Sensitivity study for KM3NeT-ORCA to Sterile Neutrinos

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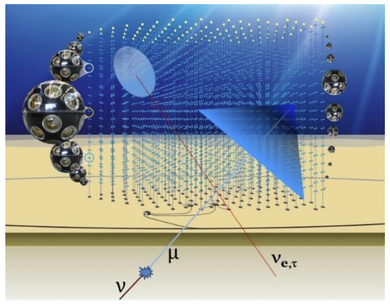
Sterile Neutrino Search with KM3NeT-ORCA

- The low energy configuration of KM3NeT[1] : Oscillation Research with Cosmics in the Abyss (ORCA) will study atmospheric neutrino oscillations, with the primary goal of Neutrino Mass Ordering (NMO) determination and constrain BSM physics models such as sterile neutrinos and NSI.
- With ν_μ and ν_e atmospheric flux components, and benefitting from earth matter effects, ORCA can simultaneously constrain mixing angles θ_{14}, θ_{24} and θ_{34} in the (3+1) neutrino mixing model.
- For ORCA, the accessible L/E range spans 10 – 10^4 km/GeV, enabling it to constrain the (3+1) sterile neutrino model over $\Delta m^2_{41} \sim [10^{-4} – 1)\ eV^2$.



Artistic impression of ORCA

Analysis Procedure

- The sensitivity analysis makes use of the full ORCA MC production for the 20m detector geometry.
- A response matrix method[5] is used to map true (E,cos θ) to reconstructed (E^{rec},cos θ^{rec}) for the observed event topologies : Track-like, Shower-like and Middle-like.
- The PID scores to classify event topologies are obtained using a Random Decision Forest algorithm.
- Reconstructed Energy Range : [3,100] GeV, only the up-going events are used.
- Event rate calculations include all CC disappearance and appearance channels, as well as the NC disappearance channel.
- The NuFit v4.1 global fit results[3] are used as benchmark oscillation parameters.
- Atmospheric Neutrino Flux, HKKM 2014 at Gran Sasso site [6] has been used for this analysis.
- We assume Normal mass ordering for 3-flavor sector, $\Delta m^2_{41} > 0$, and the solar oscillation parameters are fixed for all cases.

$$U = R_{34}(\theta_{23})R_{24}(\theta_{24},\delta_{24})R_{14}(\theta_{14})R_{23}(\theta_{23})R_{13})(\theta_{13},\delta_{13})R_{12}(\theta_{12},\delta_{12})$$

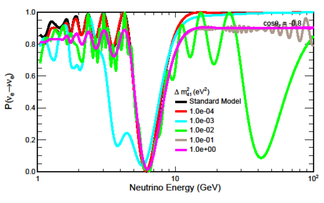
(3+1) Mixing Matrix Parametrization

$$V_{matter} \equiv \sqrt{2}G_F \begin{pmatrix} (N_e - N_n/2) & 0 & 0 & 0 \\ 0 & -N_n/2 & 0 & 0 \\ 0 & 0 & -N_n/2 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

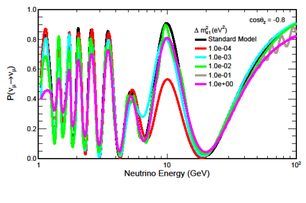
Matter Potential

For baselines relevant to ORCA, matter effects play an important role in governing neutrino oscillation probabilities at $\Delta m^2_{41} \sim \Delta m^2_{31}\ eV^2$.

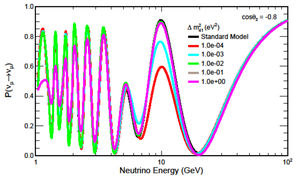
Illustrative Oscillation Probability Plots



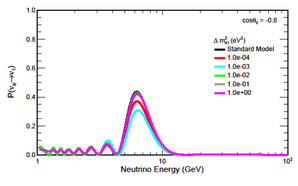
P ($\nu_e \rightarrow \nu_e$), $\sin^2\theta_{14}$ = 0.05



P ($\nu_\mu \rightarrow \nu_\mu$), $\sin^2\theta_{24}$ = 0.05



P ($\nu_\mu \rightarrow \nu_\mu$), $\sin^2\theta_{34}$ = 0.05



P ($\nu_e \rightarrow \nu_t$), $\sin^2\theta_{34}$ = 0.05

Oscillation probabilities are obtained using the publicly available OscProb package[2]. NuFit v4.1[3] oscillation parameter values and the PREM density profile[4] with 44 density layers have been used. The probabilities are averaged over energy with a resolution σ_E/E=0.10.

