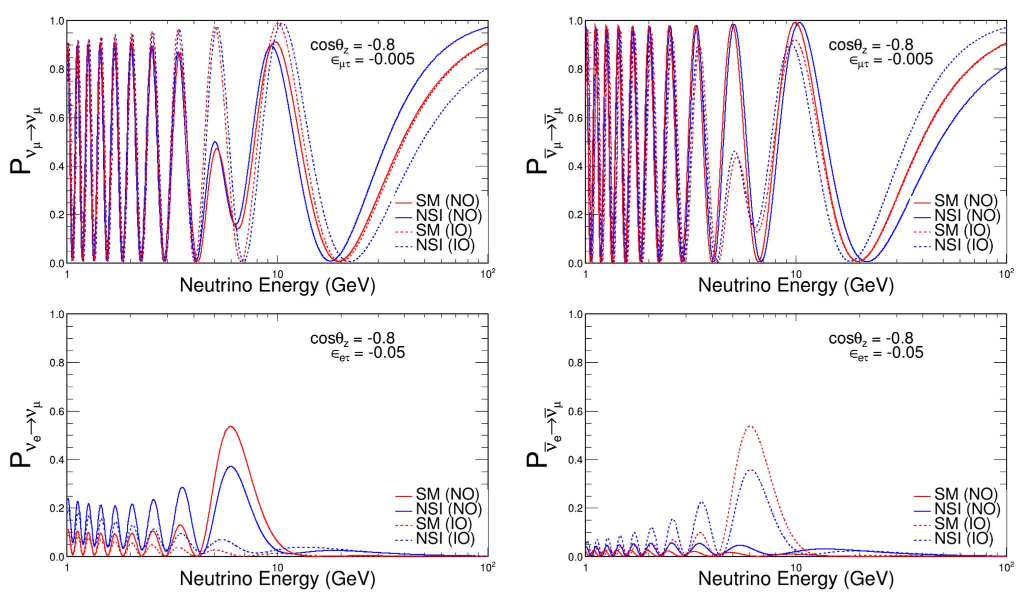
NEUTRINO OSCILLATIONS AND NON-STANDARD INTERACTIONS WITH KM3NET-ORCA

N. R. Khan Chowdhury on behalf of the KM3NeT Collaboration

IFIC – Instituto de Física Corpuscular (Univ. de Valencia – CSIC), E-46980 Paterna, Spain

Contact: nafis.chowdhury@ific.uv.es

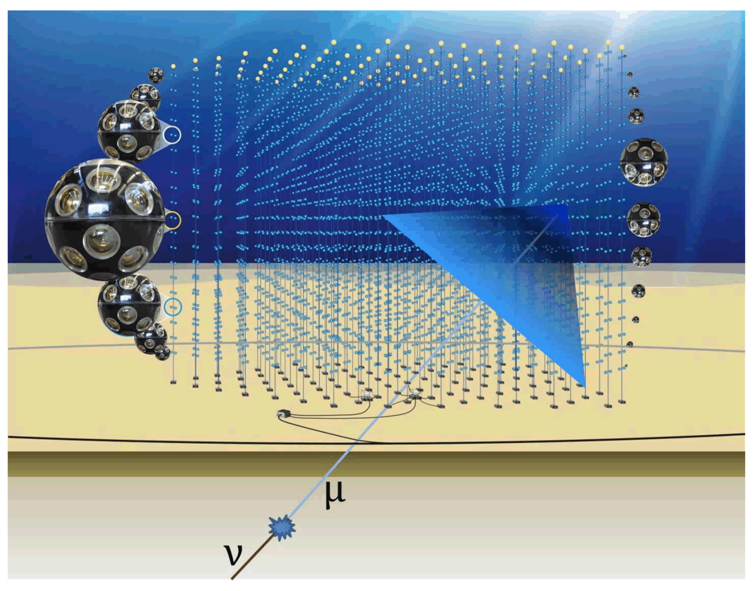


Neutrino oscillation probabilties in vacuum undergo distortions due to (flavour non-changing) charged current (CC) elastic scattering interactions of ν_e s with electrons in matter. These modifications are different in Normal Ordering (NO) and Inverted Ordering (IO) hypotheses.

