Study of sensitivities of the P2O project

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The sensitivities of the project to some oscillation parameters as a function of power and systematic errors are studied.

I. INTRODUCTION

P2O is the project [1] of neutrino beam from IHEP Protvino to KM3NeT/ORCA [2]

II. TECHNICAL NOTES ON THE REPOSITORY

The files for this project, including Papers and Notes, are kept in https://github.com/kirsanov-protvino/P2O . In order to work on them one should create account on github. Next step is to create an SSH key. Add this key to your account on the page https://github.com/settings/keys. After that you will be able to clone the repository using the command git clone git@github.com:kirsanov-protvino/P2O.git and push your changes in it. The command above is shown when you click the green button "Code" on the repository page and switch to SSH instead of HTTPS. To check that your repositiry clone is "pushable" type inside it "git remote -v".

III. TECHNICAL NOTES ON THE GLOBES PROGRAM RUNNING

In order to check that the statistics corresponds to the Proposal, the following call was used:
glbGetChannelRatePtr(0, ichannel, GLB_PRE). It returns the numbers of events in energy bins, to be summed over the them. It is to be called AFTER the calculation of sensitivities, otherwise some variables are not initialized. It is found that with the normalization factor 40 in the glb file the total number of events corresponds to the one in Figure 7 of the Proposal [1] (20000 $\nu_\mu CC$ events by eye from the figure, after scaling from 90 MW to 450 MW).

In the Globes running the file p2o.glb was used. Some parameters there, such as energy resolution of 30%, are taken from the Proposal [1], some from the proposal of KM3NET https://iopscience.iop.org/article/10.1088/0954-3899/43/8/084001.

IV. STUDY OF THE EXPERIMENT RESOLUTION

The parameters of the proposed experiment are described in [1] and [2]. Some of them can be changed, for example the detector mass (several construction stages are possible), others, such as the energy resolution, and identification probabilities, are more difficult to change. However, there are ideas how to improve them, and may be significantly [3]. For this reason we studied how the results, in particular the δ CP measurement, depend on the experiment parameters. The value of $\sqrt{\chi^2}$ as a function of hypothetical δ for the true values $\delta = \pi/2, \pi, 3\pi/2$ is shown in Fig. 1. The energy resolution here is nominal, 30%, as specified in the Proposal. Here, only neutrino exposition is used.

In the next step we introduced the energy cut at 2 GeV. In order to keep the same number of $\nu_\mu CC$ events the Globes neutrino flux normalization is increased from 40 to 50.

After that we tried to substitute 0.3 of the total exposition by antineutrino. The result is in Fig. 2. The shapes and the δ CP accuracy are significantly improved. Here, also the correct distribution of the NC visible energy (for simplicity y distribution is assumed uniform from 0 to 1) is implemented.

One of the main purposes of the experiment is the measurement of δ CP. It is determined as the deviation of δ from the minimum of χ^2 at which the latter increases by 1, averaged over the left and right sides.

We studied the dependence of δ resolution on the fraction of antineutrino exposition in the total exposition. The result is shown in Fig. 4.

The resolution of δ measurement as a function of the energy resolution for the true values $\delta = 0, \pi/2, \pi, 3\pi/2$ is shown in Fig. 5 Fig. 6 (antineutrino exposition is used in the latter). As a reminder, the nominal energy resolution is $\Delta E/E = 0.3$.

The resolution of δ measurement as a function of the detector mass is shown in Fig. 7. The project detector mass is 8 mt.

V. EFFECT OF ν_e FRACTION IN THE BEAM

This fraction is specified in the spectra file. To avoid rewriting the spectra files, different fractions were simulated by changing the efficiency with which the channel "nu-e-beam" is added to the backgrounds. This is possible because the program does not have a protection against efficiencies greater than 1. For example the nominal efficiency for the ν_e appearence is 0.85. The fraction of ν_e increased by factor of 10 was simulated by increasing this efficiency to 8.5. This changes the delta CP measurement accuracy from 61.65 to 62.55 degrees (delta CP = 3/2 π). Decreasing the ν_e fraction is not visible if we print out only 3 digits of delta CP measurement.

