Sensitivity of KM3NeT/ORCA6 to light sterile neutrino mixing parameters

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KM3NeT/ORCA

Cherenkov neutrino telescope under construction in the Mediterranean sea. Atmospheric ν 1 - 100 GeV.

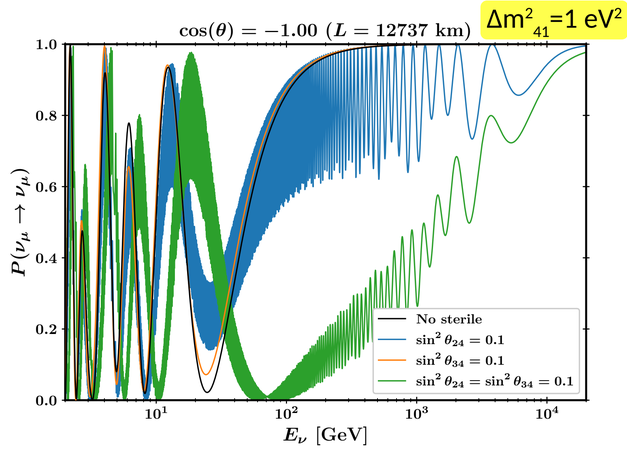
Main goal: Neutrino Mass Ordering

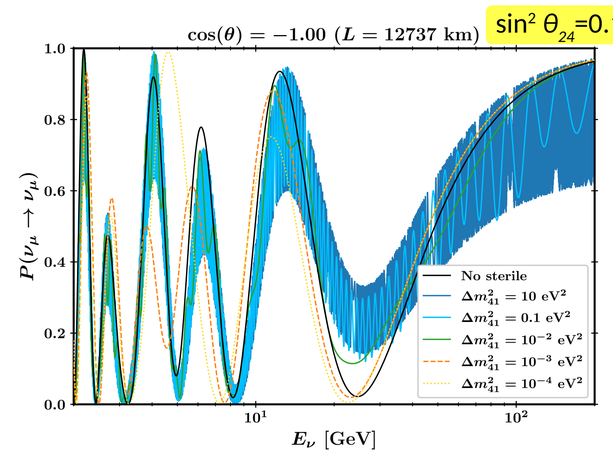
3-D array of photomultiplier tubes:
1 Digital Optical Module (DOM) = 31 PMTs

1 Detection Unit (DU) = 18 DOMs
115 DUs when complete
⇒ 7 Mton instrumented water
Here **ORCA6 (6 DUs)**, operated Jan. 2020- Nov. 2021

Light Sterile Neutrino

1) *Short BaseLine (SBL) anomaly:* $\Delta m^2_{41} \sim 1\ eV^2$
MSW resonance > 1 TeV: hard to see with ORCA
ORCA main feature on $P(\nu_\mu \rightarrow \nu_\mu)$ at 1st osc. maximum (E~25 GeV for vertical upgoing ν_μ)
θ_{24} & θ_{34} change amplitude; when both ≠0, change position depending on δ_{24} value





2) *Dependency on* Δm^2_{41}
Wide range of E & L: can scan wide Δm^2_{41} range including very-low sterile ($\Delta m^2_{41} < 10^{-2}\ eV^2$) mass, not yet constrained by cosmology.
E~25 GeV feature disappears for very low-mass, instead effects at ≤ 10 GeV (L/E > 1000 km/GeV)

Analysis workflow

HONDA 2014 @ Fréjus, solar minimum

Std osc. params: NuFit 5.0 w/o SK + Daya Bay for Δm^2_{31}

GENIE

3 classes: ***low*** VS ***high-purity (LP / HP) tracks*** VS ***showers*** (BDT)

$$\phi^{\nu_y}_{atm}(E_t,\theta_t) \times P_{\nu_y \rightarrow \nu_x}(E_t,\theta_t) \times \sigma_{\nu_x}(E_t) \times M^{\nu_x}_{eff}(E_t) \times R_i(E_t,\theta_t,\nu_x,E_r,\theta_r) \Rightarrow n_i(E_r,\theta_r)$$

ν_{hor}/ν_{ver} skew
$\nu_e/\bar{\nu}_e$ skew
$\nu_\mu/\bar{\nu}_\mu$ skew
ν_μ/ν_e skew
Spectral index
Overall norm.

