KM3NeT/ORCA: Status, first data & perspectives for neutrino oscillation measurements

WIN 2021

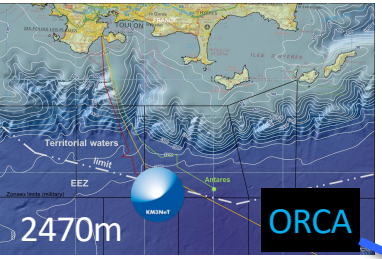
Véronique Van Elewyck
(APC & Université de Paris)

for the
KM3NeT Collaboration

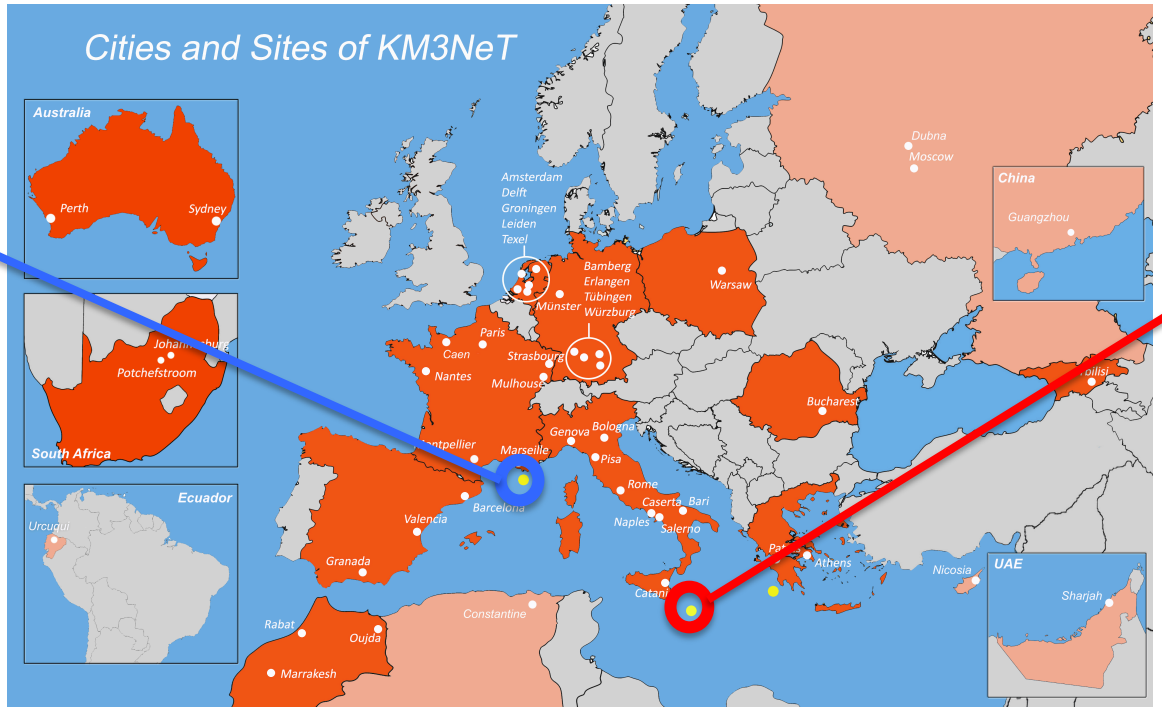
The KM3 Neutrino Telescope

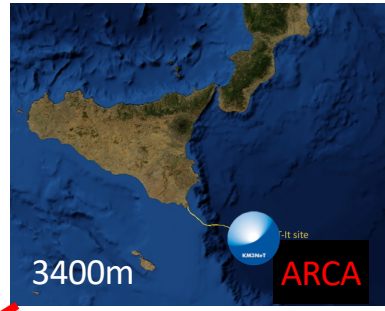
KM3NeT is a distributed research infrastructure with 2 main physics topics:

Oscillations and **A**stroparticle **R**esearch with **C**osmics in the **A**byss



~40 km offshore
Toulon (France)
close to ANTARES





~100 km offshore
Capo Passero
(Sicily)

📖 *KM3NeT LoI:*
J.Phys.G 43 (2016) 8, 084001

1collaboration, 1 technology, 2 detectors

The KM3NeT Technology

Multi-PMT DOM:

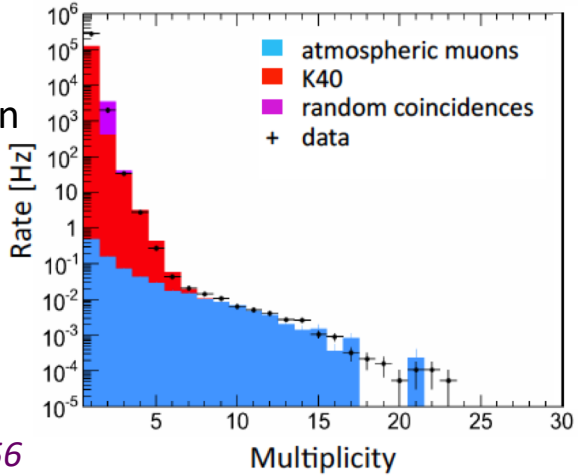
- Digital Optical Module
- 31 x 3” PMTs

(+ reflector rings)

- Gbit/s on optical fiber
- Positioning & timing

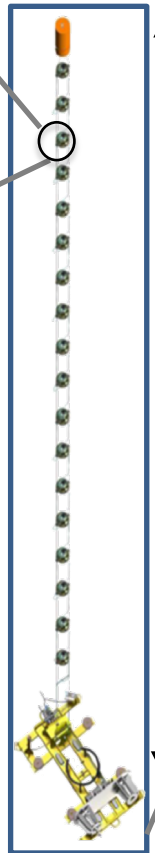
- ~4 π sr coverage
- photon counting
- directional information

single-DOM atmospheric muon detection:

