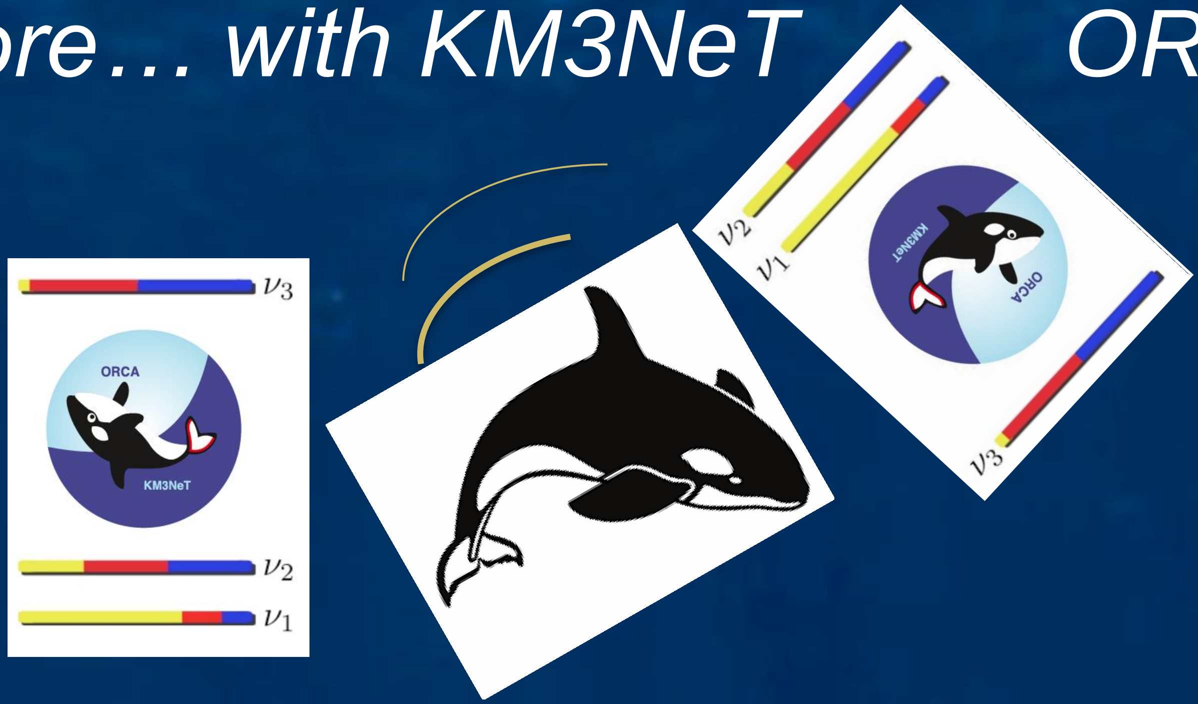
Measuring the neutrino mass ordering and more… with KM3NeT ORCA



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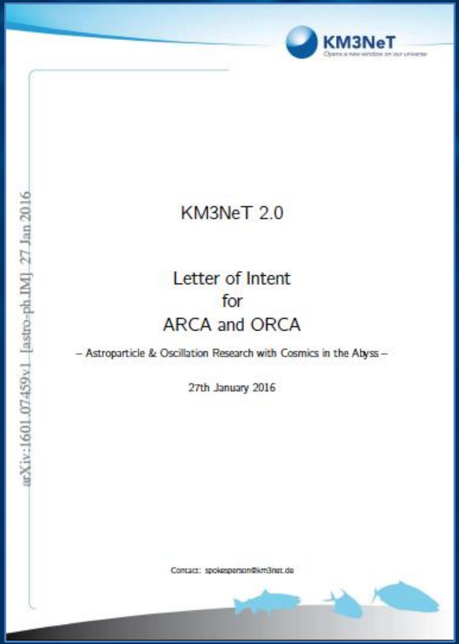
on behalf of KM3NeT/ORCA

Preamble

- Letter of Intent published last year (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]*

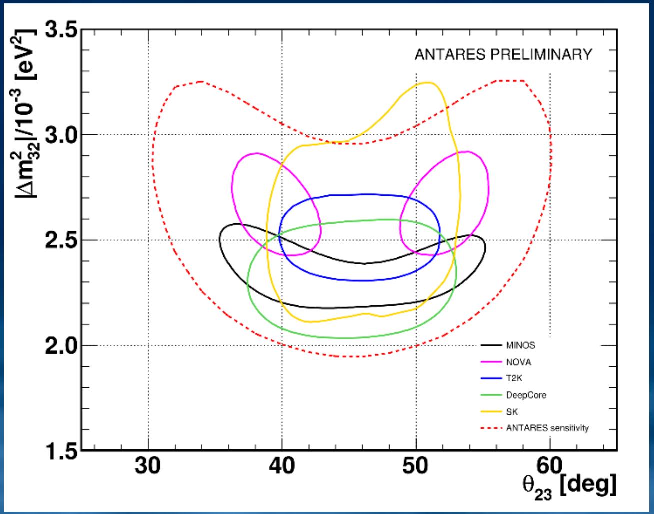


- Powerful event reconstruction method implemented:
  - *S. Adrián-Martínez et al., JHEP 05 (2017) 008*

- KM3NeT opportunity: a multi-disciplinary platform in deep-sea - Same technology for neutrino oscillations and neutrino astronomy!

  KM3NeT = ARCA + ORCA (Astroparticle and Oscillation Research with Cosmics in the Abyss)

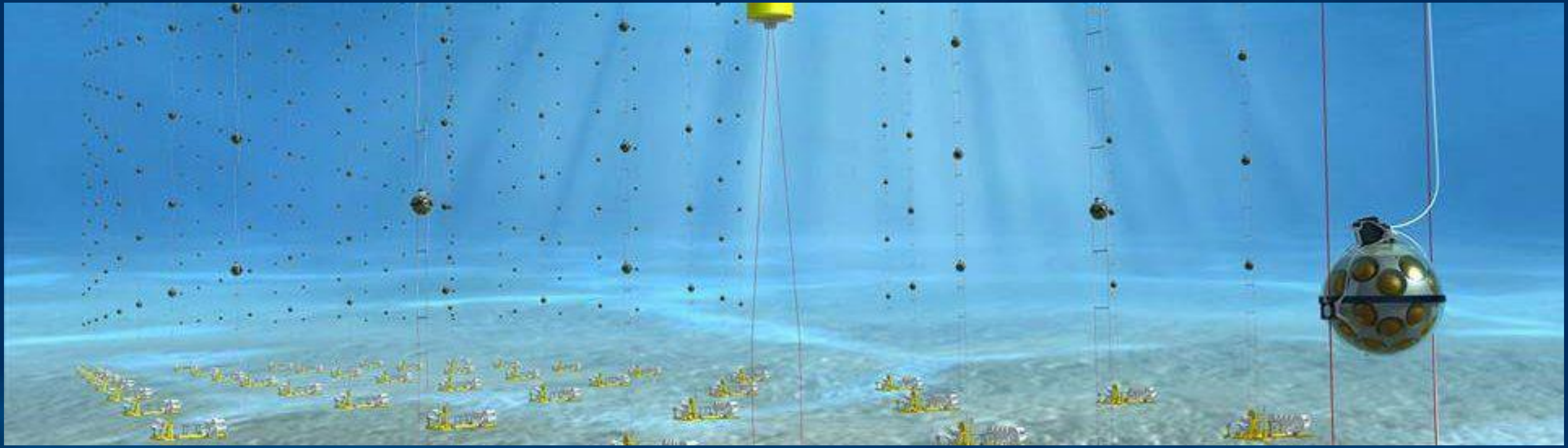
- Building on the expertise acquired with ANTARES (non-optimized for neutrino oscillations!)



