NOvA in 10 minutes

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for the NOvA Collaboration

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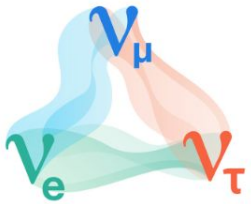
New Perspectives 2024

Neutrino oscillations

Neutrinos produced as one flavor can be detected some distance away as a different flavor- oscillation!



$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

Neutrinos can be represented in the mass basis (propagation) or the flavor basis (interaction)

PMNS matrix relates mass basis to flavor basis and depends on 3 mixing angles and a complex phase

Probability of oscillation depends on differences between mass states, PMNS matrix elements, neutrino energy, and distance traveled

$$P(\nu_\alpha \to \nu_\beta) \sim \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

(Two-flavor approximation)

Image from Symmetry Magazine

Open questions in neutrino oscillations

Do neutrino oscillations violate CP symmetry? Could tell us about origins of matter-antimatter asymmetry

Which is the heaviest mass state? Important for origins of neutrino mass

What is the octant of θ_{23}? Is it less than $\pi/4$ or greater? Or is it exactly $\pi/4$, which would point to a new symmetry?

Are there only three neutrino flavors? Are there other components to neutrino mixing that we don't yet understand?

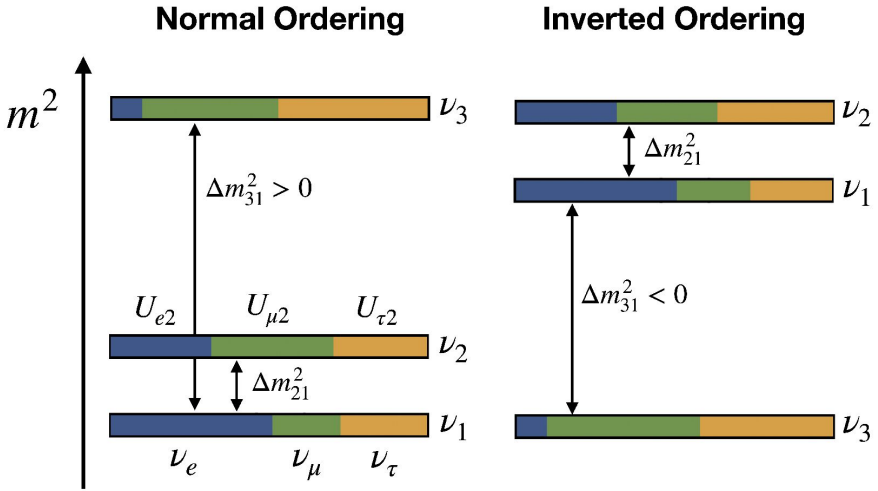


Image from Phys. Sci. Forum 2023, 8(1), 7; https://doi.org/10.3390/psf2023008007

The NOvA experiment

Long-baseline neutrino experiment with two functionally identical detectors, one at Fermilab and one in northern Minnesota

Look for muon (anti)neutrino disappearance and electron (anti)neutrino appearance from a muon (anti)neutrino beam

NOvA physics goals

3-flavor oscillations- tells us about CP symmetry, mass ordering, θ_{23} octant

Sterile neutrino search, search for non-standard interactions (NSI)- are there other components to neutrino oscillations?

Neutrino cross sections

“Exotics”- dark matter, magnetic monopoles, neutrino magnetic moment, neutrino decay

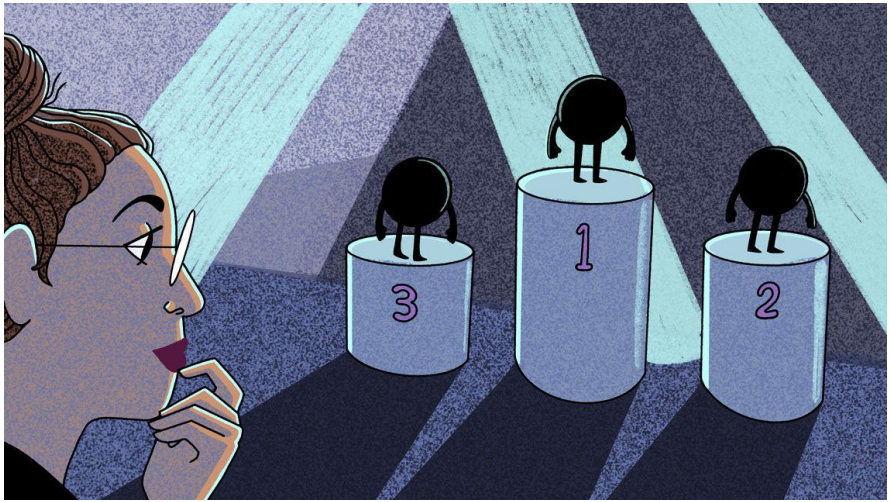
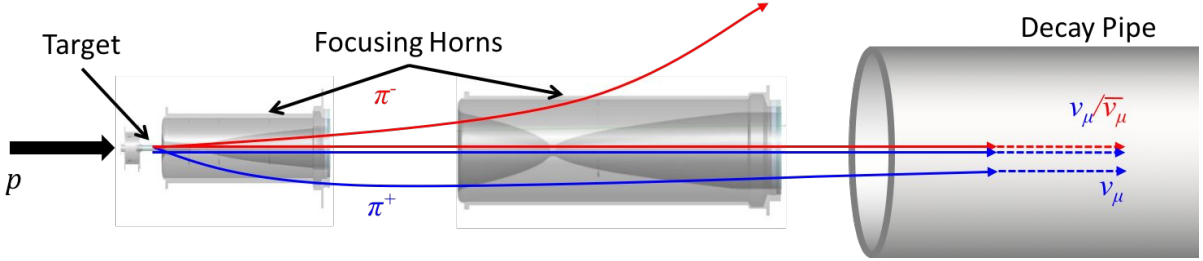


Image from Symmetry Magazine

NuMI beam



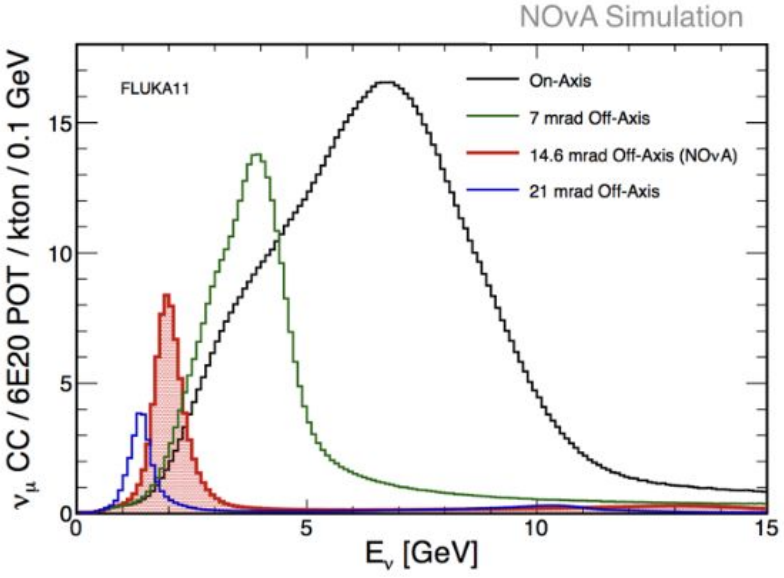
Beam of 120 GeV protons impinges on graphite target, producing mainly pions and kaons

