PROCEEDINGS OF SCIENCE

ESSnuSB Detector Performance

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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 the design of 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 is presented in more detail, focusing on the migration matrices and detector efficiencies for detecting relevant neutrino flavours.

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1. Introduction

ESSnuSB is a design study for an experiment to measure the CP violation in the leptonic sector by observing neutrino oscillations in the second oscillation maximum [1],[2]. The main goal is to measure the difference in the neutrino oscillation probabilities, meaning the probability of muon neutrinos oscillating to electron neutrinos and muon anti-neutrinos oscillating to electron anti-neutrinos. As can be seen in Figure 1, the sensitivity to the CP violation effect in the second neutrino oscillation maximum is around 2.7 times larger with respect to the first oscillation maximum. Hence, ESSnuSB will focus on the second neutrino oscillation maximum, proposing to use the very powerful accelerator that is currently under construction in Lund, Sweden.

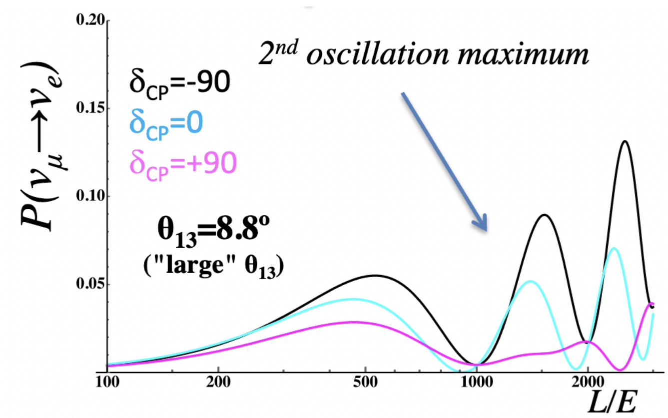

Figure 1: Oscillation probability for the $\nu_\mu \rightarrow \nu_e$ channel as a function of energy/distance. Different colours correspond to different values of the δ_{CP} parameter.

1.1 ESS

The ESS linac is a proton accelerator, currently under construction in Lund, Sweden, and will be the most powerful proton accelerator. The kinetic energy of the protons will be 2 GeV, with an average beam power of 5 MW. Some modifications are needed, for the realization of the ESSnuSB project. Firstly, 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. Half of the beam will be dedicated to the ESS neutron program, while the other half will be used to produce a super dense neutrino beam. Secondly, an accumulator ring with a circumference of about 400 m will have to be built to compress the long 2.86 ms ESS proton pulses to four short 1.3 μs pulses. Thirdly, the target station will be composed of four neutrino production targets enveloped by magnetic horns. Finally, a pion decay tunnel of 50 m long and 4 m in diameter will be built downstream of the target station, ending with a hadron stop and muon monitors [3].

2. The Detectors

The ESSnuSB project is planning to include two detectors. The Near Detector (ND) which be located in Lund close to the ESS accelerator and the Far Detector (FD) located in a mine many kilometers away from ESS.

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2.1 The Near Detector

The main purpose of the ND is to measure the neutrino flux, to measure the flavour composition of the beam and to calculate the cross section of neutrino-water interactions. The ND will be comprised of an emulsion detector, a Super Fine-Grained Detector (SFGD) scintillator detector and a 0.5 kt Water Cherenkov detector [5]. A schematic of the ND can be seen in Figure 2.

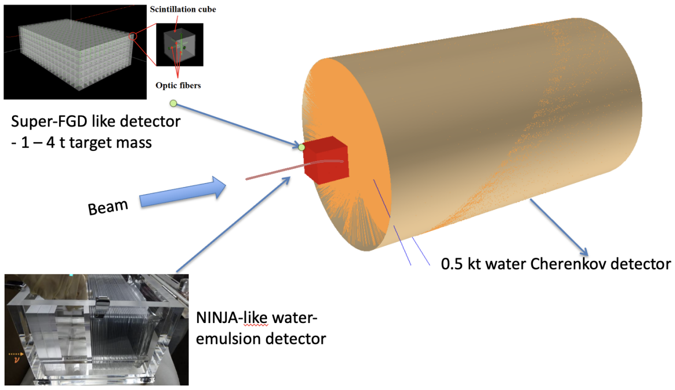
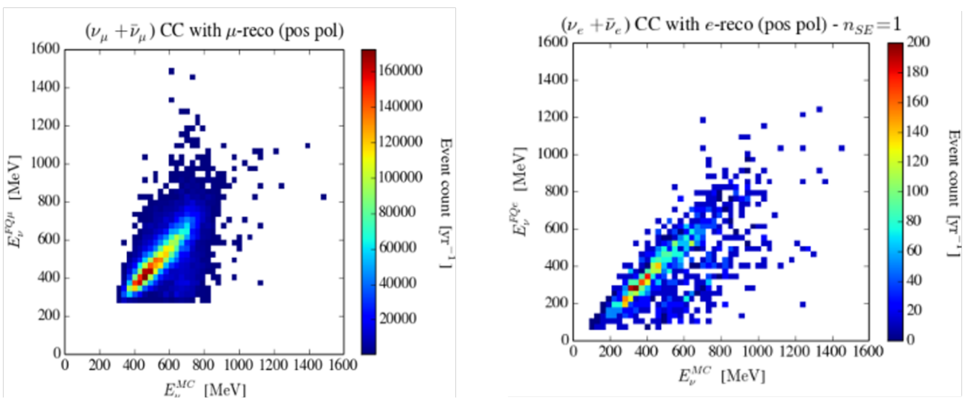


Figure 2: Near Detector Schematic.

