NOvA Oscillation Measurements

Lepton-Photon 2025 – Madison

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What is NOvA

Long-baseline neutrino experiment

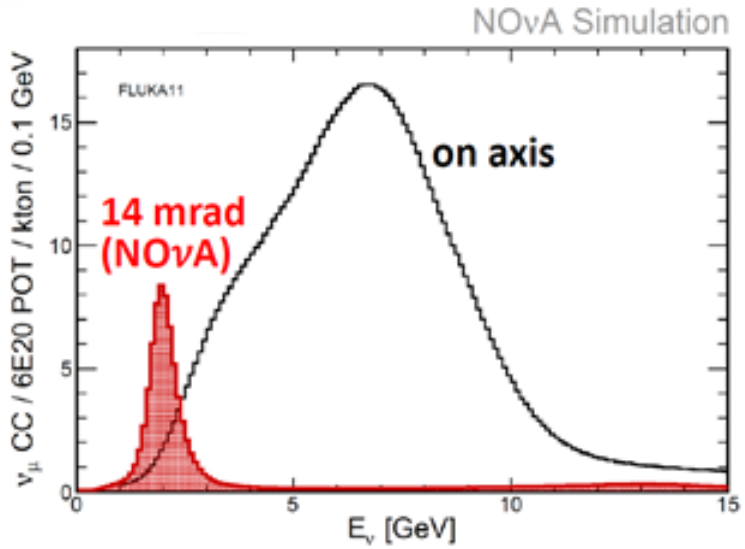
- E ≈ 1.9 GeV (off-axis narrow band beam)
- L = 810 km
- Oscillations governed by Δm^2_{32} (Δm^2_{31})

NuMI beam produced at Fermilab

- ν_μ and $\bar{\nu}_\mu$ beam modes
- $\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_\mu$ and $\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$ oscillations

Two detector experiment

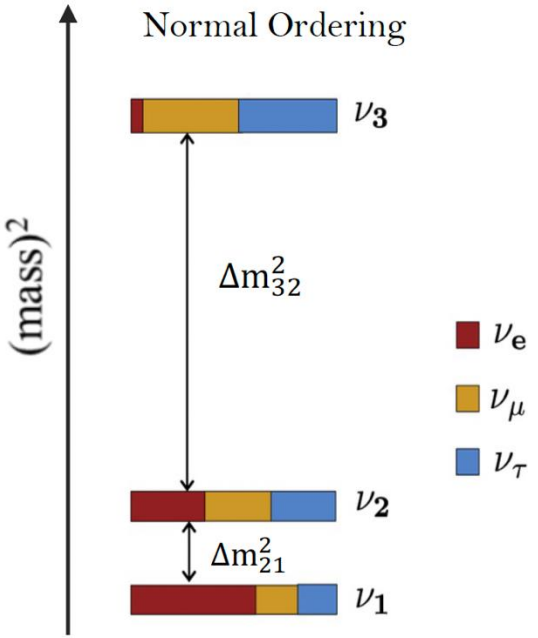
- Near detector (Fermilab, IL)
  - ~1km from production target
  - Measure beam before standard oscillation
- Far Detector (Ash River, MN)
  - Measure oscillated beam



Long-Baseline Accelerator Neutrino Experiments

Physics Sensitivity

Oscillations governed by Δm^2_{32} (Δm^2_{31})



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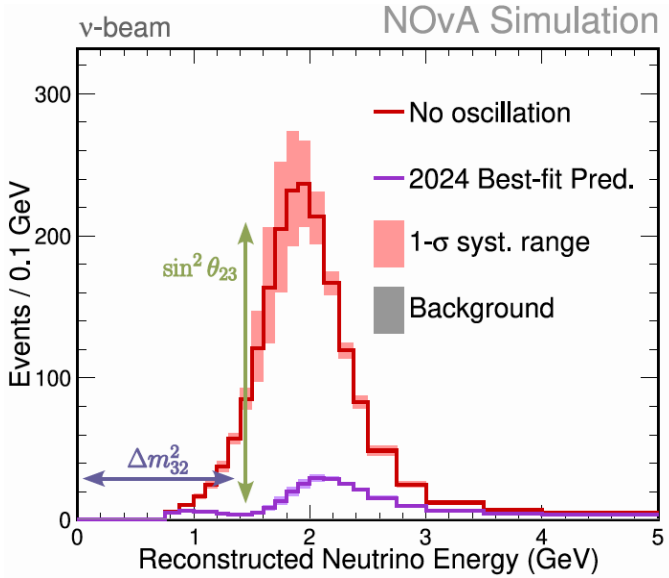
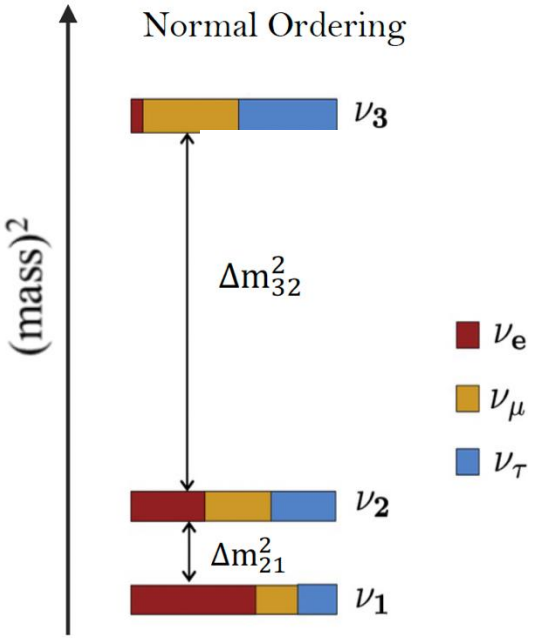
Disappearance Channel is sensitive to

$|\Delta m^2_{32}|$ Mass-Squared Splitting

$\sin^2(2\theta_{23})$: Maximal Mixing





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$\lvert\Delta m^2_{32}\rvert$	Mass-Squared Splitting
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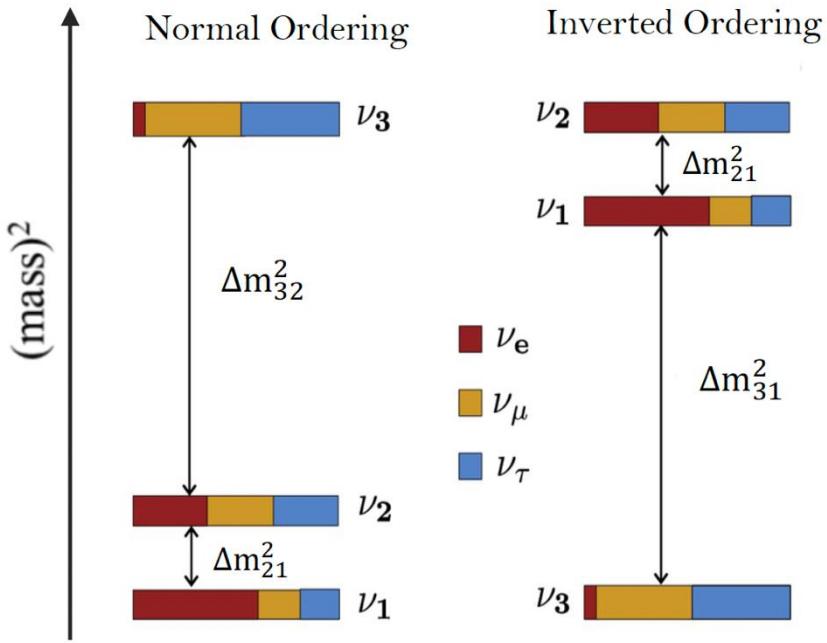
Appearance Channel is sensitive to

Sign of Δm^2_{32}	Mass Ordering
$\theta_{23} > 45^o$ or $\theta_{23} < 45^o$	Octant of θ_{23}
δ_{CP}	CP-Violation ($\delta_{CP} \neq n\pi$)