Focus charged pions and kaons into beam

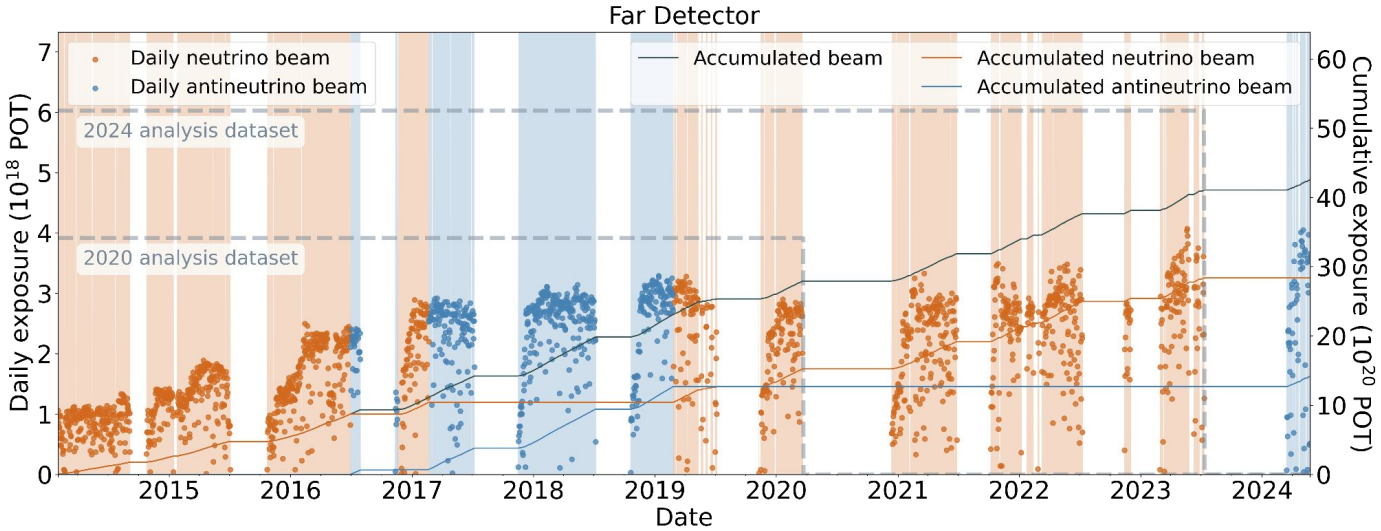
Provide space to decay into muon neutrinos and material to stop additional particles

Neutrino beam is 96.3% pure, antineutrino beam is 83.5% pure

NOvA is slightly off-axis of NuMI to provide desired energy spectrum



NuMI beam



Delivers ~5e13 protons per beam spill. Thanks to the Accelerator Division for such high-quality beam!

Most powerful neutrino beam in the world, with a recent record 1 MW of power!

NOvA detectors

Near Detector

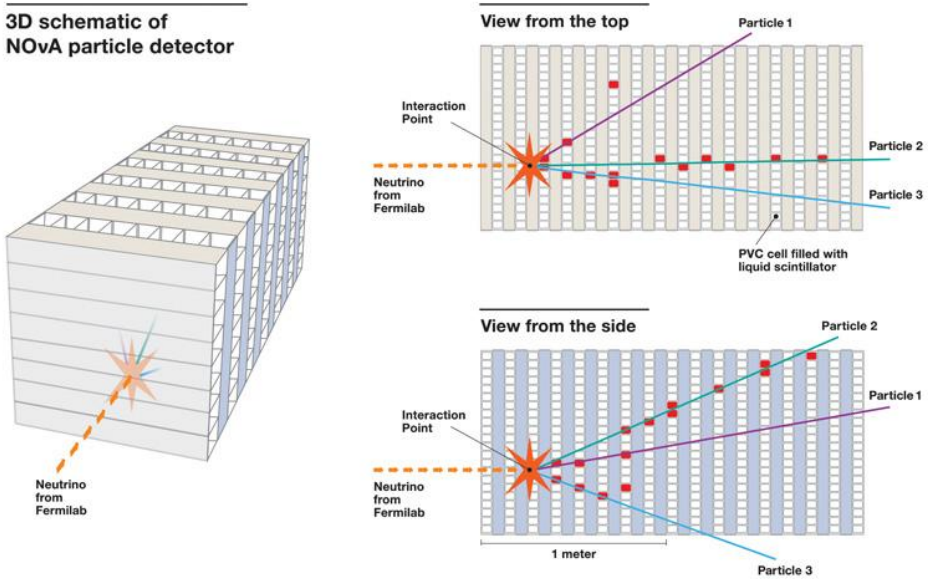
Functionally identical tracking calorimeters

