ESSnuSB detector performance

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ESS NEUTRINO SUPER BEAM

Funded by the Horizon 2020 Framework Programme of the European Union

Abstract: ESSnuSB is a design study for a high precision future experiment at ESS, which will measure CP violation in the lepton sector at the second neutrino oscillation maximum. The experiment is based on a neutrino superbeam and will feature both near and far detectors. This poster reports on the baseline configuration of the near and far detectors. The progress of design and simulation of the far Cherenkov detectors will be presented in more detail, focusing on the migration matrices and detector efficiencies for detecting relevant neutrino flavors.

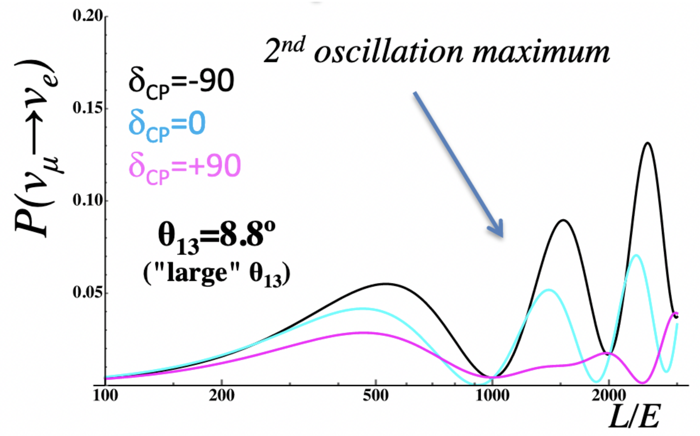
What is ESSnuSB

- ESSnuSB is a design study for an experiment to measure the CP violation in the leptonic sector by observing neutrino oscillations.
- Main goal: observe the difference in the neutrino oscillation probabilities, (probability of muon neutrinos oscillating to electron neutrinos and muon anti-neutrinos oscillating to electron anti-neutrinos)

$$P(\nu_\mu \to \nu_e) \neq P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

- The second neutrino oscillation maximum is selected because the CP violation effect is ~2.7 times larger with respect to the first oscillation maximum

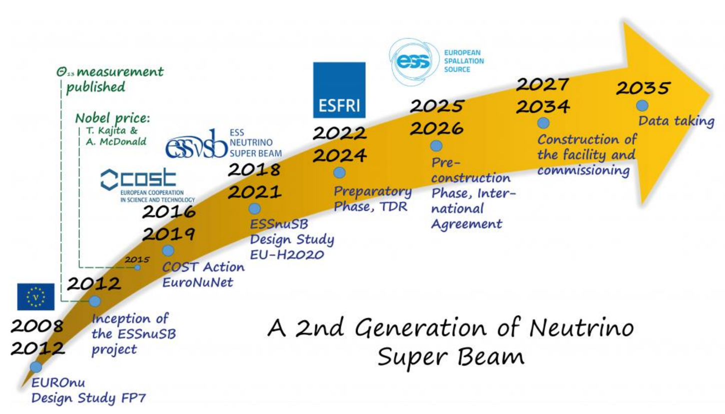
$$\frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) \mid 2^{nd}\ oscillation\ maximum}{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) \mid 1^{st}\ oscillation\ maximum} \sim 2.7$$



How will we get a neutrino beam?

ESS linac is a proton accelerator, currently under construction, and will be the most powerful proton accelerator (2 GeV kinetic energy / average beam power of 5MW).
Modifications needed:

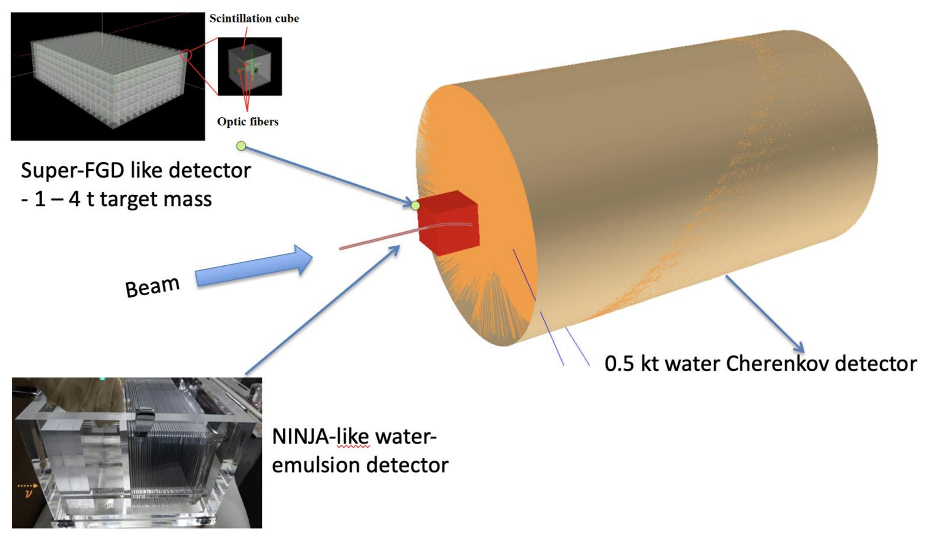
- The rate of the linac will need to be doubled from 14 Hz to 28 Hz, and the proton kinetic energy will have to be increased from 2.0 GeV to 2.5 GeV
- The accumulator ring with a circumference of about 400 m will be built to compress the long 2.86 ms ESS proton pulses to four short 1.3 μs pulses.
- The target station will be composed of four neutrino production targets enveloped by magnetic horns.
- A pion decay tunnel 50 m long and 4.0 m in diameter will be built downstream of the target station, ending with a hadron stop and muon monitors.



Near Detector

The Near detector will be comprised of:

- an emulsion detector
- a Super Fine Grained Detector (SFGD) scintillator detector
- a 0.5 kt Water Cherenkov detector.



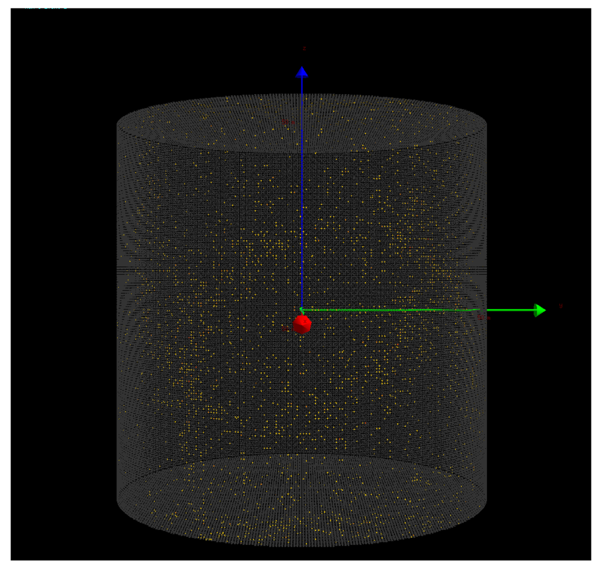
The main purpose of the near detector is

- to measure neutrino flux
- to measure flavour composition of the beam
- to calculate the cross section of neutrino-water interactions

Far Detector

The Far detector will be comprised of 2 large Water Cherenkov detectors

- cylindrical shape (H = D = 78 m)
- water mass that reaches 746 kt
- 20 " photomultipliers
- 30% optical coverage



2 possible locations for the Far Detectors:

- Zinkgruvan mine
  360 km away from the ν source
- Garpenberg mine
  540 km away from the ν source

The Garpenberg mine covers the entire 2nd oscillation maximum, while the Zinkgruvan mine covers partially both the 1st and the 2nd oscillation maximum.

