



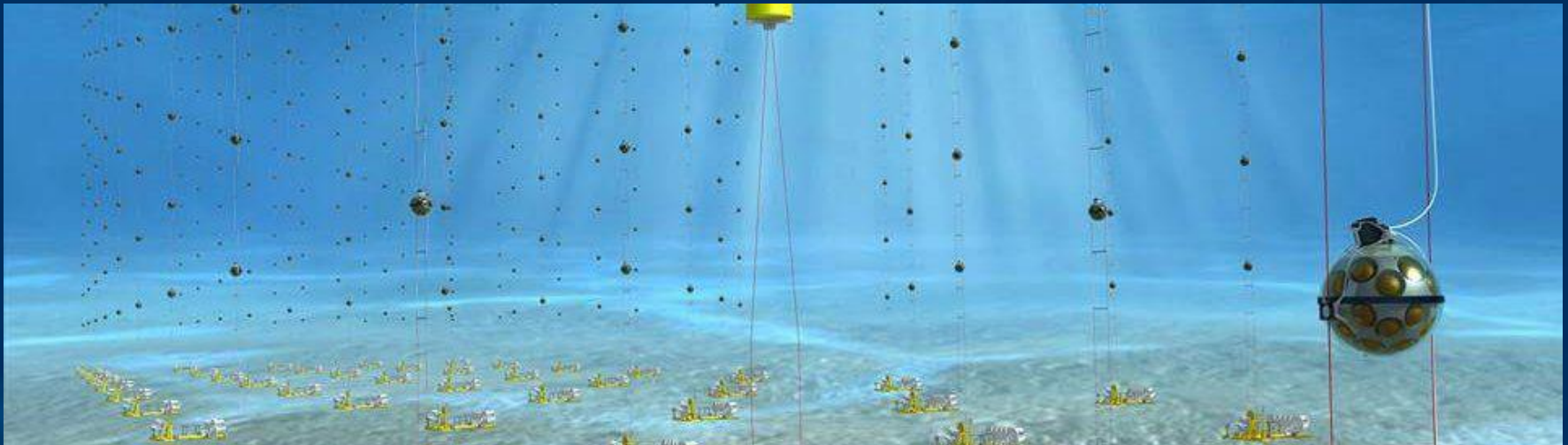
Measuring neutrino oscillations with KM3NeT ORCA

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on behalf of KM3NeT



KM3NeT ORCA

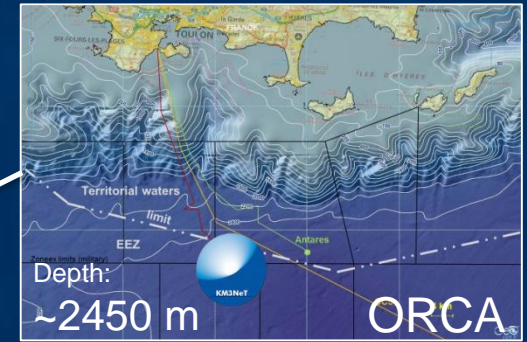
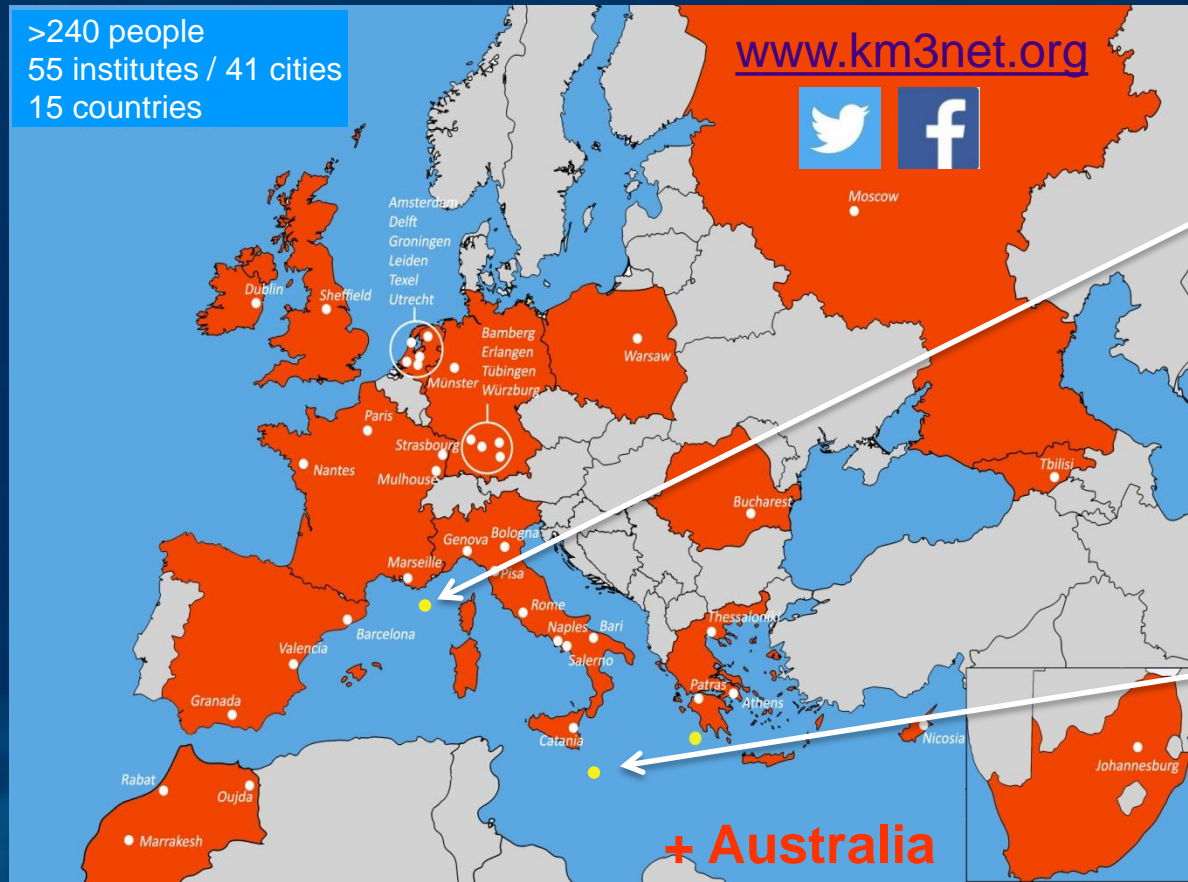
- ▣ Large, deep detector in the Mediterranean Sea
- ▣ Unique opportunity to study oscillations of atmospheric neutrinos
- ▣ Rich physics program
- ▣ Multi-disciplinary observatory on the bottom of the sea



KM3NeT: the next generation Neutrino Telescopes in the Mediterranean

A distributed research infrastructure with 2 main physics topics:

>240 people
55 institutes / 41 cities
15 countries



Oscillation Research
with Cosmics In the Abyss

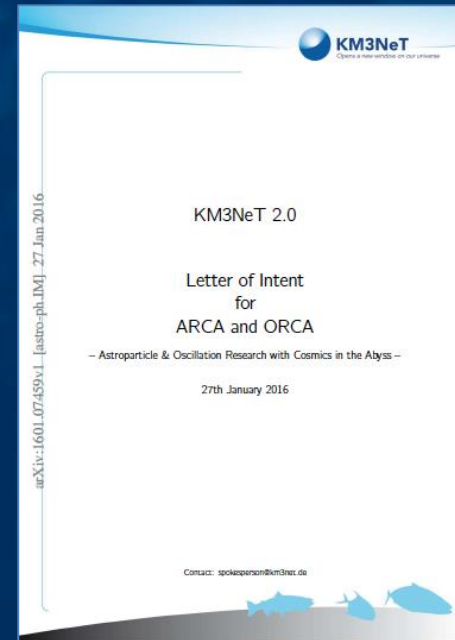


Astroparticle Research
with Cosmics In the Abyss

Single Collaboration, Single Technology

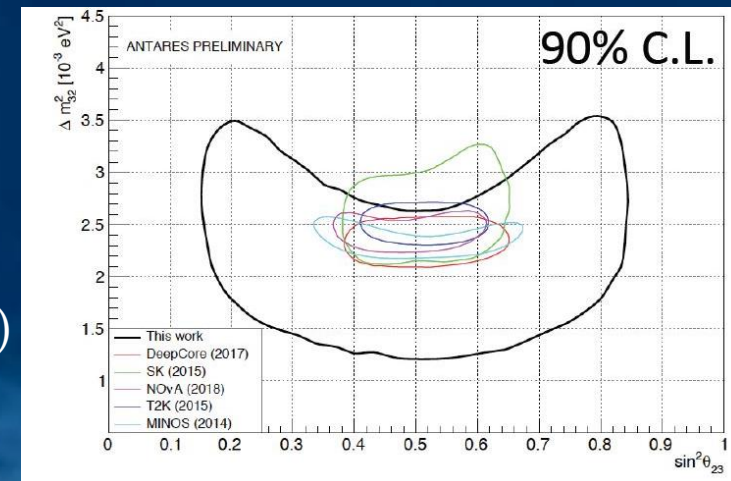
Background

- Letter of Intent (including optimization of detector layout based on benchmark detector)
 - *S. Adrián-Martínez et al., J. of Phys. G: Nuclear and Particle Physics, 43 (8), 084001, 2016 – KM3NeT Letter of Intent [LoI]*
- Powerful event reconstruction method implemented, reaching close to the achievable limit
 - *S. Adrián-Martínez et al., JHEP 05 (2017) 008*



- Building on the expertise acquired with ANTARES (non-optimized for neutrino oscillations!)

Latest results from ANTARES



The ORCA detector

Digital Optical Module (DOM)

← 17" →



31 x 3"
PMTs

Bottom view
of a DOM

- Uniform angular coverage
- Directional information
- Digital photon counting
- Wide angle of view
- Optimal background rejection
- All data to shore

~8 Mt instrumented
115 strings (detection units, DUs)
18 DOMs / DU (~50 kt ~ 2 × SK)
31 PMTs / DOM (~3 kt ~ MINOS)
Total: 64k x 3" PMTs

Inter-DU:
~23 m

Inter-DOM:
~9 m

~200 m

~225 m

Depth = 2450 m

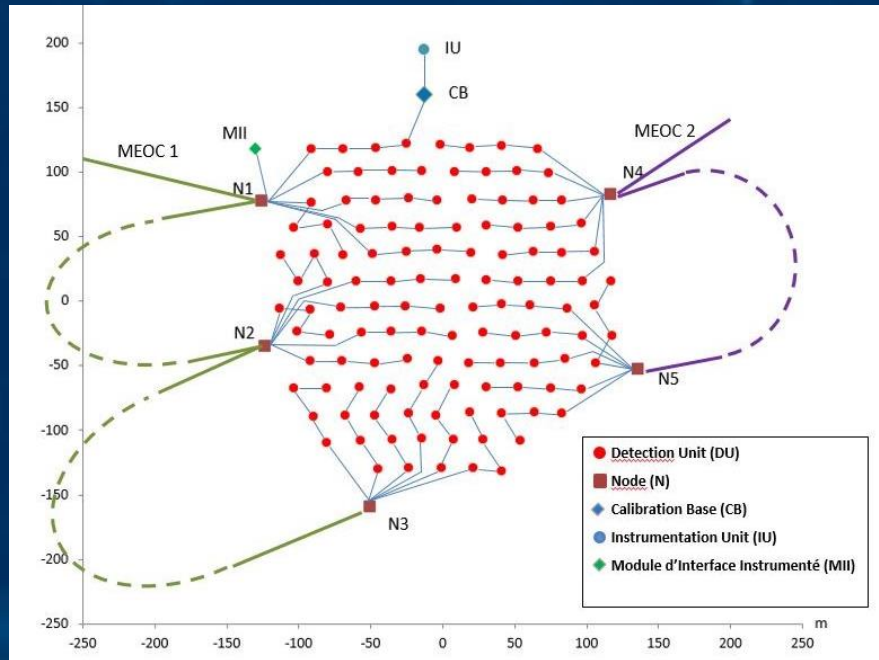
Light absorption length ~ 60 m



More on detector layout (and simulations)

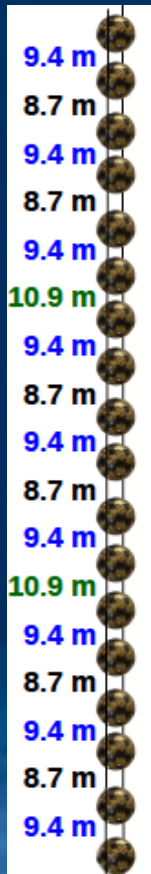
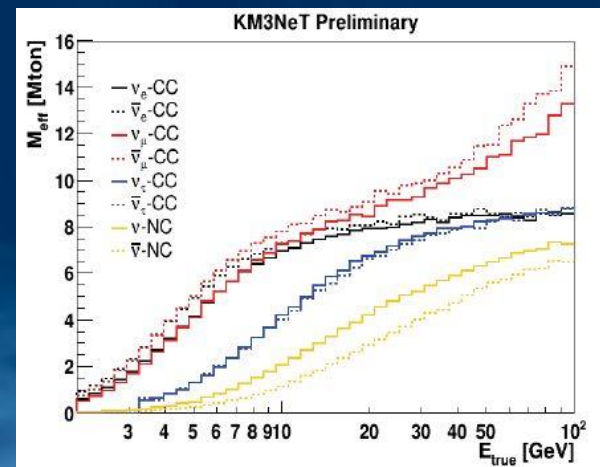
Detailed simulations ongoing to study the detector performance with final layout:

Geometry	Vertical spacing (between DOM)	horizontal spacing (between strings)
LoI-based	9 m on average with alternate 6 m and 12 m	20 m
New	realistic (9 m average)	23 m



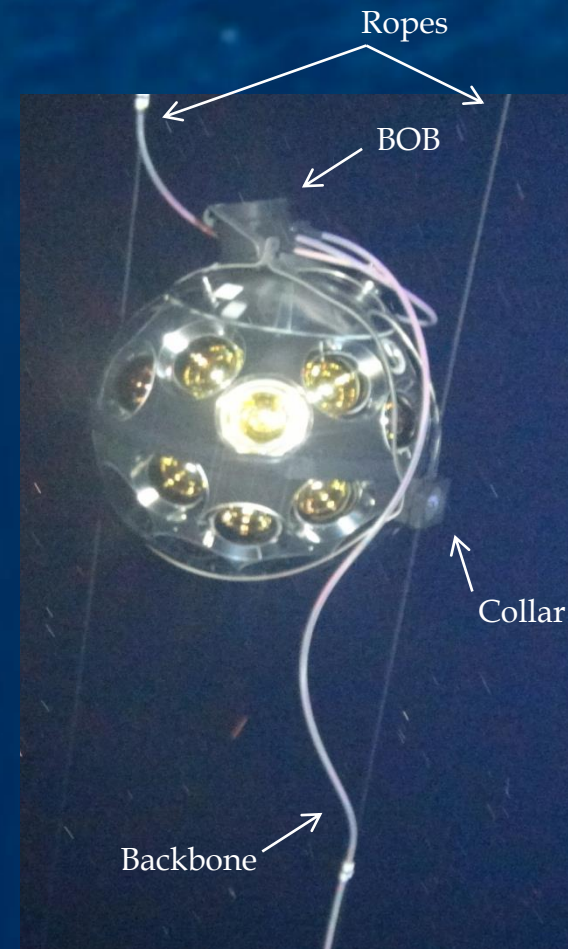
← All technical constraints included in simulations →

Instrumented volume:
from 5.7 Mton (LoI) to ~8 Mton
(with same number of DOMs)