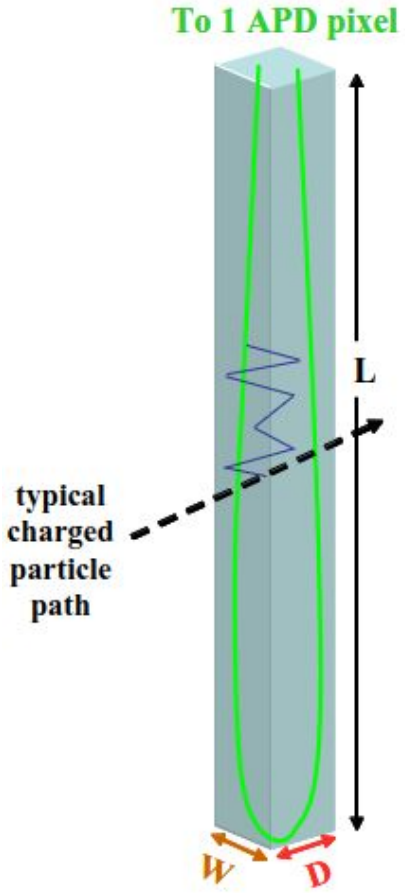
Near Detector:
- 100 m underground
- 1 km from NuMI
- 300 tons

Far Detector:
- Above ground with 3 mwe rock overburden
- 810 km from NuMI
- 14 ktons

Far Detector

NOvA detectors



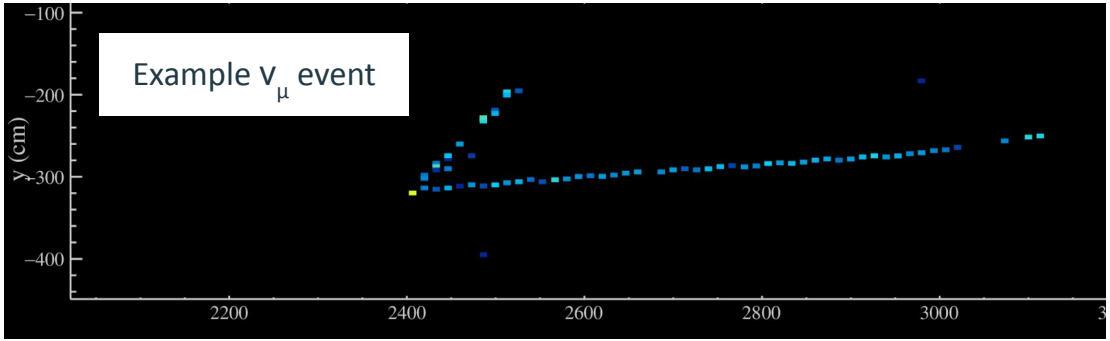


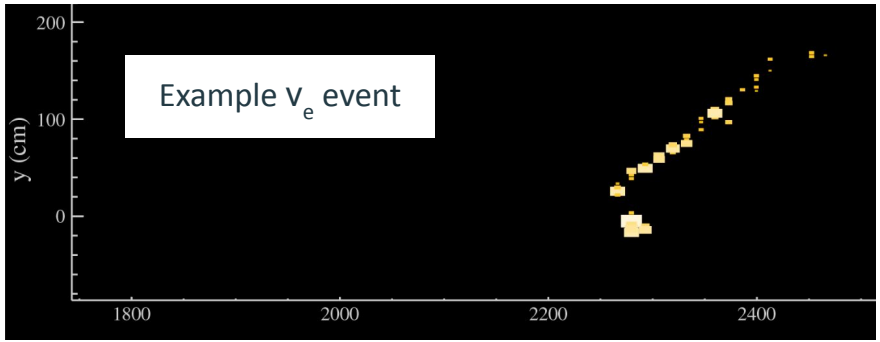
Alternating horizontal and vertical PVC cells allow for 3D particle tracking