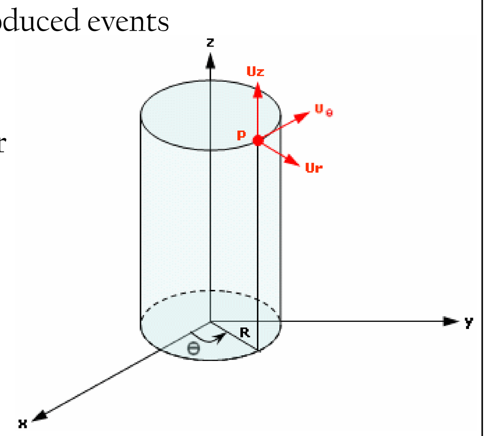
Simulations

Multiple algorithms/frameworks are used to fasilitate Far Detector Simulations

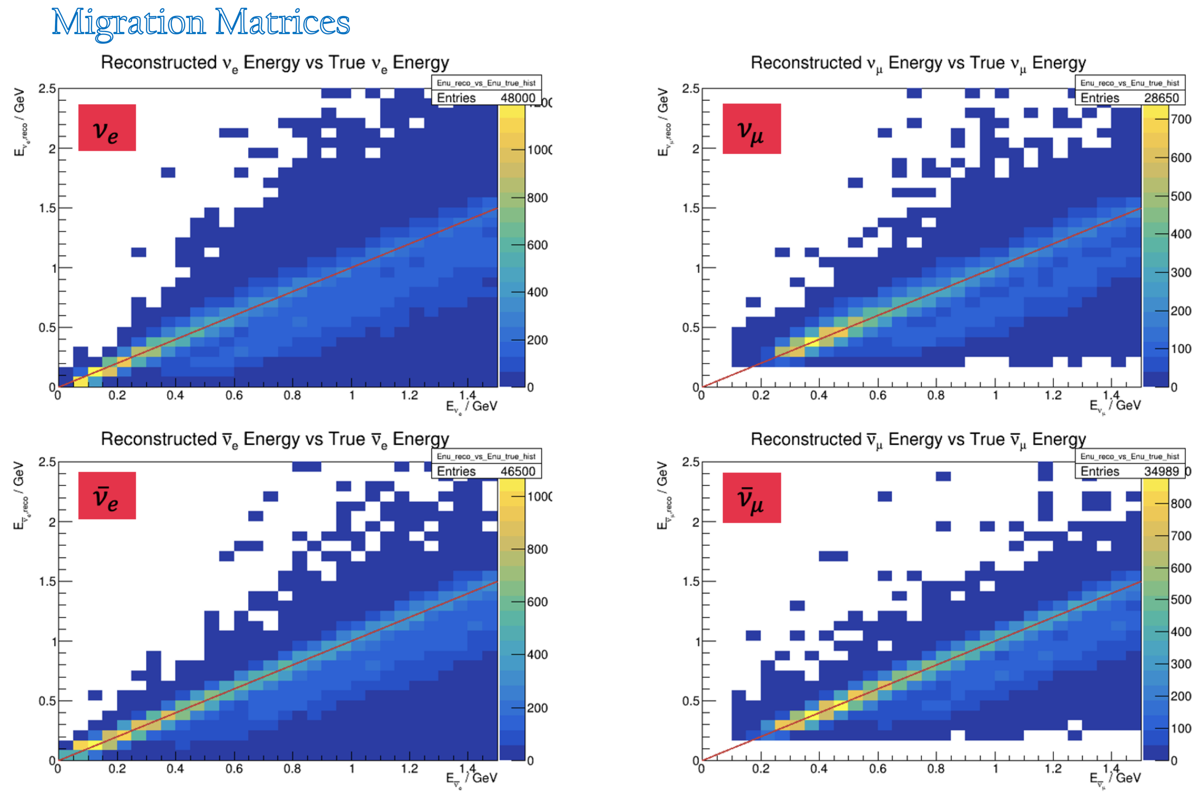
- GENIE MC Event Generator to simulate neutrino or charged-lepton interactions with nucleons or nuclei
- WCSim for developing and simulating large water Cherenkov detectors
- fiTQun reconstruction algorithm to reconstruct produced events

