PROCEEDINGS OF SCIENCE

# Physics potential of the ESS$\nu$SB facility

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The European Spallation Source Neutrino Super Beam (ESS$\nu$SB) is a proposed neutrino oscillation experiment to be held in Lund and which takes advantage of the ESS linac firstly designed to study spallation neutrons. Here we study the capability of this facility to discover the yet unknown parameters in the neutrino sector, such as the existence of *CP* violation. We optimize the physics performance as a function of the baseline and running time of the experiment in each polarity and make an in depth study of the impact of particular systematic errors.

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## 1. Introduction

The main goal of the next generation of neutrino oscillation facilities is to establish if the *CP* symmetry is also violated in the lepton sector. The best probe for *CP* violation is the interference between the atmospheric and solar driven oscillations through the channel $\nu_\mu(\overline{\nu}_\mu) \to \nu_e(\overline{\nu}_e)$ [1].

The *ESSνSB* [2] is proposed to have a 5 MW power proton beam at 2.5 GeV with a 1 Mton *MEMPHYS*-like water Cherenkov detector [3]. Thanks to its high power the experiment can have enough events so as to study *CP* violation at the second oscillation maximum, where the relative importance of the interference term is larger [4]. One of the possible locations for the detector is the Garpenberg mine at 540 km.

## 2. Physics potential

We use the *GLoBES* software [5] to simulate the *ESSνSB* experiment. The fluxes, cross sections and migration matrices are the same as from Ref. [2], while we adopt the same treatment for the systematic errors as in Ref. [6].

In Fig.1 we study the optimal baseline ($L$) and $\nu$ mode running time ($t_\nu$) with a total of 10 years running time between positive and negative focusing fixed. We use as a performance indicator the *CP* fraction above $5\sigma$, which corresponds to the fraction of all possible values that $\delta_{CP}$ could have for which the facility would be able to claim a $5\sigma$ discovery of *CP* violation. The left panel of Fig.1 shows the *CP* fraction as a function of $L$ for different sets of systematic errors: the “Optimistic” and “Default” from Ref. [6], and an overall $\mathcal{O}(3\%)$ in line with the most recent estimates in Ref. [7] when a smaller detector mass (374 kton fiducial volume) and improved photocoverage are assumed (“RV/IP”). As one can see the *ESSνSB* performance is not very sensitive to the value of the systematic errors for $L > 300$ km where *CP* violation is studied near the second oscillation maximum as expected from Ref. [4], whereas the opposite happens at shorter baselines where the distance between the red and blue dots is much larger. The optimal baseline would be $L \sim 400$ km close to the Garpenberg option (540 km). Regarding $t_\nu$, the optimal configuration would be a rather symmetric splitting of the total time around 5 years in $\nu$ mode and 5 years in $\overline{\nu}$ mode.

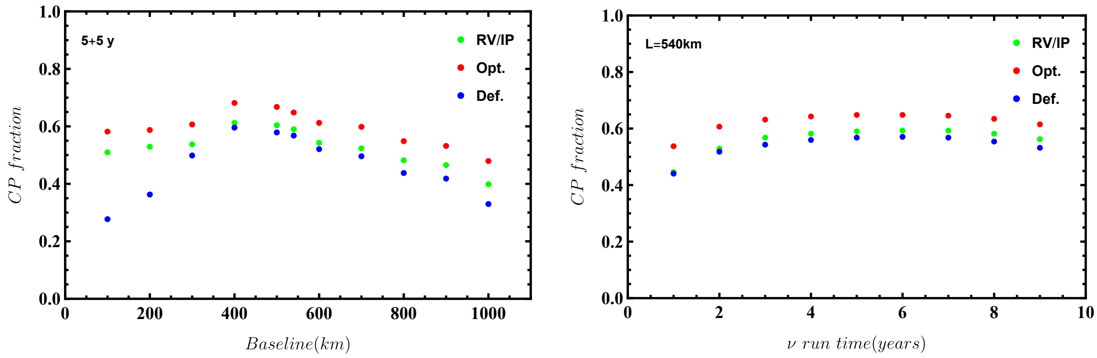


**Figure 1:** Dependence of the *CP* fraction on the baseline (left panel) and the $\nu$ mode running time (right panel), such that the total running time is 10 years, for different choices of systematics.