Long-Baseline Accelerator Neutrino Experiments

Physics Sensitivity: Matter-Antimatter Differences

CP-Violation

δ_{CP} has opposite impact on appearance probability for neutrinos and antineutrinos

Enhancement or Reduction

Mass Ordering

Matter Effect has impact on on appearance probability

Enhancement or **Reduction** depends on **Ordering**

Source of degeneracy

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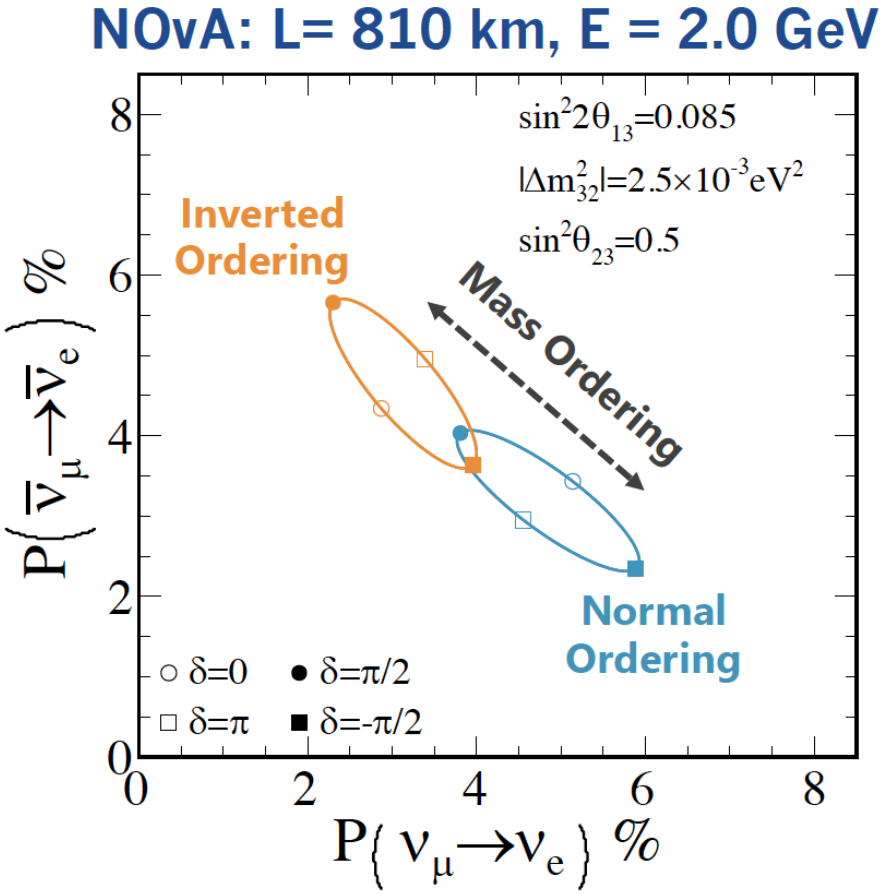
Enhance or Reduction



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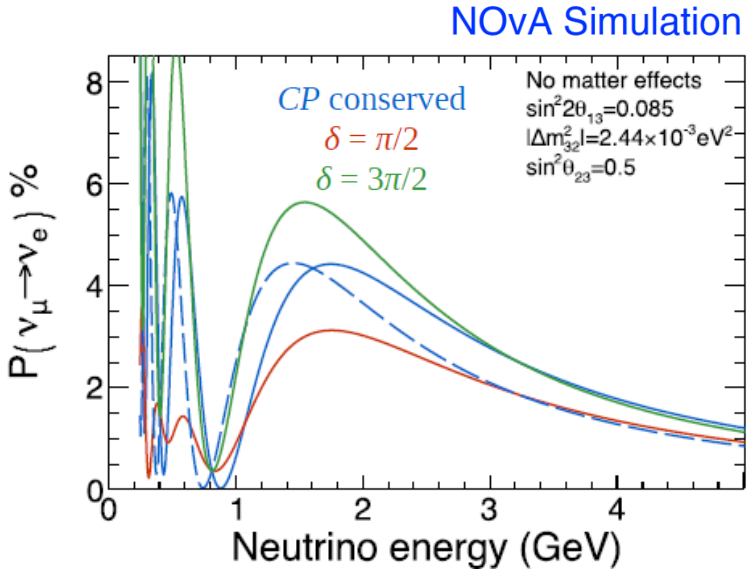
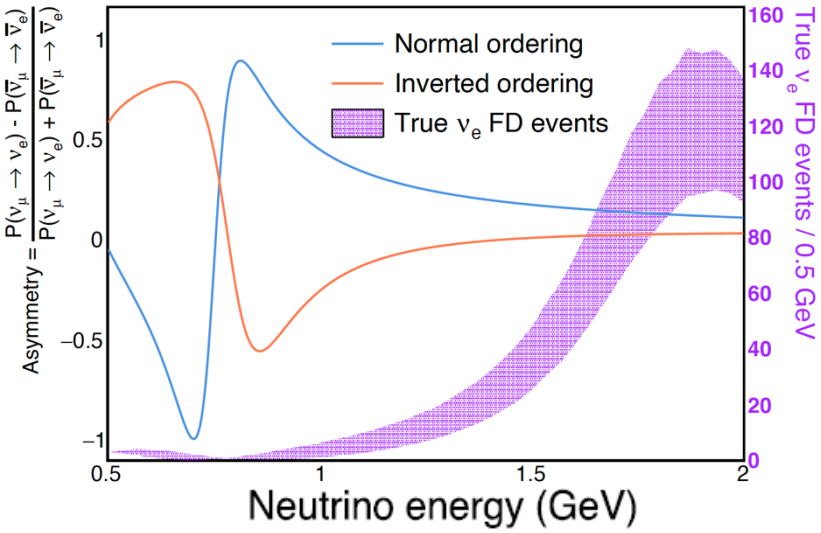
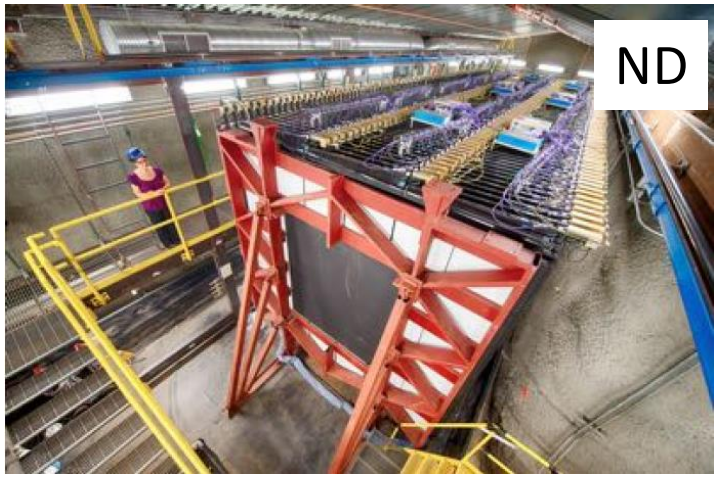


