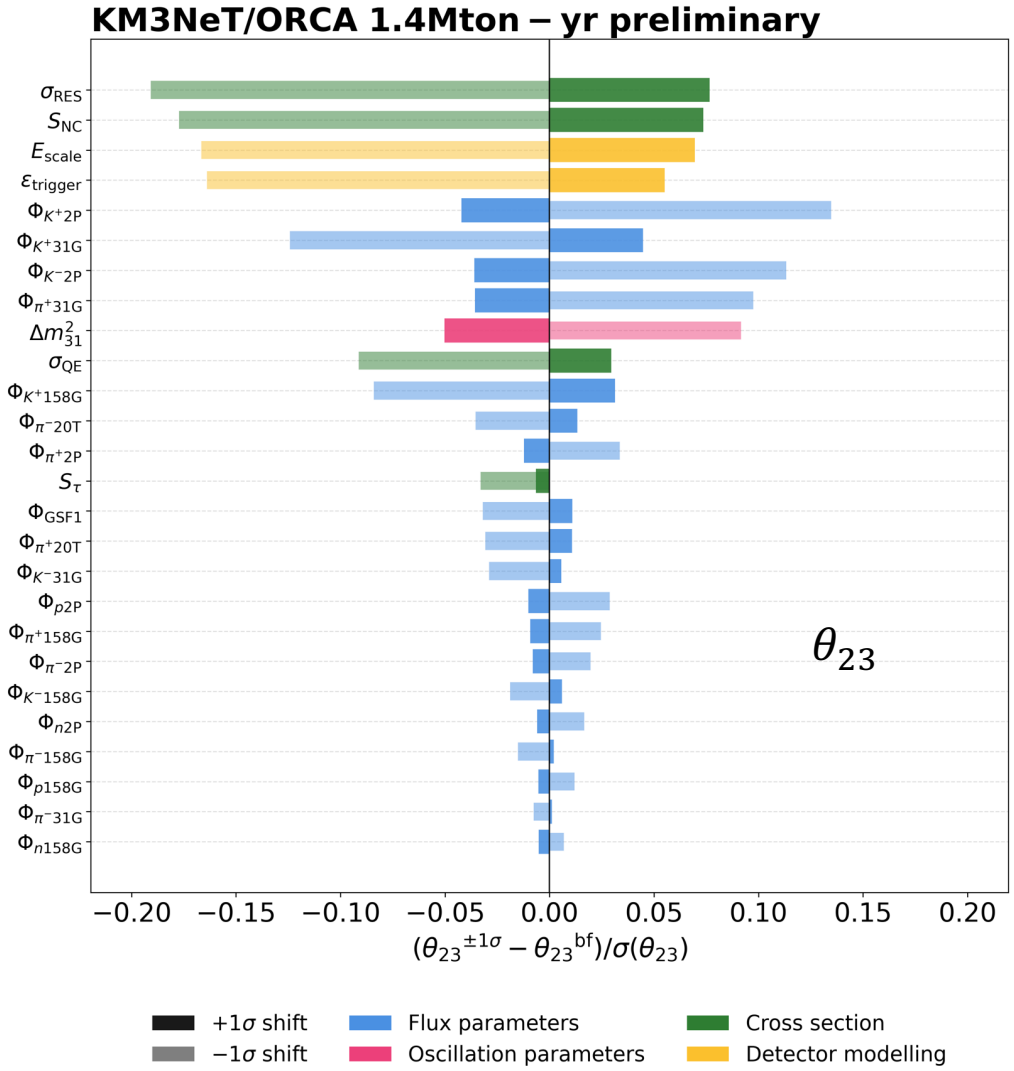
Goodness of Oscillations Fit

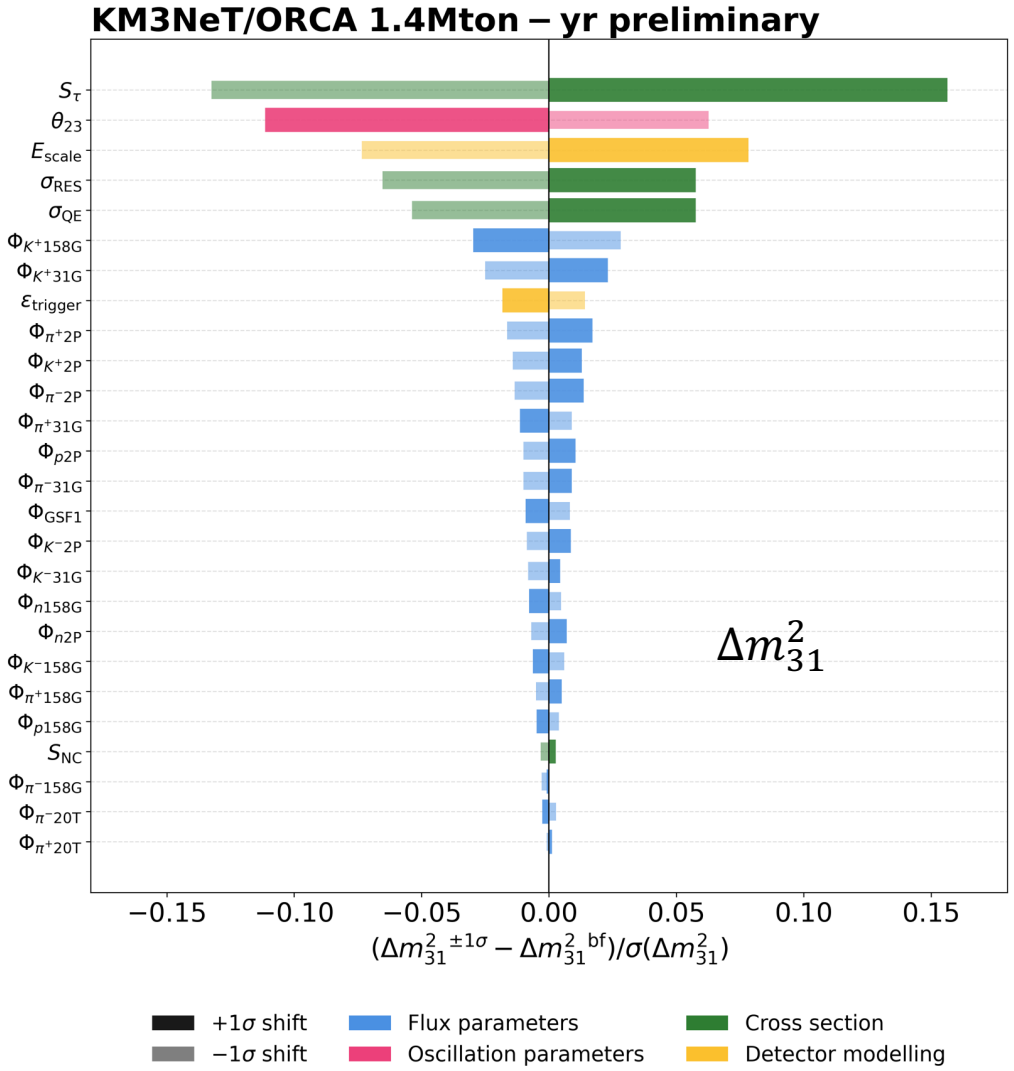


Fit results

Parameter	Pre-fit		Post-fit	
	Central value	σ_{prior}	Best-fit	1σ uncertainty
Oscillation parameters				
Δm^2_{31} $[10^{-3}$ eV$^2]$	2.51	—	-2.08	$^{+0.08}_{-0.09}$
$\sin^2\theta_{23}$	0.47	—	0.45	$^{+0.16}_{-0.05}$
Flux systematics				
Φ_{GSF_1}	0.0	±1.0	0.1	±0.9
$\Phi_{\text{K}^-_{158G}}$	0.0	±1.0	0.0	±1.0
$\Phi_{\text{K}^-_{2P}}$	0.0	±1.0	1.5	±0.7