In addition to the Standard Model (SM) MSW resonance, hypothetical flavour changing neutral current (NC) Non-Standard Interactions (NSI) of neutrinos (of all flavours) with fermions (e, u and d-quarks) present in Earth would alter the oscillation probabilities. This leads to departure from the expected flavour content at the detector. NSI in propagation can be modelled as

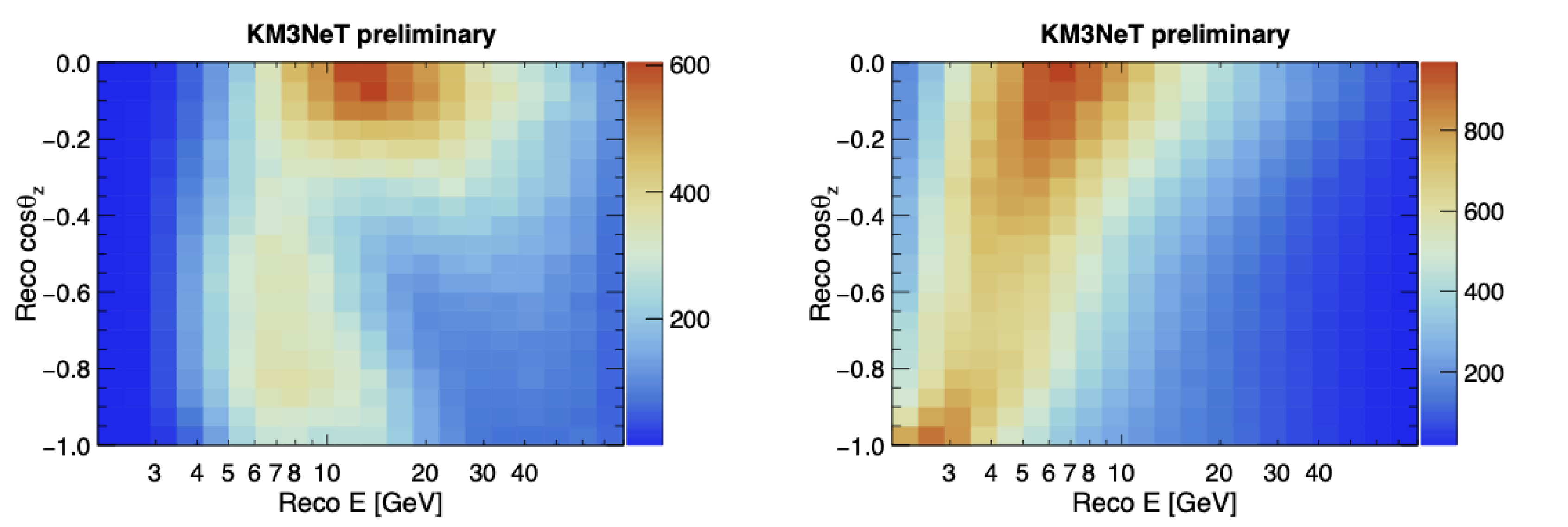
$$\mathbf{H} = \mathbf{H_{SM}} + \mathbf{H_{NSI}} = \mathbf{H_{vacuum}} + \mathbf{H_{matter}} + \mathbf{H_{NSI}}$$
$$= \frac{1}{2E} U \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{bmatrix} U^\dagger + 2\sqrt{2} G_F N_e(x) \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} + 2\sqrt{2} G_F N_f(x) \begin{bmatrix} \epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{bmatrix}.$$

The KM3NeT-ORCA detector [2], currenty under construction at a depth of 2450m in the Mediterranean sea, will consist of 115 detection units (DUs), each of which will comprise 18 spherical, 17" diameter Digital Optical Modules (DOMs) housing 31 3" PMTs and associated electronics. The vertical spacing between the DOMs is 9 m and the horizontal spacing between the DUs is 20 m, amounting to a total instrumented mass of ~8 Mton.

