Recent Results of T2K and NOvA and their joint fit

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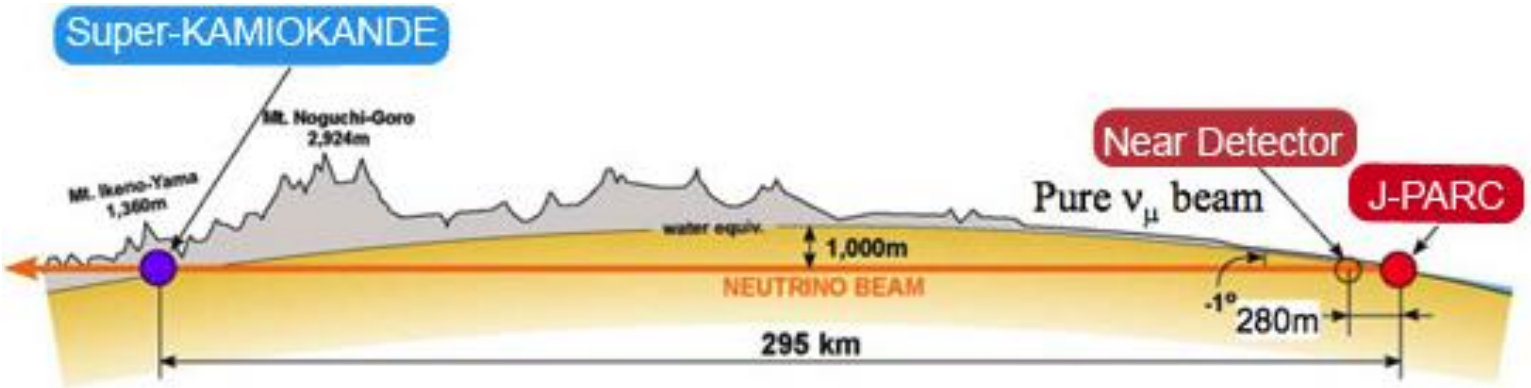
MAPS in-person meeting
IRB, Zagreb, 29 June - 3 July 2026

Current Experiments

Designed such that: $\Delta m^2_{31}\ L$ / E $= \frac{\pi}{2}$



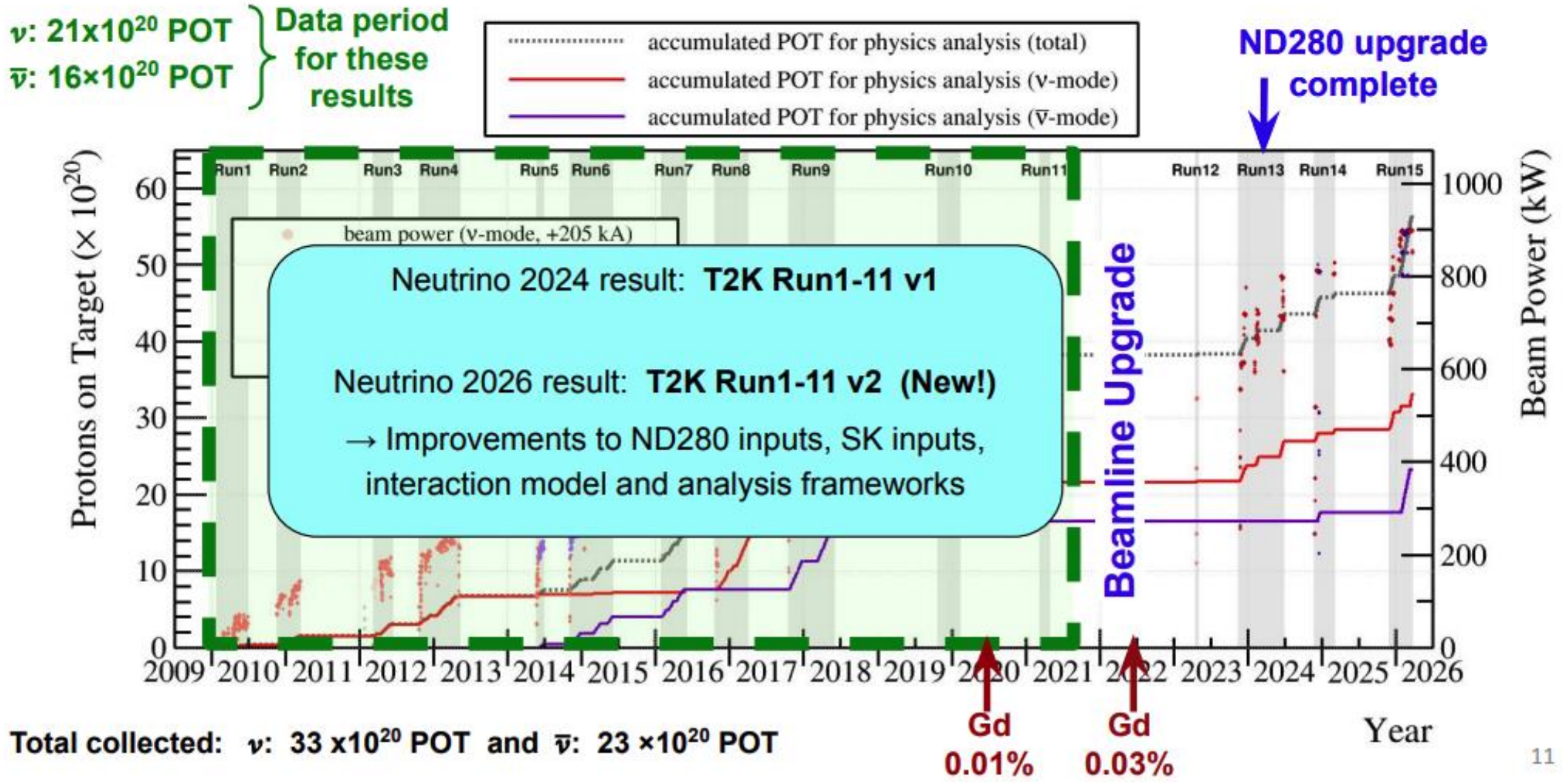
T2K in Japan: 295 km, 0.6 GeV

NOvA in USA: 800 km, 2 GeV

T2K POT

Sophie King, Neutrino 2026

Collected Data: Protons on Target (POT)



T2K Cross-section

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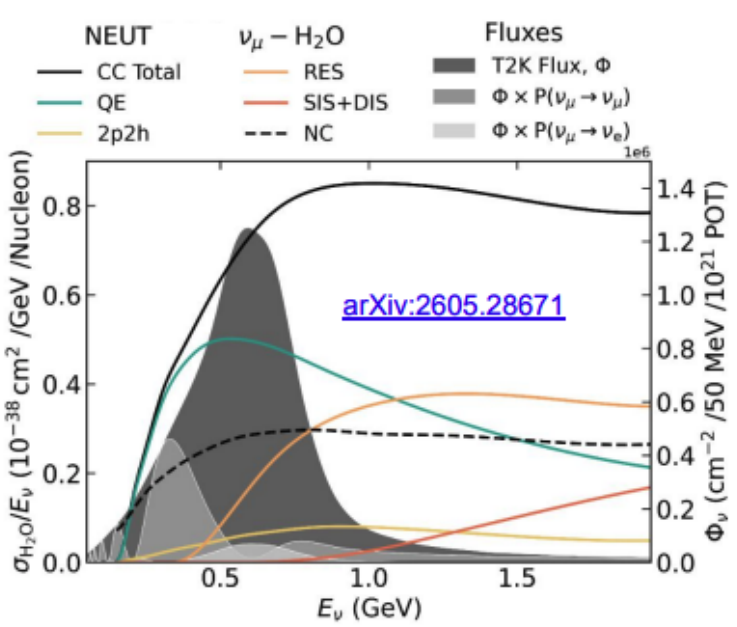
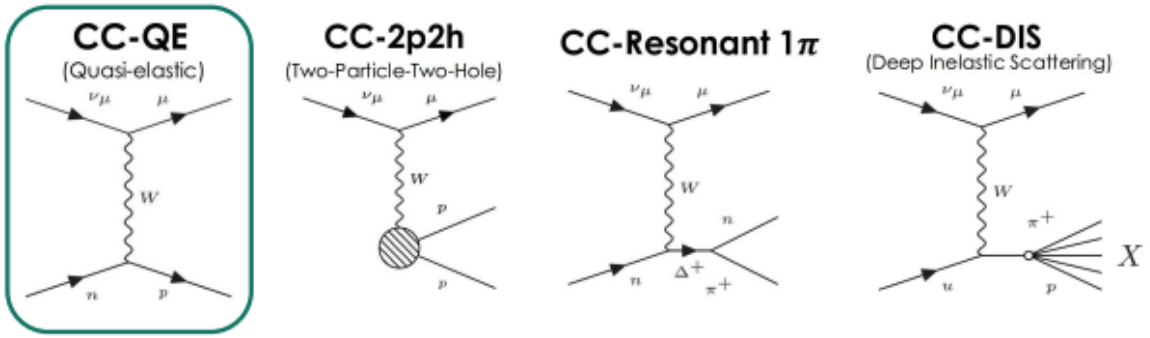
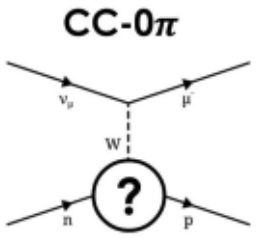
Neutrino Interactions in T2K





Interactions occur with nucleons bound inside a nucleus → Nuclear effects!
e.g. Final State Interactions (FSI) and nucleon-nucleon corrections



NEUT simulates neutrino-nucleus interactions: *EPJ ST* **230**, 4469–4481 (2021)