Some results of the simulation runs for the ND are shown in Figure 3 where the reconstructed energy of the incoming neutrino is shown as a function of the simulated incoming neutrino energy. For the reconstructions, the quasi-elastic assumption has been used. In the Figure 3(a) the reconstruction of the incoming muon (anti)neutrinos can be seen. Most points lie in diagonal of the plane, indicating a well-reconstructed population of muon (anti)neutrino events. A similar conclusion is obtained from Figure 3(b), for the electron (anti)neutrino events.



(a) (b)

Figure 3: Near Detector Simulations. Reconstruction of the incoming neutrino energy with the most probable identification of the charged lepton in the final state. (a) muon (anti)neutrinos and (b) electron (anti)neutrinos.

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2.2 The Far Detector

2.2.1 Design of the Far Detector

The FD will be comprised of two large Water Cherenkov detectors installed in a mine. The possible locations of installation is either the Zinkgruvan or the Garpenberg mine respectively at 360 km and 540 km away from the neutrino source (Figure 4(b)). The Garpenberg mine covers the entire 2^{nd} oscillation maximum, while the Zinkgruvan mine covers partially both the 1^{st} and the 2^{nd} oscillation maximum.

(a) (b)

Figure 4: (a) Far Detector Water Cherenkov cylinder schematic. Simulated neutrino interaction. (b) Map of possible mine sites. Garpenberg and Zinkgruvan are the final two options.

Each of the two Water Cherenkov FD, will be of cylindrical shape (H = D = 78 m) and the combined water mass will reach 746 kt. The 20-inch photomultipliers that will be used will offer 30% coverage. In Figure 4(a), a schematic of the FD is presented together with a simulated neutrino interaction, using EsbRootView, the event display software for ESSnuSB [4].

2.2.2 Simulations and Results

Various algorithms/frameworks were used to facilitate the FD Simulations. The GENIE Monte Carlo Event Generator was used to simulate neutrino and charged-lepton interactions with nucleons or nuclei. The WCSim package was used for developing and simulating large water Cherenkov detectors and finally the fiTQun reconstruction algorithm was used to reconstruct the produced events.

A Hyper-K like geometry with 40% optical coverage was initially used for the simulations. The beam direction was following y-axis, while the neutrino vertices were randomly distributed inside the water volume of the FD. The generated neutrinos had a flat interacting energy up to 1.5 GeV. A fiducial volume cut of 2 m from the walls of the tank was applied. The results concerning the neutrino energy reconstruction and the reconstructed neutrino energy resolution can be seen in Figure 5 and Figure 6 respectively. The energy reconstruction for all neutrino flavors is successful, and the absolute reconstructed neutrino energy resolution is below 35%, while in the region of interest (0.2 GeV - 0.4 GeV) the absolute reconstructed neutrino energy resolution is below 10%. The calculation of the event selection efficiency is derived from the addition of all the numbers in the migration matrices of the reconstructed energy bins for a given true energy bin. From Figure 7 it is obvious that for electron neutrinos, in some bins, there is a 100% efficiency and overall, a more than 80% efficiency is obtained [6].

