Project-ANR-19-CE31-0009

Sensitivity of the KM3NeT/ORCA detector to the neutrino mass ordering and beyond

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https://arxiv.org/abs/2103.09885

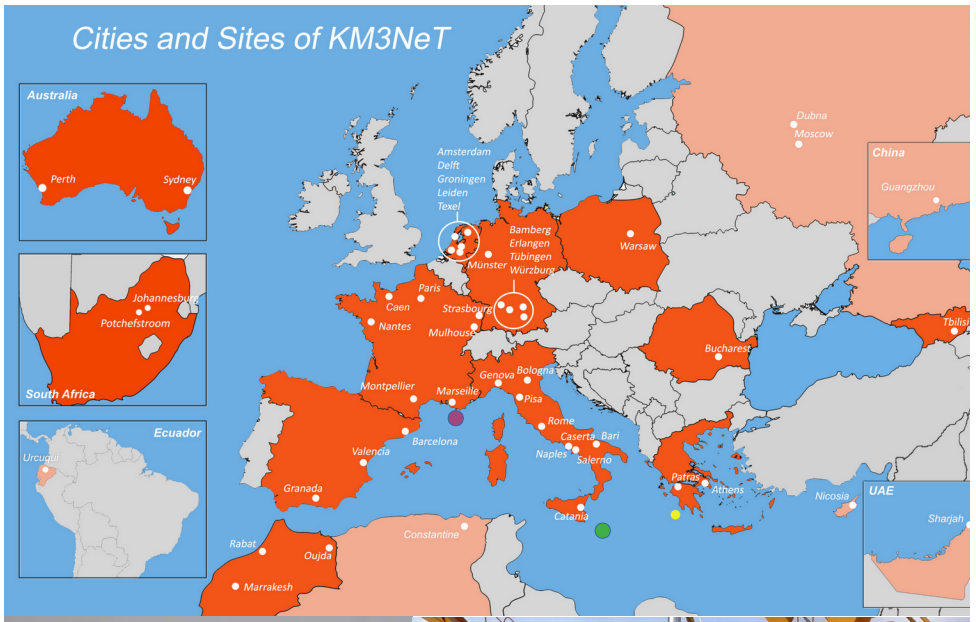
Outline

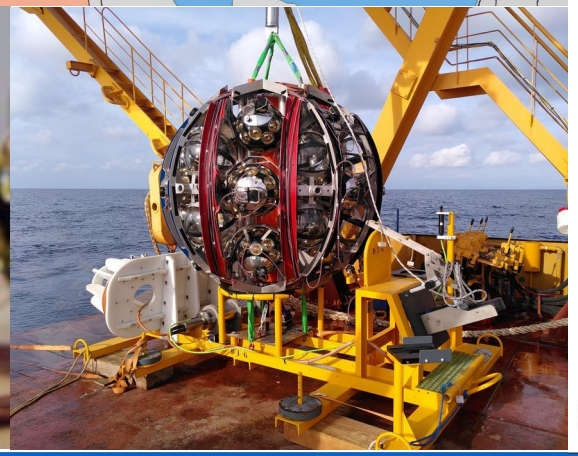
- Introduction
- Neutrino Oscillation with KM3NeT-ORCA
- A new kind of long baseline experiment with KM3NeT-ORCA

KM3NeT ORCA

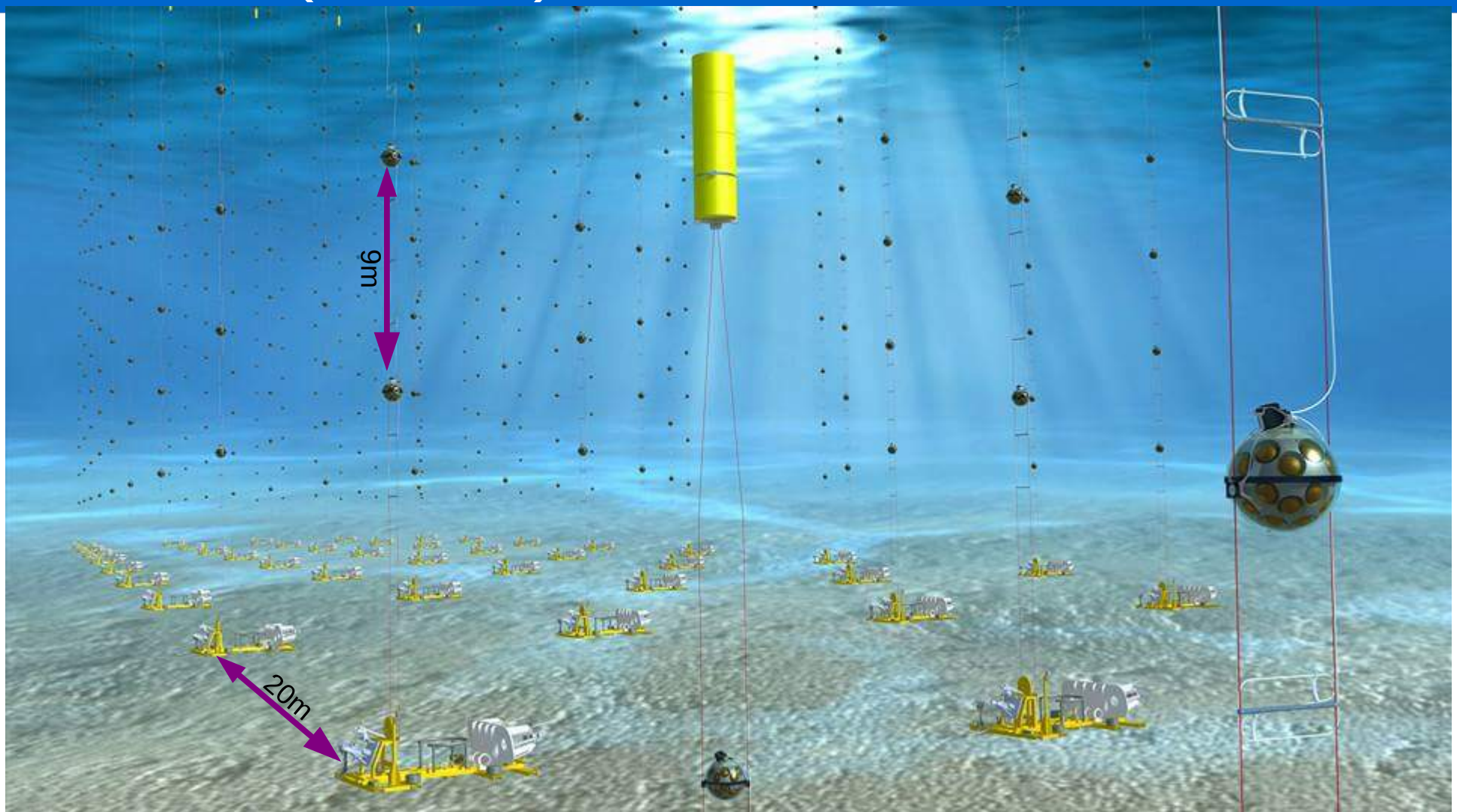
- KM3NeT Collaboration is building **two neutrino telescopes** in the abyss of the Mediterranean sea
  - **ARCA** (Italy): **TeV → PeV ν**
    [6 operational lines]