Improved model since Neutrino 2024 (T2K Run 1-11 v1 → T2K Run 1-11 v2) **:**

e.g. overhaul of low-energy transfer treatment and improved nucleon FSI

Alternate models are used to test robustness

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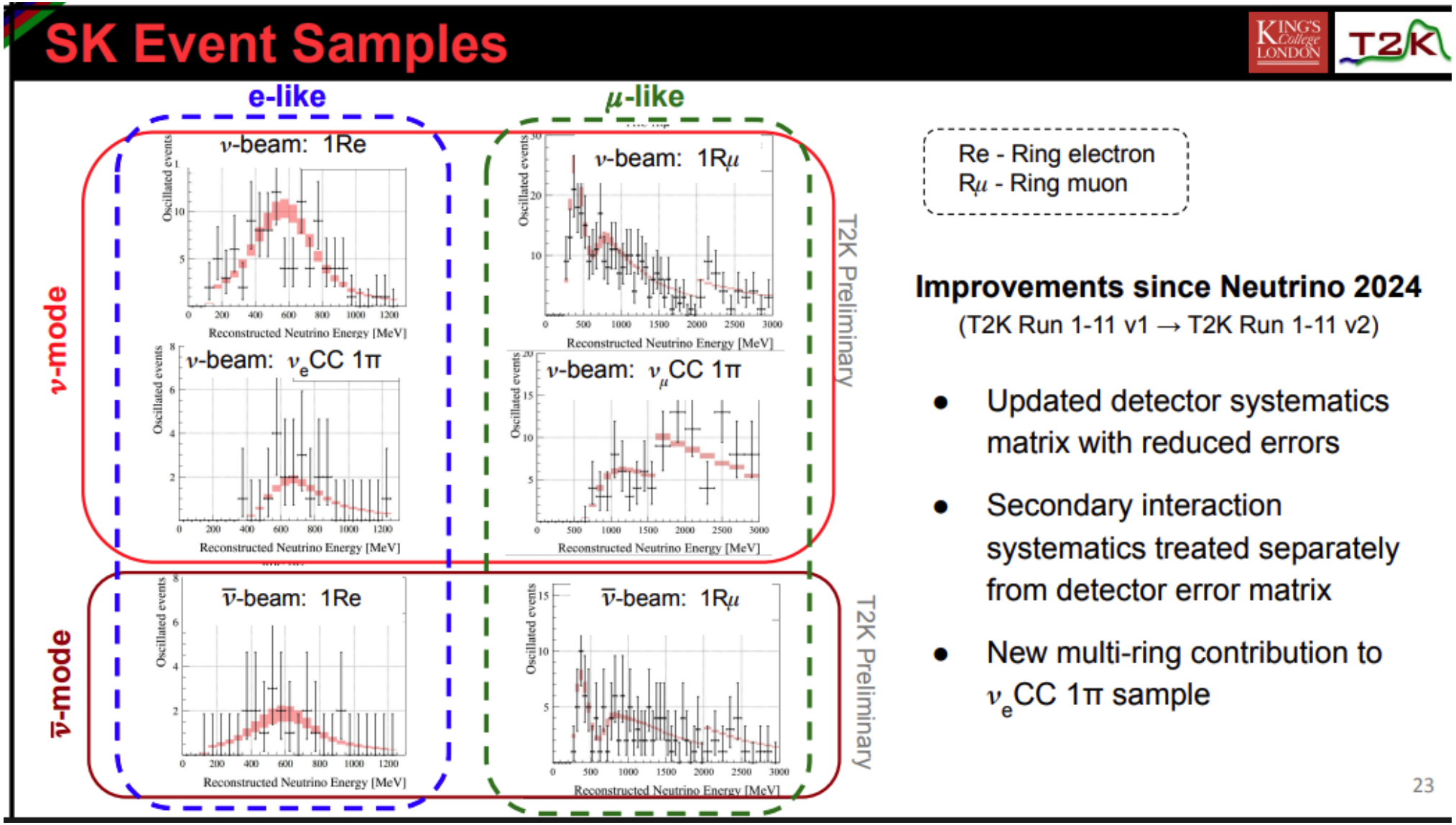
T2K event sample

SK Event Samples



Re - Ring electron
Rμ - Ring muon

Improvements since Neutrino 2024
(T2K Run 1-11 v1 → T2K Run 1-11 v2)

- Updated detector systematics matrix with reduced errors
- Secondary interaction systematics treated separately from detector error matrix
- New multi-ring contribution to ν_eCC 1π sample

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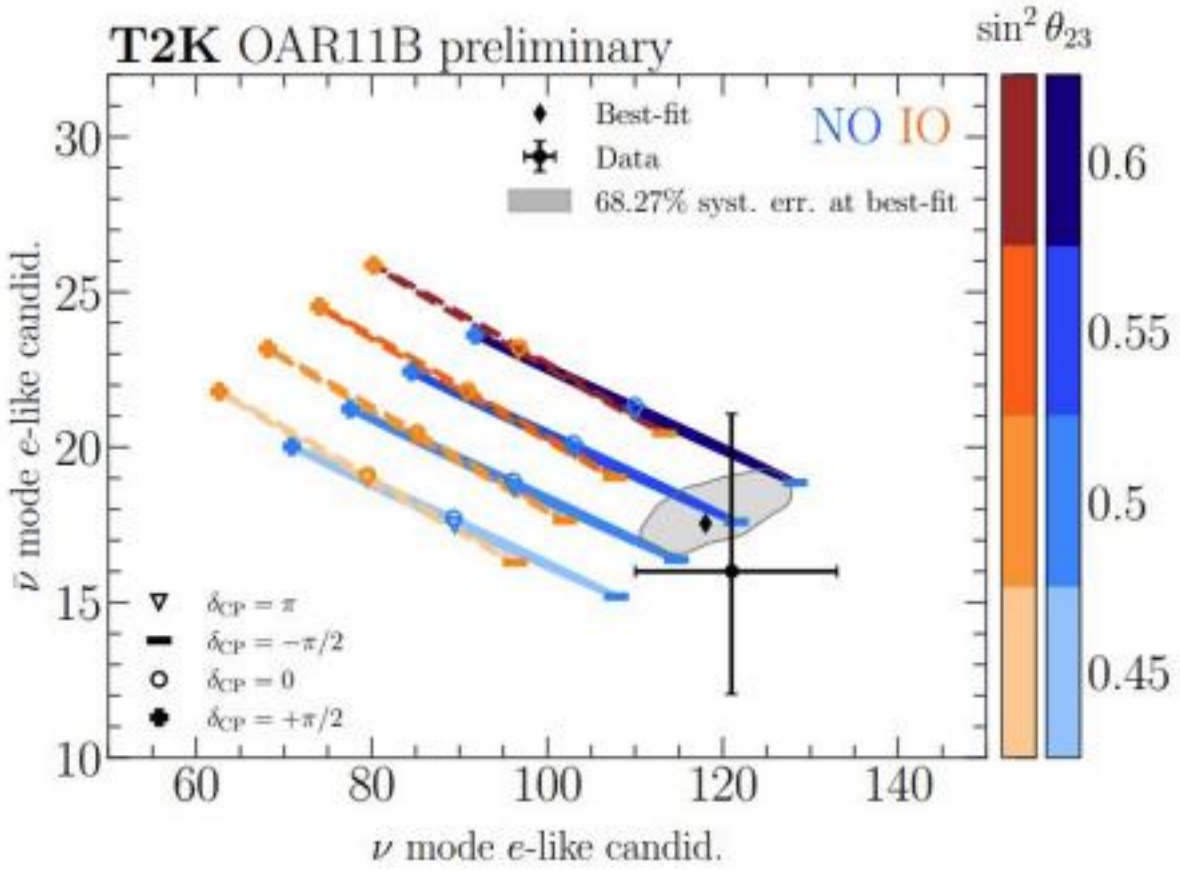
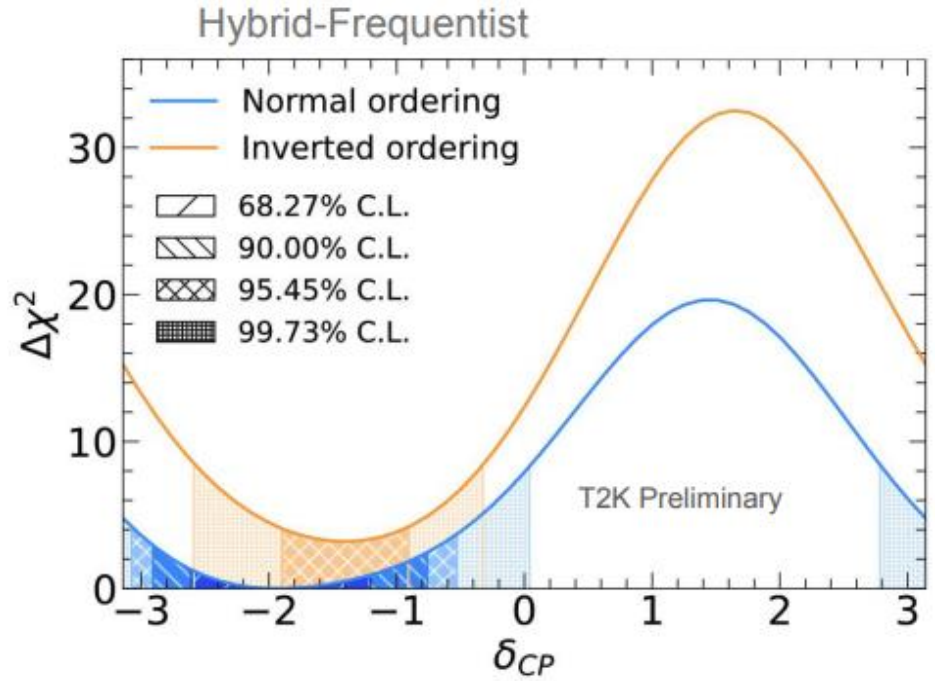
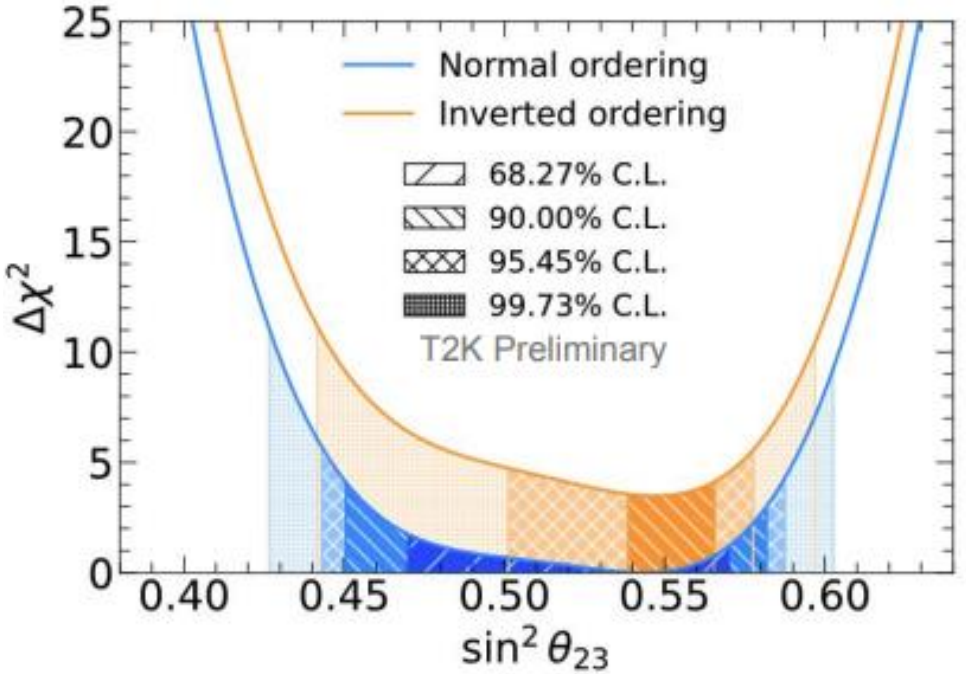
Results from T2K







