Latest Constraints on Three-Flavor Neutrino Oscillation Parameters from the NOvA Experiment

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Abstract. NOvA, is a two-detector, long-baseline neutrino oscillation experiment located at Fermilab, Batavia, IL, USA. The NOvA experiment was designed primarily to constrain neutrino oscillation parameters by analyzing $\nu_\mu(\bar{\nu}_\mu)$ disappearance and $\nu_e(\bar{\nu}_e)$ appearance data observed at the far detector using a high purity beam of neutrinos and anti-neutrinos from Fermilab's NuMI beamline. The NOvA experiment consists of two functionally identical, finely granulated liquid tracking calorimeters, both situated 14.6 mrad off-axis to the beam direction. The NOvA near detector, situated 100 meters underground and 1 kilometer from the beam source, detects the non-oscillated $\nu_\mu(\bar{\nu}_\mu)$ and beam $\nu_e(\bar{\nu}_e)$ events. The far detector, located in Ash River, MN, USA, 810 kilometers from the beam source, records the non-oscillated $\nu_\mu(\bar{\nu}_\mu)$ and the oscillated $\nu_\mu(\bar{\nu}_\mu) \to \nu_e(\bar{\nu}_e)$ events. The most recent measurements of three flavor neutrino oscillation parameters based on an analysis of the data collected from neutrino-beam exposure of 26.60×10^{20} POT and anti-neutrino beam exposure of 12.50×10^{20} POT including an additional low energy ν_e sample, will be discussed here.

1 Introduction

The NOvA experiment [1, 2] is a long-baseline neutrino oscillation experiment situated at Fermilab, IL, USA, that observes $\nu_\mu(\bar{\nu}_\mu) \to \nu_\mu(\bar{\nu}_\mu)$ disappearance and $\nu_\mu(\bar{\nu}_\mu) \to \nu_e(\bar{\nu}_e)$ appearance oscillations. The experiment consists of two segmented and functionally equivalent detectors filled with pseudocumene-based liquid scintillators [3] both situated 14.6 mrad off-axis to the NuMI [4] beam direction. The most recent measurement of neutrino oscillation parameters from neutrino-beam exposure of 26.60×10^{20} POT and anti-neutrino beam exposure of 12.50×10^{20} POT including an additional low energy ν_e sample will be discussed here. The standard 3-flavor neutrino oscillation analysis strategy is outlined in section 2. Section 3 highlights the results from most recent analysis of the NOvA data. Finally, the document is being summarized in section 4.

2 The Analysis Strategy

We perform a combined fit of the far detector data across all oscillation channels[4] using simulations adjusted via a data-driven technique called extrapolation which makes use of the high-statistics near detector $\nu_\mu/\bar{\nu}_\mu$ data to correct far detector simulations [5, 2]. The most recent three-flavor neutrino analysis was carried out on data collected between 2014 and 2024, equivalent to neutrino-beam exposure of 26.60×10^{20} POT and anti-neutrino beam exposure of 12.50×10^{20} POT including a low energy ν_e sample [5]. Figure 1 shows the distributions of the observed $\nu_\mu(\bar{\nu}_\mu)$ disappearance and $\nu_e(\bar{\nu}_e)$ appearance data and predictions at the far detector.

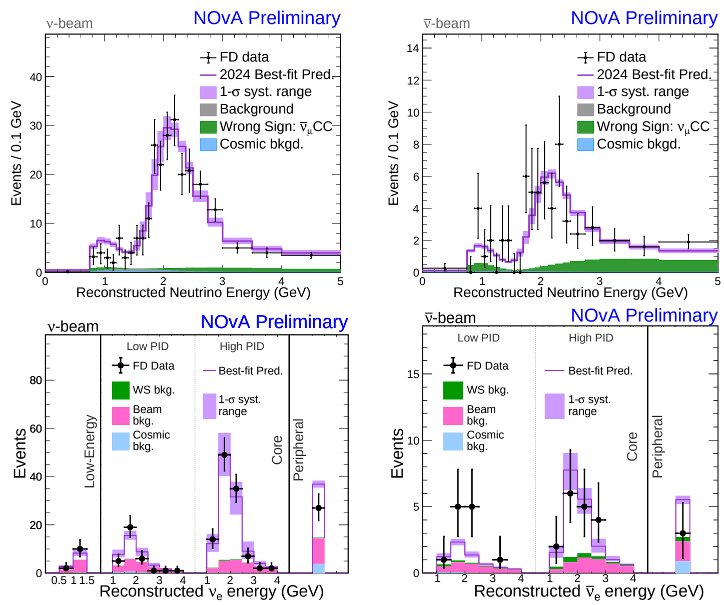

Fig. 1. The observed and simulated data at the far detector with $\pm 1\sigma$ systematic uncertainty bands. The $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ appearance spectra are split in bins of purity including the low energy ν_e sample.

