Off-Axis-NOTE-SIM-22

Extraction of θ_{13} , δ_{CP} and the mass hierarchy

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Abstract

This memo describes the studies made to determine the sensitivity of an off-axis detector for the determination of θ_{13} , δ_{CP} and the mass hierarchy. Some comparisons to the JHF facility are included.

1 Introduction

The calculations presented in this memo are based on the reconstruction methods described in memo [1] and on the optimization of signal identification and background rejection described in memo [2].

The following assumptions have been made:

- 5 year exposure.
- 50 kiloton detector with an 85% fiducial volume.
- 10 km off the axis at 735 km.
- medium energy beam.

The procedure is as follows.

Using the method and programs described in [2], the number of background events, B, and signal events, N_{stand}, for $\sin^2(2\theta)$=0.1, δ_{CP} =0 degrees and a normal mass hierarchy were calculated. The oscillation probability for this combination of parameters, P_{stand} was computed using a program kindly supplied to me by Stephen Parke.This gives me a number of signal events per unit oscillation probability, $N_{unit} = N_{stand}/P_{stand}$.

For any different combination of θ_{13} , δ_{CP} and hierarchy, an oscillation probability was computed using Stephen's program, P_{test}, and the number of expected signal events calculated using the number of signal events per unit oscillation probability, N_{test}= $N_{unit} \times P_{test}$. This assumes that the efficiency to identify signal events is not significantly different between this new combination and the one used to calculate the number of signal events per unit oscillation probability. This will be true if the energy spectra of signal events in the two combinations does not differ significantly. The number of background events is always kept constant.

The uncertainty on this measurement was calculated given the statistical uncertainties of the signal and background.

This uncertainty was translated into an uncertainty on P_{test}, σ_{test}.

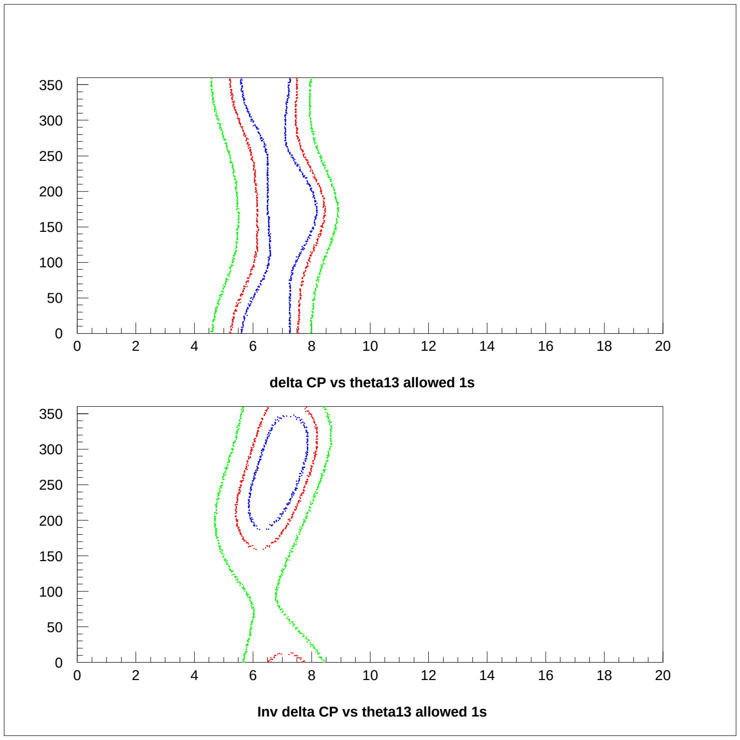

Figure 1: The regions of δ_{CP} and θ_{13} compatible with the "measurement" at one sigma (blue), two sigma (red) and three sigma (green). The input was $\theta_{13} = 6.46$ degrees, delcp=0 degrees and normal hierarchy. The top plot are the regions compatible with the measurement assuming a normal hierarchy and the bottom plot for an inverted hierarchy.

This was repeated for an antineutrino run, dividing the running into 1.5 years for neutrinos and 3.5 years for antineutrinos.

Using a triple raster scan (θ_{13} , δ_{CP} and hierarchy) the regions of oscillation probabilities, P_{try}, compatible with P_{test}, within its uncertainty, at the one, two and three sigma levels were identified using a χ^2 test.

$$\chi^2 \quad = \quad \frac{(P^{\nu_\mu}_{test} - P^{\nu_\mu}_{try})^2}{(\sigma^{\nu_\mu}_{test})^2} + \frac{(P^{\bar{\nu}_\mu}_{test} - P^{\bar{\nu}_\mu}_{try})^2}{(\sigma^{\bar{\nu}_\mu}_{test})^2}$$

This in turn yielded the regions of θ_{13} and δ_{CP} compatible with the "measurement" for each of the two hierarchies. An example is shown in Fig. 1.