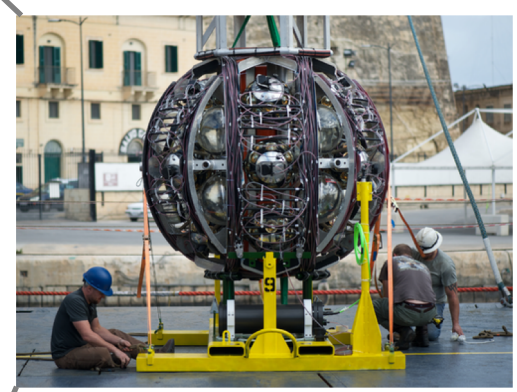


📖 *KM3NeT Collaboration, Eur.Phys.J.C 74 (2014) 9, 3056*

Detection Unit

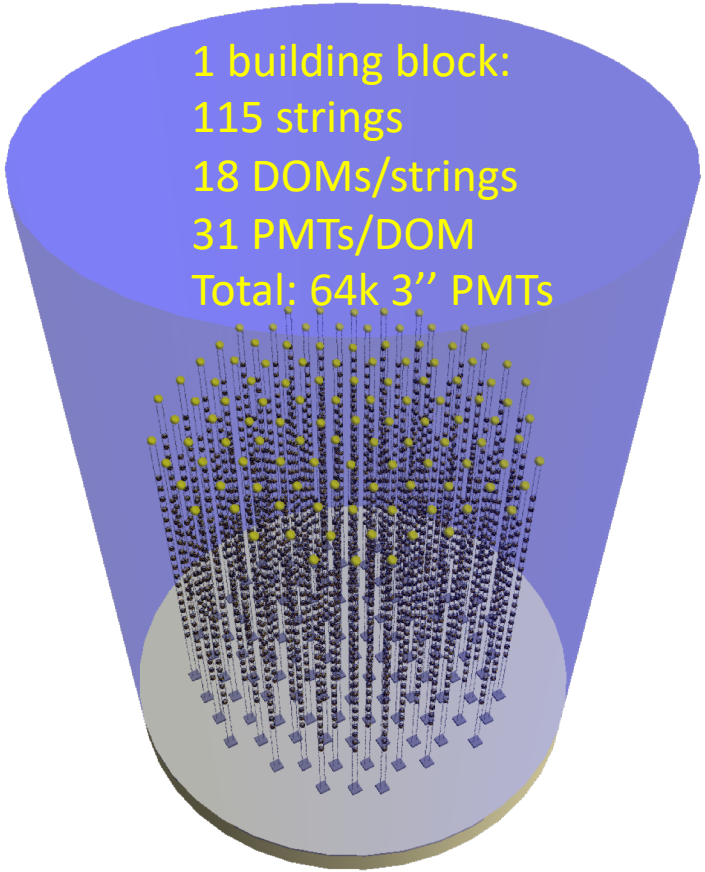


Launcher Module



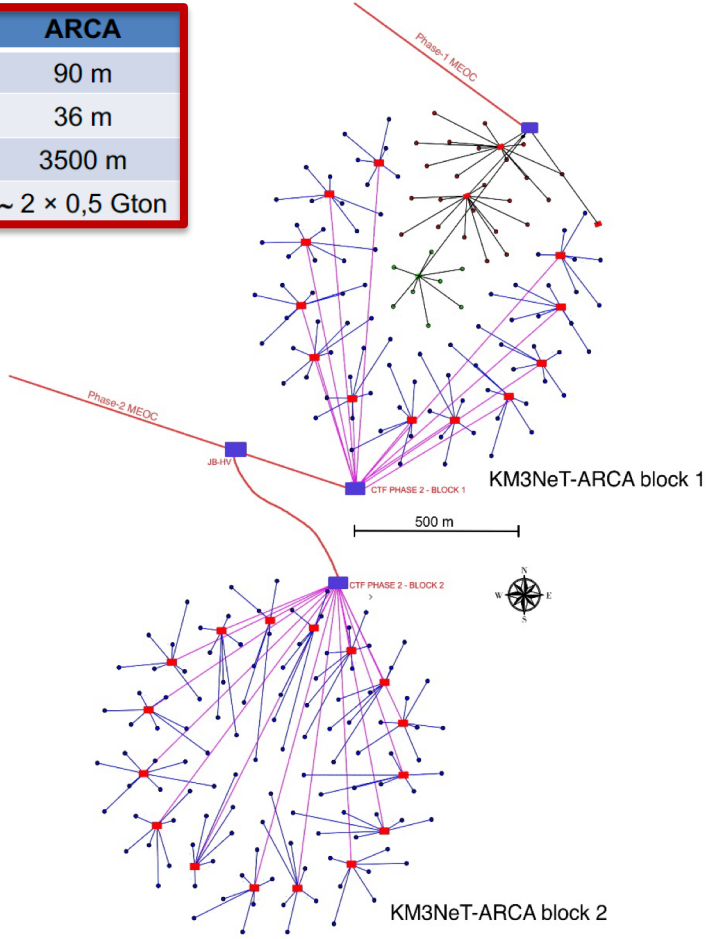
- Rapid deployment
- Multiple strings/sea campaign
- Autonomous/ROV unfurling
- Reusable

The KM3NeT Technology

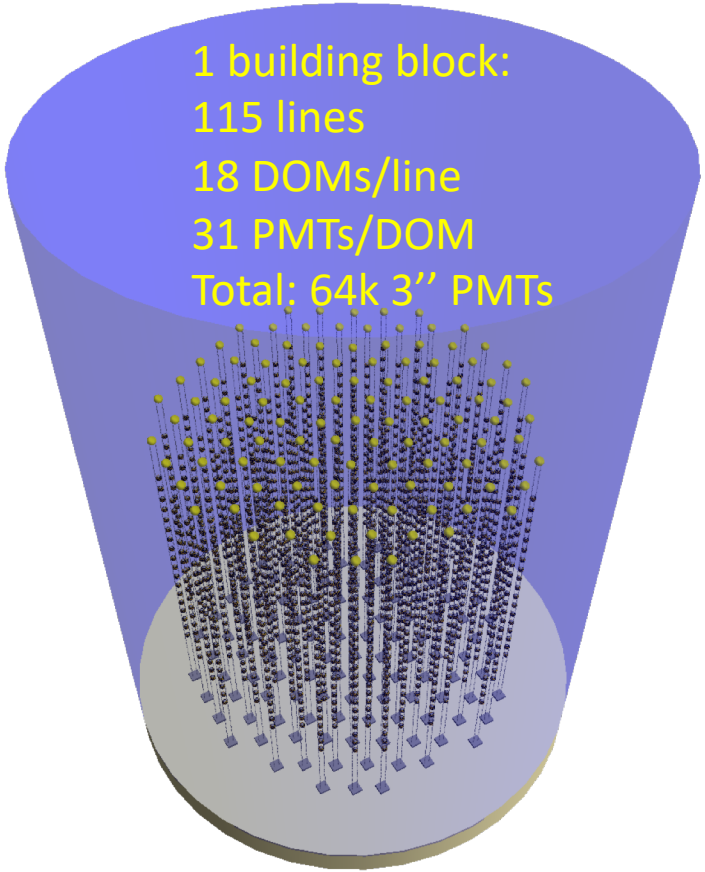


	ORCA	ARCA
String spacing	20 m	90 m
OM spacing	9 m	36 m
Depth	2470 m	3500 m
Instrumented mass	~ 7 Mton	~ 2 × 0,5 Gton

ARCA:
2 building blocks
~Gton instrumented mass



The KM3NeT Technology

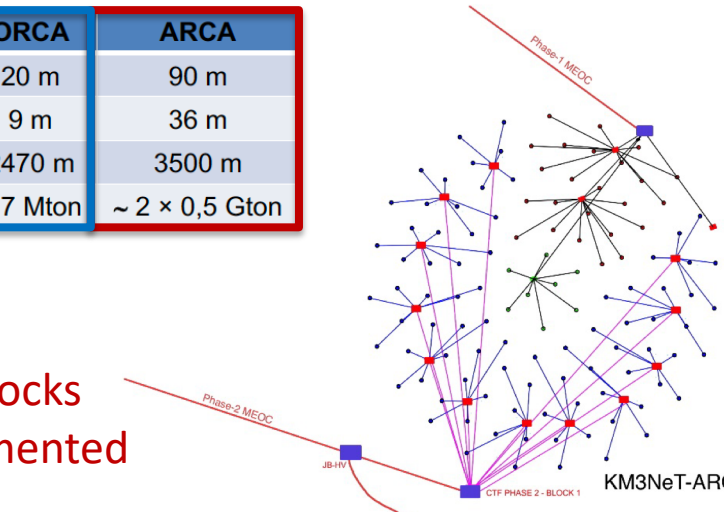


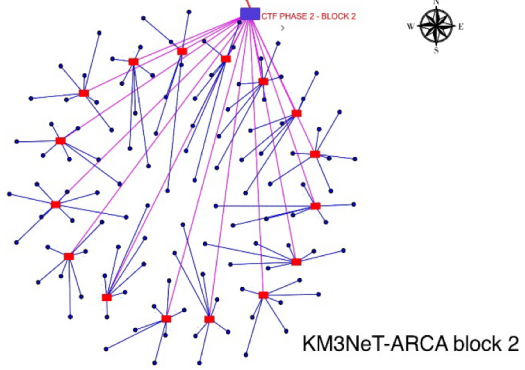
	ORCA	ARCA
String spacing	20 m	90 m
OM spacing	9 m	36 m
Depth	2470 m	3500 m
Instrumented mass	~ 7 Mton	~ 2 × 0,5 Gton

ARCA:
2 building blocks
~1 Gton instrumented mass

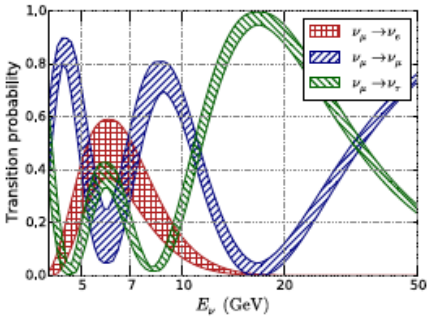
ORCA:
1 building block
~7 Mton instrumented mass

