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KM3NeT/ORCA: status and prospects

M. Perrin-Terrin

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KM3NeT ORCA

NuFact 2019, Daegu, Korea

Mathieu PERRIN-TERRIN

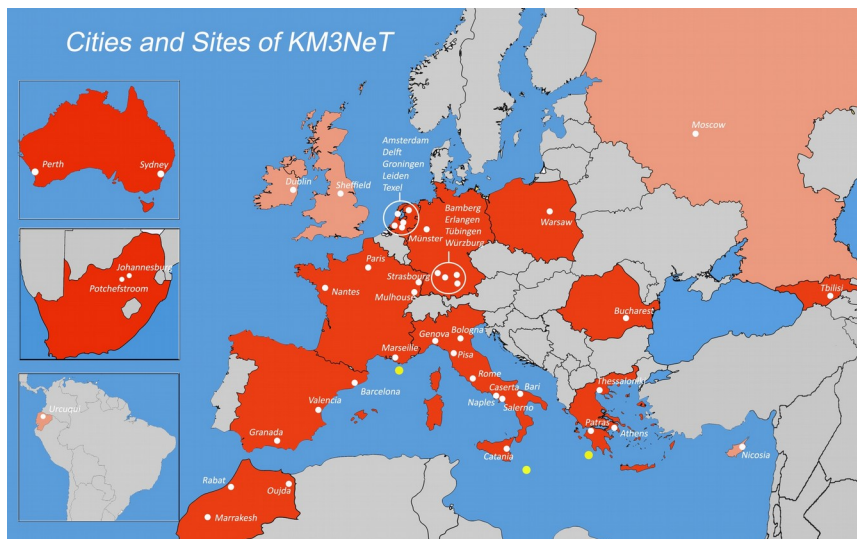
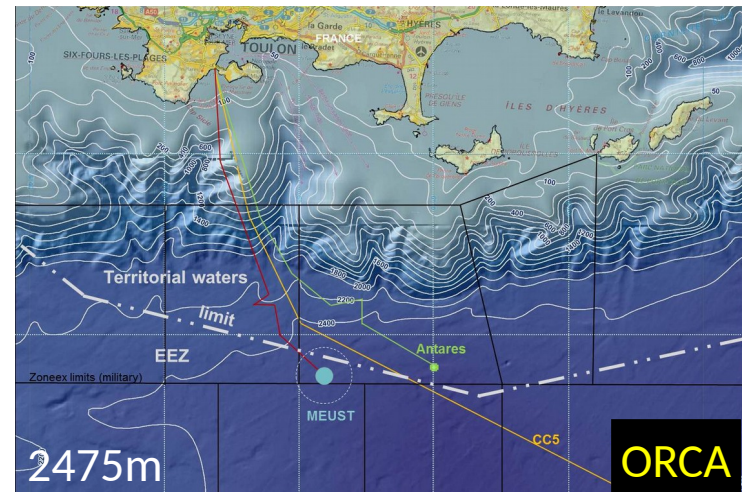
on behalf of the KM3NeT Collaboration

Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France.



The KM3NeT Collaboration

- Two detectors with the same technology:
 - ORCA : neutrino mass hierarchy (few GeV)
 - ARCA : neutrino astronomy (TeV-PeV)

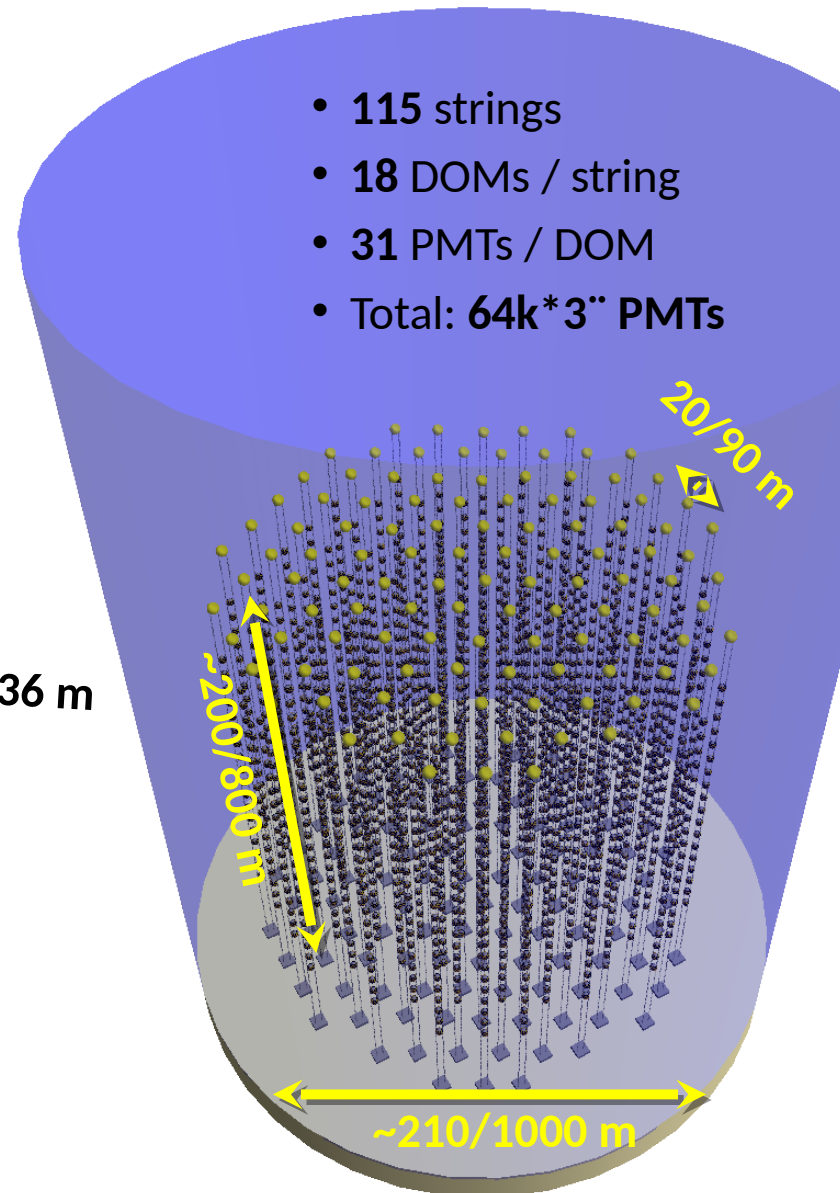


KM3NeT Technology

- Digital Optical Module
 - 31 x 3" PMTs / DOM
 - Uniform angular coverage
 - Directional information