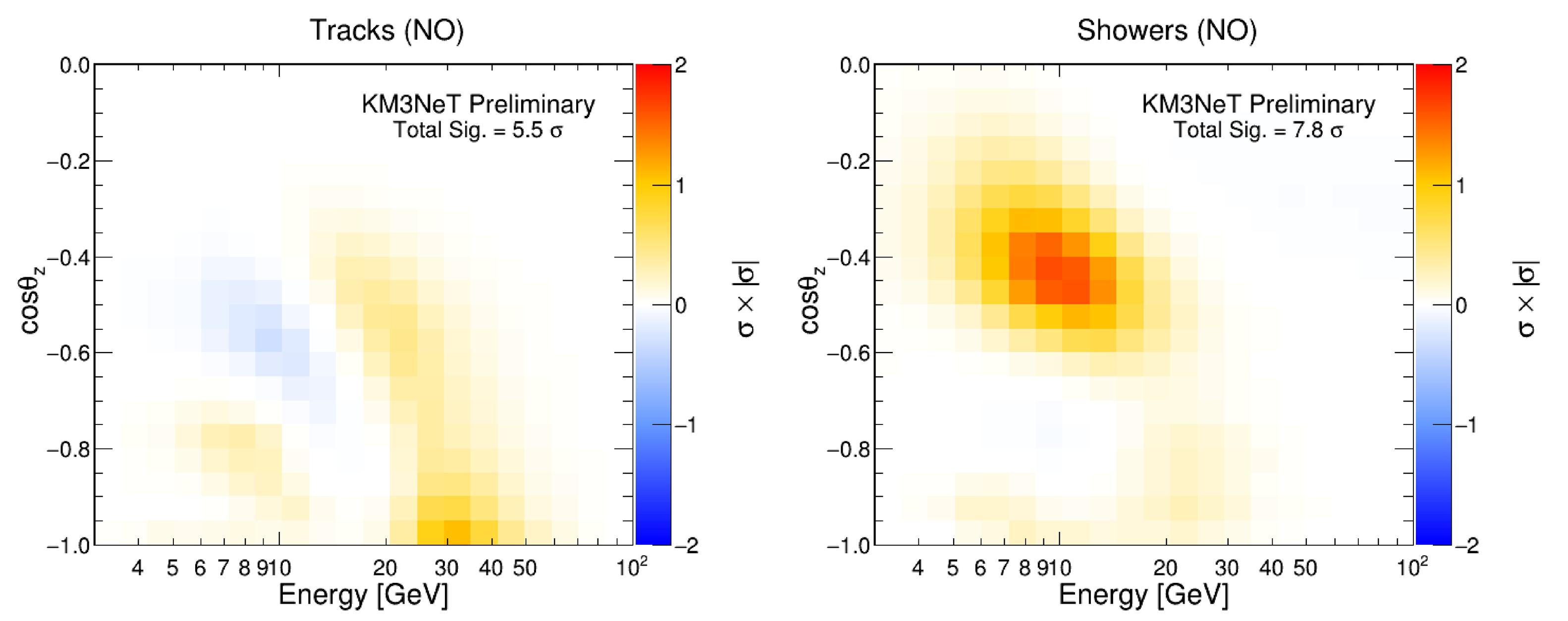


An artist's impression of the detector is shown. The blue line represents an upgoing neutrino undergoing ν_μ - CC interaction close to the fiducial volume leading to track-like event and creating a Cherenkov cone along its path.