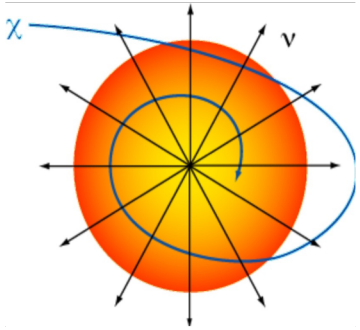
to scale →

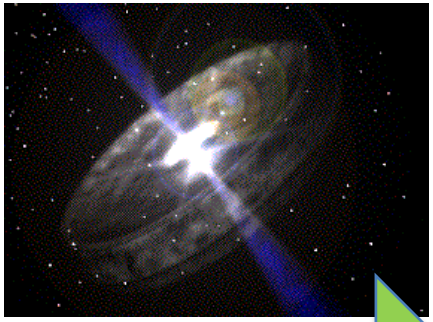




The KM3NeT Science







MeV **GeV** **TeV** **PeV**

Supernova ν

ν Oscillations, Mass ordering

Dark matter, exotics

HE ν astronomy
Cosmic accelerators

ORCA

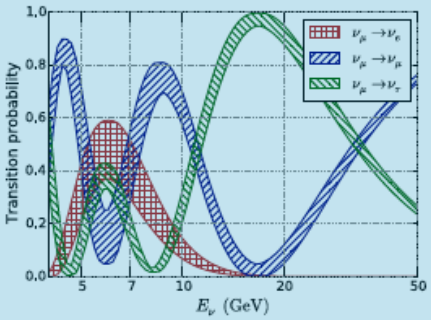
ARCA

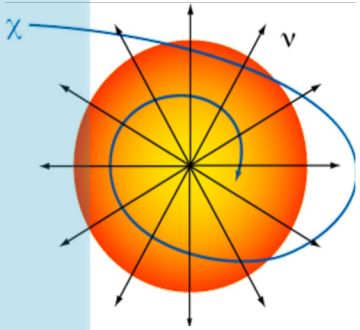
ORCA

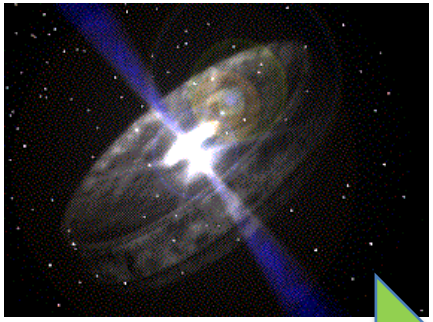
THIS TALK

For ARCA (& ANTARES),
see talk by Sergio Navas
(Astroparticle Physics session)

The KM3NeT Science







MeV — **GeV** — **TeV** — **PeV**

Supernova ν

ν Oscillations, Mass ordering

Dark matter, exotics

HE ν astronomy
Cosmic accelerators

ORCA

ARCA

ORCA

THIS TALK

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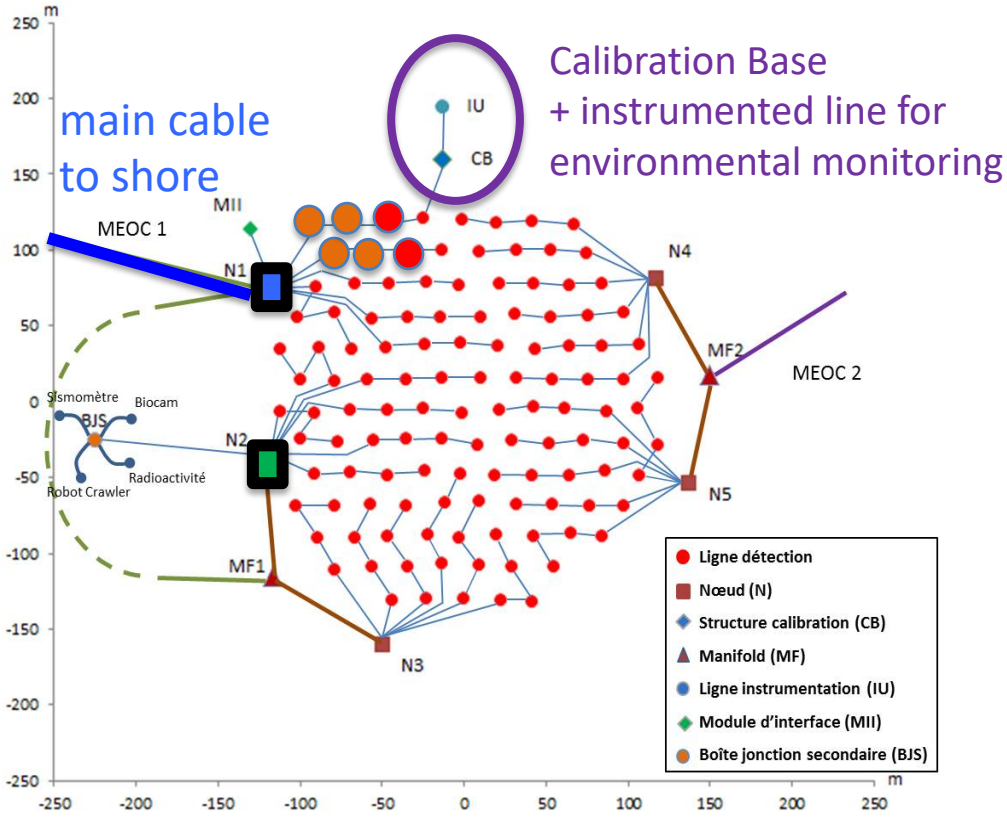
The ORCA detector

ORCA4 since July 2019
~4.5 months data sample
Sanity checks & first physics results
- see later in this talk

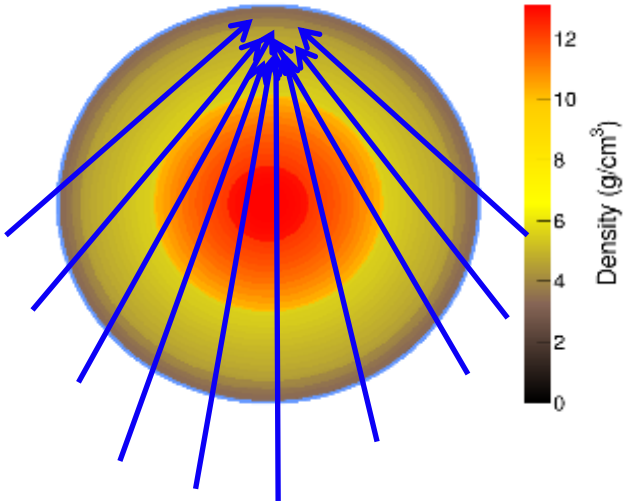
ORCA6 since January 2020
>1 year data on tape, being analyzed

Node2 since October 2020
→ capacity to connect 52 DUs

More sea operations planned for 2021/2022: DUs and Calibration Unit



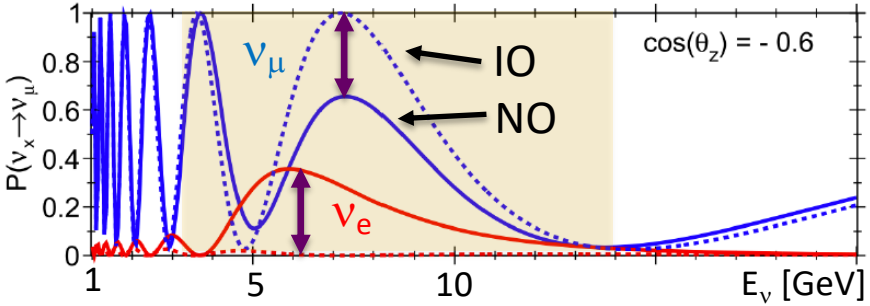
ORCA science goals



❖ Atmospheric neutrino measurement above 1 GeV:
A "free beam of known composition ($\nu_e/\overline{\nu}_e$ and $\nu_\mu/\overline{\nu}_\mu$)
Different energies (few GeV – few 100 GeV)
Different baselines