Simulation specification

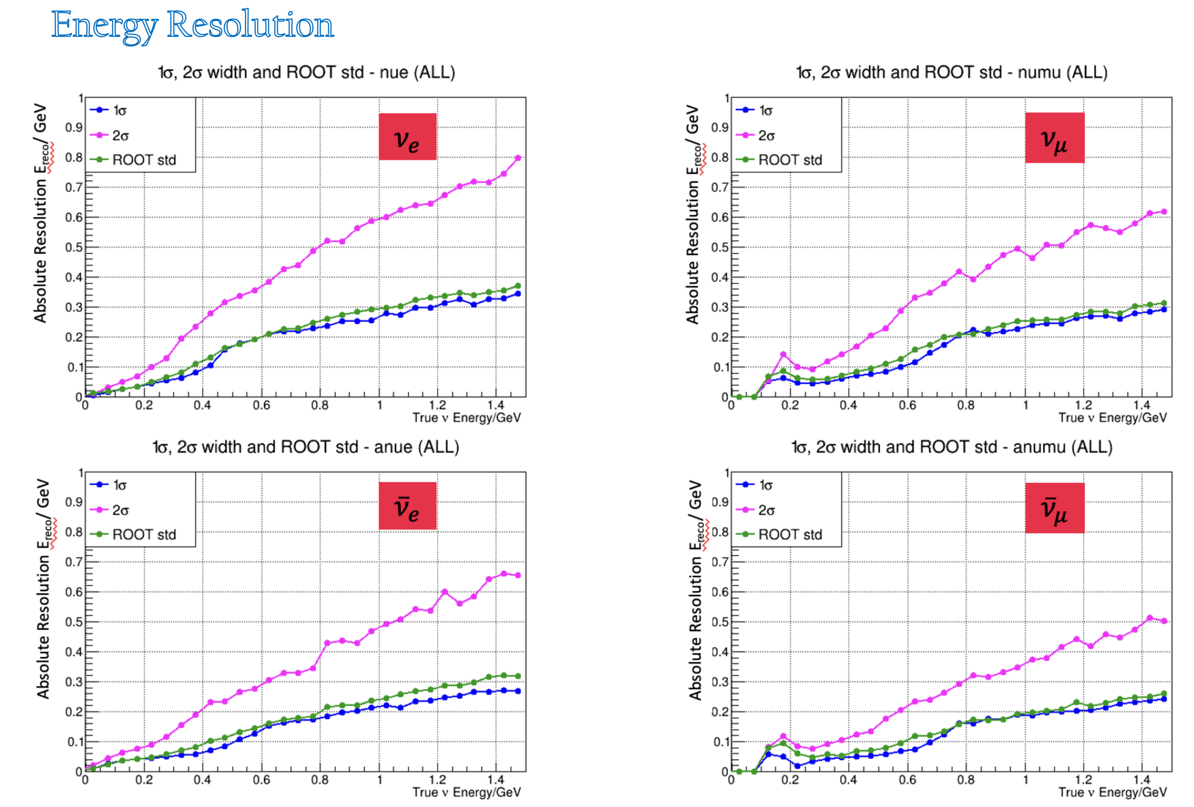
- Hyper-K like geometry (soon ESSnuSB Far Detector Geometry will be implemented)
- beam y direction
- ν vertices distributed randomly inside the water volume of the Far Detector
- flat interacting neutrino energy up to 1.5 GeV
- 40% optical coverage
- Fiducial Volume Cut 2 m from the walls of the tank