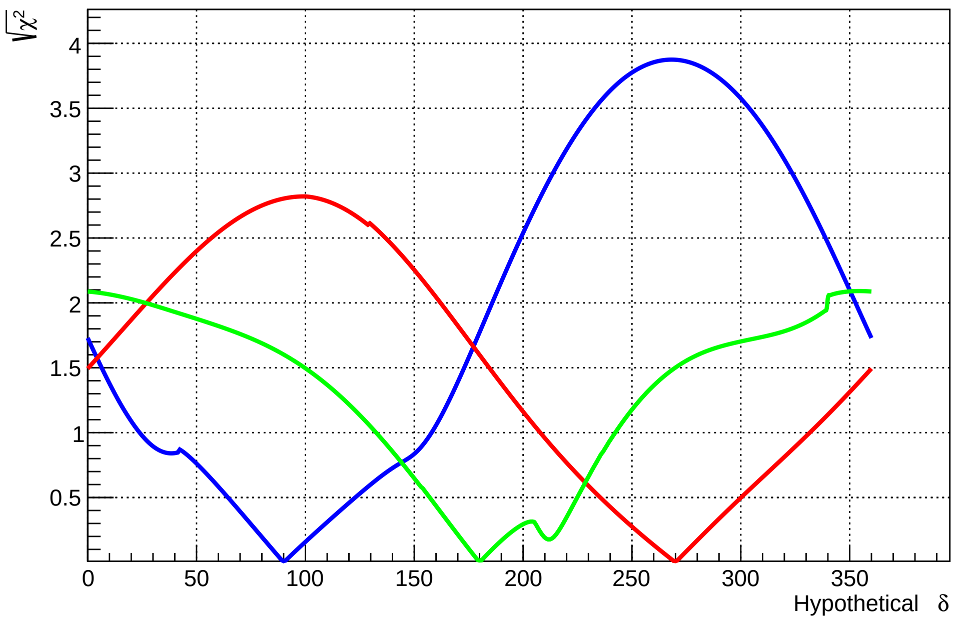

FIG. 1. Value of $\sqrt{\chi^2}$ as a function of hypothetical δ for $\delta = \pi/2$ (blue), π (green), $3\pi/2$ (red). Energy resolution is 30%.

I understand this small effect like this. All events without identified muon are summed up ("shower type" events) and used in the analysis. In the model described in our glb file we have one error specified for this: 5%. So the effect of increased ν_e fraction remains small if the fraction of ν_e in the total number of "shower type" events does not dominate.

The effect of ν_e fraction can be more significant if we assume that we don't know it with sufficient accuracy and specify this separate accuracy in the glb file. "Sufficient" here means a value of the order of 5% mentioned above.

VI. EFFECT OF THE TYPE OF SYSTEMATIC ERROR

No significant effect was observed when it was changed from "chiSpectrumCalib" to "chiSpectrumTilt". Artefacts in the dependencies also did not change.

