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Sterile Neutrino Sensitivity at DUNE

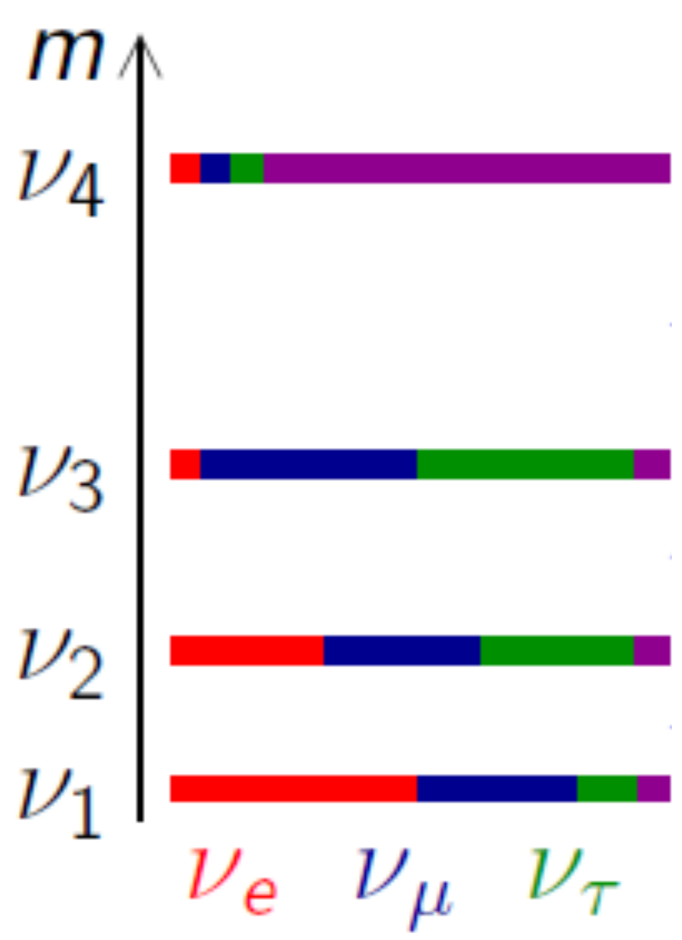
Simulation

The code for the simulation here was written in C using the GLoBES library[1]. The simulation involved two specifications; one for the near detector and the other for the far detector. Both of these simulations were combined, and then a chi squared test was performed to compare a null and alternative hypothesis concerning mass ordering and the existence of a sterile neutrino.

The code used in the simulation here can be found by scanning the QR code in the bottom right hand corner of this poster.

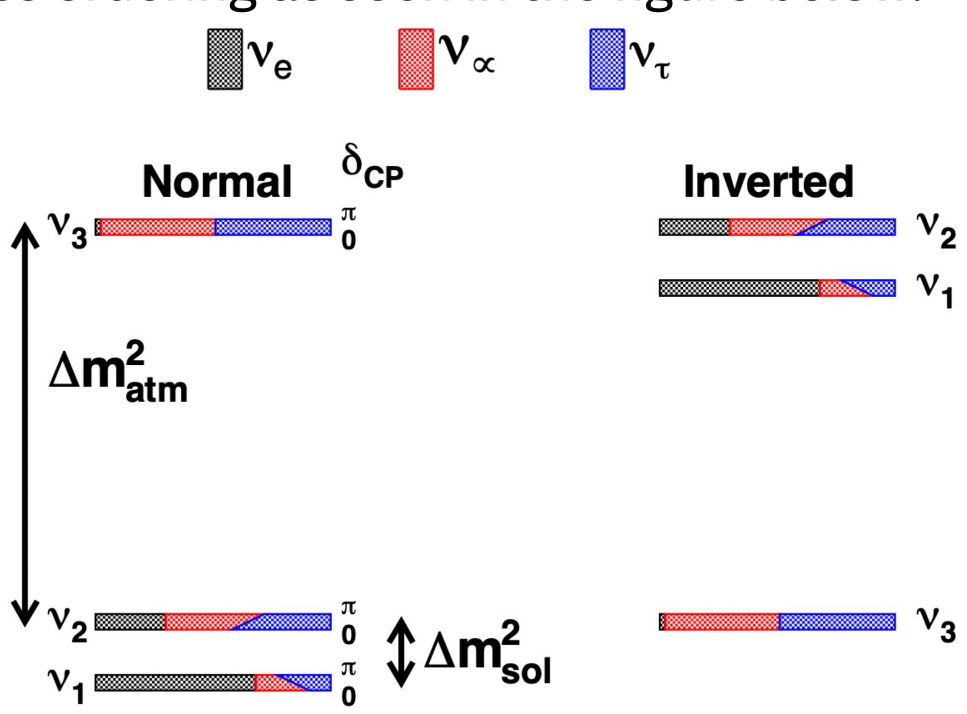
Sterile Neutrinos

In the standard model there are three neutrino flavours: electron muon and tau. These can oscillate between each other when propagating as they propagate as mass eigenstates (not flavour eigenstates). Introducing a fourth heave, sterile (no interaction with the weak force)[2] neutrino results in alterations to the oscillation probabilities. Mass splitting terms refer to the difference in masses squared between states.



Mass ordering

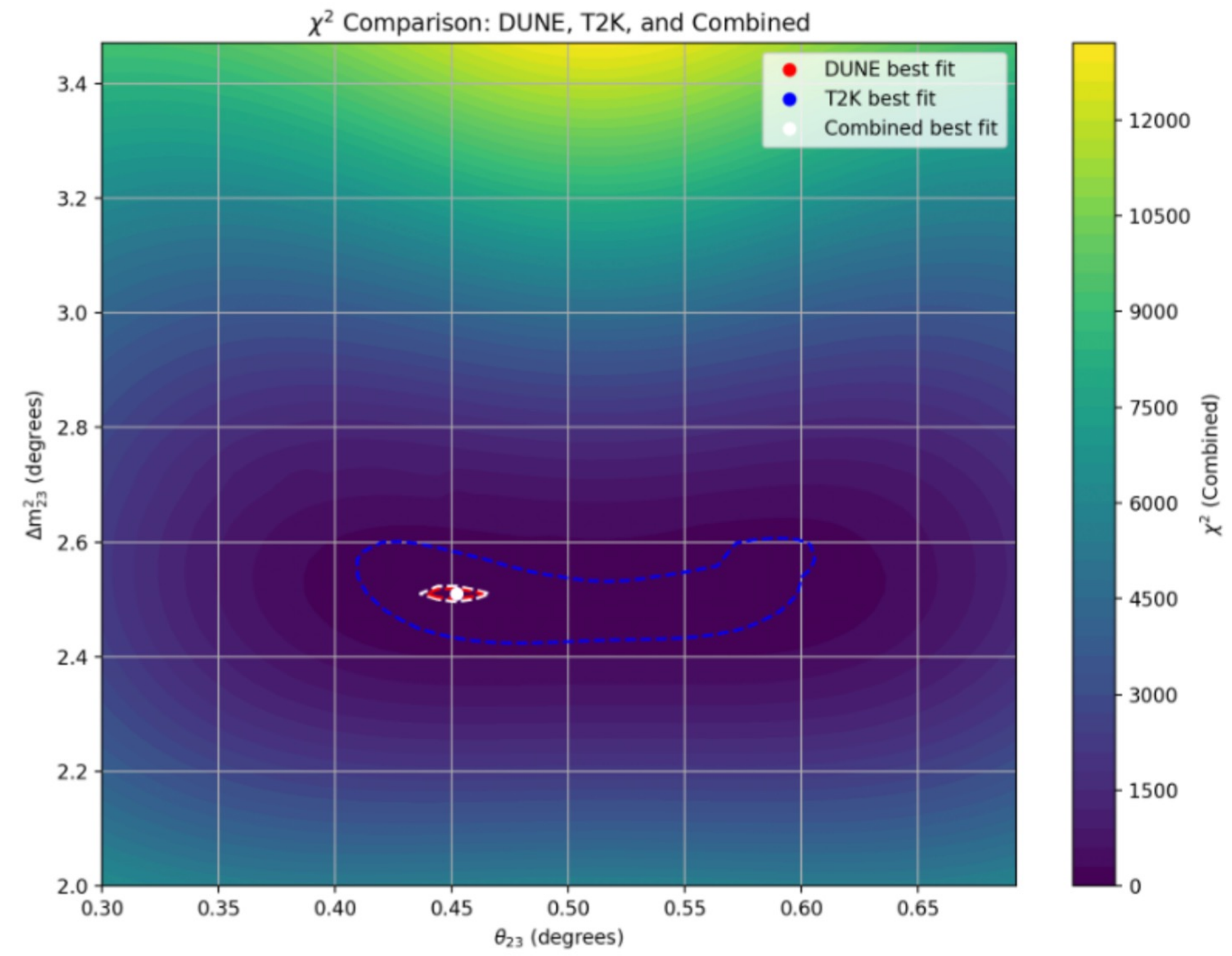
Mass ordering refers to how heavy the neutrino mass eigenstates are in relation to each other. In the three-neutrino model there are two options: normal mass ordering, and inverted mass ordering as seen in the figure below:[3]



