Neutrino non-standard interactions with the KM3NeT/ORCA detector

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Non-Standard Interactions

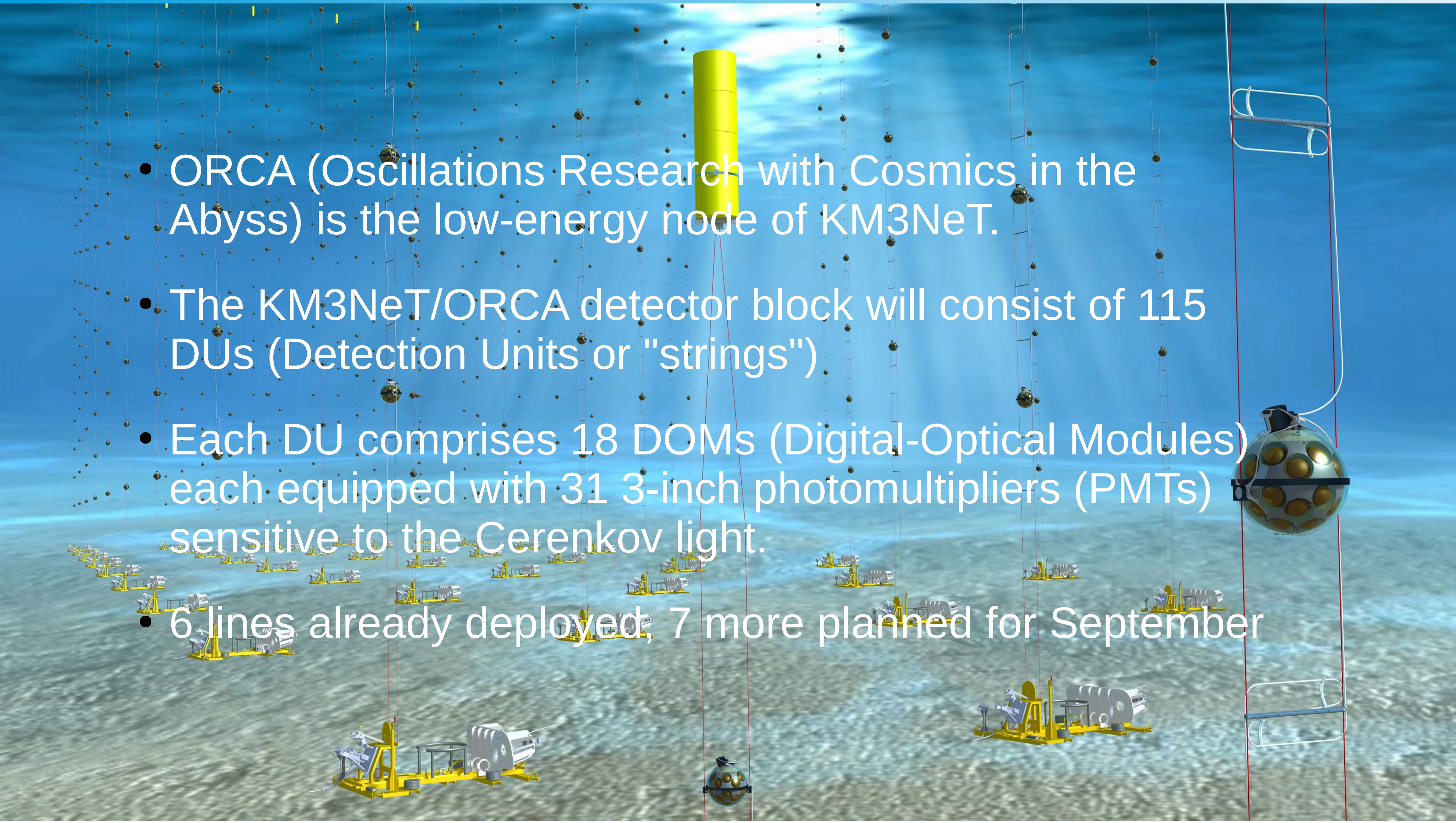
NSI are a subset of possible interactions not present in the Standard Model that involve left-chiral neutrinos and left and right-chiral fermions. Neutral current NSI would inuence the neutrino propagation through the Earth according to an effective Hamiltonian:

$$H_{eff} = \frac{1}{2E} U_{PMNS} \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{bmatrix} U^{\dagger}_{PMNS} + V_{CC} \begin{bmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{bmatrix}$$

$$\epsilon_{\alpha\beta} = \epsilon^{eC}_{\alpha\beta} + \frac{n_u}{n_e}\epsilon^{uC}_{\alpha\beta} + \frac{n_d}{n_e}\epsilon^{dC}_{\alpha\beta},$$

For simplicity interaction on fermions other than d-quarks neglected
Study done only for $\varepsilon_{\mu\tau}$ assuming other NSI parameters at 0

KM3NeT/ORCA detector



- ORCA (Oscillations Research with Cosmics in the Abyss) is the low-energy node of KM3NeT.
- The KM3NeT/ORCA detector block will consist of 115 DUs (Detection Units or "strings")
- Each DU comprises 18 DOMs (Digital-Optical Modules) each equipped with 31 3-inch photomultipliers (PMTs) sensitive to the Cerenkov light.
- 6 lines already deployed, 7 more planned for September

Samples and event selection

- ORCA115 – 3 Patcile Identification (PID) classes, machine learning background suppresion
- ORCA6 – Only track reconstruction, no PID details of the selection provided in the presentation in this conference:

First neutrinooscillation measurement with KM3NeT/ORCA (Presenter-Forum Number: 345).

Analysis method

To study the ORCA115 sensitivity for ORCA115, a profile Poisson likelihood ratio is calculated with respect to the non-NSI pseudo-data nominal parameters:

$$-2\log\left(\frac{L(\varepsilon_{\mu\tau},\eta)}{L(0,\eta_{nominal})}\right)=2\sum_{bins}\left[N_{NSI}(\varepsilon_{\mu\tau},\eta)-N_{STD}(0,\eta_{nominal})+N_{STD}(0,\eta_{nominal})\log\left(\frac{N_{STD}(0,\eta_{nominal})}{N_{NSI}(\varepsilon_{\mu\tau},\eta)}\right)\right]+\frac{\sum_{syst}\eta-\bar{\eta}}{2\sigma_{\eta}^{2}}$$