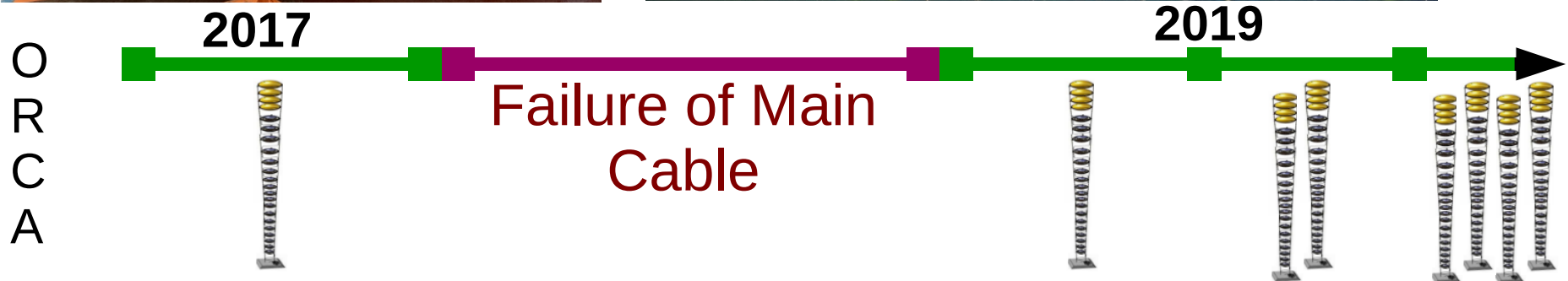
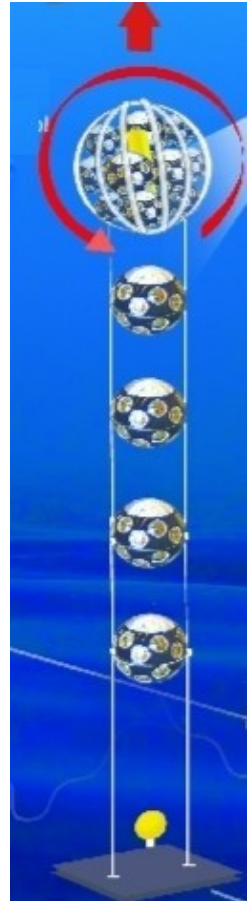
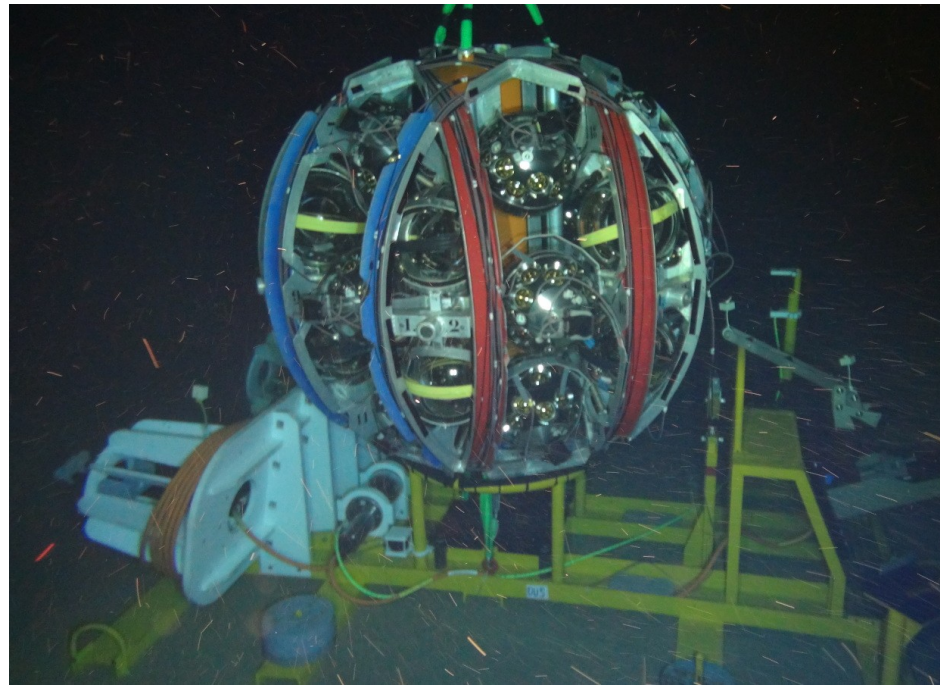
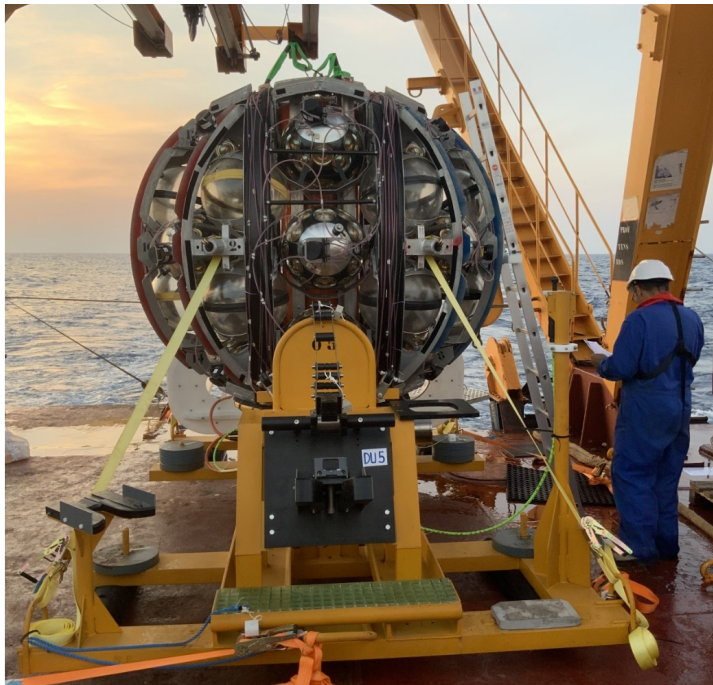


- DOM arranged in lines rolled in a launching vehicle



Construction Status

- 4 lines operational at ORCA (2 DU installed in July)
- 1 line operational at ARCA

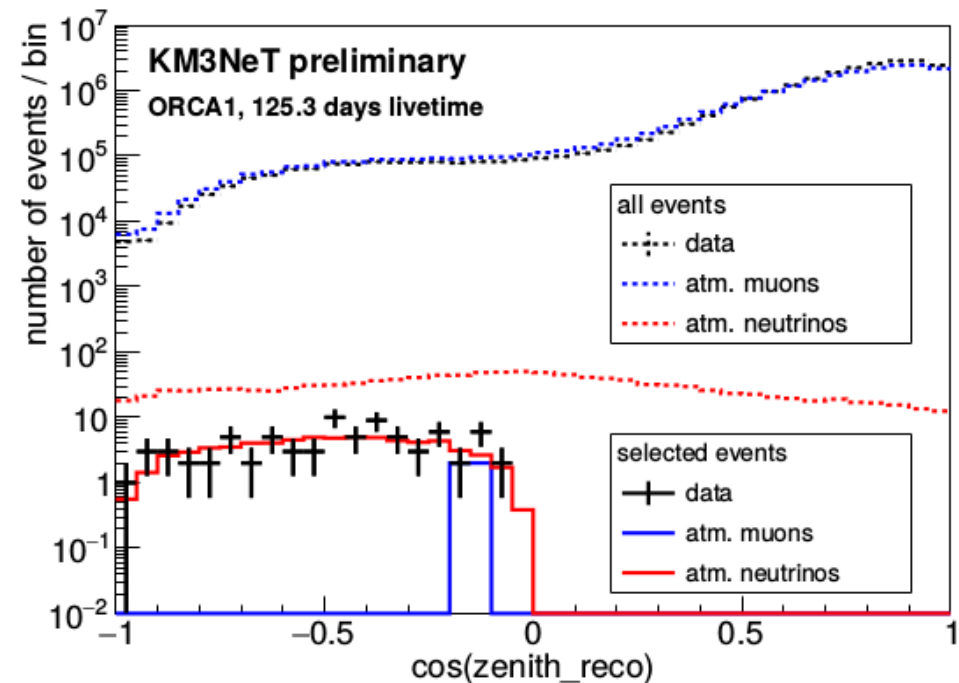
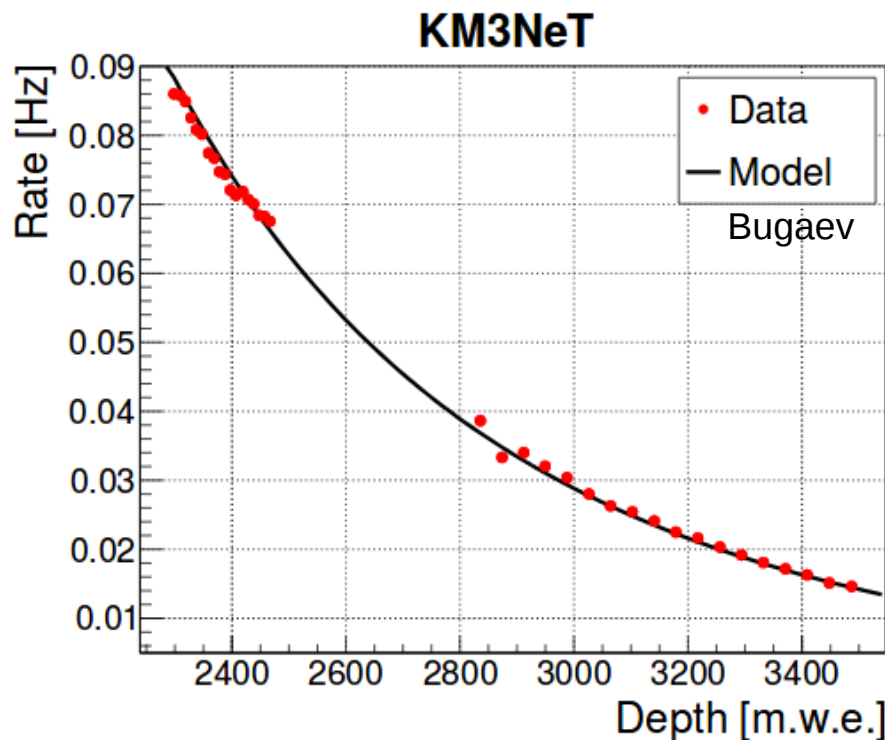


