KM3NeT-ORCA for neutrino oscillation physics

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Outline

1. Introduction to KM3NeT
2. NMO analysis
3. ORCA 1-line results
4. Deployment
5. Summary & outlook
Introduction to KM3NeT

KM3NeT - large volume neutrino telescopes at the bottom of the Mediterranean.

- **ARCA** - high energy $\nu$ astronomy.
- **ORCA** - oscillation research with atm. $\nu$.

Images from [1, 2].
Figure: Illustration of $\nu_\mu$ and $\nu_e$ event topologies [3].
Introduction to KM3Net

Rich scientific programme in ORCA:

1. Neutrino mass ordering (this talk);
2. $\nu_T$ appearance;
3. Non-standard interactions;
4. Sterile neutrinos;
5. Dark matter;
6. Neutrinos from supernova collapses;
8. ...

Most of these topics probe the boundaries of the Standard Model.
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Most of these topics probe the boundaries of the Standard Model. **Plus HE $\nu$-physics with ARCA!**
- $\nu$ oscillations mean $\nu_1 \neq \nu_2 \neq \nu_3$.
- Current experiments have determined $\Delta m^2_{21}$ and $\Delta m^2_{31}$, but not mass-ordering.

Figure: Illustration of two possible mass orderings [1].
NMO analysis: intro

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2. Osc. patterns in \( (E_\nu, L, \rho_e) \equiv (E_\nu, \cos \theta) \) are sensitive to the sign of \( \Delta m^2_{31} \).

\[ \nu_\mu + \bar{\nu}_\mu, \text{ normal ordering} \]

\[ \cos \theta_{true}, \nu_\mu + \bar{\nu}_\mu, \text{ inverse ordering} \]

\[ (\text{NO} - \text{IO})/\text{NO} \]

\[ \text{Asymmetry} \]

\[ E_\nu^{true} \]
NMO analysis: how-to

NMO measurement how-to:

1. Put lines in water and get data.
2. Separate events to track-like and shower-like.
3. Reconstruct $E, \cos\theta$.
4. Fit a model to data to establish $\Delta m_{31}^2$. 

Diagrams showing tracks and showers with reconstructed $\nu$, $\bar{\nu}$ distributions.
NMO analysis: PID & reco

Examples of PID classification efficiency and energy reconstruction.

**Figure:** Fraction of particles classified as tracks [3, 4].

**Figure:** Energy reconstruction of shower events [5].
NMO analysis: the model

Flux → Atm. flux \( \frac{1}{m^2 \cdot y} \)

+Oscillation → Osc. flux \( \frac{1}{m^2 \cdot y} \)

+Cross-sec. → Interacted \( \frac{1}{\text{MTon} \cdot y} \)

+Eff. mass → Detected \( \frac{1}{y} \)

Leads to a predicted number of events for each \( \nu_{e, \mu, \tau}^{\text{NC/CC}} \) in \( E^\text{true} \), \( \cos \theta^\text{true} \) bins.

Effective mass curve from [3].
NMO analysis: the model

Final step by detector response:

\[ E_{f,i}^{\text{true}}, \cos \theta_{f,i}^{\text{true}} \rightarrow E_{c}^{\text{reco}}, \cos \theta_{c}^{\text{reco}}, \]  

(1)

where \( f \) = flavor, \( i \) = NC/CC, \( c \) = reco class (track or shower).
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NMO analysis: the model

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**Figure:** Expectation values for tracks, 3 years, NO [3].

**Figure:** Expectation values for showers, 3 years, NO [3].
Currently, we have the model but no data.

Visualise the sensitivity from expectation values for NO & IO.

\[
\text{signed } \chi^2 = \frac{(\text{NO} - \text{IO})|\text{NO} - \text{IO}|}{\text{NO}}.
\]

**Figure:** Signed $\chi^2$ for tracks, 3 years [3].

**Figure:** Signed $\chi^2$ for showers, 3 years [3].
NMO analysis: sensitivity estimation

One method: Log-likelihood ratio ratio LLR:

\[ TS = -2 \ln \frac{\max \mathcal{L}_{\text{NO}}}{\max \mathcal{L}_{\text{IO}}} = \chi^2_{\text{min}}(\text{NO}) - \chi^2_{\text{min}}(\text{IO}). \]
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Second method: \textit{Asimov} method [3].
NMO analysis: sensitivity estimation

Sensitivities to NMO with the two methods for two mass orderings.

**Figure:** Sensitivity to NMO in 3 years, normal ordering [3].

**Figure:** Sensitivity to NMO in 3 years, inverse ordering [3].
ORCA 1-line results: neutrino analysis

Neutrino candidates from 1 ORCA line.

Figure: Comparison of Monte-Carlo end detected events with 82 days live-time with 1 ORCA line. Analysis by D. Zaborov.
Figure: Atm. muon rate depth dependence measured by DOM multiplicities. Analysis by L. Massimiliano.
Several new lines will be deployed in the immediate future.

Interesting physics can be done already with a few lines!

Figure: Illustration of the deployment mechanism [2].

https://www.youtube.com/watch?v=omlFkdCkbYk
Summary & outlook

1. Main concepts for several analyses in place.
2. Exciting period of fast development: expectation for new lines and new sea data in the immediate future!
3. ORCA future prospects talks by Jannik and Dmitry.

Don't forget: we will also have the big ARCA detector!

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Sources:


