Status and prospects of the KM3NeT/ORCA

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on behalf of the KM3NeT collaboration

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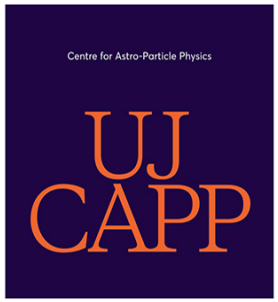
Conference on Neutrino and Nuclear Physics (CNNP) 2020



Kleinmond, South Africa.
February 2020

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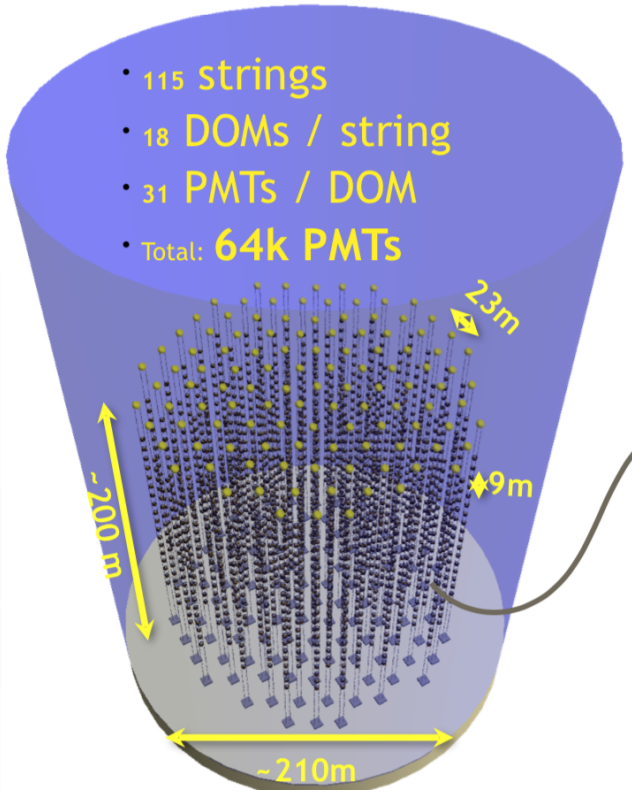
ORCA detector

- The KM3NeT-ORCA infrastructure is located at 42^{o} 48' N 06^{o}02' E coordinates, at a depth of 2450 m underneath sea level, about 40 km offshore from Toulon, France, in the Mediterranean sea. [1].
- It will consist of 115 strings, called Detection Units (DUs). Each DU holds 18 Digital Optical Modules (DOMs) housing 31 PMT (Photo multiplier Tube) each one. Optimal detection in neutrino energy range 1-100 GeV.
- At the beginning of 2020 ORCA detector works with 6 DUs and the total construction time is estimated to be around 3 years more.

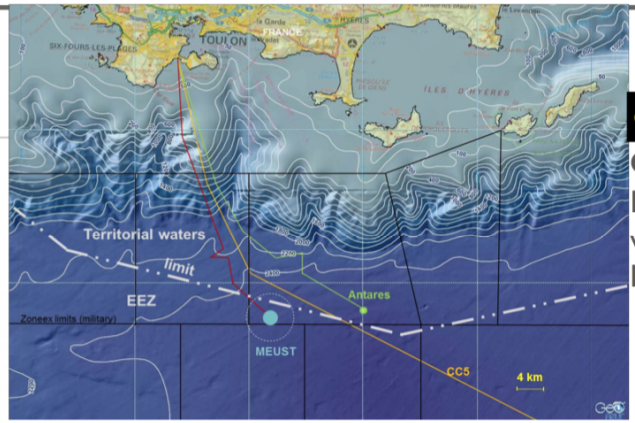
[1] [KM3Net Collaboration], Letter of intent for KM3NeT 2.0, J. Phys. G **43**, no. 8, 084001 (2016)

Total Instrumented Volume ~ 8 Mton

- 115 strings
- 18 DOMs / string
- 31 PMTs / DOM
- Total: **64k PMTs**



Detection Unit (DU)

