3 flavor oscillation analysis of 10 years of NOvA data

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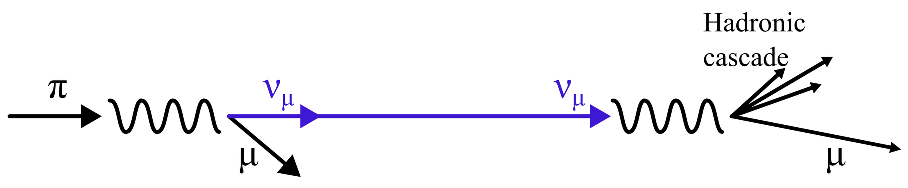
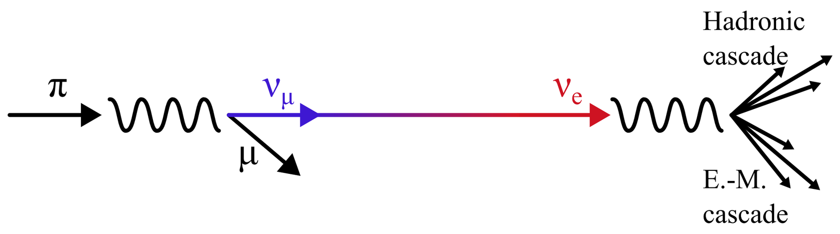
1. The NOvA experiment

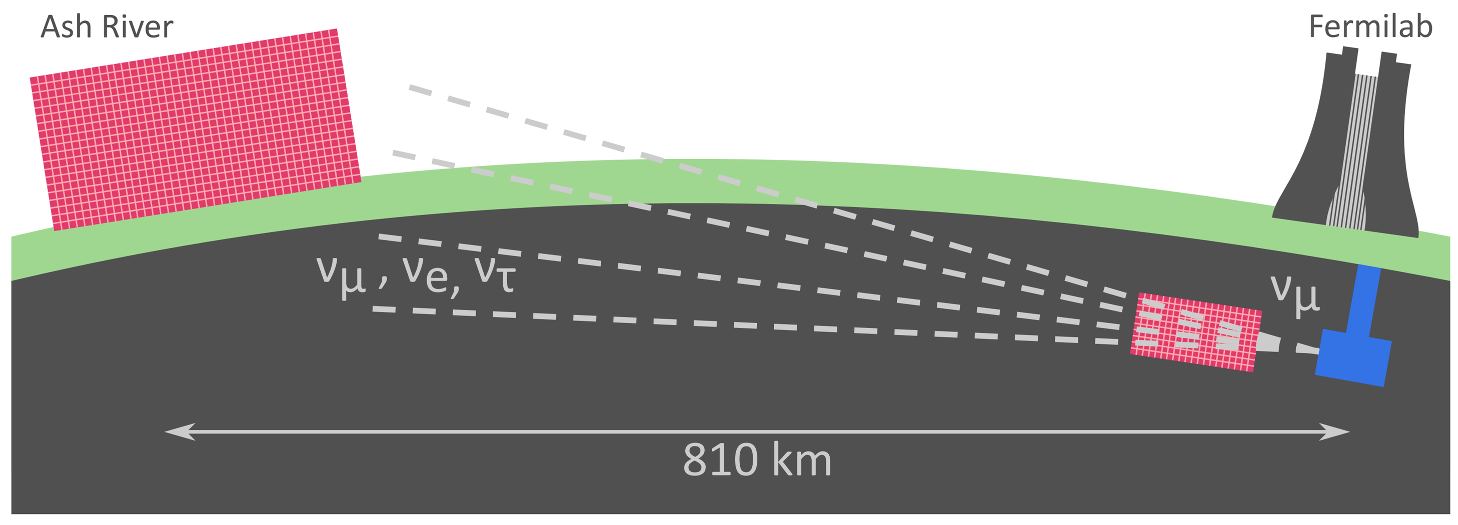
- NOvA is a long-baseline off-axis neutrino oscillation experiment in US.
- Neutrino source is Fermilab's Megawatt-capable NuMI beam.
- Two functionally identical, finely granulated detectors, filled with liquid scintillator.