ORCA DOMs and DUs

- 31 PMTs of 3" photocathode, each equipped with a 1" reflection ring, optically coupled to the glass sphere, in each DOM
- Electronics, optics for long-range communications and calibration devices (including: 'nanobeacon' LED pulser, compass/tiltmeter, and piezo-sensor for acoustic measurements) installed inside the sphere – each DOM acting as an individual, autonomous detection node
- Connection to the rest of the apparatus requires two conductors (+12 V power) and one optical fibre through a single penetrator
- The DOM is mounted in a collar, which is attached to two ropes running from an anchor on the sea floor to a top (submersed) buoy
- A backbone, built with an oil-filled pressure-balanced hose, connects all DOMs to a DU interface module placed on the anchor – the connection between consecutive segments of the backbone and the DOM is made through a Break-out Box (BOB), which hosts a DC/DC converter and breaks out the fibre and the power leads to the DOM



DOM14 of ORCA-DU1
(depth: ~2300 m)

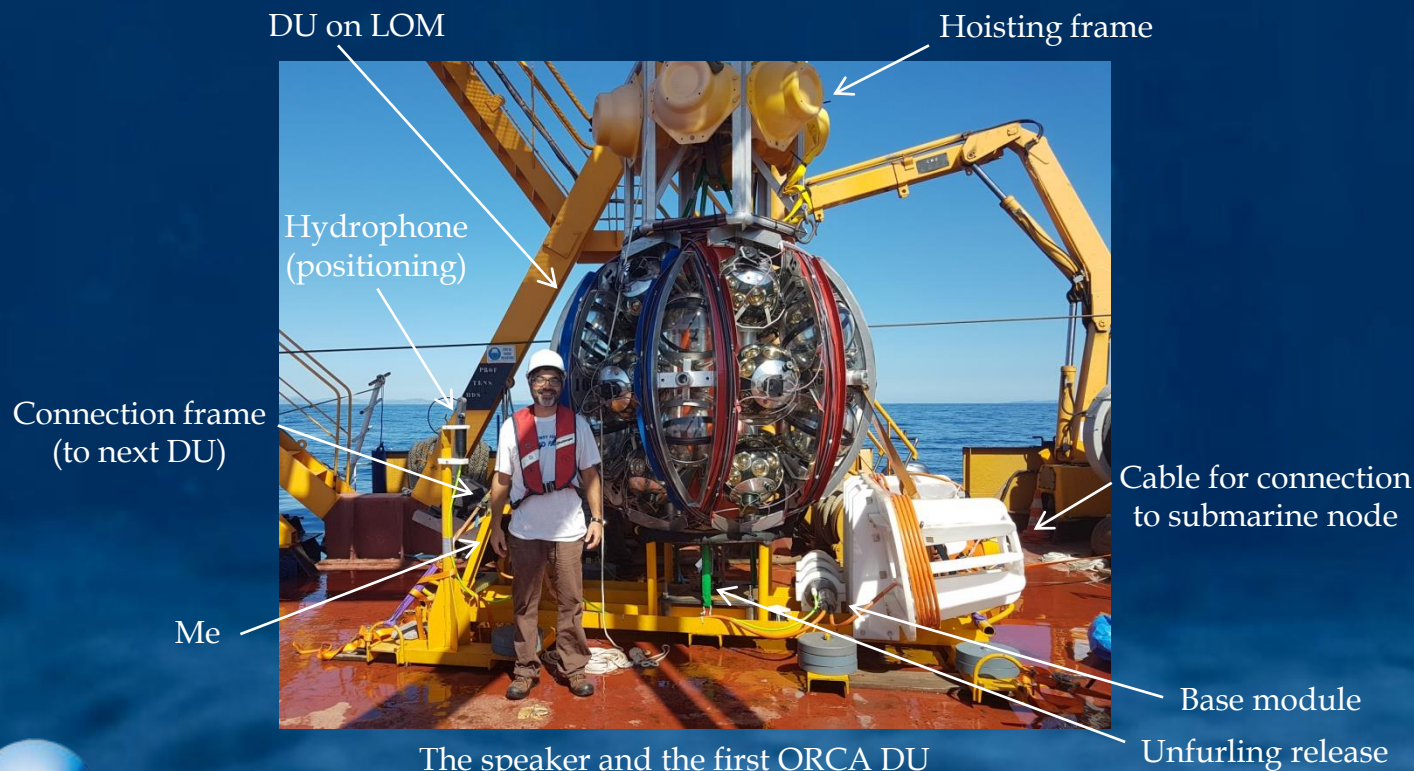
Performance of prototype DOMs in deep sea have been published in:

- *S. Adrián-Martínez et al., Eur. Phys. J. C 74 (2014) 3056*
- *S. Adrián-Martínez et al., Eur. Phys. J. C 76 (2016) 54*



ORCA DOMs and DUs (cont.)

- The DU is packed on a launcher vehicle (LOM) and installed on the anchor
- After deployment on sea bed, unfurling is triggered by opening a ROV-operable release
- LOM and hoisting frame are recovered after unfurling



The speaker and the first ORCA DU on the installation ship (21 Sept. 2017)



DU unfurling

Installation of first ORCA DU, Sept. 2017

Operation performed with 2 ships

A deployment ship (Foselev Castor) transports sets of (up to) 4 detection units, in packed configuration, and installs them on the sea floor

Ship controlled with Dynamic Positioning

Accuracy of installation of detection units:
within ~1 m from target position



Credit: CNRS Images



← A ROV (Remotely Operated Vehicle) is controlled from a second ship (Comex Janus) to:
Assist deployment of structures on the sea bed (at proper location and with proper orientation)

Perform submarine connections

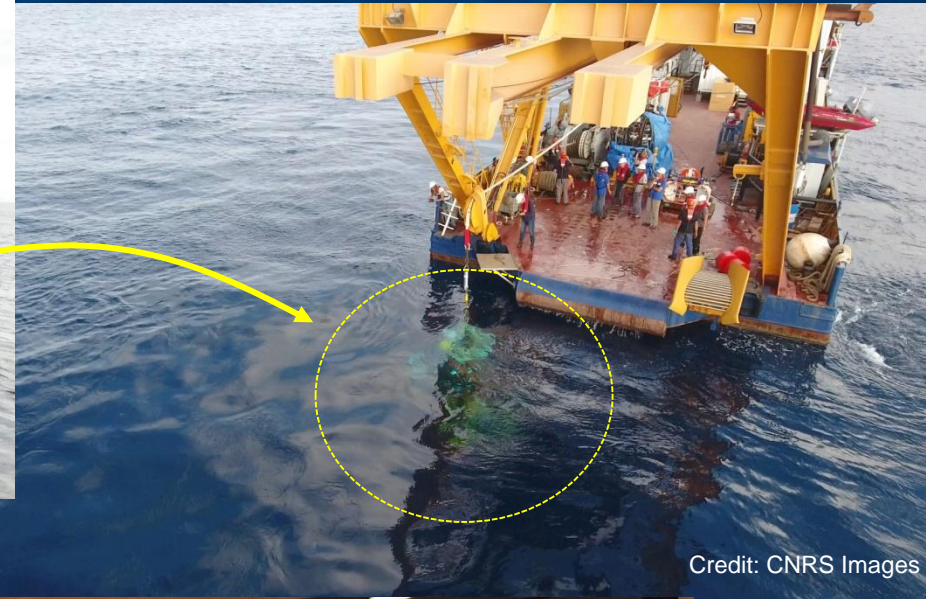
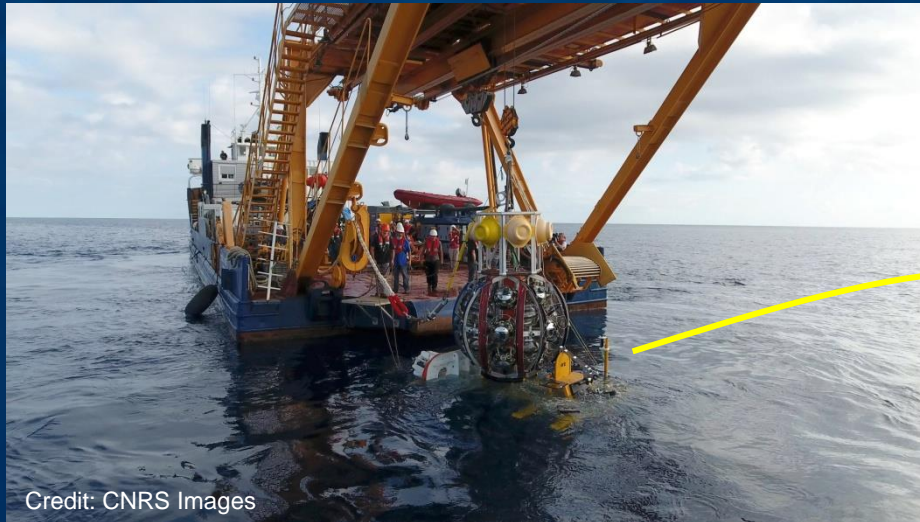
Trigger DU unfurling