$\Phi_{\text{K}^-_{31G}}$	0.0	±1.0	0.0	±1.0
$\Phi_{\text{K}^+_{158G}}$	0.0	±1.0	0.17	±1.0
$\Phi_{\text{K}^+_{2P}}$	0.0	±1.0	1.5	±0.7
$\Phi_{\text{K}^+_{31G}}$	0.0	±1.0	-0.19	±1.0
$\Phi_{\pi^-_{158G}}$	0.0	±1.0	-0.18	±1.0
$\Phi_{\pi^-_{20T}}$	0.0	±1.0	-0.81	±0.9
$\Phi_{\pi^-_{2P}}$	0.0	±1.0	-0.24	±1.0
$\Phi_{\pi^-_{31G}}$	0.0	±1.0	0.0	±1.0
$\Phi_{\pi^+_{158G}}$	0.0	±1.0	-0.21	±1.0
$\Phi_{\pi^+_{20T}}$	0.0	±1.0	-0.8	±0.9
$\Phi_{\pi^+_{2P}}$	0.0	±1.0	-0.15	±1.0
$\Phi_{\pi^+_{31G}}$	0.0	±1.0	0.1	±1.0
$\Phi_{\text{n}_{158G}}$	0.0	±1.0	0.0	±1.0
$\Phi_{\text{n}_{2P}}$	0.0	±1.0	0.11	±1.0
$\Phi_{\text{p}_{158G}}$	0.0	±1.0	0.0	±1.0
$\Phi_{\text{p}_{2P}}$	0.0	±1.0	0.18	±1.0
Cross-section systematics				
S_{NC}	1.0	±0.2	1.2	±0.18
S_τ	1.0	±0.2	1.0	±0.15
σ_{QE}	0.0	±1.0	0.6	±0.9
σ_{RES}	0.0	±1.0	0.4	±0.9
Detector systematics				
E_{scale}	-0.1	±0.1	-0.05	±0.03
$\epsilon_{\text{trigger}}$	-1.0	±1.0	-1.2	±0.5