ν_μ disappearance
mass splitting Δm^2_{32}, mixing angle θ_{23}

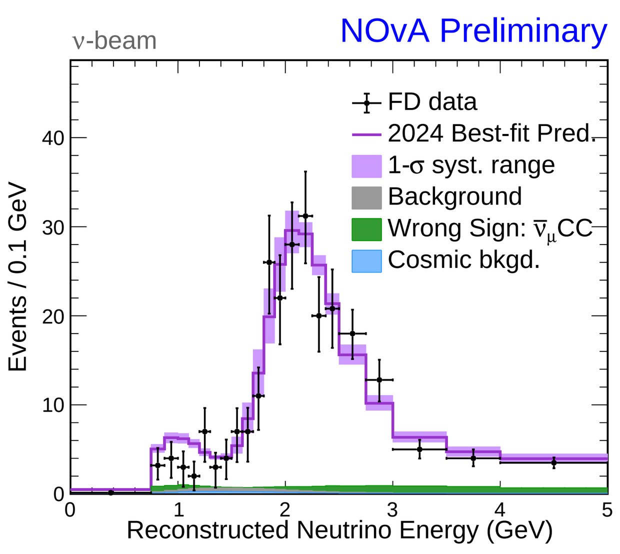


ν_e appearance
CP-violation, ν mass ordering (MO), θ_{23} octant, mixing angle θ_{13}

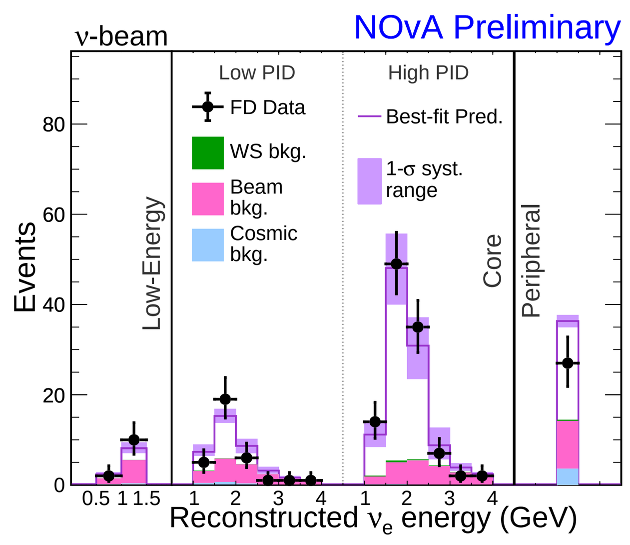


2. New data

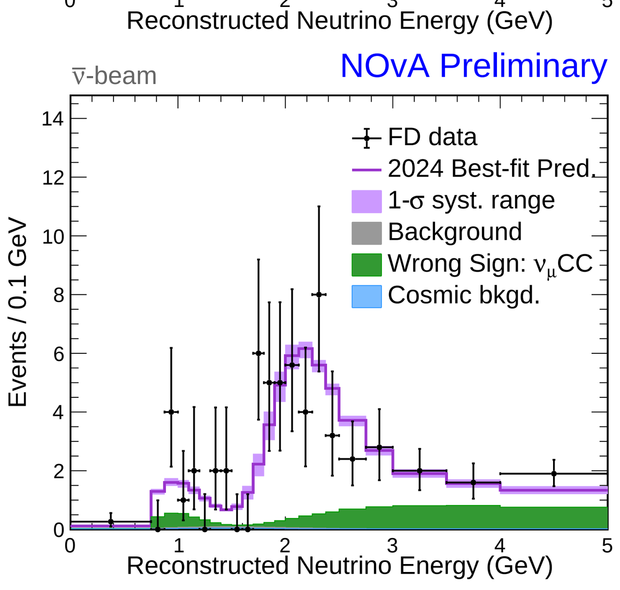
- The neutrino data have been doubled, comparing to analysis in 2020 [1]. The summed exposure is 26.6 × 10^{20} protons on target (POT).
- The exposure of antineutrino data is 12.5 × 10^{20} POT.
- New selection algorithm is to reclaim low energy ν_e events between 0.5 and 1.5 GeV.