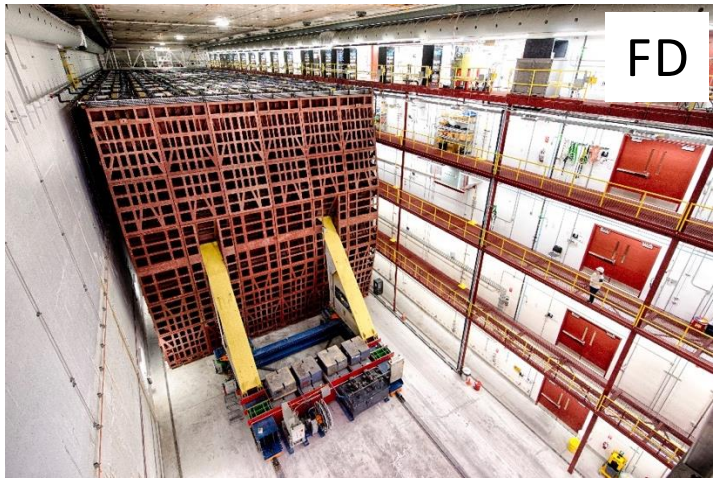


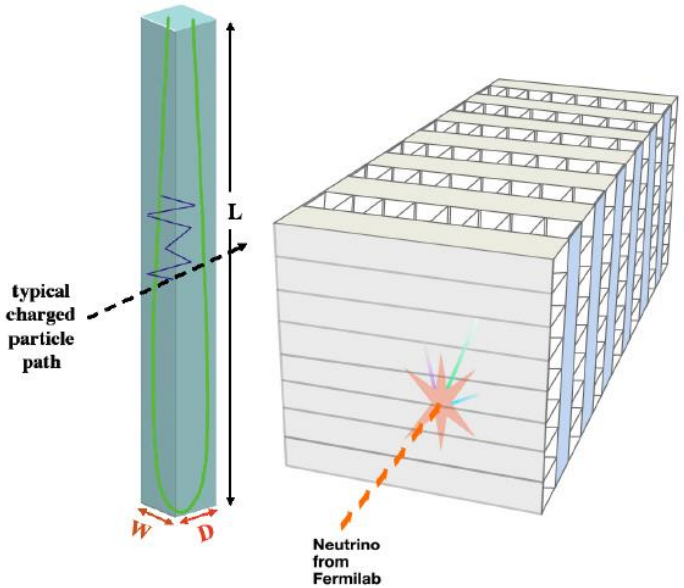
The NOvA Near Detector

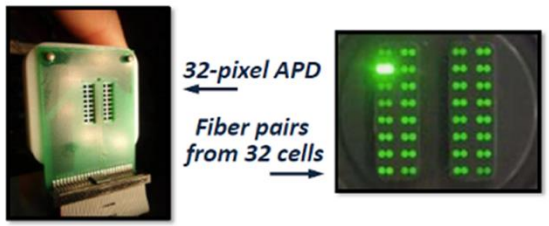
Giant hydrocarbon nuclear targets

67% C, 11% H with 16% Cl, 3% Ti, 3% O







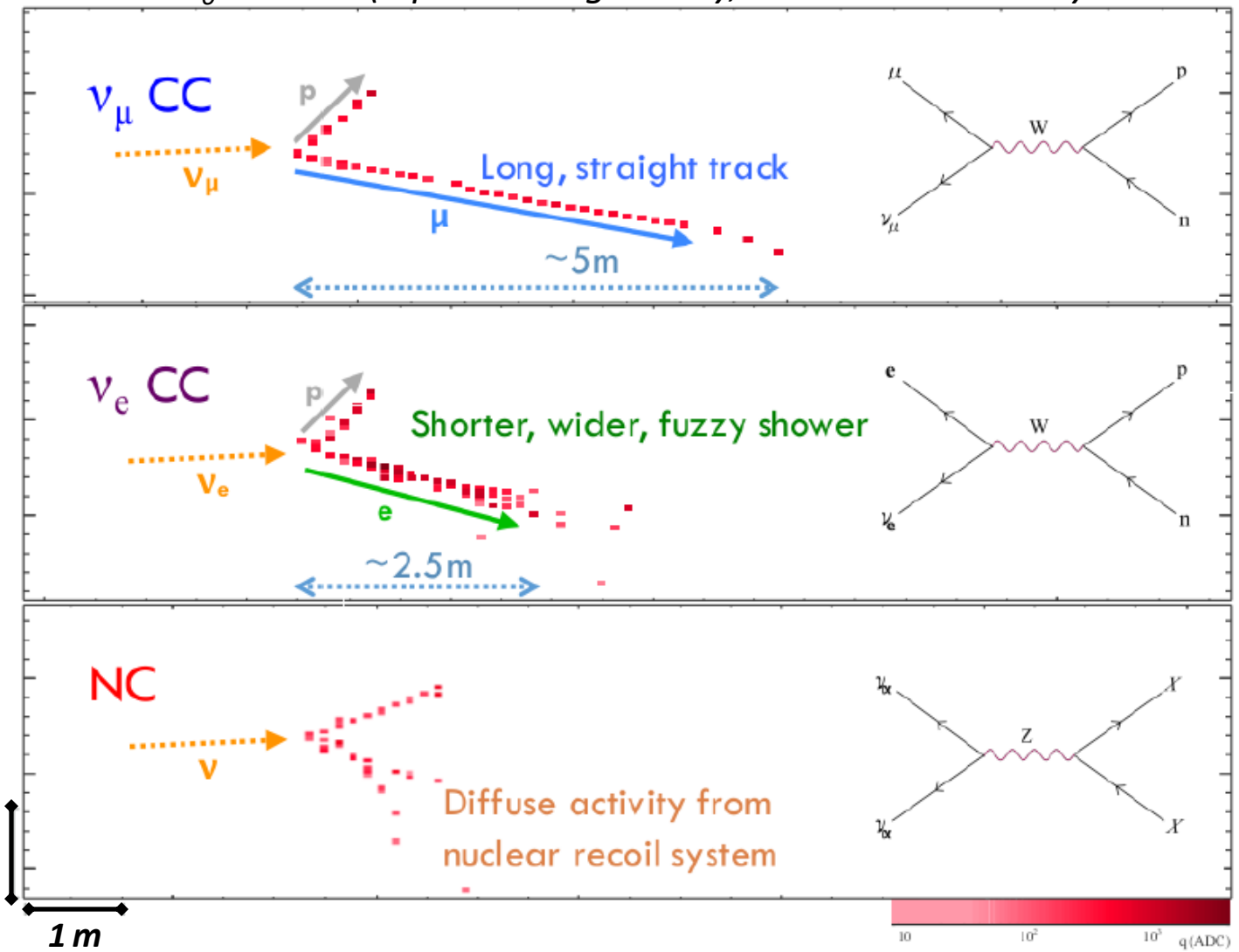


Tracking Calorimeter

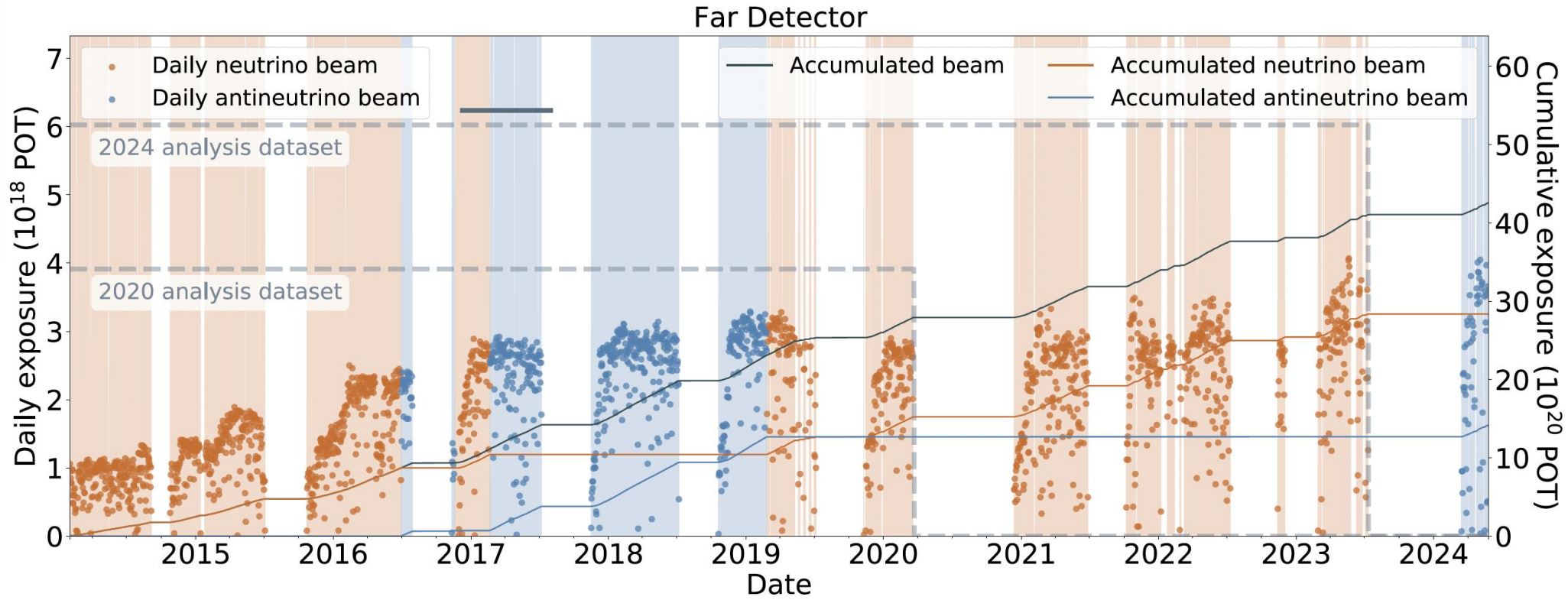
- Liquid scintillator filled PVC tubes
- Far Detector
  - 896 planes
  - 340,000 channels
- Near Detector
  - 206 planes
  - 18,000 channels
  - Muons catcher at end
    - -10 steel planes alternating between 11 active pairs
    - -Stops 3 GeV muons