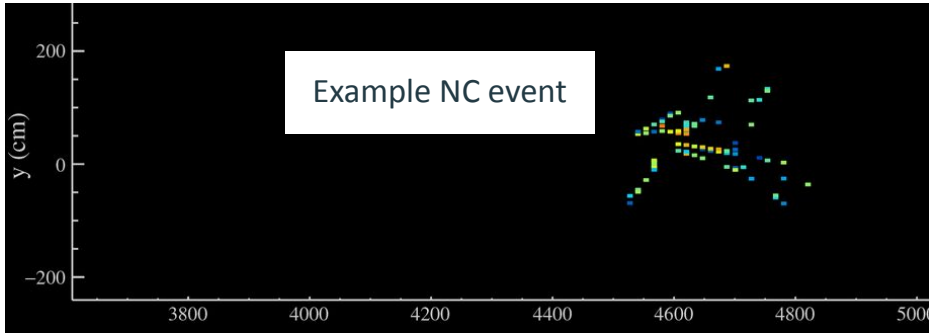
Cells are filled with liquid scintillator

Optimized for good EM shower resolution and identification

Detect scintillation light with a wavelength shifting fiber looped in each cell


Example ν_μ event
y (cm)
−100
−200
−300
−400
2200
2400
2600
2800
3000


Example ν_e event
y (cm)
200
100
0
1800
2000
2200
2400


Example NC event
y (cm)
200
0
−200
3800
4000
4200
4400
4600
4800

Test beam

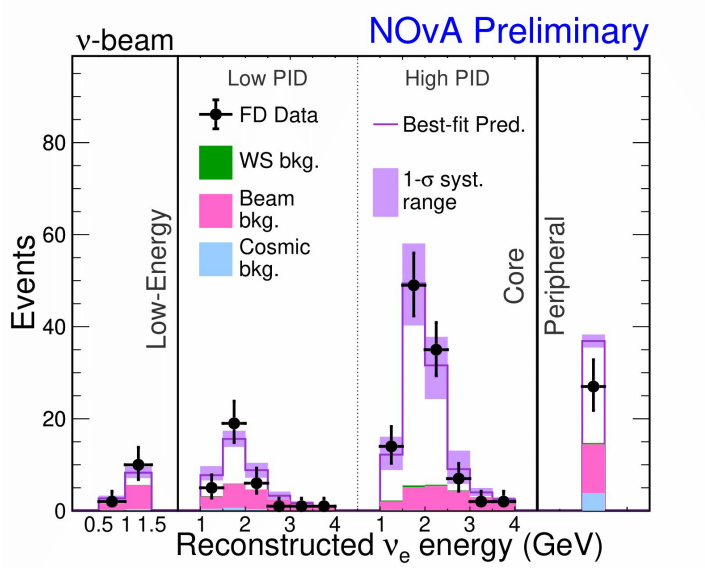
Study how particles with known identities and energies interact in a small version of the NOvA detectors