The HKKM 2014 flux tables (Gran Sasso site) [3] are interpolated in $\log_{10}$(E) and cosθ_z and multiplied with the detector effective mass in megatons to calculate the rate of events for each interaction channel: ν_x CC, $\bar{\nu}_x$ CC (x = e, μ, τ), ν NC and $\bar{\nu}$ NC. Depending on the Cherenkov signatures of the outgoing lepton, two distinct event topolgies are observed at the detector: track-like (left) and shower-like events (right). Normal Ordering is assumed.



Statistical signed $\chi^2 = (N_{NSI} - N_{SM}) \times |N_{NSI} - N_{SM}| / N_{SM}$ is shown as a function of reconstructed energy and cosine zenith for both topologies assuming 3 years of ORCA livetime.



A 20×10 binning in reconstructed $\log_{10}$(E) with E ∈ [3, 100] GeV and $\cos\theta_z$ ∈ [-1, 0] is adopted to fold in the detector response. An overall larger statistics-only sensitivity is observed in the shower channel for an NSI model represented by $\epsilon_{e\tau}$ = -0.05.

The final sensitivity of the experiment to NMO (or NSI) is estimated with a log-likelihood ratio test statistic [4] based on the Asimov method:

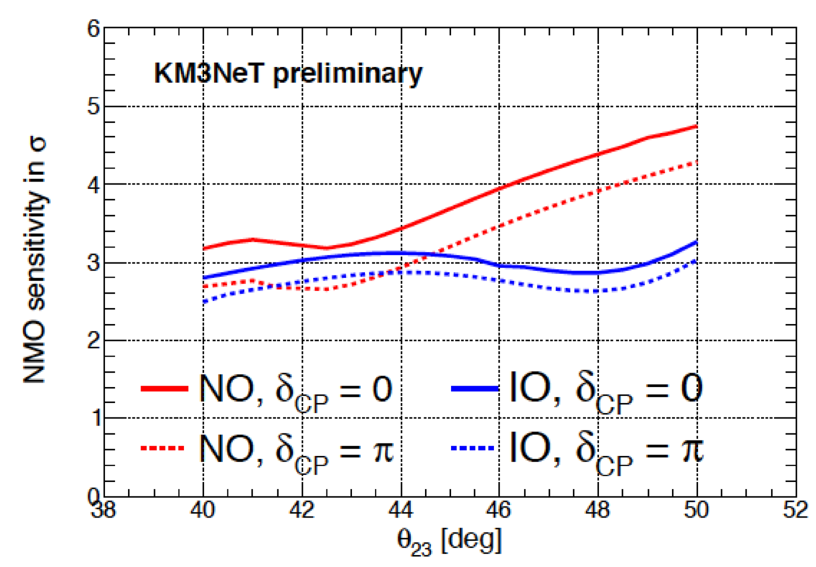
$$\chi^2_{NMO/NSI} = 2\sum_{E,\theta_z}\left(N^{WO/NSI}_{E,\theta_z} - N^{RO/SM}_{E,\theta_z} + N^{RO/SM}_{E,\theta}\ln\frac{N^{RO/SM}_{E,\theta_z}}{N^{WO/NSI}_{E,\theta_z}}\right) + syst.$$