NOvA Event Topologies

X_0 = 38 cm (6 planes longitudally, 10 cells transversely



Analysis Sample

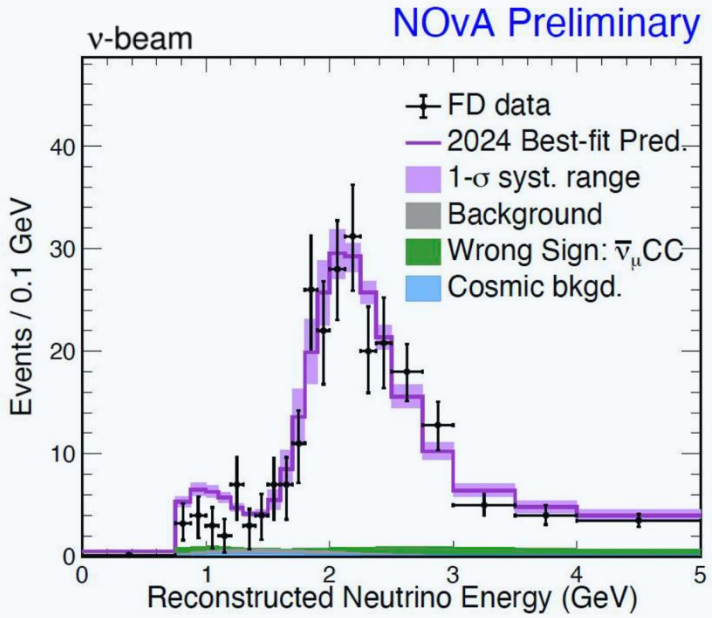


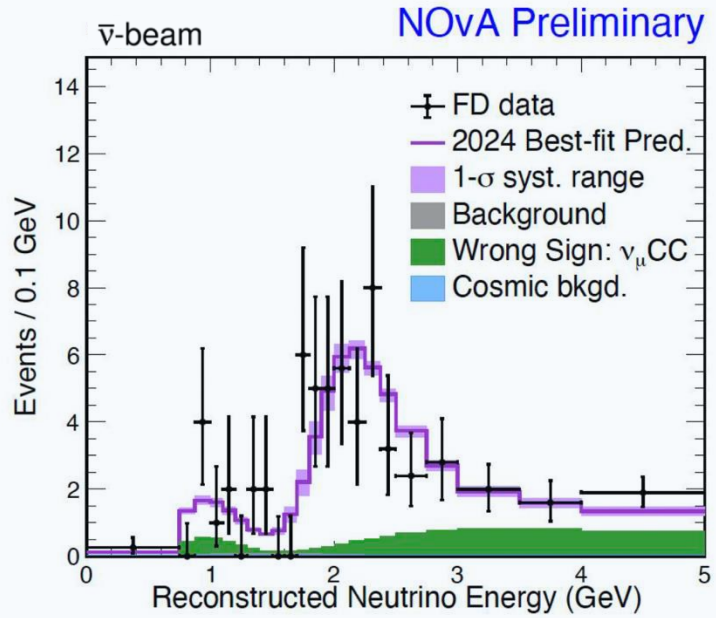
Neutrino Mode: 26.61×10^{20} POT (protons-on-target)