Inspect the structure after unfurling

The ROV Apache of COMEX,
operated from the Janus



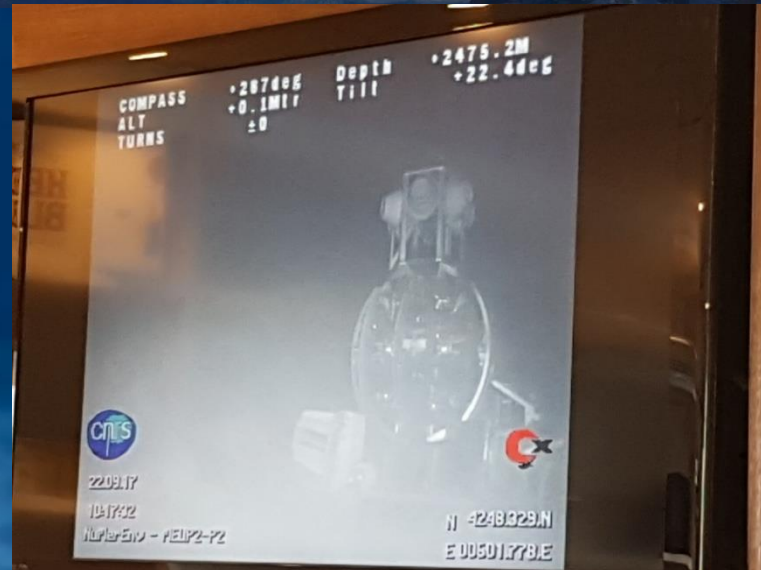
Installation of first ORCA DU, Sept. 2017 (cont.)



The DU is overboarded from the back deck and transferred to the deep-sea winch

The journey to the abyss is started!

The meeting with the ROV is at the sea bed
(credit: COMEX)



Installation of first ORCA DU, Sept. 2017 (cont.)



Wet-mateable connectors on the submarine node

After connection to the submarine node,
the DU is tested and then unfurled to reach its full size.

**Data taking with the first ORCA DU started
Friday 22 Sept, 10:20 p.m. CEST**

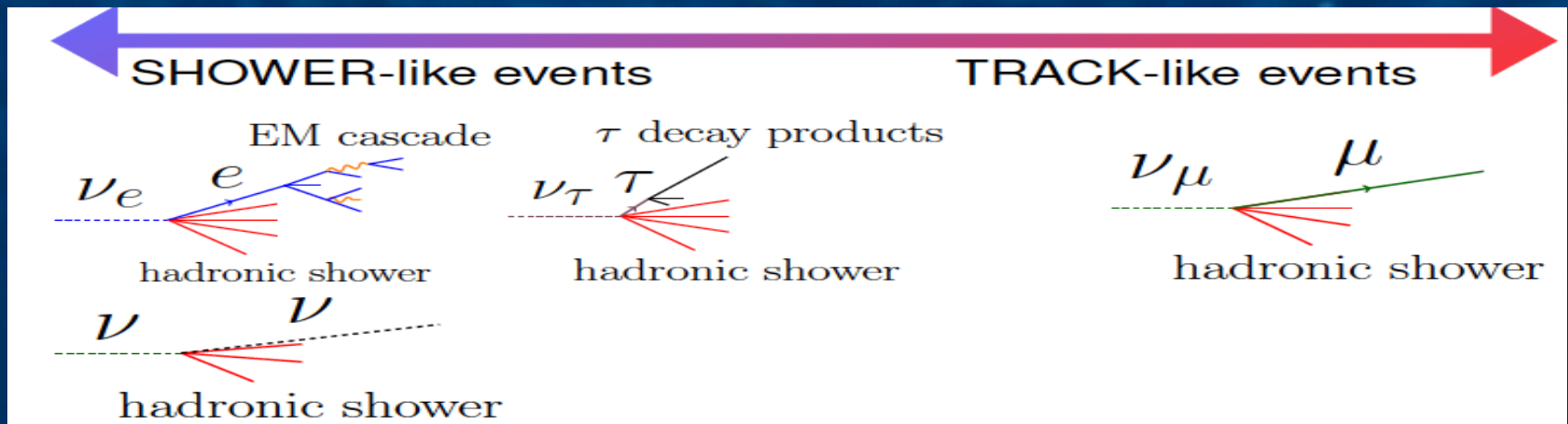


Inspection of the DU after unfurling

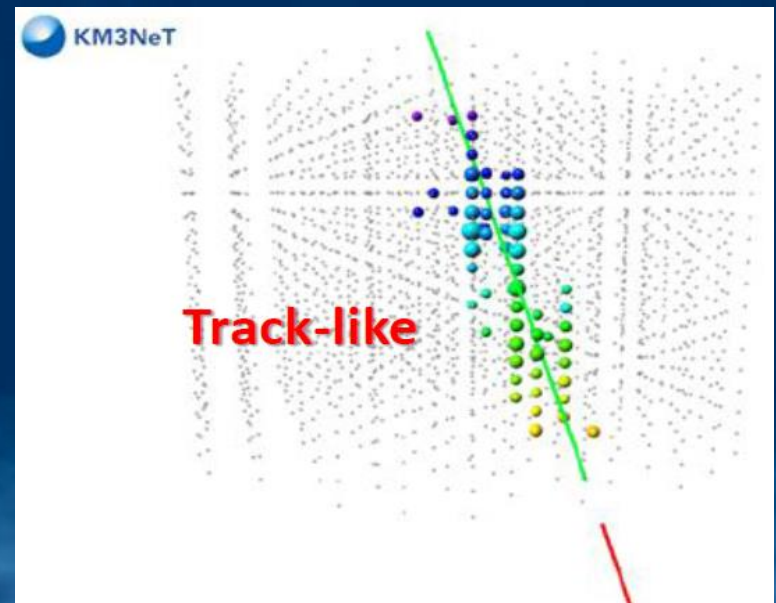
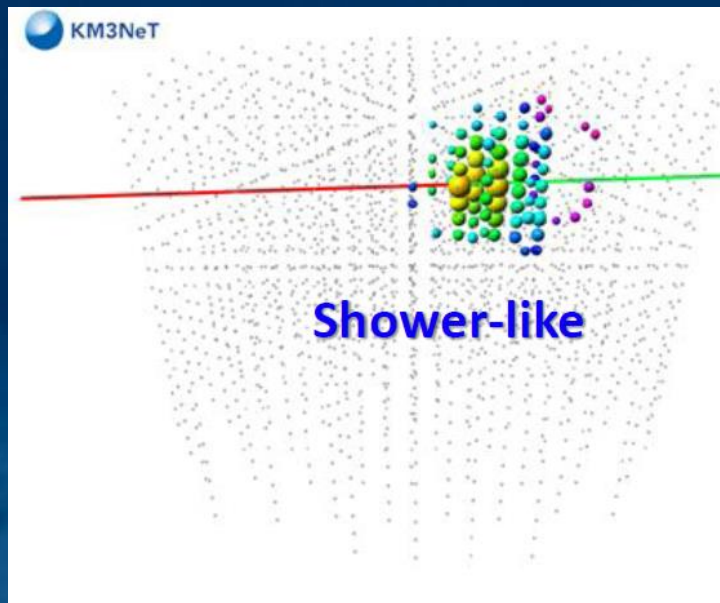