First Results from Data

- Muon Rate Depth Dependence by ARCA and ORCA

arXiv:1906.02704v1

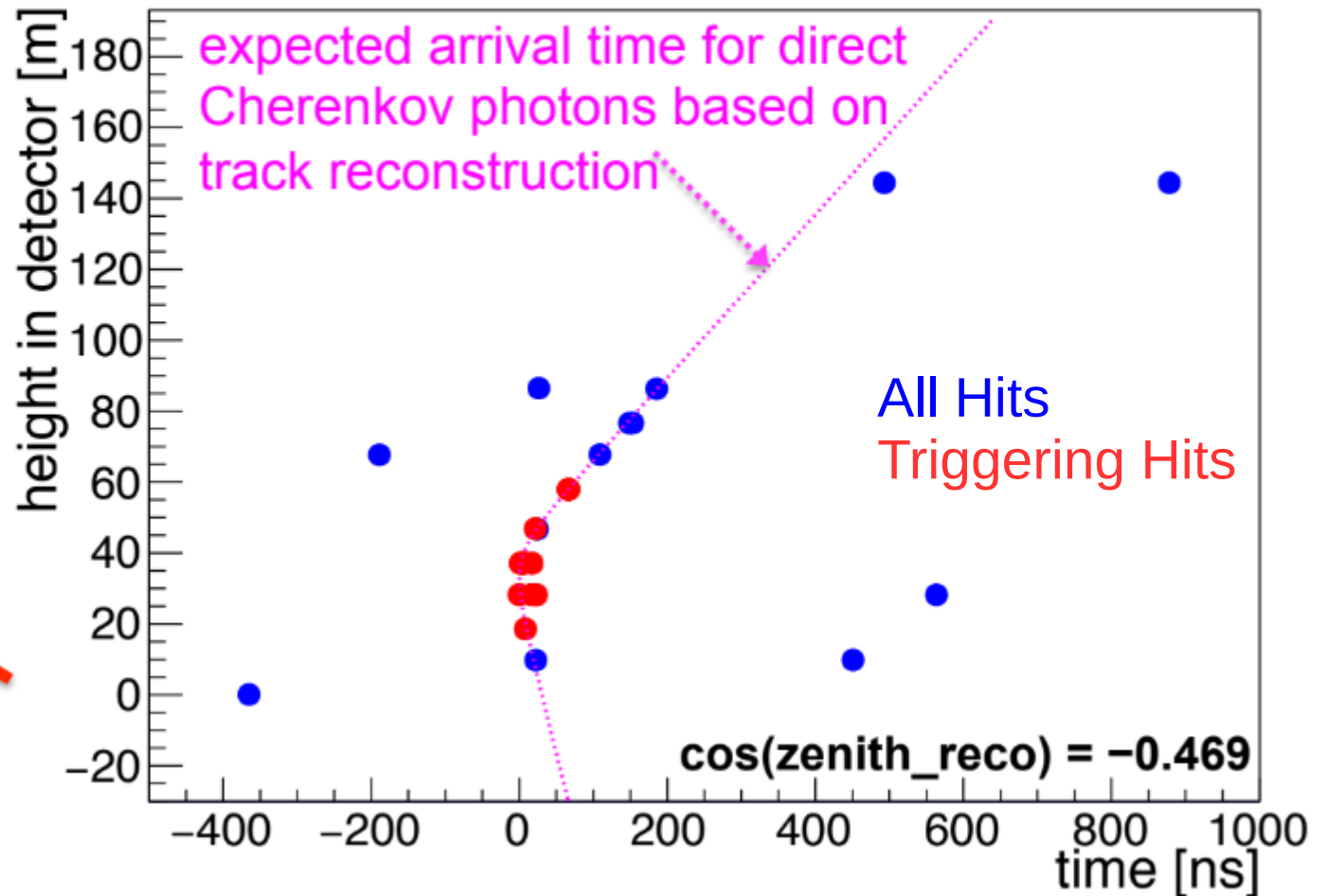
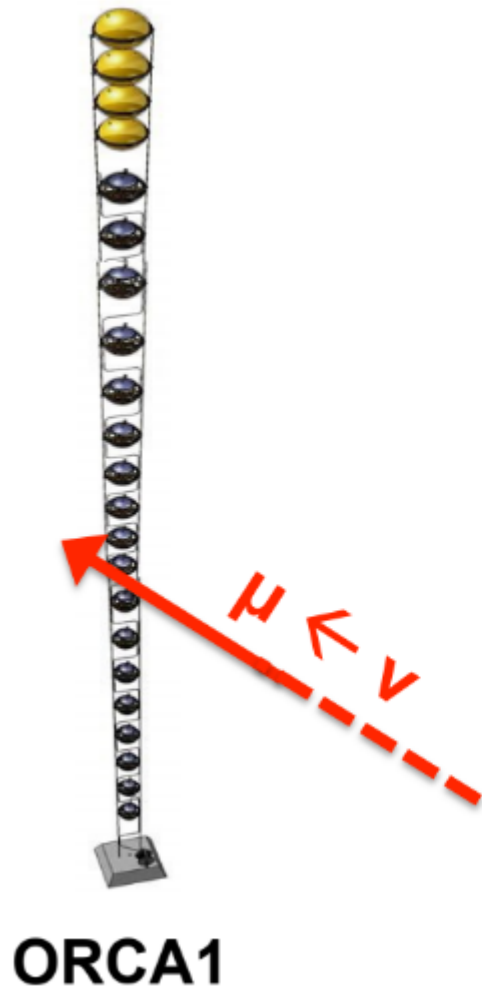
- Neutrinos with 1 ORCA Line
 - 77 upgoing candidates observed in 125.3 days
 - Expected: $67.4 \nu + 4 \mu$
 - Good agreement Data/MC



Event Display

- Up-going neutrino

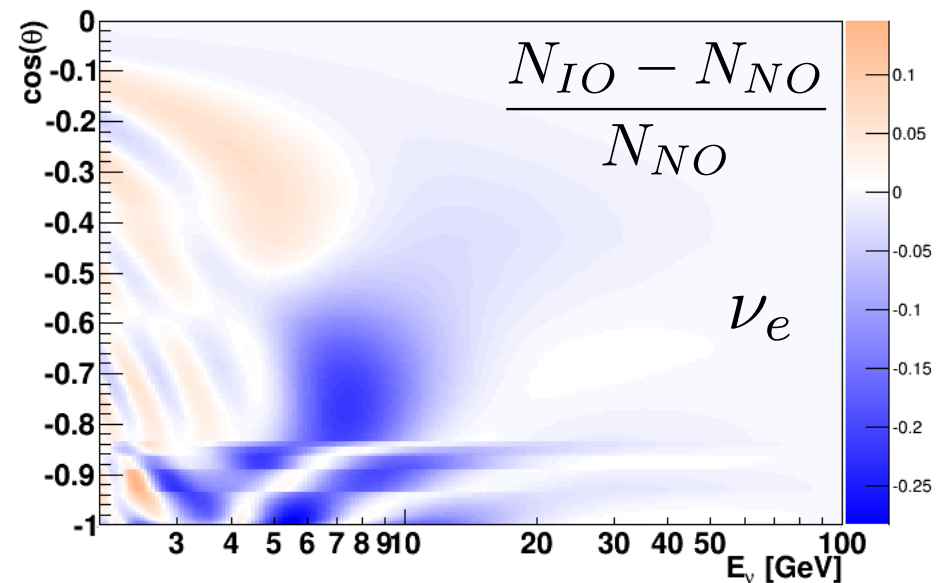
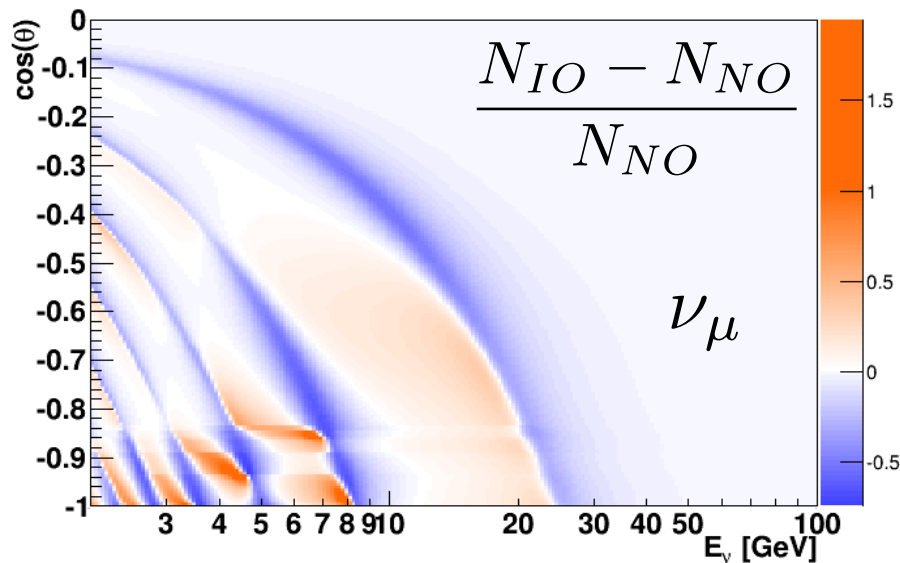
event=1668, run=2974, #hits=26, $\cos(\text{zenith_reco})=-0.469$
DU 2