Normal Ordering, Upper Octant, δ_{CP} = -90°

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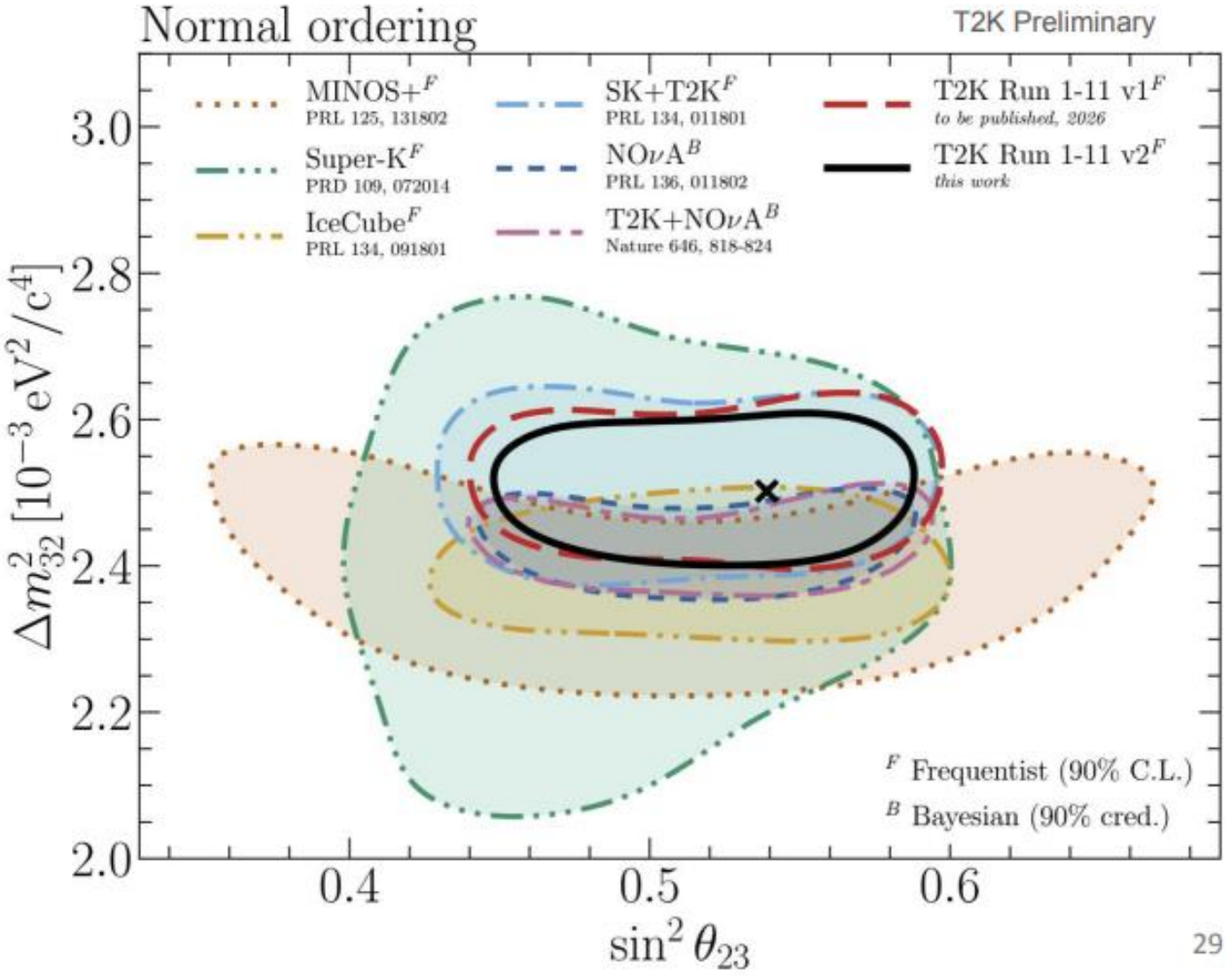
Results from T2K

The biggest improvement in the latest T2K result is due to the improved interaction model



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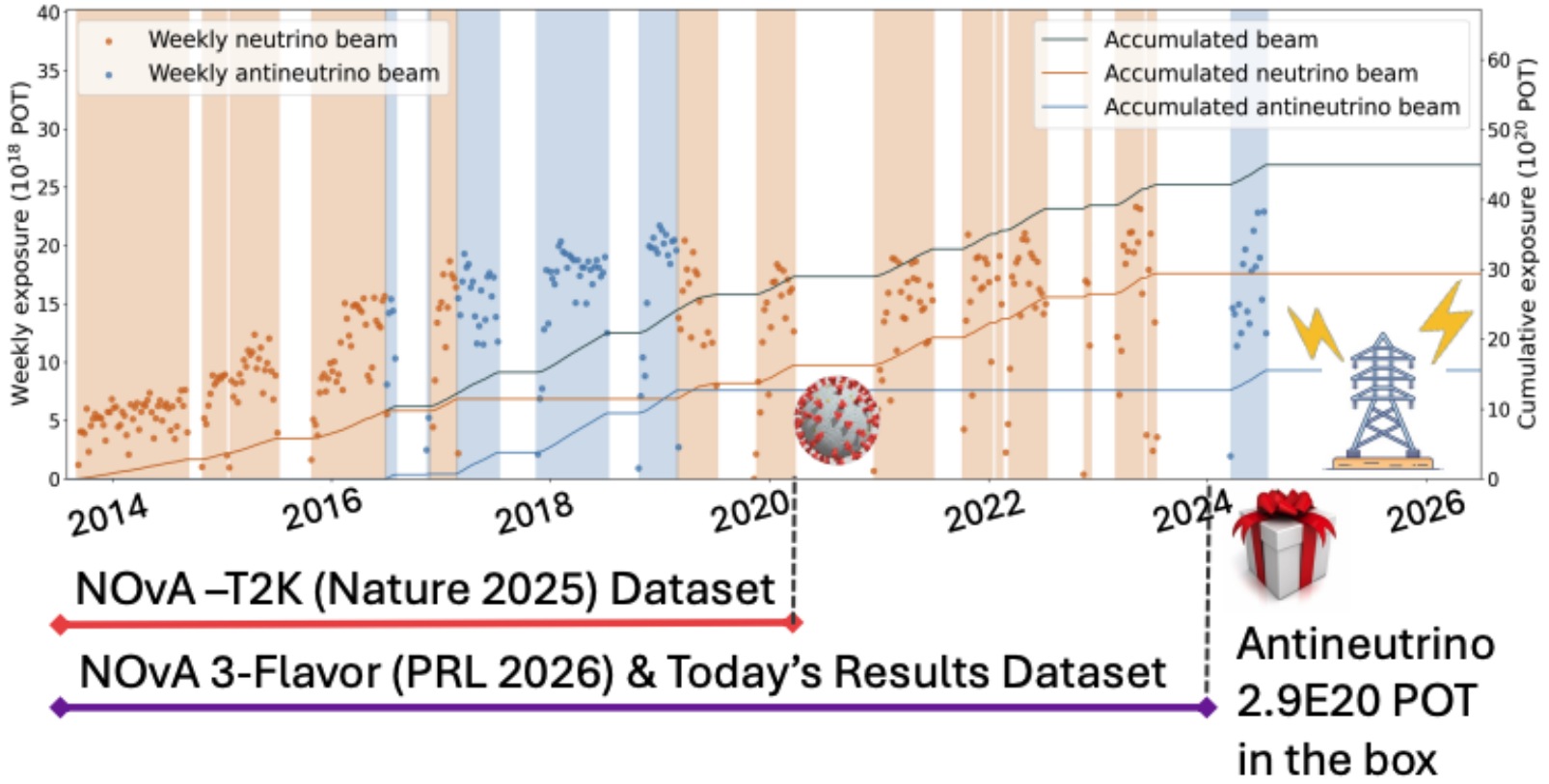
NOvA POT

More Data

- NuMI reached record power of > 1MW in 06/2024.
  - No beam since 07/2024.
- Expected return ~09/2026 for a final run.



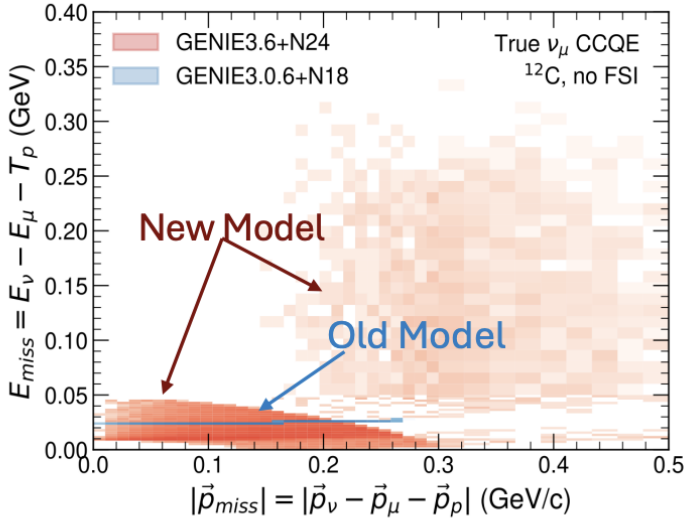
NOvA Cross-section

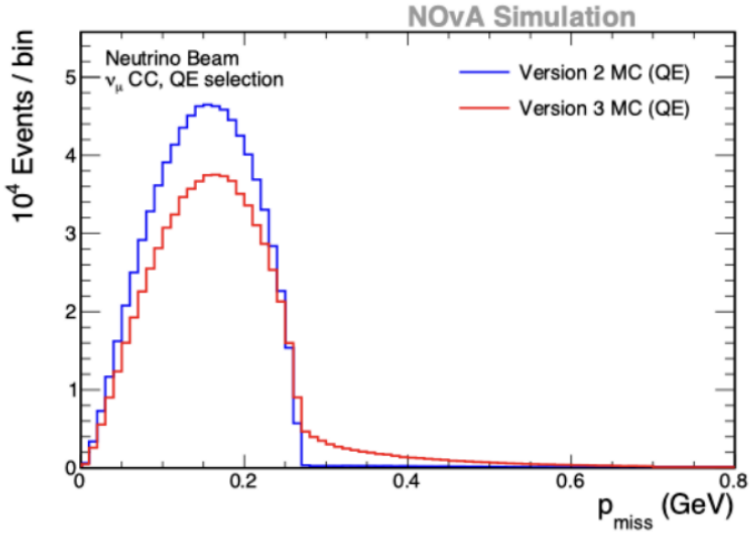
New Interaction Model

#241 Cross-Section Model: Bryan Ramson, Georgia Nissen, Jeremy Wolcott

- New production with updated cross-section model used **across Fermilab experiments ("AR-23")** with custom NOvA adjustments. GENIE 3.6.0 with N24_20i_02_11b model.