Refined plot of ANTARES sensitivity

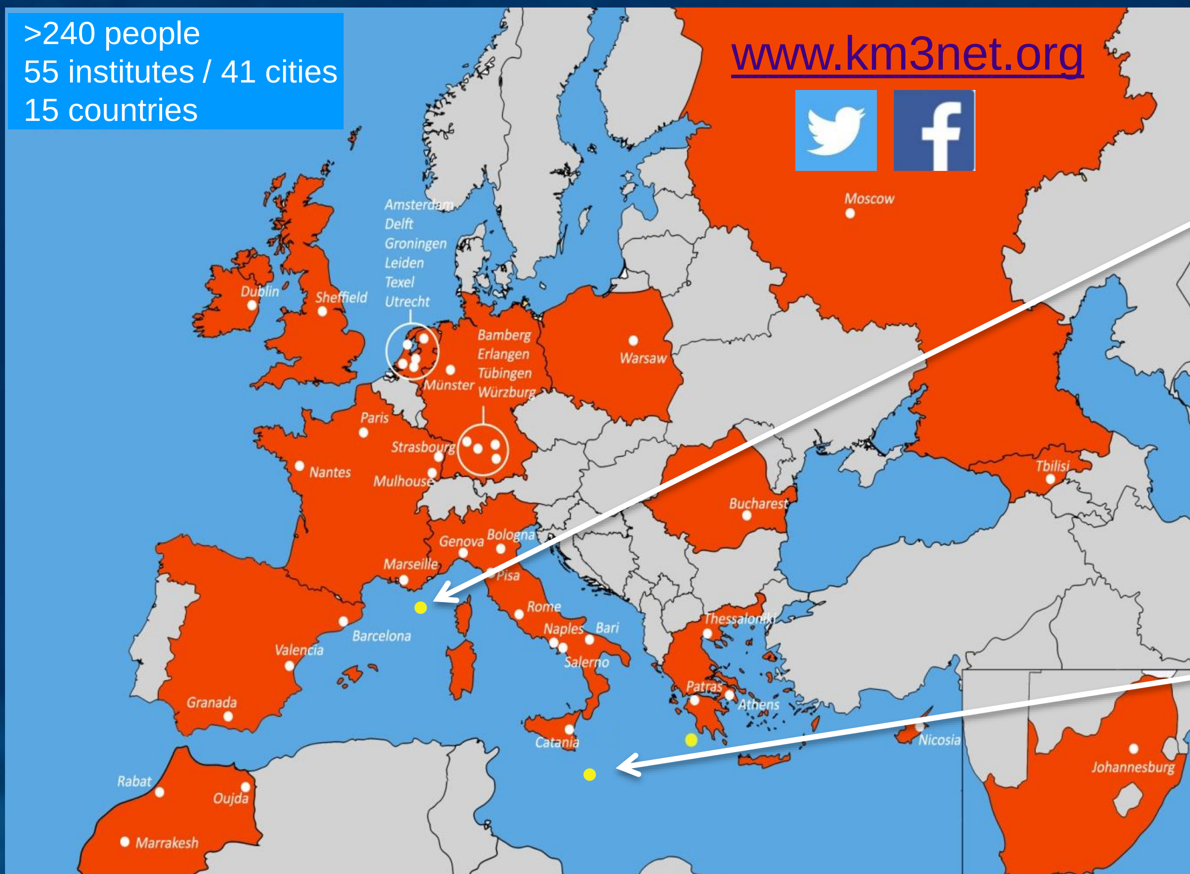
Spotlight in this talk on:

- Detector design, installation of first detection unit
- Performance of detector, including recent news from simulations

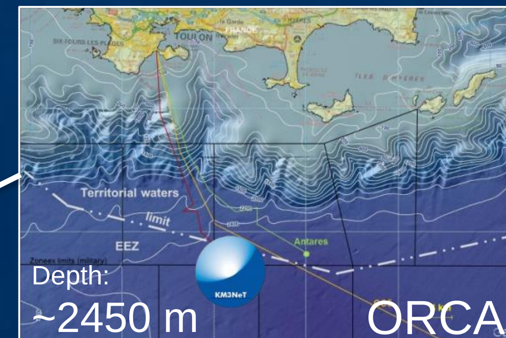


KM3NeT: the next generation Neutrino Telescope in the Mediterranean

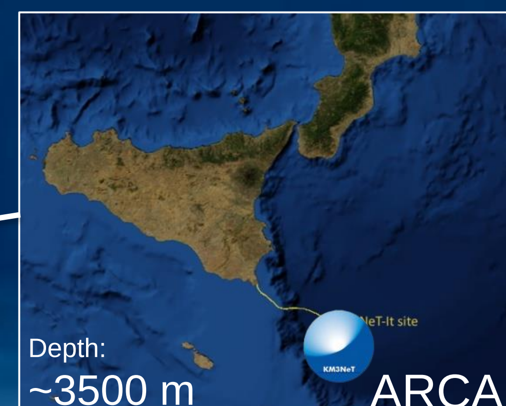
A distributed research infrastructure with 2 main physics topics:



Single Collaboration, Single Technology

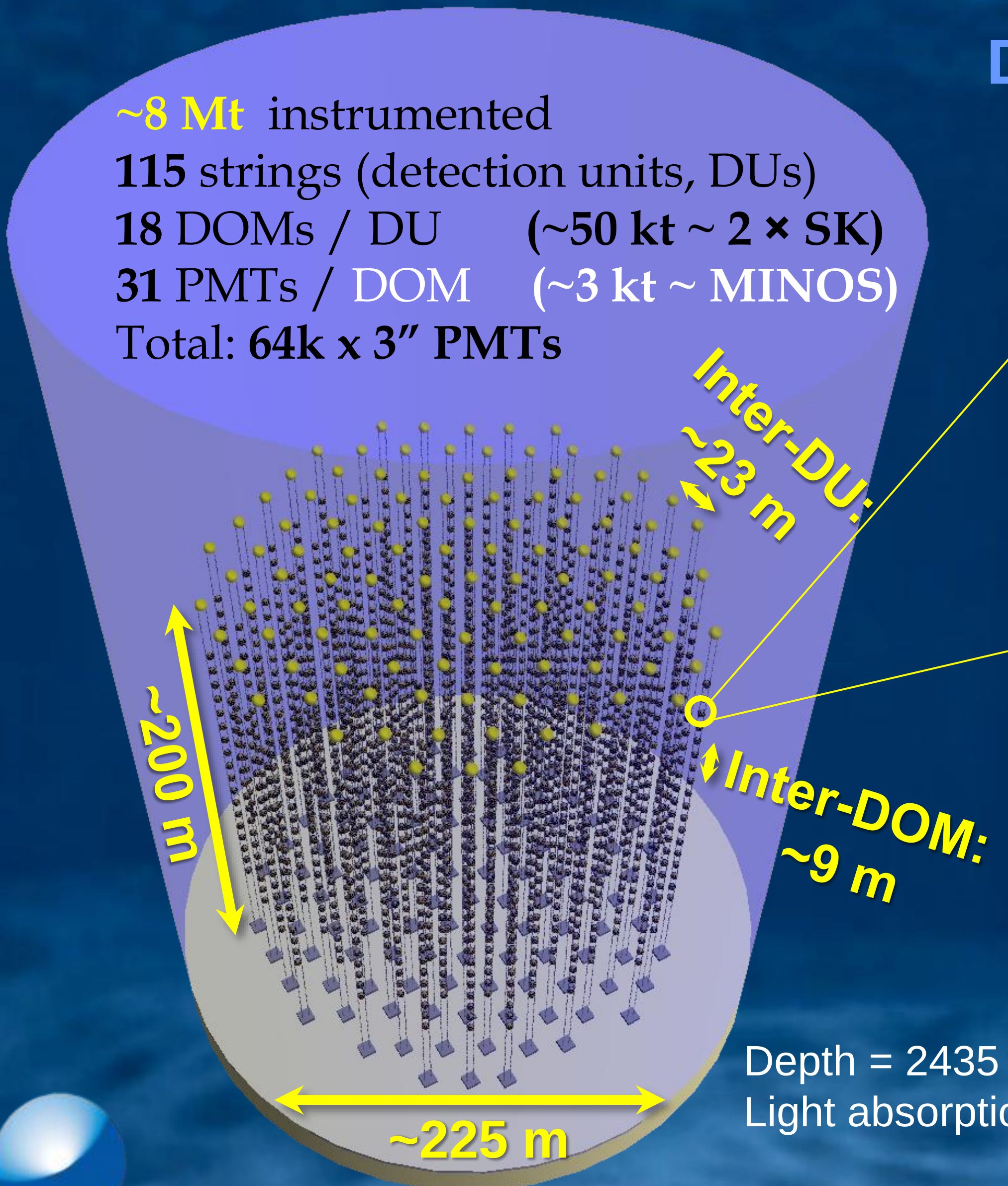


Oscillation **R**esearch with **C**osmics In the **A**byss



Astroparticle **R**esearch with **C**osmics In the **A**byss

The ORCA detector



Digital Optical Module (DOM)

17"

31 x 3" PMTs

Bottom view of a DOM

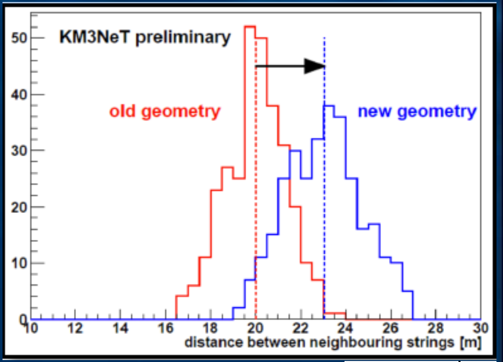
- Uniform angular coverage
- Directional information
- Digital photon counting
- Wide angle of view
- Optimal background rejection
- All data to shore

