Bayesian Fit for the NOvA Three Flavor Oscillation Analysis

Ben Jargowsky [1] and Liudmila Kolupaeva [2] (for the NOvA Collaboration)

[1]University of California, Irvine and [2]JINR

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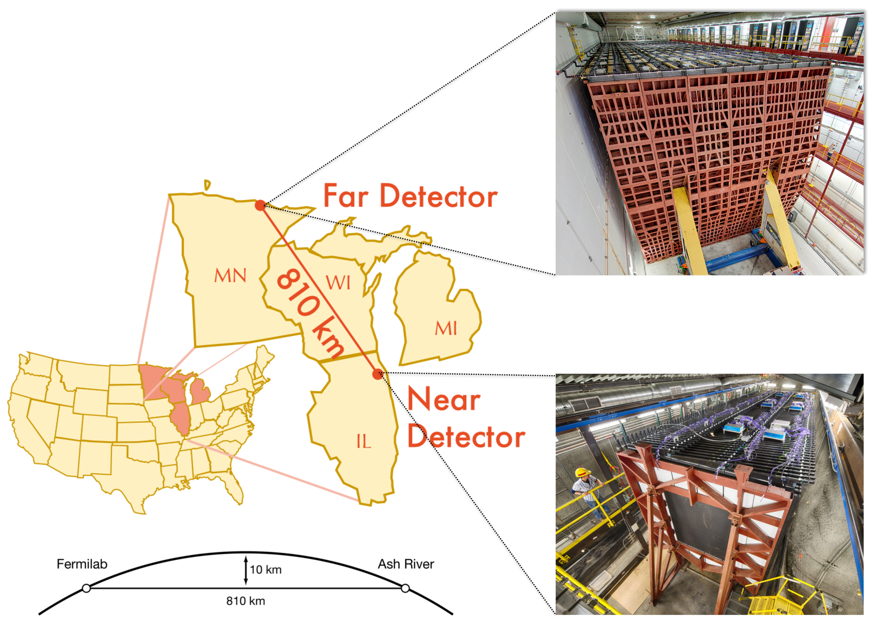
The NOvA Experiment

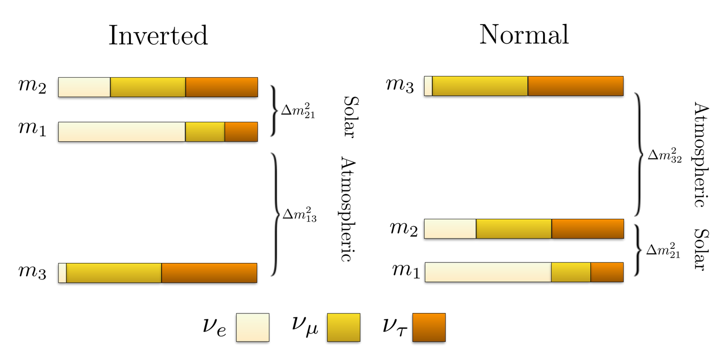
The NOvA experiment is a long baseline neutrino oscillation experiment utilizing the world's most powerful ν_μ ($\bar{\nu}_\mu$) beam—the NuMI beam at Fermilab.

- Two functionally identical detectors (Far and Near).
- Fine-grained, low-Z liquid scintillator calorimeters.
- 14 mrad off the NuMI beam axis.



Physics motivations for studying ν_e ($\bar{\nu}_e$) appearance and ν_μ ($\bar{\nu}_\mu$) disappearance:

- Determine Neutrino Mass Hierarchy.
- Probe δ_{CP} violating phase.
- Resolve the octant of θ_{23} mixing angle.
- Precise measurement of Δm^2_{32}.