Neutrino Mass Ordering at ORCA

- NMO determined using matter effect
- Event distribution depends on NMO

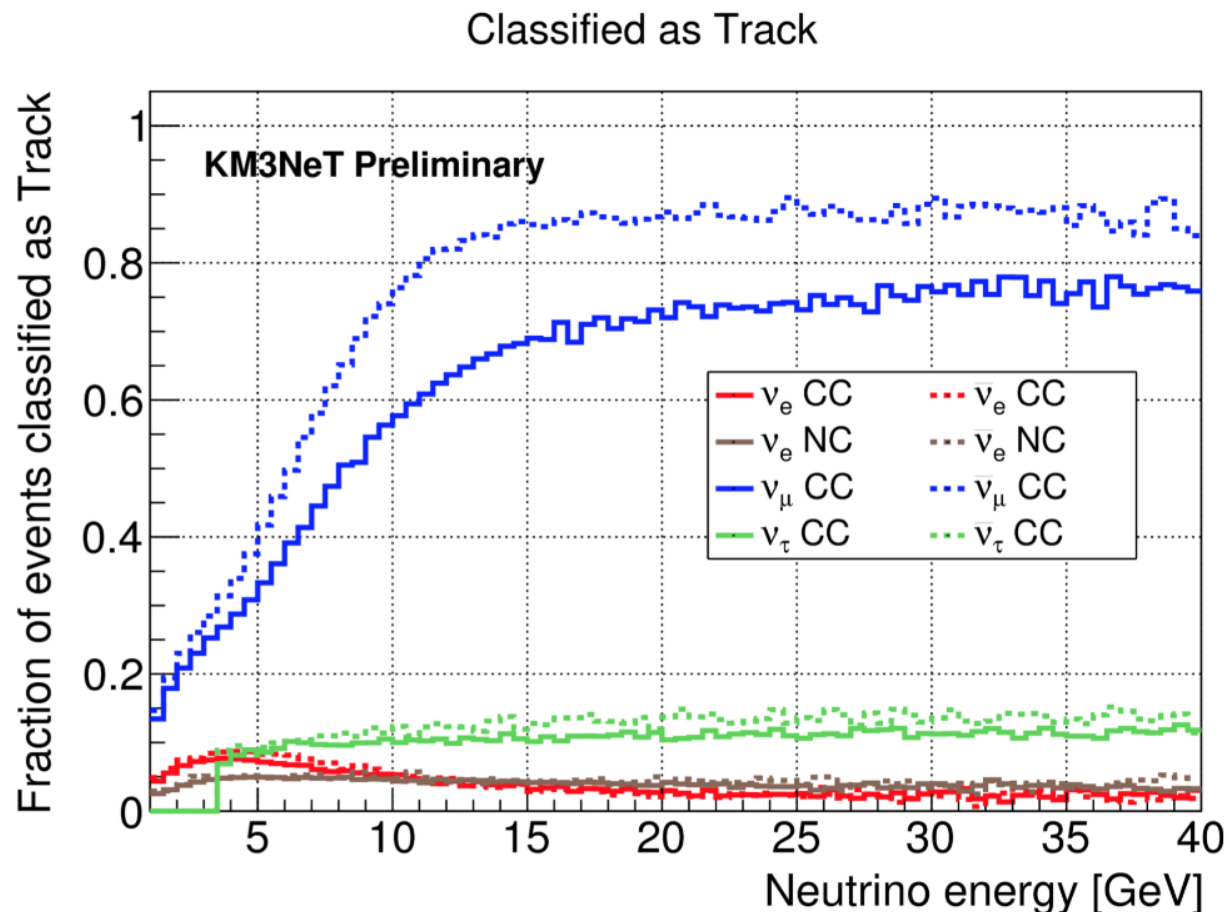
~63k events / year:
ν_e CC: 20.4k
ν_μ CC: 31.2k
ν_τ CC: 4.2k
NC : 6.8k



- Asymmetry NO/IO smeared by detector performance (PID, resolution)

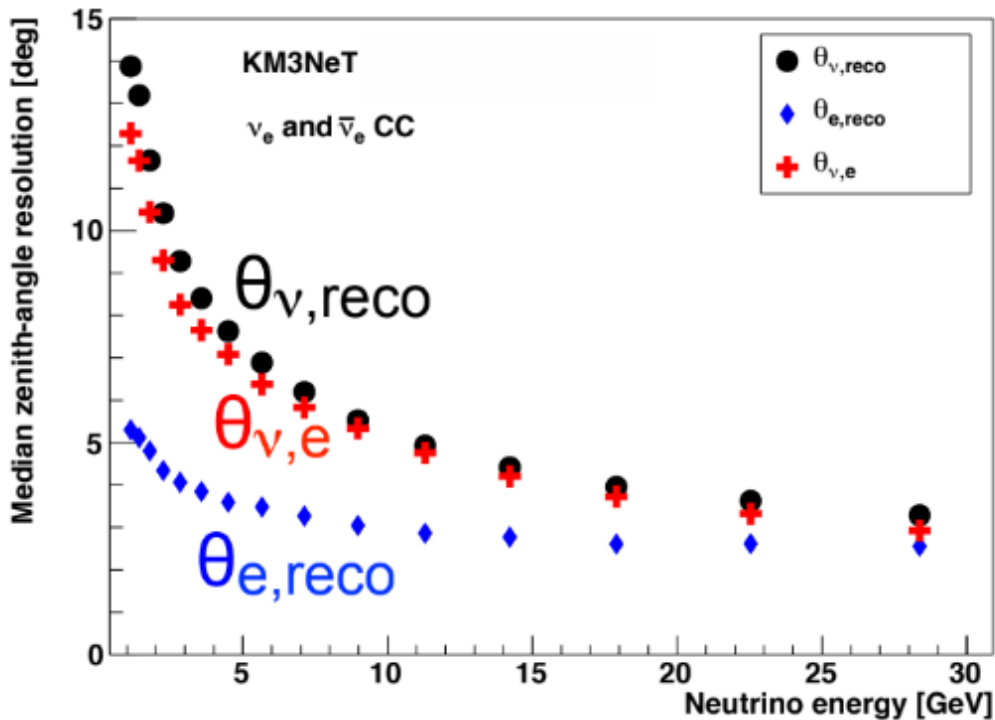
ORCA Expected Performance

- PID: ability to separate track ($\nu_\mu, \nu_\tau \rightarrow \mu$) from shower ($\nu_e, \nu^{NC}, \nu_\tau^{had}$).

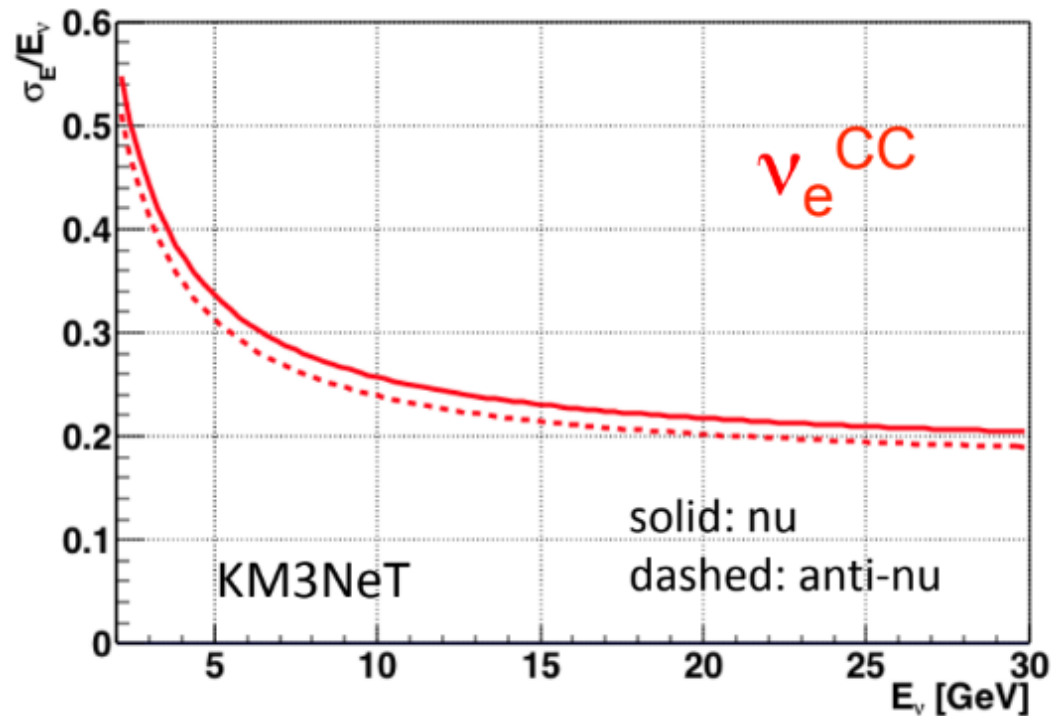


ORCA Expected Performance

- Energy and Angular resolution for Showers (similar for Tracks)



