# TAU NEUTRINO APPEARANCE: AN EXAMPLE OF NEUTRINO OSCILLATION ANALYSIS

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# Introduction

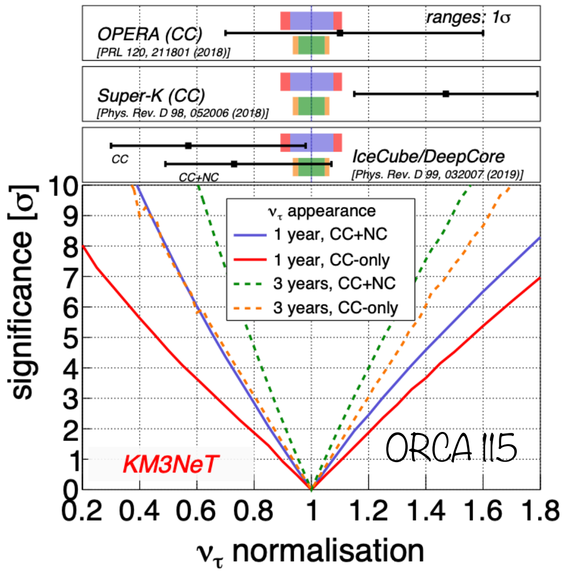
- Tau neutrino appearance search in KM3NeT/ORCA is currently carried out by three institutions: CPPM (Luc C., Chiara L., Mathieu P.-T.), ECAP (Nicole G., Rodrigo G.-R., Lukas H.), and NIKHEF (Bouke J.)

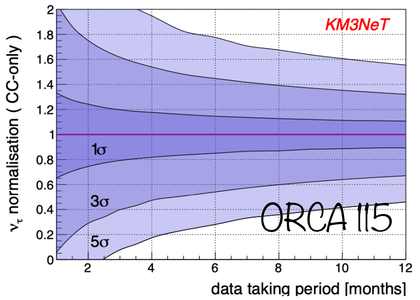
  ❍ two scenarios:

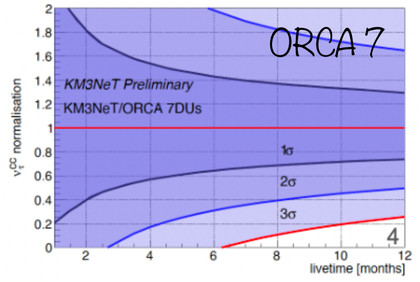
  1. same fit approach as proposed in NMO paper (excess of $\nu_\tau$ in shower sample) Short-term goal (ICRC 23)

  2. identify $\nu_\tau$ in the shower sample

- in full KM3NeT/ORCA, 3000 $\nu_\tau$/year are expected from the oscillation of pure $\nu_\mu$ and $\nu_e$ atmospheric neutrino flux crossing the earth
- preliminary studies in ORCA 7 showed still a good sensitivity



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  ❍ two scenarios:

  1. same fit approach as proposed in NMO paper (excess of $\nu_\tau$ in shower sample)
  2. identify $\nu_\tau$ in the shower sample — Medium/long-term goal (end 2023-24)

- improvement in sample(s) purity and fit strategy (systematics, impact on event selection and classification)
- extrapolate sensitivity toward larger intermediate geometries

# From the selection to the fit

- Three main topics under development and that can be improved:

**PID**
(more MC info and define/identify new features for better shower-like and $\nu_\tau$ events identification)

**sample purity**
(both shower-like and $\nu_\tau$ sample: improved pre-selection and selection)

**$\nu_\tau$ normalization fit**
(sensitivity in ORCA-6 geometry, extrapolation toward larger intermediate geometries, and update full-ORCA results)

❍ definition of **variables** and **features** for **particles identification (PID)** > stored in aanet and DST files

> **km3net-dataformat**, two **maximum likelihood algorithms** provide the **reconstruction** of each event:

**JGandalf** and **JShowerFit** respectively optimized for track-like and shower-like events (only recently, JShF included in the full ORCA6 production)

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❍ **pre-selection**: so far, **cut-based** approach on **DST** variables to reject downing and anti-noise events

> pre-selection may be modified depending on the specific analysis

❍ **event classification**: **paramPID** (Boosted Decision Tree) + other neural network, **NN**, and **GNN** techniques as an alternative