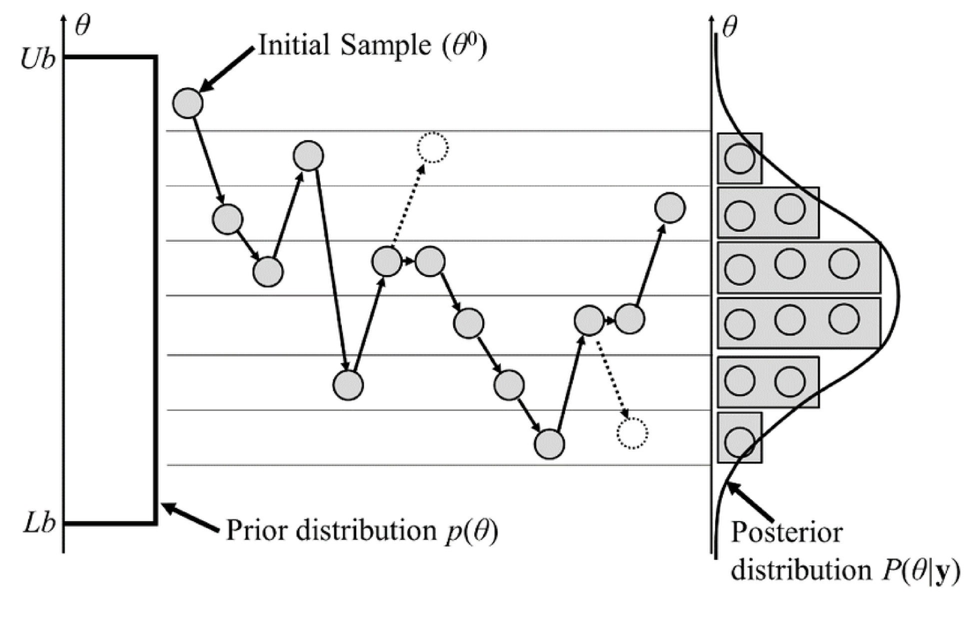


Markov Chain Monte Carlo (MCMC) for Bayesian Analysis

Bayes theorem in practice:

$$P(\theta|Data) = \frac{f(\theta)\mathcal{L}(data|\theta)}{\int f(x)\mathcal{L}(data|x)dx}$$

MCMC is a method to efficiently sample from a distribution by randomly choosing a new sample point based on the last point.



(image taken from L. Jaewook et. al. (2015). Energies. 10.3390/en8065538.)

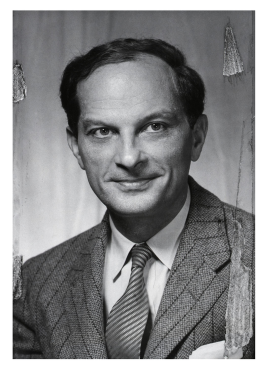
NOvA has implemented two different MCMC methods to its analysis:

- "ARIA": MR^{2}T^2 Algorithm – The Metropolis–Rosenbluth–Rosenbluth–Teller–Teller algorithm
- "Stan": Hamiltonian Monte Carlo

We choose uniform priors for the oscillation parameters, except $sin^2 2\theta_{13}$, which is constrained with measurements from reactor experiments.

NOvA's Bayesian MCMC Fitter was also used for the first NOvA+T2K analysis (see poster 463).