NOvA Version	CMC	Initial State	QE	Res	MNI/MEC	DIS	FSI	FSI Tune
Version 2	**N18_10j_00_000***	LFG	Valencia	Berger-Seghal	Valencia	Bodek-Yang*	IntraNuke hN2018	None
Version 3	**N24_20i_02_11b**	LFG*	Valencia*	Berger-Seghal	SuSAv2 2p2h*	Bodek-Yang*	IntraNuke hA2018	Free-Nuke



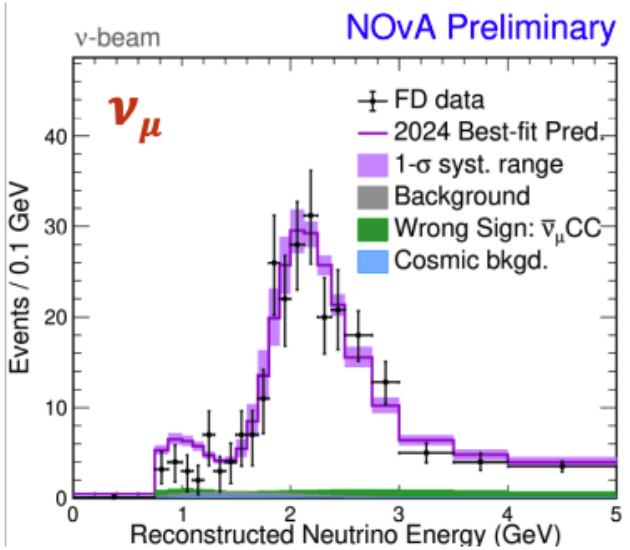


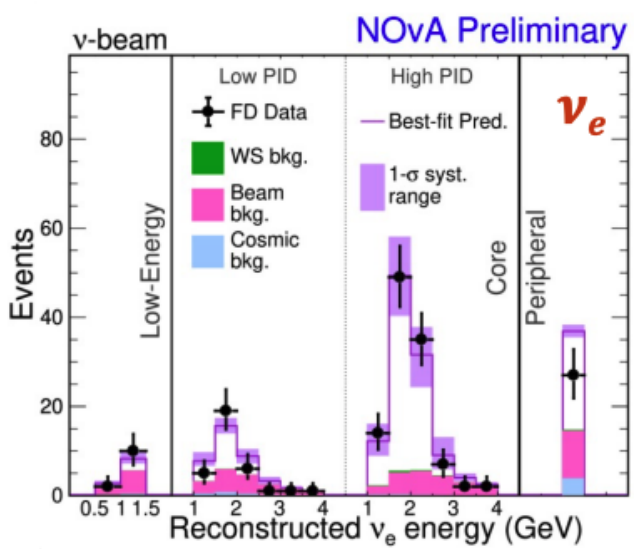
NOvA event sample

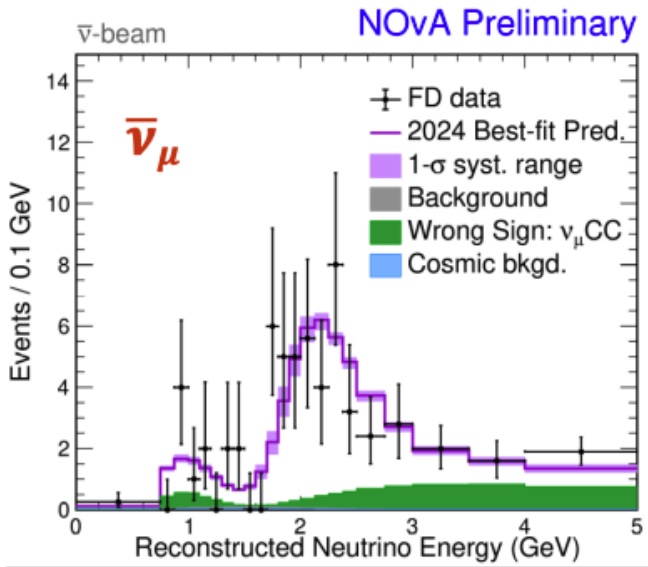
NOvA 2024 Dataset

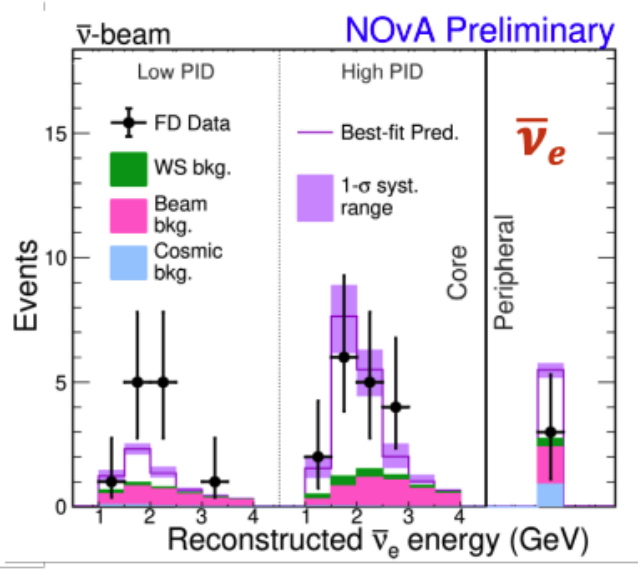
- The 3-Flavor fit describes the data well.
- NOvA performs one frequentist and two Bayesian (ARIA: MR²T²H and STAN: Hamiltonian MCMC) fits. All fits agree well with each other.

Channel	2024 Dataset	PPP value = 0.48
ν_e	169 (ν_e) 12 (*Low E*)	0.58 (ν_e) 0.72 (*Low E*)
$\bar{\nu}_e$	32	0.19
ν_μ	384	0.59
$\bar{\nu}_\mu$	106	0.39