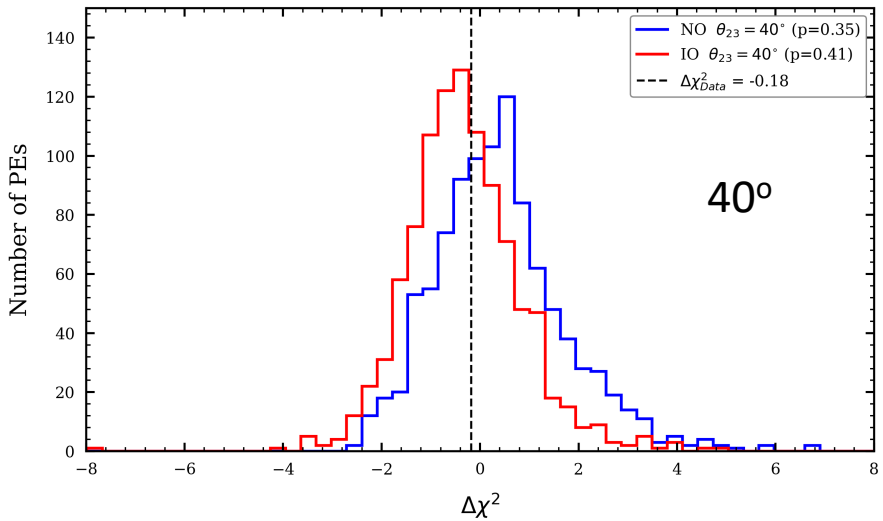
Systematics Impact



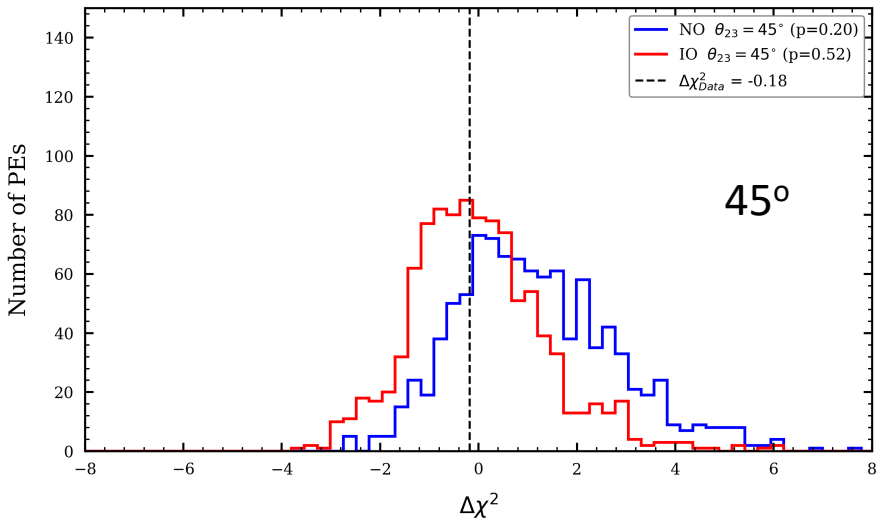


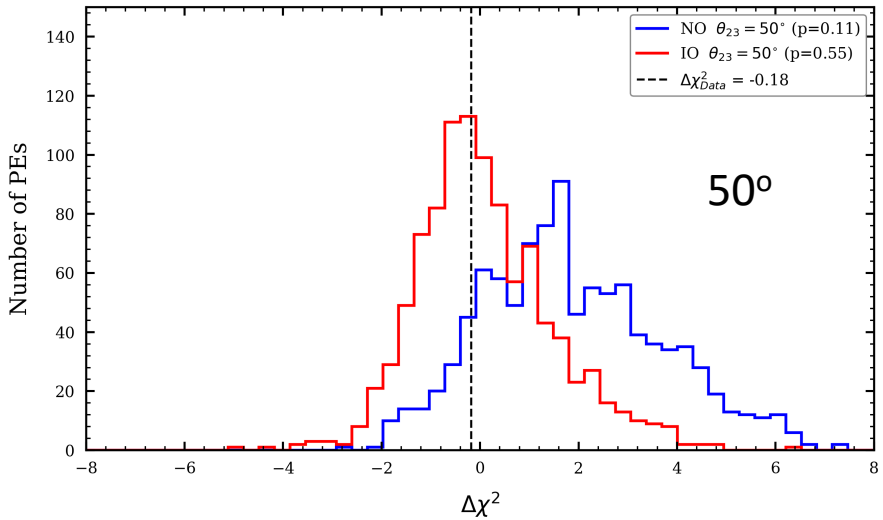
NMO sensitivity for various θ_{23}

KM3NeT Preliminary

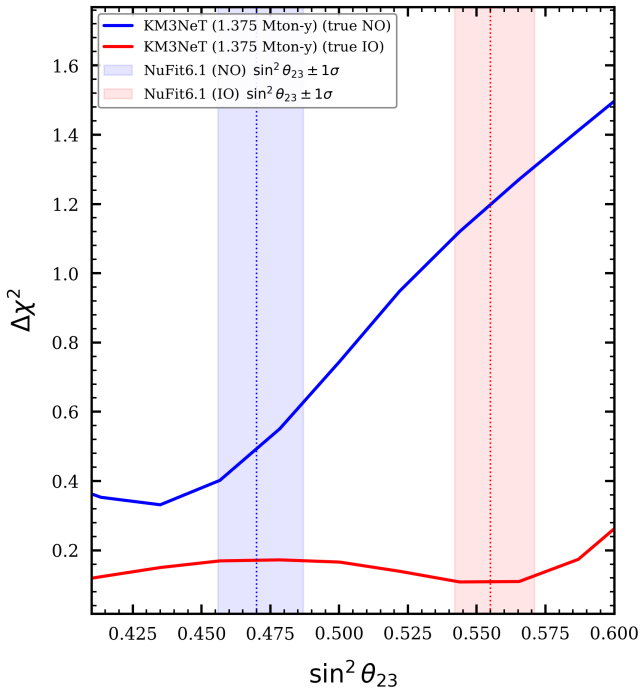


KM3NeT Preliminary





KM3NeT Preliminary