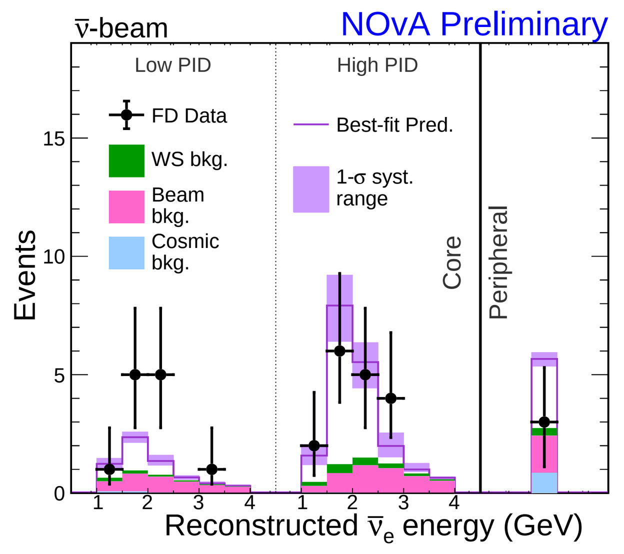
Observed 384
Tot. bkg. 11.0



Observed 181
Tot. bkg. 62.5



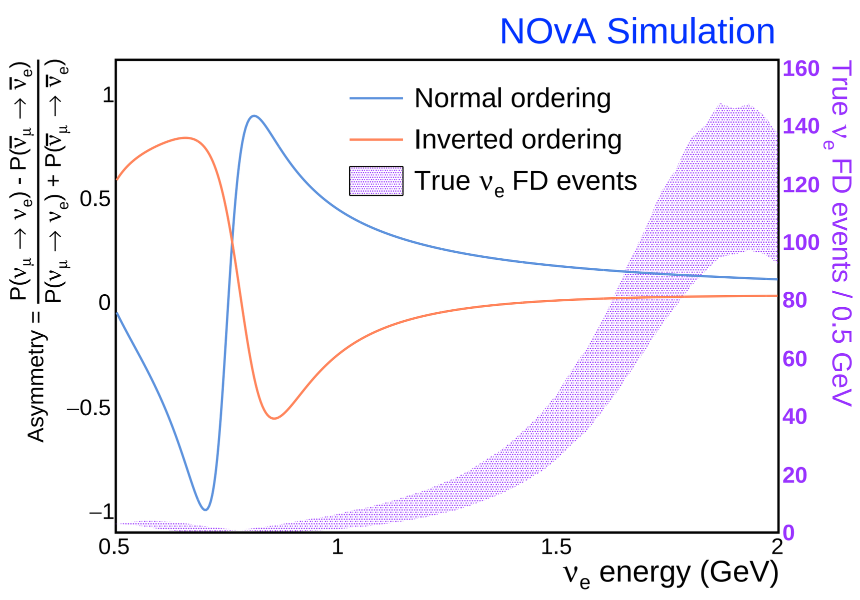
Observed 106
Tot. bkg. 1.7



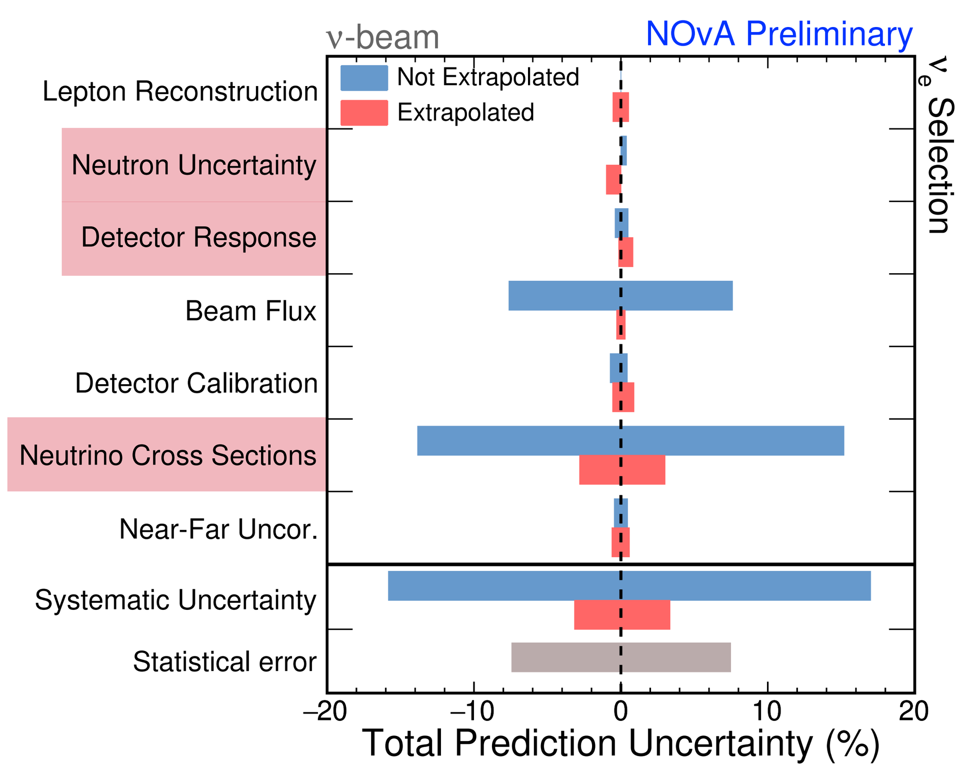
Observed 32
Tot. bkg. 12.2

3. Low energy ν_e events

- The oscillation asymmetry function exhibits significantly different behavior at low energy, depending on whether the neutrino mass ordering is normal or inverted.
- A brand new, independent sample designed to slightly improve the mass ordering sensitivity.
- 12 ν_e candidates were observed, with expected background 7.1.