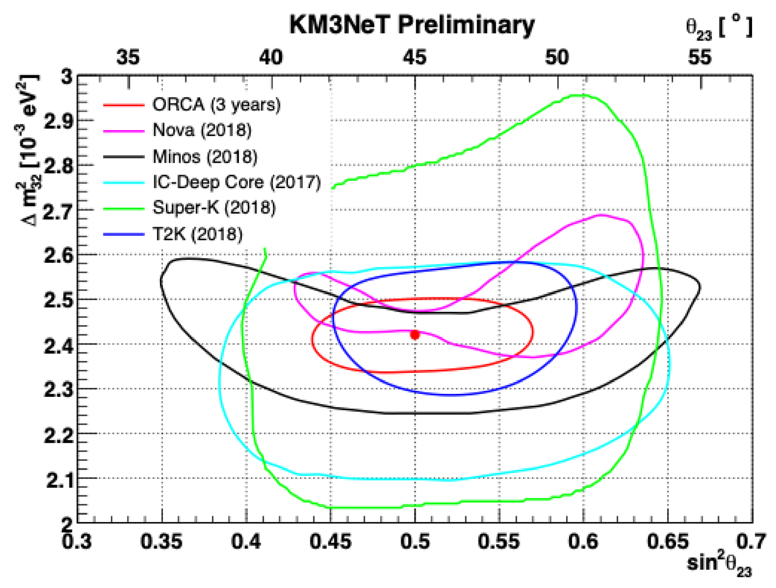
N^{RO}_{E,θ_z} (N^{WO}_{E,θ_z}) denotes the expected number of track / shower events in a given [E, θ_z] bin for the right ordering (wrong ordering) hypothesis in the standard 3ν oscillation framework. In the case of NSI sensitivity estimation, N^{NSI}_{E,θ_z} (N^{SM}_{E,θ_z}) is the predicted number of events for an asummed mass ordering in presence (absence) of NSI.

The table lists the oscillation parameters and systematics over which marginalisation is done along with their statistical treatment and priors (if any).

parameters	treatment	true values	prior
$\Delta m^2_{21}/10^{-5}eV^2$	fix	7.40	-
$\Delta m^2_{31}/10^{-3}eV^2$	fitted	2.494	free
$\theta_{12}(^\circ)$	fix	33.62	-
$\theta_{13}(^\circ)$	fitted	8.54	0.15
$\theta_{23}(^\circ)$	fitted	47.2	free
$\delta_{CP}(^\circ)$	fitted	234	free
Flux norm.	fitted	1	10%
NC scale	fitted	1	5%
Energy scale	fitted	1	3%
ν_μ/ν_e skew	fitted	0	5%
$\nu/\bar{\nu}$ skew	fitted	0	3%

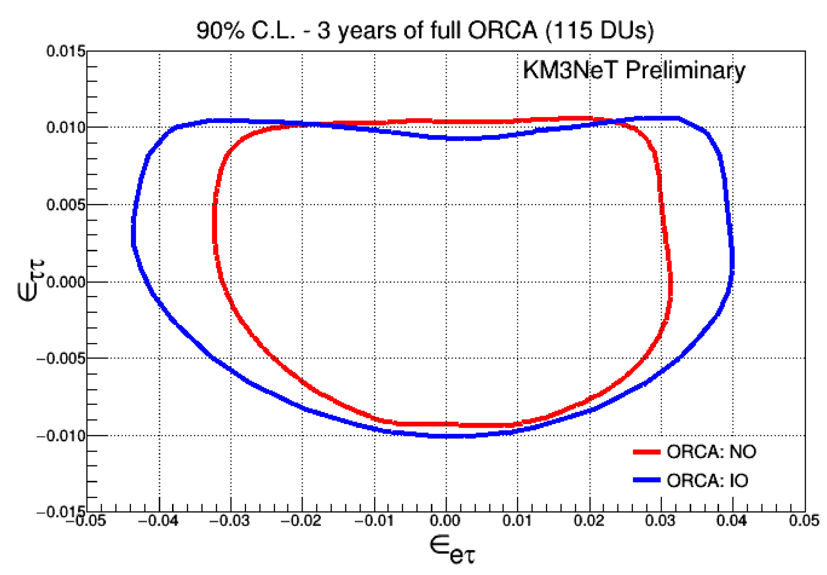
The χ^2_{NMO} is minimised over the expected dataset for the wrong ordering along with systematic uncertainties. The results are shown for both assumed true orderings and the most favourable and least favourable δ_{CP} values.