KM3NeT review talk : D. Samtleben, June 30

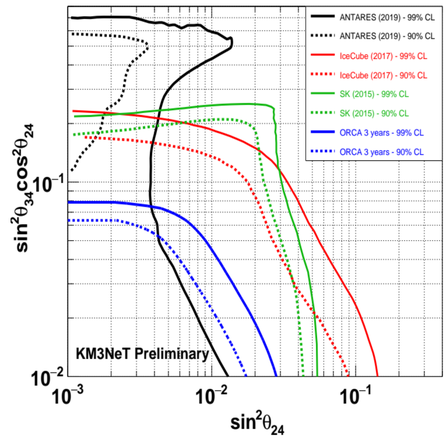
List of Fitted Parameters

Fitted Parameters	Central Value	Prior
TrackNorm	1	free
MiddleNorm	1	free
ShowerNorm	1	free
ν_μ/anti-ν_μ flux skew	0	0.05
ν_e/anti-ν_e flux skew	0	0.05
ν_μ/ν_e flux skew	0	0.05
Energy slope	0	0.05
Zenith angle slope	0	0.02
Flux E-Scale	1	0.05
NC scale	1	0.1
θ_{23}	48.6°	free
Δm^2_{31}	2.528 x 10^{-3} eV^2	free
θ_{13}	8.6°	0.13°
δ_{CP}	221°	free

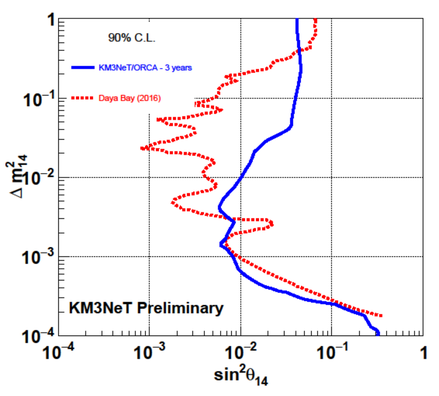
References

(1) The KM3NeT Collaboration, *Letter of Intent for KM3NeT 2.0*, Journal of Physics G: Nuclear and Particle Physics, 43 (8), 084001, 2016
(2) OscProb package, J. Coelho, https://github.com/joaoabcoelho/OscProb/
(3) NuFit collaboration, http://www.nu-fit.org/
(4) Adam M. Dziewonski and Don L. Anderson. Preliminary reference Earth model. Physics of the Earth and Planetary Interiors, 25(4):297–356, 1981.
(5) S. Bourret, Ph.D thesis, http://www.theses.fr/2018USPCC247
(6)M. Honda et al., Atmospheric neutrino flux calculation using the NRLMSISE-00 atmospheric model. Phys. Rev., D92(2):023004, 2015.

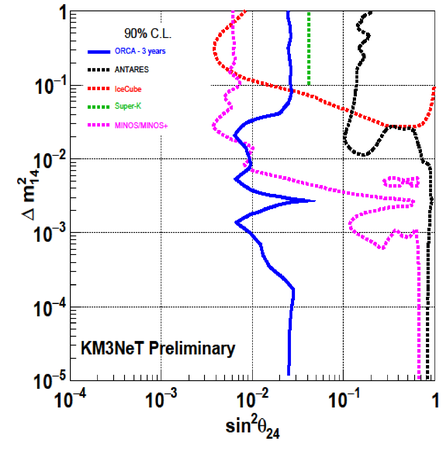
Asimov Sensitivity Results



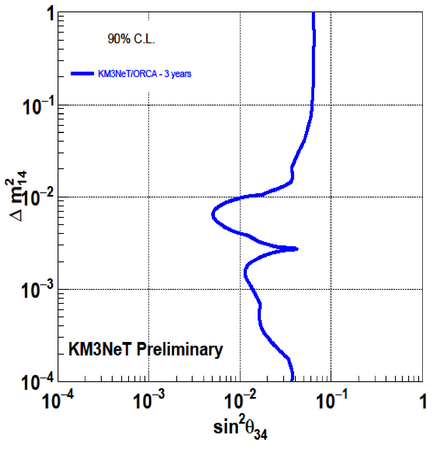
Δm^2_{41} = 0.3 eV^2, δ_{24} fixed



θ_{24} and θ_{34} fitted , δ_{24} fixed



θ_{14} and θ_{34} fitted , δ_{24} fixed



θ_{14} and θ_{24} fitted , δ_{24} fixed

- **At Δm^2_{41} = 0.3 eV^2, ORCA will improve bounds in the parameter space $\sin^2\theta_{24} – \sin^2\theta_{34}\cos^2\theta_{24}$.**
- **For $\Delta m^2_{41} < 0.1$ eV^2, all three sterile neutrino mixing angles can be tightly constrained, providing complementary information to the eV-scale sterile neutrino searches.**

3 years runtime, 115 strings

Neutrinos