Antineutrino Mode: 12.50×10^{20} POT

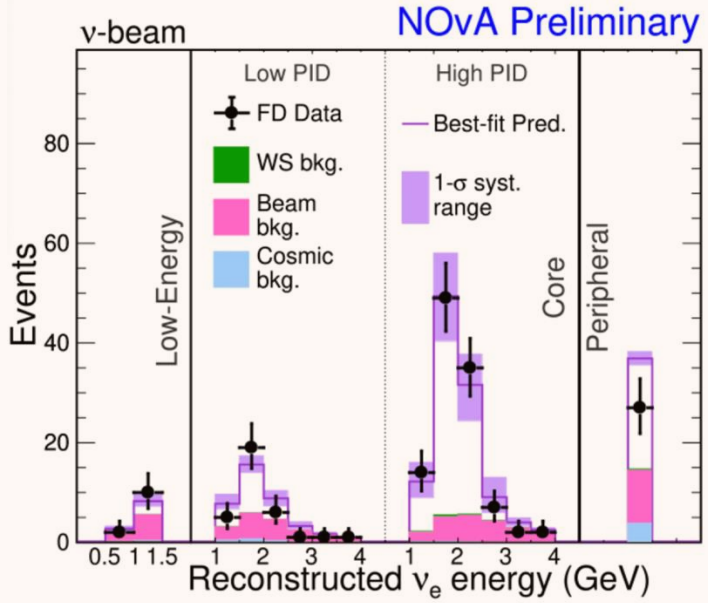
FD Selected Events

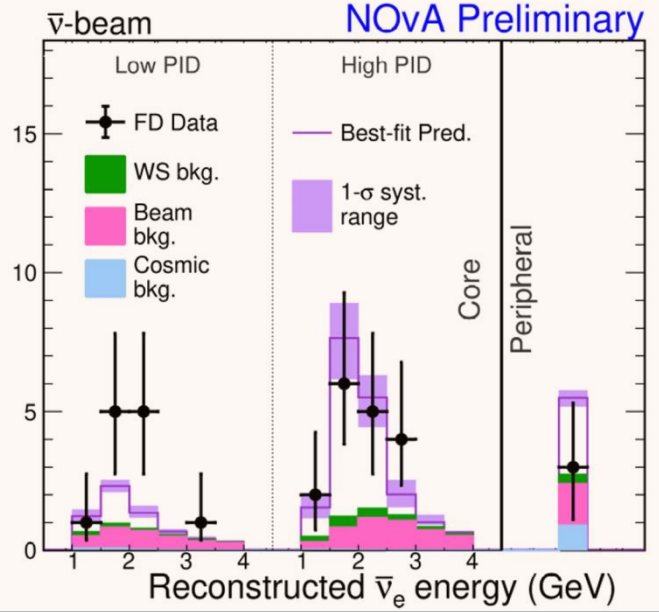
Disappearance Channel



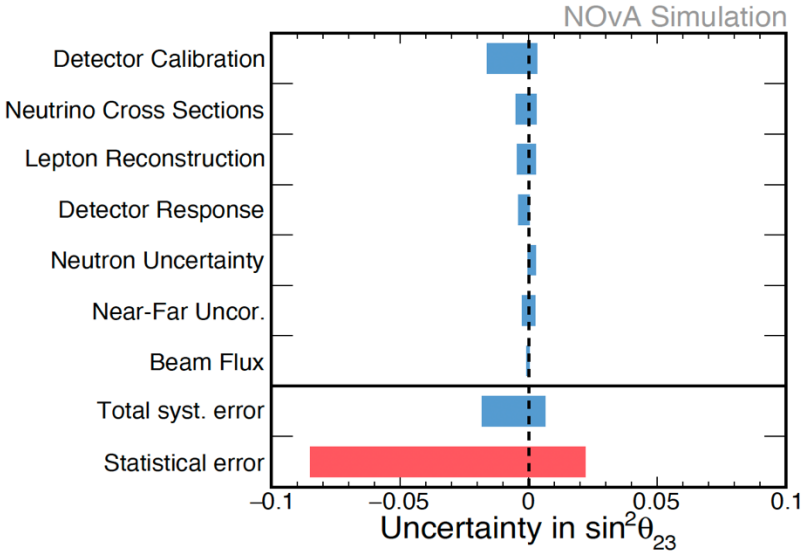


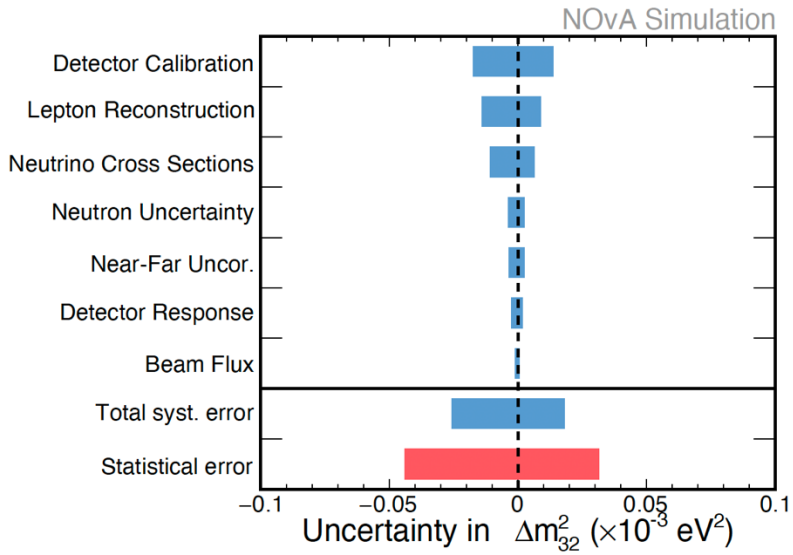
Appearance Channel

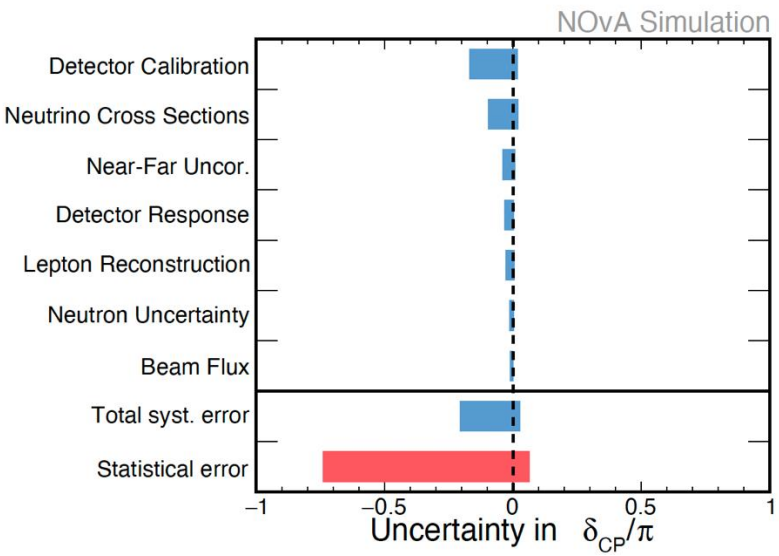