ARIA named after Arianna Rosenbluth

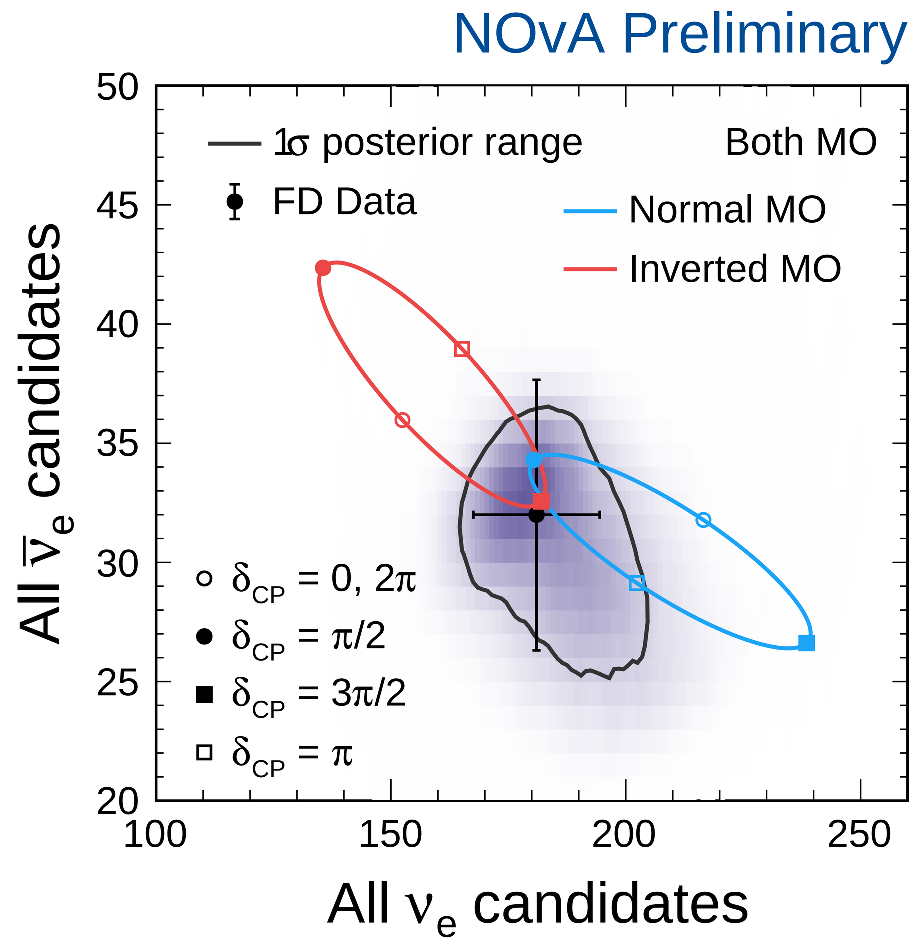


Stan named after Stanislaw Ulam

New NOvA 3Flavor Results in 2024

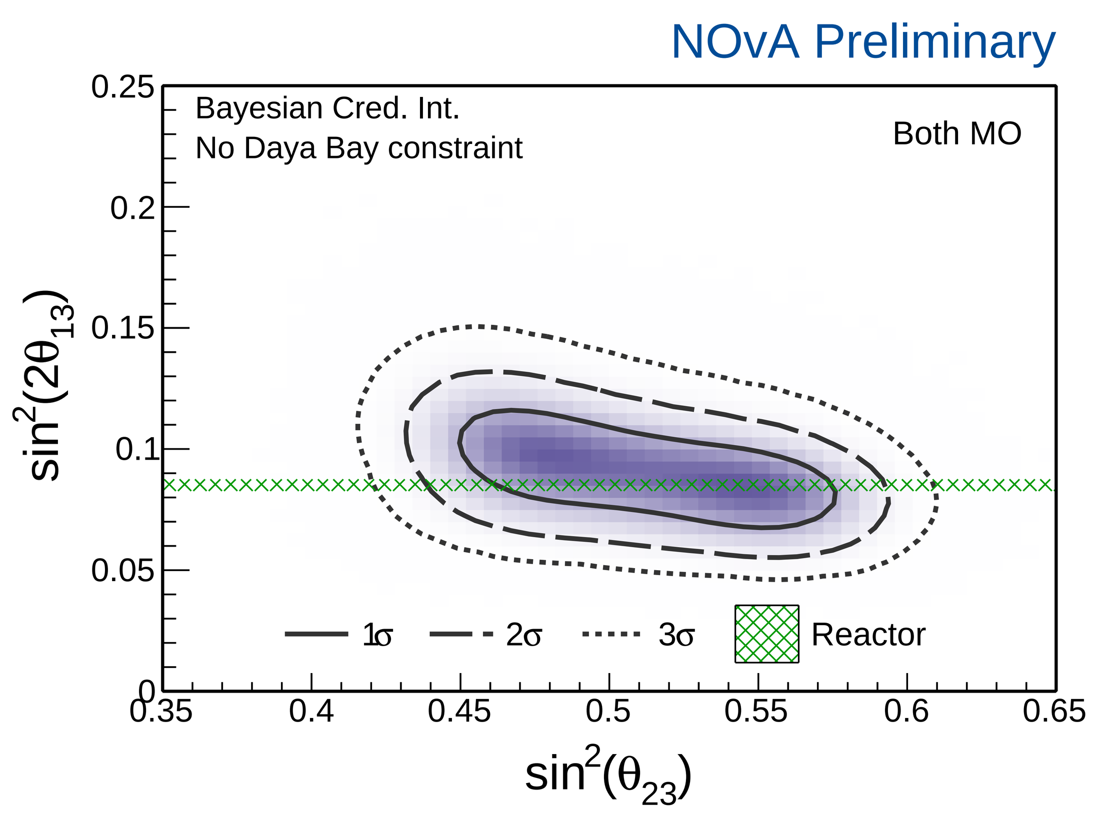
This year NOvA presents new three-flavor results obtained with 26.6 $\times 10^{20}$ POT with ν beam and 12.5 $\times 10^{20}$ POT with $\bar{\nu}$ beam (+95.6% more statistics with ν beam than in 2020).
For more details see J. Wolcott's plenary talk.
Accompanying this result, there is a Frequentist result presented at this conference, see poster 456.