    ORCA (France): **3-100 GeV ν**
    [6 operational lines]
- **A shared technology**: multi PMT modules arranged in detection lines
- Modules and lines spacing set the **energy threshold**
- Line **deployed furled** from a boat and **unrolled from the sea bed**



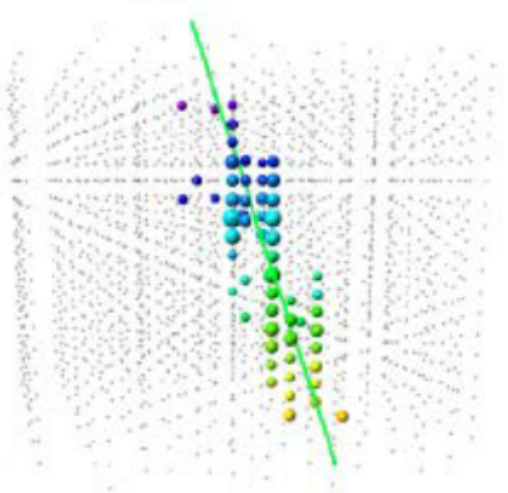


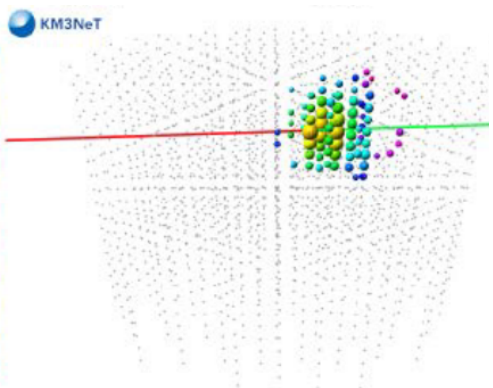
(Artist's) View for the water

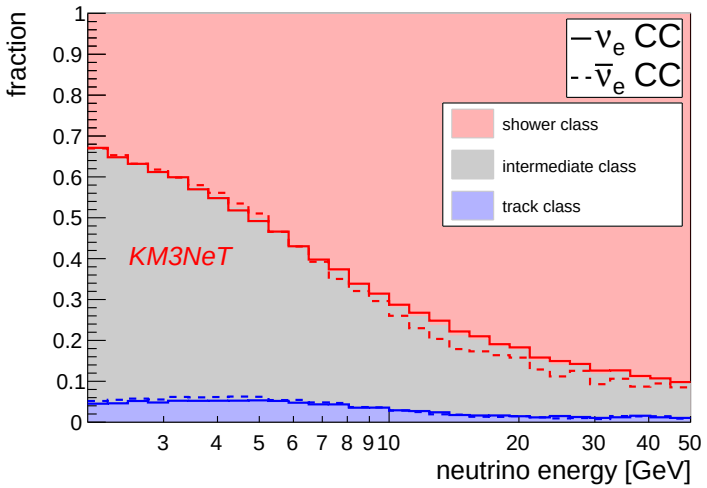


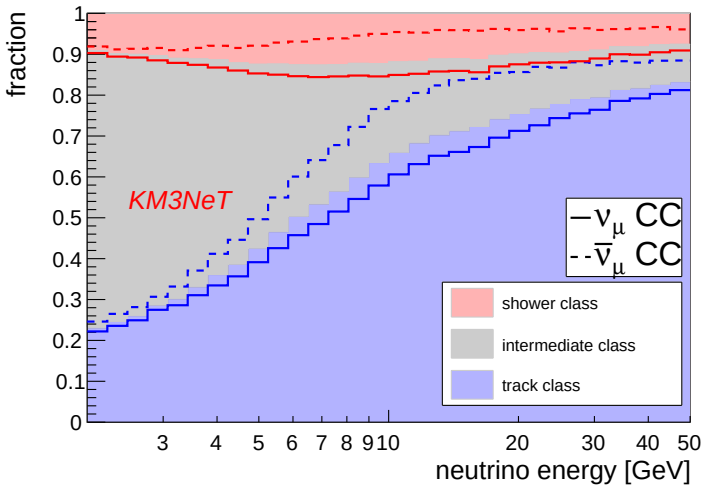
Neutrinos in KM3NeT-ORCA

- Two typical **event topologies**
  - **TRACK**: νμ Charged Current (CC) (+ ντ)
  - **SHOWER**: Neutral Current (NC) and νe-CC (+ ντ hadronic)
- Algorithms trained to **classify events in 3 categories**
  - Track, Shower and Intermediate



