ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Tau neutrino appearance with KM3NeT / ORCA

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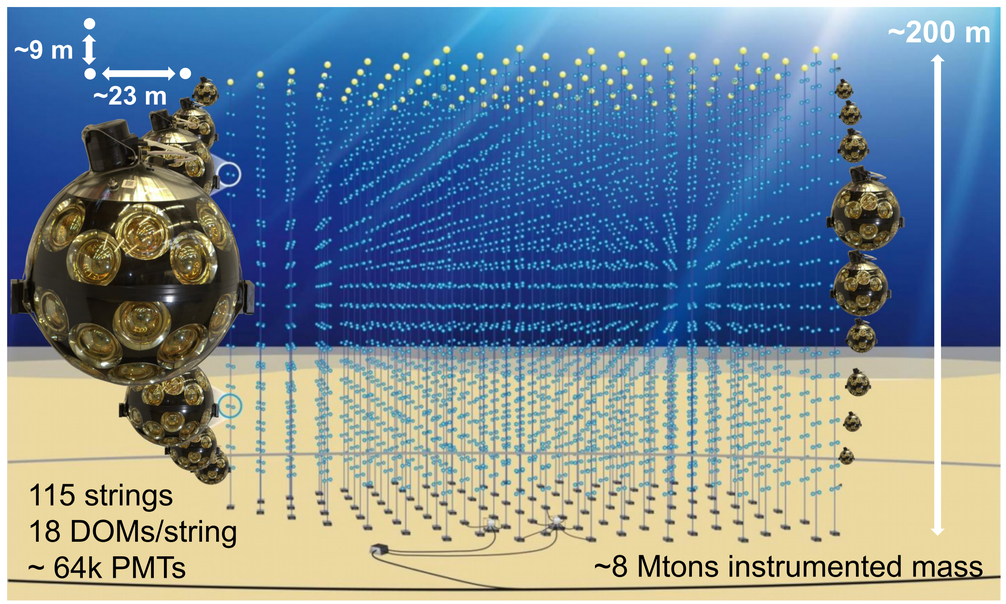
Measuring tau neutrinos in ORCA

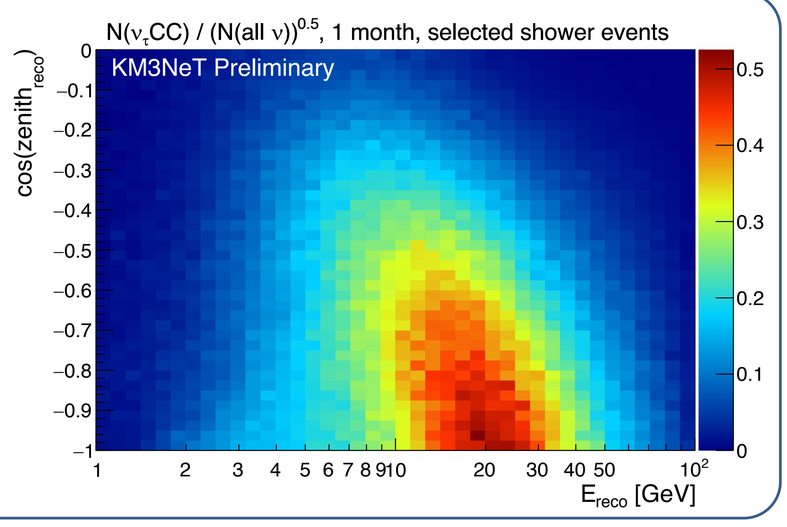
Strong experimental tests of the unitarity of the 3-flavour PMNS mixing matrix are very challenging, as direct observations of tau neutrino oscillations are difficult. A statistically highly-significant detection of tau neutrinos from $\nu_\mu \rightarrow \nu_\tau$ oscillations of atmospheric neutrinos could make an important contribution to further constrain the tau-related matrix elements. The discovery of a non-unitary 3ν-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.