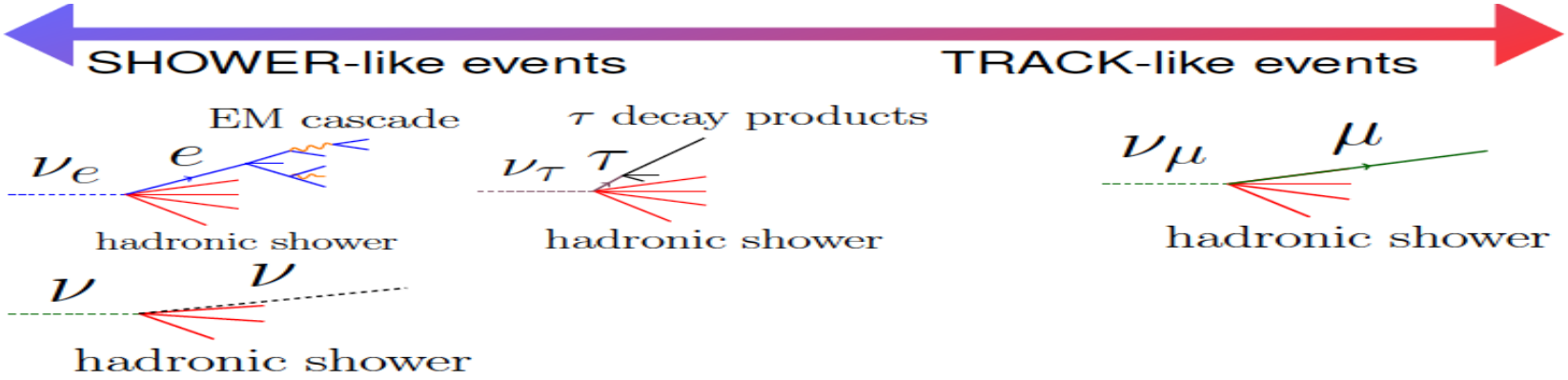
❖ Probe neutrino oscillations in the atmospheric sector: sensitivity to θ_{23} and Δm^2_{31} (+ θ_{13} , δ_{CP})

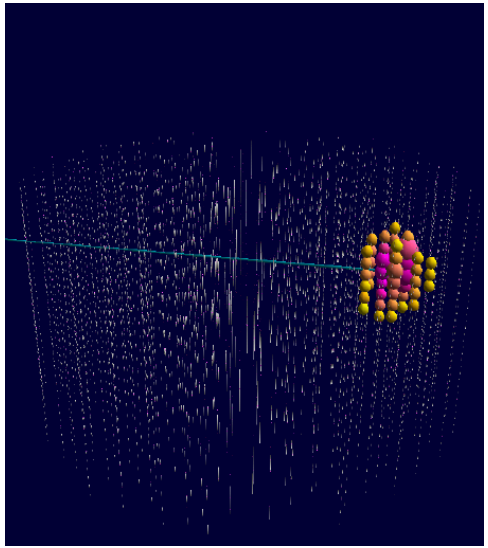
❖ Determine the neutrino mass ordering (IO/NO)
by exploiting matter effects in neutrino oscillations



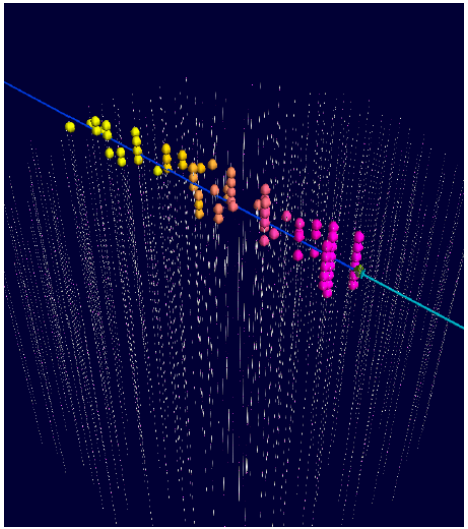
need good event reco/ID performances
+ careful treatment of systematics

ORCA detection principle



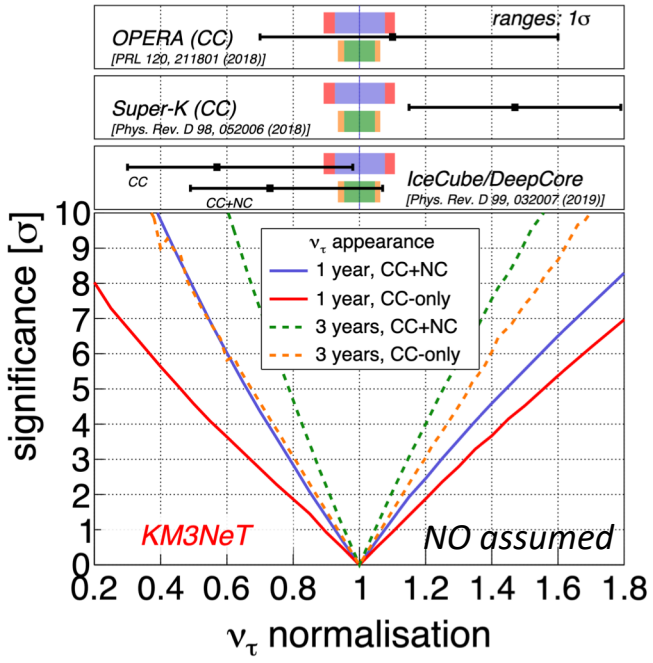


Discrimination of tracks, showers and atmospheric muons (~%) via Random Decision Forests (RDF)



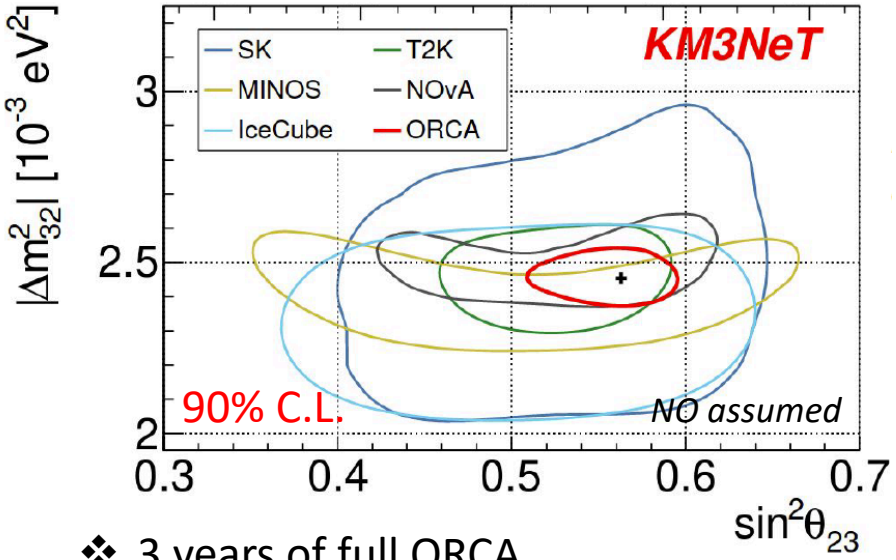
ORCA sensitivity projections

ν_τ appearance



- Confirmation possible after a few months operation with full ORCA
- Fit robust against θ_{23} and mass ordering

Oscillation parameters

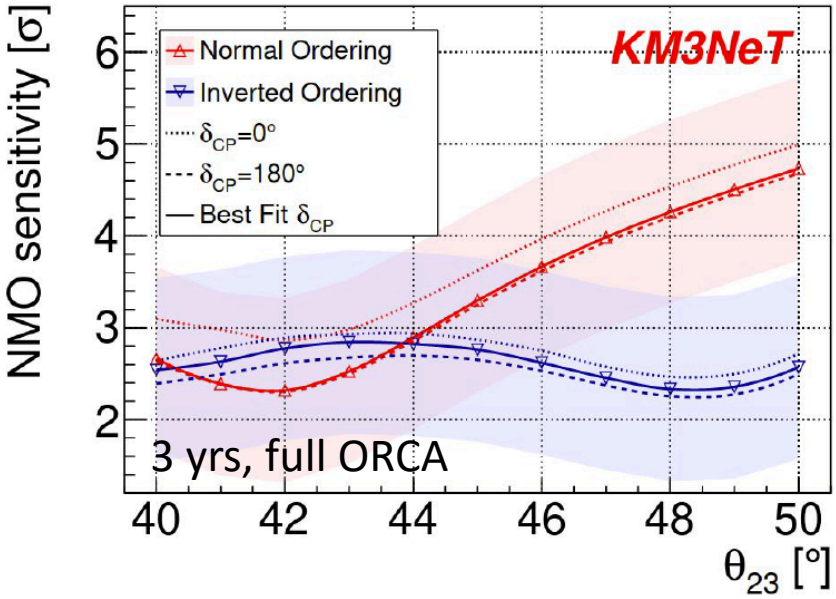


- 3 years of full ORCA
- Normal ordering, $\theta_{23} = 48.6°$ (NuFit v4.1)