The LOM is recovered after unfurling

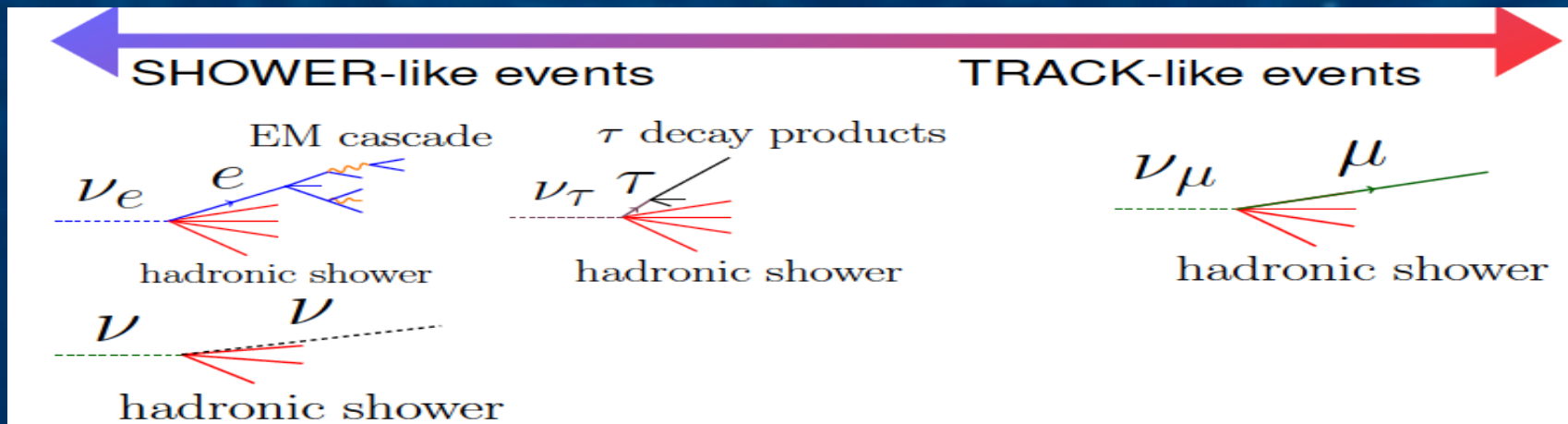
Event reconstruction in ORCA



Discrimination of tracks, showers and atmospheric muons (~%) via RDF



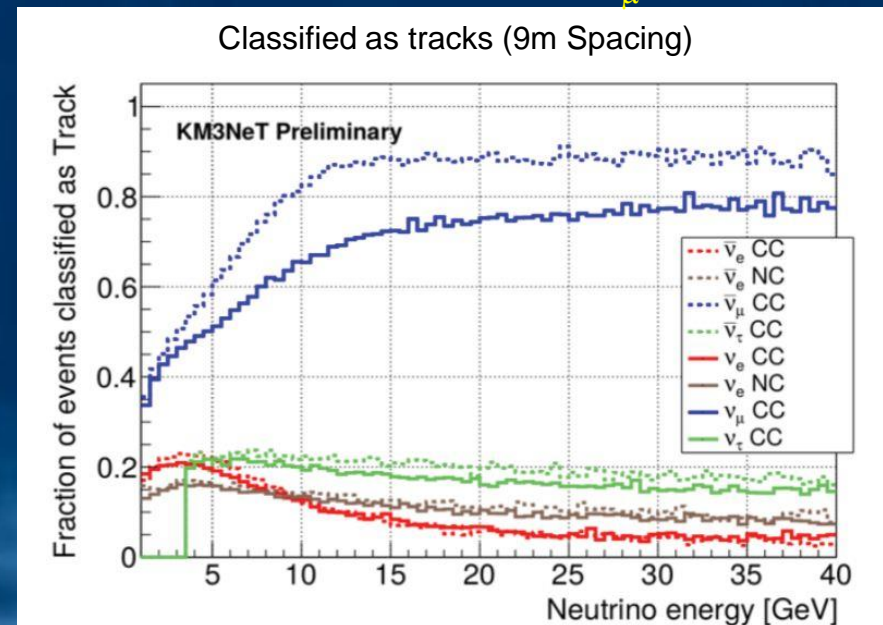
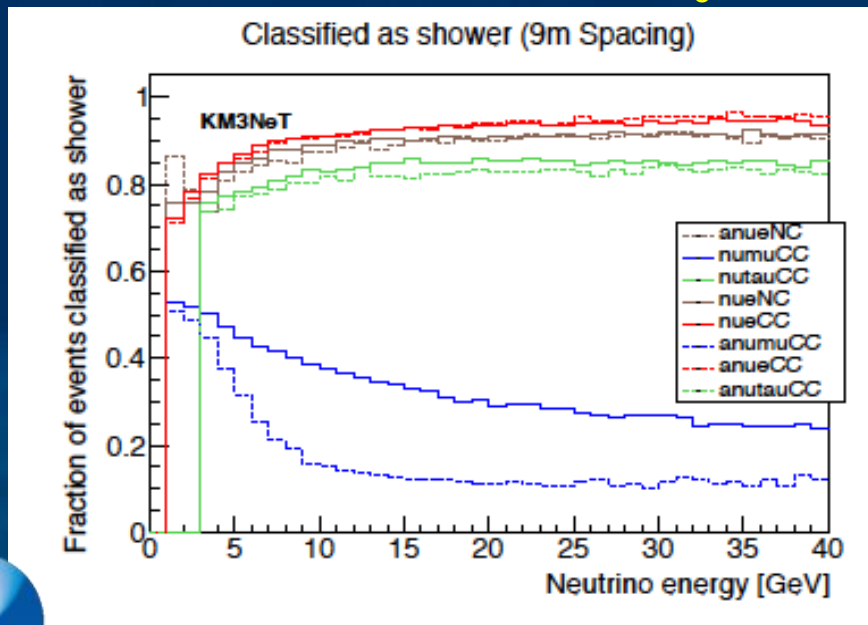
Event reconstruction in ORCA



At 10 GeV:

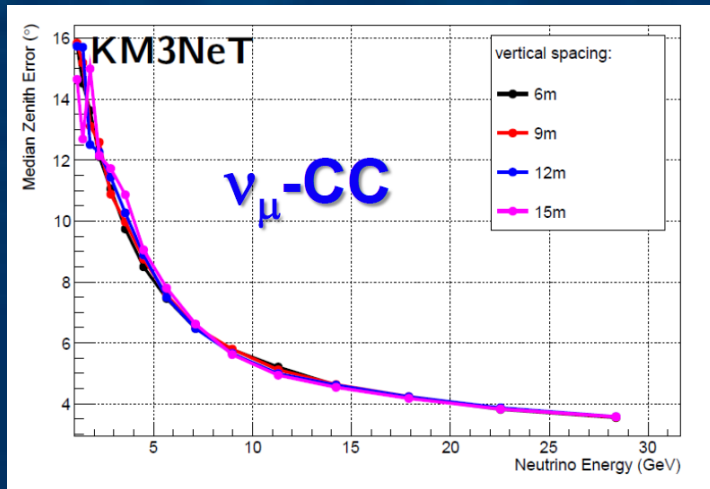
~90% correct ID of ν_e^{CC}

~70% correct ID of ν_μ^{CC}

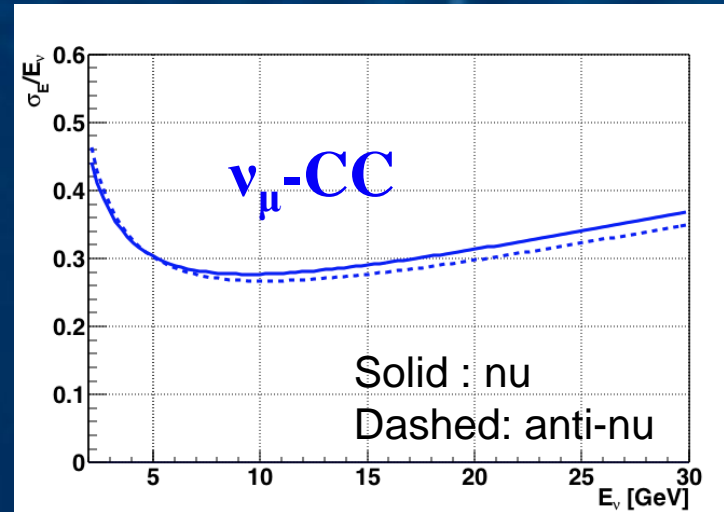


Reconstruction performance

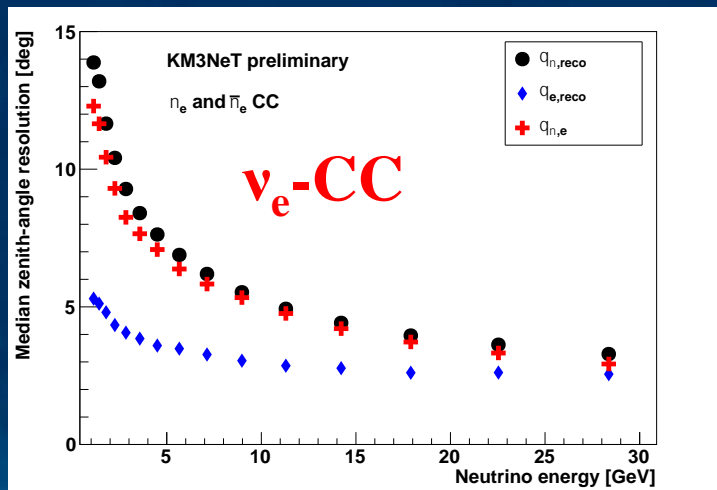
θ Res.



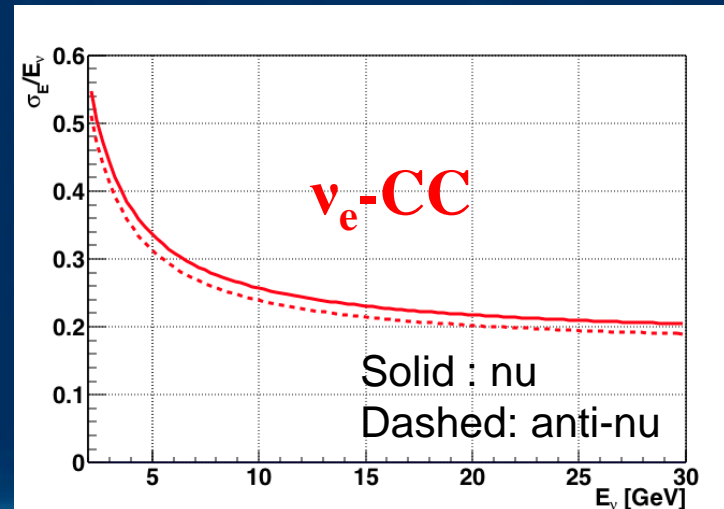
E Res.



θ Res.



E Res.



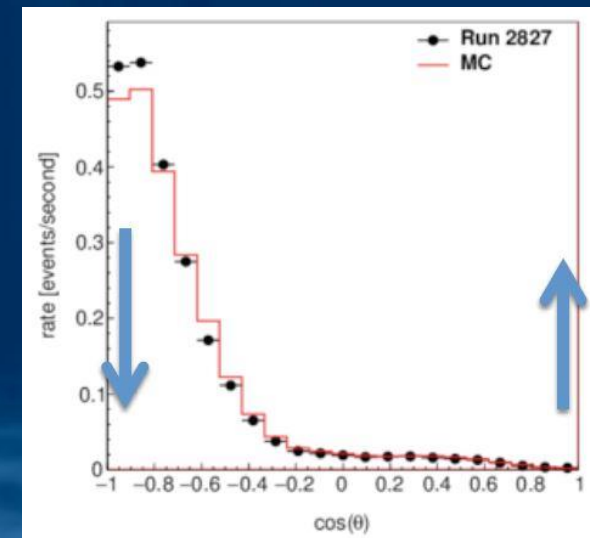
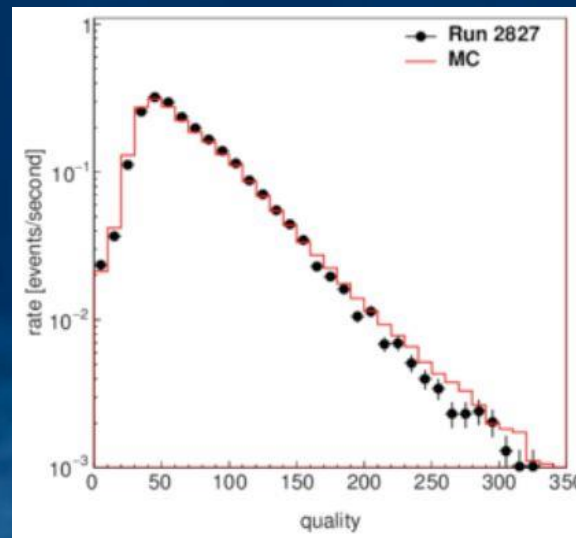
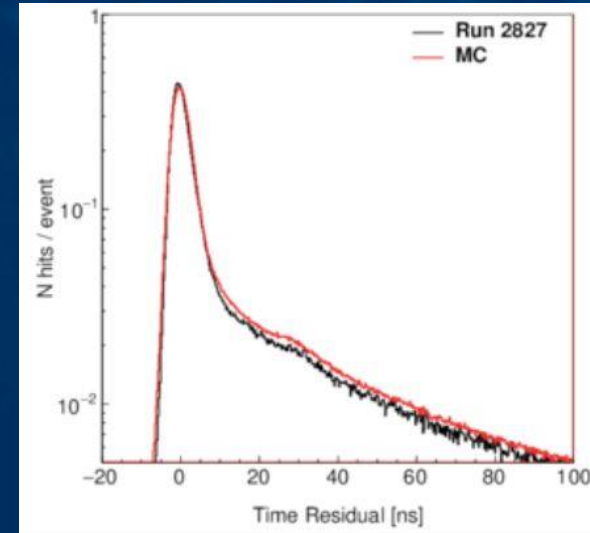
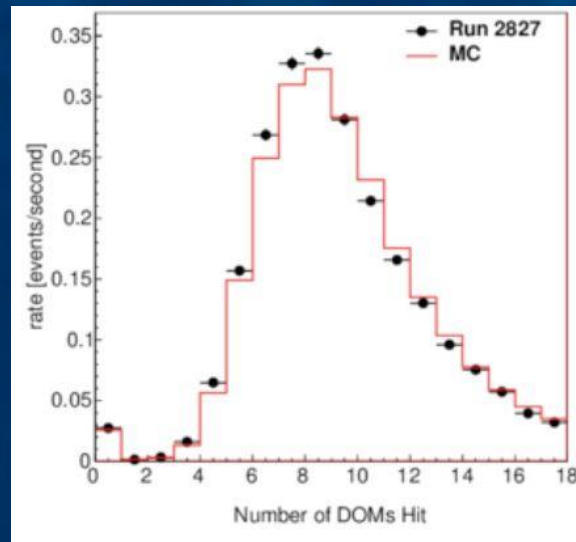
7°(5°) for 5(10) GeV for both channels
Dominated by kinematic smearing

Energy resolution below 30%
in relevant energy range



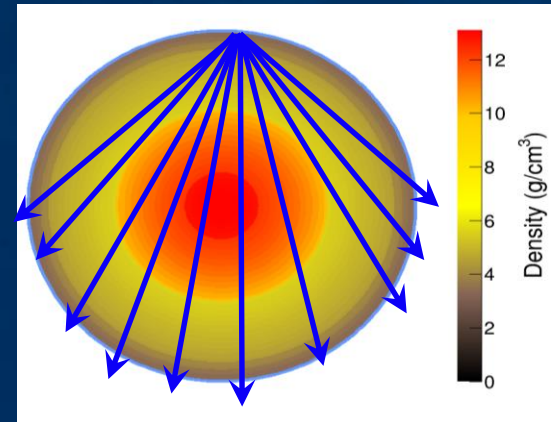
Data from the first ORCA DU

All plots
KM3NeT prel.