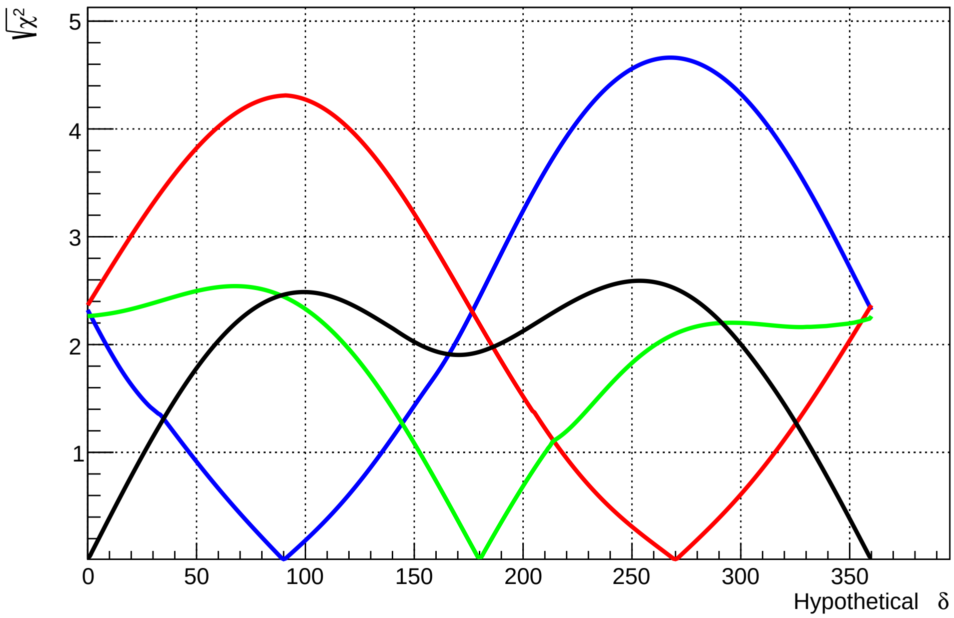

FIG. 2. Value of $\sqrt{\chi^2}$ as a function of hypothetical δ for $\delta = 0$ (black), $\pi/2$ (blue), π (green), $3\pi/2$ (red). Exposition 3 years. The antineutrino exposition 0.3 of total is added. In addition, the energy cut at 2 GeV is applied in the analysis. Energy resolution is 30%. The corresponding resolutions on δ measurements are: 27.9, 44.55, 28.8, 48.6 degrees.

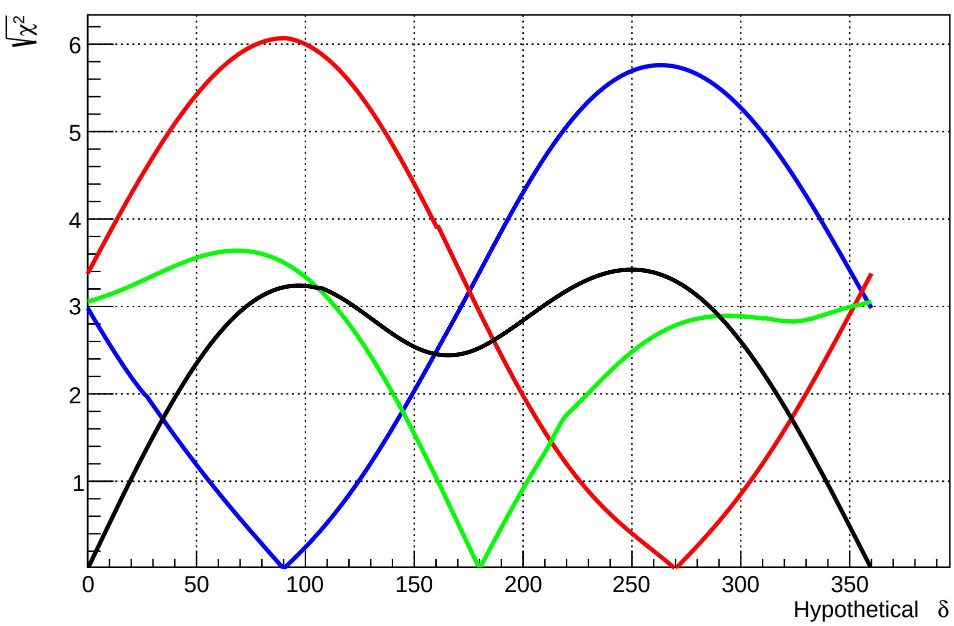

FIG. 3. Value of $\sqrt{\chi^2}$ as a function of hypothetical δ for $\delta = 0$ (black), $\pi/2$ (blue), π (green), $3\pi/2$ (red). Exposition 10 years. The antineutrino exposition 0.3 of total is added. In addition, the energy cut at 2 GeV is applied in the analysis. Energy resolution is 30%. The corresponding resolutions on δ measurements are: 19.8, 34.2, 20.7, 39.15 degrees.