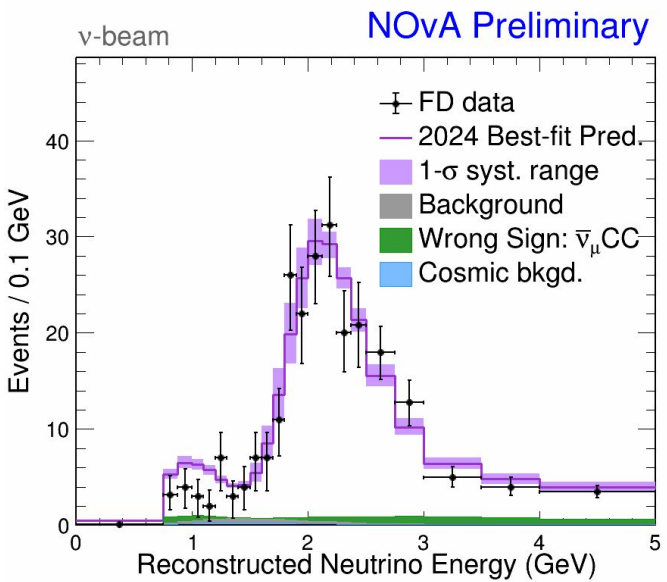
Can help reduce systematic uncertainties by improving particle identification, energy resolution

3-flavor oscillations

New analysis recently released! Since last analysis, retained a sample of low-energy electron neutrinos and doubled neutrino exposure

See Ishwar's talk on recent analysis

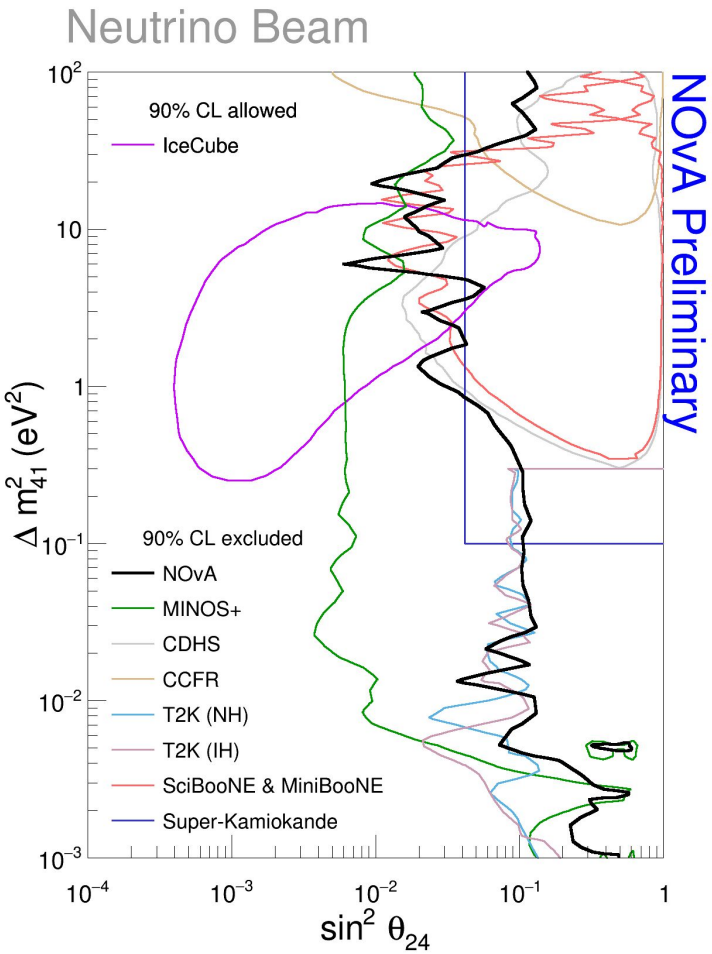




Beyond standard oscillations

Sterile neutrino search finds no evidence for active to sterile neutrino oscillations and places competitive limits on 3+1 flavor oscillation parameters