	Neutrino beam				Antineutrino beam
	ν_μ	ν_e	ν_e LE	$\bar{\nu}_\mu$	$\bar{\nu}_e$
Signal	398.2	121.6	2.9	96.7	18.2
Background	11.3	54.9	6.8	1.7	12.2
Total pred	409.5	176.5	9.7	98.4	30.4
Observed	384	169	12	106	32
P-values:	0.68	0.65	0.82	0.45	0.20

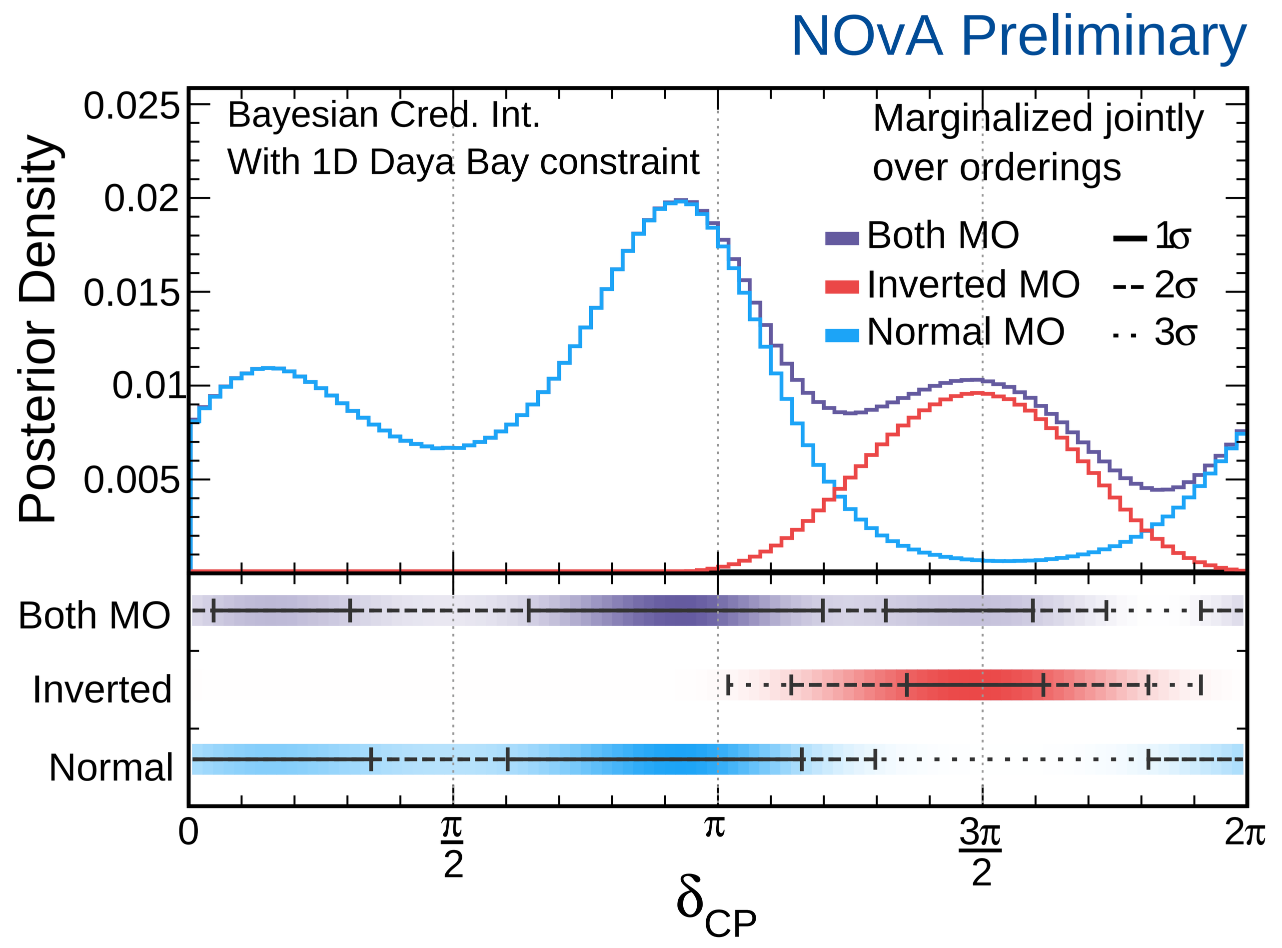


Mixing Angles

Without including an external constraint on θ_{13}, we can make a measurement of θ_{13} with NOvA data alone, showing consistency with reactor experiments' measurements. Here, the prior for $sin^2 2\theta_{13}$ is uniform.
NOvA prefers the upper octant, with 69% for the 1D reactor constraint. Without reactor constraint the octant preference changes.