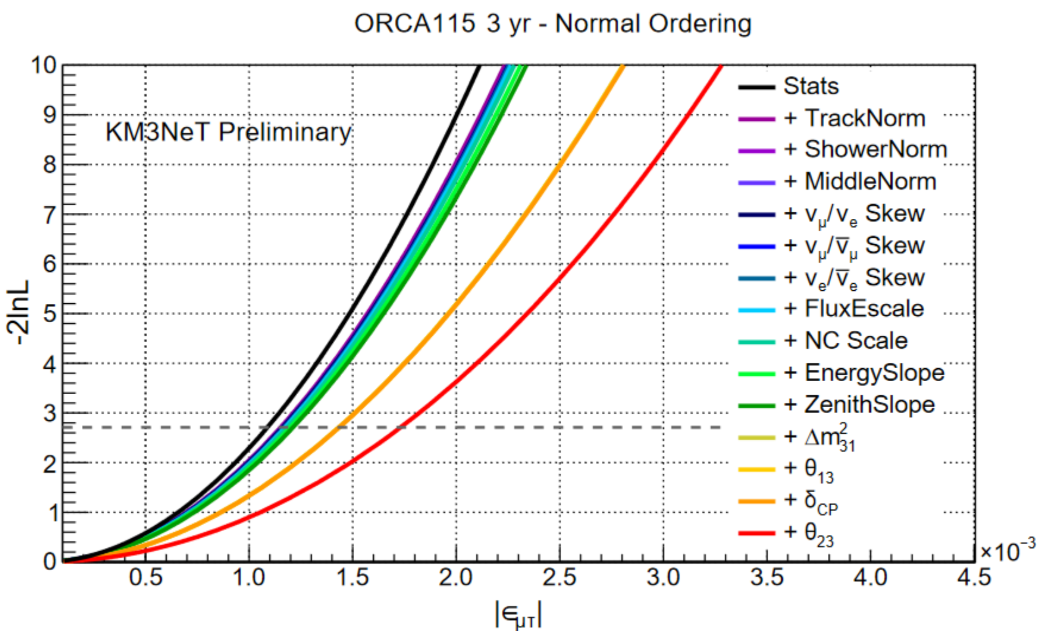
Gaussian external contraints

η – nuisance parameters

For ORCA6 no fits are performed and the likelihood proling for each scanned value of $\varepsilon_{\mu\tau}$ is done only over the mass ordering with NuFit