PROCEEDINGS OF SCIENCE

Overview of ESSnuSB experiment to measure δ_{CP}

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In this proceeding we will present the capability of the ESSnuSB experiment to measure leptonic CP phase δ_{CP}. In particular we will study: (i) sensitivity for different baseline options, (ii) the effect of systematic errors and (iii) optimisation of the neutrino to antineutrino run ratio. In addition we will also discuss a comparative analysis between ESSnuSB and T2HK, pointing out the physics differences between these two experiments in measuring δ_{CP}.

The 21st international workshop on neutrinos from accelerators (NuFact2019)
August 26 - August 31, 2019
Daegu, Korea

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PoS(NuFact2019)038

1. Introduction

In the standard three flavour framework the phenomenon of neutrino oscillation is described by six parameters which are: three mixing angles, θ_{12}, θ_{13} and θ_{23}, two mass squared differences, Δm^2_{21} and Δm^2_{31} and one Dirac type CP phase δ_{CP}. Among these six parameters the current unknowns are: (i) neutrino mass ordering or the sign of Δm^2_{31} (normal ordering or NO, $\Delta m^2_{31} > 0$/inverted ordering or IO, $\Delta m^2_{31} < 0$), (ii) the octant of the mixing angle θ_{23} (lower octant or LO, $\theta_{23} < 45°$/higher octant or HO, $\theta_{23} > 45°$) and (iii) δ_{CP}. The current best-fit value of δ_{CP} is around $-90°$ [1] which mainly comes from data of the currently running experiment T2K [2] and NOνA [3]. One of the main goals of the future neutrino oscillation experiments is to measure this parameter more precisely. ESSnuSB [4] is an example of such an experiment. ESSnuSB is a proposed long-baseline experiment in Europe. In this experiment, neutrinos will be produced from an accelerator in Lund, Sweden having 2.5 GeV proton beam. These neutrinos will be detected using a 507 kt water Cherenkov detector. At present there are two proposed baseline option for this experiment which are 540 km and 360 km. The proposed total run-time of this experiment is 10 years. The unique feature of this experiment is that it will measure the CP phase δ_{CP} at the second oscillation maximum. As the variation of the neutrino oscillation probability with respect to δ_{CP} is larger in the second oscillation maximum, this experiment will be capable of measuring δ_{CP} to an excellent precision even with small statistics.

In this proceeding we will discuss, the capability of the ESSnuSB experiment to measure δ_{CP}. In particular, we will study (i) the difference in the sensitivity in the two different baseline options, (ii) how the sensitivity depends on the neutrino to antineutrino run ratio and (iii) effect of systematic uncertainty in the sensitivity. We will also present a comparative study between ESSnuSB and T2HK [5] which is another proposed long-baseline experiment in Japan aiming to measure δ_{CP} with higher precision.

2. CP sensitivity of ESSnuSB experiment

We have performed our analysis using the software GLoBES [6]. The systematic uncertainty we have taken from [7] and given in Fig. 1.

In Fig. 2, we have presented the CP violation sensitivity in the left column and CP precision sensitivity in the right column. The top row shows the sensitivity for different baseline options which is for 5 years running in neutrino mode and 5 years running in antineutrino mode. In these plots the green line corresponds to the case when half of the detector is placed at a distance of 540 km and another half of the detector is placed at a distance of 360 km from the neutrino source. From these panels we note that the best sensitivity is obtained for the 360 km baseline. This is because at smaller distance the number of events are higher. The middle row shows the effect of neutrino to antineutrino running ratio. In these curves, the rest of the 10 years is running in antineutrino mode. From these curves we understand that for CP violation dominant neutrino run gives best sensitivity and for CP precision full neutrino run gives best sensitivity. The lower row shows the effect of systematic uncertainty. The green dots correspond to a detector volume of 374 kt with 3% overall systematics. Here we see with improved systematics, the sensitivity improves significantly.

Detector	Systematic uncertainty on near detector fiducial volume	0.5%	0.2%
Detector	Systematic uncertainty on far detector fiducial volume	2.5%	1%
Beam	Systematic uncertainty signal neutrino component	7.5%	5%
Beam	Systematic uncertainty background neutrino component	15%	10%
Detector	Systematic uncertainty on QE cross section	15%	10%
Detector	Systematic uncertainty on electron to muon neutrino ratio of QE cross	11%	3.5%
Location	Systematic uncertainty on matter density along neutrino beam	2%	1%

Figure 1: Table of systematics. We will refer to the numbers in the third (fourth) column as default (optimistic) values of the systematic uncertainty.