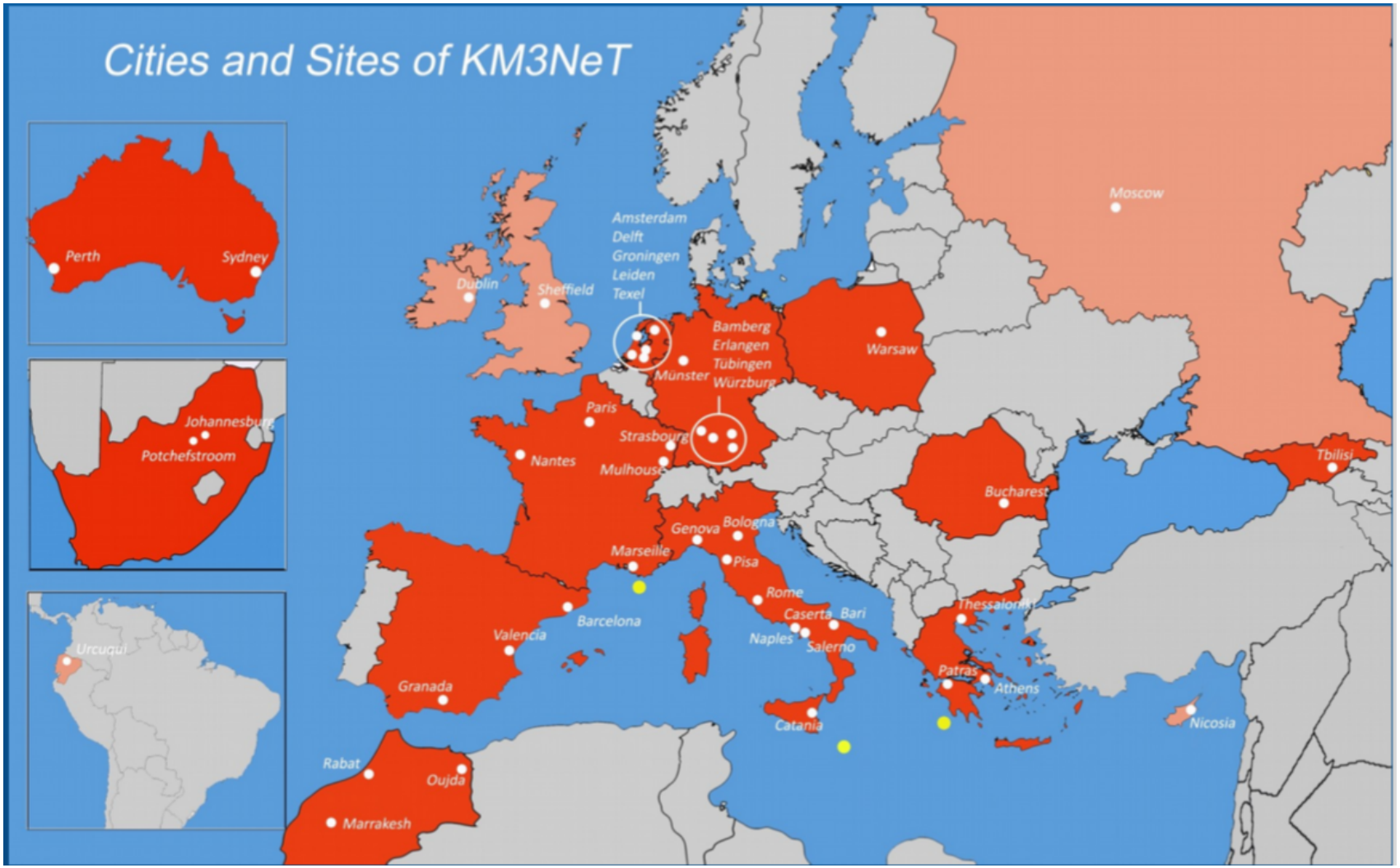


ORCA : -2450m

Oscillation
Research
with **C**osmics
In the **A**byss

ORCA: Low energy physics ~ few GeV
(Neutrino Oscillations)

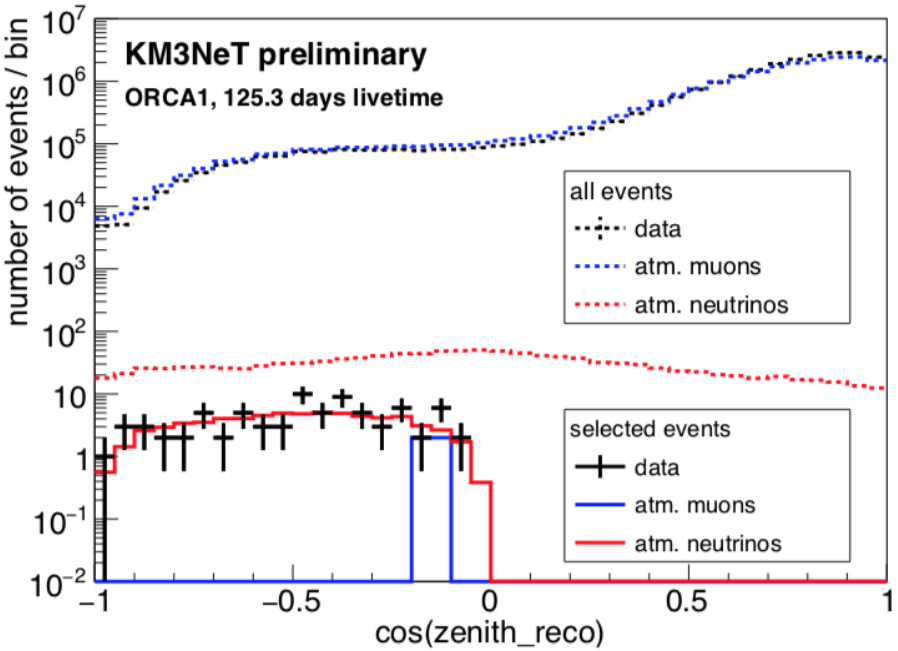
The KM3NeT DOM
housing 31 3" PMTs

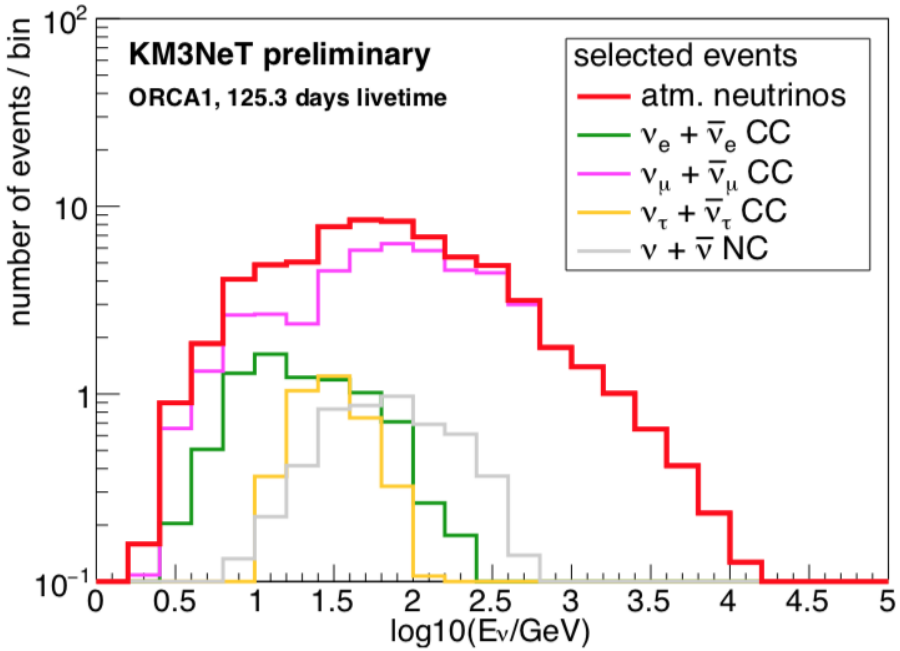


KM3NeT Members

Atmospheric Neutrinos

- First Atmospheric Neutrino analysis has been done with data of one single DU.
- It covers periods from 28th September to 13th December 2017, and 13th March to 15th May 2019.
- Effective livetime is 123.3 days. This detector configuration is called ORCA1.
- 77 up going neutrino candidates were detected.
- From simmulations 67.5 events were expected to be atmospheric neutrinos and 4 more atmospheric muons. In terms of flavors about 50 ν_μ CC, 8.3 ν_e CC, 3.9 ν_τ CC and 5.3 NC events are predicted.
- The contamination of atmospheric muons is estimated to be up to 10%.