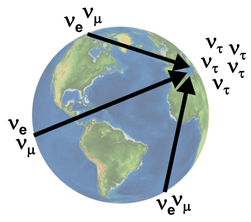
ORCA: a water Cherenkov detector in the deep sea



Letter of Intent for KM3NeT 2.0, J.Phys. G43 (2016) no.8, 084001

- 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

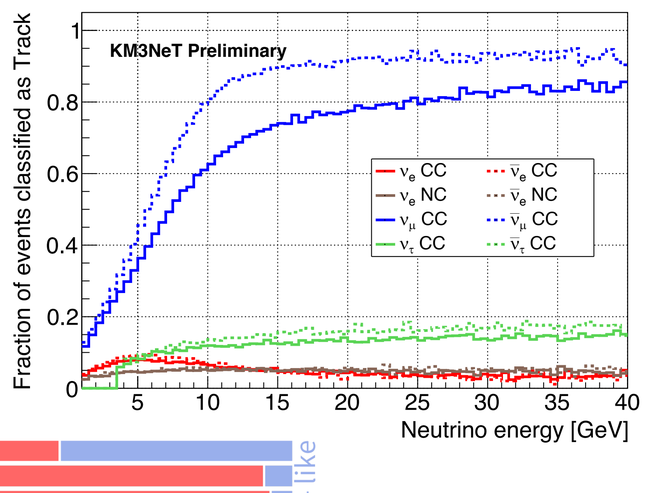


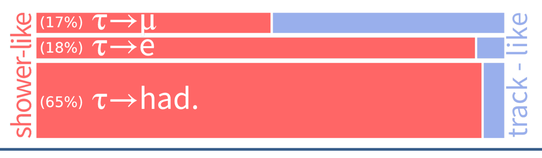


Random Decision Forest

- Shallow Learning approach with decision trees trained on random subsets of events and high-level reconstruction variables
- Events classified as track-like and shower-like based on majority vote
- Threshold value for separation optimised to obtain maximum sensitivity

→ ν_τ-events predominantly classified as shower-like

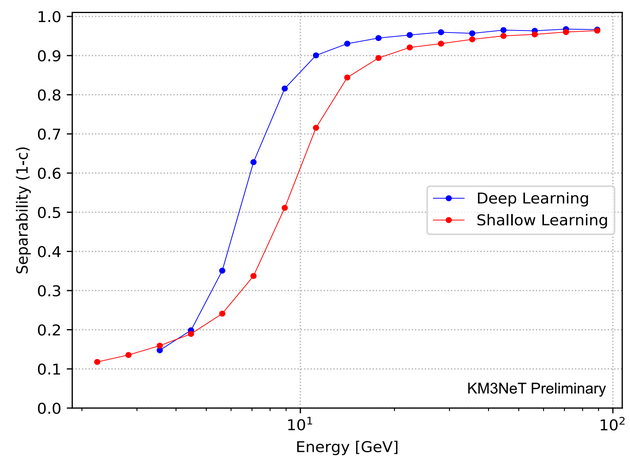


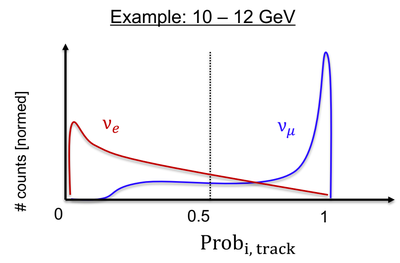


Deep Learning

- 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:

$$S(E) = 1 - c = 1 - \frac{\sum_i P^{\nu_\mu}_{i,\,\mathrm{track}}(E) \cdot P^{\nu_e}_{i,\,\mathrm{track}}(E)}{\sqrt{\sum_i (P^{\nu_\mu}_{i,\,\mathrm{track}}(E))^2 \cdot \sum_i (P^{\nu_e}_{i,\,\mathrm{track}}(E))^2}}$$





[1] http://github.com/ViaFerrata/OrcaNet

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-sample
- Asimov dataset approach with $\Delta\chi^2$ fit in the reconstructed energy and zenith-angle plane

Systematics included in fit

- Oscillation parameters: θ_{13}, θ_{23}, ΔM^2, δ_{CP}
- Flux / cross section: ν/anti-ν ratio, spectral index
- Normalisation terms: ν_μ-CC, ν_e-CC, NC

