1 Introduction

This session is meant to familiarize you some with the *OscProb* software package, which allows you to straight forwardly explore the phase space of oscillation patterns with varying settings (different travel lengths, energies, oscillation parameters), and can with that help for direct insights e.g. for the comparison of different experiments. A doxygen is available here:
https://joaoabcoelho.github.io/OscProb/doxygen/html/annotated.html

We suggest to start your exploring with the following:

1) Several neutrino experiments are making use of the abundant atmospheric neutrinos to measure the oscillation patterns of neutrinos passing through the Earth.
a) Check the different patterns of neutrinos and antineutrinos for the different mass orderings and compare to the typical energy range of neutrino telescopes. Note also that neutrino telescopes can not distinguish between neutrinos and antineutrinos, is this a problem for the measurement of the mass ordering?
b) Vary θ_{13} in order to understand the impact on the discrimination of the mass ordering using atmospheric neutrinos (how is the oscillation pattern affected by setting $\theta_{13} = 0deg, 10deg, 30deg$?).

2) Compare the difference of the oscillation patterns for few of potential beamlines for neutrino experiments. A neutrino beam from Protvino to the KM3NeT/ORCA site has been proposed (arXiv 1902.06083) to allow the measurement of δ_{CP}. Would you consider it equally good to send the beam to Lake Baikal (where the GVD Baikal neutrino telescope is under construction)? What would the oscillation pattern look like for a baseline from FermiLab to IceCube?

3) The relevant observables for neutrino telescopes to study oscillations are the neutrino energy and direction. Create a 2D histogram showing the oscillation probabilities for atmospheric neutrinos as function of energy and zenith.

2 Setting up the routines

You can log in to the interactive node of stoomboot via:

ssh -Y stbc-i1.nikhef.nl

You can then load the require settings via:

bash
source /project/antares/public_student_software/env_scripts/env_topicallectures2019

Make your own directory in your home and copy the routines from $OSCPROBDIR/tutorial/

mkdir osc
cd osc
cp $OSCPROBDIR/tutorial/ .*

You can now start using the routines. E.g. you can look at the oscillation probabilities for electron and muon neutrinos on their way through Earth using the routine 'DrawFixedCosT.C', for which the arguments will define
- direction you are looking at (provide cos(zenith)), which determines the path through Earth
- neutrino or antineutrino

In root first load the OscProb library and then run the routine

root.exe
gSystem->Load("/project/antares/public_student_software/OscProb/libOscProb.so")
.x DrawFixedCosT.C(-0.8,"true")

You can then edit the code of DrawFixedCosT.C (with your favorite editor) to change the oscillation parameters. In order to change θ_{13} or δ_{CP} you can add lines to the code (e.g. after ' p.SetIsNuBar(isNuBar)).

p.SetAngle(1,3,theta13_in_radian)
p.SetDelta(1,3, dcp)

In order to explore different baselines an example macro can be found here: /project/antares/dosamt/oscprobexample/DrawBaseLine.C It expects as arguments:
- Baseline length
- Neutrino/antineutrino flag (true/false)
- θ_{13}
- δ_{CP}

You can run it similar to the previous macro

root.exe
gSystem->Load("/project/antares/public_student_software/OscProb/libOscProb.so")
.x DrawBaseLine.C(Baseline_in_m,"true",theta13_in_radian,delta_cp_in_radian)

For the creation of a 2D oscillogram you can modify the routine MakeOscillogram.C. Feel free to also explore the other routines provided with the tutorial.