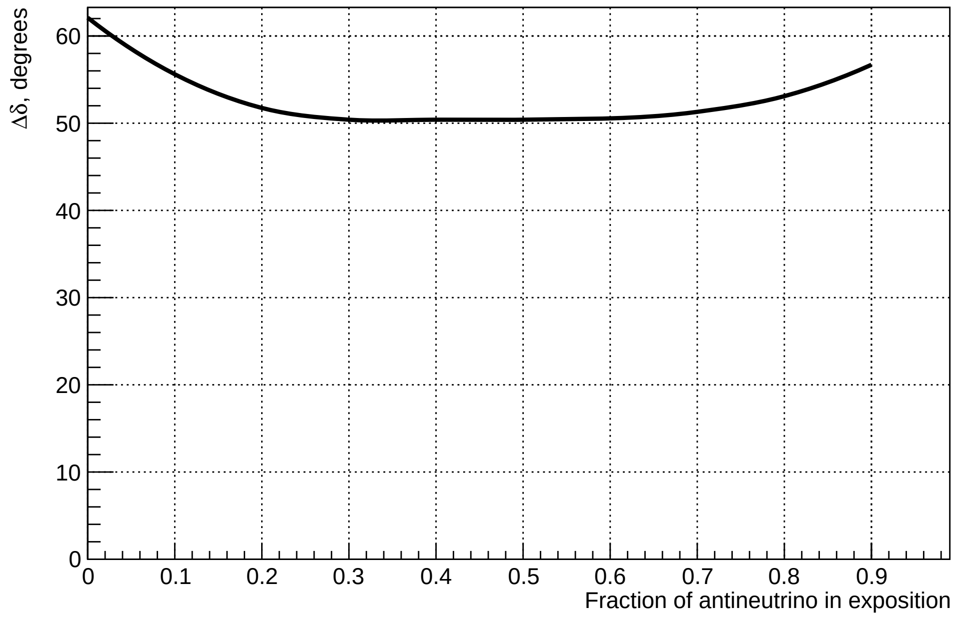

FIG. 4. Resolution of the δ CP measurement as a function of the antineutrino exposition fraction for the true value $\delta = 3\pi/2$.

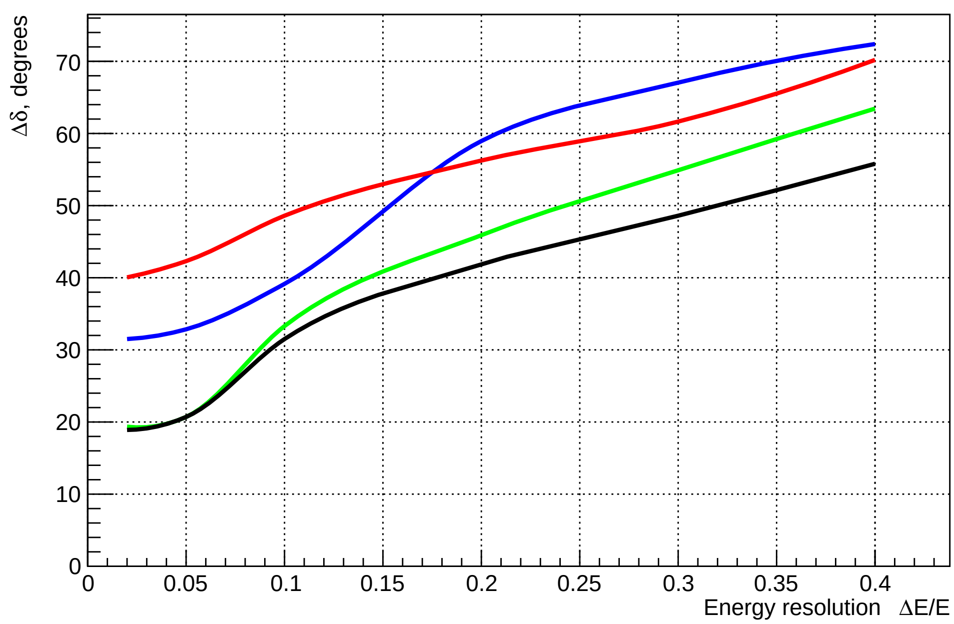

FIG. 5. Resolution of the δ CP measurement as a function of energy resolution for the true values $\delta = 0$ (black), $\pi/2$ (blue), π (green), $3\pi/2$ (red).