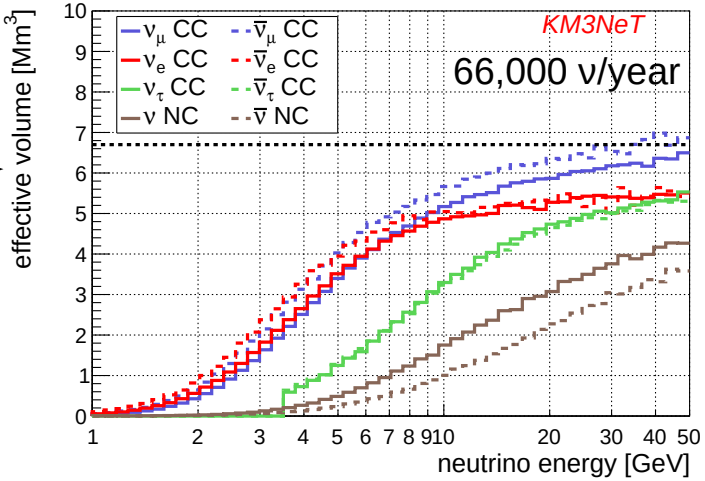


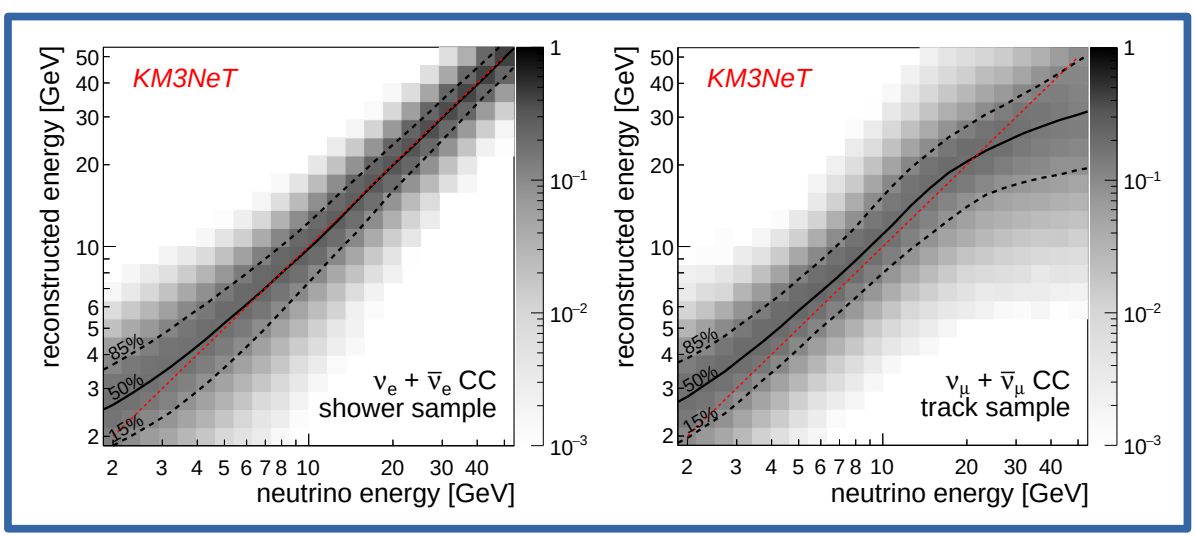


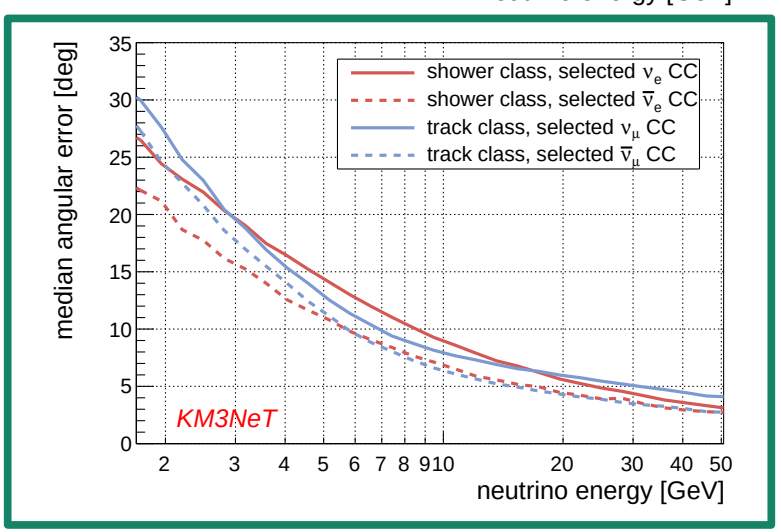


KM3NeT-ORCA Performances

- Performances estimated based on **simulations**
- Detector **effective volume** around **5-6 Mm³** (instrumented volume for 115 lines is 6.7 Mm³)
- **Energy resolutions** at 10 GeV
  - ► 25 % for νe
  - ► 35% for νμ
- **Angular resolution** dominated by ν-lepton angle