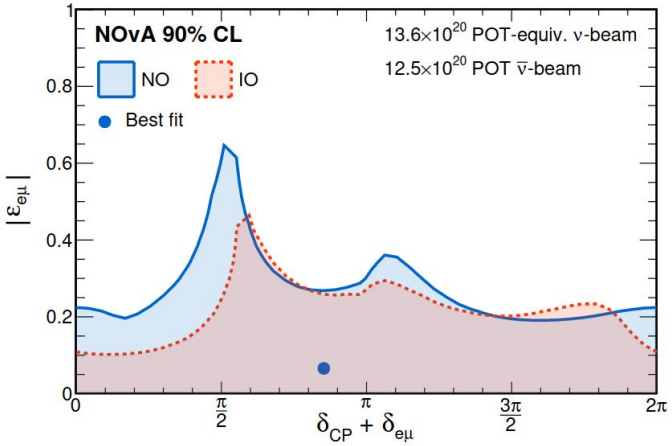
See Shivam's talk on improvements for future sterile analyses

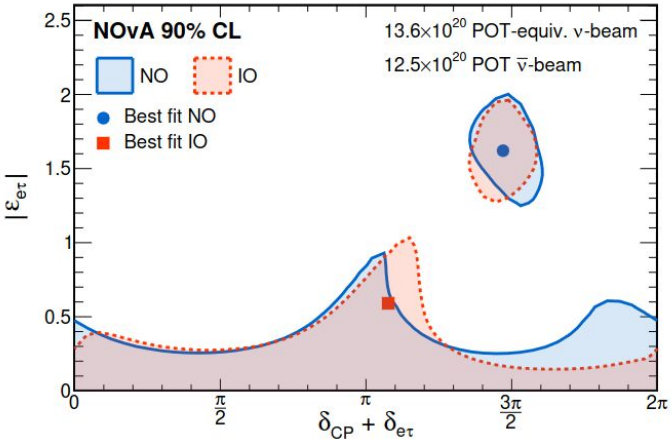


Beyond standard oscillations

Search for NSI in neutrino oscillations places limits on NSI parameters

Analysis finds that the presence of NSI would impact sensitivity to δ_{CP}





Summary and future prospects

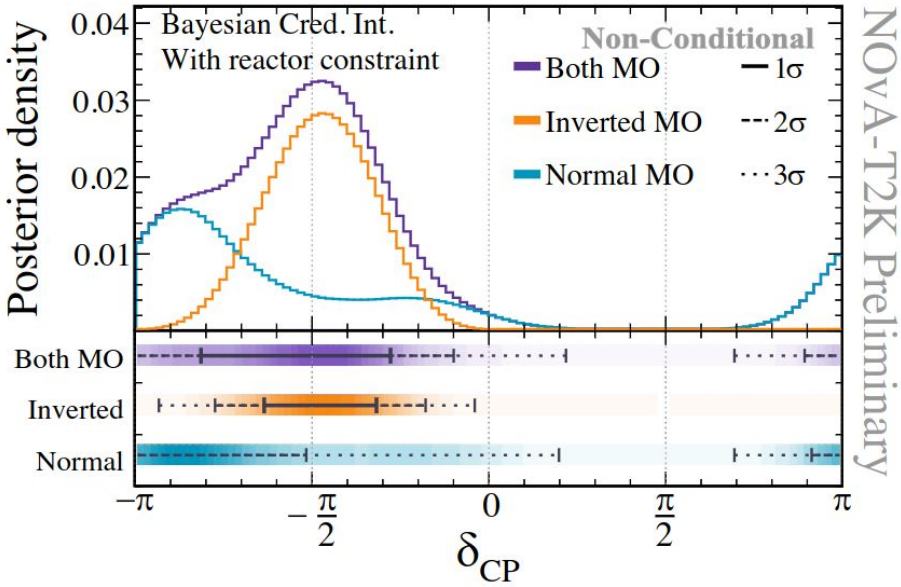
Other recent results include a joint fit with T2K that shows 3-σ rejection of $\delta_{CP} = 0$ for inverted ordering

Recent NuMI power record of 1 MW! Thanks AD!