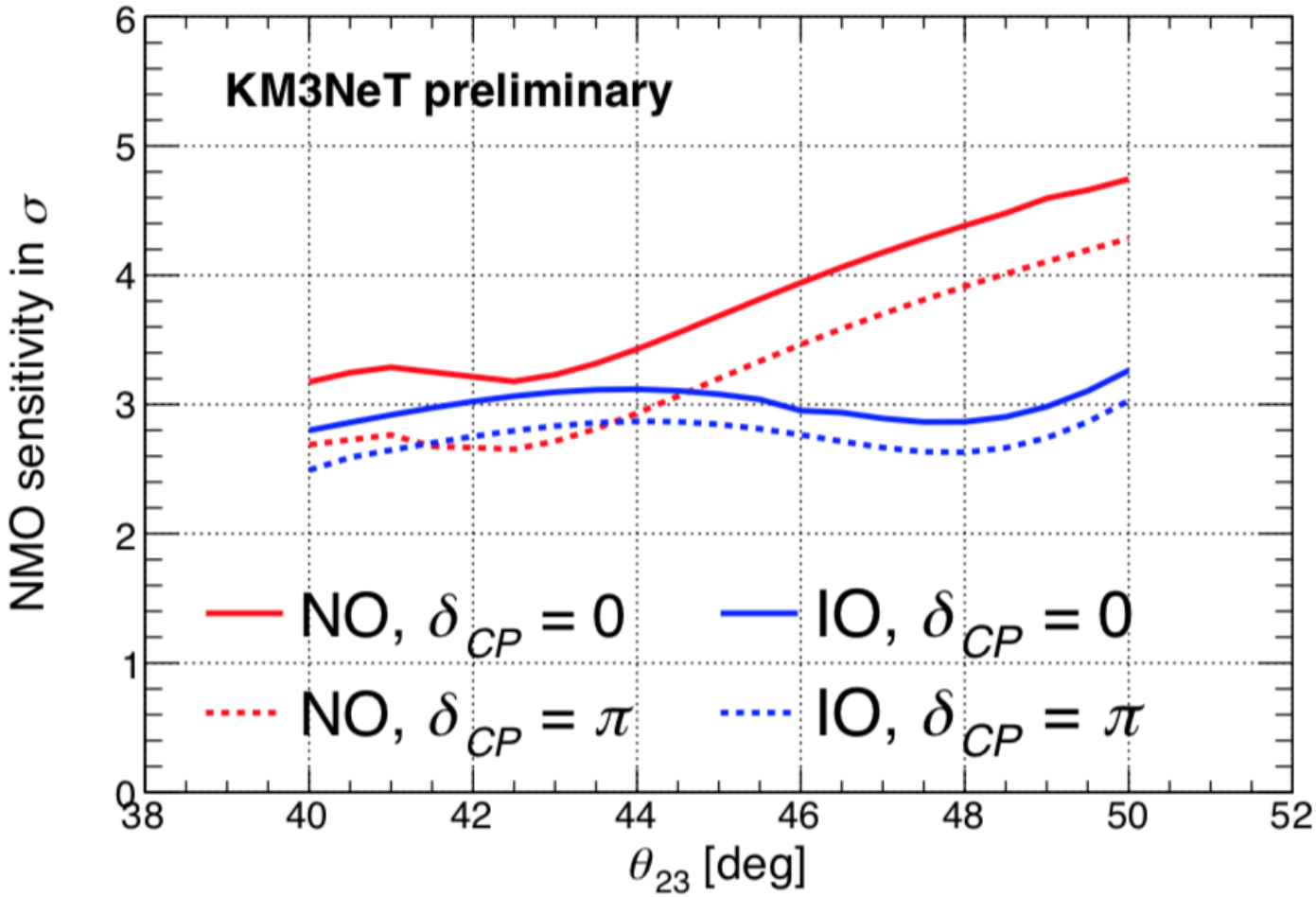


Left: distribution of the cosine of the reconstructed zenith angle in ORCA1 data. Right: distribution of true neutrino energy E_ν for events expected to fulfill the event selection criteria for ORCA1 [2].

[2] [KM3NeT Collaboration], Atmospheric Neutrinos Detected with the first KM3NeT Detection Units of ARCA and ORCA, PoS(ICRC2019)910.

Neutrino Mass Ordering (NMO)

- Goal: To measure sign of $\triangle m^2_{31}$.
- For three years of data, the number of events for bidimensional bins of reconstructed neutrino energy vs reconstructed neutrino zenith direction are obtained.
- Cases: normal-ordered (NO) and inverted-orderer (IO) hierarchy with CP values 0 and π radians, and θ_{23} values in [40^o ,50^o] range.
- Maximum likelihood calculation is done comparing dataset sample with opposite hierarchy model. For the theoretical model parameters are fixed leaving δ_{CP} , $\triangle m^2_{31}$ and θ_{23} unconstrained.

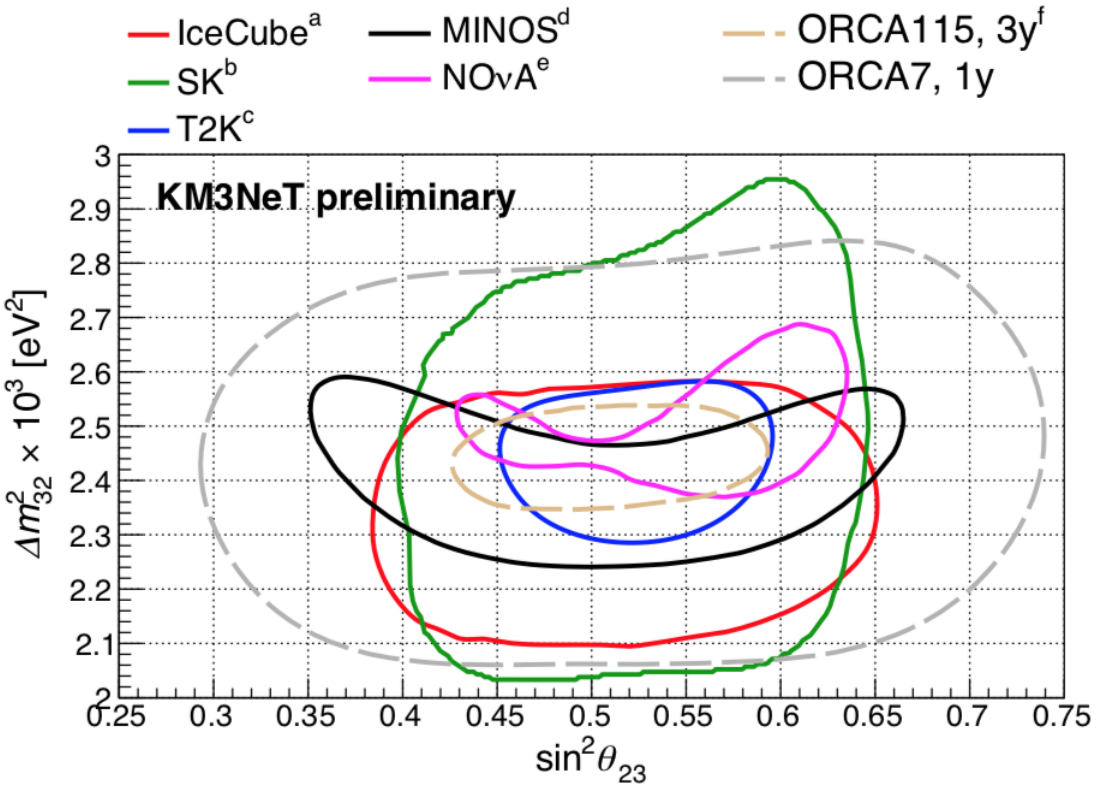


NMO sensitivity of the full KM3NeT/ORCA detector after 3 years [3].