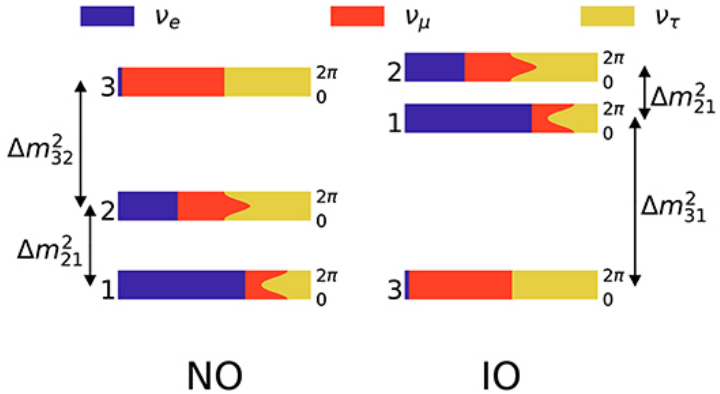




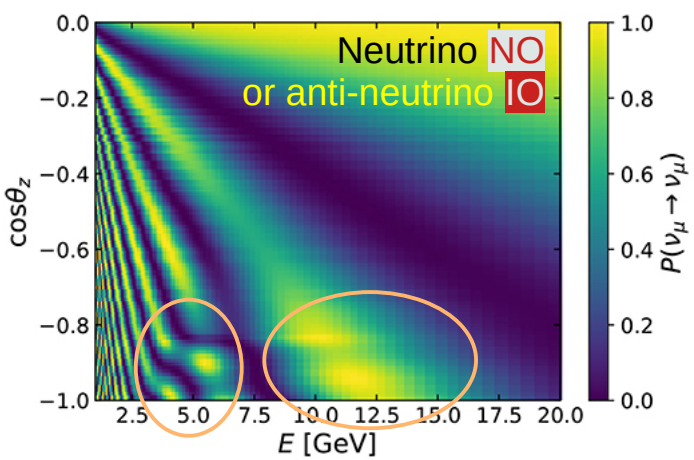


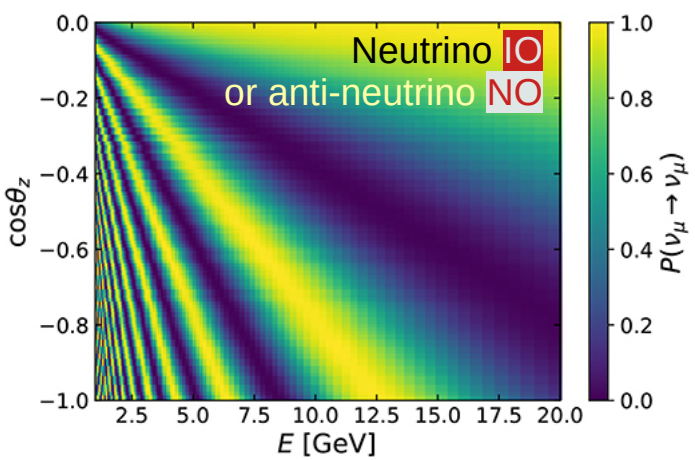
Neutrino Mass Ordering with Atmospherics

- **Neutrino mass ordering** (NMO)
  - Normal (NO): $m_1<m_2<m_3$
  - Inverted (IO): $m_3<m_1<m_2$



- Measure NMO using **matter effects** with atmospheric neutrino oscillation:
  - **NO**: matter induces resonance for **ν** **IO**: matter induces resonance for **$\bar{\nu}$**
  - **Net effect** on (ν+$\bar{\nu}$) as ν **cross-section** is twice as large as for $\bar{\nu}$





Credits : https://doi.org/10.3389/fspas.2018.00036

NMO Sensitivity

- Oscillation parameters taken from **NuFit4.1** Esteban,et al. DOI10.1007/JHEP01(2019)106.
- **Syst. uncertainties** on oscillation param., ν flux, x-sec, and detector response

Name	Prior
Δm^2_{32}	free
δCP	free

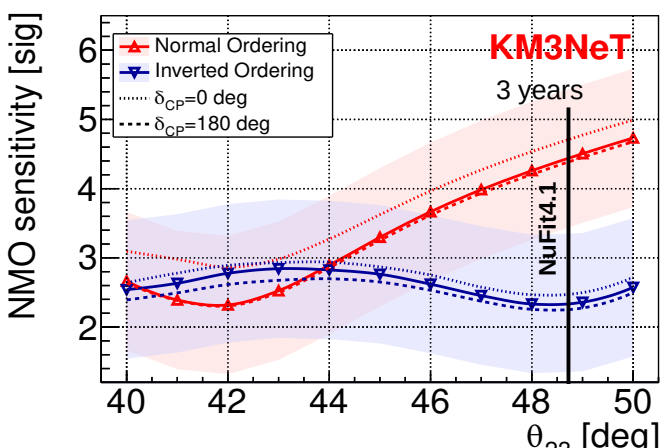
θ_{13}	0.13°
θ_{23}	free
Spectral Index	free

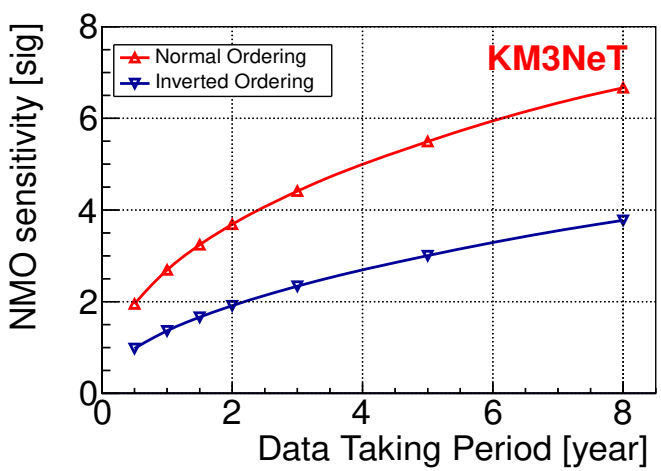
# ν-up / # ν-horiz	2%
# νe / # νμ	2%
# νe / # anti-νe	7%