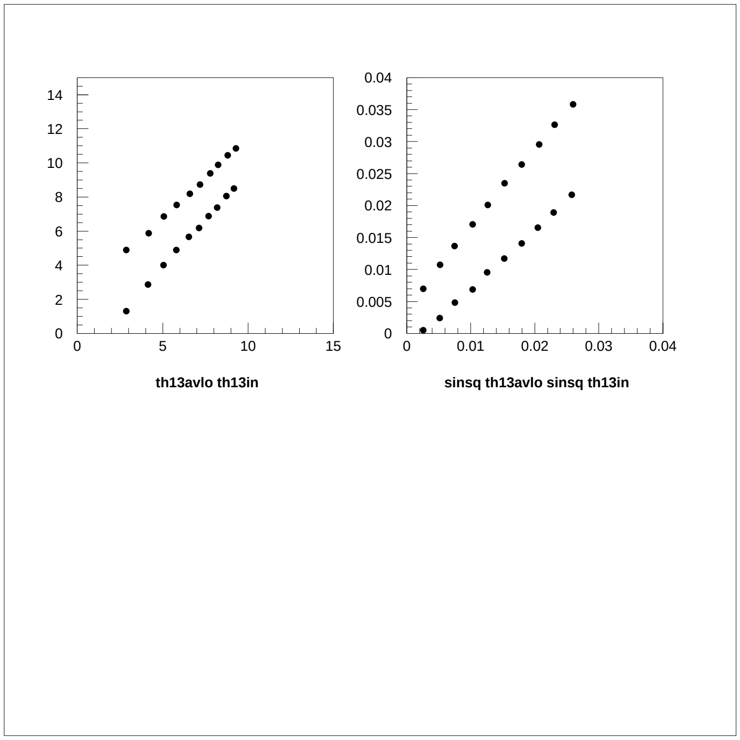

Figure 2: Left plot: NUMI Off-axis: The range of θ_{13} compatible with the accuracy of the measurement for several values of input θ_{13} . Right plot: As for the left plot but presented as a function of $\sin^2(\theta_{13})$.

2 NUMI

Using this technique the range of values of θ_{13} compatible with the precision of the measurement at the one sigma level were computed for a series of input θ_{13} . Of course both hierarchies were considered to determine this range. The results are shown in Fig. 2, both as a function of θ_{13} and $\sin^2(\theta_{13})$. A significant measurement can be obtained down to values of θ_{13} of about 4 degrees.

3 JHF

The same exercise was repeated for the JHF situation using the number of signal and background events presented in Table 2 of [3]. No antineutrino running is mentioned for Phase I in this proposal so just 5 years of neutrino running were assumed. The χ^2 expression was modified accordingly. The range of values of θ_{13} compatible with the precision of the measurement at the one sigma level were computed for a series of input θ_{13} and are presented in 3. It can be seen

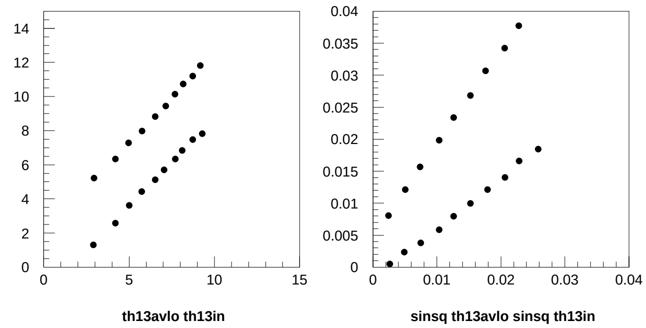

Figure 3: Left plot: JHF Project: The range of θ_{13} compatible with the accuracy of the measurement for several values of input θ_{13} . Right plot: As for the left plot but presented as a function of $\sin^2(\theta_{13})$.

that the precision of the measurement is worse than for NUMI.

4 NUMI and JHF

The exercise was also repeated combining the "data" of the two runs above, modifying the χ^2 expression to include three terms. The ranges of θ_{13} obtianed are shown in Fig. 4. They are not significantly different from the limits obtained with NUMI alone.

References

[1] L. Camilleri, A. Para. The Reconstruction of ν_μ and ν_e Monte Carlo events. Off-Axis-NOTE-SIM-11.

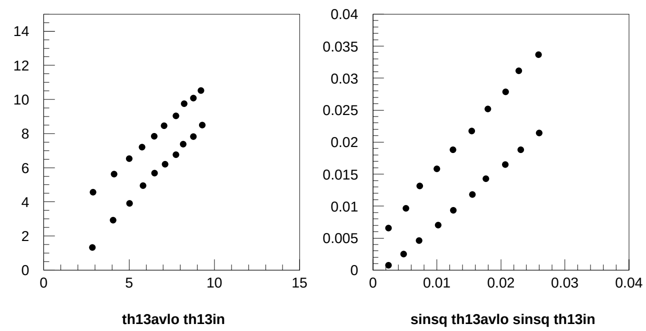

Figure 4: Left plot: JHF and NUMI Projects: The range of θ_{13} compatible with the accuracy of the measurement for several values of input θ_{13} . Right plot: As for the left plot but presented as a function of $\sin^2(\theta_{13})$.

[2] L. Camilleri, A. Para. A Study of an Off-axis Detector Performance as a Function of Sampling Frequency. Off-Axis-NOTE-SIM-12.

[3] The JHF-Kamioka neutrino project. hep-ex/0106019 v1 5 June 2001.