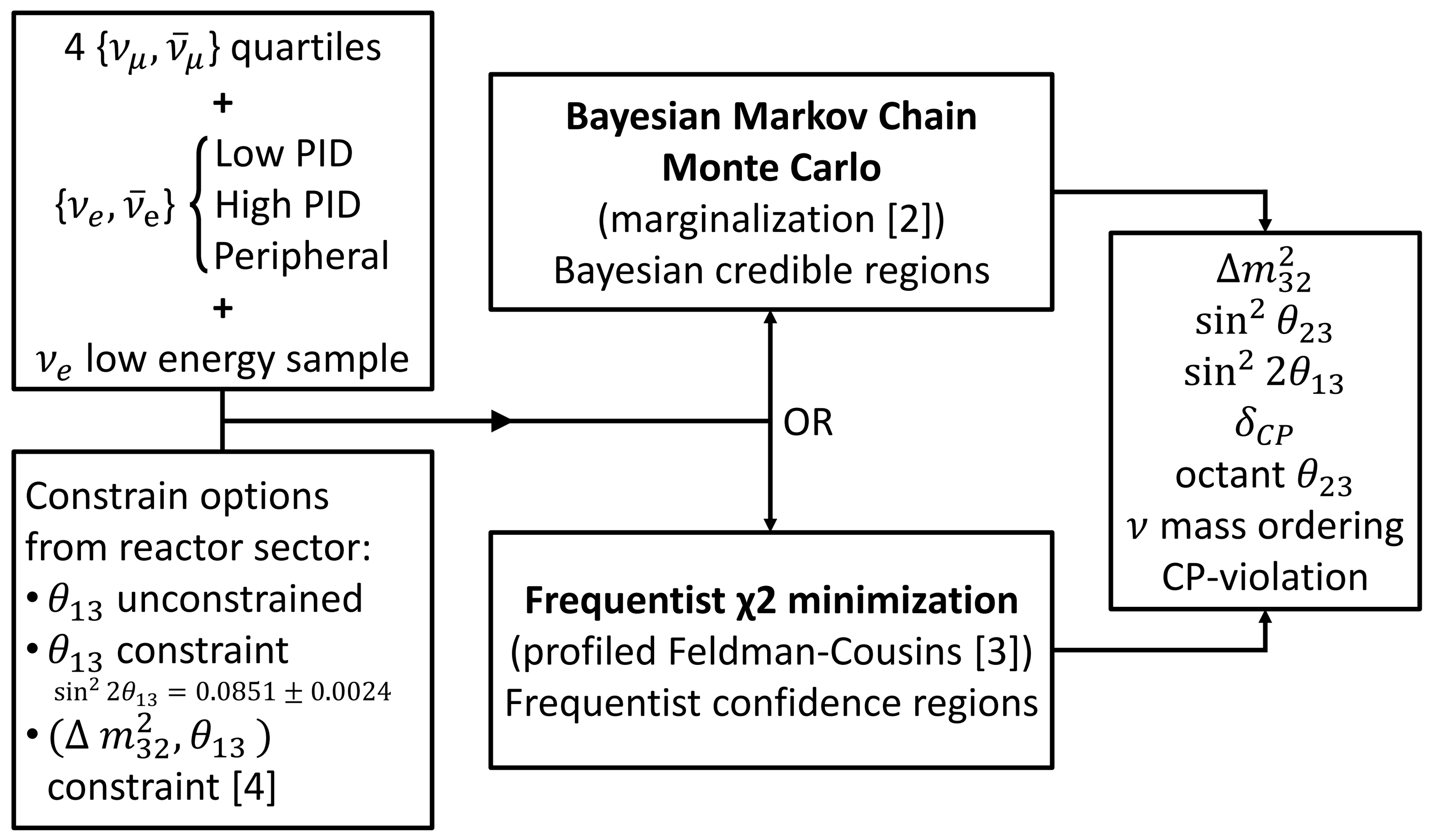
4. Systematics uncertainties



- A new pion-production syst. unc., an improved light response model and a neutron propagation uncertainty.
- Using an extrapolation procedure, Near Detector constraints reduce the syst. unc. in the Far Detector predictions from ∼ 18% to ∼ 4%.
- Statistical uncertainties are dominant in the oscillation measurement.

5. Far detector fitting procedure

- A simultaneous fit of all samples is performed, using Bayesian [2] or Frequentist [3] techniques.
- External constraints are used for the solar parameters and optionally reactor constraint on θ_{13} from Daya Bay [4].