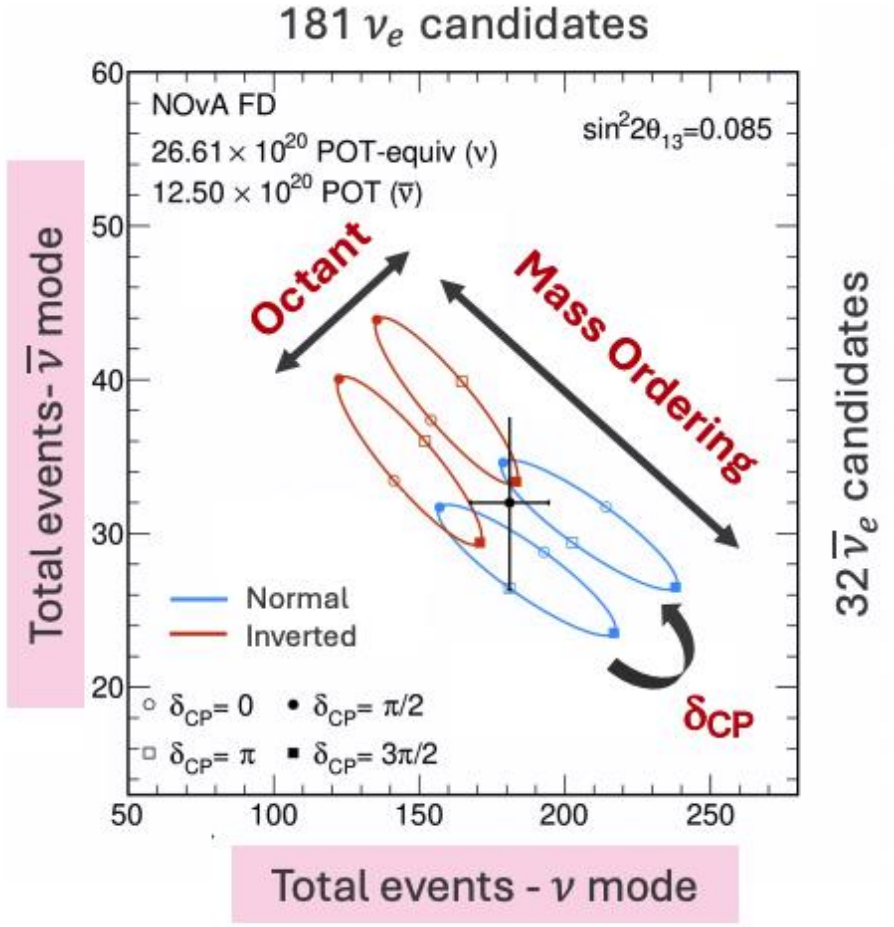


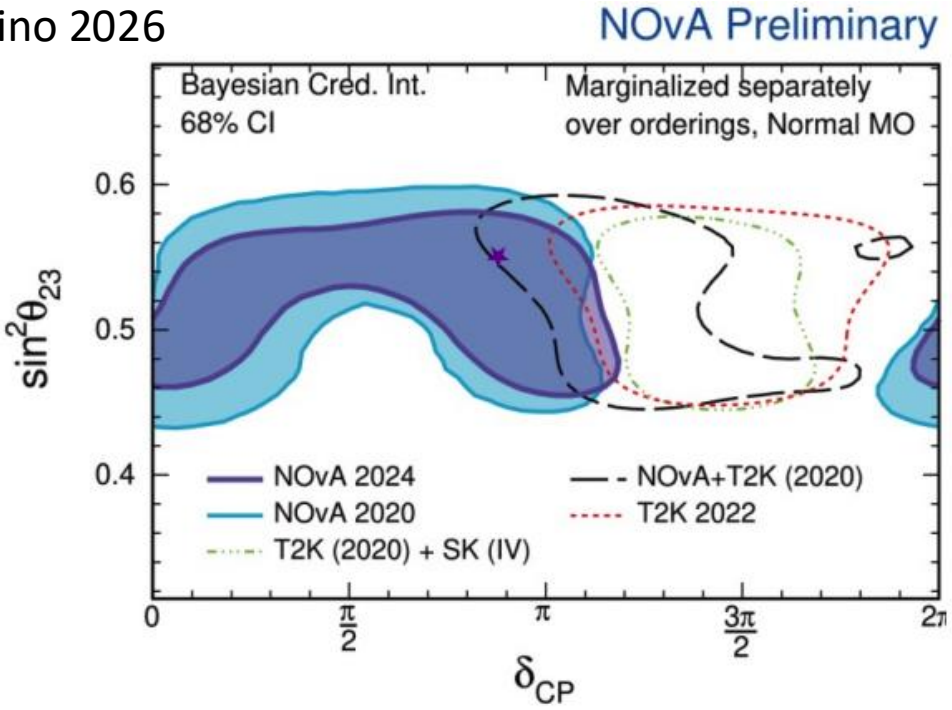


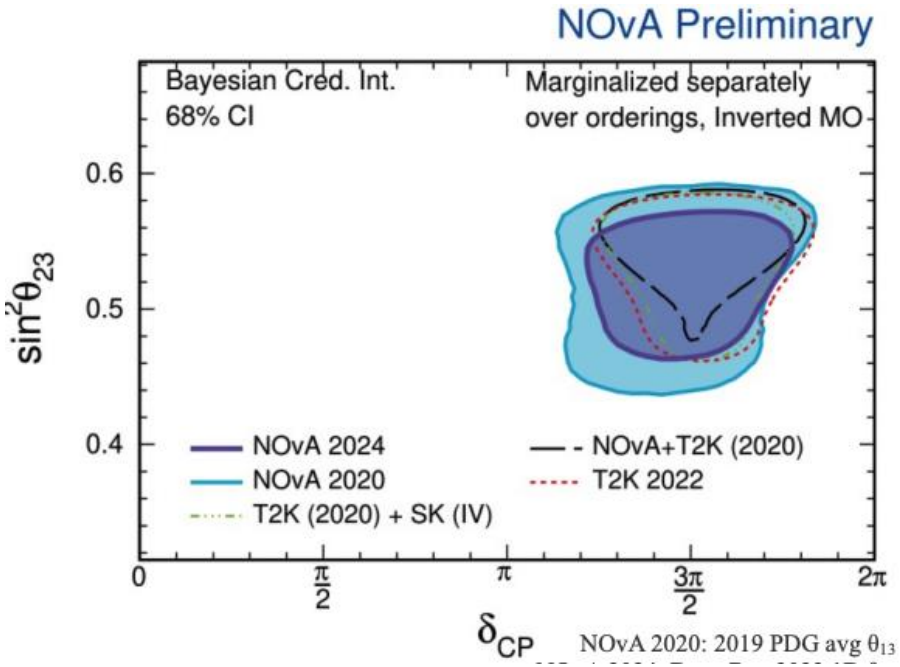


Results from NOvA

Zoya Vallari, Neutrino 2026







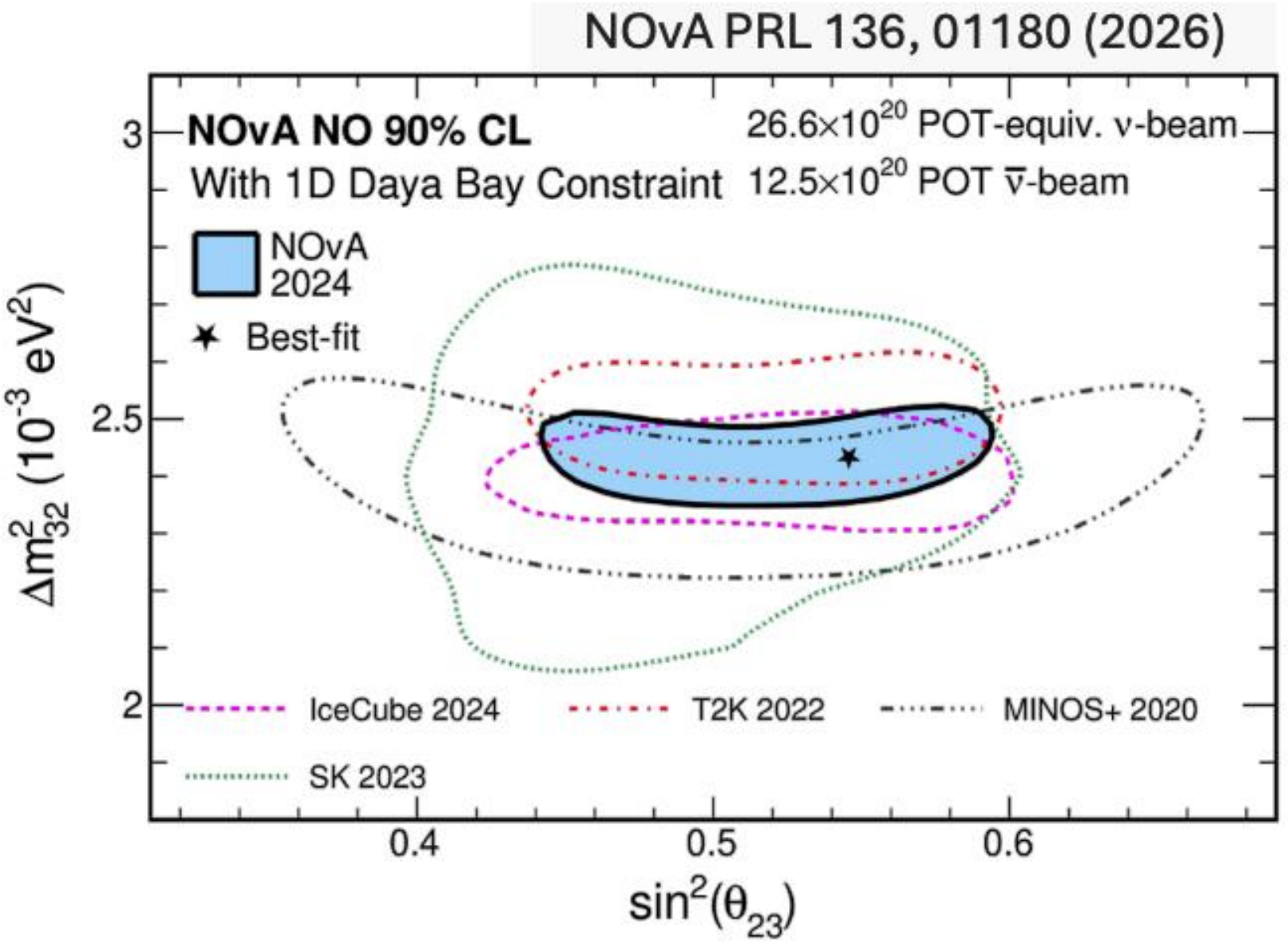
Zoya Vallari, Neutrino 2026

Normal Ordering, Upper Octant, δ_{CP} = 180°

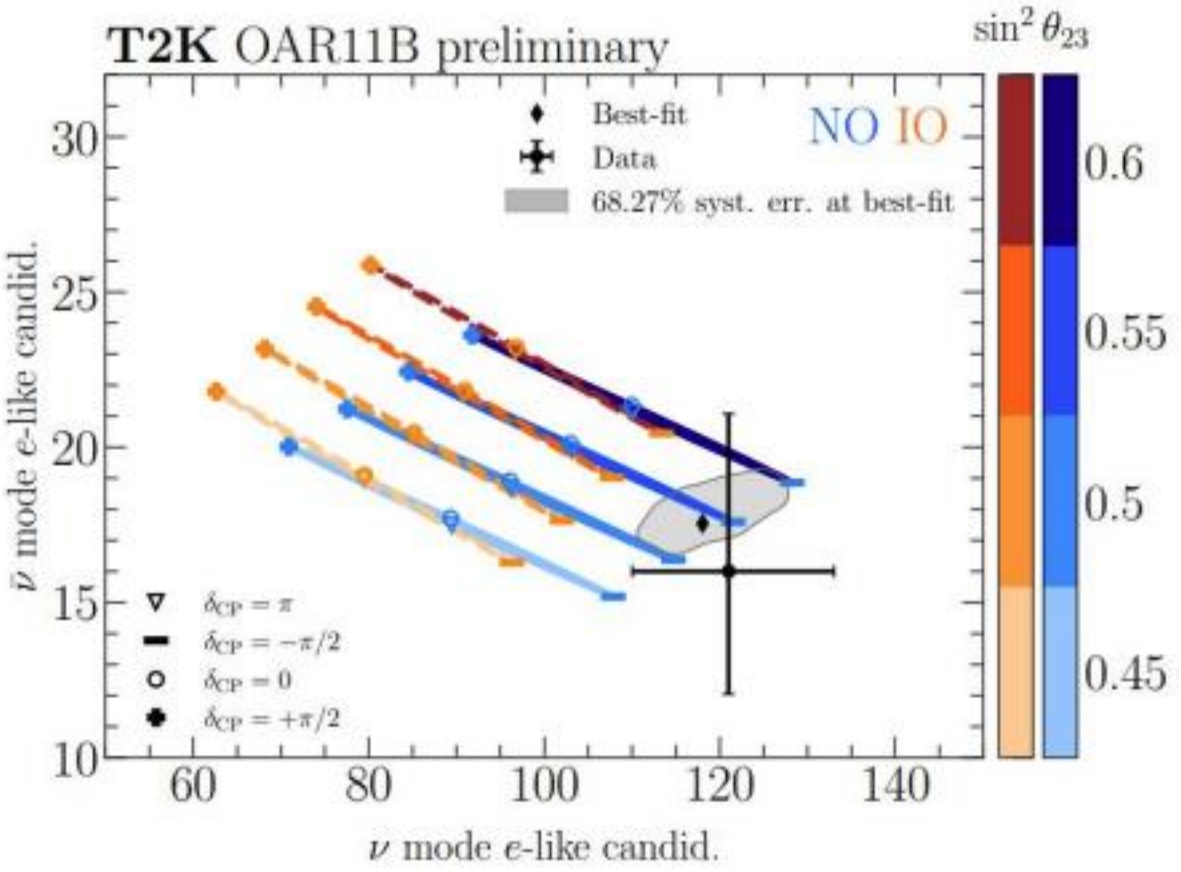
Results from NOvA

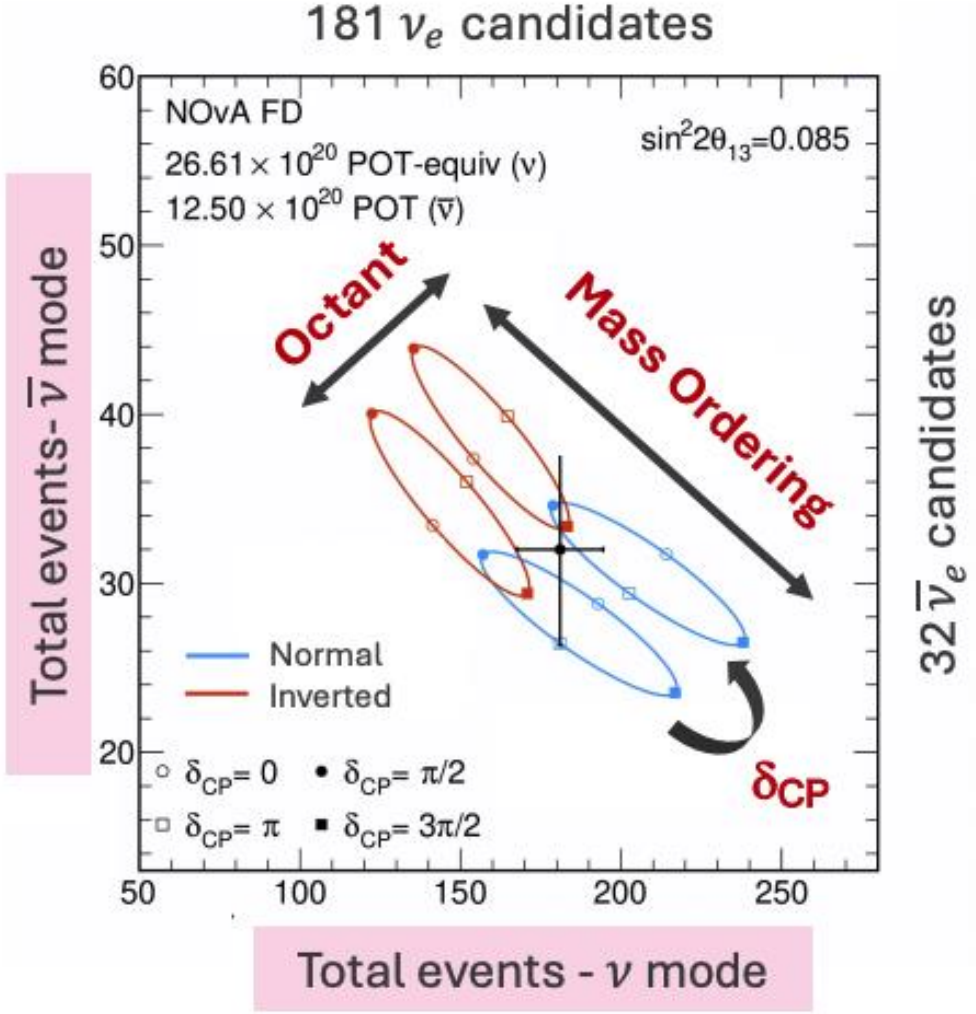
Zoya Vallari, Neutrino 2026

Global agreement among atmospheric and accelerator experiments.



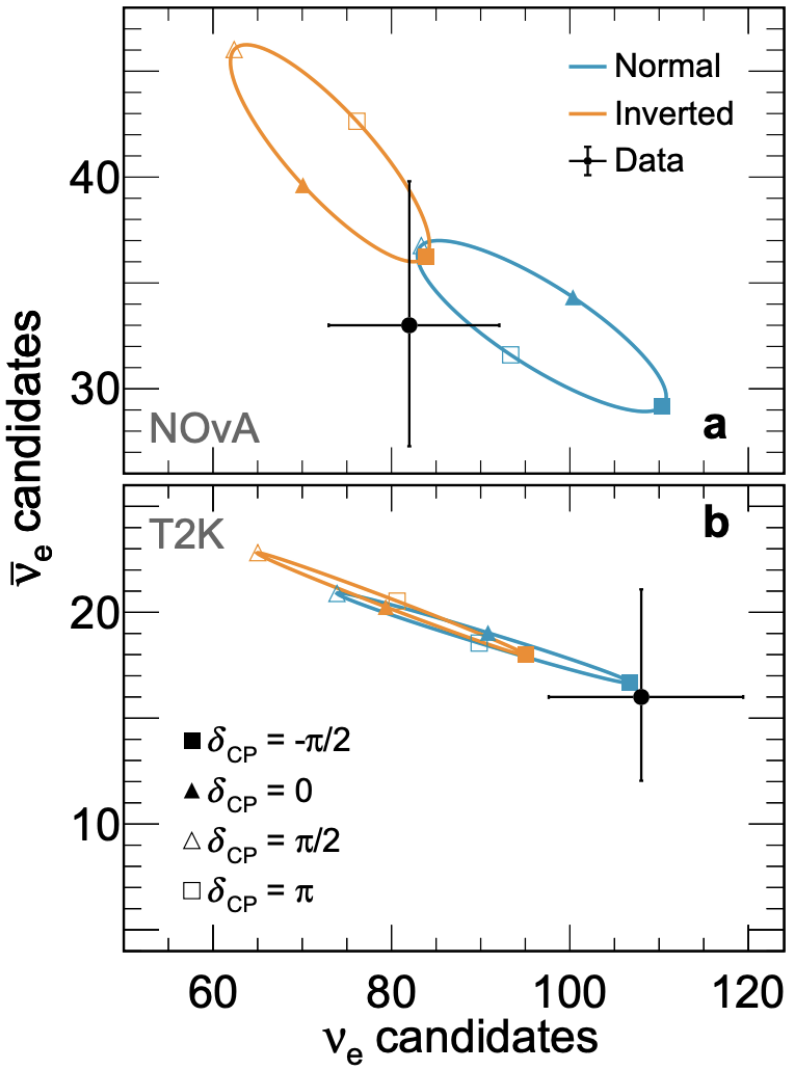
The Mismatch

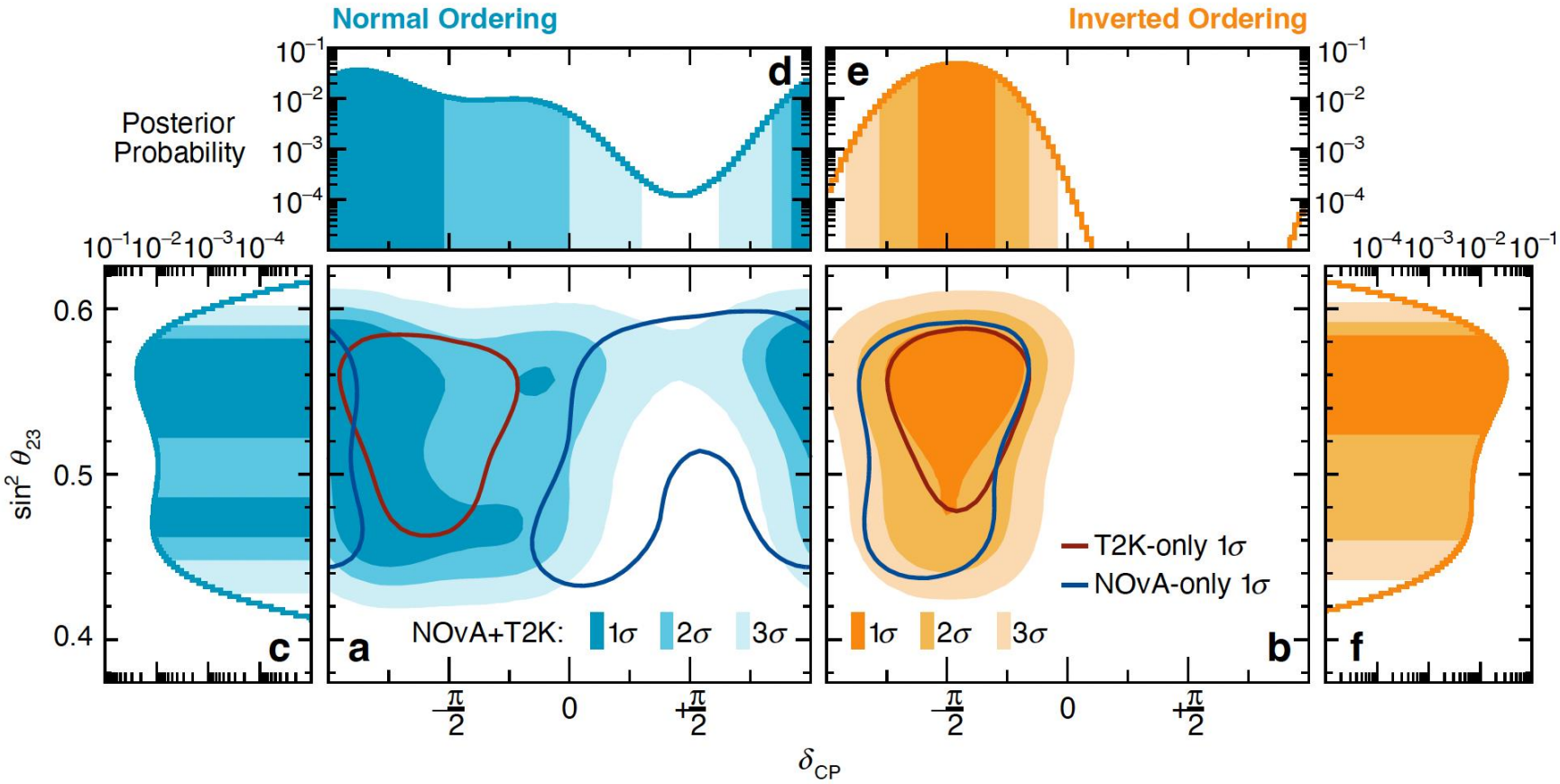




- Both Normal ordering, NOVA
- Both Higher Octant
- CP Phase - Interesting

Joint-Fit





- Both ordering is favoured
- Higher Octant
- CP Phase- Interesting

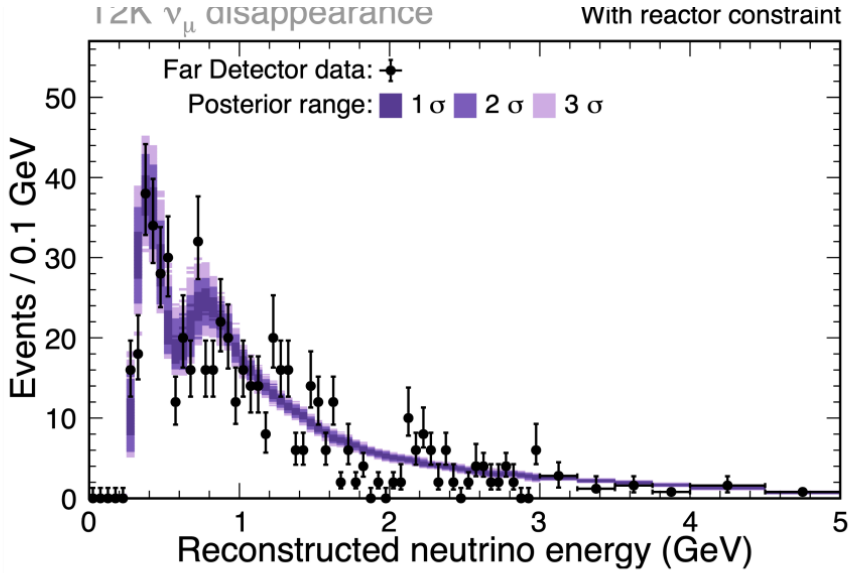
S. Abubakar et al. [T2K and NOvA], Nature 646, no.8086, 818-824 (2025), arXiv:2510.19888

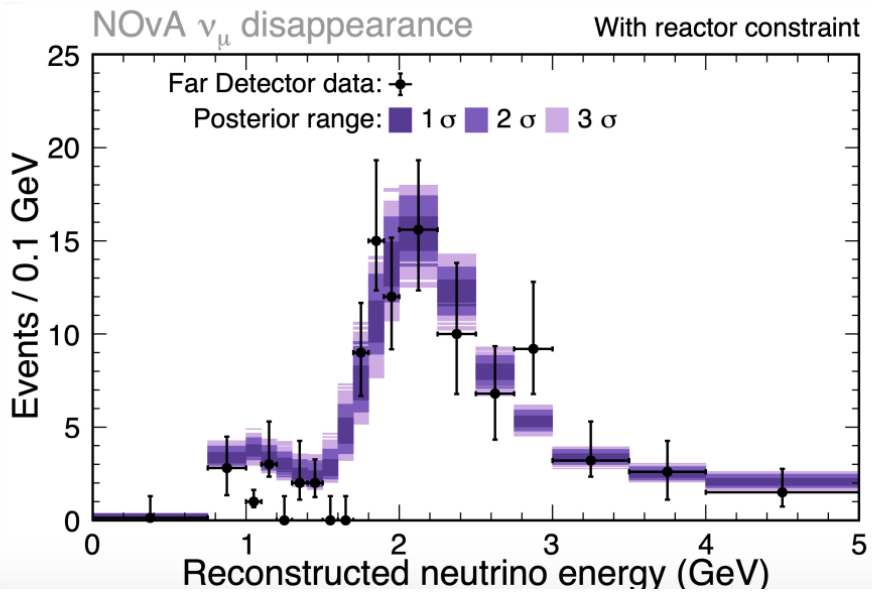
Joint Fit

FD Data Samples

- The joint-fit uses the data collected by each experiment up until 2020.
- Using both experiments data roughly doubles the total statistics at the far detectors.