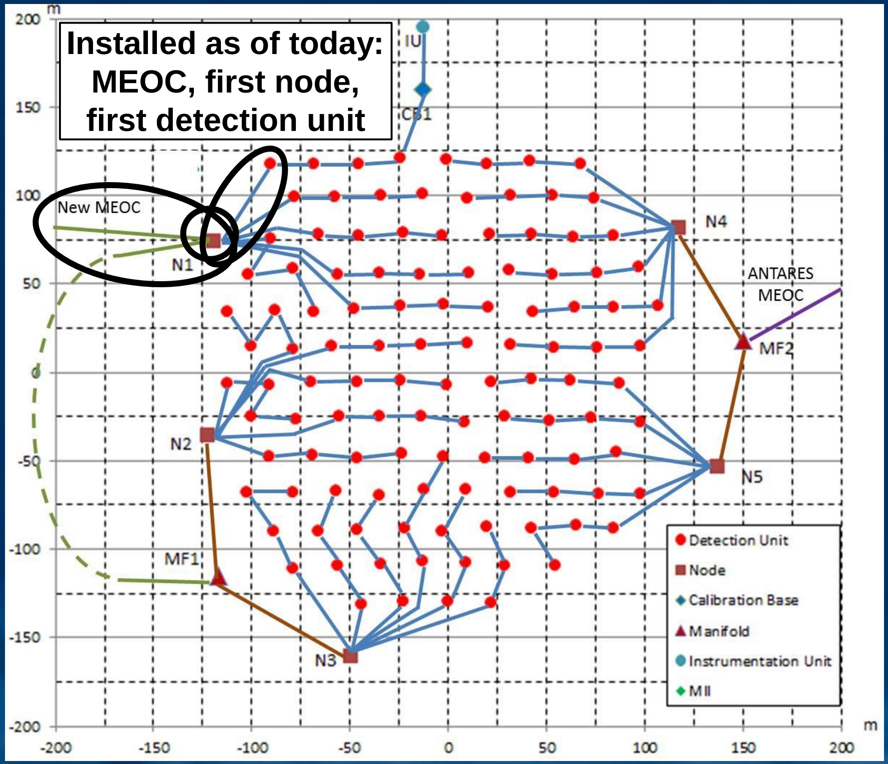
Depth = 2435 m
Light absorption length ~ 60 m

More on detector layout (and simulations)

Simulations ongoing to study the detector performance with final layout:

Geometry	Vertical spacing (between DOM)	horizontal spacing (between strings)
LoI-based [3]	9 m on average with alternate 6 m and 12 m	20 m
New	realistic (9 m average)	23 m

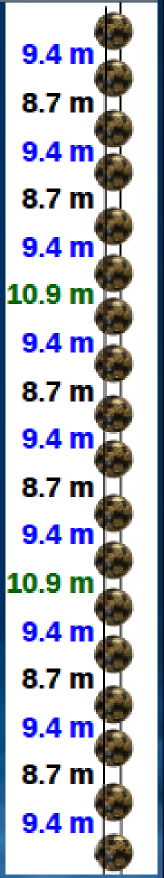




All technical constraints (now) included in simulations

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

New set of simulations launched with new geometry, improving in various areas:
Trigger + reconstruction + PID + background rejection



Some fresh results will be shown later

ORCA DOMs and DUs

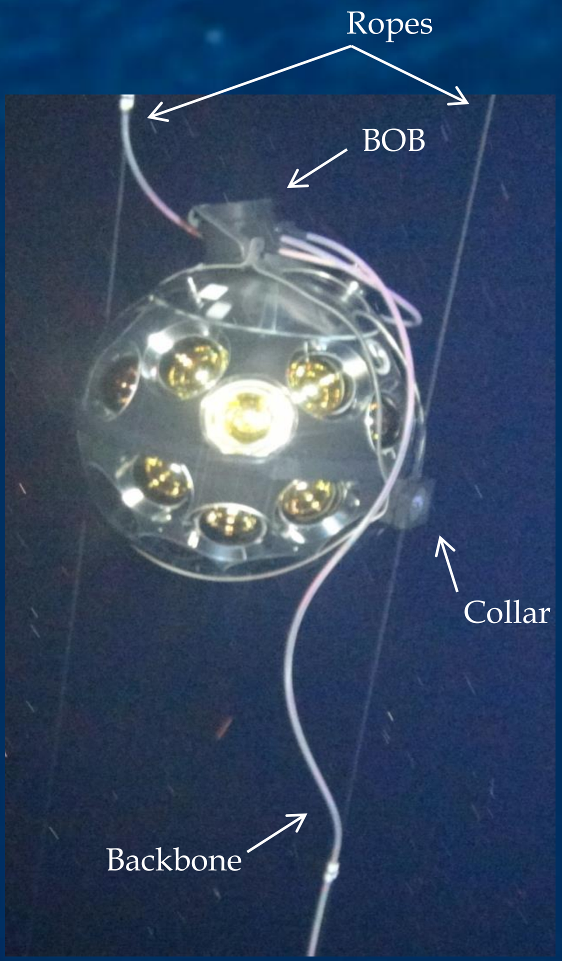
• 31 PMTs of 3” photocathode, each equipped with a 1” reflection ring, optically coupled to the glass sphere, in each DOM

• 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



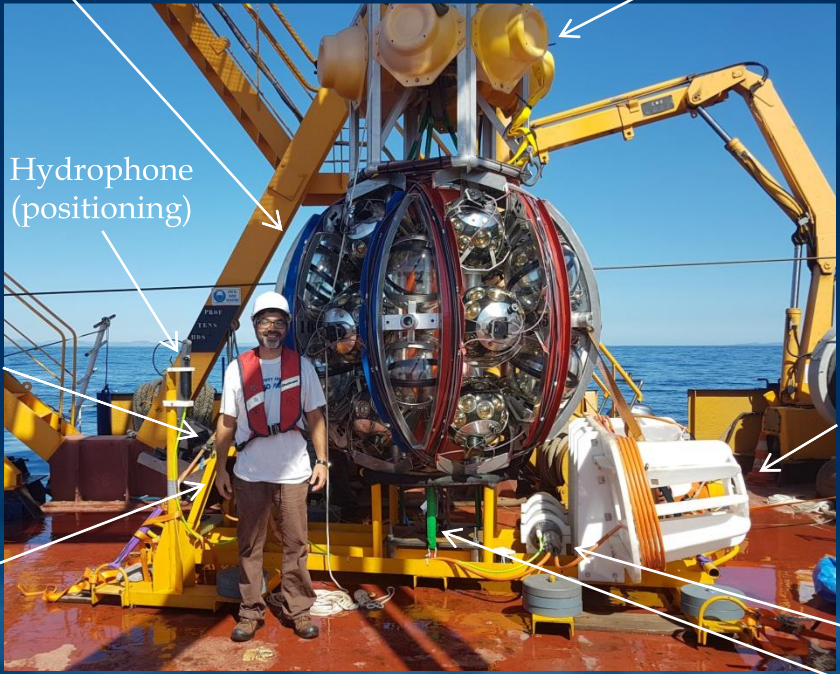
DOM14 of ORCA-DU1
(depth: ~2300 m)

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 ORCA-DU1 on the installation ship (21 Sept. 2017)

DU unfurling

First ORCA DU installed

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

The ROV Apache of COMEX, operated from the Janus

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

First ORCA DU installed (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

First ORCA DU installed (cont.)