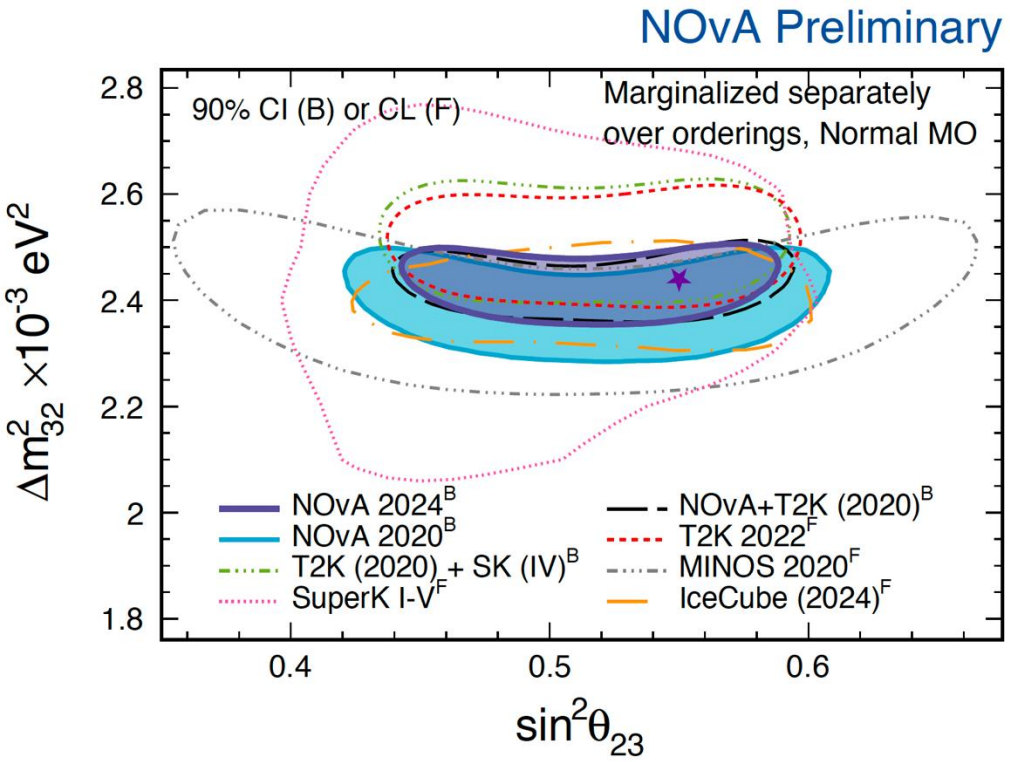
Systematic Uncertainties

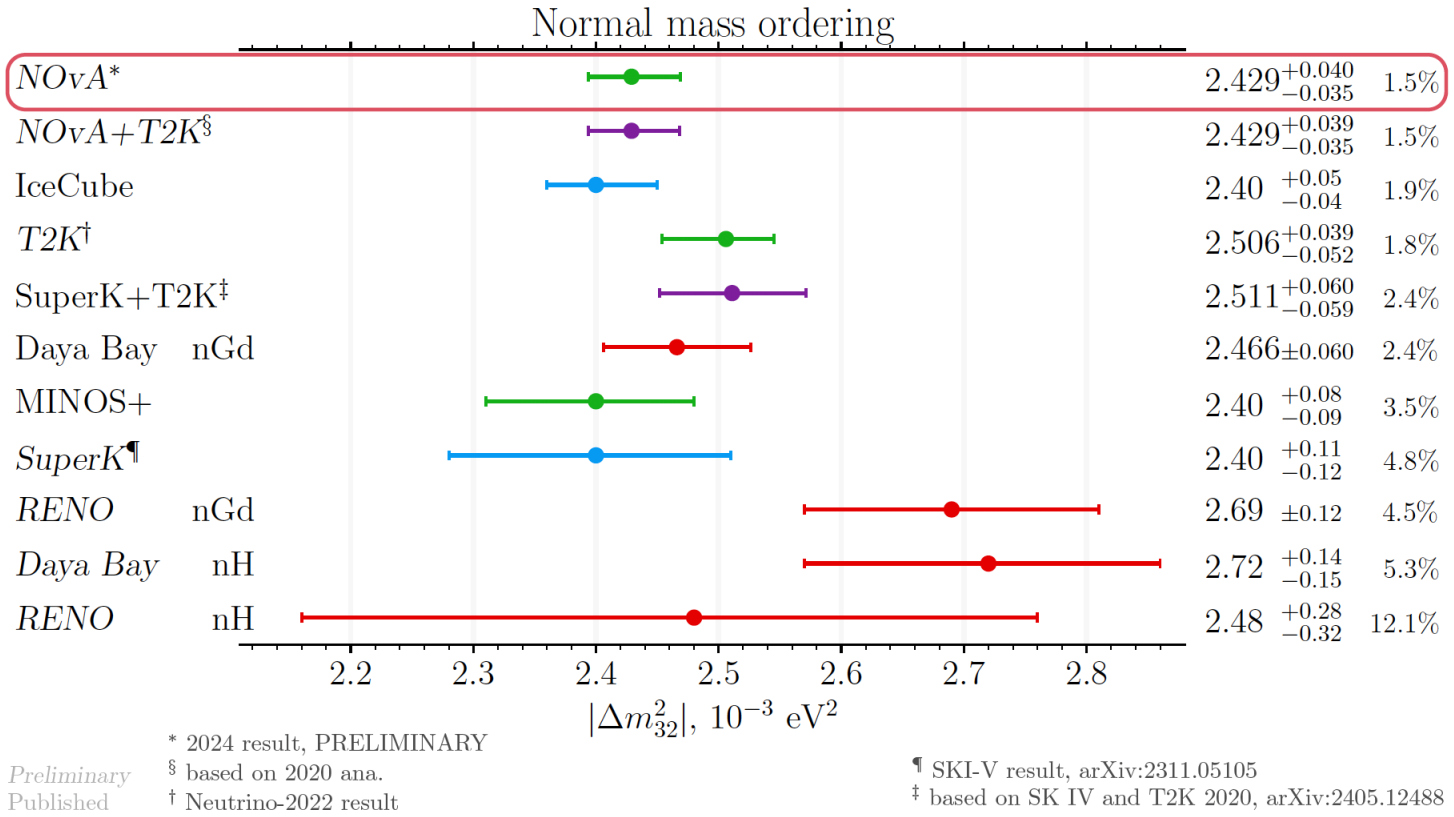






Parameter Extraction





NOVA has the best measurement from a single experiment of Δm^2_{32} at a 1.5% precision

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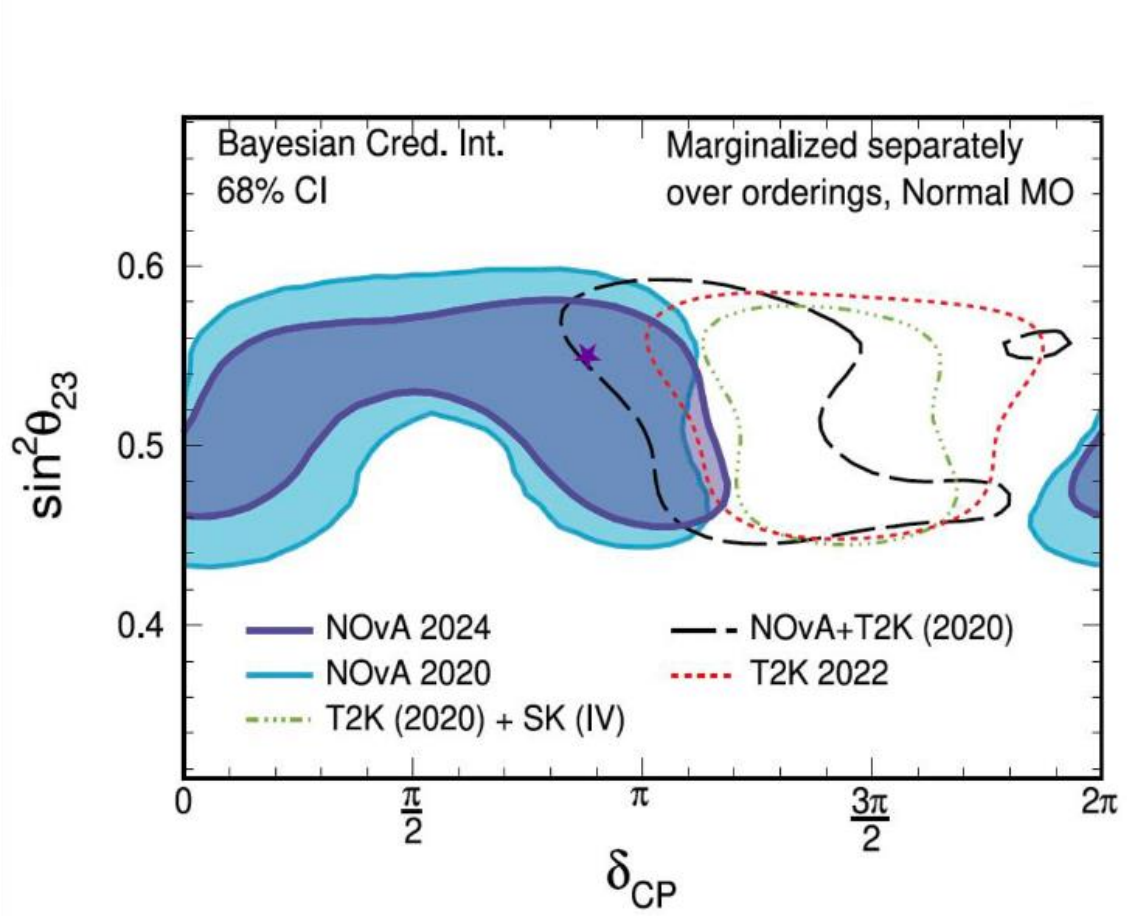