Angular reso. 5° at 10 GeV,
dominated by decay kinematics



Energy reso. 25 % at 10 GeV,
dominated by light yield
fluctuation

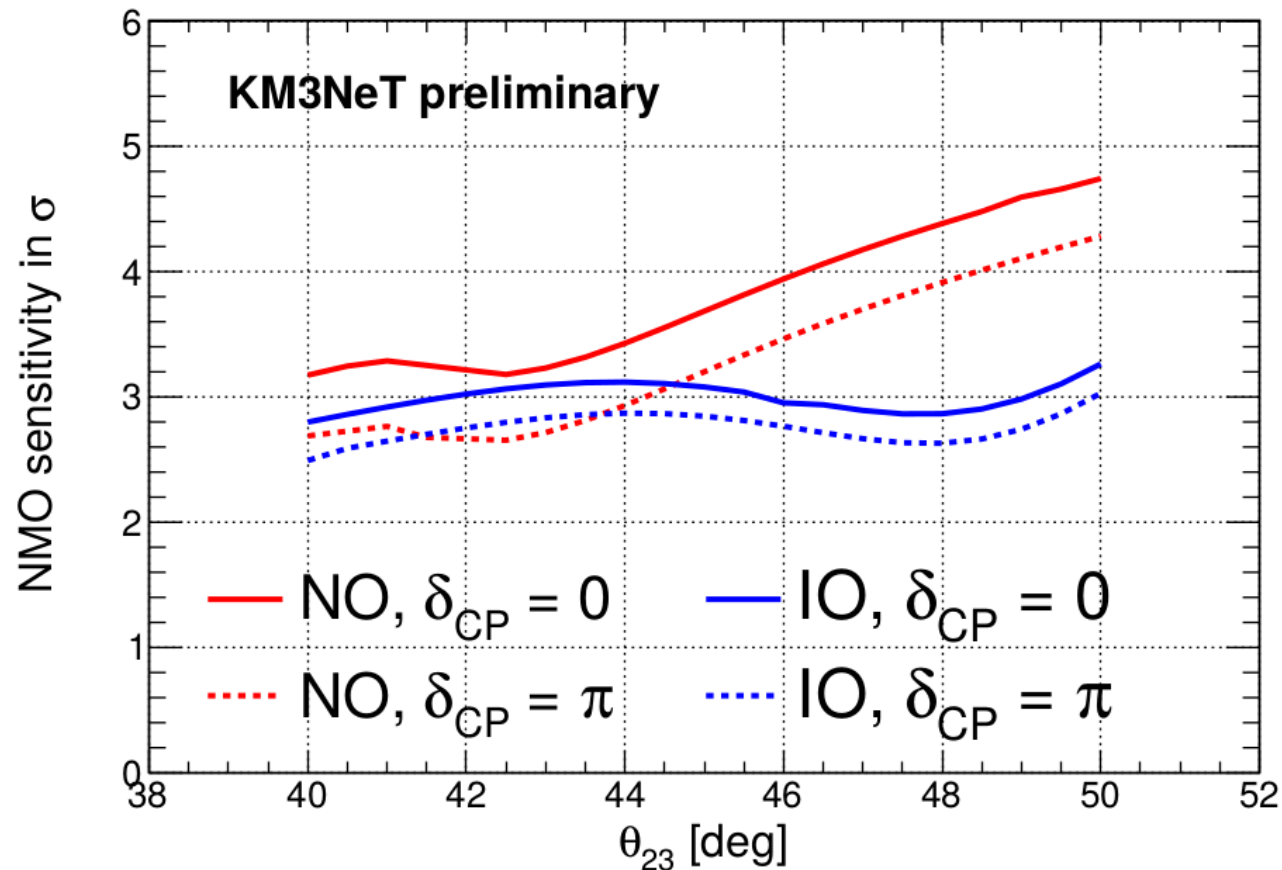
NMO Analysis Method

- Fit E- θ event distribution expected for a given NMO with the other NMO
- Data set split in 3 categories track-like, shower-like and mixed
- Fit strategy and systematics :

Δm_{21}^2	fixed to $7.4 \cdot 10^{-5} \text{ eV}^2$	flux E-tilt	free
$\sin^2 \theta_{12}$	fixed to 33.62°	flux cos θ -tilt	free
$\sin^2 \theta_{13}$	$8.54^\circ, 0.15^\circ$ prior (NO), $8.58^\circ, 0.14^\circ$ prior (IO) ¹	NC cross-sec. norm.	10% prior
δ_{CP}	free	norm. track-like	free
flux $\nu_\mu \leftrightarrow \bar{\nu}_\mu$ skew	10% prior	norm. shower-like	free
flux $\nu_e \leftrightarrow \bar{\nu}_e$ skew	10% prior	norm. middle sample	free
flux $\nu_\mu \leftrightarrow \nu_e$ skew	10% prior		

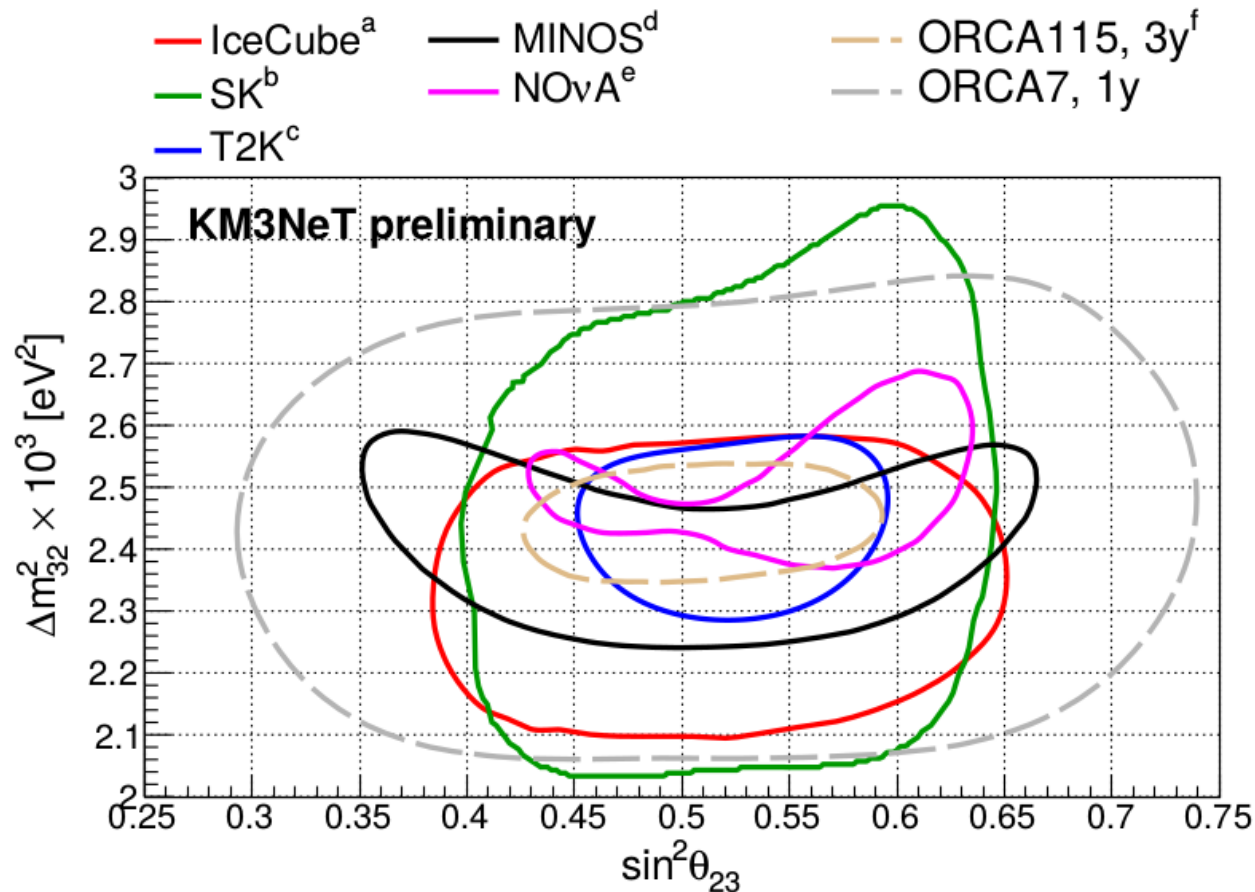
Prospects for NMO

- 3 years of data taking with full ORCA (115 lines)
- Sensitivity $> 3\sigma$ excepted if NMO=NO and θ_{23} in the second octant



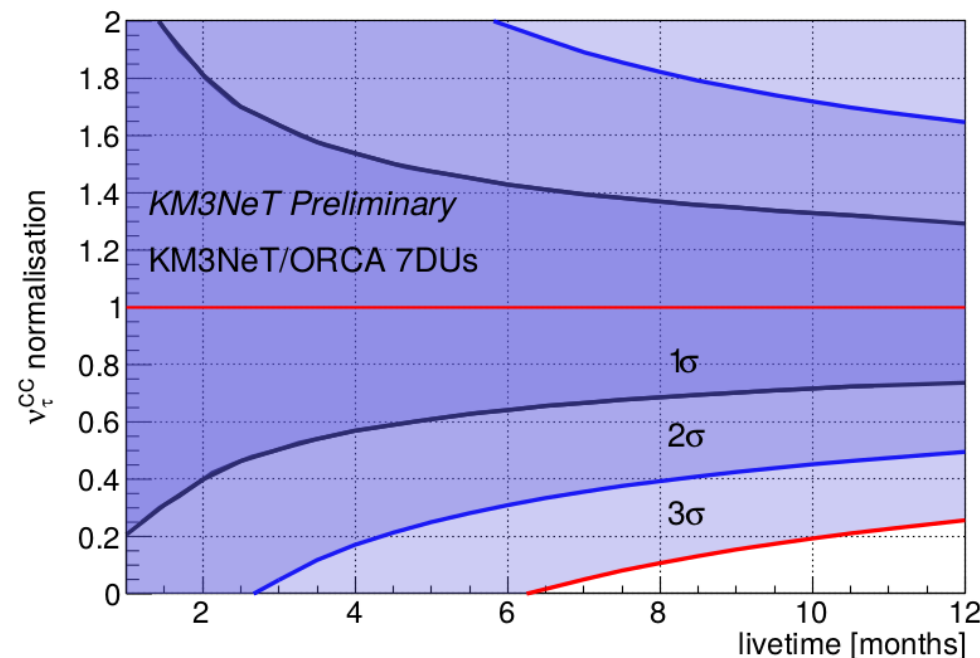
δm_{23}^2 and θ_{23} with 7 ORCA Lines

- With 7 lines ORCA starts bringing informations to determine the oscillation parameters