Wet-mateable connectors on the submarine node

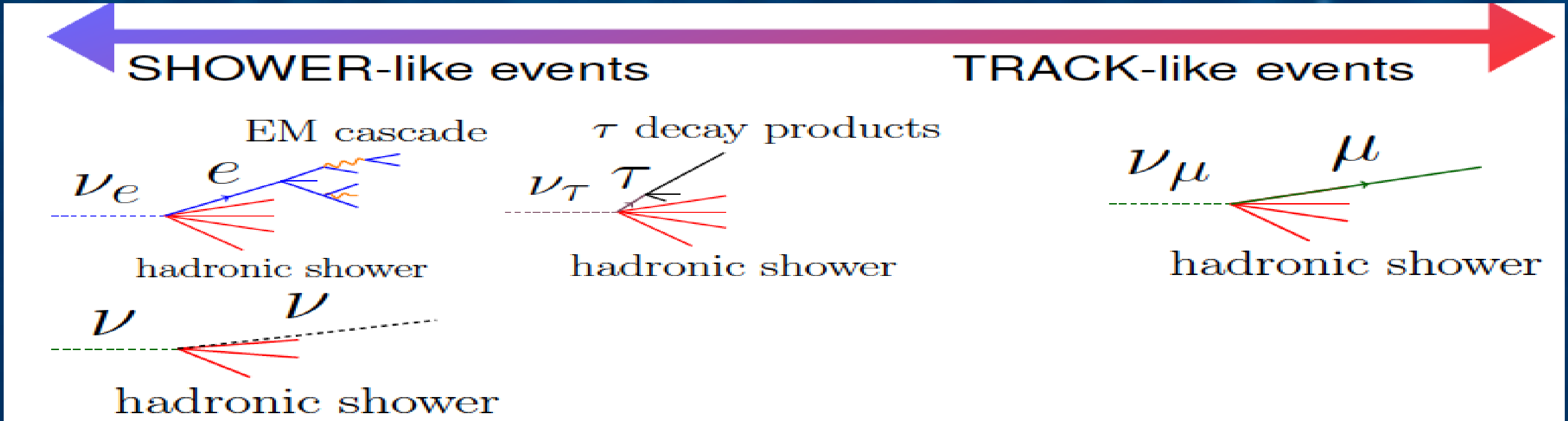
Inspection of the DU after unfurling

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

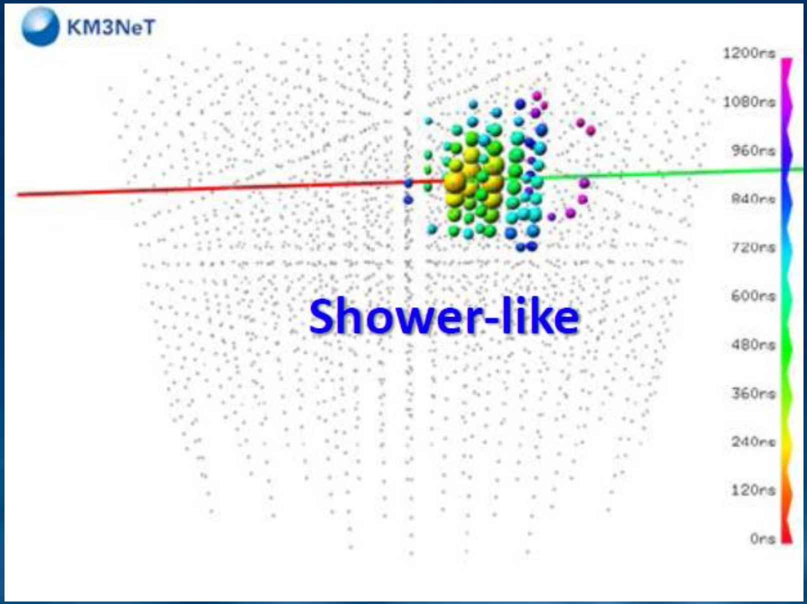
Data taking with first ORCA DU started Friday 22 Sept, 10:20 p.m. CEST

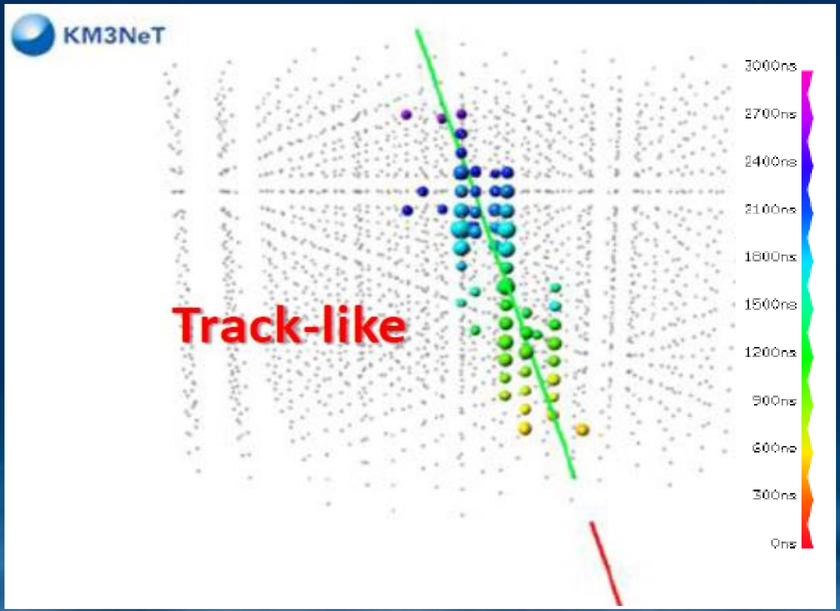
The LOM is recovered after unfurling

Event reconstruction in ORCA

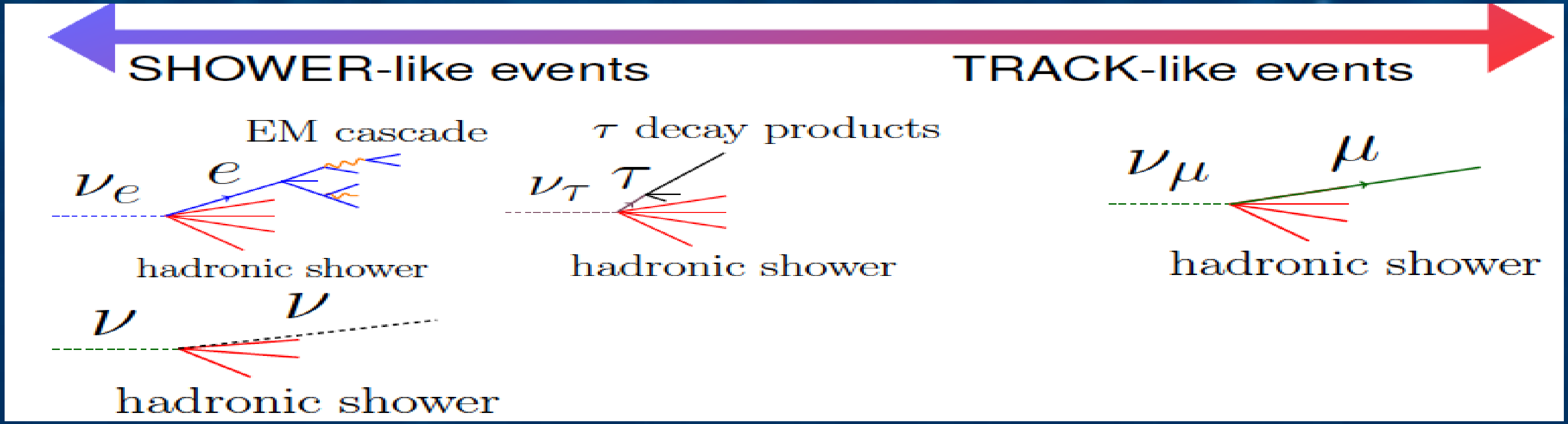


Discrimination of tracks, showers and atmospheric muons (~%) via RDF



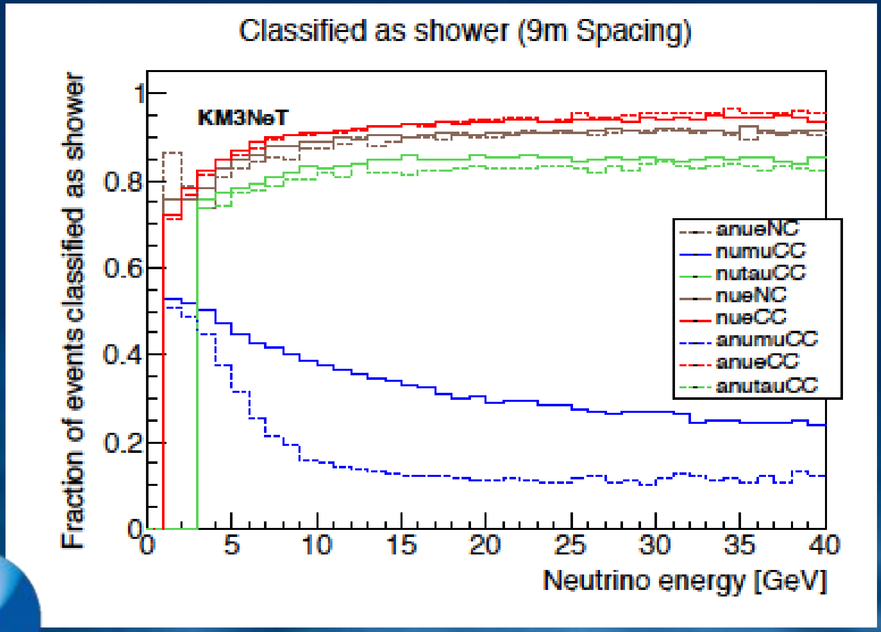


Event reconstruction in ORCA

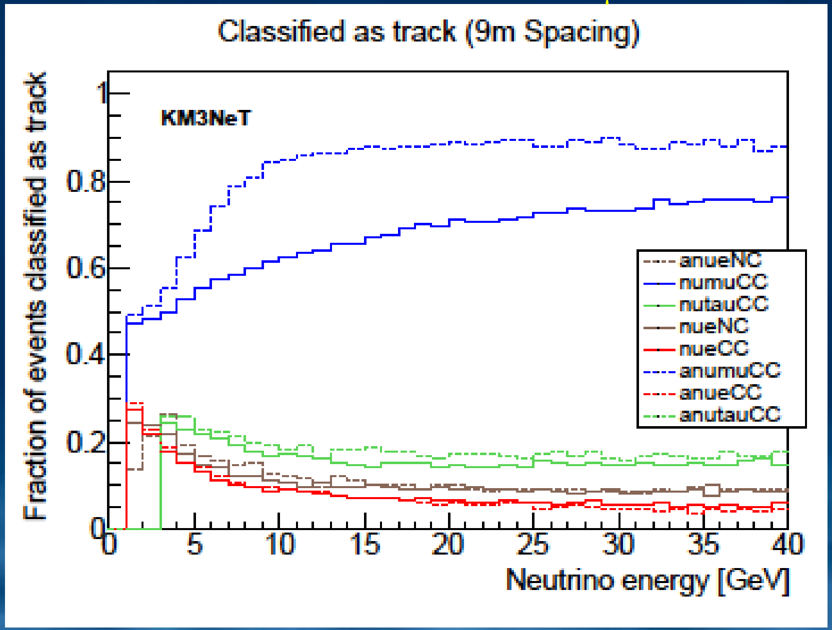


At 10 GeV:

~90% correct ID of ν_e^{CC}

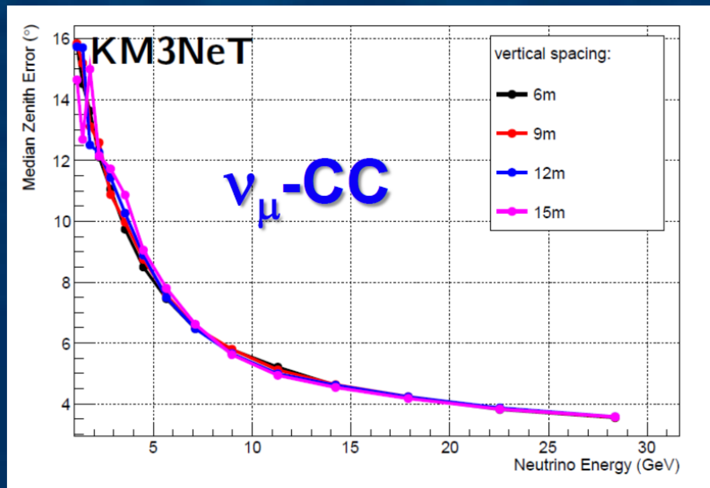


~70% correct ID of ν_μ^{CC}

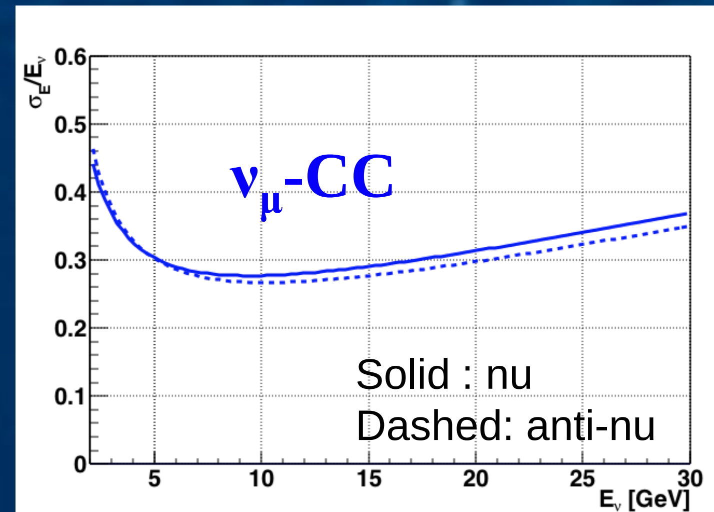


Reconstruction performance

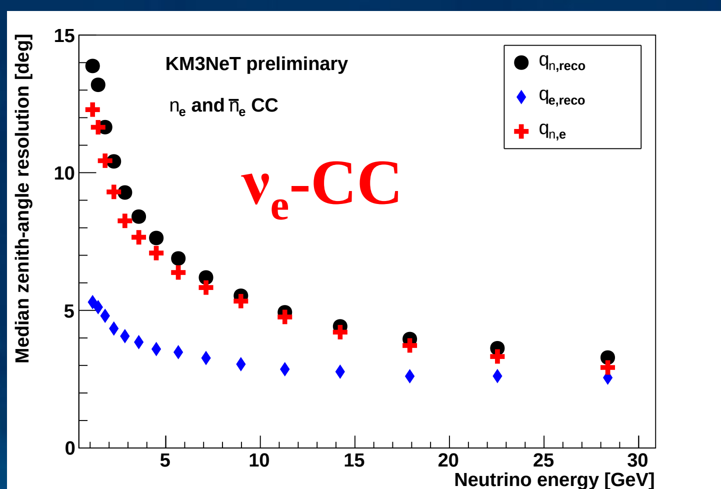
θ Res.



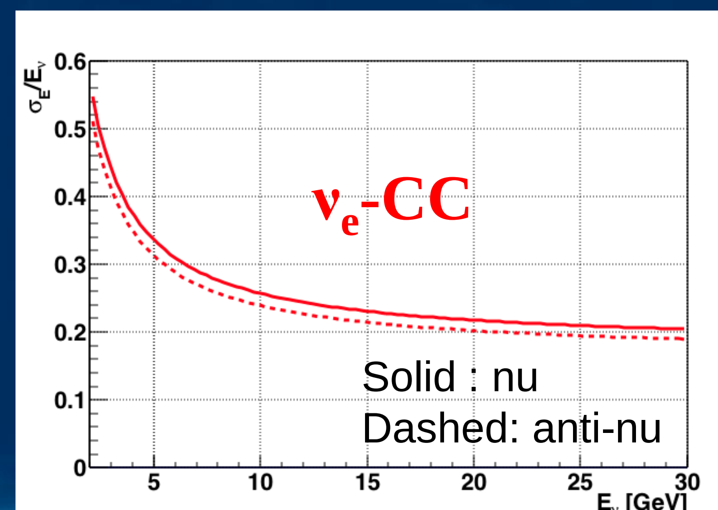
E Res.



θ Res.



E Res.

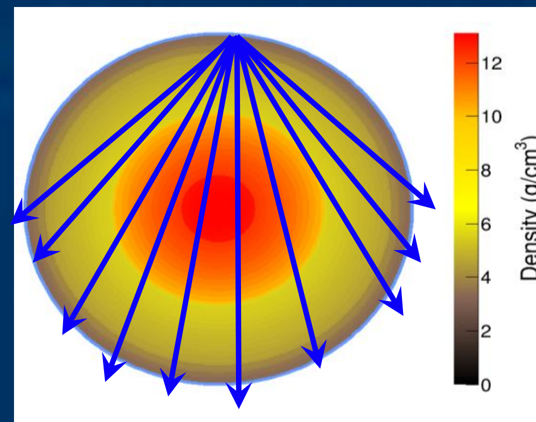


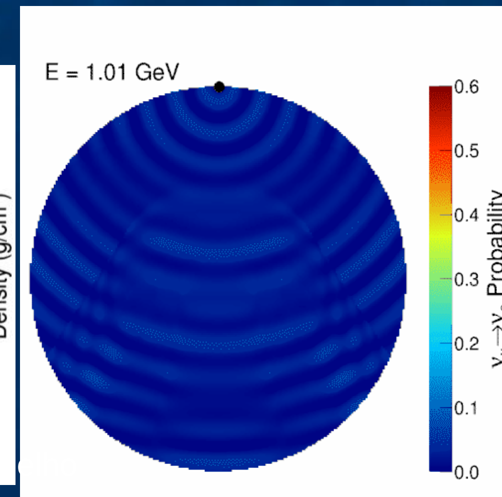
7°(5°) for 5(10) GeV for both channels
Dominated by kinematic smearing

Energy resolution below 30%
in relevant energy range

Neutrino mass hierarchy with ORCA

- A "free beam" of known composition (ν_e, ν_μ)
- Wide range of baselines (50 → 12800 km) and energies (GeV → PeV)





- Oscillation affected by matter (ordering-dependent):