❍ **sample selection**: cutting on **muon** and **track scores** (by paramPID) + Random Search Grid (RGS) alternative

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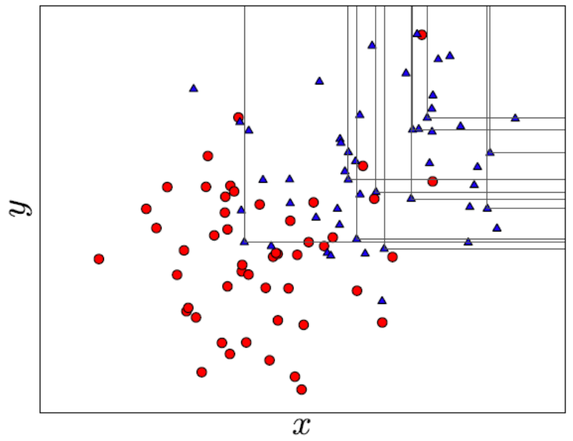
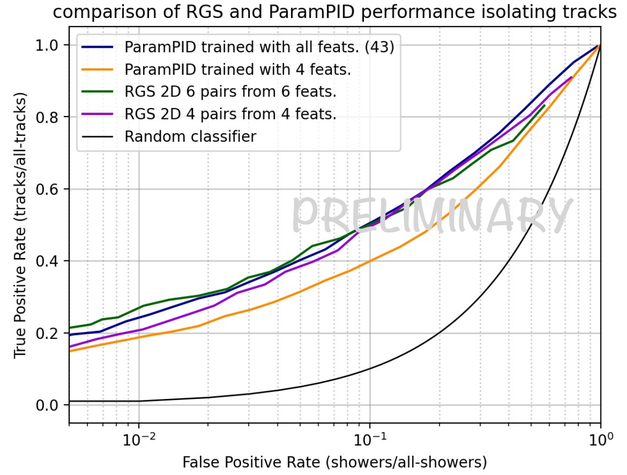
❍ step 1: **pre-selection**, **classification**, and **selection** from standard neutrino oscillation analysis

+ using **RGS** (optimized cut-based approach to be more effective in the signal region)



Credits: arXiv:1706.09907v2

- training not needed
- each event can be a cut
- with only a few variables even better performance than paramPID



# From the selection to the fit: current approach and further improvements

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❍ step 2: specifically for the tau-appearance analysis, **improve the pre-selection** (not to reject too many shower-candidates), **re-train paramPID** (ideally with more features), compare with **RGS selection**, identify a **more pure shower-sample**

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❍ identify common figures of merit for comparing the performance of different selection methods

❍ quantify the purity of the final sample

❍ in order to compare different samples and kinds of fit software, a common "summary"-file should be produced (same structure, independently from the selection techniques, and usable for both fit softwares)

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❍ SWIM and paramNMH as two alternatives software for the fit in this study