- Assumed true oscillation parameters: θ_{13}=8.42°, θ_{23}=45°, others taken from PDG 2014

Expected sensitivity

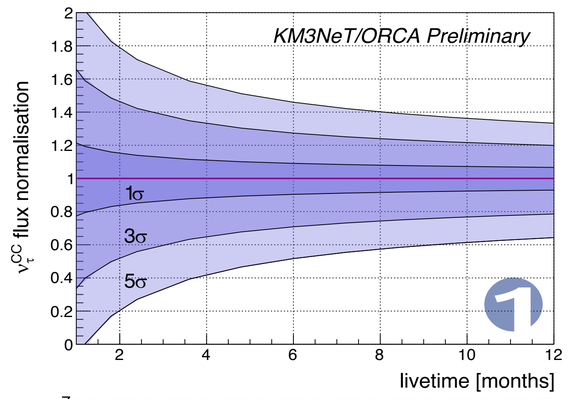
Normalisation = **1** indicates PMNS assuming unitary mixing

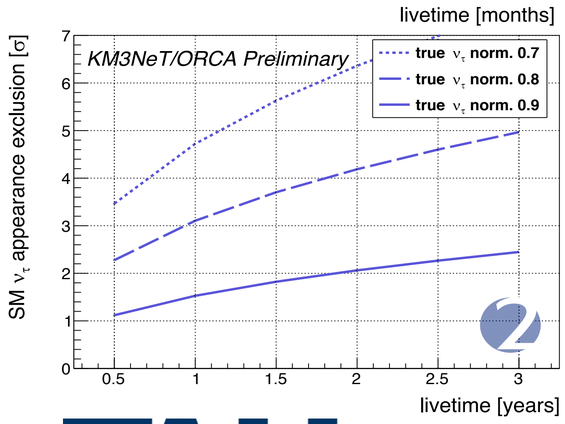
1. Non-appearance (=0) exclusion at 5σ-level possible within two months of operation with full ORCA detector

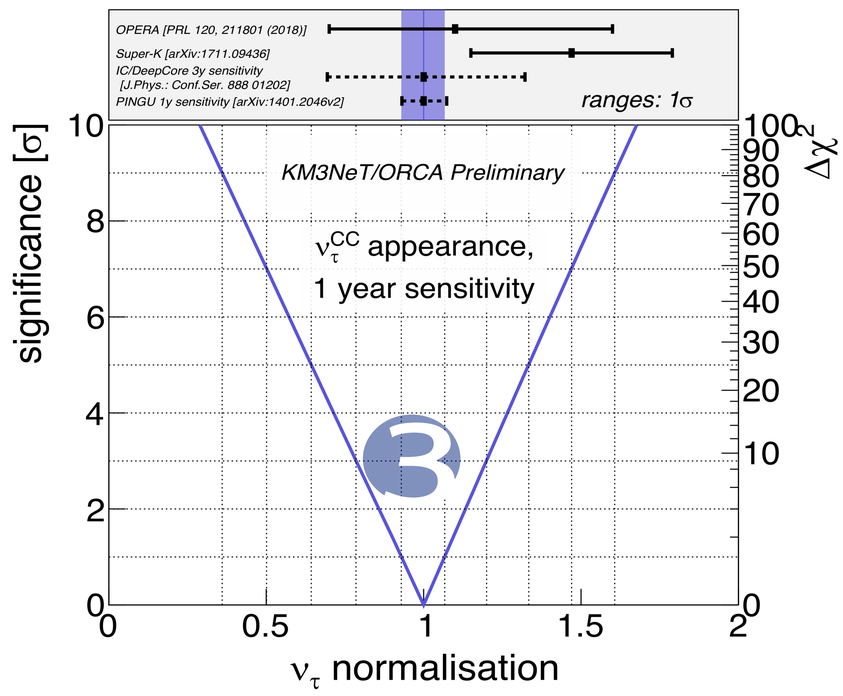
   Fit result robust against θ_{23} and assumed mass ordering → expect first physics result during construction phase

2. In case of significant deviation from unitary mixing: possibility to exclude unitarity assumption in the longer term

3. Very competitive sensitivity of ORCA: 20% constraint at 3σ on tau normalisation after one year







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