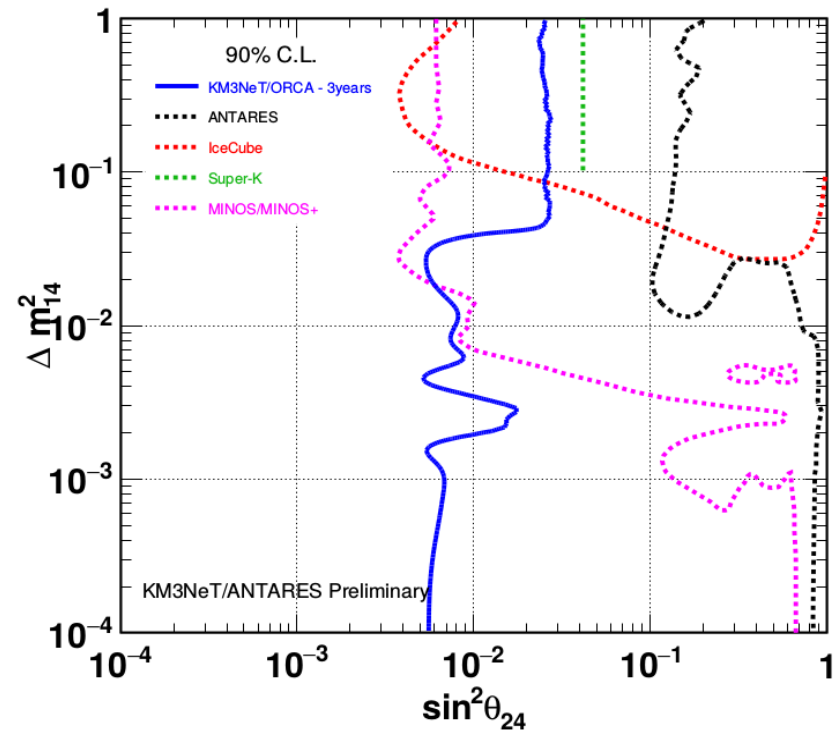
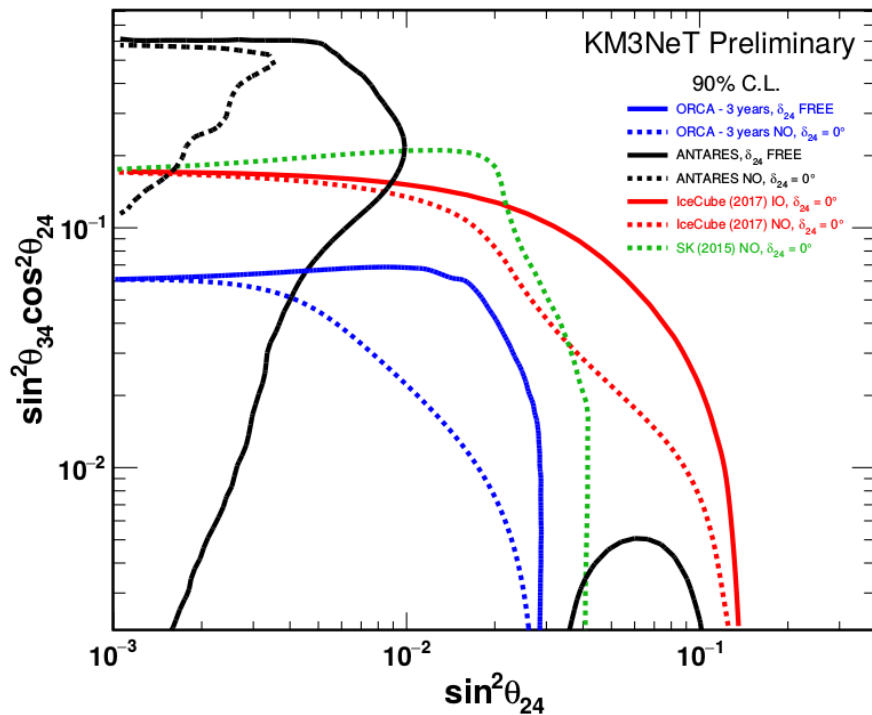
ν_τ appearance with 7 ORCA Lines

- Most ν_τ are detected as shower and cause an excess of shower at 25GeV where $\nu_\mu \rightarrow \nu_\tau$ is maximal
- ν_τ Norm is essential to probe PMNS unitarity (ie. Normalisation=1)



Sterile Neutrino (3+1)

- Atm. ν sensitive to $|U_{\mu 4}|^2$ and $|U_{\tau 4}|^2$ via $\nu_{\mu} \leftrightarrow \nu_{\tau}$ osc.
- Limits strongly improves at low Δm_{41}^2

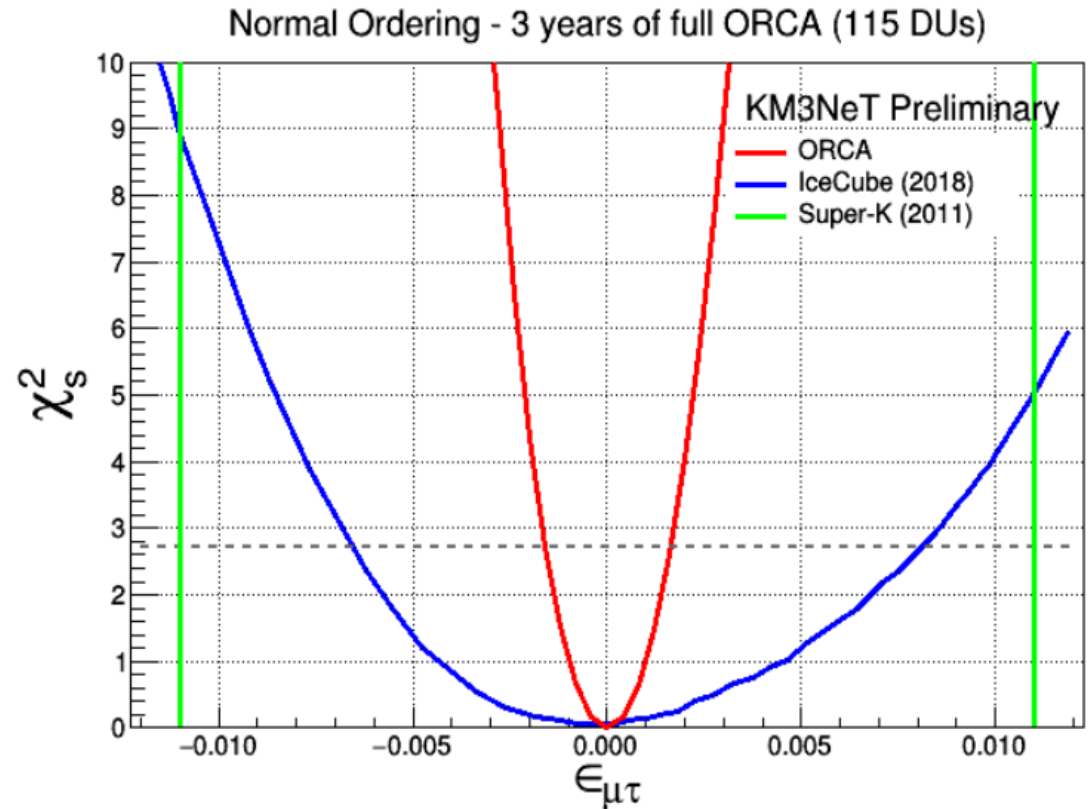


Non Standard Interactions

- Probe Neut. Curr. NSI of ν with Earth matter:

$$H = \frac{1}{2E} U \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m_{21}^2 & 0 \\ 0 & 0 & \Delta m_{31}^2 \end{bmatrix} U^\dagger +$$

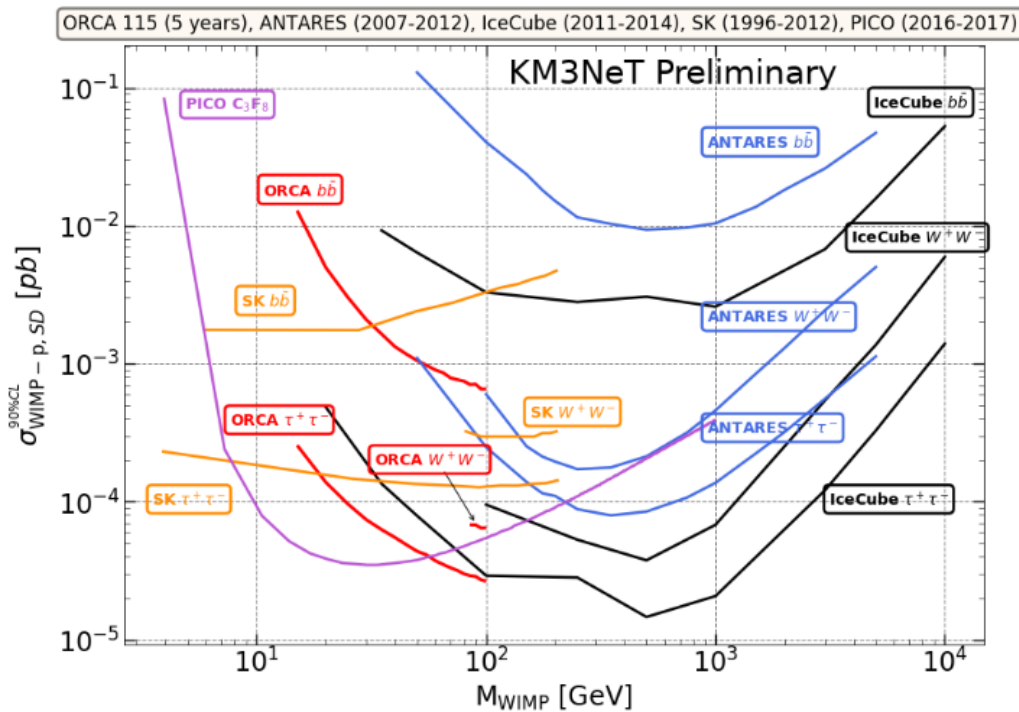
$$+ 2\sqrt{2}G_F N_e(x) \begin{bmatrix} 1 + \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon_{e\mu}^* & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon_{e\tau}^* & \epsilon_{\mu\tau}^* & \epsilon_{\tau\tau} \end{bmatrix}$$