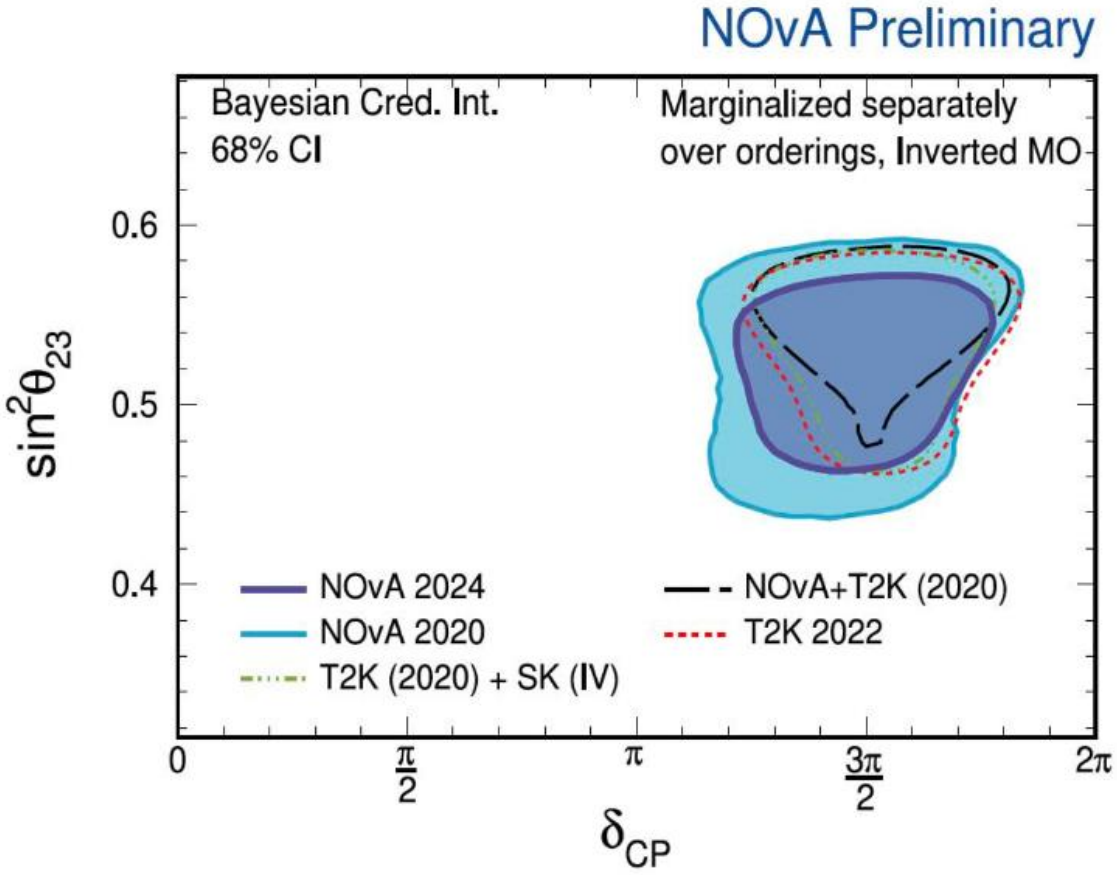

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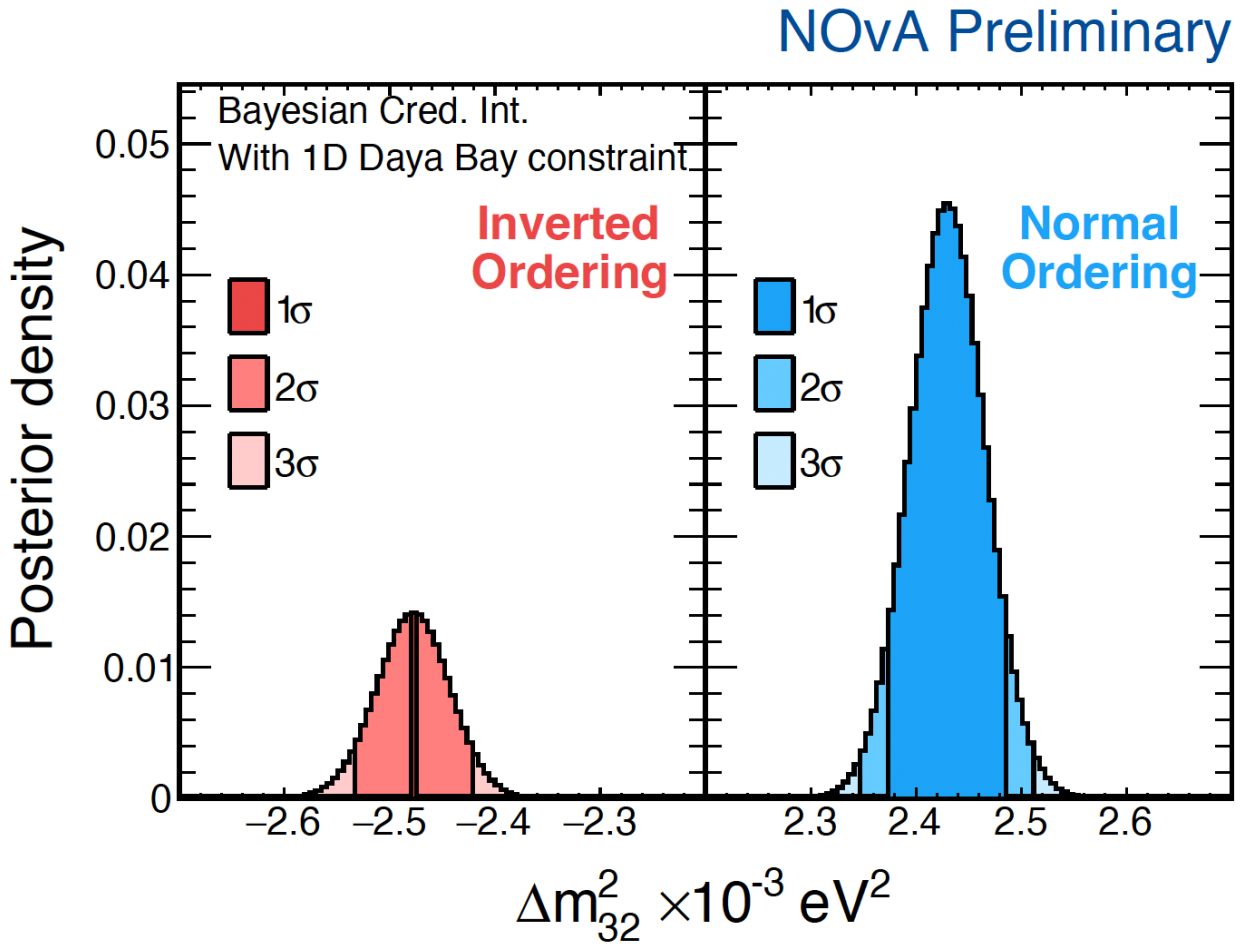
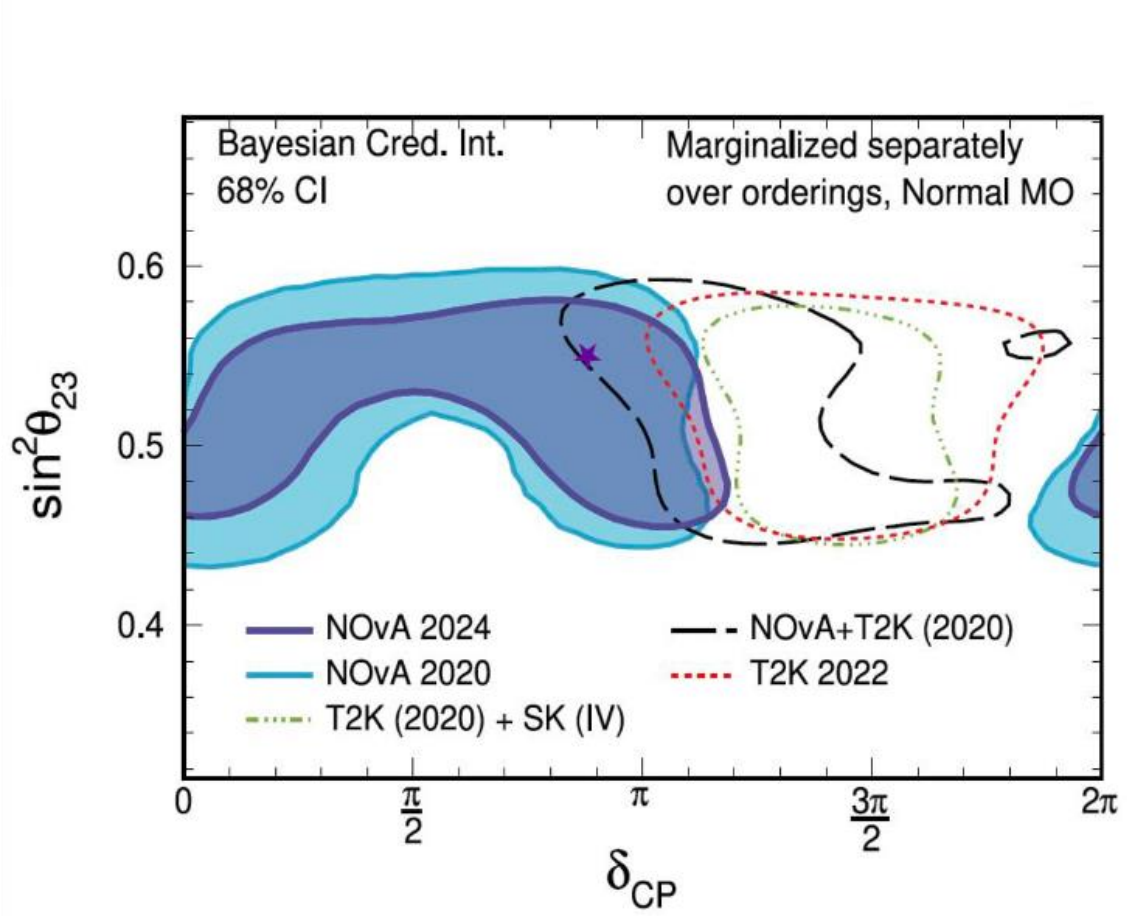
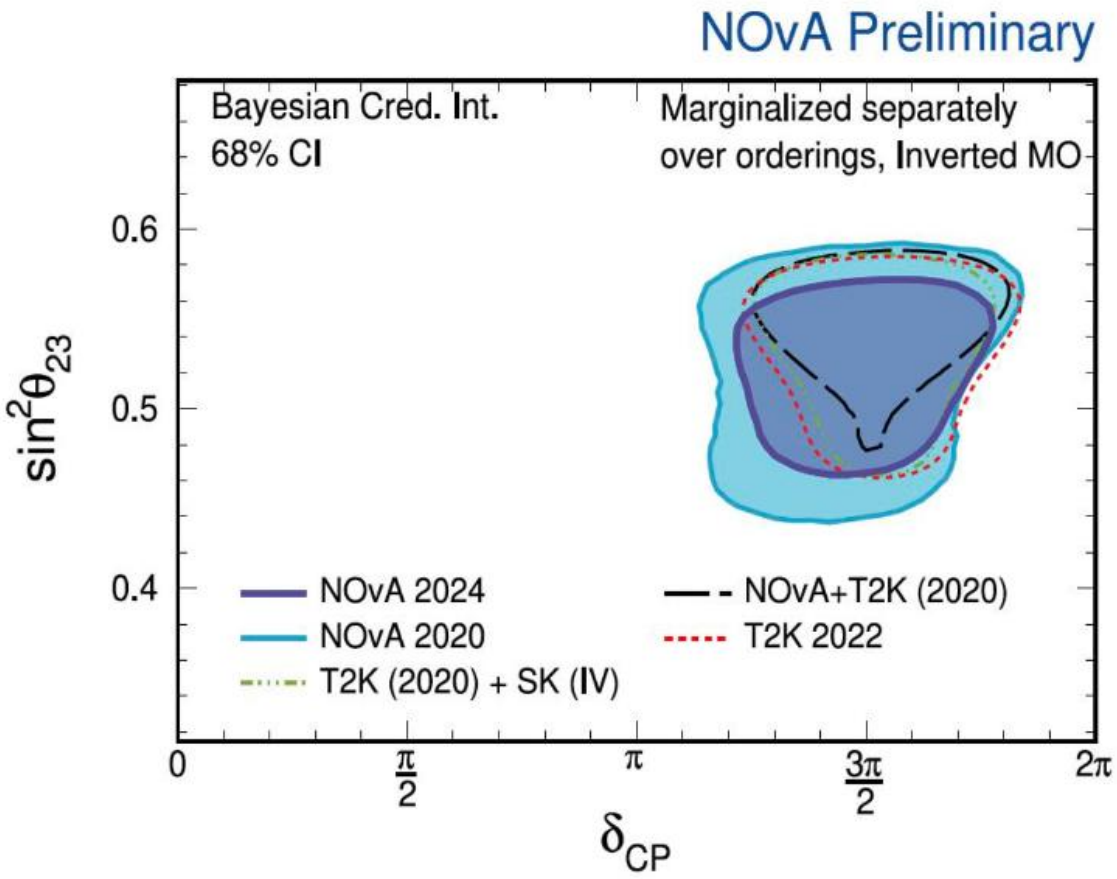