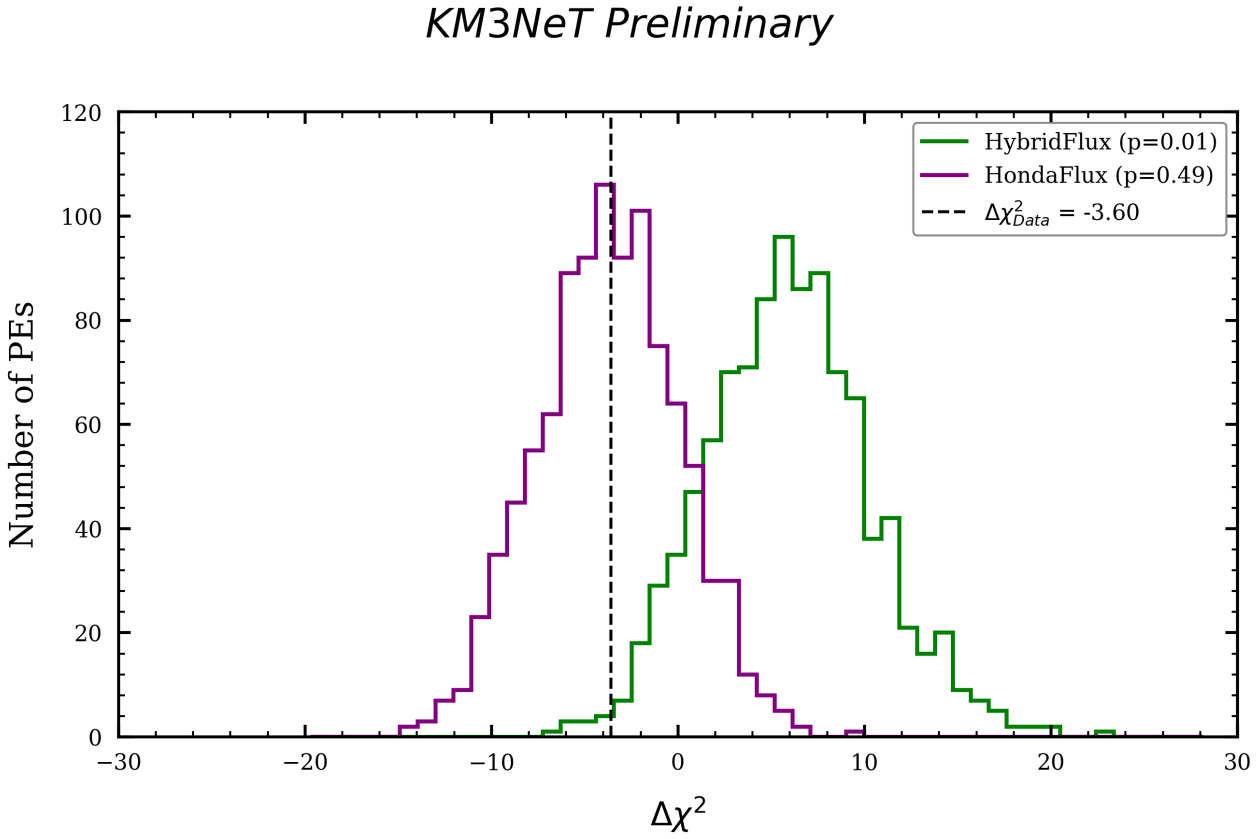


Flux preference

Fit on data prefers Honda by $\Delta\chi^2 = 3.6$

Generating pseudo-experiments with NuFit6.1 parameters, looking at $\Delta\chi^2$ between fitting with Honda and fitting with HybridFlux, and comparing with the actual fit in our data, we observe:

p(Honda flux) = 0.49
p(HybridFlux) = 0.01

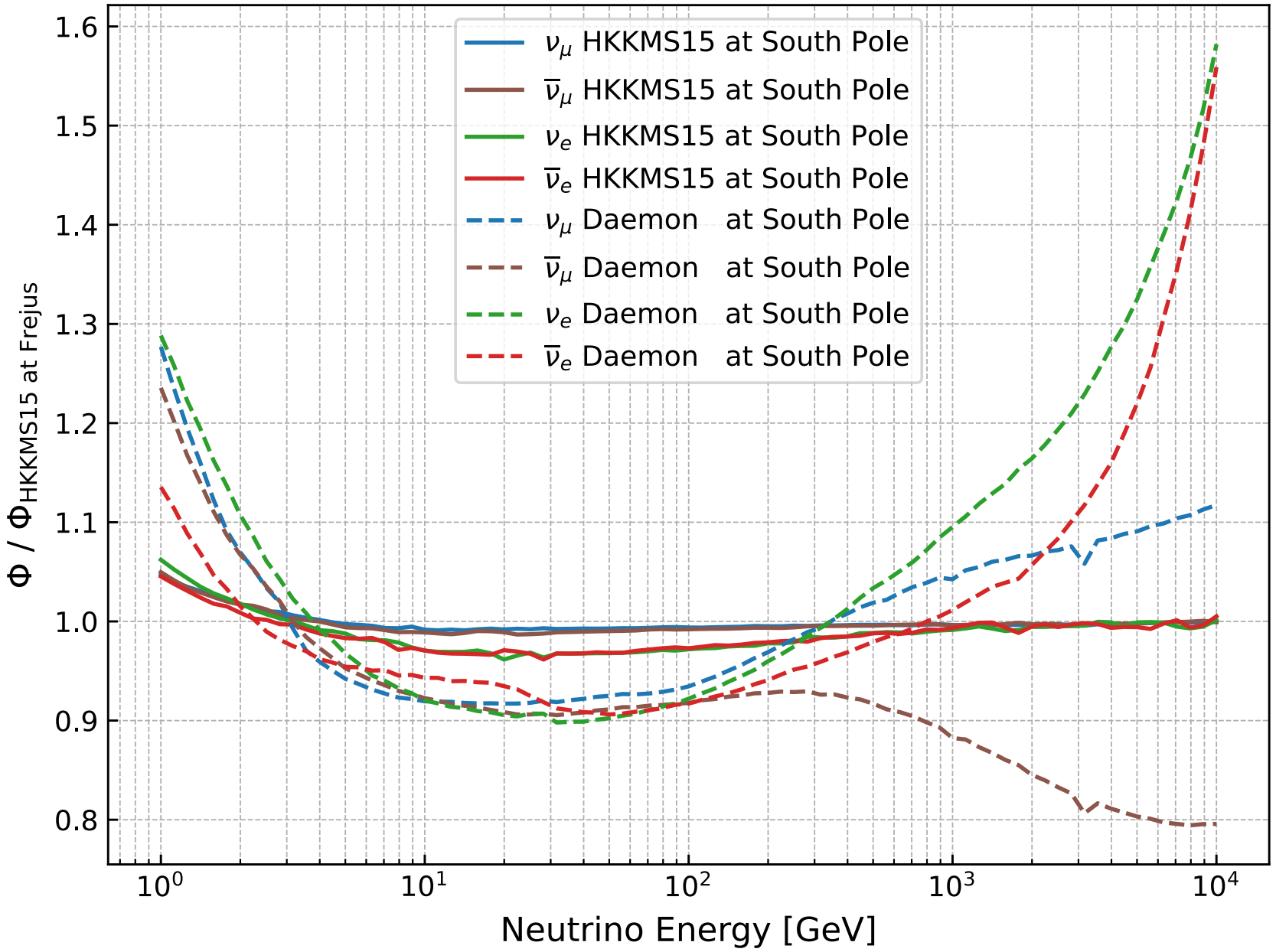


We know HybridFlux is not complete yet:

- evaluated at South Pole, not ORCA location
- no geomagnetic effects
- large difference with Honda at low energies, to be understood.

We look forward to a future DaemonFlux with all these implemented.

Flux ratios


ν_μ HKKMS15 at South Pole
$\overline{\nu}_\mu$ HKKMS15 at South Pole
ν_e HKKMS15 at South Pole
$\overline{\nu}_e$ HKKMS15 at South Pole
ν_μ Daemon at South Pole
$\overline{\nu}_\mu$ Daemon at South Pole
ν_e Daemon at South Pole
$\overline{\nu}_e$ Daemon at South Pole
Φ / $\Phi_{\text{HKKMS15 at Frejus}}$
Neutrino Energy [GeV]
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
10^0
10^1
10^2
10^3
10^4

Water absorption length, PMT Quantum Efficiency