Next, we study separately the impact on the *CP* fraction at $5\sigma$ of each individual systematic error listed in Ref. [6]. We have done so by varying one systematic error at a time between several values, while keeping the rest of systematics fixed at their "Default" value. In Fig.2 we observe that the systematics which have a larger impact on the final sensitivity are the flux background for $\nu(\overline{\nu})$ and the ratio between the electron and muon neutrino cross sections, since the near detector events are mostly $\nu_\mu(\overline{\nu}_\mu)$ while the far detector signal is $\nu_e(\overline{\nu}_e)$.

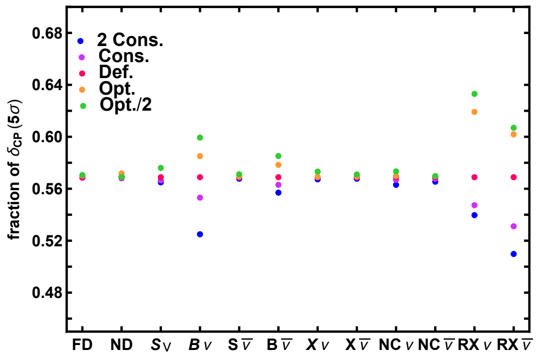


**Figure 2:** Change in the *CP* fraction above $5\sigma$ for different values of the systematic errors.

The *ESSνSB* does not have strong matter effects, as the $\nu$ energy is $E_\nu \sim 0.4$ GeV and one needs $E_\nu \sim 6$ GeV so that the oscillation probability is near the resonance [8, 9]. However, it can distinguish the wrong hierarchy around $3\sigma$.

## References

[1] A. Cervera, A. Donini, M. B. Gavela, J. J. Gomez Cadenas, P. Hernandez, O. Mena et al., *Golden measurements at a neutrino factory*, *Nucl. Phys.* **B579** (2000) 17 [hep-ph/0002108].

[2] ESSNUSB collaboration, E. Baussan et al., *A very intense neutrino super beam experiment for leptonic CP violation discovery based on the European spallation source linac*, *Nucl. Phys.* **B885** (2014) 127 [1309.7022].

[3] MEMPHYS collaboration, L. Agostino, M. Buizza-Avanzini, M. Dracos, D. Duchesneau, M. Marafini, M. Mezzetto et al., *Study of the performance of a large scale water-Cherenkov detector (MEMPHYS)*, *JCAP* **1301** (2013) 024 [1206.6665].

[4] P. Coloma and E. Fernandez-Martinez, *Optimization of neutrino oscillation facilities for large $\theta_{13}$*, *JHEP* **04** (2012) 089 [1110.4583].

[5] P. Huber, J. Kopp, M. Lindner, M. Rolinec and W. Winter, *New features in the simulation of neutrino oscillation experiments with GLoBES 3.0: General Long Baseline Experiment Simulator*, *Comput. Phys. Commun.* **177** (2007) 432 [hep-ph/0701187].

[6] P. Coloma, P. Huber, J. Kopp and W. Winter, *Systematic uncertainties in long-baseline neutrino oscillations for large $\theta_{13}$*, *Phys. Rev.* **D87** (2013) 033004 [1209.5973].

[7] HYPER-KAMIOKANDE collaboration, K. Abe et al., *Hyper-Kamiokande Design Report*, 1805.04163.

[8] L. Wolfenstein, *Neutrino Oscillations in Matter*, *Phys. Rev.* **D17** (1978) 2369.

[9] S. P. Mikheyev and A. Yu. Smirnov, *Resonance Amplification of Oscillations in Matter and Spectroscopy of Solar Neutrinos*, *Sov. J. Nucl. Phys.* **42** (1985) 913.