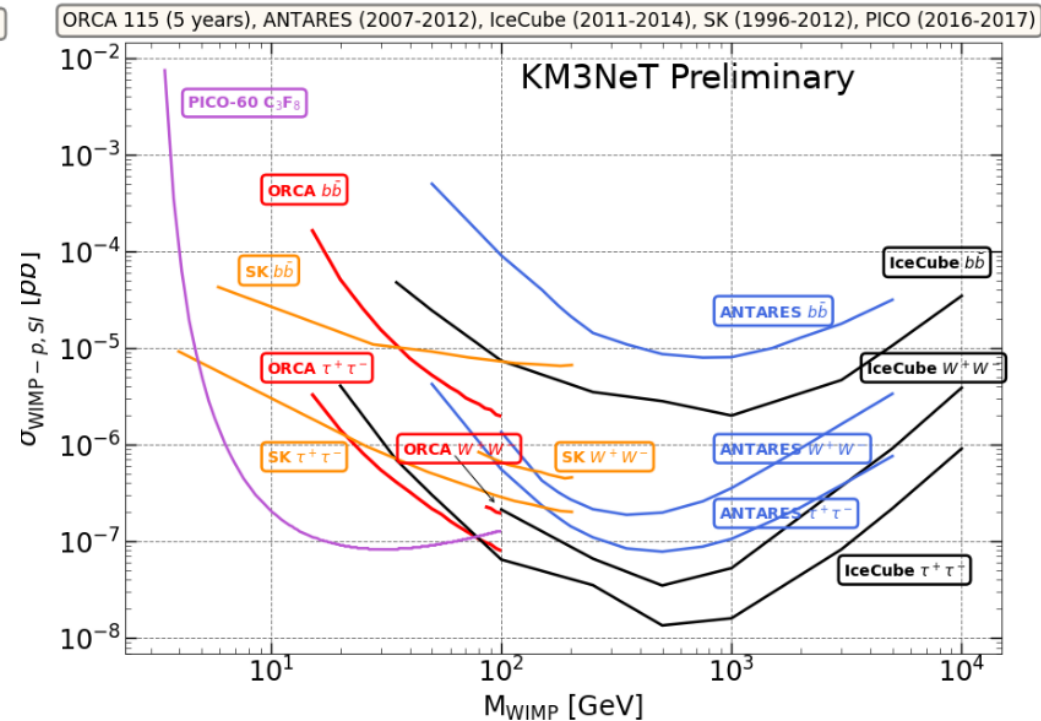
- For 2-flavour hybrid model ORCA will improve current limits by a factor ~ 4

Dark Matter in the Sun

- WIMP (e.g. neutralino χ) can be captured in the sun
- Produce ν when annihilating via : $\chi\chi \rightarrow \tau\tau, bb, WW$



Spin Dependent Capture

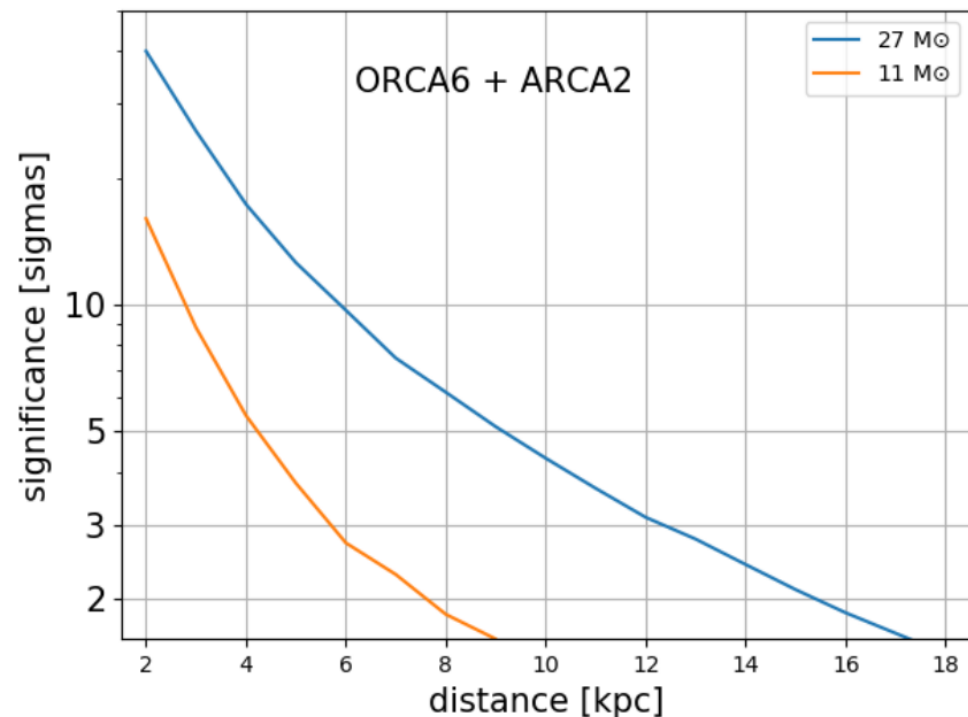
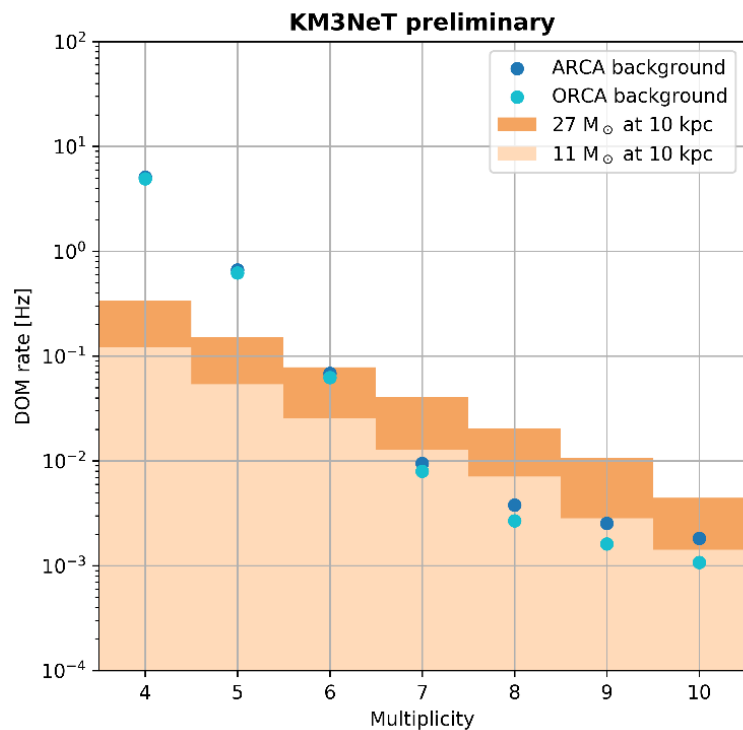


Spin Independent Capture

Supernovae

- A core-collapse supernovae produces a burst of $O(\text{MeV})$ neutrinos lasting $O(100)\text{ms}$
- Burst induces a increase of in-time hits on a DOM
- 5σ discovery with 6 ORCA + 2 ARCA lines for a $11(27)\text{M}_\odot$ SN at 4(9) kpc

KM3NeT preliminary



Possible Upgrade: Protvino to ORCA

- U70 accelerator complex:
 - Proton at 70GeV, 15kW
 - Beam line to be constructed