Neutrino mass hierarchy with ORCA

- A “free beam” of known composition (ν_e, ν_μ)
- Wide range of baselines (50 \rightarrow 12800 km) and energies (GeV \rightarrow PeV)
- Oscillation affected by matter (ordering-dependent):
maximum difference IO vs. NO at $\theta = 130^\circ$ (7645 km) and $E_\nu = 7$ GeV
- Opposite effects on neutrinos and anti-neutrinos: $\text{IO}(\nu) \approx \text{NO}(\text{anti-}\nu)$

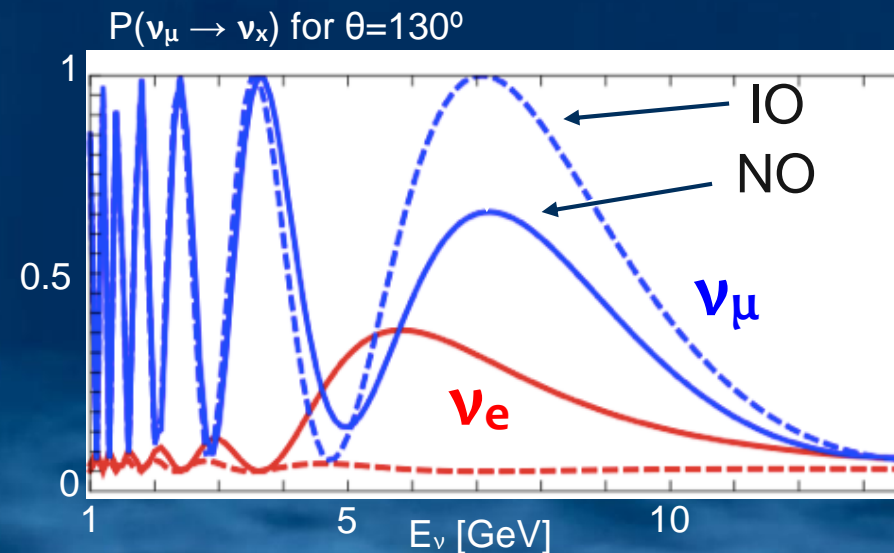


But differences in flux and cross-section:

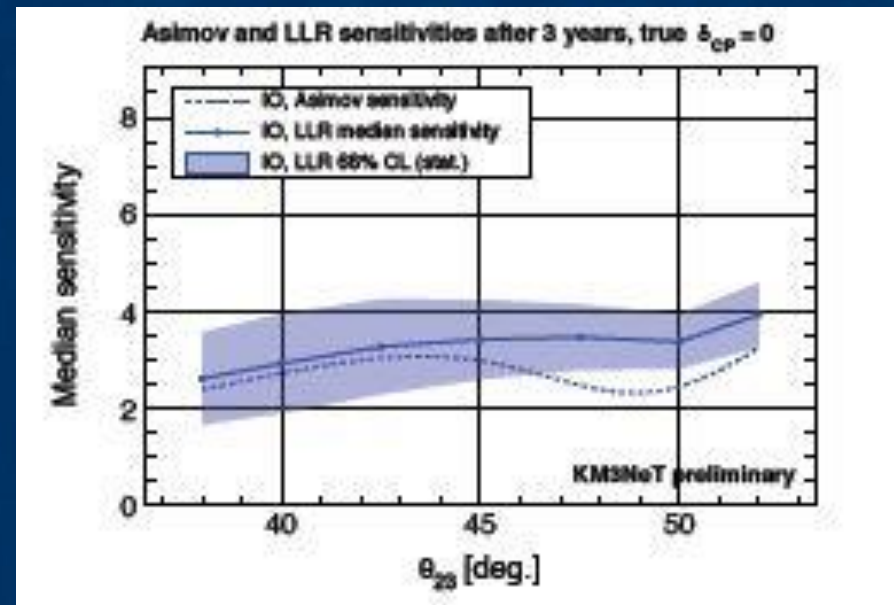
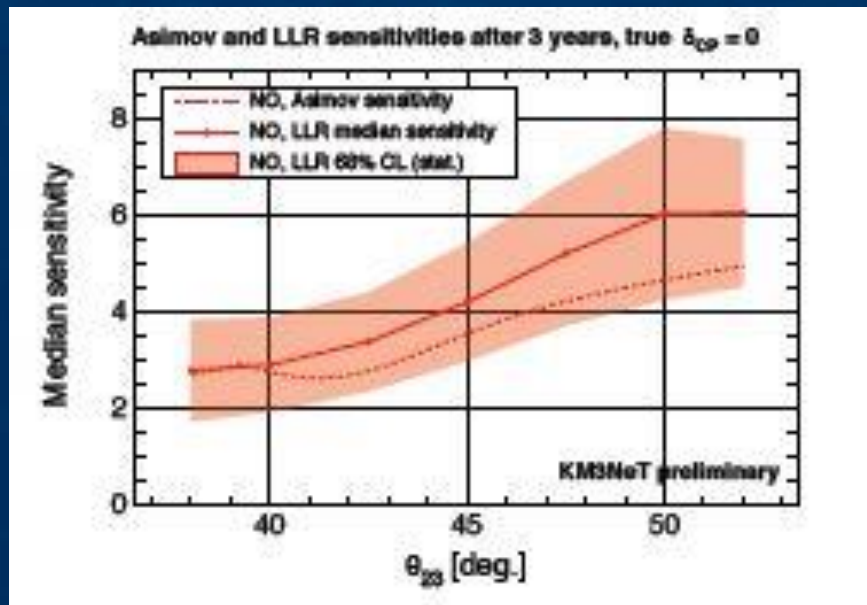
$$\Phi_{\text{atm}}(\nu) \approx 1.3 \times \Phi_{\text{atm}}(\text{anti-}\nu)$$

$$\sigma(\nu) \approx 2\sigma(\text{anti-}\nu) \text{ at low energies}$$

- Approach: measure zenith angle and energy of upgoing atmospheric GeV-scale neutrinos, identify and count track and shower channel events
- Careful treatment of systematics mandatory