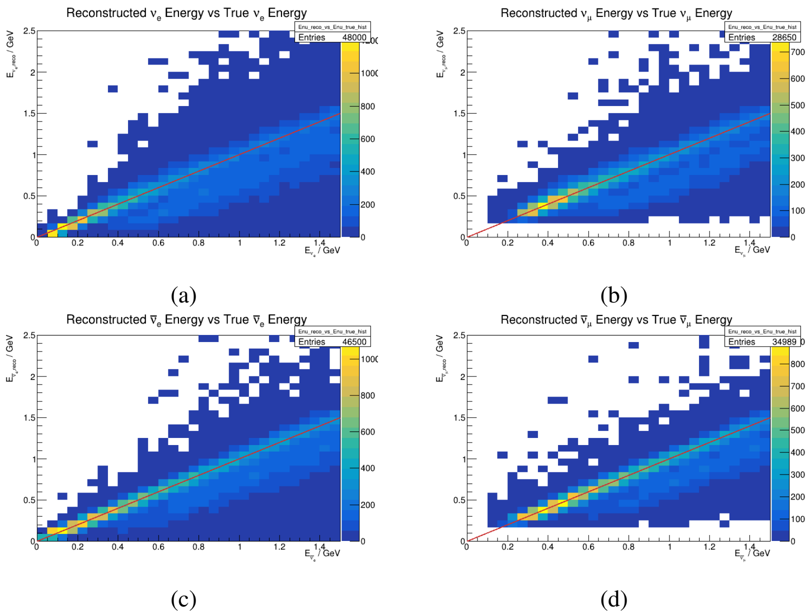


Figure 5: Migration Matrices, Reconstructed neutrino energy with respect to true (simulated) neutrino energy. (a) electron neutrinos, (b) muon neutrinos, (c) electron anti-neutrinos, (d) muon anti-neutrinos.

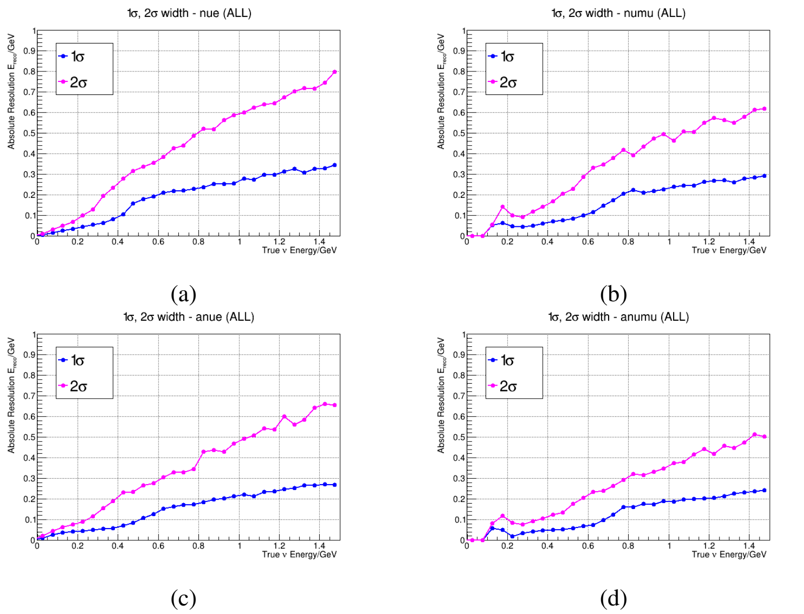
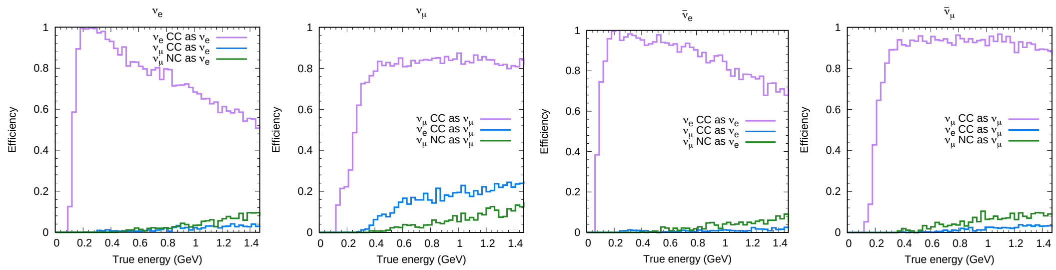


Figure 6: 1σ and 2σ absolute resolution of the reconstructed neutrino energy with respect to true (simulated) neutrino energy. (a) electron neutrinos, (b) muon neutrinos, (c) electron anti-neutrinos, (d) muon anti-neutrinos.

3. Summary

The ESSnuSB Conseptual Design Report is soon to be delivered and extensive studies on Near and FD efficiencies are coming to a successful conclusion.



(a) (b) (c) (d)

Figure 7: Efficiency of event selection. (a) electron neutrinos, (b) muon neutrinos, (c) electron anti-neutrinos, (d) muon anti-neutrinos.

The ND can monitor the neutrino flux by measuring muon (anti)neutrino interactions in the Water Cherenkov and, thus, deliver predictions for the rate in the FD. Moreover, the SFGD itself in combination with the Water Cherenkov can measure the electron (anti)neutrino cross-section with a reasonable purity of the sample. The addition of an emulsion detector for measuring the muon (anti)neutrino cross-section in water (in combination with the other two detectors) increases the robustness of the measurements and decreases their systematics.
The FD simulations showed that the reconstruction procedure has given excellent results for the determination of the Migration Matrices. The Relative Energy Resolution is 20% for antineutrinos and 30% for neutrinos. For the energy range of the ESS neutrino beam (peaking at about 0.4 GeV) the efficiency of the energy reconstruction is over 80%. The current in-process final Monte Carlo production includes the implementation of the ESSnuSB FD geometry, using 20-inch photomultipliers with 30% optical coverage and an event tagging algorithm.

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