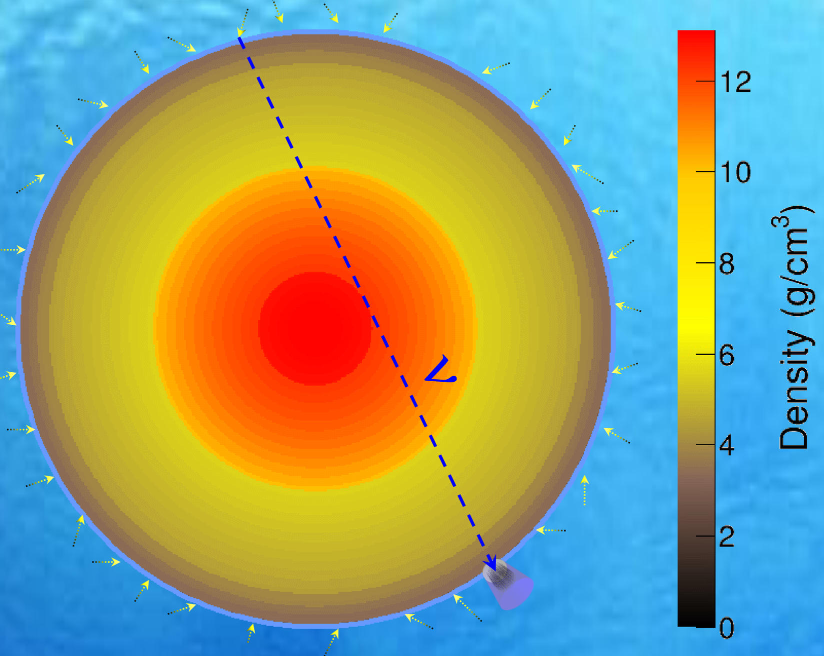
Probing new physics with atmospheric neutrinos at KM3NeT-ORCA

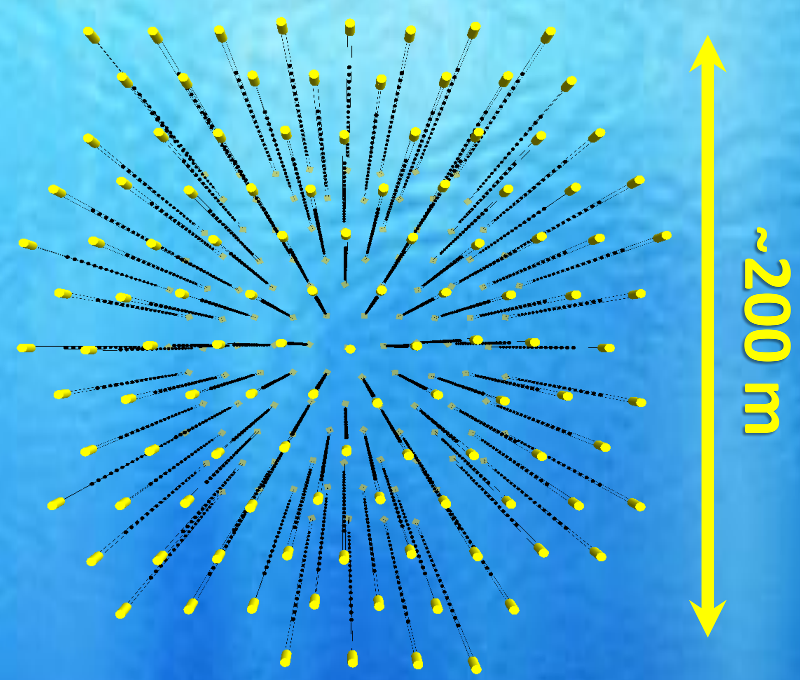
João A. B. Coelho for the KM3NeT Collaboration

APC Laboratory

jcoelho@apc.in2p3.fr

- Atmospheric neutrinos traverse large amounts of dense matter inside the earth.
- Matter effects can significantly alter the neutrino oscillation probabilities.
- A Mton size detector with good energy and angle resolution can take advantage of these substantial matter effects to look for physics beyond the Standard Model.