📖 *KM3NeT Coll., arXiv: hep-ex/2103.09885 , submitted to EPJ C*

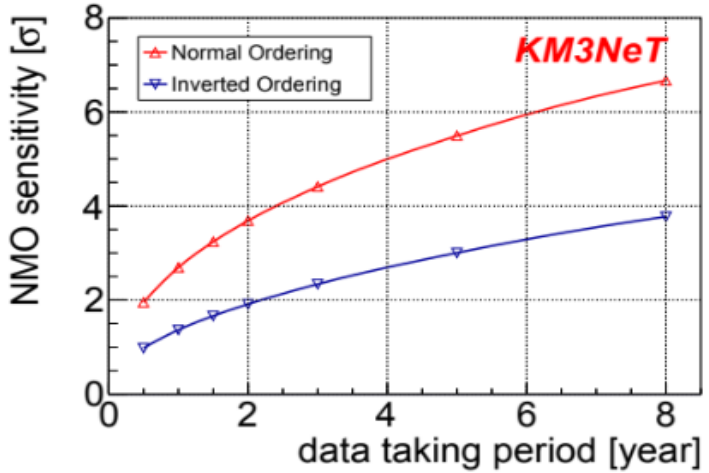
ORCA sensitivity projections

Neutrino mass ordering



68% sensitivity bands (Asimov);
Oscillation parameters from NuFit 4.1

- Favourable scenario: Normal Ordering
→ measurement at 5σ after 4 years
- For Inverted Ordering scenario:
→ measurement at 3σ after 5 years
- moderate impact of δ_{CP} on sensitivity

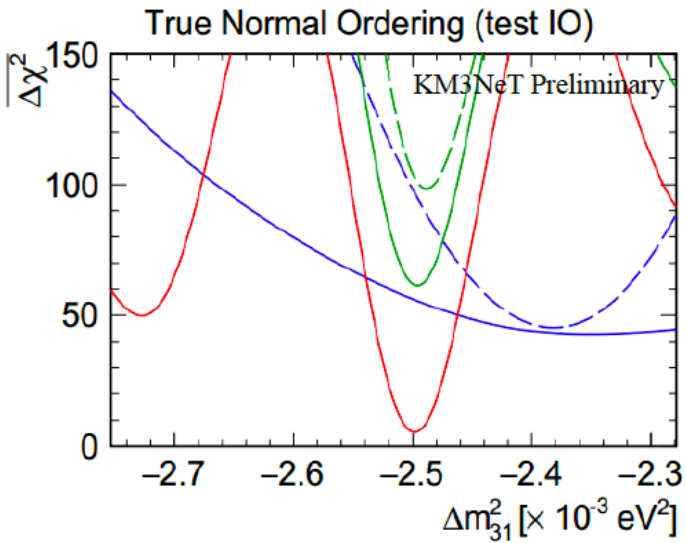


📖 *KM3NeT Coll., arXiv: hep-ex/2103.09885 , submitted to EPJ C*

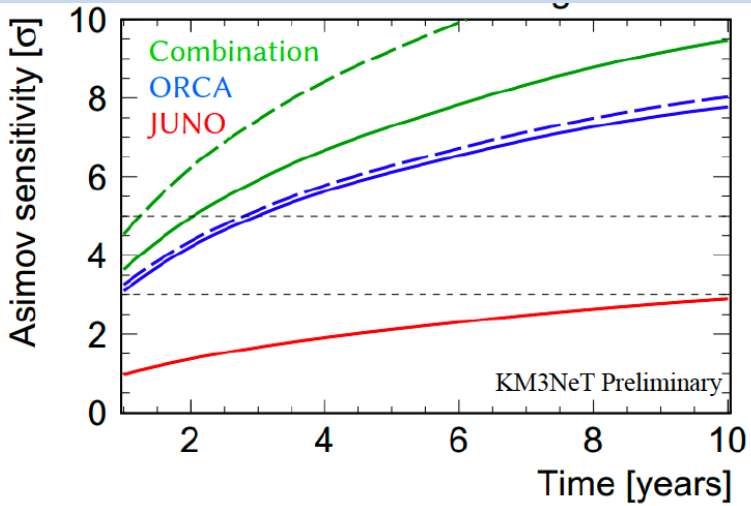
ORCA sensitivity projections

Neutrino mass ordering: combination with JUNO

Tension between the best-fit Δm^2_{31} with a wrong ordering assumption enhances sensitivity when combining ORCA+JUNO



❖ 5σ discrimination achievable for all hierarchy/octant scenarios in < 6 yr
(5σ in 2 years in case of normal ordering)
❖ detail of energy-scale systematic are important