n νμ / n anti-νμ	5%
ντ cross section	free
NC cross section	free

energy scale	5%
had. energy scale	free
normalisations	free

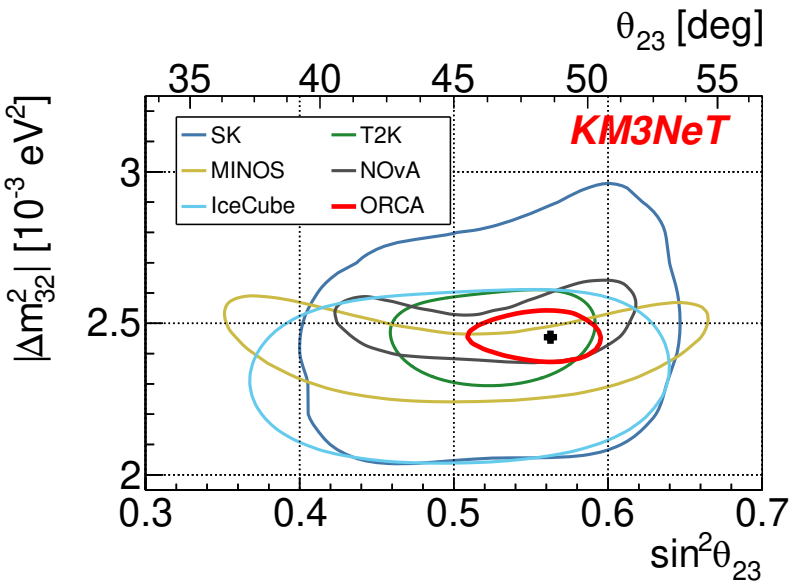
- With **3 years** the NMO determined at
  - **4.4 σ** if NMO = **NO**
  - **2.3 σ** if NMO = **IO**



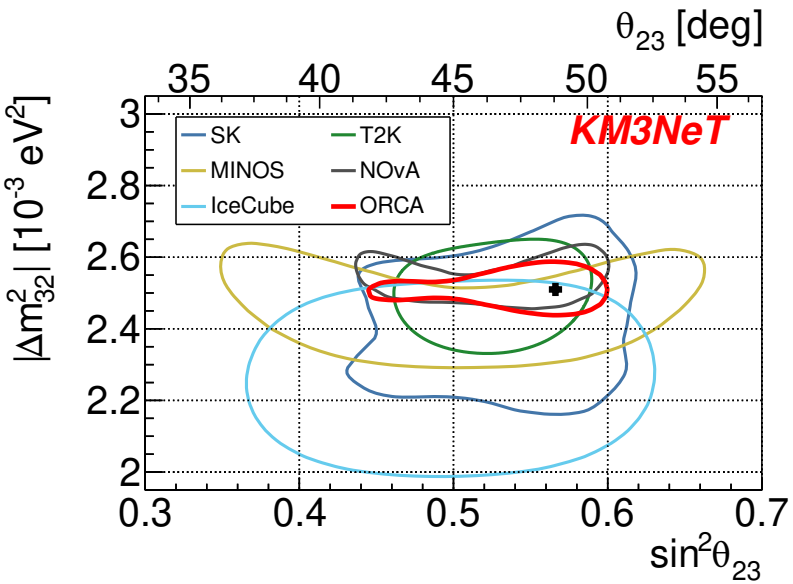


Atmospheric Oscillation Parameters

- Atmospheric neutrino can also be used to **measure θ_{23} and Δm^2_{32}**
- Assuming **3 years of data** and known NMO, the contour would improve a lot with respect to the current ones.