[3] [KM3NeT Collaboration], Neutrino Oscillation research with KM3NeT/ORCA, PoS(ICRC2019)1019.

Sensitivity to $\triangle m^2_{32}$ and θ_{23}

- Last analysis corresponds to KM3NeT configuration with 1 year of data and 7DUs.



It is shown 90% confidence level plane of ORCA detector for 3 years and 115 Dus, and ORCA sub-array after 1 year (ORCA 7) of data taking. [4]

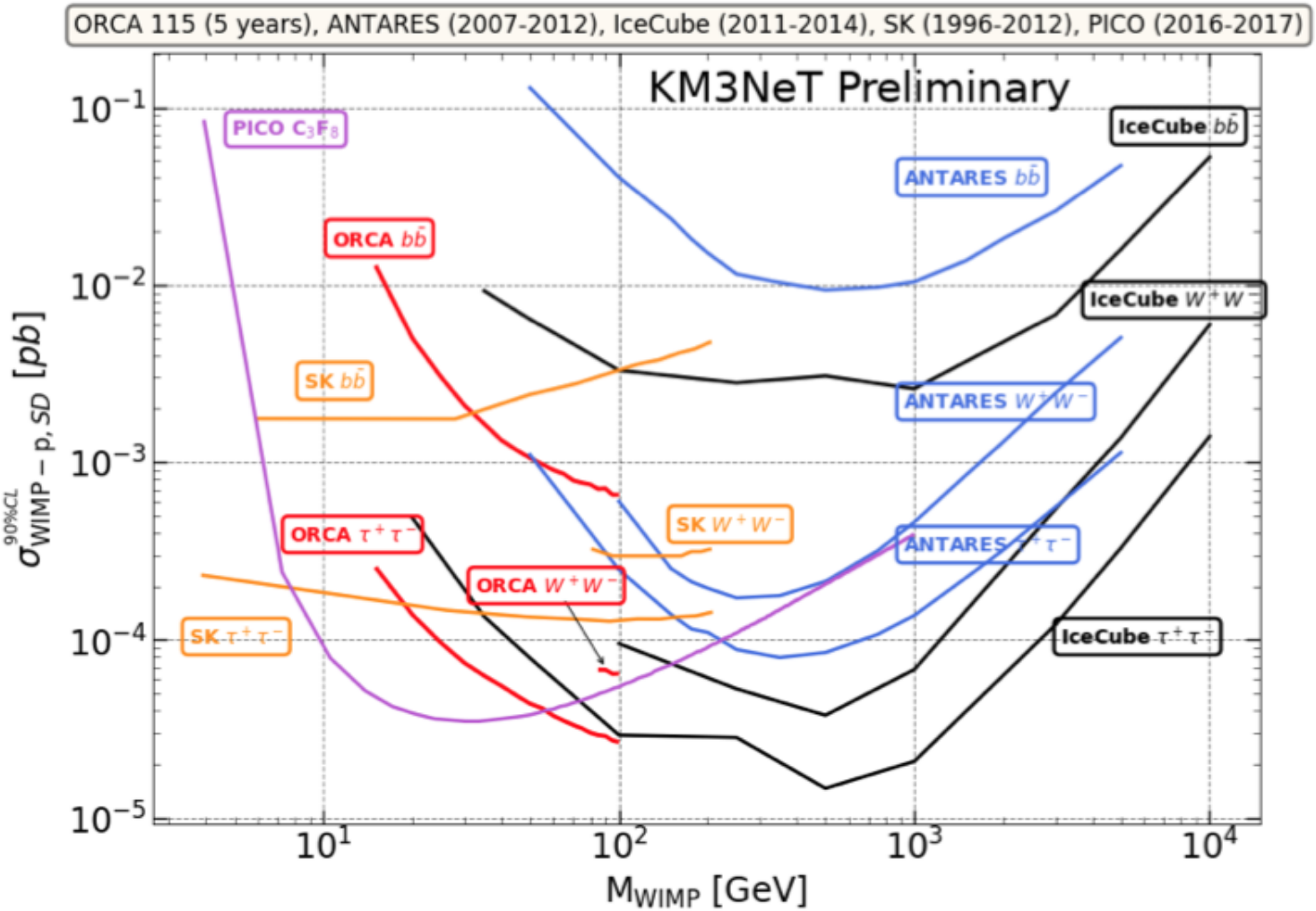
[4] [KM3NeT Collaboration], Neutrino Oscillation reseach with KM3NeT/ORCA, PoS(ICRC2019)1019.