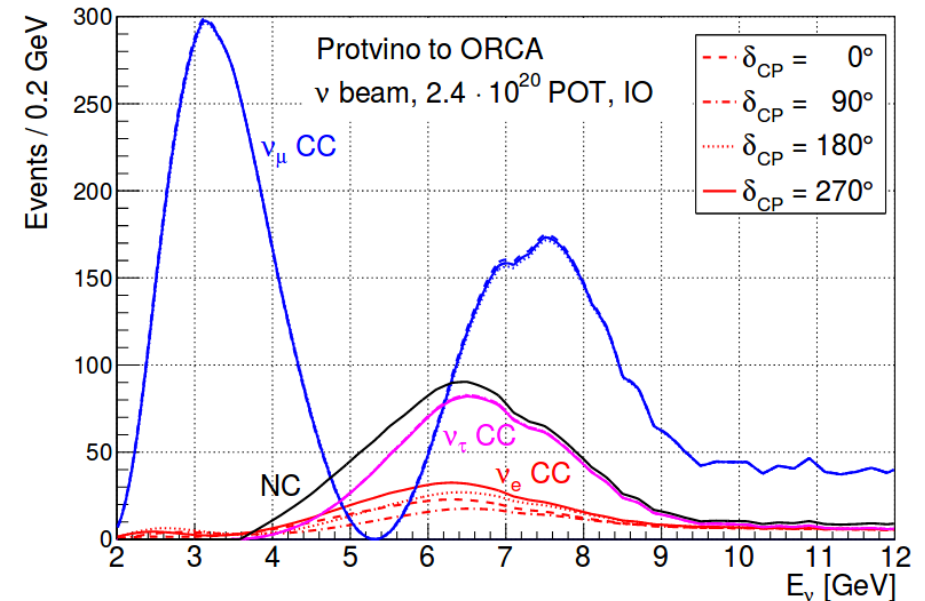
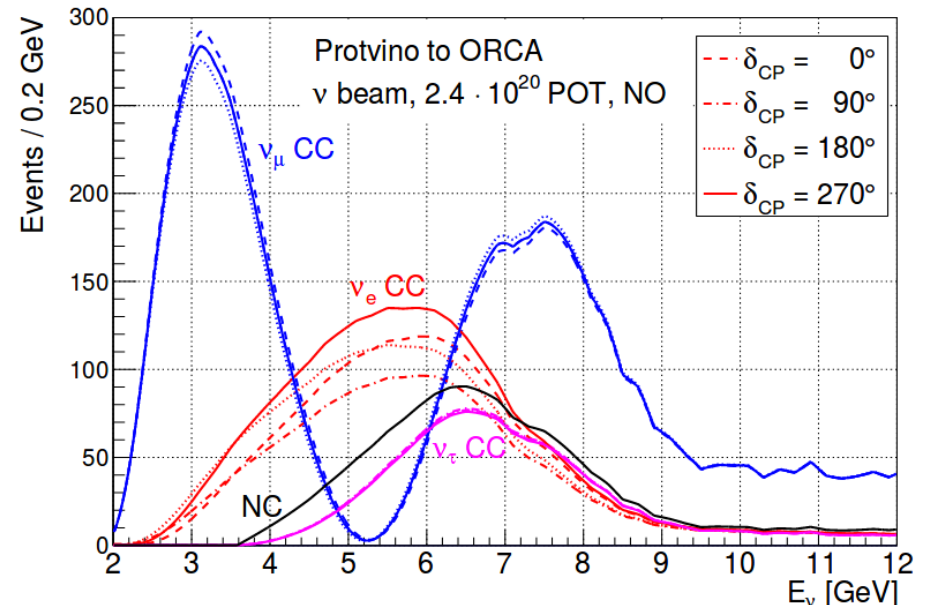
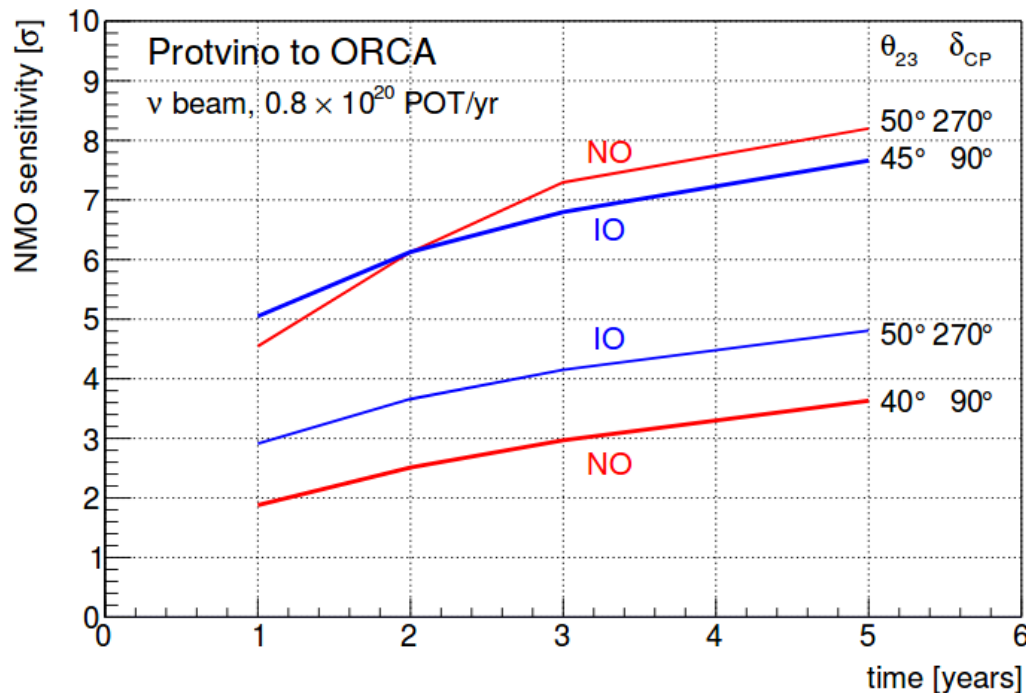
Letter of Interest arXiv:1902.06083



- First Stage : U70 @ 90kW to ORCA
 - Minor accelerator upgrade to reach 90kW (now 15kW)
- Second Stage : U70 @ 450kW to Denser ORCA
 - Major accelerator upgrade (new injector)
 - Super ORCA : 10x denser, 1/2 size

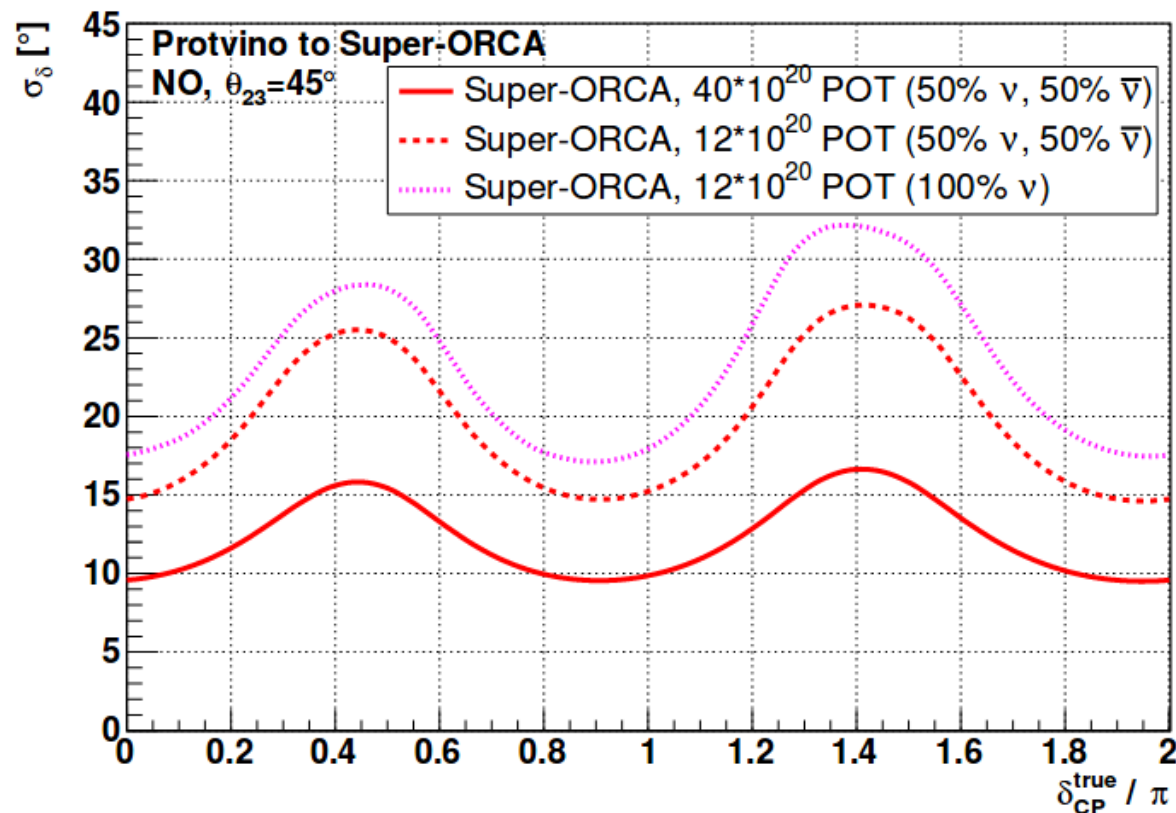
1st Stage: NMO with P2O

- 3σ determination of the NMO regardless of Ordering or CP phase
- 4000 neutrinos per year !



2nd Stage: CP Phase with P2SO

- With a 10x denser detector (Super ORCA) :
 - Lower energies and better PID (Cerenkov ring fuzziness)
- Measure CP Phase with $10\text{-}16^\circ$ precision in 10 years



Conclusions

- KM3NeT-ORCA has a rich physics programme
- First detection line operational since 2017
- Data shows a very good quality
- First physics results expected in the coming year
- Upgrade programme being prepared: P2O