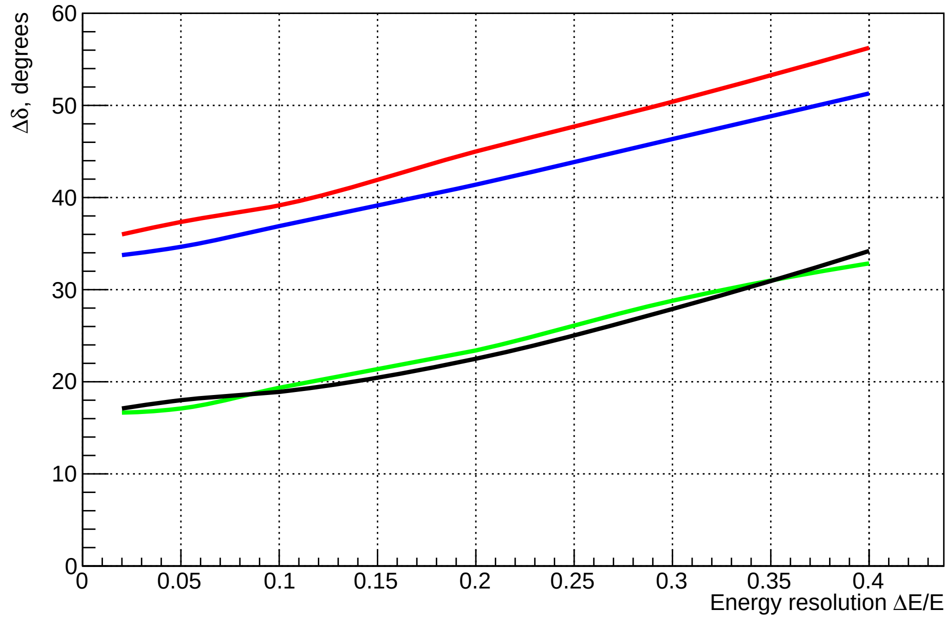

FIG. 6. Resolution of the δ CP measurement as a function of energy resolution for the true values $\delta = 0$ (black), $\pi/2$ (blue), π (green), $3\pi/2$ (red). Antineutrino exposition is used, energy window 2 - 10 GeV.

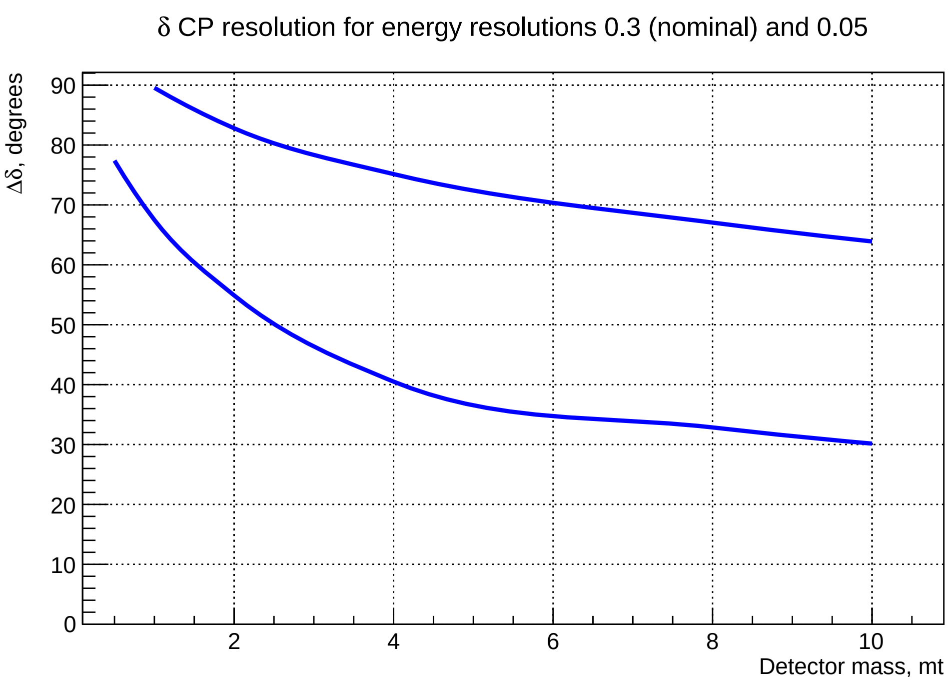

FIG. 7. Resolution of the δ CP measurement as a function of the detector mass for the true value $\delta = \pi/2$ and energy resolutions 0.3 (nominal value, upper curve) and 0.05 (lower curve).

[1] A. V. Akindinov *et al.*, Eur. Phys. J. C **79**, 758 (2019), arXiv:1902.06083 [physics.ins-det].
[2] S. Adrián-Martínez *et al.*, Journal of Physics G: Nuclear and Particle Physics **43**, 084001 (2016).
[3] M. Perrin-Terrin, The European Physical Journal C **82**, 10.1140/epjc/s10052-022-10397-8 (2022).