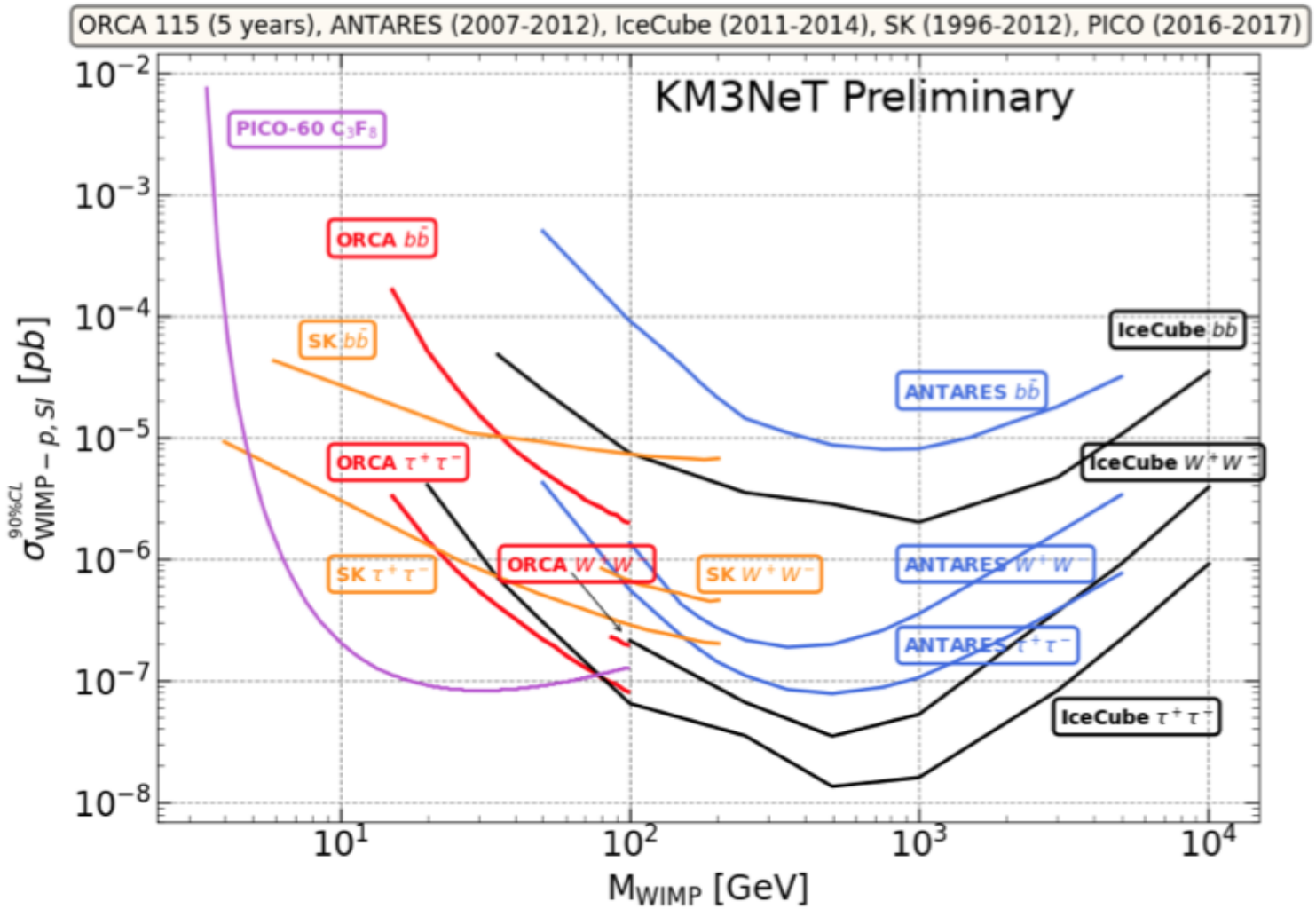
Dark Matter

- ANTARES and KM3NeT seek for indirect detection of Weakly Interactive Massive Particles (WIMPs). In principle, WIMPs are captured in massive objects due to gravitational force. Annihilation of these DM particles will produce pairs of c,b,t quarks, lepton, and W,Z and H bosons. The Standard model particles will decay increasing final neutrino flux.

- KM3NeT detector mission to discover dark matter as a particle. In case of non-detection, we will set limits on cross-sections, which can be divided in a Spin Dependent (SD) and Spin Independent (SI) component.

- Analyses are in progress.


ORCA 115 (5 years), ANTARES (2007-2012), IceCube (2011-2014), SK (1996-2012), PICO (2016-2017)
KM3NeT Preliminary
PICO C_3F_8
ORCA $b\bar{b}$
SK $b\bar{b}$
ORCA $\tau^+\tau^-$
ORCA W^+W^-
SK $\tau^+\tau^-$
SK W^+W^-
ANTARES $b\bar{b}$
ANTARES W^+W^-
ANTARES $\tau^+\tau^-$
IceCube $b\bar{b}$
IceCube W^+W^-
IceCube $\tau^+\tau^-$
$\sigma^{90\%CL}_{WIMP-p,SD}$ [pb]
M_{WIMP} [GeV]

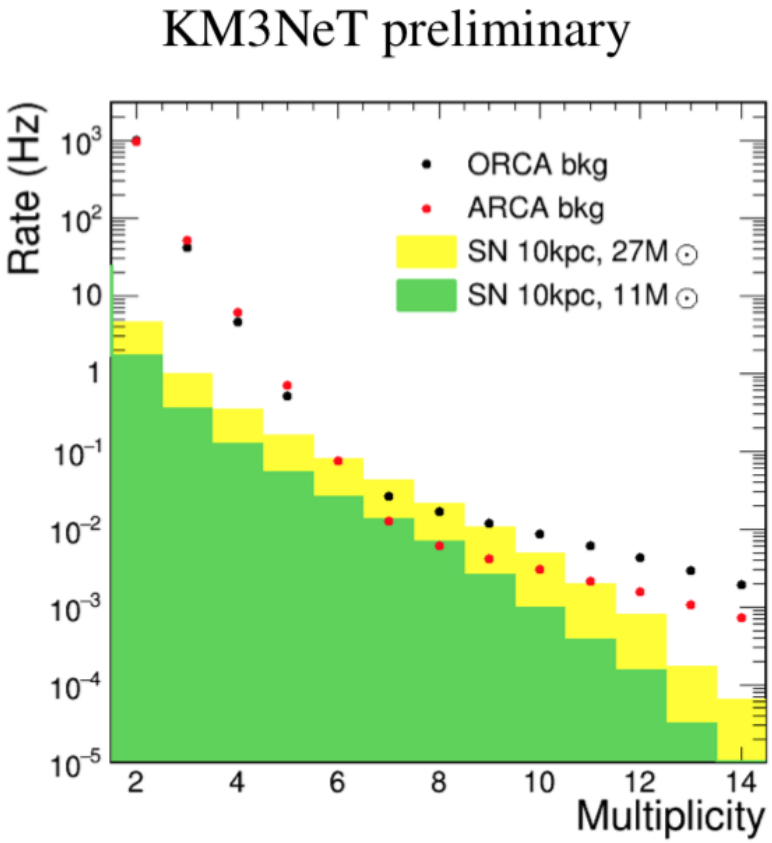


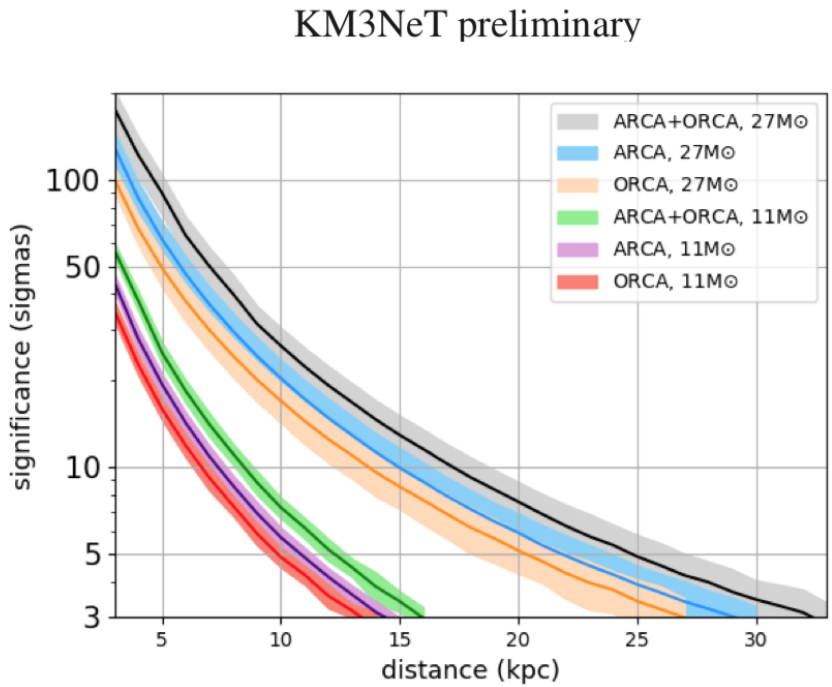
WIMP-proton SD (up) and SI (bottom) scattering cross-sections limits as a function of WIMP mass for the three annihilation channels considered. [5]

[5] [KM3NeT Collaboration], PoS(ICRC2019)536.