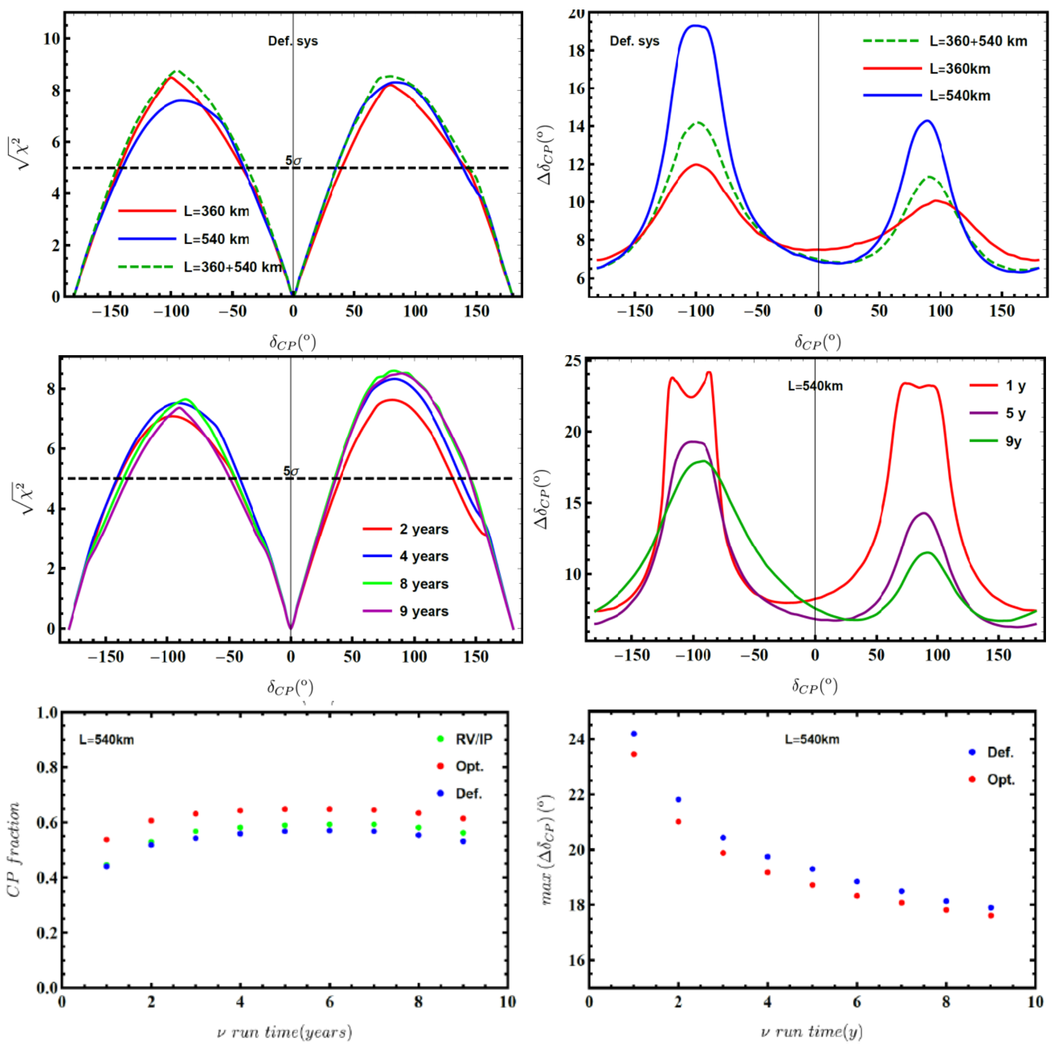

Figure 2: CP violation and CP precision sensitivity. Figures taken from Ref. [8].