Δm^2_{31}
θ_{23}
Constrained
No prior

ν_τ-CC norm.
NC norm.

Energy scale
HE light sim.
HP track norm.
Shower norm.
Muon norm.

Systematics

Compare measured $n_{i,j}$ VS predicted $\mu_{i,j}$ 2D $(E_r, \cos\theta_r)$ reconstructed event distributions for each class i

Determine parameters of interest $\boldsymbol{x}$ through Maximum Likelihood Estimator:
(Poisson + Gaussian for constrained nuisance parameters $\boldsymbol{\eta}$')

$$l(\boldsymbol{x},\boldsymbol{\eta}) = 2\sum_{i=1}^{N_{classes}}\sum_{j=1}^{N_{bins}}\left[\mu_{i,j}(\boldsymbol{x},\boldsymbol{\eta}) - n_{i,j} + n_{i,j}\ln\left(\frac{n_{i,j}}{\mu_{i,j}(\boldsymbol{x},\boldsymbol{\eta})}\right)\right] + \sum_{k=1}^{N_{priors}}\left(\frac{\eta_k' - \langle\eta_k'\rangle}{\sigma_k}\right)^2$$

Sensitivity Results

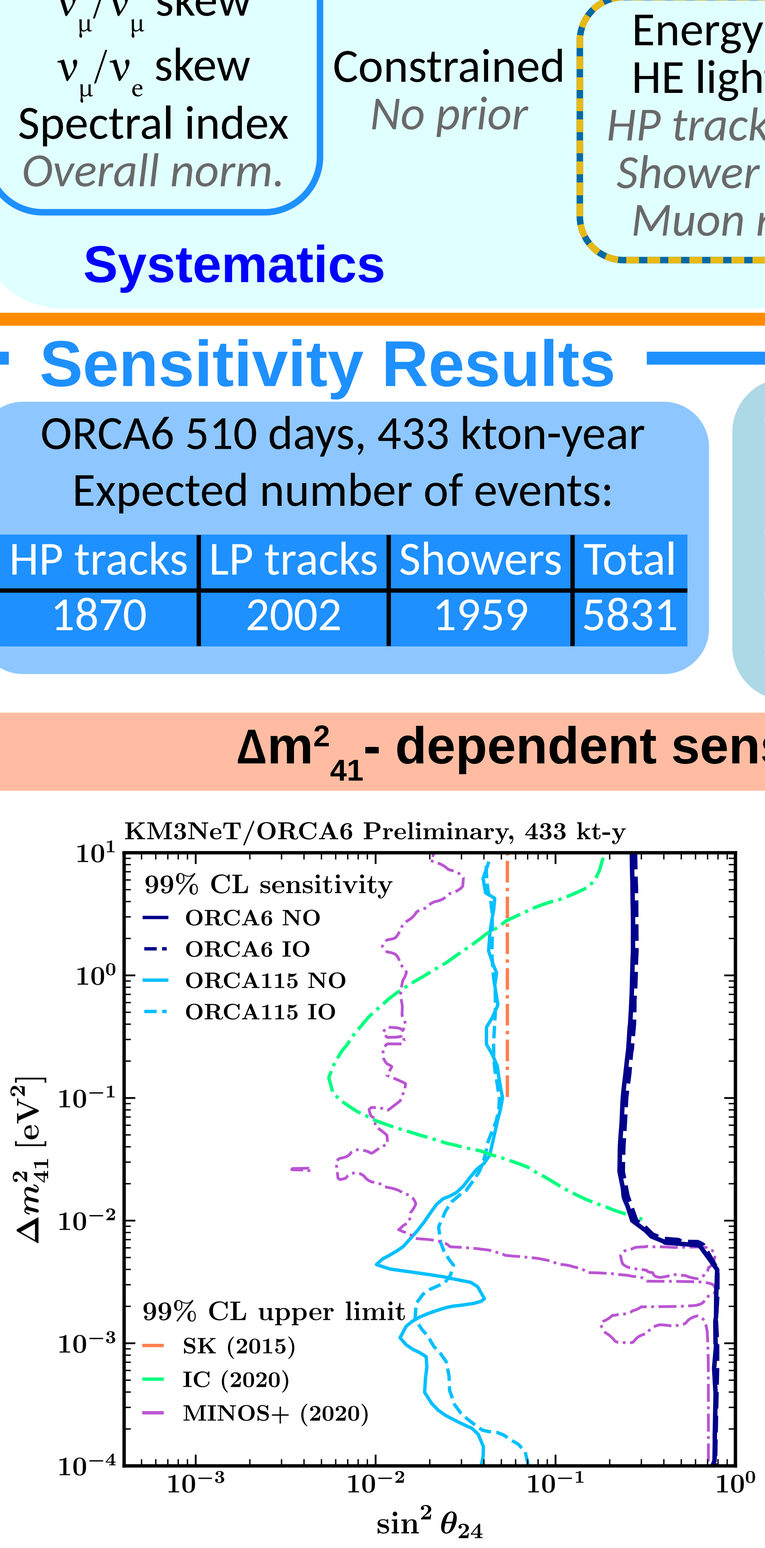
ORCA6 510 days, 433 kton-year
Expected number of events:

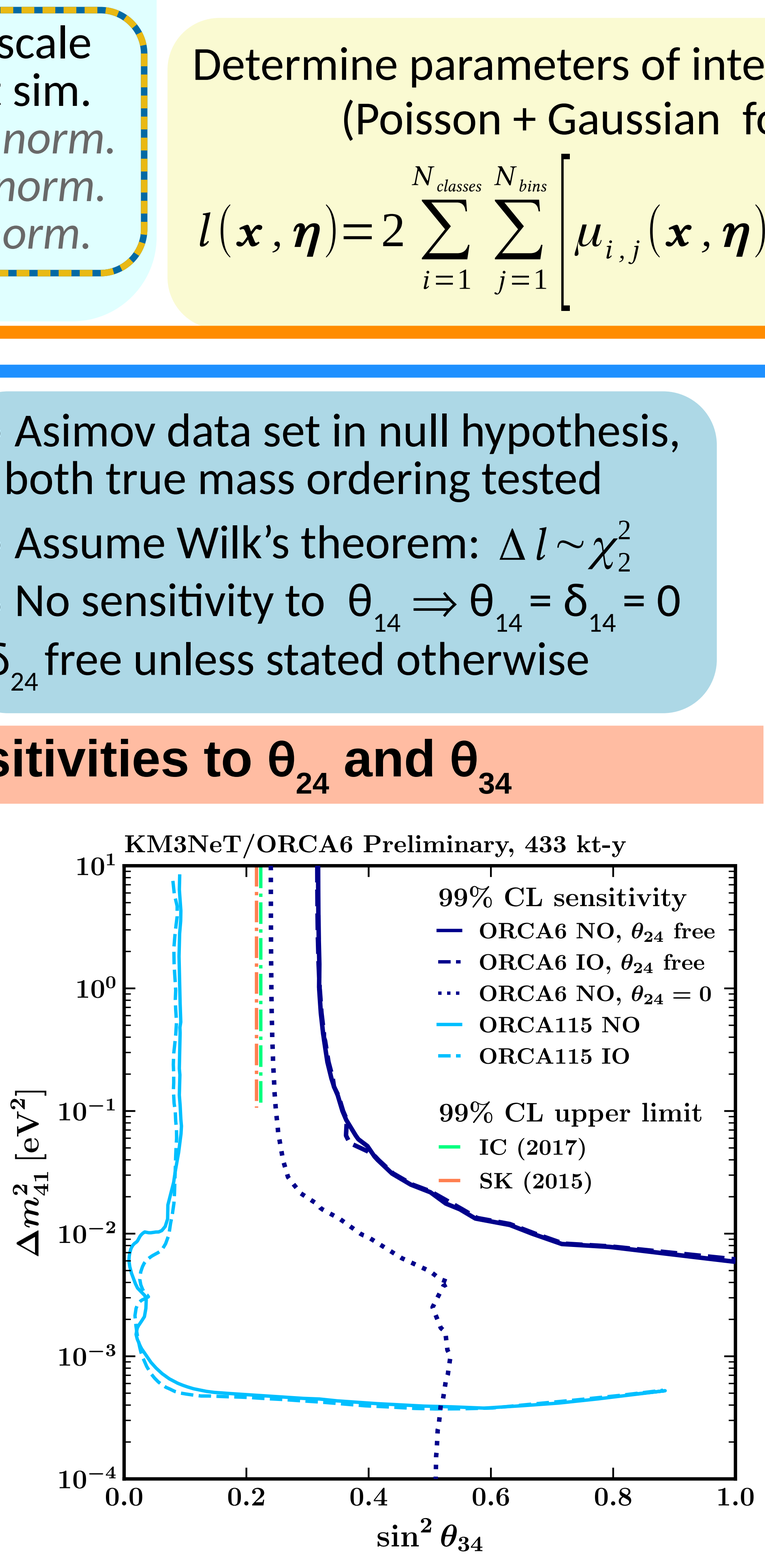
HP tracks	LP tracks	Showers	Total
1870	2002	1959	5831