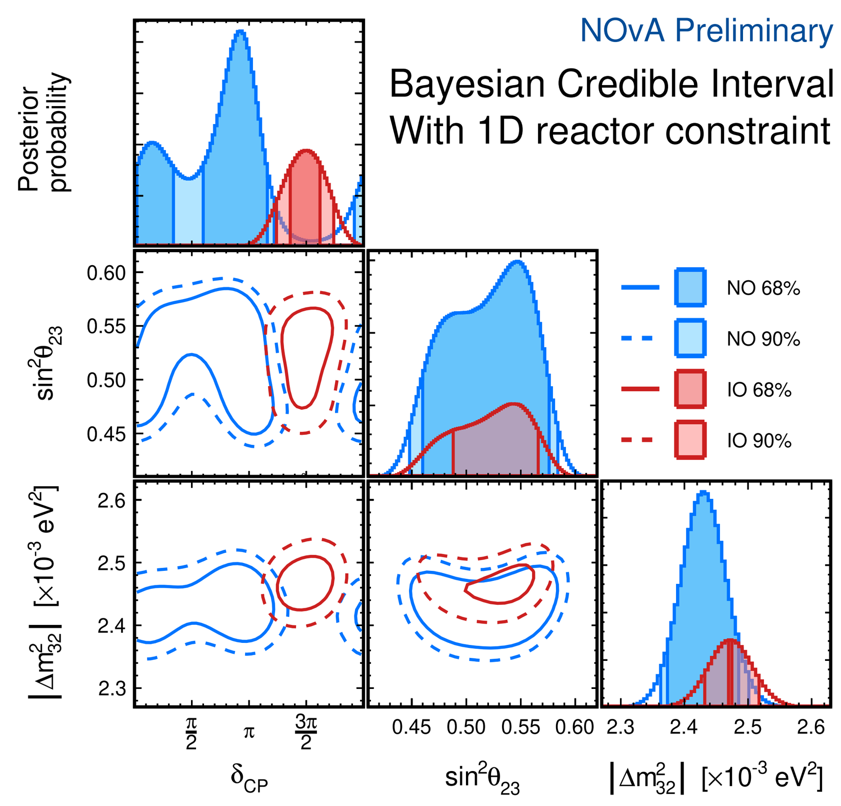


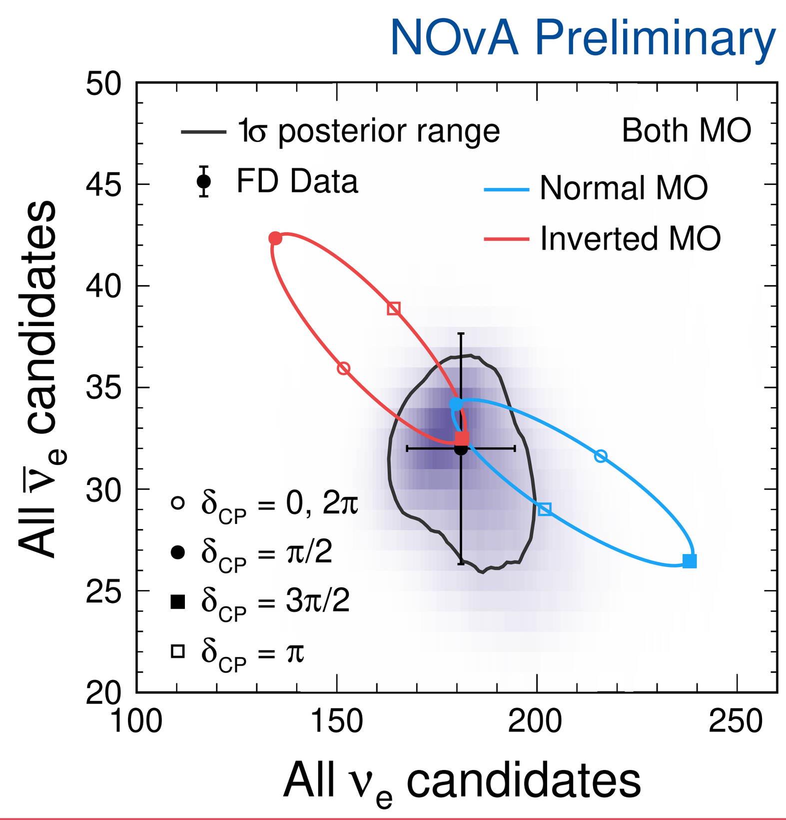
6. Analysis results

- The highest posterior density points and 1σ ranges for δ_{CP}, $\sin^2\theta_{23}$, and Δm^2_{32} with Daya Bay one-dimensional (1D) constraint on $\sin^2 2\theta_{13}$:

Parameter	Normal ordering (NO)	Inverted ordering (IO)
$\delta_{CP}(\pi)$	0.93 [0.04; 0.30], [0.62; 1.14]	1.49 [1.30; 1.70]
$\sin^2\theta_{23}$	0.550 [0.484; 0.566]	0.550 [0.484; 0.566]
$\Delta m^2_{32}(\times 10^{-3}\text{eV}^2)$	2.429 [2.405; 2.469]	-2.477 [-2.533; -2.469]

- The new NOvA result is consistent with the previous one [2].
- Data prefer CP-conserving values for normal MO and CP-violating for inverted MO.
- With 1D reactor constraints on θ_{13}:
  - normal MO is preferred at 77% posterior probability, corresponding to a Bayes factor of 3.3;
  - upper octant of θ_{23} is preferred at 68% (2.2 Bayes factor).
- NOvA has achieved a new world-leading precision of 1.5% uncertainty for Δm^2_{32} measured in a single experiment.
- Data disfavor regions with large $\nu_e/\bar{\nu}_e$ asymmetry.





References

[1] M. A. Acero et al. Improved measurement of neutrino oscillation parameters by the NOvA experiment. *Phys. Rev. D*, 106(3):032004, 2022.
[2] M. A. Acero et al. Expanding neutrino oscillation parameter measurements in NOvA using a Bayesian approach. *Phys. Rev. D*, 110(1):012005, 2024.
[3] M. A. Acero et al. The Profiled Feldman-Cousins technique for confidence interval construction in the presence of nuisance parameters. *arXiv:2207.14353*, 2024.
[4] F. P. An et al. Precision Measurement of Reactor Antineutrino Oscillation at Kilometer-Scale Baselines by Daya Bay. *Phys. Rev. Lett.*, 130(16):161802, 2023.

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