KM3Net DOM
31x3" PMTs

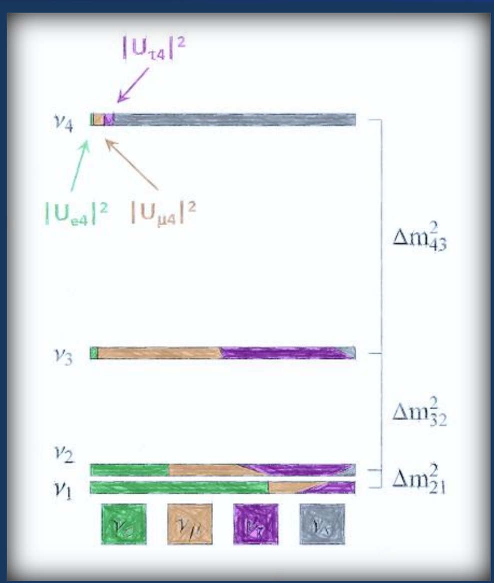
43 cm

- 5.7 Mton detector
- 115 lines
- 18 DOMs per line
- 31 PMTs per DOM

- 1 DOM ~ 3 kton equiv.
- 1 line ~ 50 kton equiv.

For Comparison:
- Super-K: 25 kton
- NOvA: 10 kton
- MINOS: 4 kton

Sterile Neutrinos



- Almost all neutrino oscillation data can be well described by a set of 3 neutrino mass eigenstates coupling to the 3 charged leptons according to the PMNS matrix.
- Some hints of a 4th neutrino mass eigenstate, with very weak coupling to the charged leptons have been found, most notably by the LSND [1] and MiniBooNE [2] collaborations.
- This new, eV scale, mass eigenstate changes the effective oscillation Hamiltonian and generates new resonant transition effects due to propagation in matter [3].

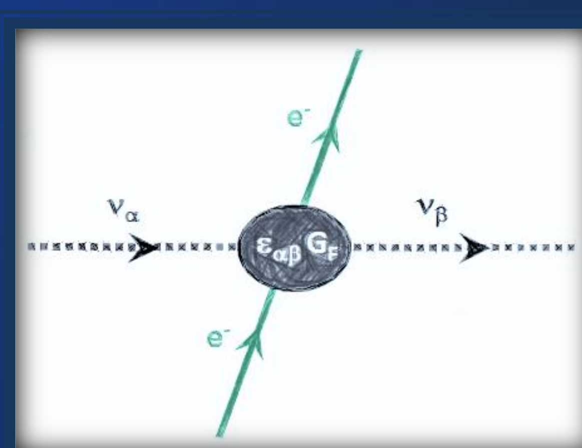
$$H_{eff} = U_S \begin{pmatrix} 0 & 0 & 0 & 0 & \cdots \\ 0 & \frac{\Delta m^2_{21}}{2E} & 0 & 0 & \cdots \\ 0 & 0 & \frac{\Delta m^2_{31}}{2E} & 0 & \cdots \\ 0 & 0 & 0 & \frac{\Delta m^2_{41}}{2E} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix} U_S^\dagger + \begin{pmatrix} V_e & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & V_n/2 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

$$U_S = U_{N-1,N} \cdots U_{34} U_{24}^{(c)} U_{14}^{(c)} U_{23} U_{13}^{(c)} U_{12}$$

[1] Phys. Rev. D 64, 112007 (2001)
[2] Phys. Rev. Lett. 110, 161801 (2013)
[3] JHEP 0712, 014 (2007)

Non-Standard Interactions

- Matter effects arise from coherent CC forward scattering of neutrinos on electrons in the earth's interior, introducing a flavour imbalance.
- If additional neutrino-electron interactions exist beyond the Standard Model, they may modify the neutrino effective propagation Hamiltonian.
- Strong bounds exist on some NSI couplings, but limits on ε_{ee}, $\varepsilon_{e\tau}$ and $\varepsilon_{\tau\tau}$ are currently larger than G_F [4].
- Atmospheric neutrinos provide an excellent probe of these NSI, since strong matter effects are expected to occur at the scale of the Fermi interaction.



$$\begin{pmatrix} |\epsilon_{ee}| < 4.2 & |\epsilon_{e\mu}| < 0.33 & |\epsilon_{e\tau}| < 3.0 \\ & |\epsilon_{\mu\mu}| < 0.07 & |\epsilon_{\mu\tau}| < 0.33 \\ & & |\epsilon_{\tau\tau}| < 21 \end{pmatrix}$$

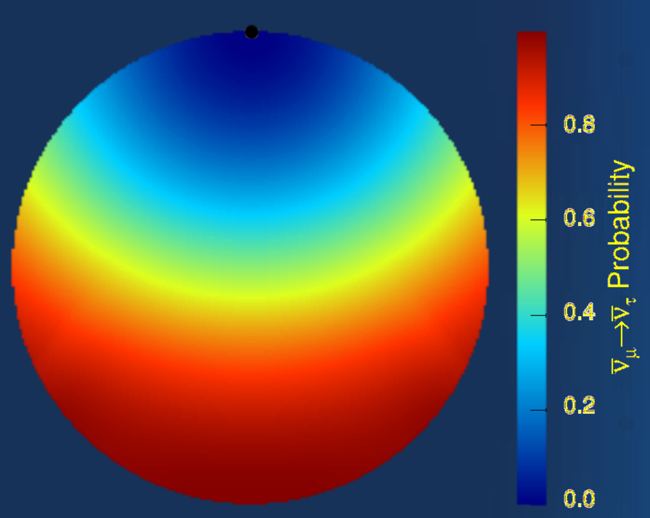
$$H_{eff} = U \begin{pmatrix} 0 & 0 & 0 \\ 0 & \frac{\Delta m^2_{21}}{2E} & 0 \\ 0 & 0 & \frac{\Delta m^2_{31}}{2E} \end{pmatrix} U^\dagger + V_e \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} &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

[4] Rept. Prog. Phys. 76, 044201 (2013)

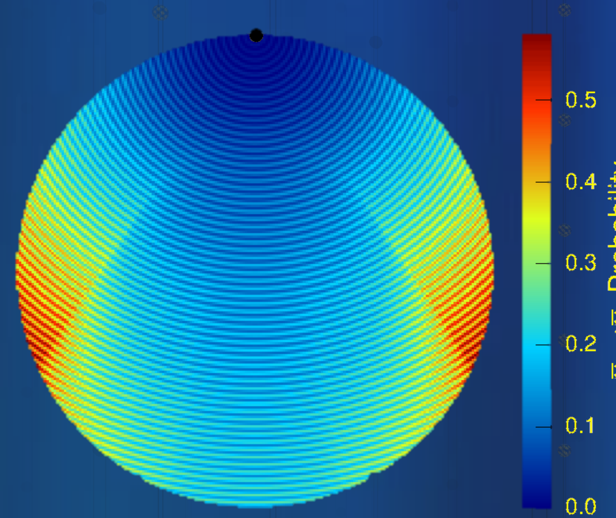
9 m vertical spacing

~20 m horizontal spacing

Standard Osc.



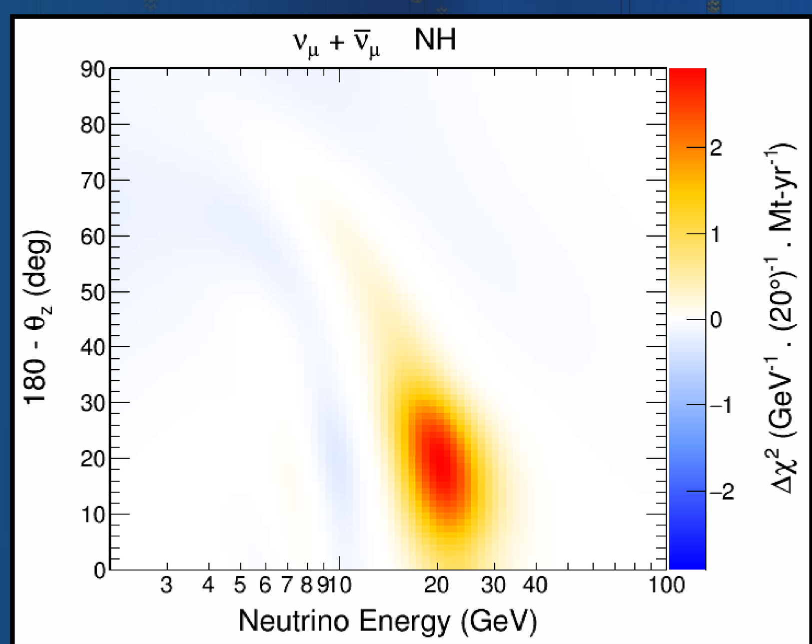
Sterile (3+1)



Examples:
- E = 24 GeV
- Δm^2_{41} = 0.3 eV²
- $|U_{e4}|^2$ = 0.04
- $|U_{\mu4}|^2$ = 0.02
- $|U_{\tau4}|^2$ = 0.18