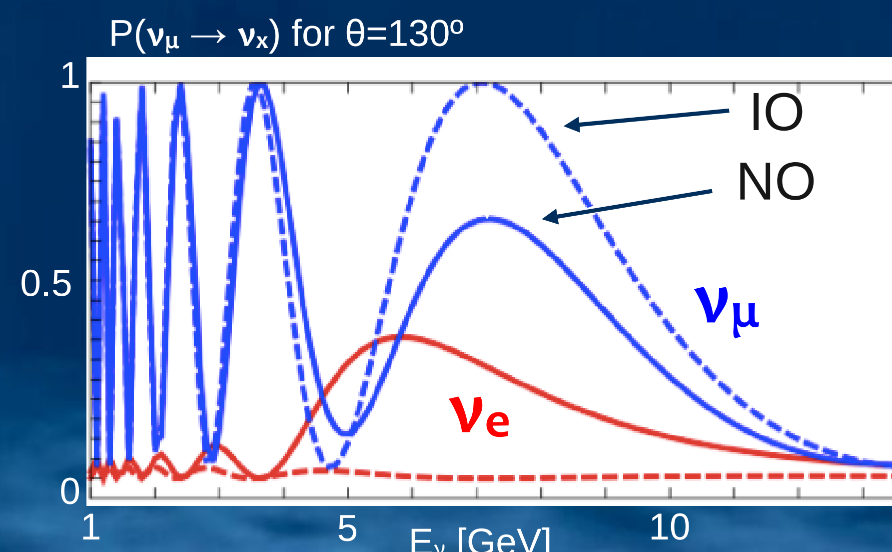
  maximum difference IO vs. NO at
  $\theta = 130°$ (7645 km) and $E_\nu = 7$ GeV

- Opposite effects on neutrinos and anti-neutrinos: IO(ν) ≈ NO(anti-ν)

But differences in flux and cross-section:
$\Phi_{atm}(\nu) \approx 1.3 \times \Phi_{atm}$(anti-$\nu$)
$\sigma(\nu) \approx 2\sigma$(anti-$\nu$) at low energies

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

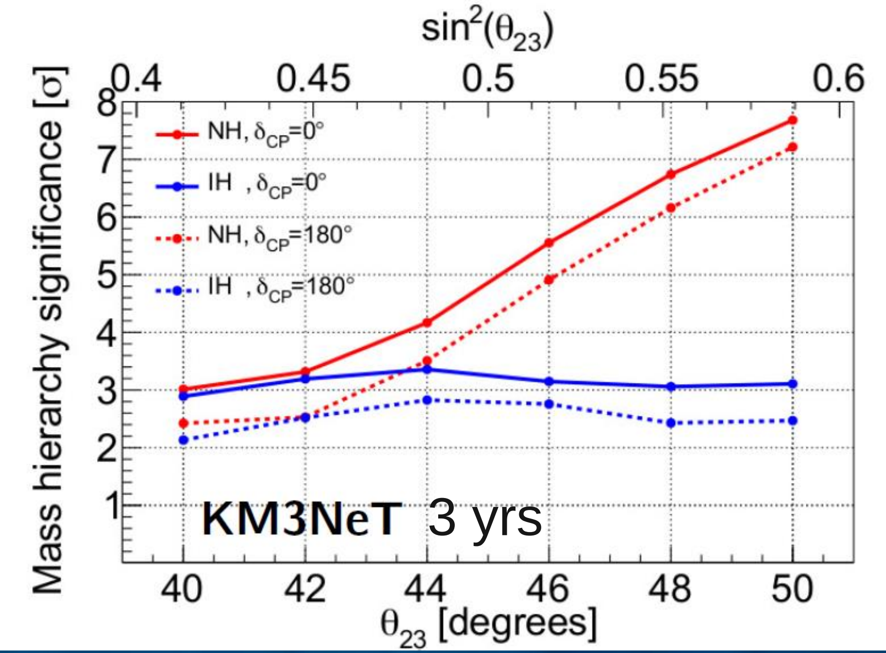
- Careful treatment of systematics mandatory

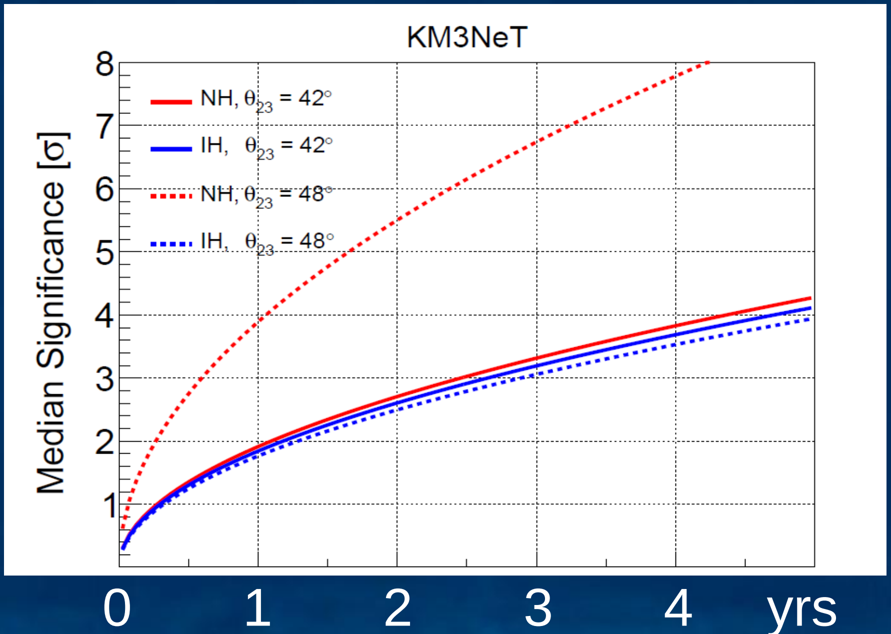


Sensitivity to mass hierarchy

Systematics

parameter	*true value distr.*	*initial value distr.*	*treatment*	*prior*
overall flux factor	1	$\mu = 1, \sigma = 0.1$	fitted	yes
NC scaling	1	$\mu = 1, \sigma = 0.05$	fitted	yes
$\nu/\bar{\nu}$ skew	0	$\mu = 0, \sigma = 0.03$	fitted	yes
μ/e skew	0	$\mu = 0, \sigma = 0.05$	fitted	yes
energy slope	0	$\mu = 0, \sigma = 0.05$	fitted	yes





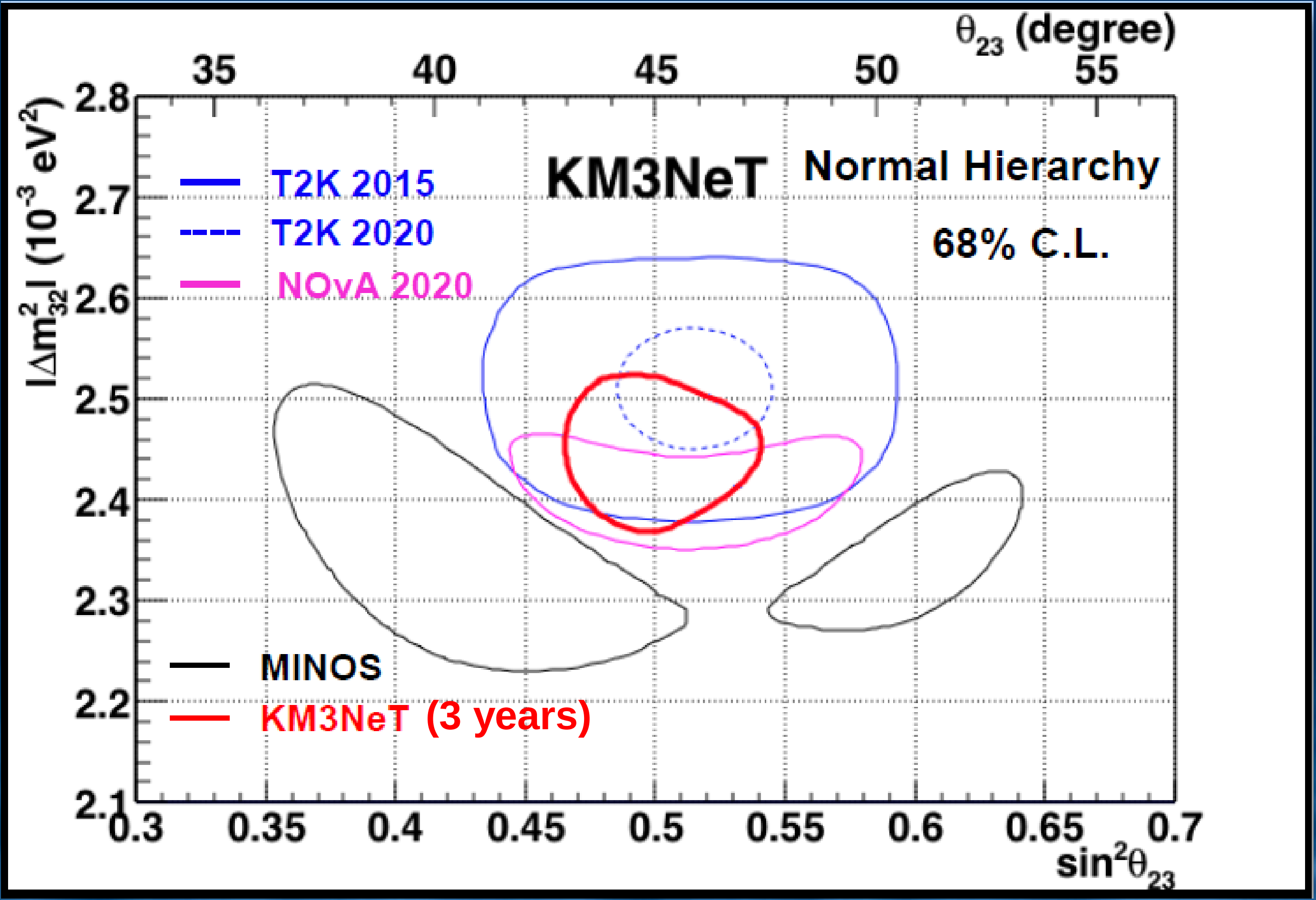
Worst case: 3σ in 4 years

Combination of **NO and upper octant of $\theta_{23} \Longrightarrow$ 5σ in 3 years**

