Measuring tau neutrinos in ORCA

Strong experimental tests of the unitarity of the 3-flavour PMNS mixing matrix are very challenging, as direct observations of tau neutrino oscillations are difficult. A statistically highly-significant detection of tau neutrinos from $\nu_e \to \nu_\tau$ oscillations of atmospheric neutrinos could make an important contribution to further constrain the tau-related matrix elements. The discovery of a non-unitary 3-$\nu$ mixing would be a clear sign for new physics, e.g. new types of neutrino interactions or the presence of sterile neutrinos. ORCA is a megaton-sized water Cherenkov detector for GeV-energy atmospheric neutrinos under construction in the Mediterranean Sea. About 3000 tau neutrinos per year, generated in flavour oscillations, will be detected in ORCA on a statistical basis. Tau neutrino interactions in ORCA result dominantly in events characterized by photon emission from particle cascades located close to the interaction vertex (shower-like events), while track-like muon events contribute <20%. Strong event-type identification is thus essential to quantify the tau-induced shower-like events.

- Significance map for tau neutrino appearance in the atmospheric neutrino flux after traversing Earth
- Most of the tau neutrino appearance signal is expected at 10 – 30 GeV reconstructed neutrino energy and with up-going direction

Event selection
- Well-reconstructed events with reconstructed vertex close to or inside the instrumented volume
- Random Decision Forest classifier allows suppression of pure noise and atmospheric muon contamination to 3%-level with a neutrino efficiency of ~95%

Fitting procedure
- Using parametrised detector response obtained from simulated data
- Simultaneous fit of shower- and track-like sample
- Asimov dataset approach with $\Delta \chi^2$ fit in the reconstructed energy and zenith-angle plane

Expected sensitivity
Normalisation = 1 indicates PMNS assuming unitary mixing
Non-appearance ($\varnothing$) exclusion at 50-level possible within two months of operation with full ORCA detector
Fit result robust against $\delta_{23}$ and assumed mass ordering
→ expect first physics result during construction phase
In case of significant deviation from unitary mixing: possibility to exclude unitarity assumption in the longer term
Very competitive sensitivity of ORCA: 20% constraint at 3$\sigma$ on tau normalisation after one year

Systematics included in fit
- Oscillation parameters: $\theta_{13}$, $\theta_{23}$, $\Delta M^2$, $\delta_{CP}$
- Flux / cross section: $\nu_{\tau}$/anti-$\nu_{\tau}$ ratio, spectral index
- Normalisation terms: $\nu_\tau$-CC, $\nu_e$-CC, NC
- Assumed true oscillation parameters: $\theta_{13}=8.42^\circ$, $\delta_{CP}=45^\circ$, others taken from PDG 2014

Deep Learning
- OrcaNet [1]: event-type classifier to distinguish shower-like and track-like events, based on deep Convolutional Neural Networks
- Deep Learning methods self-learn relevant discriminating information
- OrcaNet optimisation in progress, performance already comparable to Random Decision Forest approach
- Comparison via track-vs-shower

Separability metric $S(E)$ using muon and electron neutrino events.

Metric defined as:

$$S(E) = 1 - c = 1 - \frac{\sum p_{\nu_\tau}^\nu - p_{\nu_e}^\nu}{\sum (p_{\nu_\tau}^\nu)^2 \cdot (p_{\nu_e}^\nu)^2}$$