Channel	NOvA	T2K
ν_e	82	94 (ν_e) 14 ($\nu_e 1\pi$)
$\bar{\nu}_e$	33	16
ν_μ	211	318
$\bar{\nu}_\mu$	105	137





$\bar{\nu}_\mu$ samples in backup

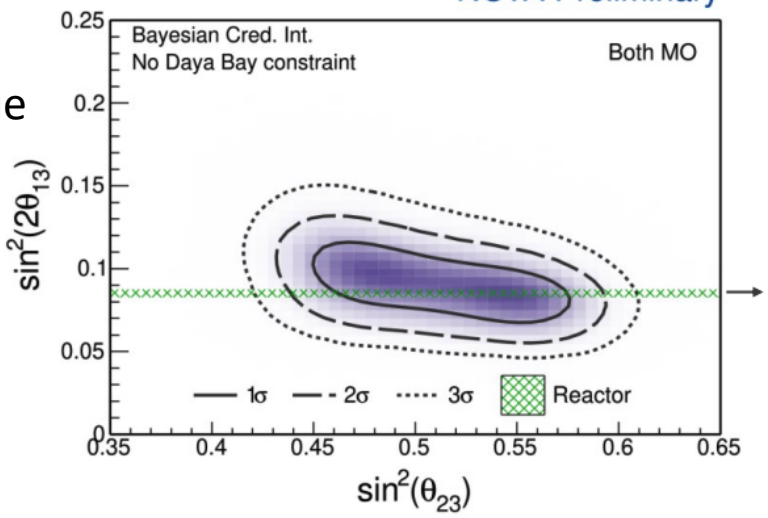
θ_{23} and θ_{13} : NOvA

Observations

- NOvA θ_{13} fit higher than the reactor value

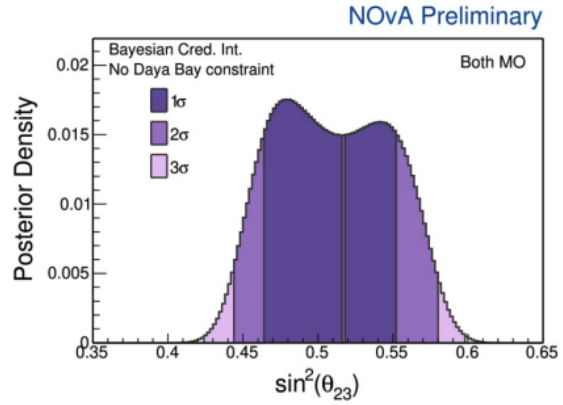
- Without reactor fit – Lower Octant
- With Reactor fit – Higher Octant

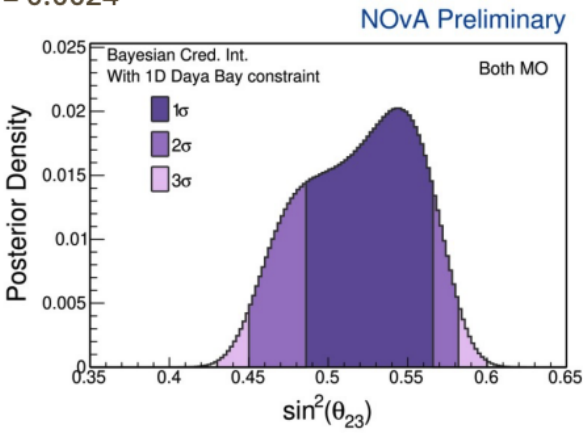
Mixing Angles: θ_{23} and θ_{13}



$\sin^2 2\theta_{13} = 0.0851 \pm 0.0024$

Daya Bay (PRL 130, 161802)





	No constraint		Daya Bay 2023 1Dθ_{13}	
	Probability	Bayes Factor	Probability	Bayes Factor
Upper Octant preference	**57%**	1.3	**69%**	2.2

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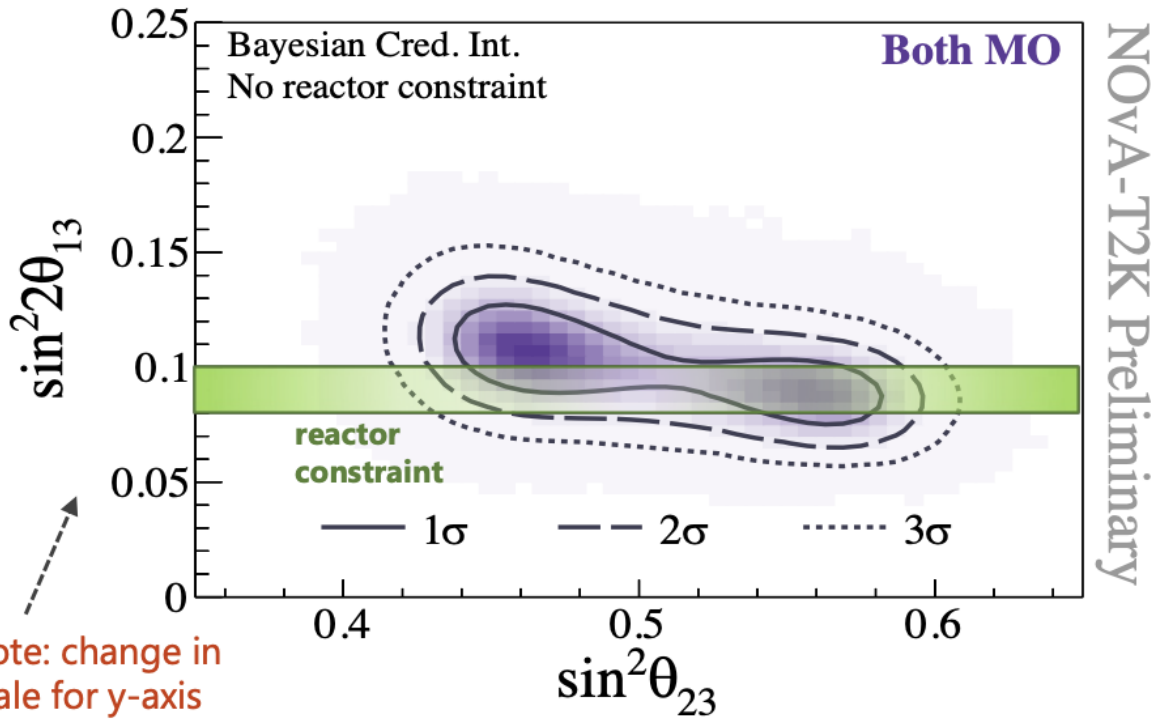
θ_{23} and θ_{13} : Joint fit

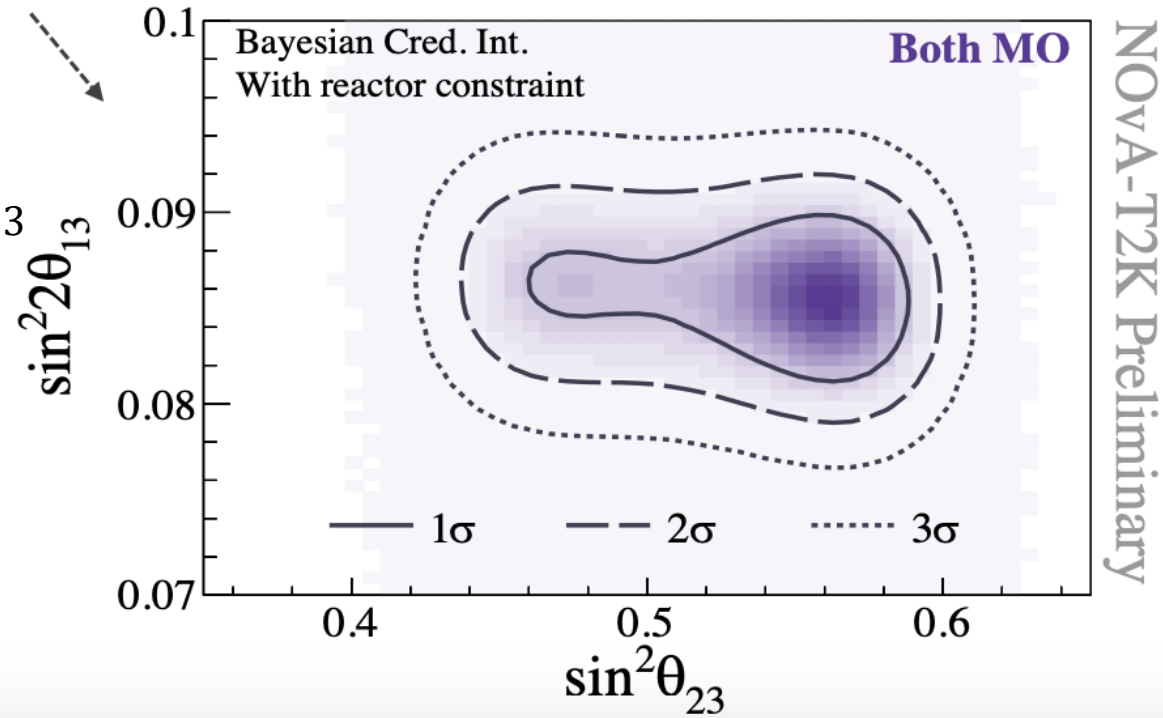
Observations and Questions

- T2K+NOvA θ_{13} fit higher than the reactor value
- Why ? New Physics ?
- What about the individual T2K and NOvA fit to θ_{13}