δ_{CP} and Mass Ordering



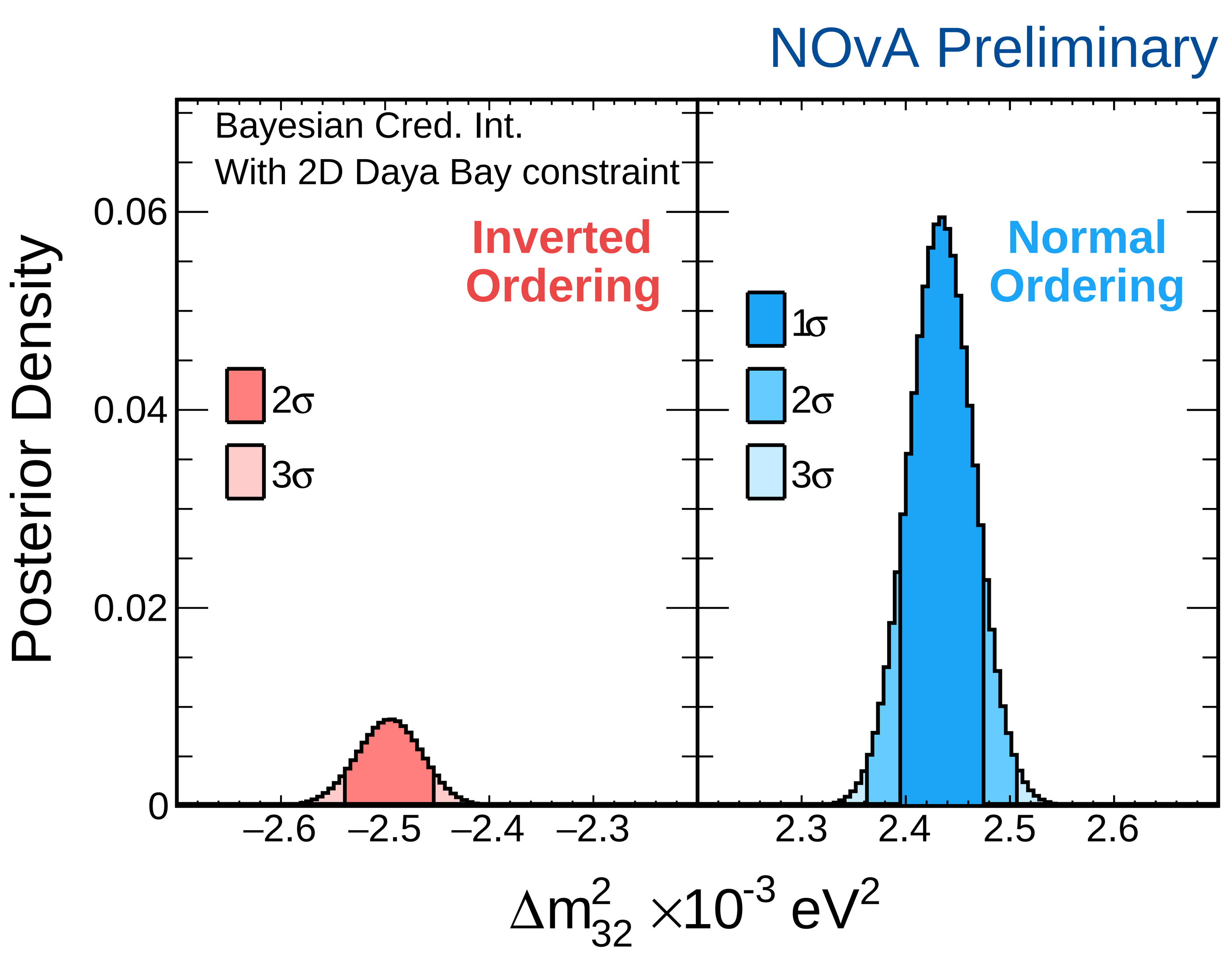
NO disfavors max CP violating points $\frac{\pi}{2}$ and $\frac{3\pi}{2}$ at >1 and >2 σ, respectively.