Migration Matrices



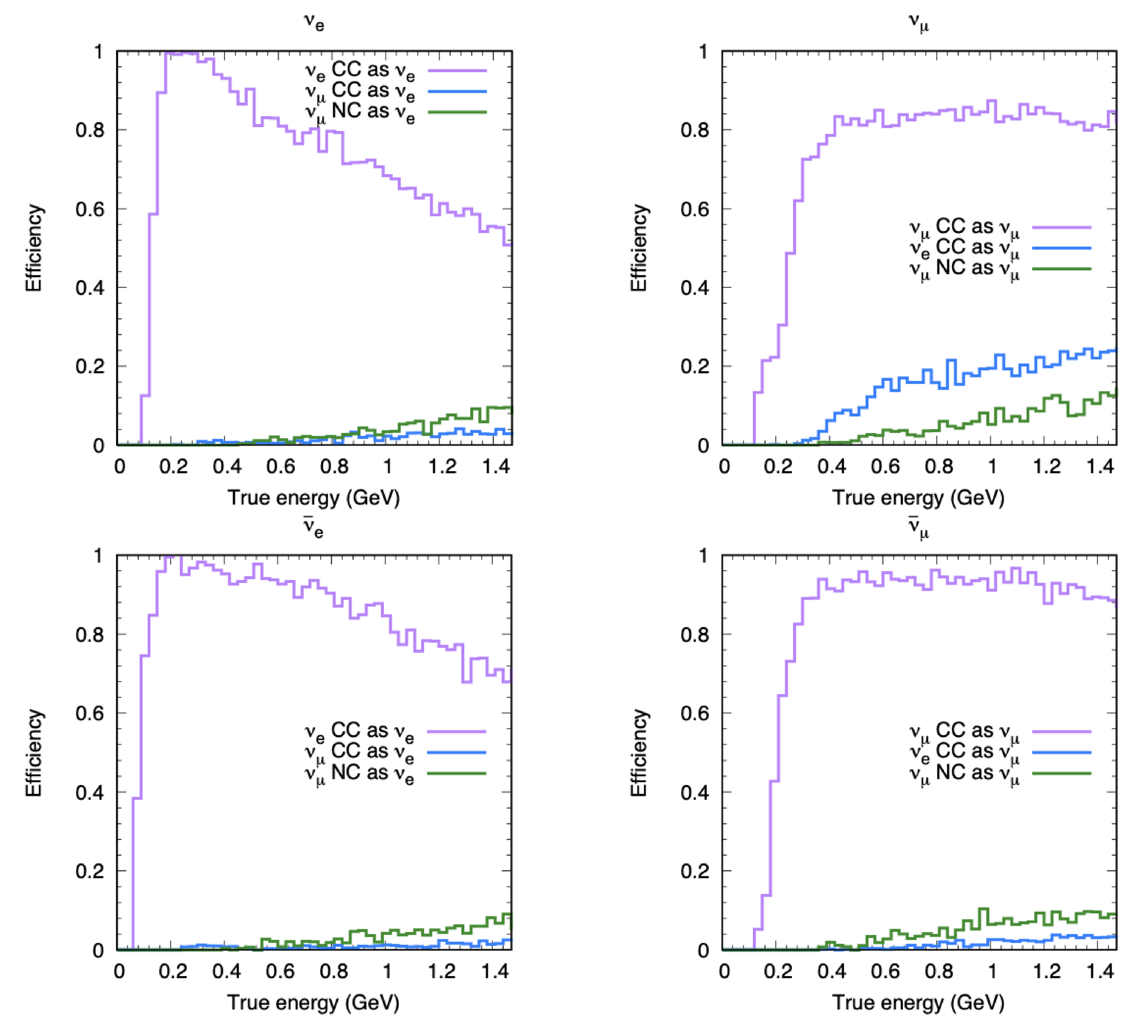
Energy Resolution



Simulations

Efficiency

Efficiency of selecting events is basically addition of all the numbers in the migration matrices of the reconstructed energy bins for a given true energy bin. From the figures we can see that for electron neutrinos, in some bins, we have 100% efficiency and overall we have more than 80% efficiency.



Summary

ESSnuSB WP5 Design Report is soon to be delivered and extensive studies on Near and Far Detector efficiency are ongoing.
More specifically, concerning Far Detector studies, particle reconstruction seems to be succesful. Energy Resolution is around 20% for antineutrinos and ~30% for neutrinos.
The currently in-process final Monte Carlo production includes the implementation of ESSnuSB Far Detector geometry and also an event tagging algorithm.

References:
[1] https://inspirehep.net/literature/1501882
[2] https://github.com/GENIE-MC/Generator
[3] https://github.com/WCSim/WCSim
[4] https://arxiv.org/pdf/1901.03230.pdf
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