- Without reactor fit – Lower Octant
- With Reactor fit – Higher Octant



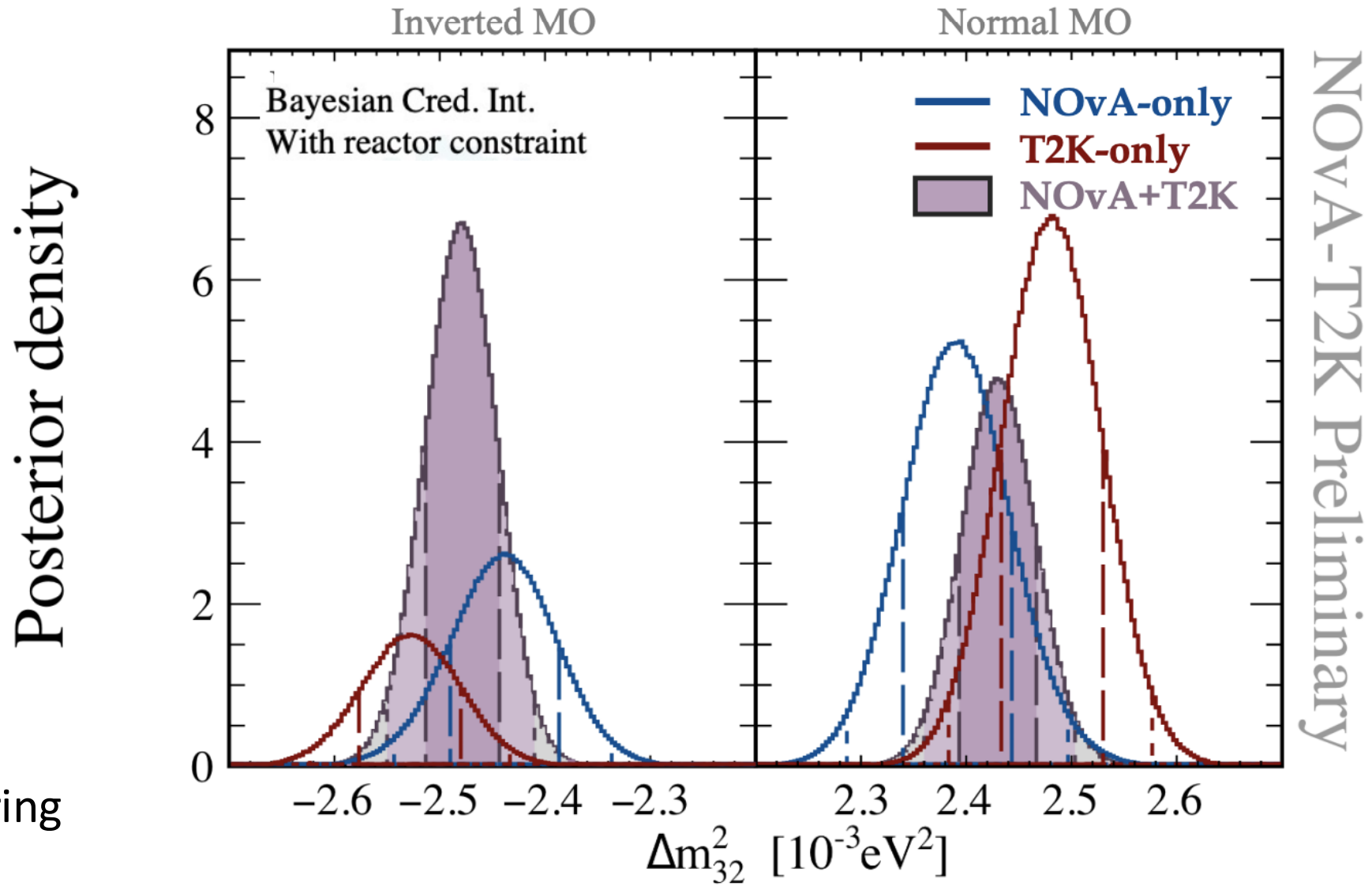
Note: change in scale for y-axis



Mass ordering

Zoya Vallari,, Fermilab 2024

T2K: Normal Ordering
NOvA: Normal Ordering
T2K+NOvA: Inverted Ordering



	NOvA only	T2K only	NOvA+T2K
Bayes factor	2.07 Normal/Inverted ~67% : ~33% posterior	4.24 Normal/Inverted ~81% : ~19% posterior	1.36 Inverted/Normal ~58% : ~42% posterior

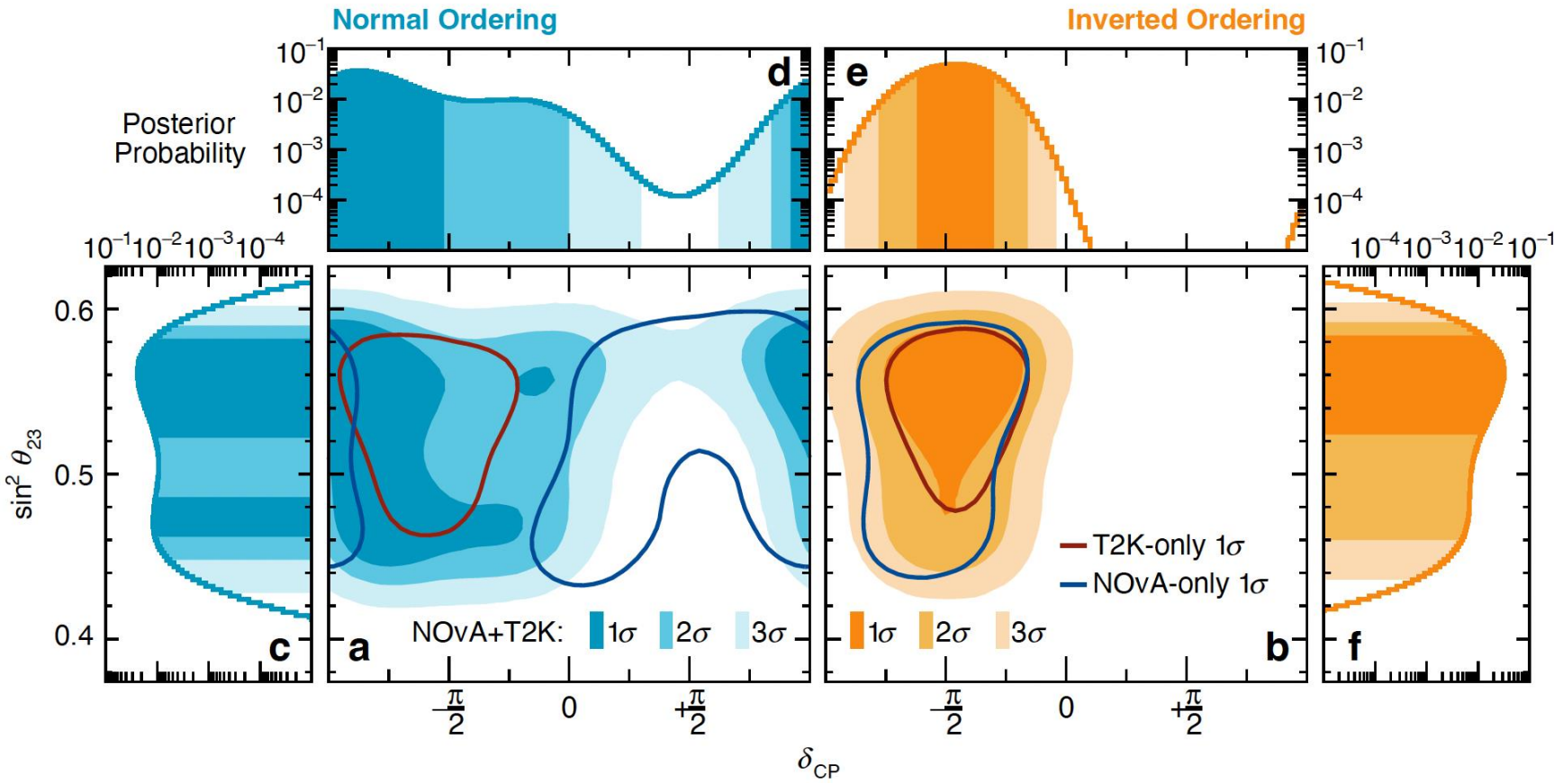
δ_{CP} and θ_{23}

Observations and Questions

T2K: -90º, NH, HO

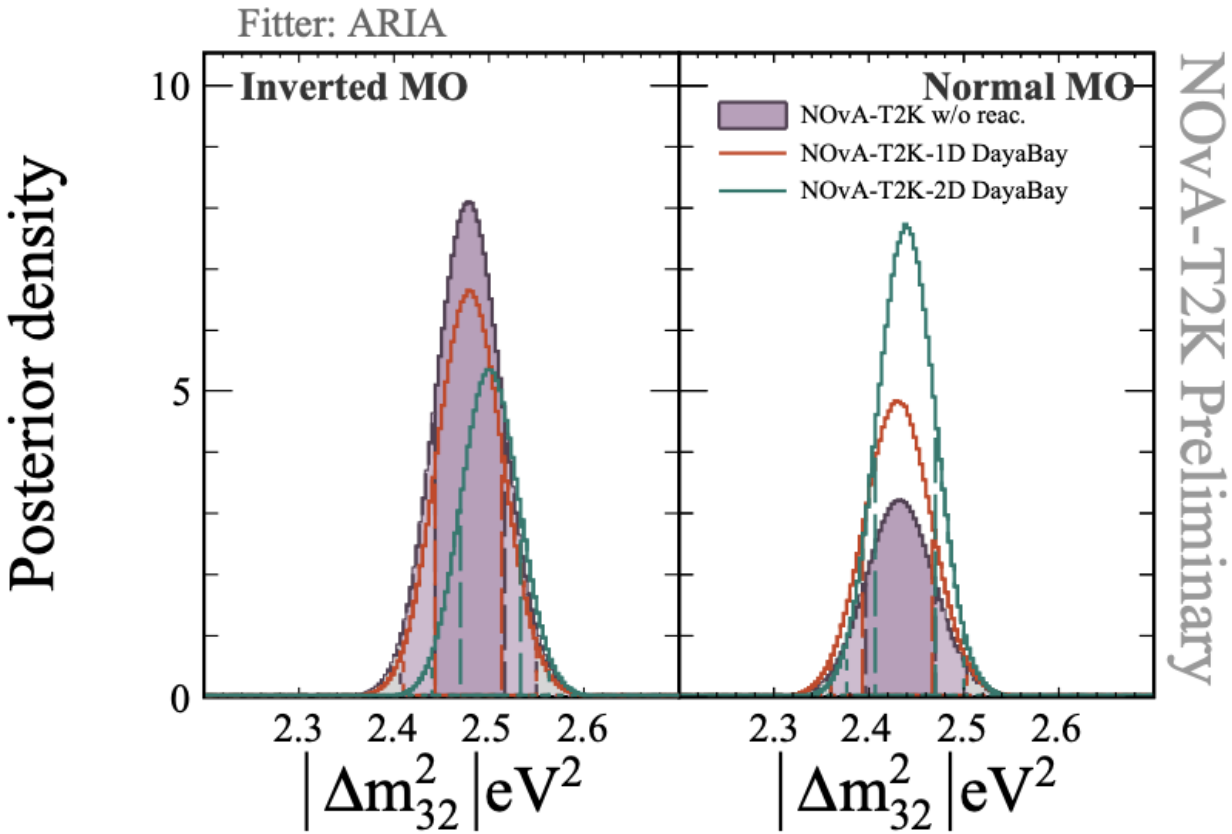
NOvA: 180º, NH, HO

T2K+NOvA: -90º, IH, HO



Effect of Reactor Prior of θ_{13} and Δm^2_{31}

	NO RC	**1D** RC	**2D** RC
Mass ordering	2.4 71%:29% IO:NO	1.3 57%:43% IO:NO	1.4 59%:41% NO:IO
θ_{23} octant	1.2 54%:46% LO:UO	3.6 78%:22% UO:LO	3.2 76%:24% UO:LO



Without Reactor: Degeneracy in Octant and clear Inverted

With Reactor θ_{13} : Degeneracy in hierarchy and clear HO

With Reactor θ_{13} and Δm^2_{31} : same as reactor θ_{13}

Tomáš Nosek, KEK 2024

Food for thought

- Why accelarator θ_{13} measurement higher that Reactors ?

- New Physics ?

- What if T2K, NOvA and T2K+NOVA data is fitted without reactors

- Does that change the fit to δ_{CP} ?
- Does that change fit to the Octant ?

- Why the mismatch in δ_{CP} in T2K and NOvA ?

- New Physics ?
- Cross-section modelling ?

- Why T2K+NOvA prefer inverted ordering ?

- Related to θ_{13} prior ?

Food for thought

- Why T2K+NOvA θ_{13} measurement higher that Reactors ?

- New Physics ?

- What if T2K, NOvA and T2K+NOVA data is fitted without reactors

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Thank You