Supernova Neutrino Detection

- CCSN (Core Colapse Super Nova) neutrino flux will increase counting rate in the photomultipliers, due to inverse beta decay, elastic scattering and interactions with oxygen atoms.
- The number of PMTs in a DOM detecting a photon within a time of 10 ns is called multiplicity (M) and is used to split CCSN signal from the ^{40}K decay and atmospheric muon background.
- The number of signal and background events after applying multiplicity cut and muon filter, are used to compute the significance as a function of the source's distance.
- A combined significance of 5σ is achieved at 25 kpc for the 27 $M_{\odot}$, which includes full Galaxy coverage.
- For 11 $M_{\odot}$ progenitor, a significance of 5σ is reached beyond the Galactic Center.





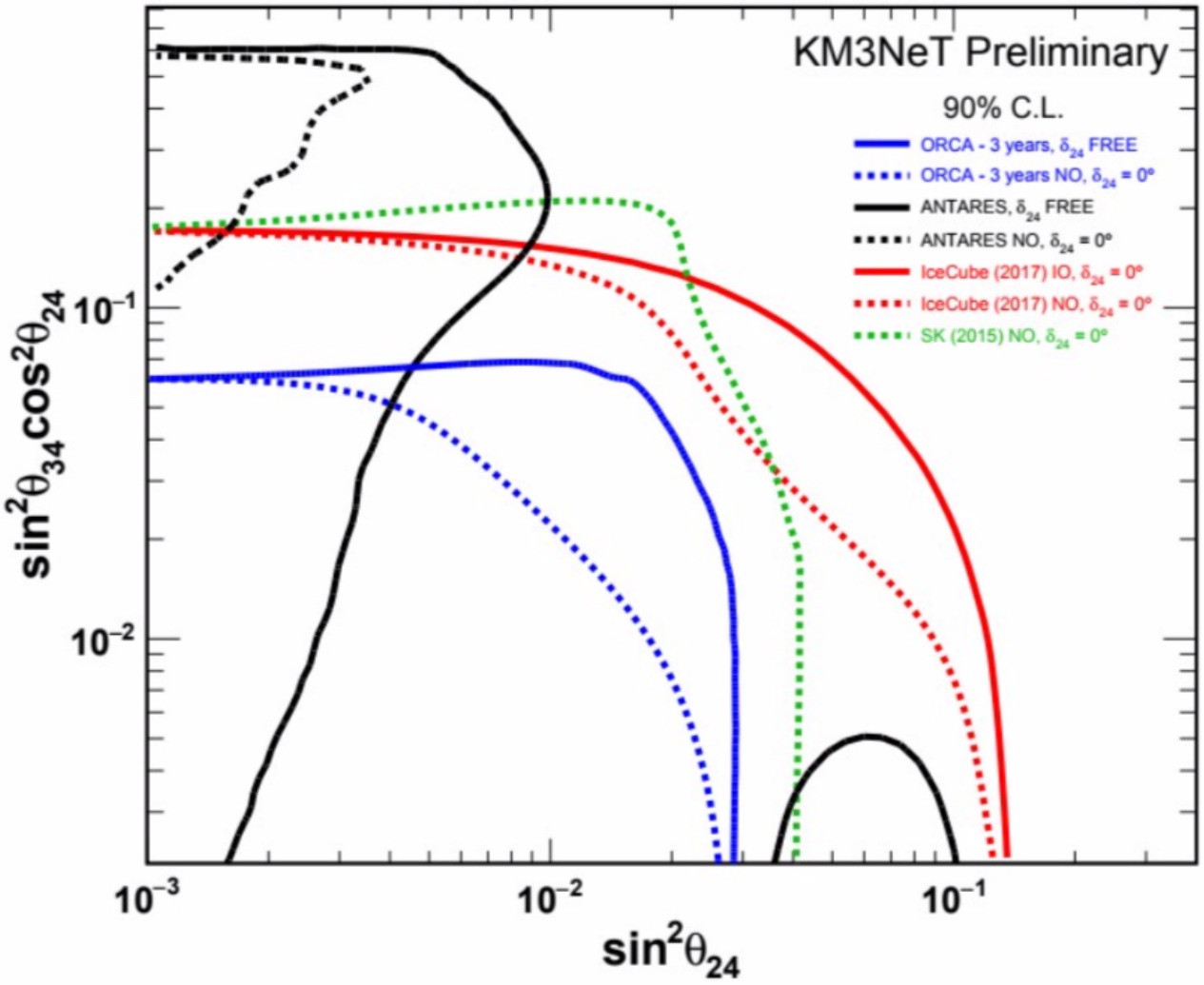
On the left, DOM background rates. On the right: Detection significance of a CCSN neutrino signal as a function of the distance to the source [6].