best t values for NO (Normal ordering) and IO (Inverted Ordering)

Systematics ORCA115

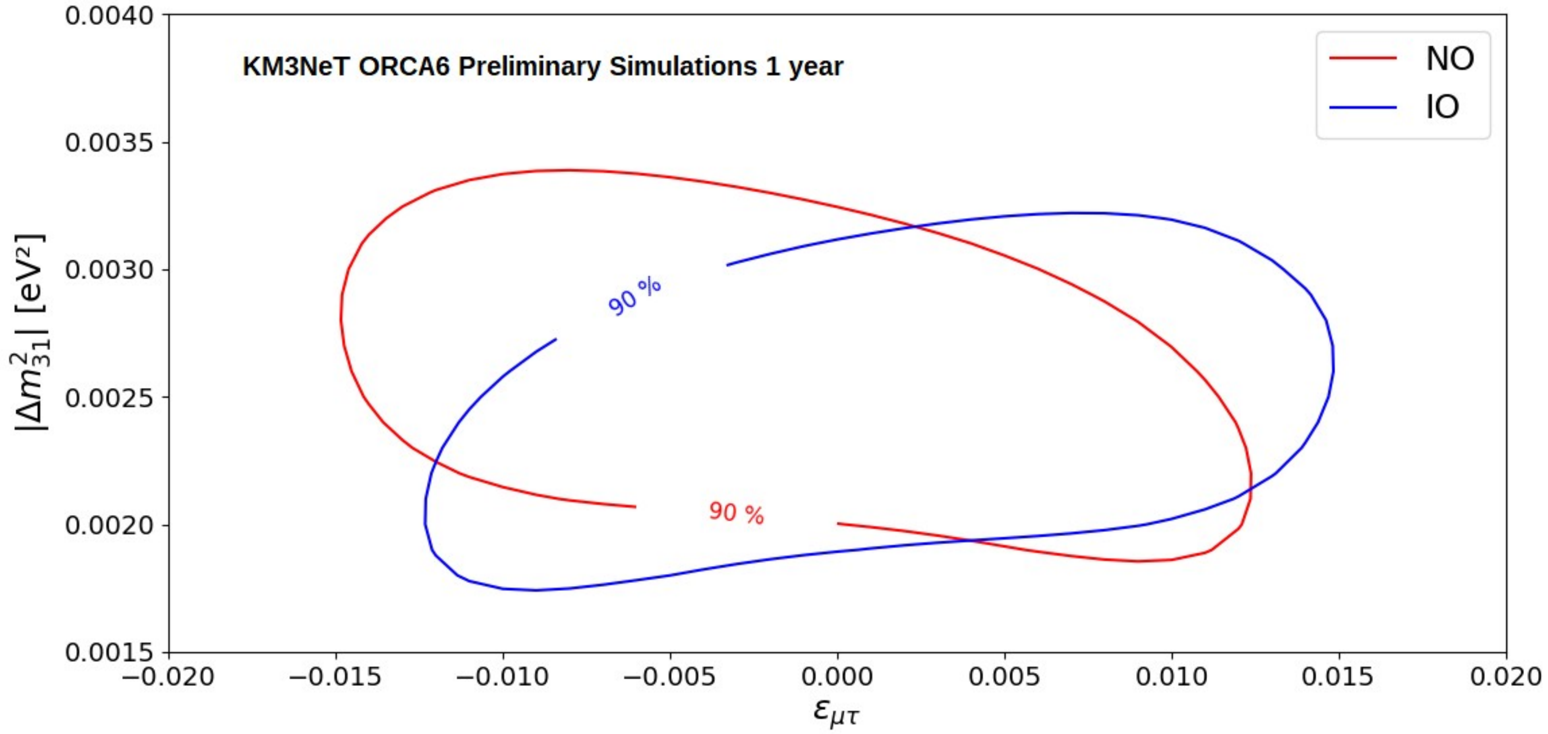
Systematics with the strongest impact for NSI study with ORCA115 are the unconstrained standard oscillation parameters