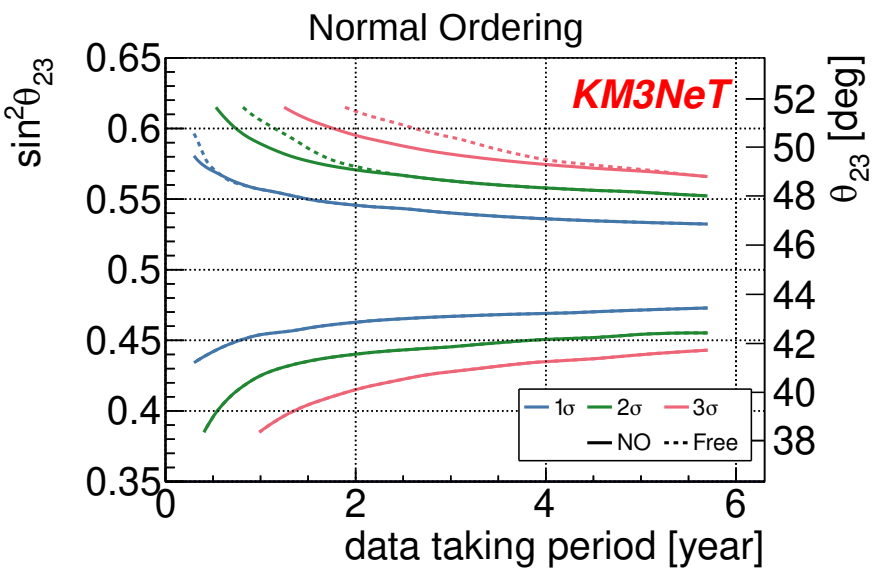
Normal Ordering

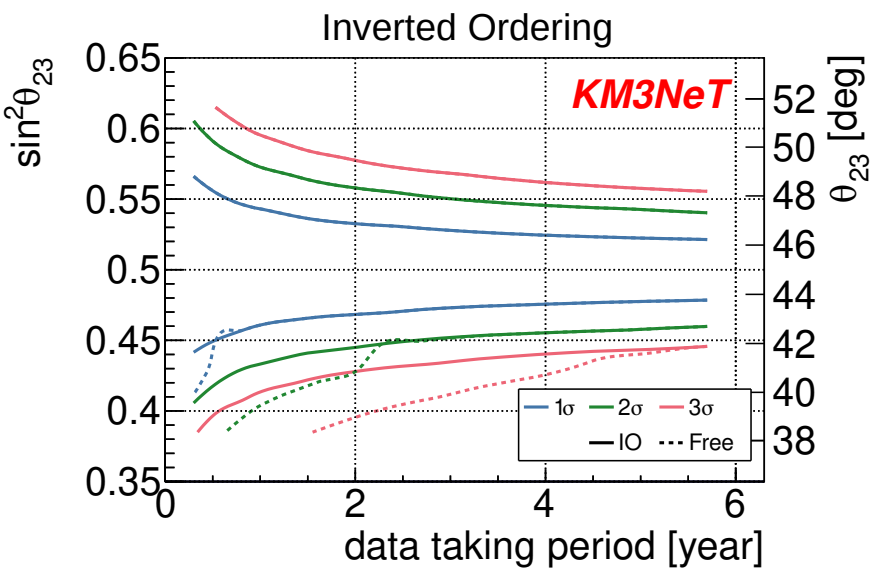


Inverted Ordering

θ_{23} Octant

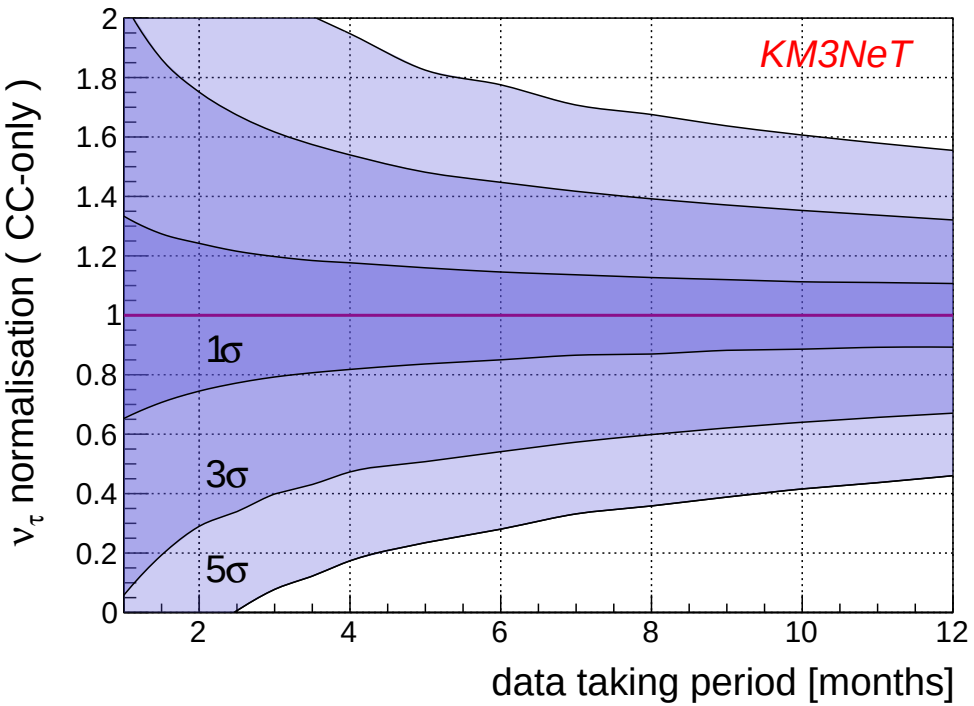
- Oscillation probabilities are almost degenerated: $P(\theta_{23}) = P(45°-\theta_{23})$
- KM3NeT-ORCA can determine the θ_{23} octant





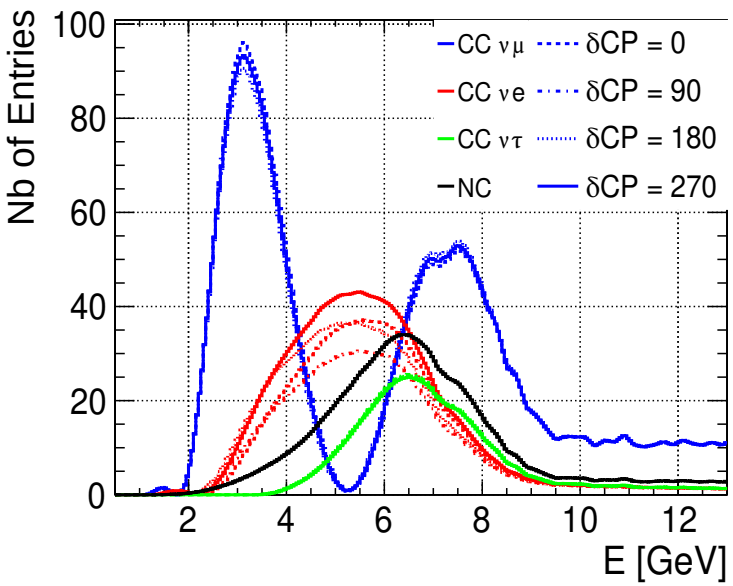
PMNS Unitary

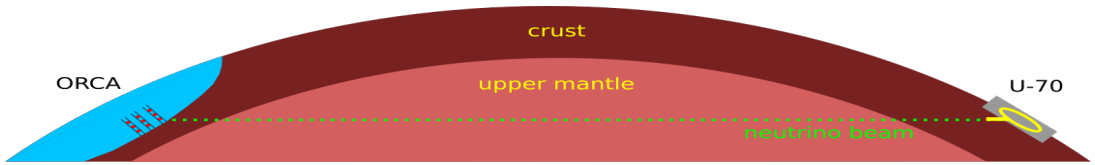
- Testing **PMNS unitarity** is challenging as it requires significant **ντ samples**
- ORCA will detect **~3,000 ντ/year** originating from ν_{atmos} oscillation: dominantly produced as up-going and between 10-30 GeV