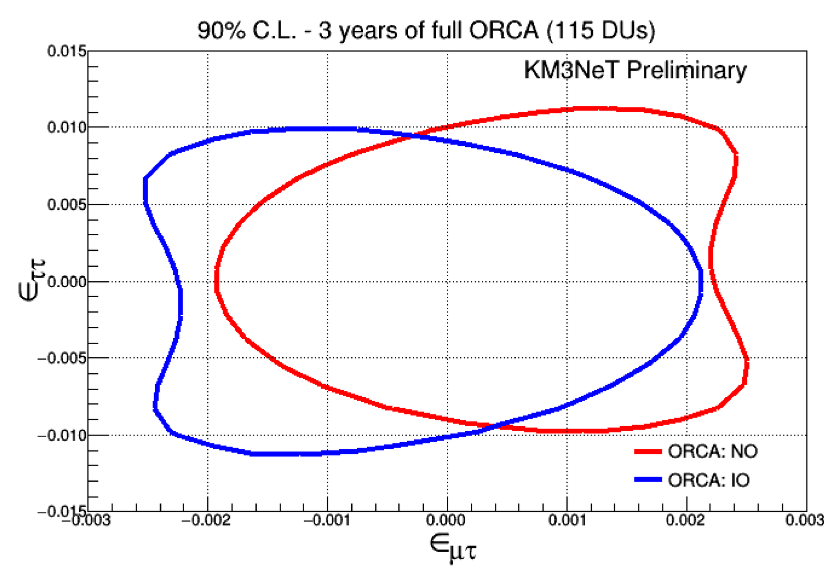




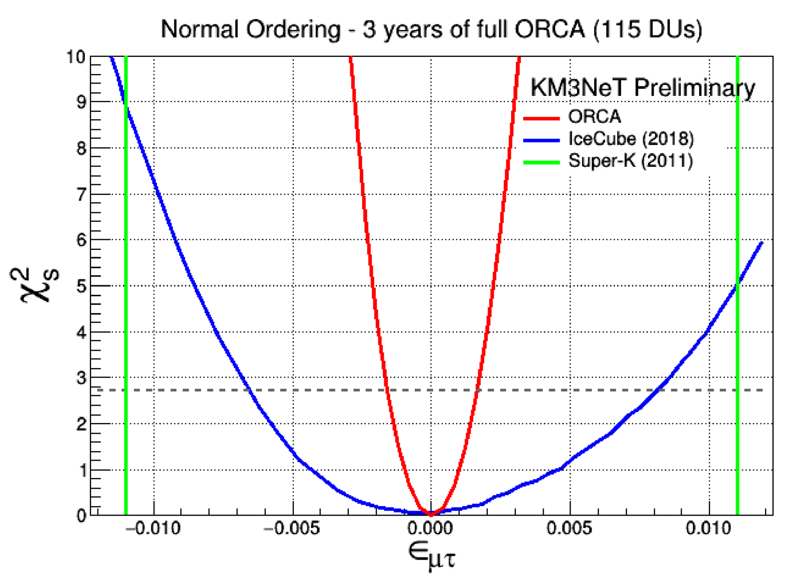
The sensitvity of ORCA to the joint determination of θ_{23} and Δm^2_{32} is shown (right) alongside current results from MINOS, NOν, Super-K and IceCube/DeepCore. The 90% CL contour is drawn assuming NO (fixed) and δ_{CP} = 0 (fitted).