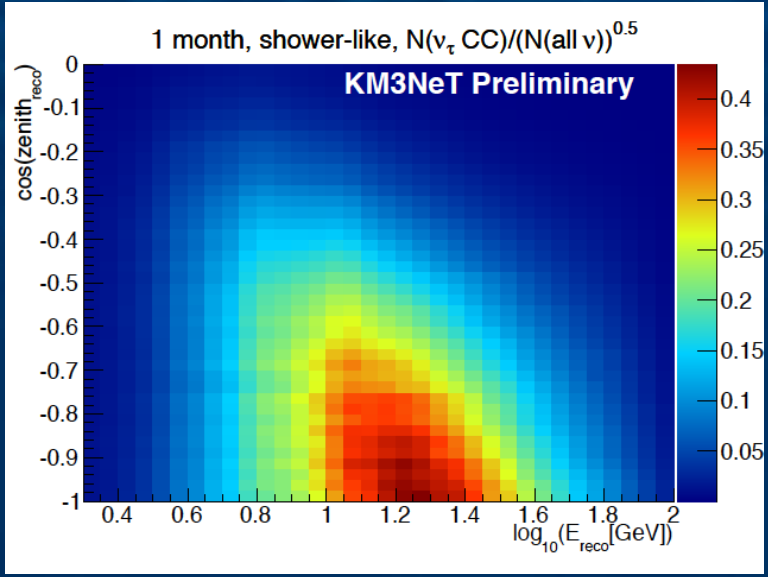
$\delta_{cp} \sim 0.5\ \sigma$ impact on sensitivity

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

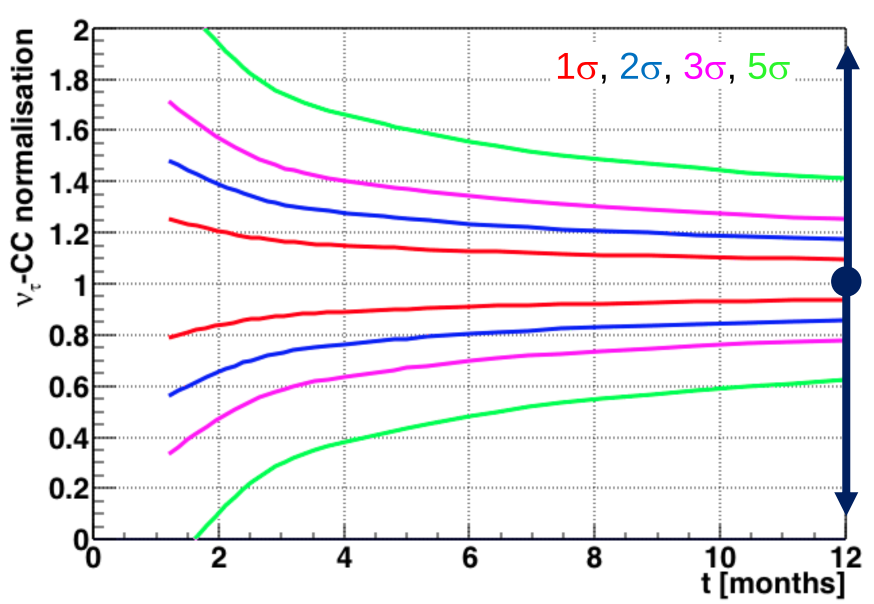
- High statistics and excellent resolution → Measure Δm^2_{32} and $\sin^2\theta_{23}$
- Competitive with NOvA and T2K projected sensitivity in 2020
- Achieve 2-3% precision in Δm^2_{32} and 4-10% in $\sin^2\theta_{23}$



ν_τ appearance



- ~3k ν_τ CC events/year with full ORCA
- Rate constrained within ~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

And also:

- Sensitivity to CP phase – possibly with:
  - Denser detector — 🕮 Razzaque & Smirnov, JHEP05 (2015) 139
  - Protvino neutrino beam to ORCA — 🕮 Brunner, arXiv:1304.6230v3
- Low Energy Neutrino Astrophysics?
  - Gamma-ray bursts, Colliding Wind Binaries — 🕮 J. Becker Tjus, arXiv:1405.0471

Recent improvements I: trigger

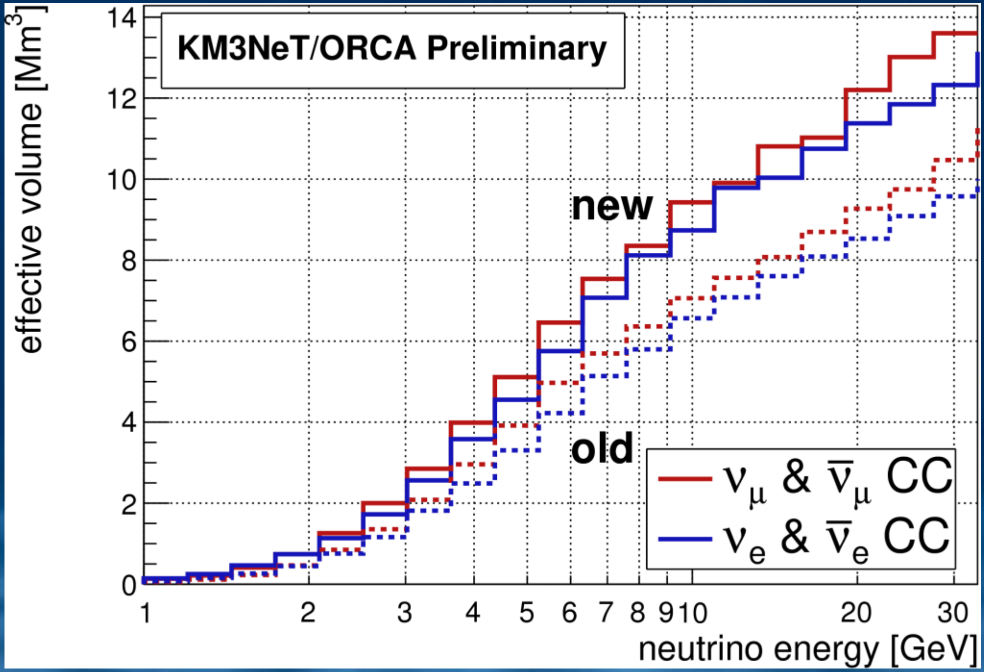
- Implementation of a new trigger with new geometry

now: just ONE local DOM coincidence (L1) plus causally-connected hits in vicinity (do not have to be coincidences)

before: cluster of 3-4 causally connected L1 coincidences

Keep bandwidth requirements: trigger rate from pure-noise smaller than irreducible trigger rate from atmospheric muons (~50 Hz).

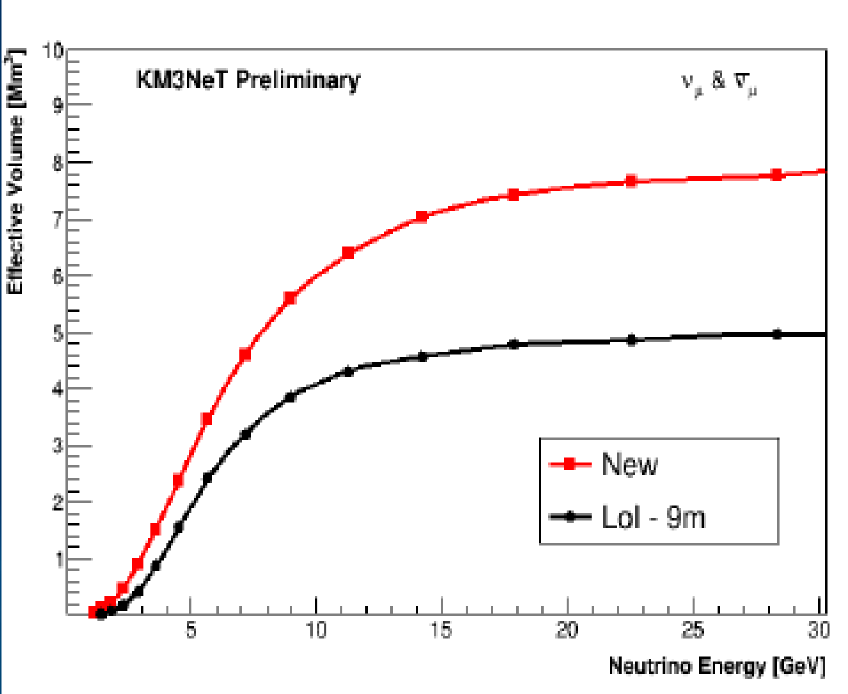
Increase of effective volume at low energies despite sparser detector!