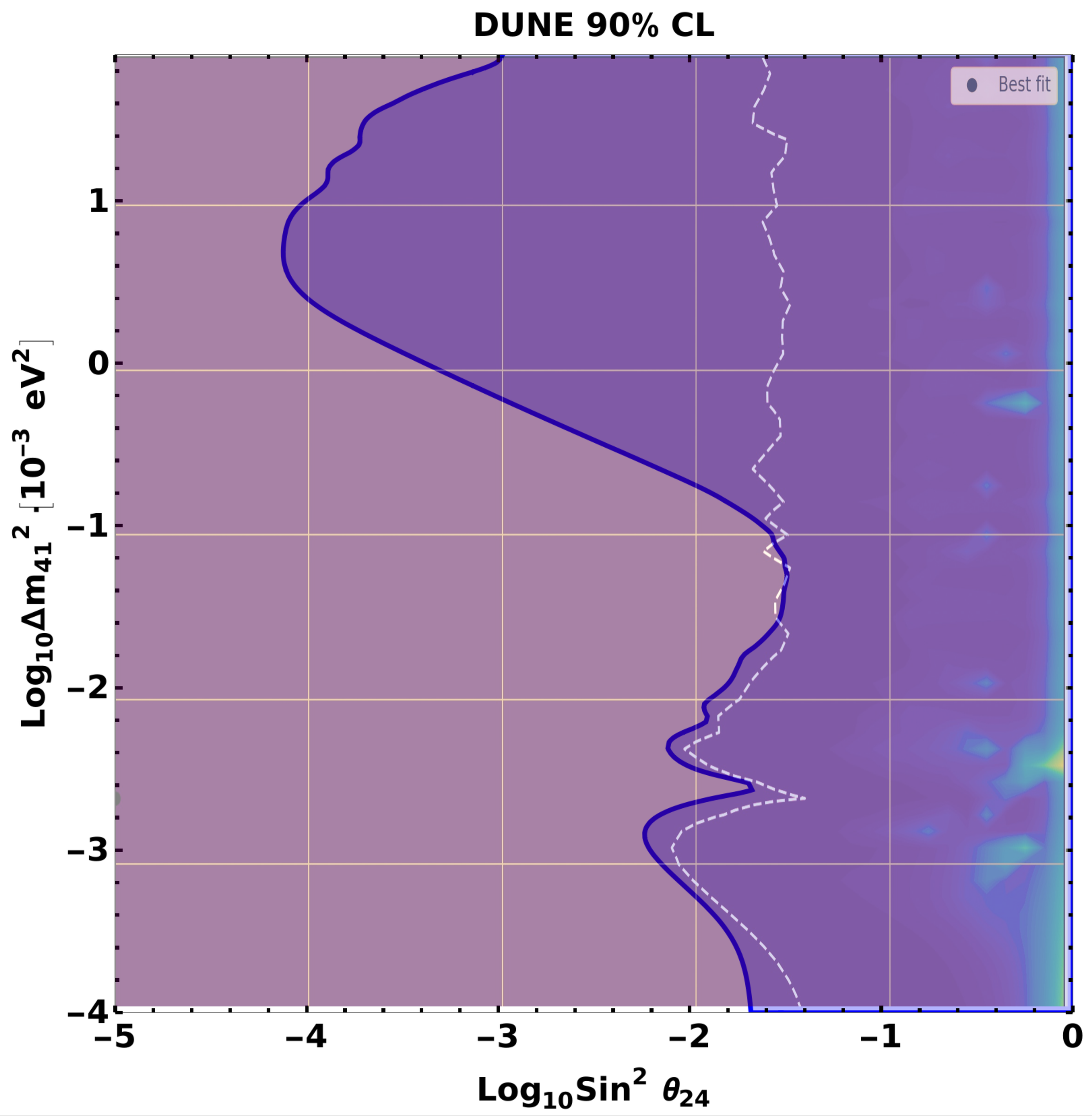
Mass states are a superposition of flavour states and vice versa. The size of the atmospheric mass splitting term is known within some constraints, but this still leaves two distinct possibilities.