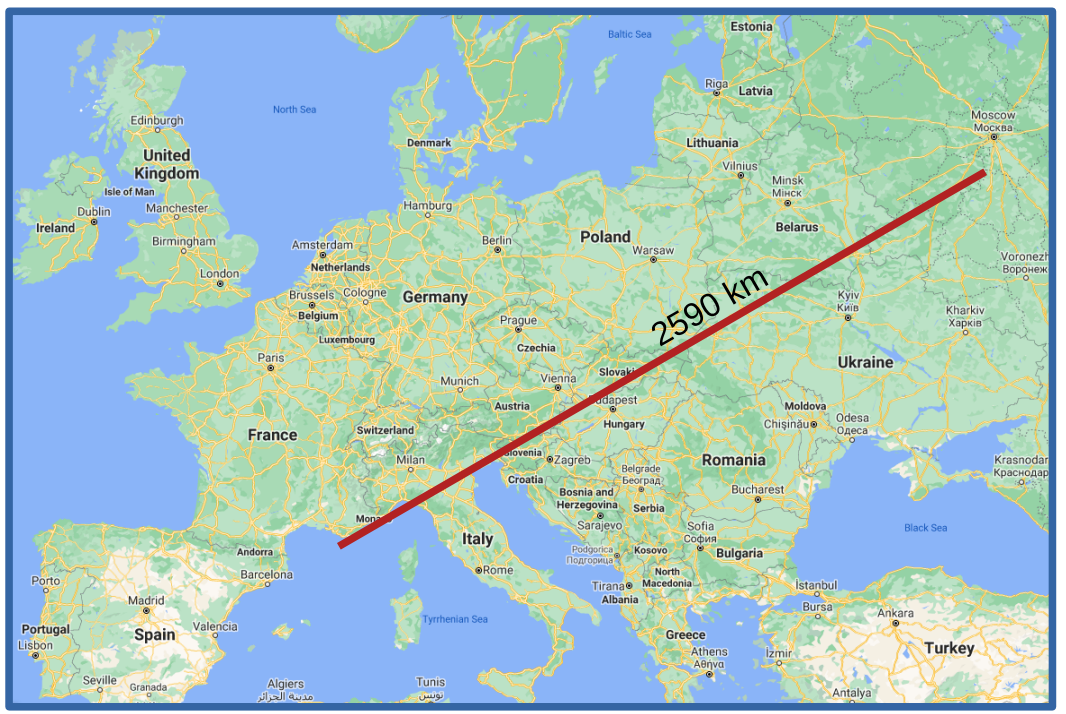


The next step: Protvino to ORCA – P2O

- Use **U70** accelerator in Protvino (Russia) to generate a **ν beam**
- Baseline is **~2600 km**
  ➜ 1st osc. max. is at 5 GeV
- Allows to measure δCP





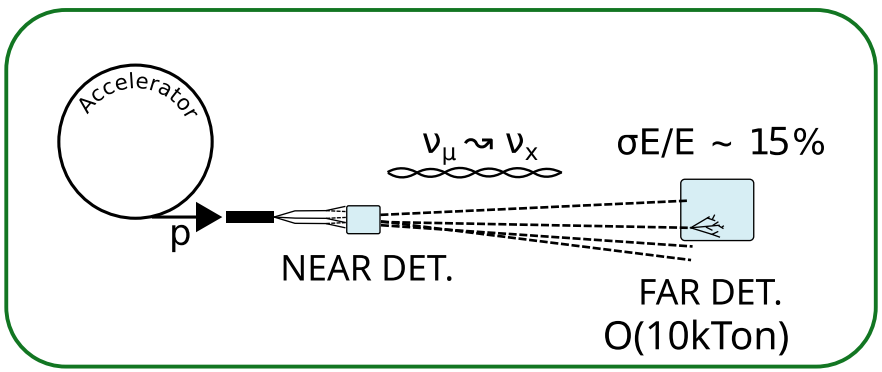


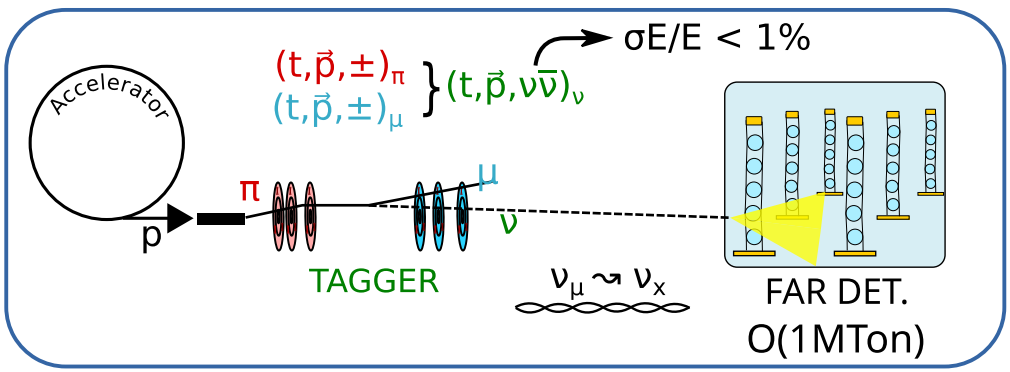
The P2O Specificity: neutrino tagging

- All future experiments aim to precisely **measure δcp**, for which they need
  - **large statistics** (beam power + large detector)
  - **low systematics** (near detector + x-sec measurements)

  } very challenging to do better than DUNE or T2HK

- **P2O** offers an **alternative** to conventional LBL's





  - ORCA **huge mass** (Mton) allows collect **large stat.** **with modest beam power**
  - **beam line can be instrumented with trackers (TAGGER)**
    - ν properties precisely known from π➔μν kine. for each and all ν
    - one-to-one association between π➔μν and interacting ν