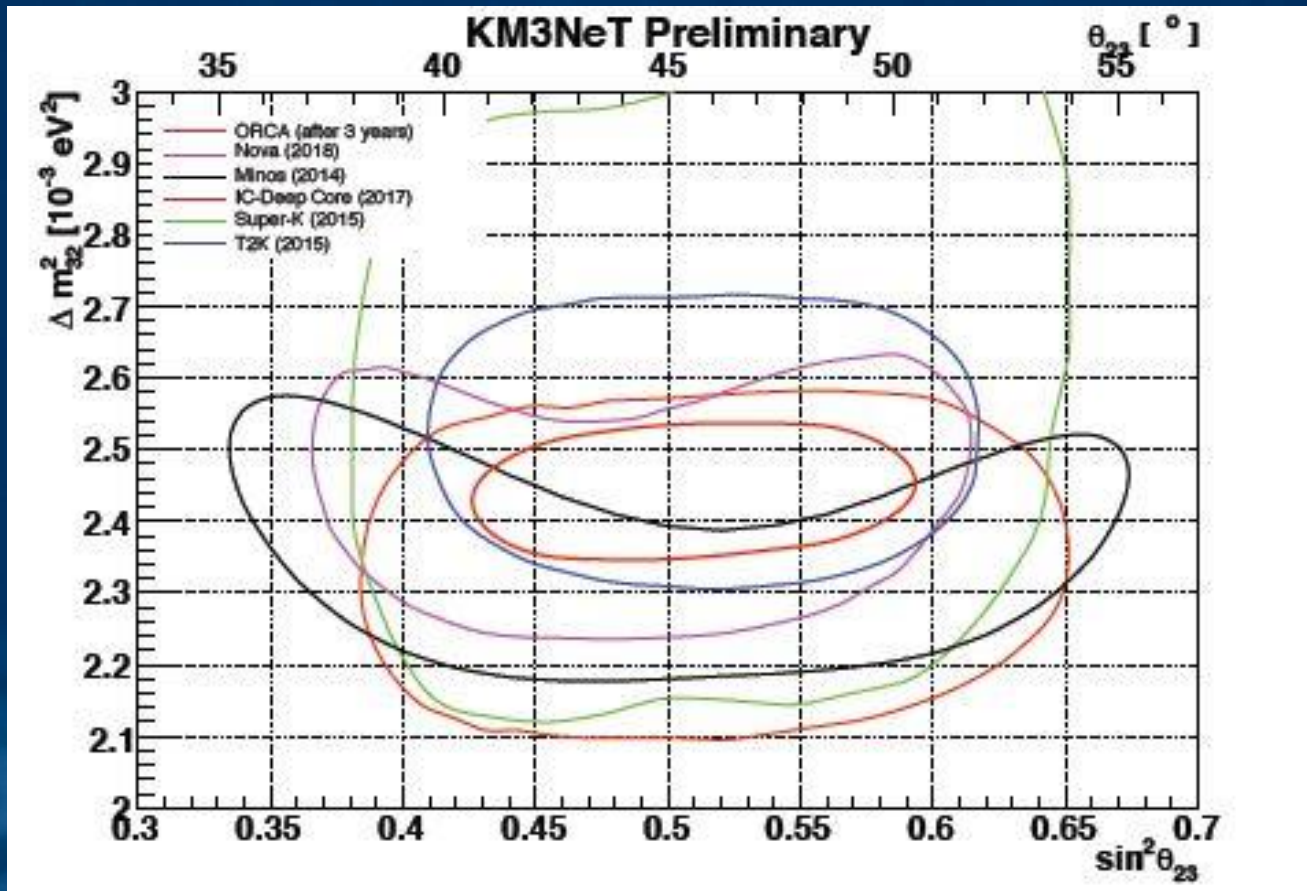
Sensitivity to mass hierarchy



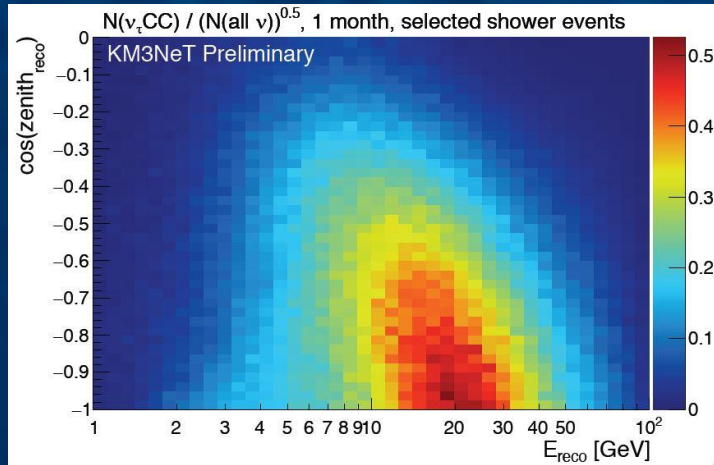
Worst case: 3σ in 4 years
Combination of **NO** and **upper octant of θ_{23}** $\Rightarrow 5\sigma$ in 3 years
 $\delta_{cp} \sim 0.5 \sigma$ impact on sensitivity

Measurement of Δm^2_{32} and $\sin^2 \theta_{23}$

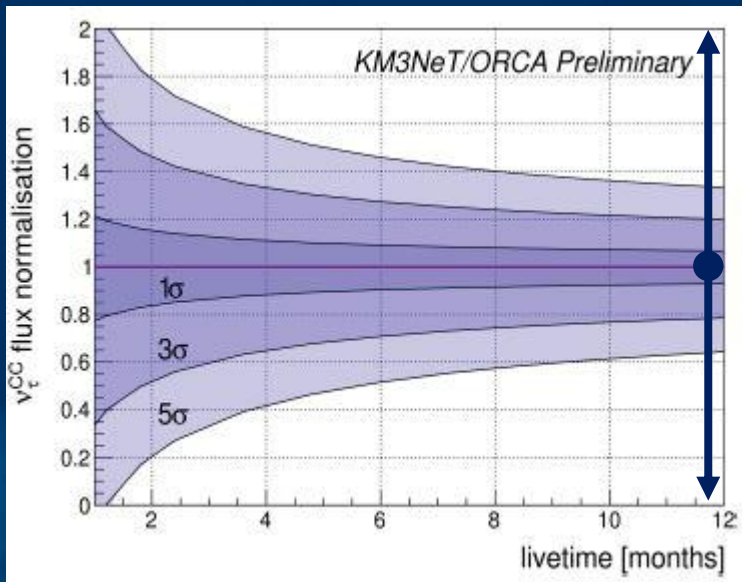
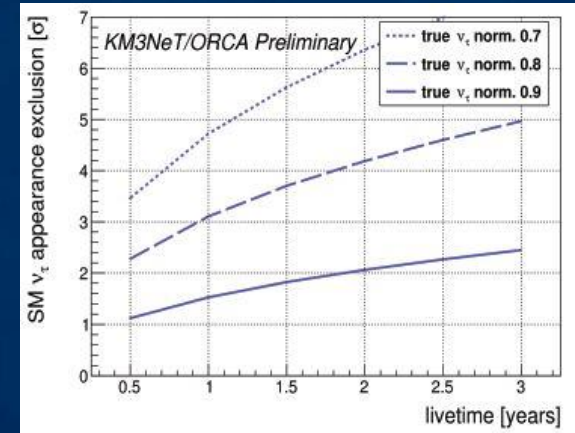
- High statistics and excellent resolution \rightarrow Measure Δm^2_{32} and $\sin^2 \theta_{23}$
- Competitive with NOvA and T2K projected sensitivities in 2020
- Achieve 2% precision in Δm^2_{32} and 5% in $\sin^2 \theta_{23}$



ν_τ appearance



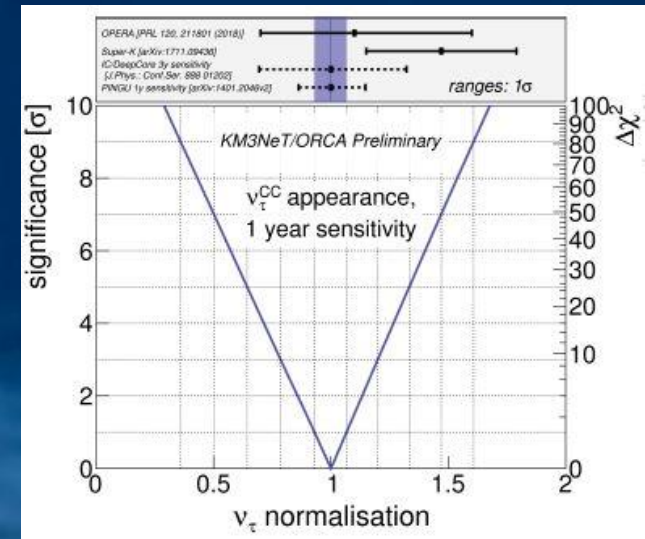
- $\sim 3k$ ν_τ CC events/year with full ORCA
- Rate constrained within $\sim 10\%$ in 1 year
- Sensitivity with few strings under study



New Phys.

Unitarity

New Phys.



Additional ongoing investigations

- Refined analysis for supernova monitoring (exploiting DOM features)
- Non-standard interactions
- Sterile neutrinos
- Earth tomography and composition
- Indirect Search for Dark Matter

<https://doi.org/10.5281/zenodo.1300648>

And also:

- Sensitivity to CP phase – possibly with:
 - Denser detector (Super-ORCA)
 - Protvino neutrino beam to ORCA
- Low Energy Neutrino Astrophysics?
 - Gamma-ray bursts, Colliding Wind Binaries

<https://doi.org/10.5281/zenodo.1292936>

<https://doi.org/10.5281/zenodo.1300743>



Outlook

- ▣ Exciting science program to be exploited
- ▣ ORCA 3σ median significance for NMH could be reached in *less than* 3 years (with full detector)
- ▣ Construction started
- ▣ First data from the deep sea collected starting last year
- ▣ Process for securing the funds for construction of full detector launched
- ▣ Plan for completing the detector by end-2020

Thank you very much for your attention!