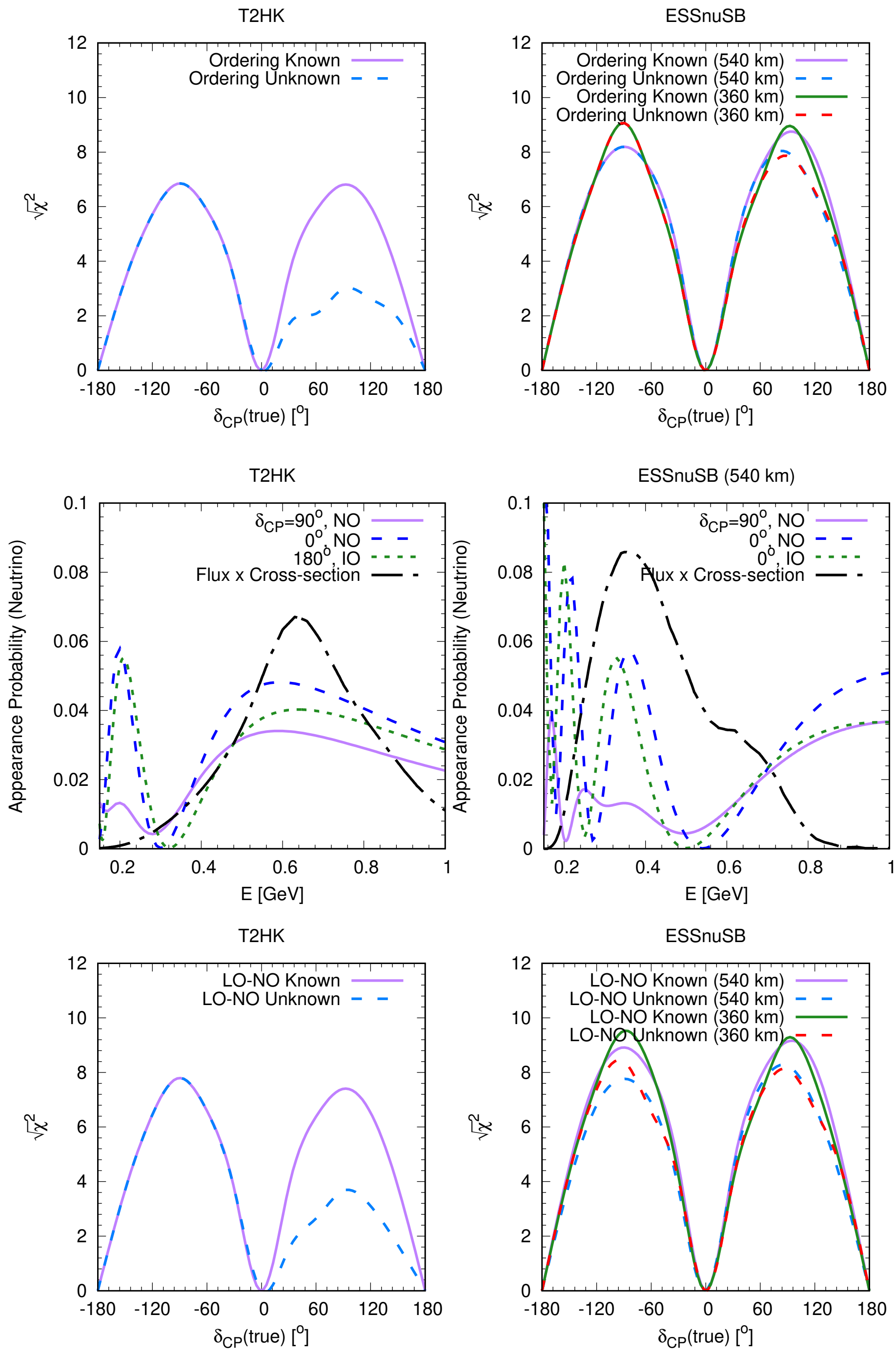

Figure 3: CPV sensitivity for ESSnuSB and T2HK for 5+5. Figures taken from Ref. [9] (published in Mod. Phys. Lett. A).

3. Comparison with T2HK experiment

In Figure 3 we have presented the CP violation sensitivity of ESSnuSB and T2HK. From top row ($\theta_{23} = 45^\circ$) we see that when hierarchy is unknown there is a significant drop in the sensitivity for T2HK around $\delta_{CP} = 90^\circ$ but for ESSnuSB the drop is negligible. This is because T2HK measures CP sensitivity in the first oscillation maximum, where it suffers from degeneracy with wrong hierarchy whereas ESSnuSB measures CP sensitivity at the second oscillation maximum, where it does not suffer from the hierarchy degeneracy. This is clear from the middle row where we see that 90° curve is close to IO curve for T2HK in the region where flux $\times$ cross-section peaks but for ESSnuSB, the 90° curve is well separated from the IO curve. From the bottom row ($\theta_{23} = 42^\circ$), we see that when octant is unknown, there is a small drop in the sensitivity around $\delta_{CP} = -90^\circ$ for ESSnuSB but for T2HK there is no such drop. This is because the octant degeneracy which is present in the ESSnuSB experiment. We have checked that with dominant neutrino run, the effect octant degeneracy gets reduced. These conclusions are true for both the baseline options of ESSnuSB.

4. Conclusion

In this proceeding we have discussed the CP sensitivity of ESSnuSB in terms of different baseline options, different running ratios between neutrinos and antineutrinos and different sets of systematic uncertainties. We also presented the a comparative analysis between ESSnuSB and T2HK regarding the measurement of δ_{CP}. For more details see Ref. [8, 9] on which this proceeding is based upon.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419". This project is supported by the COST Action CA15139 "Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery" (EuroNuNet).

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