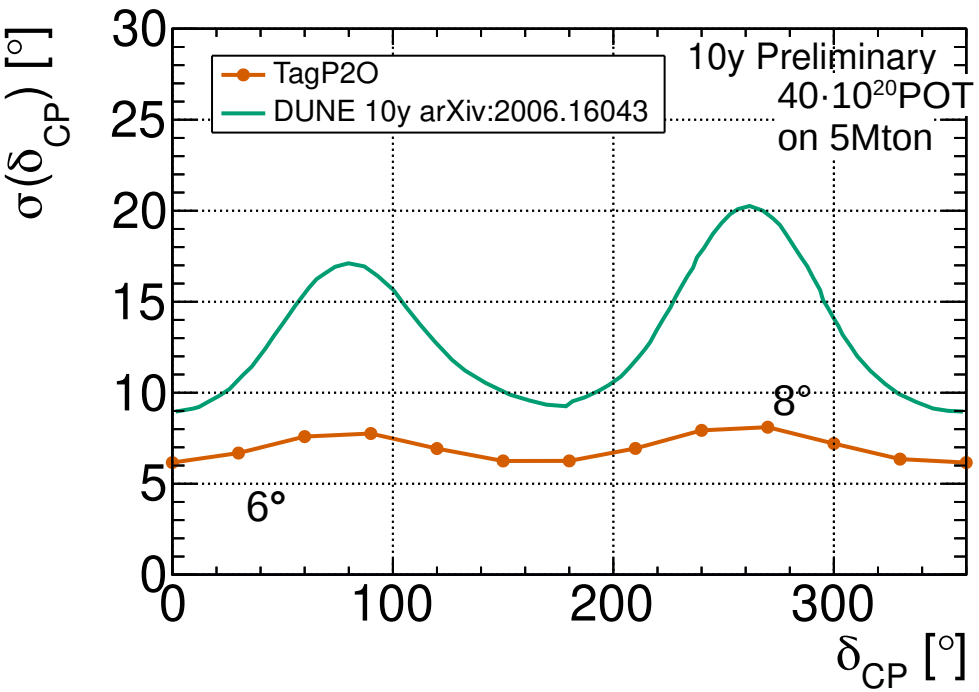
    } **no systematics**

Precision to δ_{CP} at P2O

- **Systematics** on oscillation parameters, cross section & normalisation (free)

θ13 ± 0.15°	ντ ± 10%
θ23 ± 2°	NC ± 5%
Δm²31 ± 5e-3eV²	νe=νμ ± 5%

- **Conservative** estimates:
  no PID improvement with respect to atmospheric ν was considered
- δ_{CP} precision **stable** over all values
- **<8° precision** can be achieved!



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- **Conservative** estimates:
  no PID improvement with respect to atmospheric ν was considered
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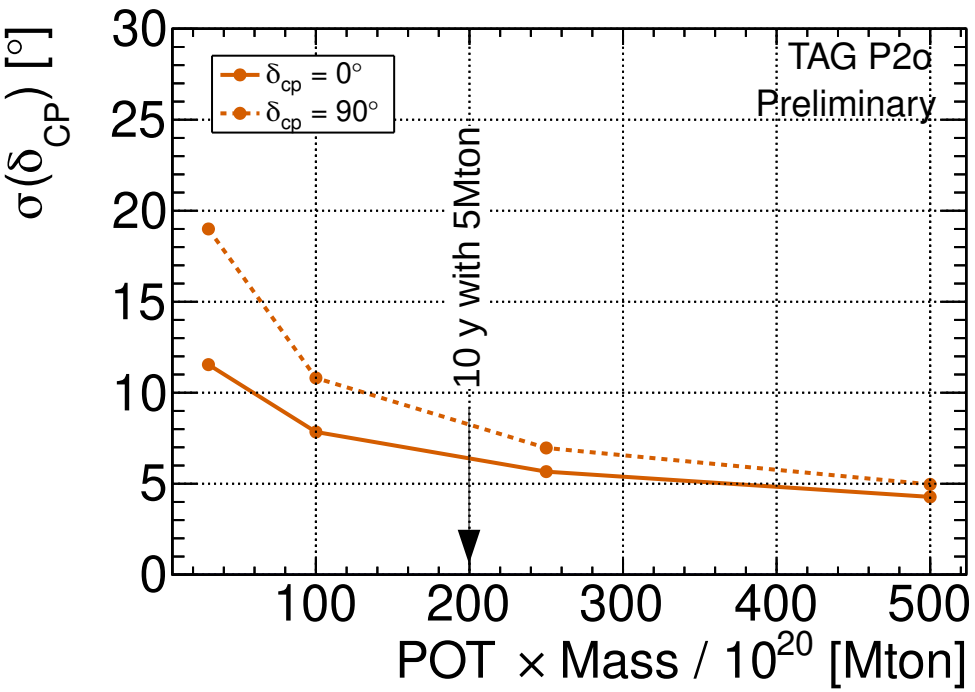
- **<8° precision** can be achieved!
- **<5°** achievable with larger detectors



Summary and Conclusion

- KM3NeT-ORCA is a **Water Cerenkov ν telescope** under construction
  - aim to instrument an effective sea water volume of **5 – 6 Mm³**
- Using **atmos. ν** and **matter effects** in the Earth ORCA will be able to
  - determine the **neutrino mass ordering**
  - improve on the **θ_{23} and Δm^2_{23} contour**
  - determine the **θ_{23} octant**
  - constrain the **PMNS unitarity** using ντ
- In the **future** ORCA could be operated as **far detector of LBL from Protvino**
  - huge mass allows to develop **new LBL concept: tagged beam**
  - **unprecedented precision on δcp**