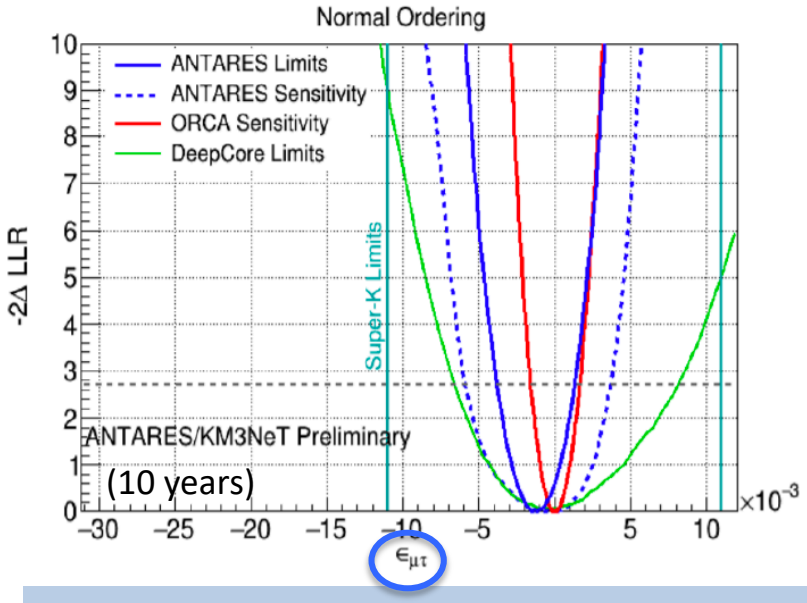


☞ *See talk by Nhan Chau, VLVnT 2021*

Oscillation parameters from NuFit 4.1

ORCA sensitivity projections

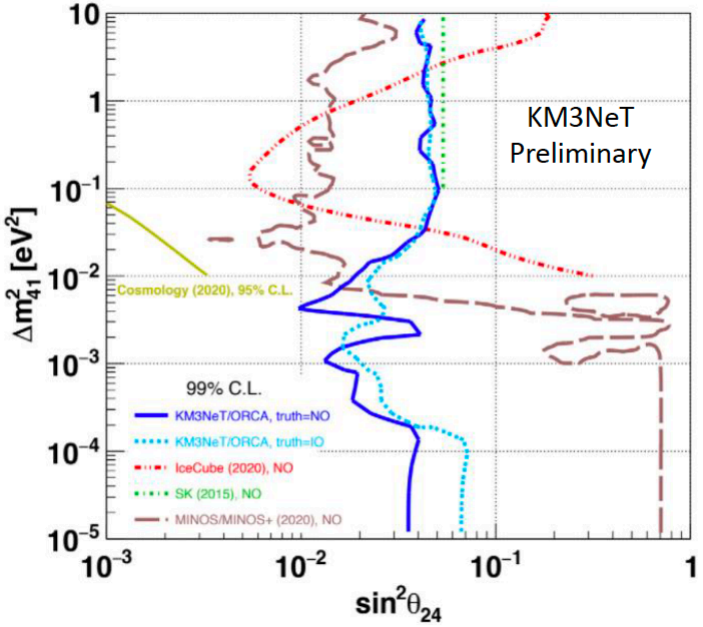
Non-standard ν interactions



❖ expected x3 improvement on already competitive limits of ANTARES

❖ expected 1% precision on full NSI Hamiltonian

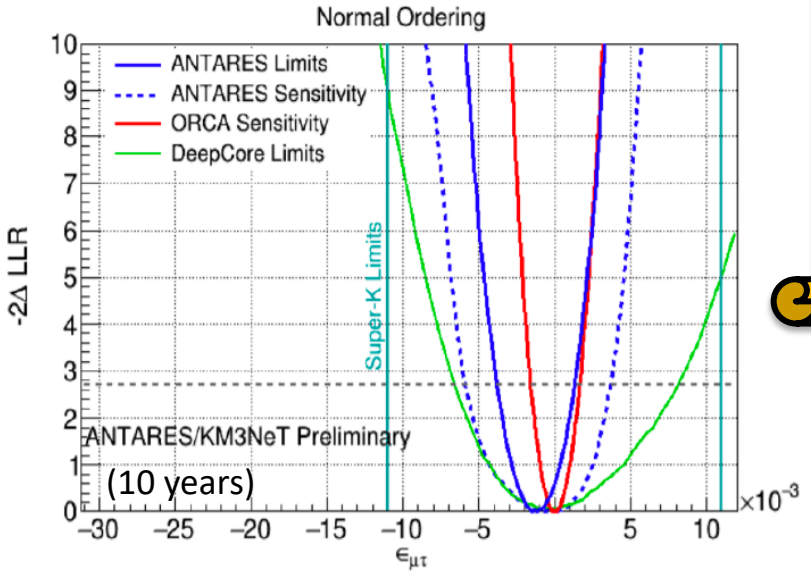
Sterile ν



❖ expected world-leading sensitivity on $|U_{\tau 4}|^2$ and test of low Δm^2_{41}

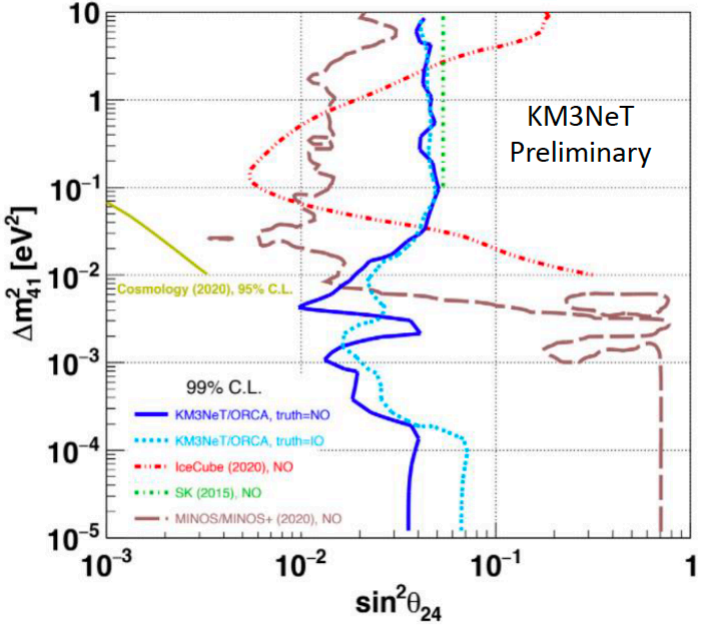
ORCA sensitivity projections

Non-standard ν interactions



See virtual poster by Joao Coelho (same session)

Sterile ν



❖ expected x3 improvement on already competitive limits of ANTARES

❖ expected 1% precision on full NSI Hamiltonian

❖ expected world-leading sensitivity on $|U_{\tau 4}|^2$ and test of low Δm^2_{41}

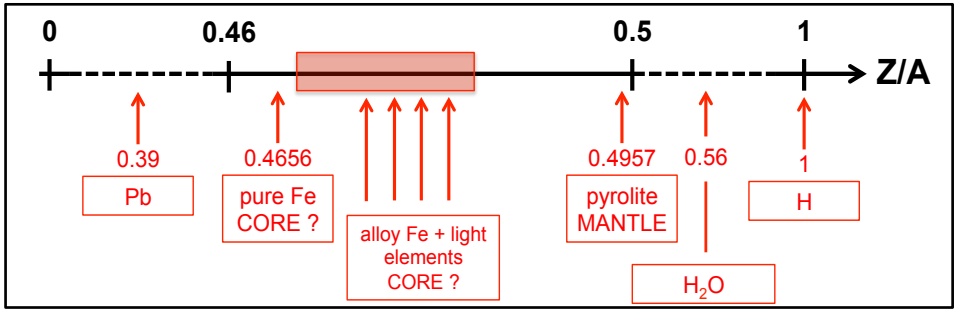
ORCA sensitivity projections

Atmospheric neutrino oscillations

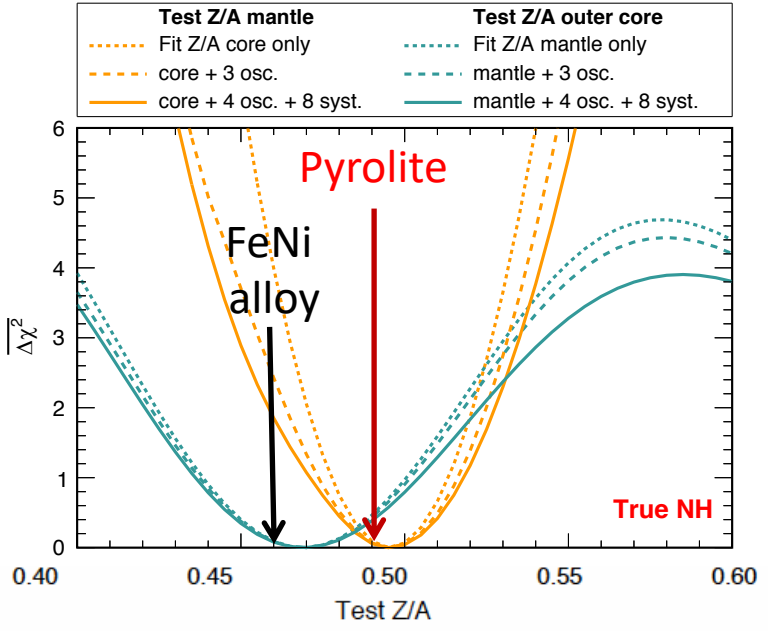
$$N_e = \frac{N_A}{m_n} \times \frac{Z}{A} \times \rho_{matter}$$

from geophysics

Constrain $\frac{Z}{A} = \sum_i w_i \frac{Z_i}{A_i}$



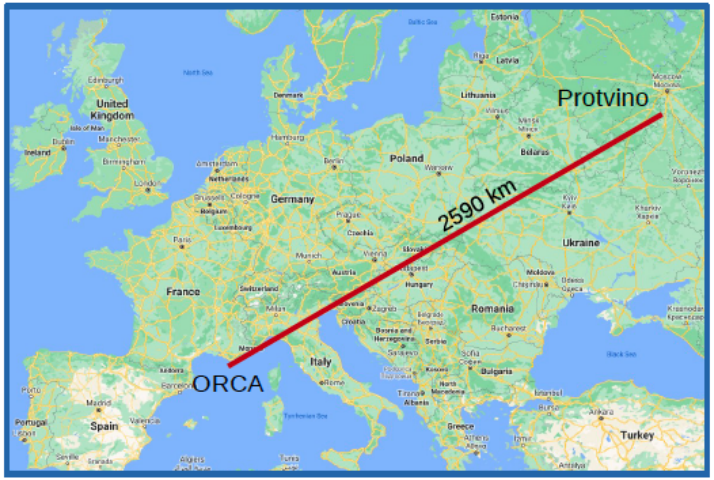
❖ 1σ sensitivity on Z/A after 10 years:
5% in mantle
6% in outer core
(systematics included, MC response & PID)