Scan for animations

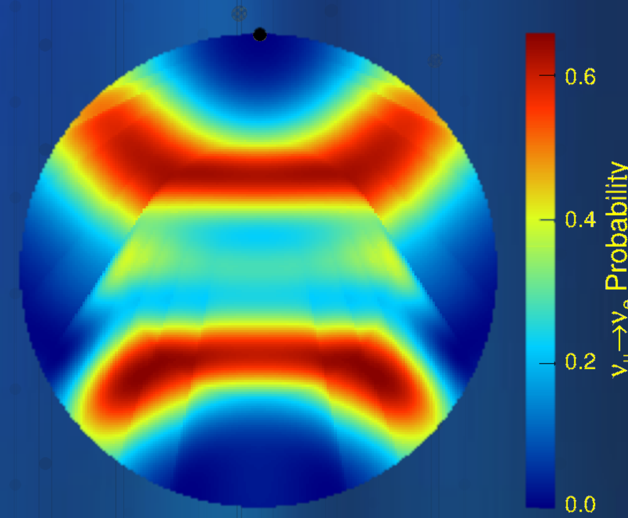
- In ORCA, the dominant effect of adding a eV scale sterile neutrino would be the suppression of ν_μ to ν_τ oscillation at ~20 GeV.
- This effect arises from an interplay of the CC and NC contributions to the matter potential.
- Resonant ν_μ to ν_τ transitions from 100 GeV to the TeV scale also occur.



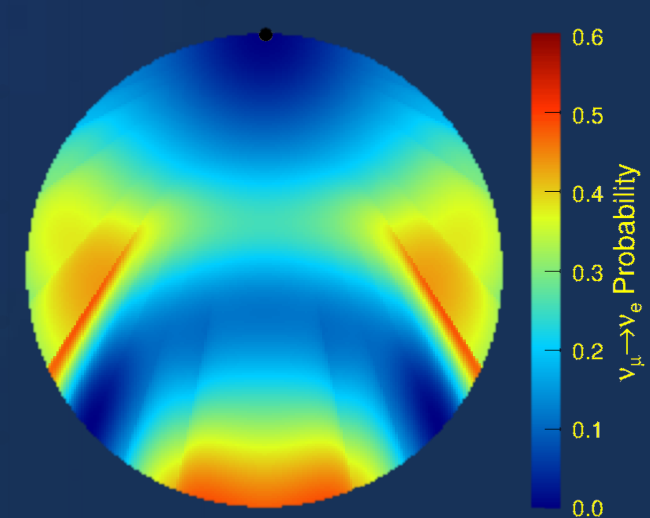
Examples:
- E = 5.3 GeV
- $\varepsilon_{e\tau}$ = 0.2
- $\varepsilon_{\tau\tau}$ = 0.04
- ε_{ee} = 0

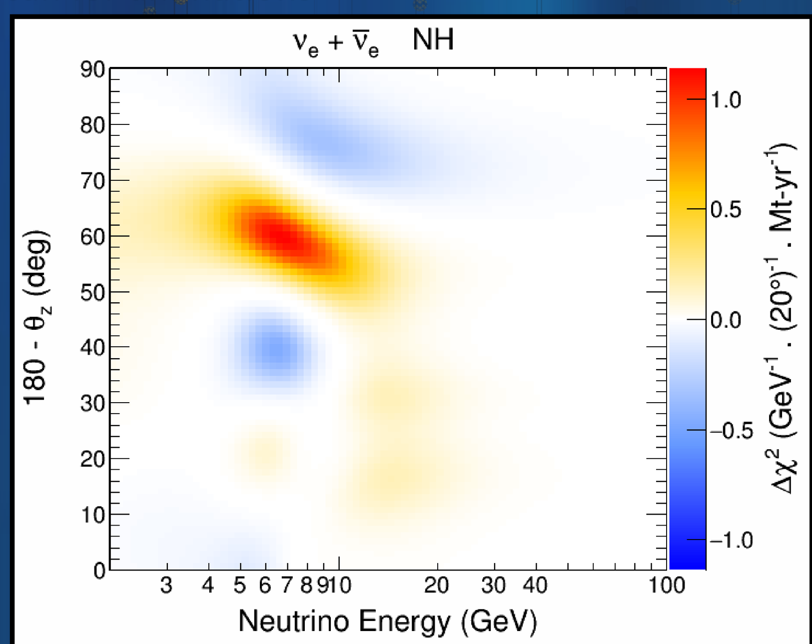
Scan for animations

Non-Std. Int.