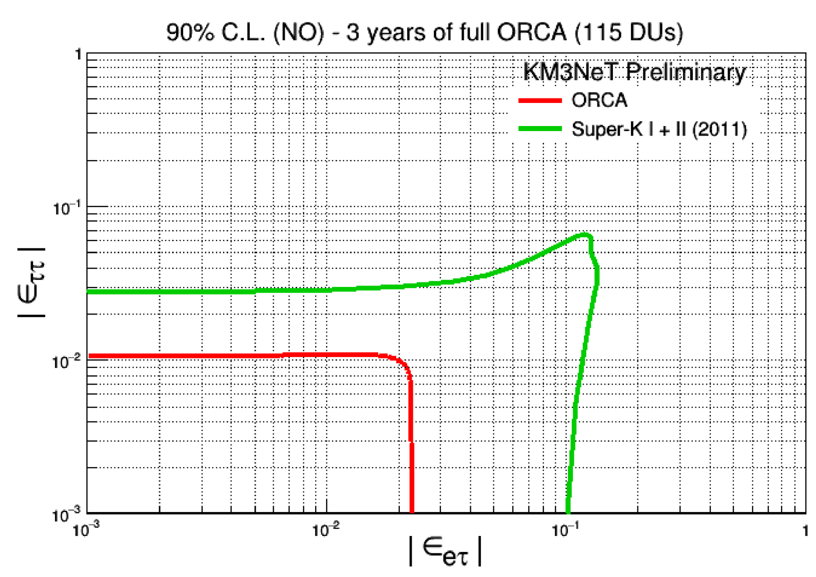
The 90% C.L. contours in correlated NSI parameter spaces: $|\epsilon_{e\tau} - \epsilon_{\tau\tau}|$ (left) and $|\epsilon_{\mu\tau} - \epsilon_{\tau\tau}|$ (right) allowed after 3 years of running of ORCA is shown below for both orderings. The NSI parameters not appearing on the plots are fixed at zero.

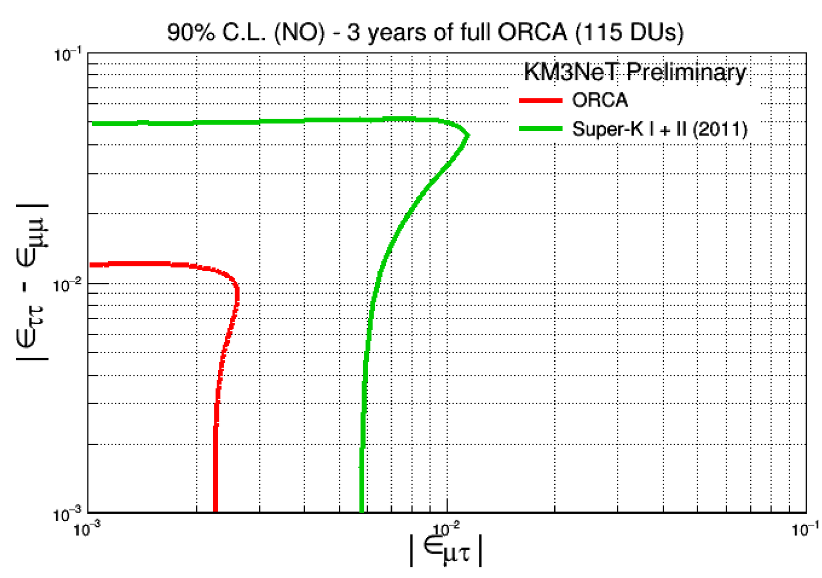




The exclusion region assuming NO in the *hybrid model* approximation (θ_{12}, θ_{13}, and $\Delta m^2_{21} = 0$) is drawn for comparison with IceCube and Super-K . With 3 years of livetime, ORCA is expected to constrain NSI parameters $\epsilon_{e\tau}$, $\epsilon_{\mu\tau}$ and $\epsilon_{\tau\tau}$ by a factor of four better than current limits.







[1] T. Ohlsson. *Rep. Prog. Phys.* 76 (2013) 044201.
[2] Letter of intent for KM3NeT 2.0 *J. of Phys. G: Nuclear and Particle Physics* 43 (2016) 084001.
[3] M. Honda et al. *Phys. Rev.* D92 (2015) 023004.
[4] R. Gandhi *et al. Phys. Rev.* D76 (2007) 073012.

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