Nuisance parameters	Treatment	Nominal values	Priors
Oscillation			
$\theta_{12}(^\circ)$	fixed	33.82	-
$\theta_{13}(^\circ)$	fitted	8.60	0.13
$\theta_{23}(^\circ)$	fitted	48.6	free
$\delta_{CP}(^\circ)$	fitted	221	free
$\Delta m^2_{21}(\times10^{-5}\text{eV}^2)$	fixed	7.39	-
$\Delta m^2_{31}(\times10^{-3}\text{eV}^2)$	fitted	2.528	free
Flux			
Track norm.	fitted	1	free
Shower norm.	fitted	1	free
Middle norm.	fitted	1	free
ν_μ/ν_e skew	fitted	0	5%
$\nu_\mu/\bar{\nu}_\mu$ skew	fitted	0	5%
$\nu_e/\bar{\nu}_e$ skew	fitted	0	5%
Energy slope ($\Delta\gamma$)	fitted	0	5%
Zenith slope	fitted	0	2%
Cross-section			
NC scale	fitted	1	5%
Detector			
Energy scale	fitted	1	10%

The nominal values and the priors from the table in are used in the second term log-likelihood ratio formula (slide 5) as the mean and standard deviation of the Gaussian external constraints on the systematic parameters.

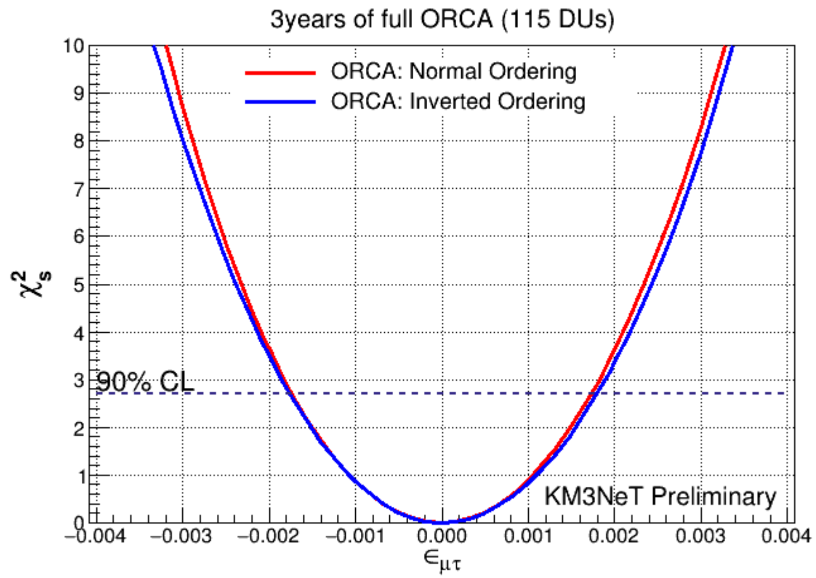
Systematics ORCA6

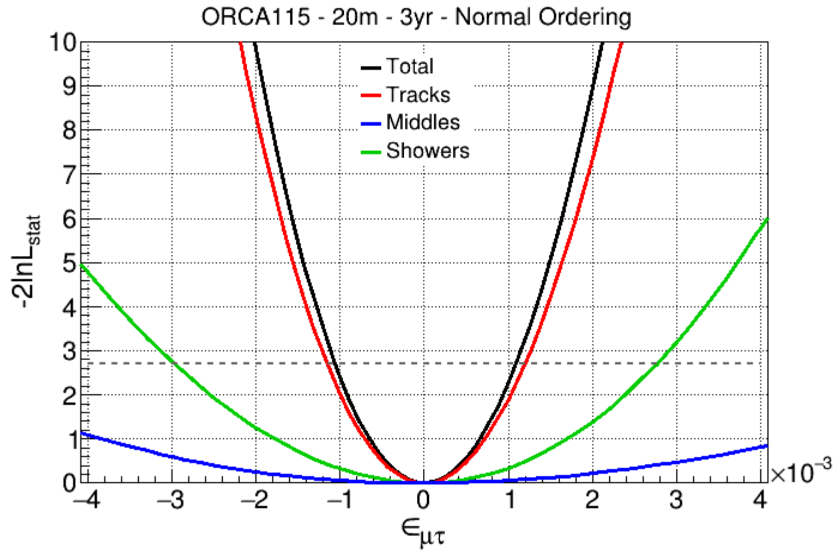


- The impact of the systematic uncertainties in the KM3NeT/ORCA6 sample is still being investigated. The nuisance parameter with the largest influence for $\varepsilon_{\mu\tau}$ the study is Δm^2_{31}.
- Despite the correlation between $\varepsilon_{\mu\tau}$ and Δm^2_{31} visible regardless of the ordering, for the current detector exposure of approx. 1 year, ORCA6 sensitivity is expected to be dominated by the sample statistics.