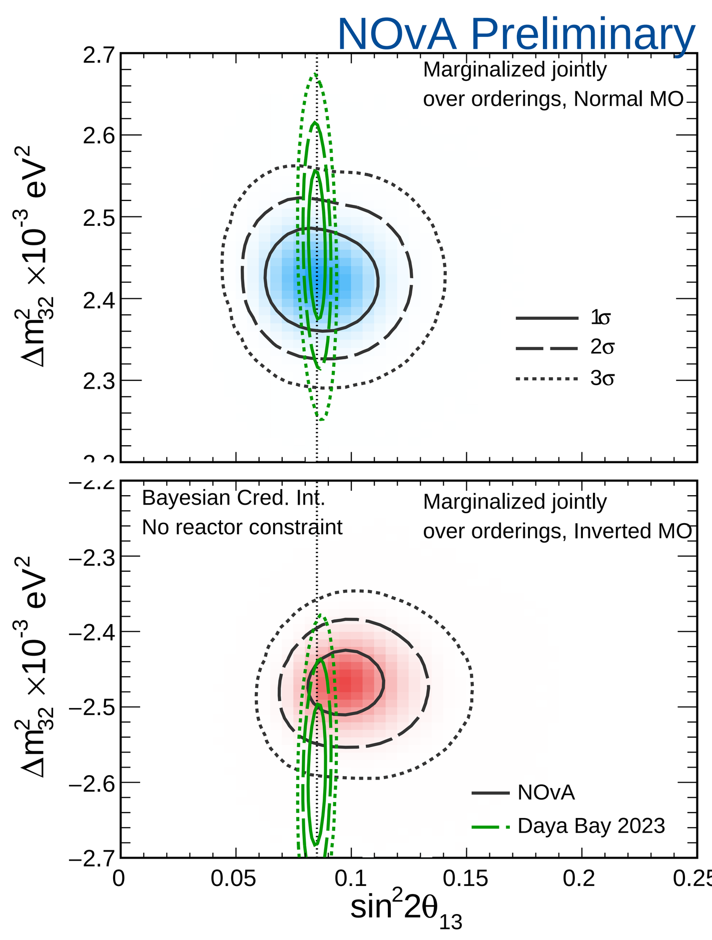
IO rejects CP conserving points, as well as $\frac{\pi}{2}$, at >3 σ.

We apply the constraint to $sin^2 2\theta_{13}$ from Daya Bay two ways:

- As a prior for $sin^2 2\theta_{13}$ only (the "1D" reactor constraint)
- As a prior for $sin^2 2\theta_{13}$ vs Δm^2_{32} from Daya Bay's 2D surface (the "2D" reactor constraint)