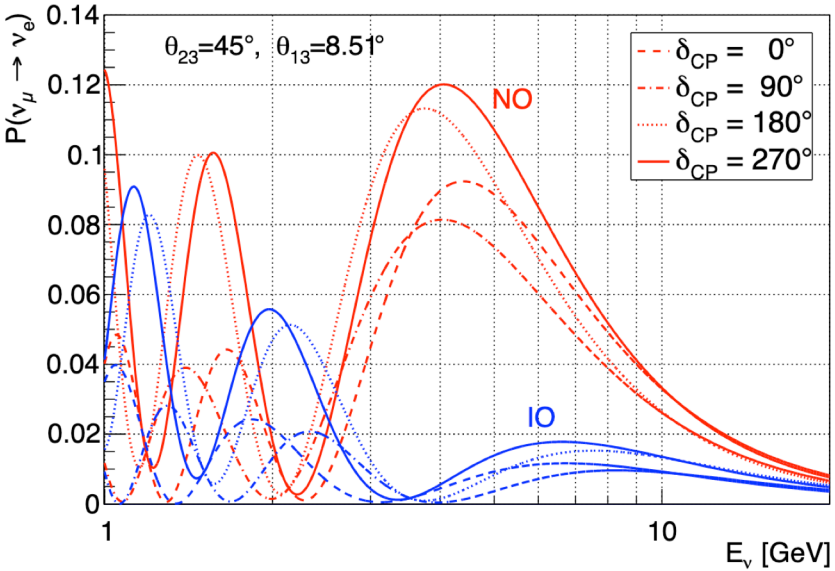
S. Bourret [KM3NeT Coll.], EPJ Web Conf. 207 (2019) 04008

A neutrino beam to ORCA ?

- from U70-Protvino (Russia) to ORCA (P2O)
- up to 450 kW beam power
- Baseline 2595 km



- First oscillation maximum ~5 GeV
- Sensitivity to mass ordering and CP violation

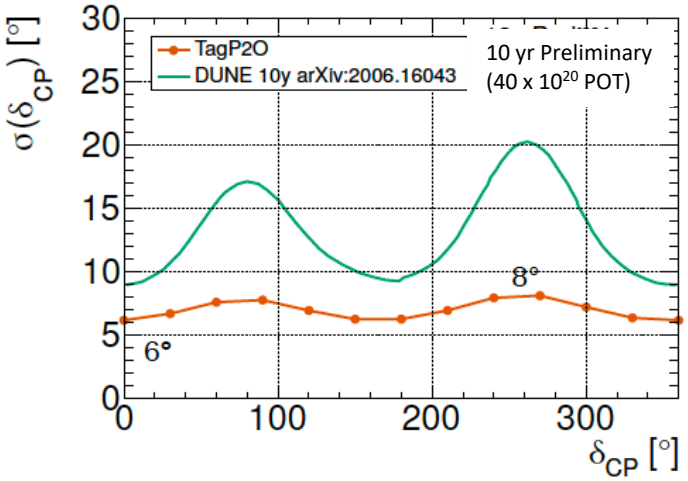


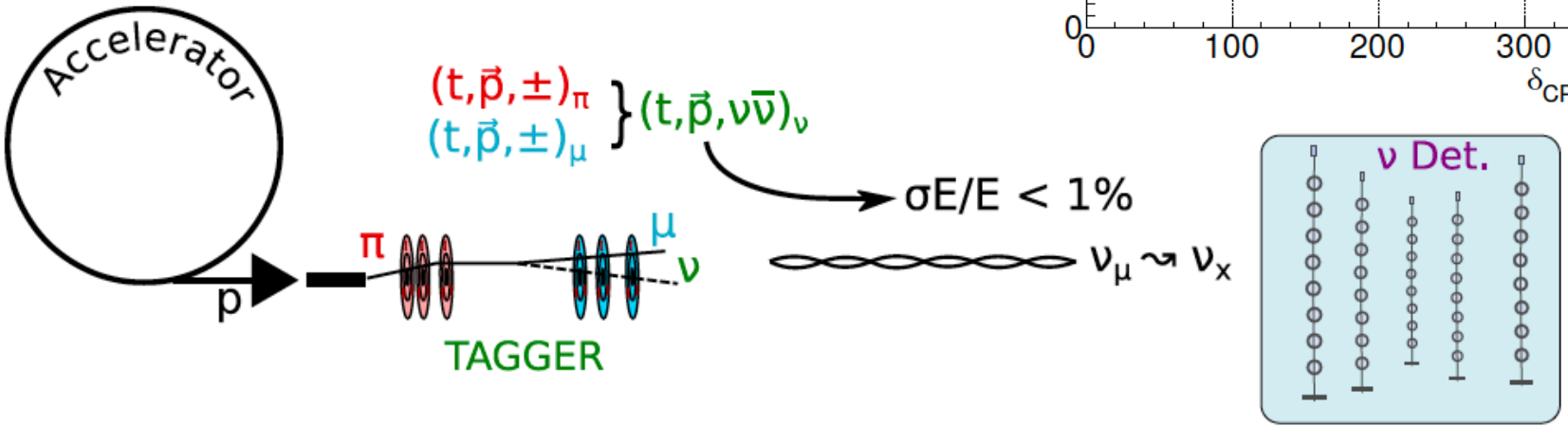
📖 *P2O LoI: Eur.Phys.J.C 79 (2019) 9, 758*

A neutrino beam to ORCA ?

- from U70-Protvino (Russia) to ORCA (P2O)
- up to 450 kW beam power
- Baseline 2595 km
- New idea: use a tagged beam

→ Improved & quasi-uniform sensitivity to δ_{CP}

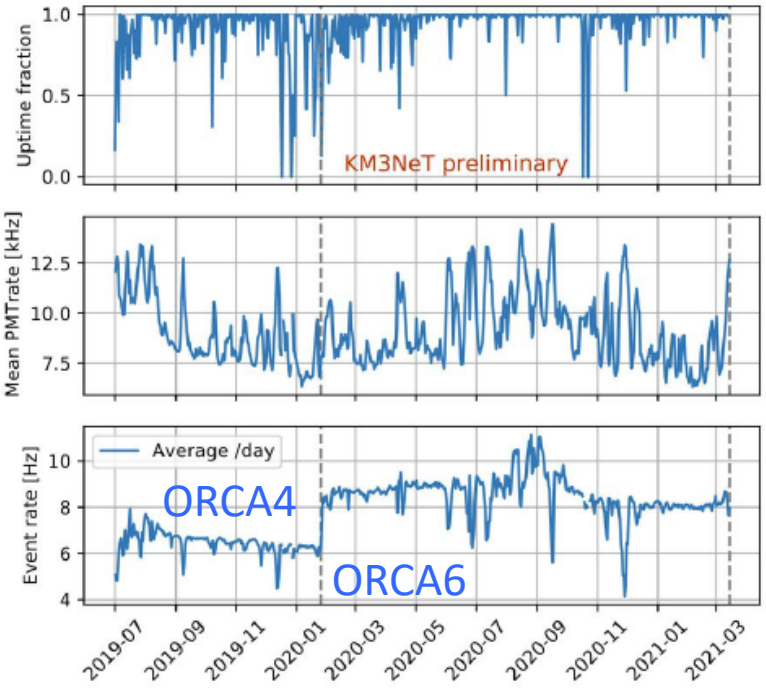




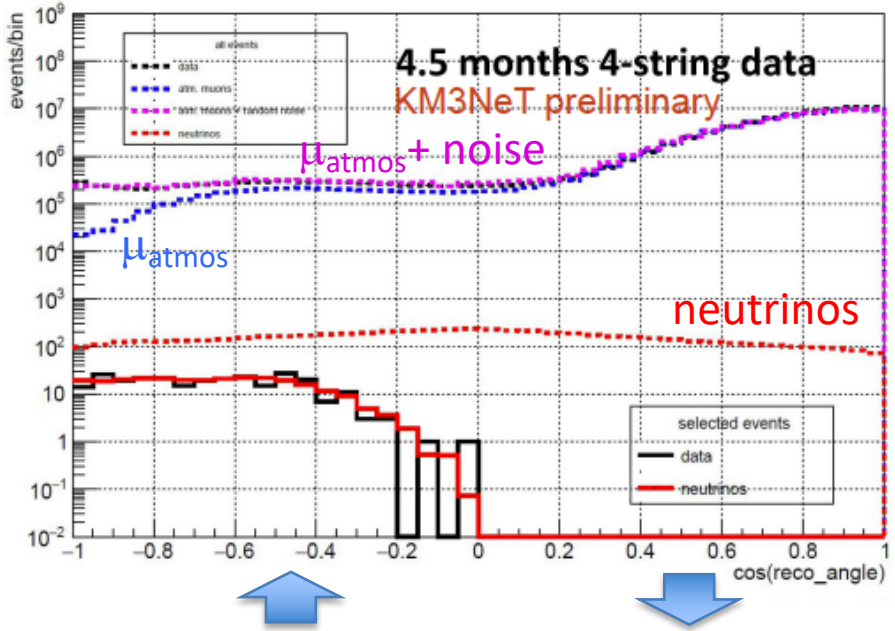
☞ *See talk by Mathieu Perrin-Terrin, VLVnT 2021*