KM3NeT/ORCA sensitivity for $\varepsilon_{\mu\tau}$

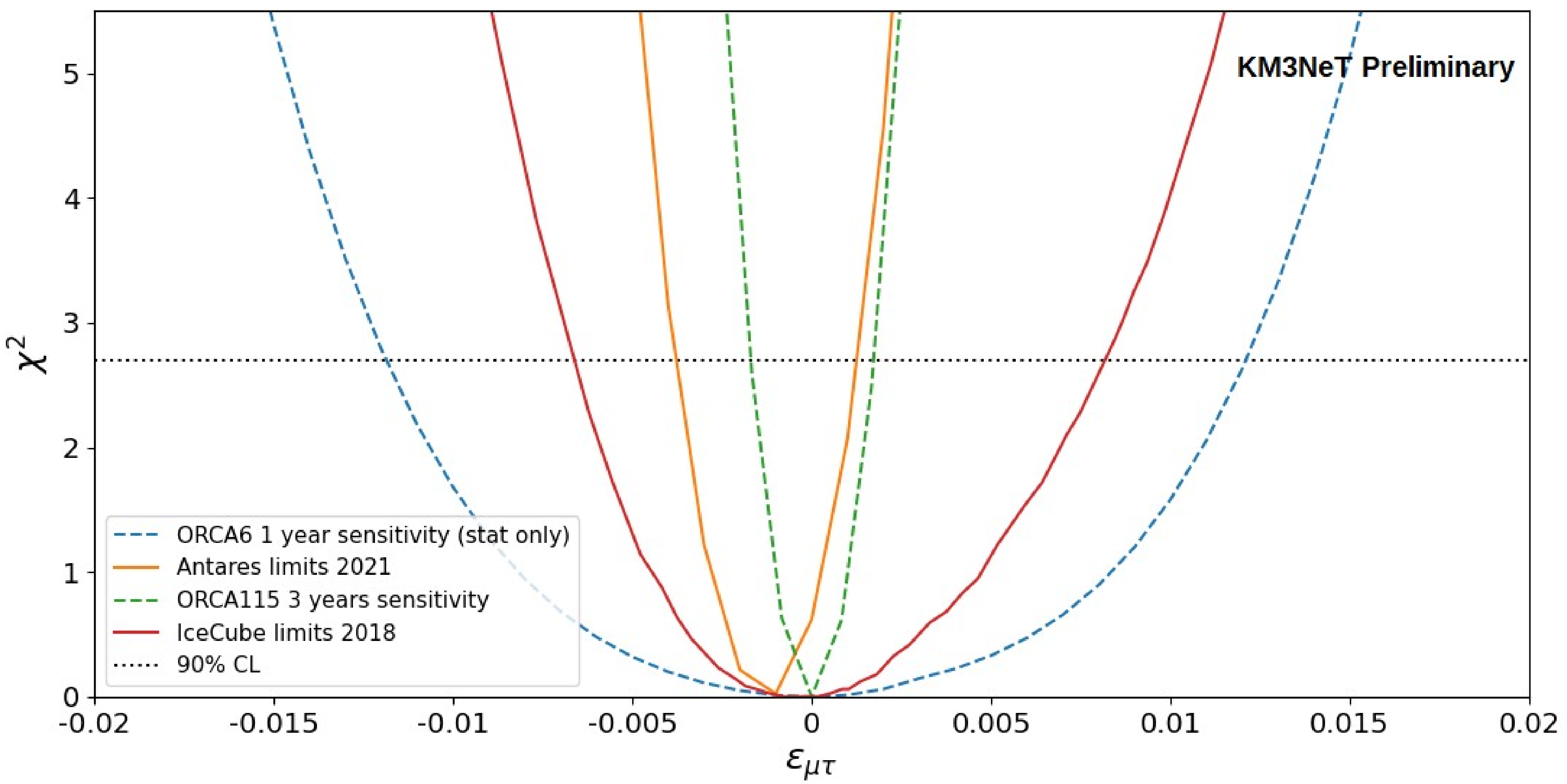
Neutrino mass ordering does not affect the KM3NeT/ORCA sensitivity to $\varepsilon_{\mu\tau}$. It is due to the anti-correlation between the sign of $\varepsilon_{\mu\tau}$ and Δm^2_{31}. Taking it into account, the final analysis was performed only with NO as the pseudo-data generation input.





Almost all the sensitivity for with KM3NeT/ORCA comes from the track events populated mainly by atmospheric muon neutrinos oscillating to tau neutrinos. Even without the shower reconstruction, ORCA6 can already give a good estimation of its nal capability to measure $\varepsilon_{\mu\tau}$

KM3NeT/ORCA sensitivity for $\varepsilon_{\mu\tau}$



90% CL ORCA6 (stat):
$-12 \cdot 10^{-3} < \varepsilon_{\mu\tau} < 12 \cdot 10^{-3}$

90% CL ORCA115 (syst):
$-1.7 \cdot 10^{-3} < \varepsilon_{\mu\tau} < 1.7 \cdot 10^{-3}$

Conclusions

- Using only one year of data-taking, the ORCA6 conguration, which constitutes about 5% of the full detector, is able to reach a measurement precision of only two to three times worse than the current limit.
- Moreover, as ORCA grows in size, not only the event statistics per running time will increase, but also the energy resolution and the highest measurable muon energy, which will improve signicantly the sensitivity to the parameter.
- When completed, the KM3NeT/ORCA detector will potentially become the world's best tool for probing neutrino non-standard interactions with atmospheric neutrinos.

References

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