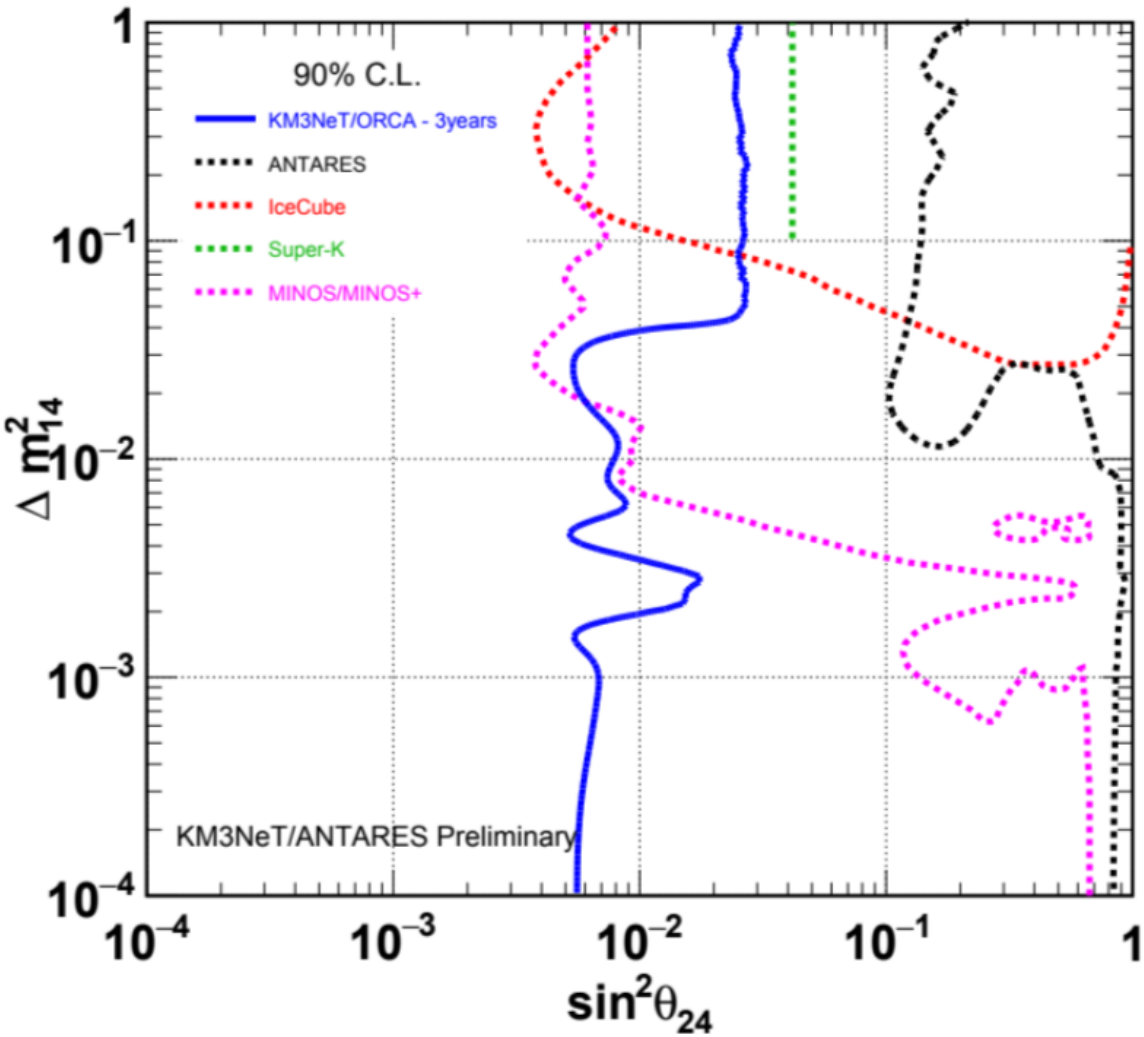
[6] M. Colomer Molla and M. Lincetto, Core-Collapse Supernova neutrino detection prospects with the KM3NeT neutrino telescopes., EPJ Web Conf. 209, 01009 (2019).

Sterile Neutrino

- Simplest model consists of one sterile neutrino plus standard three flavor (3+1).
- Sterile Neutrino will modify muon neutrino survival probability and number of events detected after crossing Earth's mantle and core.
- ORCA detector is very sensitive to low mass difference square m^2_{41} which will constrain $U_{\tau 4}$ values. Matter effect play an important role at $\triangle m^2_{41} \sim 10^{-3} eV^2$. For low $\triangle m^2_{41}$, ORCA is expected to constrain three mixing elements, U_{e4}, $U_{\mu 4}$, $U_{\tau 4}$ simultaneously with atmospheric neutrinos.
- Further part of the study is under progress. For previous result consult[7].

[7] [KM3NeT Collaboration], Particle Physics with ORCA, EPJ Web Conf. 207, 04003 (2019).


KM3NeT Preliminary
90% C.L.
ORCA - 3 years, δ_{24} FREE
ORCA - 3 years NO, δ_{24} = 0°
ANTARES, δ_{24} FREE
ANTARES NO, δ_{24} = 0°
IceCube (2017) IO, δ_{24} = 0°
IceCube (2017) NO, δ_{24} = 0°
SK (2015) NO, δ_{24} = 0°
$\sin^2\theta_{34}\cos^2\theta_{24}$
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
$\sin^2\theta_{24}$

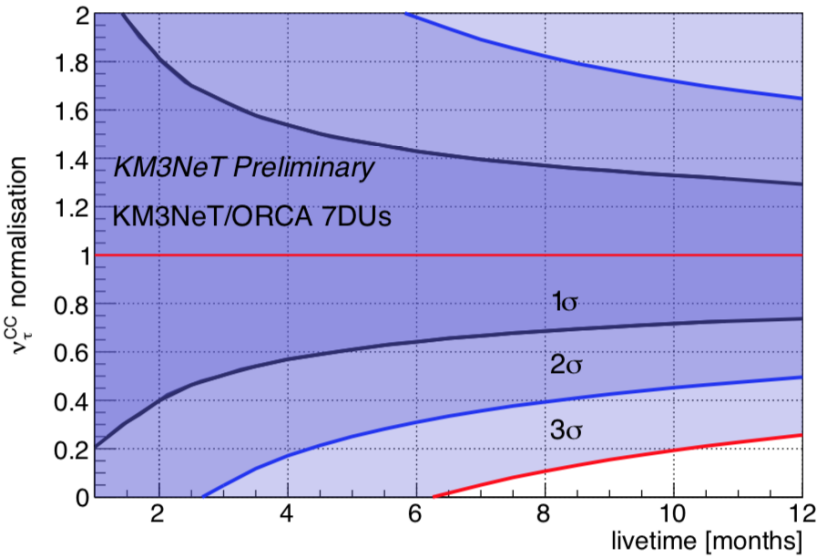


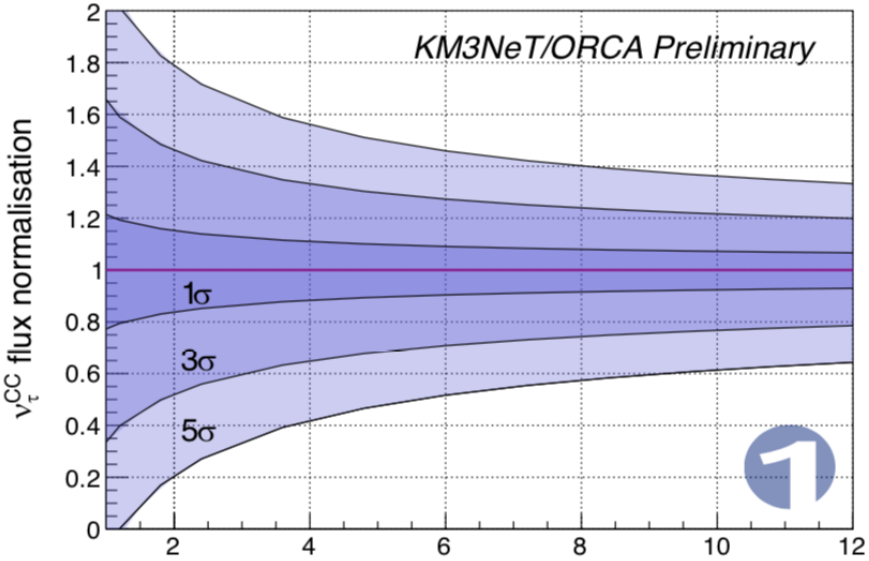
Preliminary ORCA sensitivity plots to sterile neutrino [8].