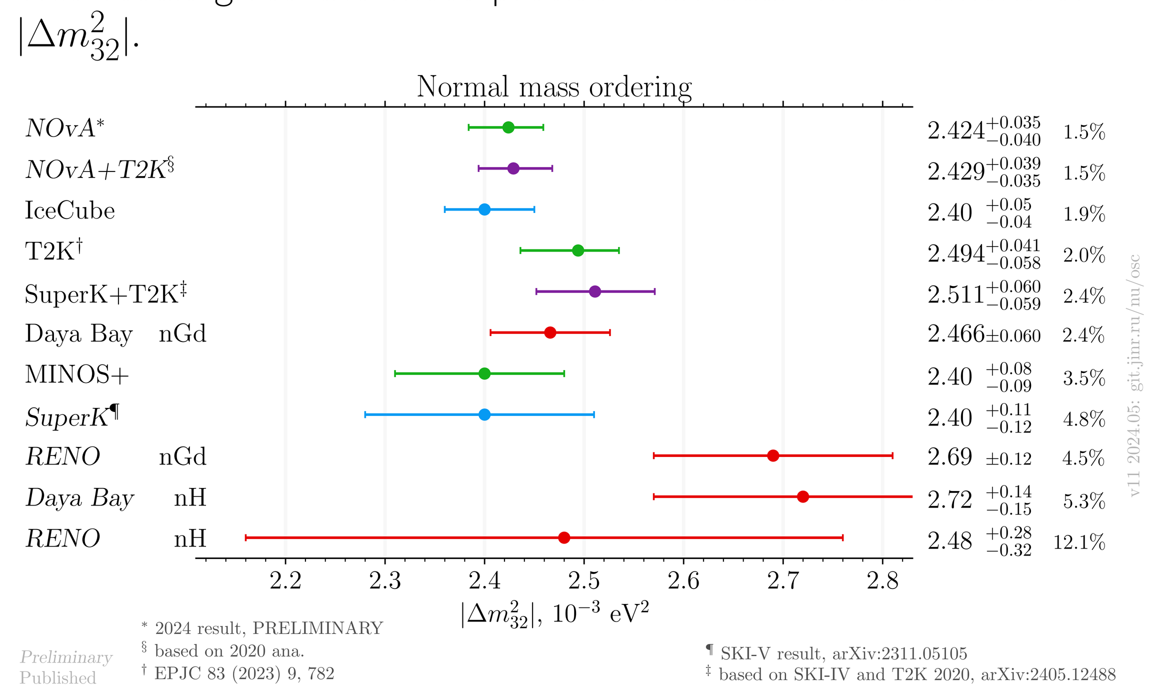
With the 1D constraint, we have 76% NO, and with 2D, we have 87% NO.



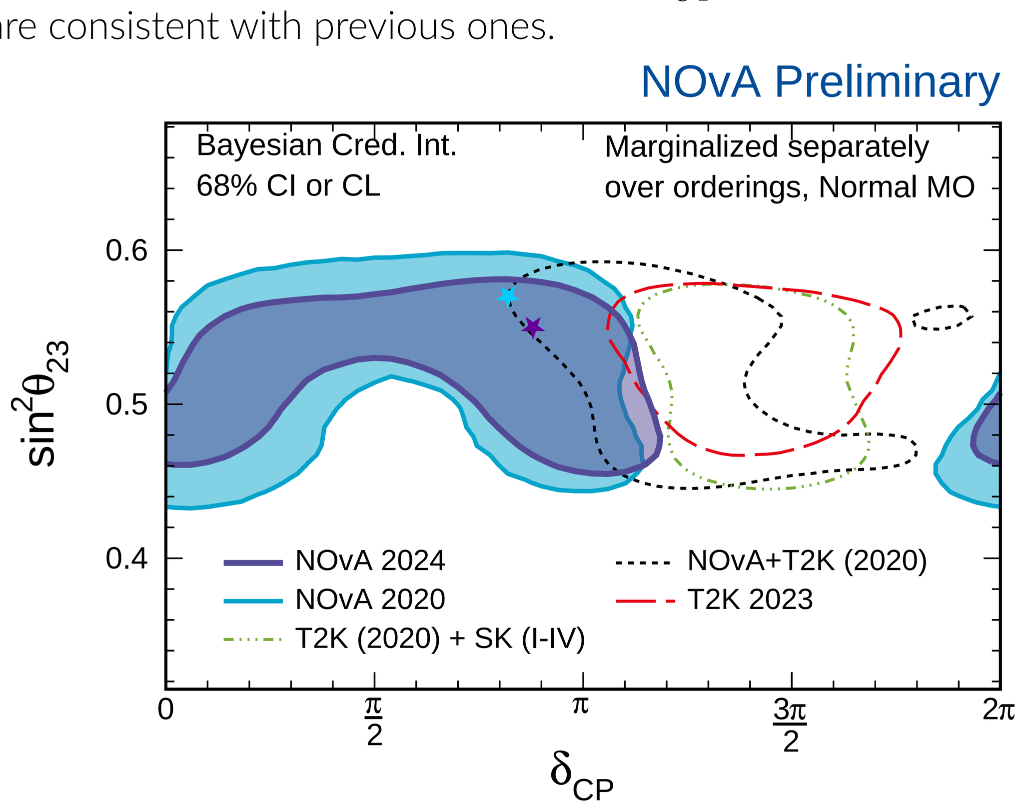


Result Comparisons with Other Experiments

This result gives the most precise individual measurement of $|\Delta m^2_{32}|$.



NOvA and T2K favor different values of δ_{CP}. New NOvA results are consistent with previous ones.



bjargows@uci.edu, kolupaeva@jinr.int