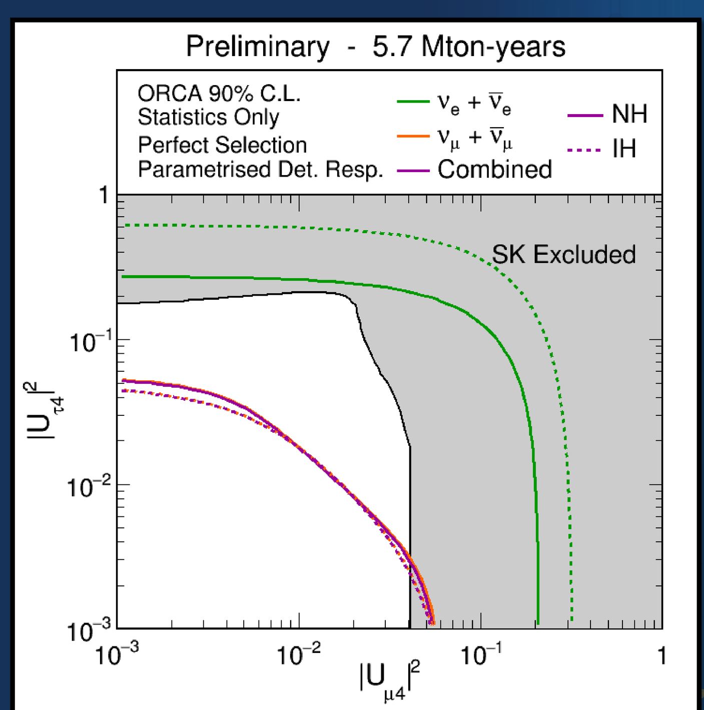


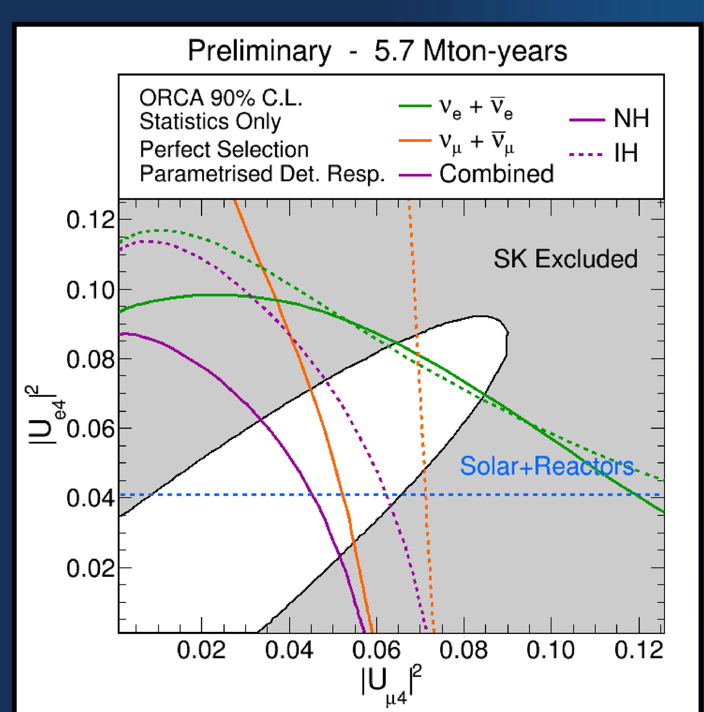
Standard Osc.





- ORCA can probe NSI by searching for changes in the oscillation pattern due to resonant transitions in both the ν_μ and ν_e channels.
- The dominant effects would occur in the same energy range used to study the neutrino mass hierarchy, but a different zenith angle dependence is expected.





- The suppression described above is strongly dependent on the $U_{\tau4}$ element of the mixing matrix.
- With 1 year of data, ORCA would be sensitive to $|U_{\tau4}|^2$ values 5x smaller than current limits set by Super-Kamiokande [5].

[5] Phys. Rev. D 91, 052019 (2015)

CAVEATS

- Sensitivities in this poster are based on a simplified analysis and do NOT make use of the full KM3NeT-ORCA MC simulation.
- Detector response has been parameterised to approximately match the performance from MC studies performed by the KM3NeT Collaboration [6].

[6] J. Phys. G: Nucl. Part. Phys. 43, 084001 (2016)

Read the KM3NeT Letter of Intent

- With 1 year of data, ORCA would be sensitive to NSI effects more than an order of magnitude smaller than their current limits.
- NSI can give rise to a very rich phenomenology and the interplay of the different NSI parameters needs to be studied carefully.
- Constraints from long-baseline experiments will pin down the vacuum oscillation parameters, which is essential for achieving ORCA's full potential.