[8] [KM3NeT Collaboration], Oscillation Physics with KM3NeT-ORCA, Talk at 4th Uppsala Workshop on Particle Physics with Neutrino Telescope, Uppsala 2019.

ν_τ appearence

- The main signal of ν_τ appears in the range between 10 to 30 GeV, where the conversion from $\nu_\mu \longrightarrow \nu_\tau$ has a broad maximum for neutrinos that have traversed the Earth.
- KM3NeT/ORCA will be able to determine the normalisation of the oscillated ν_τ flux with high precision.
- In the long term, this allows to probe deviations from the unitarity assumption of three neutrino mixing which would be a clear hint that the current picture of the neutrino sector is incomplete and new physics is at play.
- A ν_τ CC normalisation of one is expected in the case of unitary mixing.





On the left, ORCA 7 ν_τ sensitivity [9] On the right: Total KM3NeT ν_τ sensitivity [10]

[9] [KM3NeT collaboration], (ICRC2019) 1019.

[10] KM3NeT collaboration, DOI: 10.5281/zenodo.1292823 (2018)

Non Standard Interactions (NSI)

- Other possible extension of Standard Model is the existence of new mediators apart W and Z bosons. In the presence of NSI, evolution of neutrinos in matter can be described by the Hamiltonian:

$$H_{NSI} = 2\sqrt{2}G_F N_F(x) \begin{pmatrix} \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix} \quad (1)$$

- We expect differences in neutrino probabilities after crossing Earth Mantle. For very high energies $\sim$ 100 GeV they will be the dominant effect, and they will also modify results in range of few GeV.

- The exclusion region assuming NO in the hybrid model approximation (θ_{12}, θ_{13}, and $\triangle m^2_{21} = 0$) is drawn for comparison with current limits from other experiments. With 3 years of live time, ORCA is expected to constrain NSI parameters 4x smaller than IceCube and Super-K limits.

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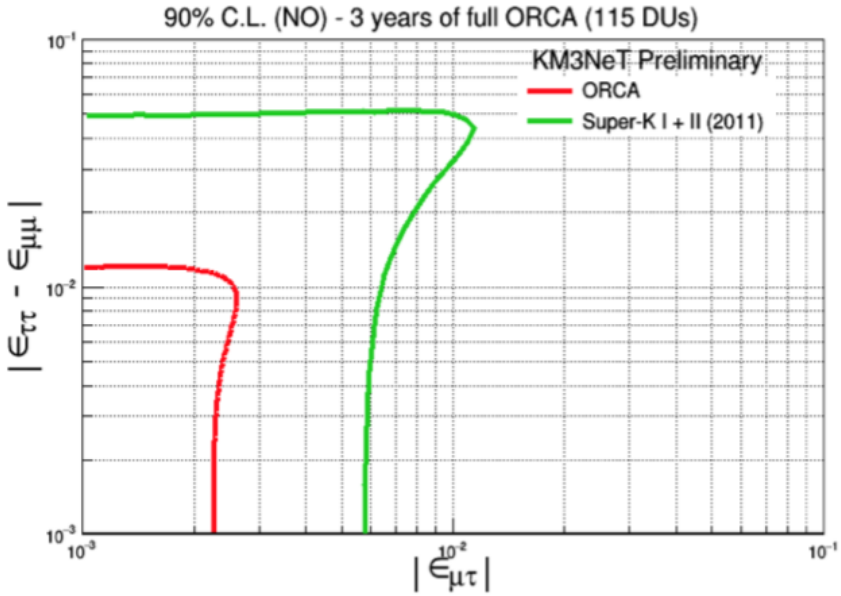

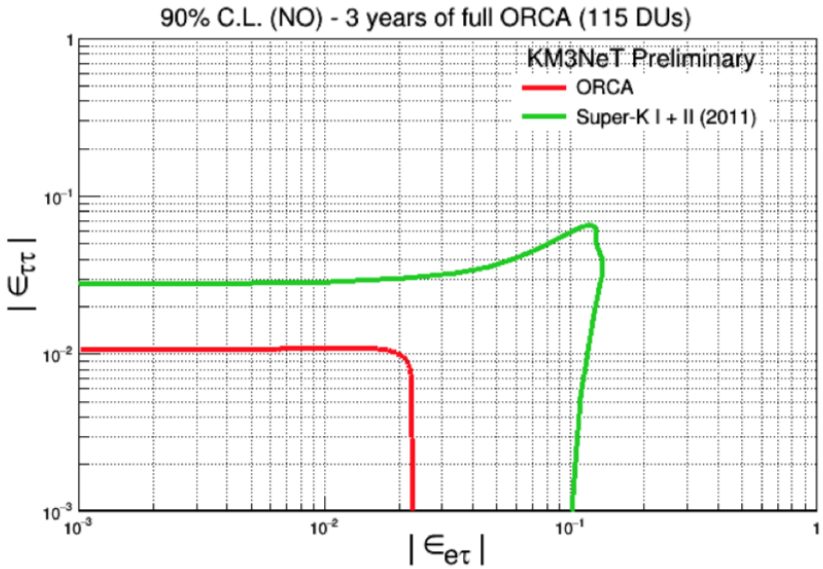

(On the left) Allowed NSI parameter region in the $|\epsilon_{\mu\tau}|$ vs $|\epsilon_{\tau\tau} - \epsilon_{\mu\mu}|$ plane in the two-flavour hybrid model, (On the right) The ORCA contour is drawn for the three-flavour hybrid model analysis considering NSI d-quark-couplings. [11].

[11] [KM3NeT Collaboration], Sensitivity to Non-Standard Interactions (NSI) with KM3NeT-ORCA, PoS(ICRC2019)931.

Other Topics

- Neutrino Decay:
  T. Thakore, PPNT 2019, Uppsala.
- Earth Tomography:
  KM3NeT Collaboration, 2017 Proc. 35th ICRC PoS (ICRC 2015)1020.
- CP phase studies:
  KM3NeT Collaboration, Measuring the leptonic CP-phase with Atmospheric Neutrinos and Beam Neutrinos. ArxiV:1907.12983.

Thank you!