3 Results

Figure 2 shows Δm^2_{32} and $\sin^2(\theta_{23})$ contours at 90% confidence limit from NOvA and other experiments e.g. IceCube, T2K, NOvA+T2K and SK+T2K joint analyses. NOvA's latest measurement of Δm^2_{32} and $\sin^2(\theta_{23})$ are consistent with measurements from the rest of the experiments. Figure 3 shows the 1σ $\sin^2\theta_{23}$

[4] $\nu_\mu \to \nu_\mu$, $\bar{\nu}_\mu \to \bar{\nu}_\mu$, $\nu_\mu \to \nu_e$, and $\bar{\nu}_\mu \to \bar{\nu}_e$

and δ_{CP} Bayesian credible intervals marginalized separately over normal and inverted mass orderings. The combined fit disfavor $\delta_{CP} = 3\pi/2$ in normal mass ordering and $\delta_{CP} = \pi/2$ in inverted mass ordering at 1σ confidence level. NOvA data prefer normal mass ordering over inverted mass ordering with an enhancement in the preference with 1D and 2D reactor constraints as shown in figure 4. NOvA's precision of 1.4% on atmospheric mass squared splitting Δm^2_{32}, is the best precise single-experiment measurement of the value.

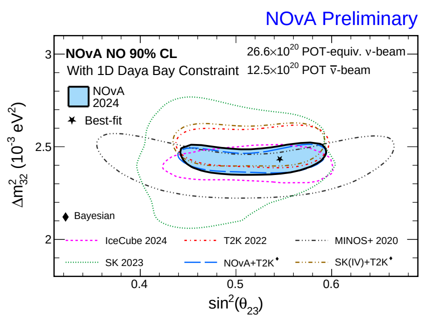

Fig. 2. The Δm^2_{32} and $\sin^2(\theta_{23})$ contours at 90% confidence limit from NOvA and other atmospheric and accelerator-based experiments.

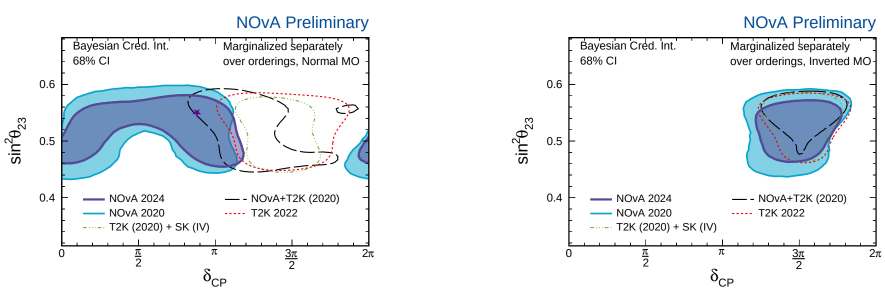

Fig. 3. The Bayesian $\sin^2\theta_{23}$ and δ_{CP} credible intervals at 1σ confidence level marginalized separately over both mass orderings overlaid with the allowed regions from other experiments.

4 Summary

The most recent results from 3-flavor neutrino oscillation analysis using data collected from 2014 and 2024 which to neutrino-beam exposure of 26.60×10^{20} POT and anti-neutrino beam exposure of 12.50×10^{20} POT were discussed.

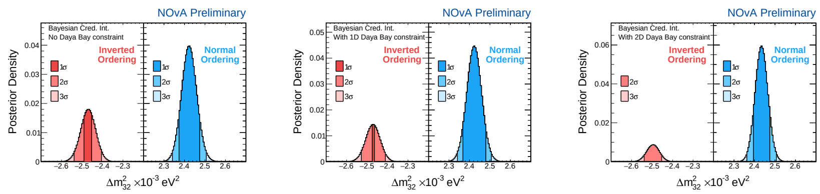

Fig. 4. The Δm^2_{32} posterior density distributions for both mass orderings from NOvA data: without any reactor constraints (left), with 1D reactor constraint (middle), and 2D reactor constraint (right) on θ_{13}.

The joint fit of the far detector data suggests that NOvA's latest measurement of Δm^2_{32} and $\sin^2(\theta_{23})$ are consistent with the measurements from the rest of the experiments. NOvA data disfavor $\delta_{CP} = \frac{3\pi}{2}$ in normal mass ordering and $\delta_{CP} = \frac{\pi}{2}$ in inverted mass ordering at 1σ confidence level with a mild preference to normal mass ordering over inverted mass ordering. NOvA achieved the most precise single-experiment measurement of the atmospheric mass squared splitting Δm^2_{32}, attaining a precision of 1.4%.

5 Acknowledgements

I would like to thank "Indian Institutions - Fermilab Collaboration in Neutrino Physics" through DST letter No. SR/MF/PS-01/2016-DU/G dated 28.03.2019 under which this collaboration on NOvA experiment has been made possible and work done. I would also like to thank the Council of Scientific & Industrial Research (CSIR), Ministry of Science and Technology, Govt. of India, for providing research fellowship from August 2019 - September 2023. This document was prepared by NOvA collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, Office of High Energy Physics HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

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