2D Reactor Constraints at T2K

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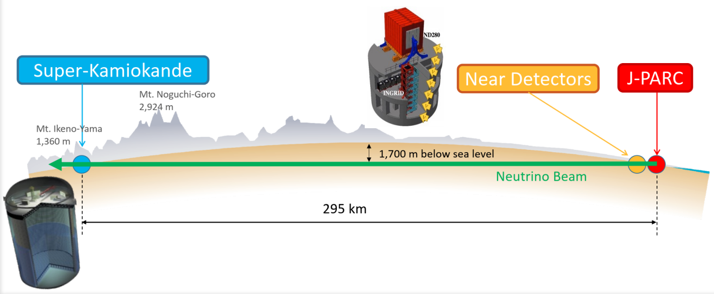
The T2K Experiment

Tokai-to-Kamiokande (T2K) is a long baseline off-axis neutrino oscillation experiment [1].

A beam of neutrinos is created at J-PARC, measured using the near detectors and then propagates through the earth's crust to Super-Kamiokande, a 50 kt water Cherenkov detector on the west coast of Japan.



MaCh3 and Reweighting

The three-neutrino Markov Chain fitter (MaCh3) is a Bayesian neutrino oscillation fitting program used by T2K.

Bayes formula is

$$P(M|D) = \frac{P(D|M)P(M)}{P(D)}.$$

Where we have a prior, $P(M)$, evidence, $P(D|M)$, normalised by the marginal probability, $P(D)$, to give a posterior $P(M|D)$.

MaCh3 uses a Markov Chain to explore the space of the distribution, but can take days/weeks, which is a problem if you want to test the effects of multiple priors on your analysis.

- To deal with this we can use **reweighting**, to test the effect of a prior without rerunning the entire chain, with the following formula

$$P(M_2|D) = \frac{P(D|M_1)P(M_1)}{P(D)} \frac{P(M_2)}{P(M_1)}$$

Reactor Constraints

While T2K has sensitivity to θ_{13}, the world best measurements of θ_{13} comes from the reactor anti-neutrino oscillation experiments (Daya Bay [2], Double Chooz [3] and RENO [4]).

It is common practice to apply the PDG combination from these experiments as a constraint on our measurements to improve our contours and break degeneracies.

Daya Bay Reactor Neutrino Experiment

Daya Bay is a reactor anti-neutrino oscillation experiment in China.

They measure the effective splitting [5]:

$$\Delta m^2_{ee} \approx \cos^2\theta_{12}|\Delta m^2_{31}| + \sin^2\theta_{12}|\Delta m^2_{32}|.$$

Recently they have published a 2D surface with correlation information between Δm^2_{32} and θ_{13} [2].

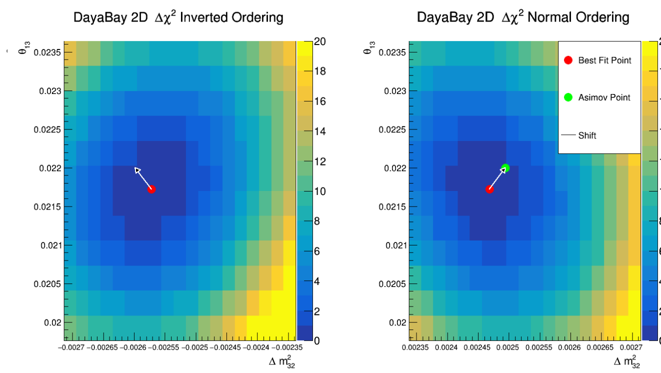
- First included as a prior via reweighting by E.A.G. Goodman as part of his thesis at the University of Glasgow [6].

Asimov Studies

We want to be able to work out the expected behavior of the fits before we run them on Data. We do this with Asimov studies, which pick a single representative point and fit against that (Here we chose "Asimov A22" the best fit point from a previous T2K oscillation analysis [7]).

The problem here is that the Asimov best fit point and the Daya Bay best fit point don't line up.

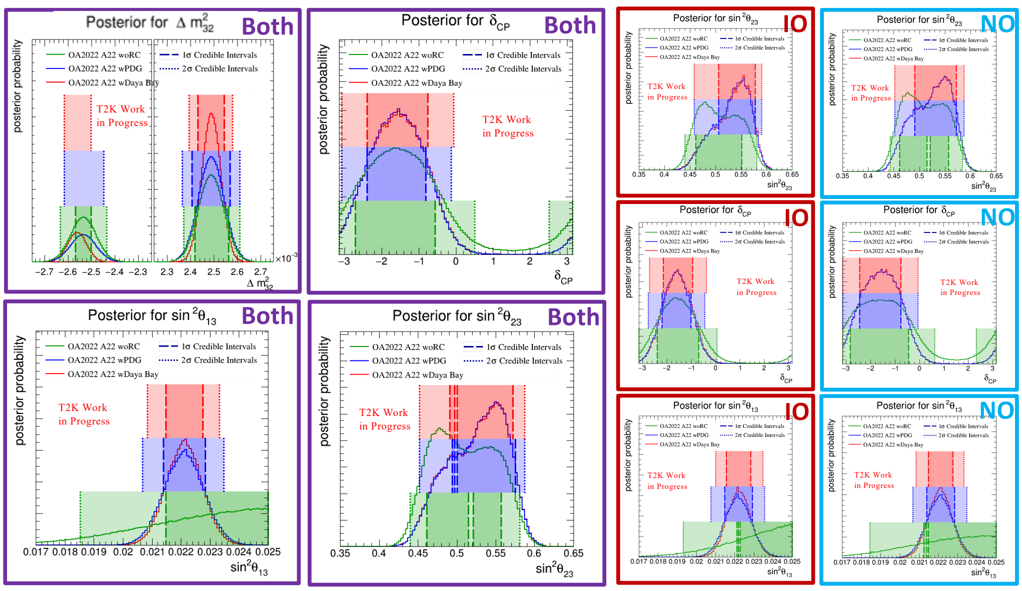
To fix this we maintain the shape of the Daya Bay surface, but shift the values so that the best fit point of the NO Daya Bay surface aligns with the Asimov A22 point as shown here:



Results:

Both Orderings
Normal Ordering
Inverted Ordering

- Improved constraints on both θ_{13} and Δm^2_{32}.
- In normal ordering we only see change in δ_{CP} and $\cos^2\theta_{23}$ at the level of sampling fluctuations.
- In inverted ordering, we see larger shifts in the confidence intervals – due to the tensions between Daya Bay and T2K's best fit point in inverted ordering.
- We see an enhancement in Normal ordering preference (but this was expected since we aligned the NO surface with the T2K best fit point).



Next steps:

- Direct comparison of Daya Bay 1D against Daya Bay 2D (as opposed to PDG 1D shown here).

References: [1] The T2K Collaboration, Nuc. Instruments & Methods **659**, 106-135 (2011). **[2]** Daya Bay Collaboration, Phys. Rev. Lett. **130**, 161802 (2023).
[3] Double Chooz Collaboration, Acta Phys. Polon. B **37**, 2027 (2006). [4] RENO Collaboration Phys. Rev. Lett. 121, 201801 [5]. H. Minakata et al. Phys. Rev. D **74**, 053008 (2006).
[6] E. A. G. Goodman, University of Glasgow 10.5525/gla.thesis.84120 (2024). [7] T2K Collaboration, Eur. Phys. J. C 83.9, p. 782 (2023).