Neutrino oscillation research with KM3NeT/ORCA

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On behalf of the KM3NeT collaboration
Nikhef, Amsterdam, Netherlands
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KM3NeT - large volume neutrino telescopes at the bottom of the Mediterranean.

Figure: Illustration of KM3NeT & $\nu_{\mu}$ detection.

Currently 4 ORCA DUs collecting data.
ORCA research programme

Sensitivity due to effects/baseline in Earth

- Neutrino mass ordering [1];
- $\nu_\tau$ appearance [1];
- Non-standard interactions [2];
- Sterile neutrinos [3];

Sensitivity not dependent on Earth properties

- Dark matter [4];
- Neutrinos from supernova collapses [5];
- Atmospheric muon flux [6];
- ...

[1] Neutrino mass ordering
[2] Non-standard interactions
[3] Sterile neutrinos
[4] Dark matter
[5] Neutrinos from supernova collapses
Figure: Illustration of two possible mass orderings [7].
NMO analysis: origin of the sensitivity

$\nu$-oscillation probabilities through Earth are sensitive to the NMO.

Figure: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ probability, depending on the NMO.
NMO analysis: origin of the sensitivity

$\nu$-oscillation probabilities through Earth are sensitive to the NMO.

- flavor (track$\leftrightarrow$shower), energy & direction reco of $\nu$ required.

![Graph showing $\nu_\mu \rightarrow \nu_\mu$, $\cos \theta = -1$](image)

**Figure:** $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ probability, depending on the NMO.
NMO analysis: origin of the sensitivity

$\nu$-oscillation probabilities through Earth are sensitive to the NMO.

- flavor (track↔shower), energy & direction reco of $\nu$ required.
- $\nu \rightarrow$ different expectation values in $E_\nu$ vs $\cos \theta_z$ histograms, depending on NMO.

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NMO analysis: origin of the sensitivity

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- flavor (track ↔ shower), energy & direction reco of \( \nu \) required.
- \( \nu \rightarrow \bar{\nu} \) different expectation values in \( E_\nu \) vs \( \cos \theta_z \) histograms, depending on NMO.

**Figure:** \( \bar{\nu}_\mu \rightarrow \bar{\nu}_\mu \) probability, depending on the NMO.

**Figure:** Example of expected track-like neutrino events after 3 years [8].
NMO analysis: sensitivity

Figure: KM3NeT/ORCA projected sensitivity to the NMO after 3 years of data taking.

Message: \( \sim 2.5 - 4.5 \sigma \) sensitivity for the NMO can be achieved after 3 years of data taking.
Early physics: intro

It will take time to reach 115-DU ORCA detector. What physics can be explored during construction? Investigate 7-DU ORCA 1-year Monte-Carlo projections for:
sensitivity to \( \nu_\tau \) oscillation parameters \( \Delta m^2 \) and \( \theta_{23} \);
sensitivity to \( \nu_\tau \) charged-current (CC) normalisation.
Early physics: intro

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- sensitivity to $\nu_\tau$ charged-current (CC) normalisation.
Early physics: $\Delta m^2_{32}$, $\theta_{23}$ with 7-DU ORCA after 1 year

Figure: 90% CL contours, reference map: a [9], b [10], c [11], d [12], e [13], f [8].

Message: potential input to global fits.
Early physics: $\nu_\tau$ CC norm.

$N_{\tau}^{cc}$ scales the expected nr. of $\nu_\tau$ CC interactions.
Early physics: $\nu_{{\tau}}$ CC norm.

$N_{{\tau}}^{cc}$ scales the expected nr. of $\nu_{{\tau}}$ CC interactions.

$N_{{\tau}}^{cc} \neq 1$ could indicate:

- Physics outside $3 \times 3$ $\nu$ oscillation.
- Deviations from the predicted cross-section for $\nu_{{\tau}}$ CC.
Early physics: $\nu_\tau$ CC norm. with 7-DU ORCA after 1 year

Figure: The sensitivity to $N_{\tau}^{cc}$ of the 7-DU ORCA, depending on the data accumulation period.

Message: early measurement of $N_{\tau}^{cc}$ is possible.
Summary & outlook

4 ORCA DUs collecting data, more lines to come!

\[ 4 \sigma \] sensitivity to the NMO can be achieved after 3 years of data taking with full KM3NeT/ORCA.

Early measurements of \((\Delta m^2_{32}, \theta_{23})\) and \(N_{\text{cc}} \tau\) are possible during construction phase.

Thank you for your attention!
Summary & outlook

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Thank you for your attention!
Appendix: parameter configuration

Configuration of oscillation and systematic parameters for Figs. 5 and 6. See [1] for more info.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>fixed/prior/free ORCA</th>
<th>fixed/prior/free sub-array</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta m_{21}^2$</td>
<td>fixed to $7.4 \cdot 10^{-5}$ eV$^2$</td>
<td>fixed to $7.4 \cdot 10^{-5}$ eV$^2$</td>
</tr>
<tr>
<td>$\sin^2 \theta_{12}$</td>
<td>fixed to 33.62°</td>
<td>fixed to 33.62°</td>
</tr>
<tr>
<td>$\sin^2 \theta_{13}$</td>
<td>8.54°, 0.15° prior (NO), 8.58°, 0.14° prior (IO)</td>
<td>fixed to 8.54°</td>
</tr>
<tr>
<td>$\delta_{CP}$</td>
<td>free</td>
<td>fixed to 234°</td>
</tr>
<tr>
<td>flux $\nu_\mu \leftrightarrow \bar{\nu}_\mu$ skew</td>
<td>10% prior</td>
<td>10% prior</td>
</tr>
<tr>
<td>flux $\nu_e \leftrightarrow \bar{\nu}_e$ skew</td>
<td>10% prior</td>
<td>10% prior</td>
</tr>
<tr>
<td>flux $\nu_\mu \leftrightarrow \nu_e$ skew</td>
<td>10% prior</td>
<td>10% prior</td>
</tr>
<tr>
<td>flux $E$-tilt</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>flux cos $\theta$-tilt</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>NC cross-sec. norm.</td>
<td>10% prior</td>
<td>10% prior</td>
</tr>
<tr>
<td>norm. track-like</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>norm. shower-like</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>norm. middle sample</td>
<td>free</td>
<td>free</td>
</tr>
</tbody>
</table>
Appendix: bibliography I


Appendix: bibliography II