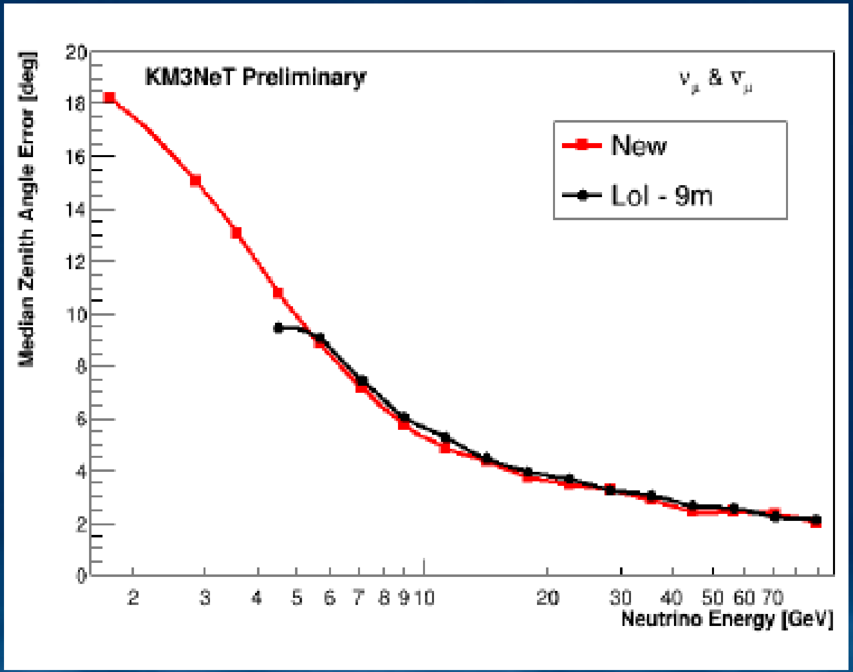


Recent improvements II: reconstruction

- Reconstruction strategies adjusted for new trigger: allow for fainter events

Tracks:
- prefit with hit selection as in new trigger algorithm
- Scan in all directions, with a step size of 5 degrees
- Full fit procedure applied to 96 “best” reconstructed tracks



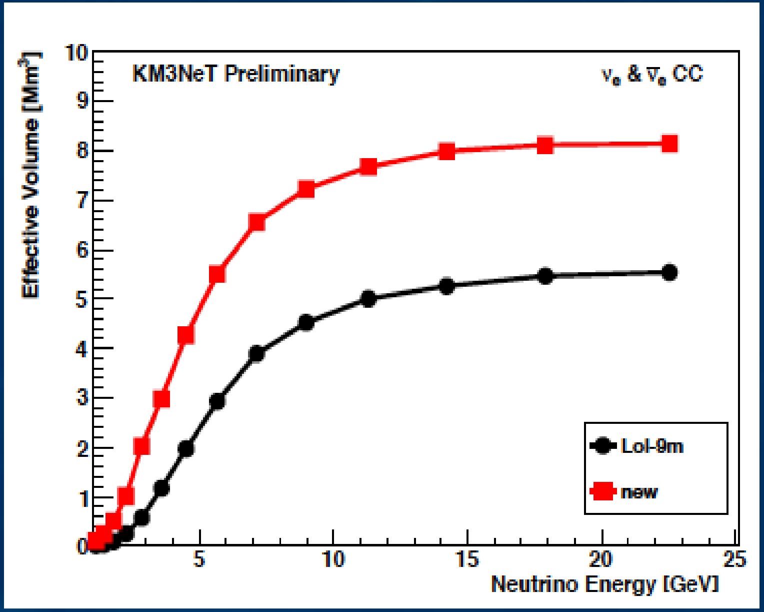


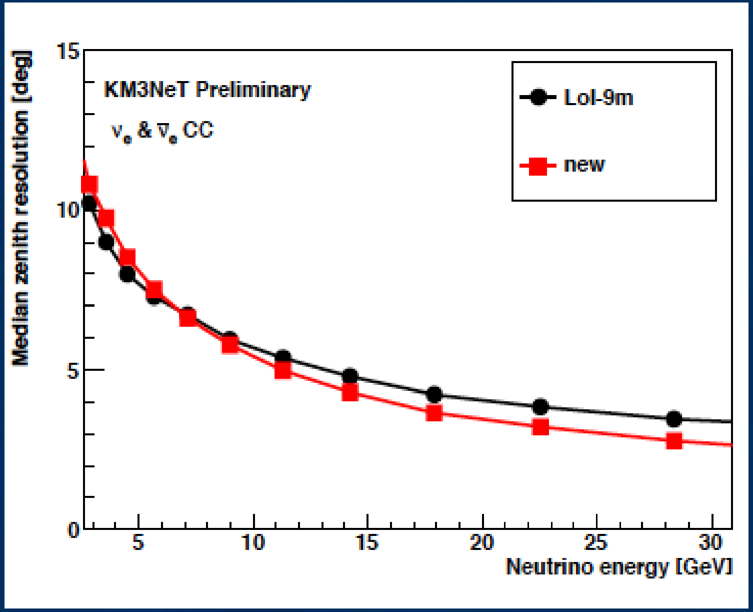
Efficiency significantly improved - angular resolution unchanged

Recent improvements III: reconstruction

- Reconstruction strategies adjusted for new trigger: allow for fainter events

<u>Showers</u>: main changes in initial hit selection (loosened)





Now 20% faster turn-on and +50% higher plateau compared to LoI-9m with similar reconstruction resolutions

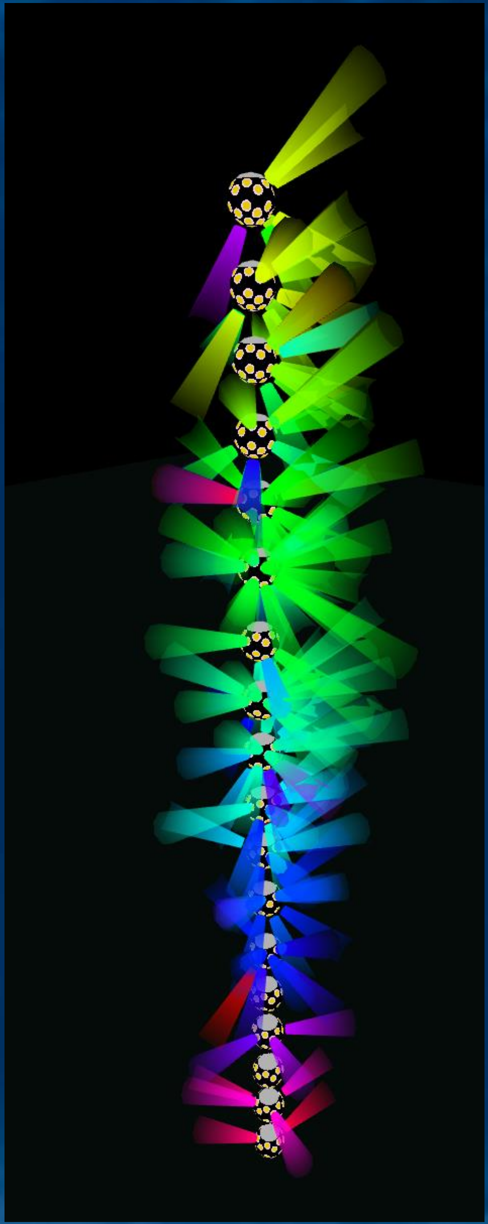
Expect an increase in sensitivity to NMH and oscillation parameters (full chain processing ongoing)

Outlook

- Increased detector volume, improved trigger and event reconstruction compared to LoI
  ⟹ working hard to determine the corresponding increase in sensitivity
- ORCA 3σ median significance for NMH could be reached in *less than* 3 years (with full detector)
- First detection unit in data taking since last week!
- Plan for completing the construction by 2020
- Process for securing the funds for construction of full detector launched

Exciting news, isnt' it?

Thank you very much for your attention!



Event display of one of the first events (muons) detected with ORCA-DU1