- Asimov data set in null hypothesis, both true mass ordering tested
- Assume Wilk's theorem: $\Delta l \sim \chi^2_2$
- No sensitivity to $\theta_{14} \Rightarrow \theta_{14} = \delta_{14} = 0$

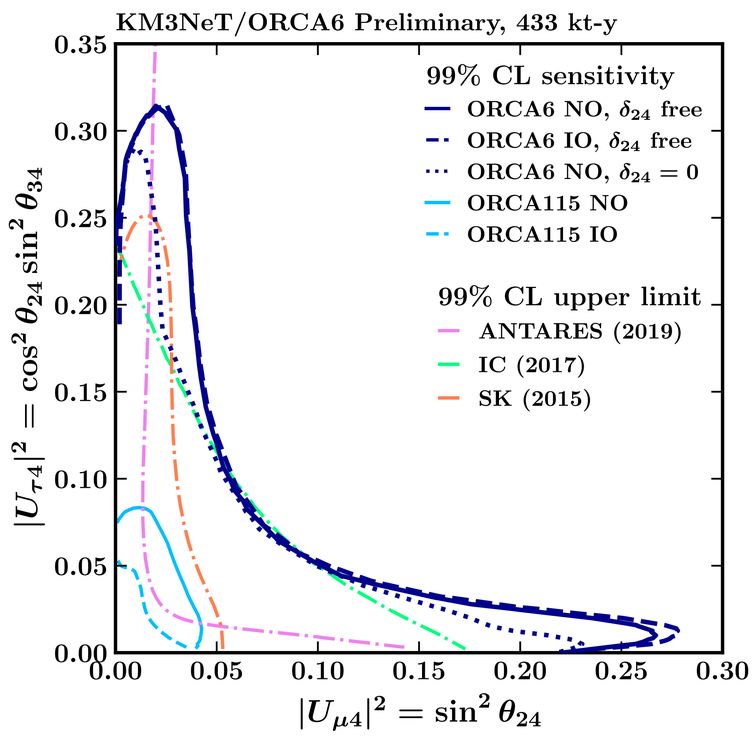
δ_{24} free unless stated otherwise

Δm^2_{41}- dependent sensitivities to θ_{24} and θ_{34}





Sensitivity to $U_{\mu 4}$ and $U_{\tau 4}$ with $\Delta m^2_{41} = 1\ eV^2$



Competitive for $U_{\tau 4}$

δ_{24} is important

ORCA6 not competitive for θ_{24}

Loss of sensitivity $<10^{-2}\ eV^2$

Close to SK and IC for θ_{34}

ORCA6 ≠ ORCA115 (21 Mt-y) ⇒ mostly from statistics

References

SK (2015): Phys. Rev. D 91, 052019
IC (2017): Phys. Rev. D 95, 112002
IC (2020): Phys. Rev. D 102, 052009
ANTARES (2019): J. HEP 2019, 113
MINOS+(2020): PRL 125, 071801
ORCA115: J. HEP 2021, 180 (2021)