- SWIM uses MC simulation for building the detector response matrix

- paramNMH uses a parametrization of the detector response

❍ MONA was used in the first ORCA6 results, but not considered in this analysis

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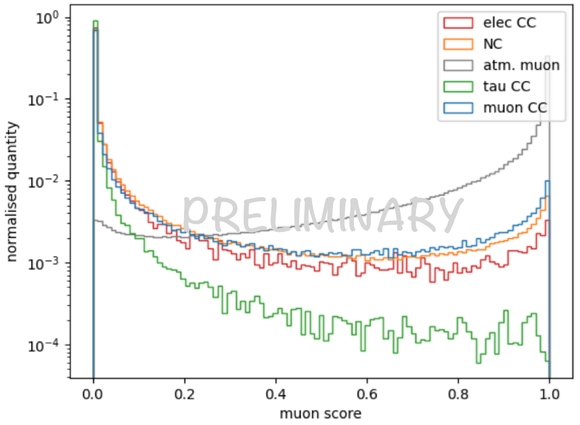
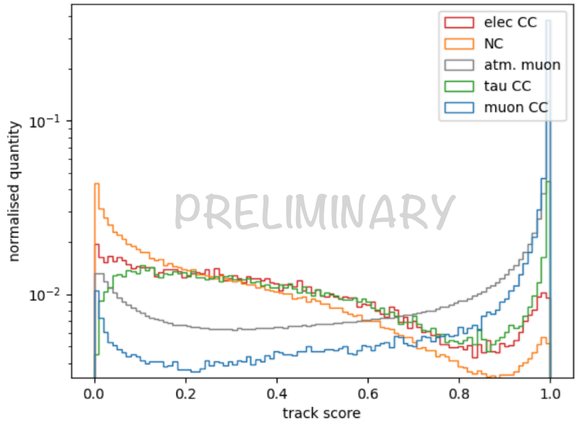
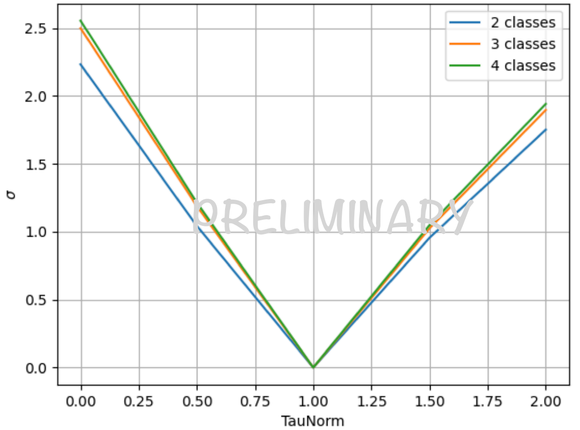
❍ <u>step 1</u>: selection from standard analysis and SWIM has been used for the first preliminary result on the $\nu_\tau$ normalization fit



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- step 1: selection from standard analysis and SWIM has been used for the first preliminary result on the $\nu_\tau$ normalization fit
- step 2: compare with the selection from the RGS method
- step 3: compare with paramNMH fit
- step 4: have the two software as cross-check one of the other
- step 5: improve the treatment of the systematics in parallel with the study for main neutrino oscillation anal.

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- a new full-ORCA MC simulation has been produced with more information (enabled in gSeaGen) useful to define **new features** (in JPP) more suitable to identify shower-like and/or $\nu_\tau$ events (lowE neutrinos, mass production approach instead of run-by-run so as to be faster - 4 clusters at CNAF and IFIC - 5 people)
- **GOAL**: develop a method valid also for intermediate geometries

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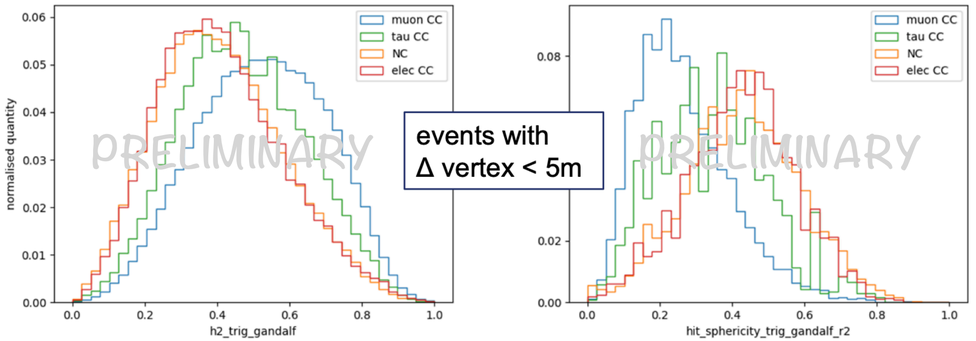
❍ preliminary studies defining **sphericity** and **planarity** of the event

❍ a first attempt of implementation in ORCA6 (v6) has not been successful yet (to be updated with ORCA6-v7 production)



# Summary

## A few thoughts...

- Current analysis strategies have reached already robust performance for the first results in ORCA-6 but a there is still room for improvement:
  - ❍ JShowerFit was only recently included in the full data sample > larger statistics, improved pre-selection and selection (using different techniques)
  - ❍ SWIM has many contributors and maintainers > paramNMH can be applied to data, both software can be thought of as complementary in cross-checks and for sensitivity studies toward larger geometries
  - ❍ Simplify the MC production can be helpful also in studies related to the treatment of systematics
  - ❍ …. etc

**...let's discuss!**