NOVA has mild preference for Normal Ordering
77% probability with Bayes Factor of 3.3

If you use 2D constraints in θ_{13} and Δm^2 from Daya Bay the probability is 87%

Parameter Extraction





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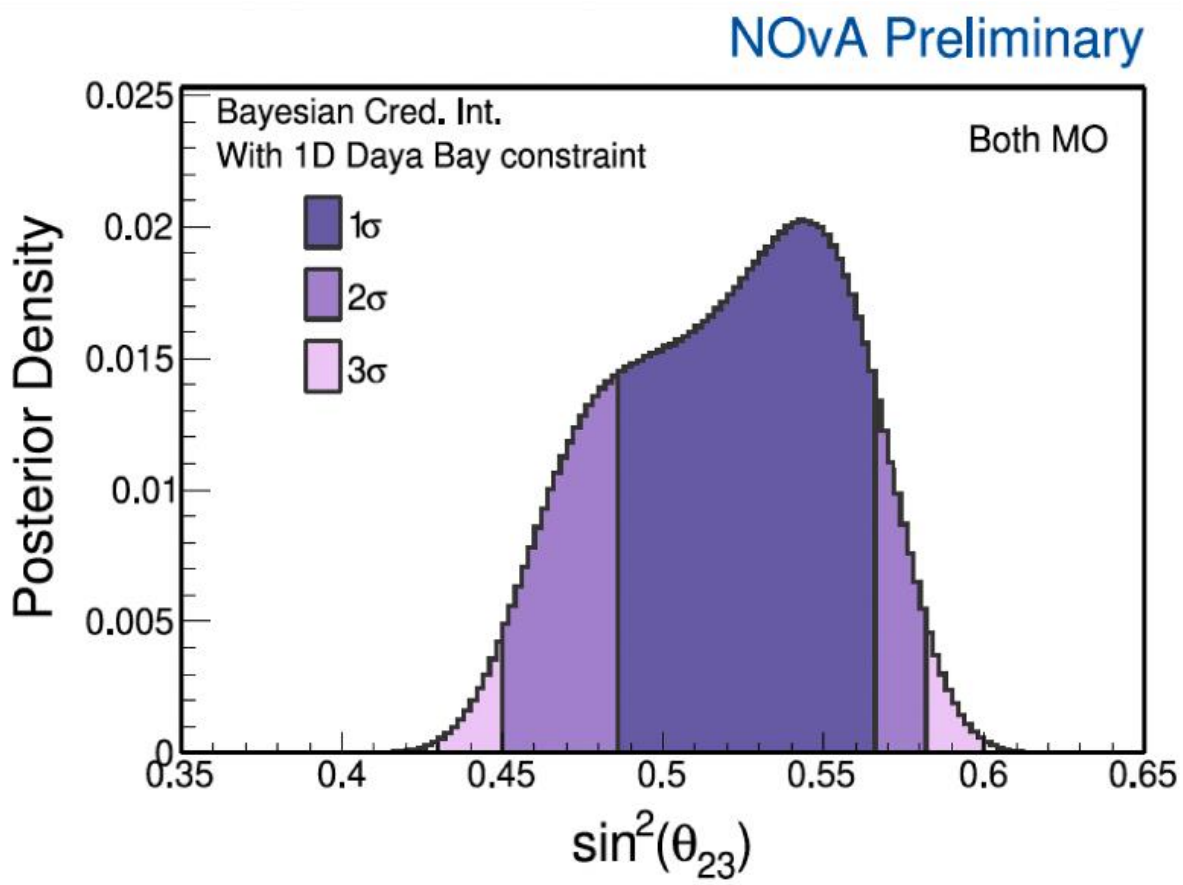

NOVA has mild preference for Upper Octant
69% probability with Bayes Factor of 2.2

Summary and Outlook

NOvA has the best single-experiment measurement of $\left|\Delta m^2_{32}\right|$ with a precision of 1.5%

Slight preference for

- Upper Octant
- Normal Mass Ordering

NOvA will operate until the beginning of 2027

- We will have updated oscillation results
- We collected a rich sample of Near Detector event that will be analyzed for cross-section analyses
- New cross-section results coming out.