ORCA4: first results

- Stable data taking since mid-2019
- Uptime 91% (2019) → 99% (2021)
- Good stability of trigger



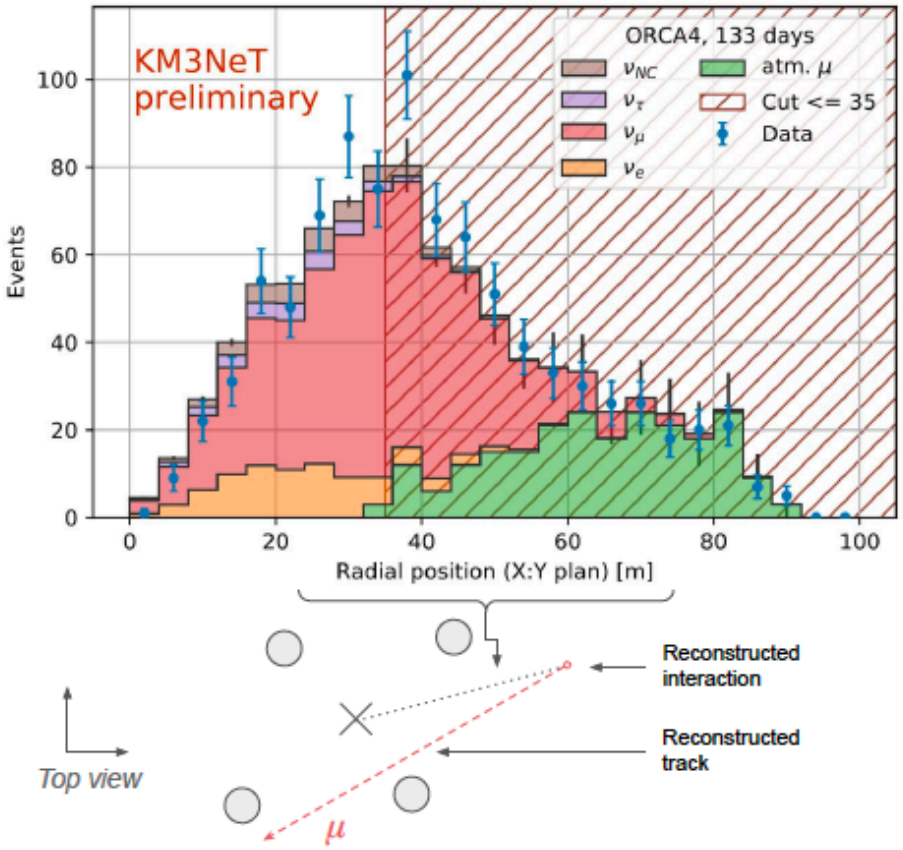
- ORCA4 data sample: 133.1 days
- Good data-MC agreement



~600 000 muons/day
~40 neutrinos/day

☞ *See talk by Vincent Pestel [KM3NeT Coll.], VLVnT 2021*

ORCA4: first results



❖ Neutrino selection:

- Upgoing tracks
- Track quality parameter
- « containment » condition on reconstructed vertex

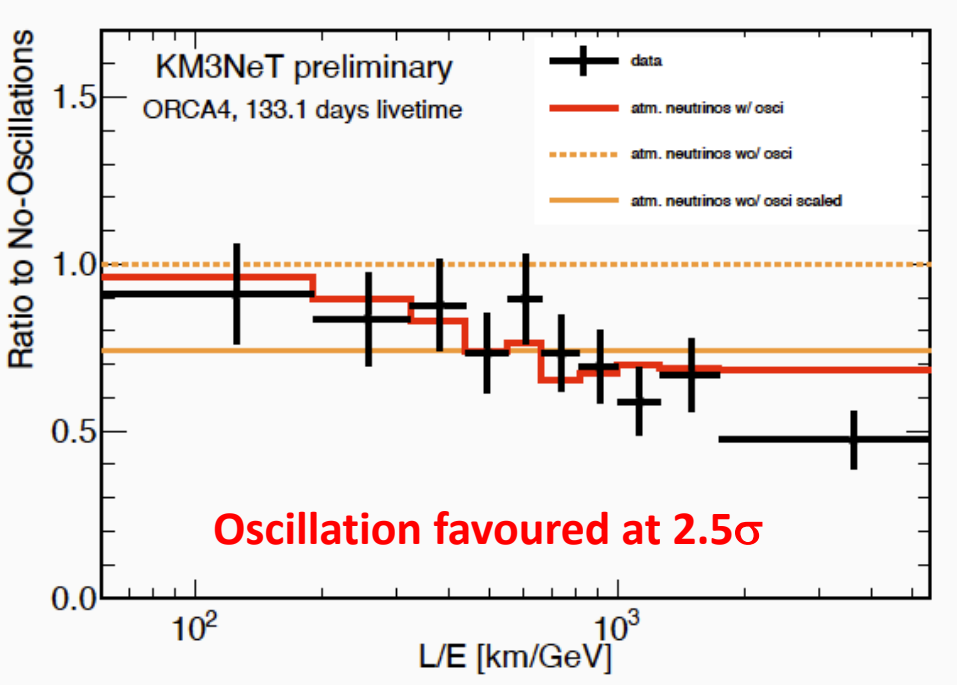
➡ High-purity neutrino sample:

• Data	2.86	± 0.15 /day
• ν_{atm}	2.92	± 0.02 /day
• $\nu_{atm\ (no\text{-}osc)}$	3.94	± 0.03 /day
• μ_{atm}	0.02	± 0.02 /day

Only stat.

☞ *See talk by Vincent Pestel [KM3NeT Coll.], VLVnT 2021*

ORCA4: first results

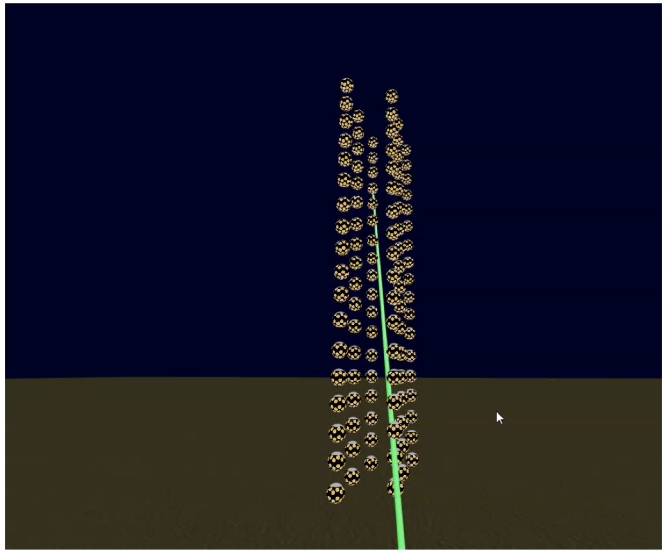


Binning adjusted for similar statistical uncertainties per bin

- First preliminary measurement
  Honda atmospheric flux + NuFit 4.0
  Flux normalization free
- Good data/MC agreement
- Statistically limited
- No track/shower separation:
  all events reconstructed as tracks
- resolutions (energy/direction) limited by small size of detector

☞ *See talk by Vincent Pestel [KM3NeT Coll.], VLVnT 2021*

Outlook



Stay tuned !

Collaborators welcome !

❖ Already 10x more neutrinos on tape with ORCA6; data sample being analyzed

❖ Detector construction proceeding and ramping up despite of CoViD:
~30 DUs expected by early 2022