Results

Comparing normal mass ordering to inverted mass ordering at DUNE (red) shows a remarkable increase in sensitivity compared to previous neutrino experiments, such as T2K (blue):



Now with a null hypothesis of a standard 3-neutrino model, and an alternative hypothesis of a 3+1 sterile neutrino model, a chi squared test was performed and the sensitivities to the oscillation parameters Δm^2_{41} and $\sin^2\theta_{24}$. The sensitivity just considering the far detector is shown by the white dotted line, whereas combining the near and far detector gives increased sensitivity (in blue).



Conclusions

DUNE has much improved sensitivity to both mass ordering and sterile neutrino oscillation parameters when compared to previous experiments. Graphs were verified by comparing to the technical design report[4]. The particular increase regarding sterile neutrinos can be attributed to the near detector specifically. This is because of several factors:

- High statistics at the near detector
- The short baseline meaning L/E is around 0.01 to 1eV – the sterile neutrino has probabilities will have maximal effect at the specific beam energy and baseline length found in the near detector resulting in the very large increase in sensitivity

There are however some drawbacks. In the lower section of the graph there is a visible large decrease in sensitivity at a particular value – which can be attributed to the atmospheric mass splitting term Δm^2_{23} becoming very close in value to Δm^2_{41} - meaning it becomes hard to differentiate between the values and hence the loss in sensitivity.

Overall, with a ten-year exposure length DUNE will be able to much improve the current constraints on neutrino oscillation parameters, and most likely rule out a sterile neutrino as the answer for LSND's reactor anomaly.

References

[1] GLoBES Manual: https://www.mpi-hd.mpg.de/personalhomes/globes/documentation/globes-manual-2.1.pdf (retrieved 28th May 2025)
[2] Sterile Neutrinos https://www.nevis.columbia.edu/daedalus/motiv/sterile.html (retrieved 7th July 2025)
[3] X. Qian, P. Vogel (2015) Neutrino Mass Hierarchy. *PPNP*, 83, 1-30
[4] DUNE Far Detector Technical Design Report Volume II (2020) *ArXiv* 2002.03005

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