NOvA is producing world-leading results in multiple areas of neutrino physics

We can reduce dominant systematic uncertainties with test beam program

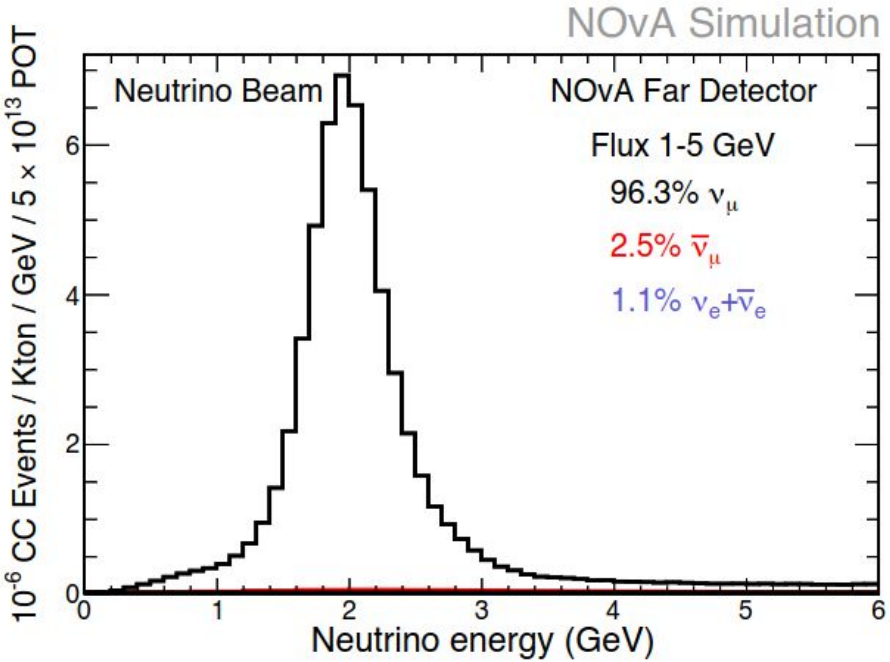
Collaboration would like to double the antineutrino exposure to reduce statistical uncertainties and increase sensitivity to δ_{CP} and mass ordering

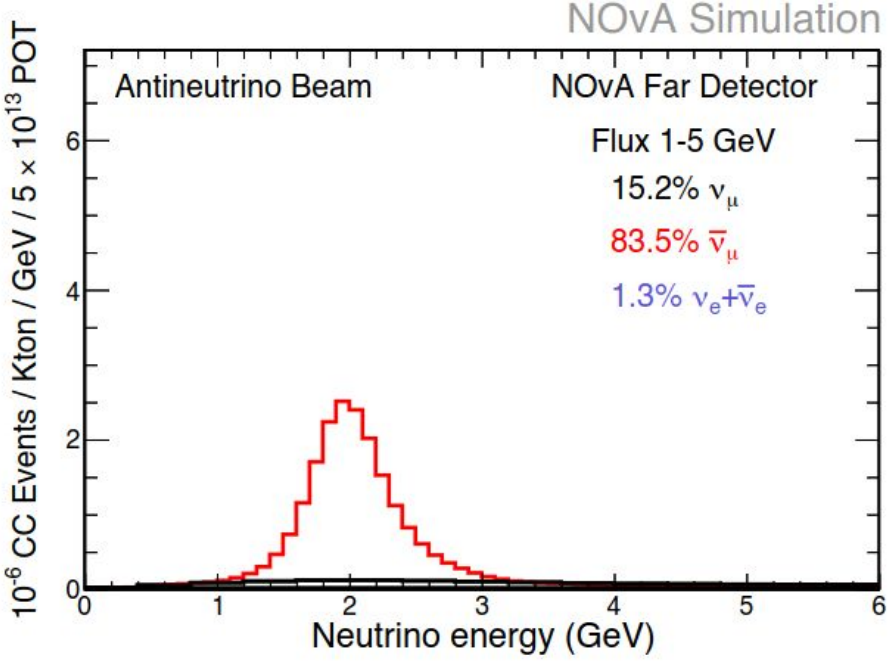


Thank you!

Backup slides

Beam purities

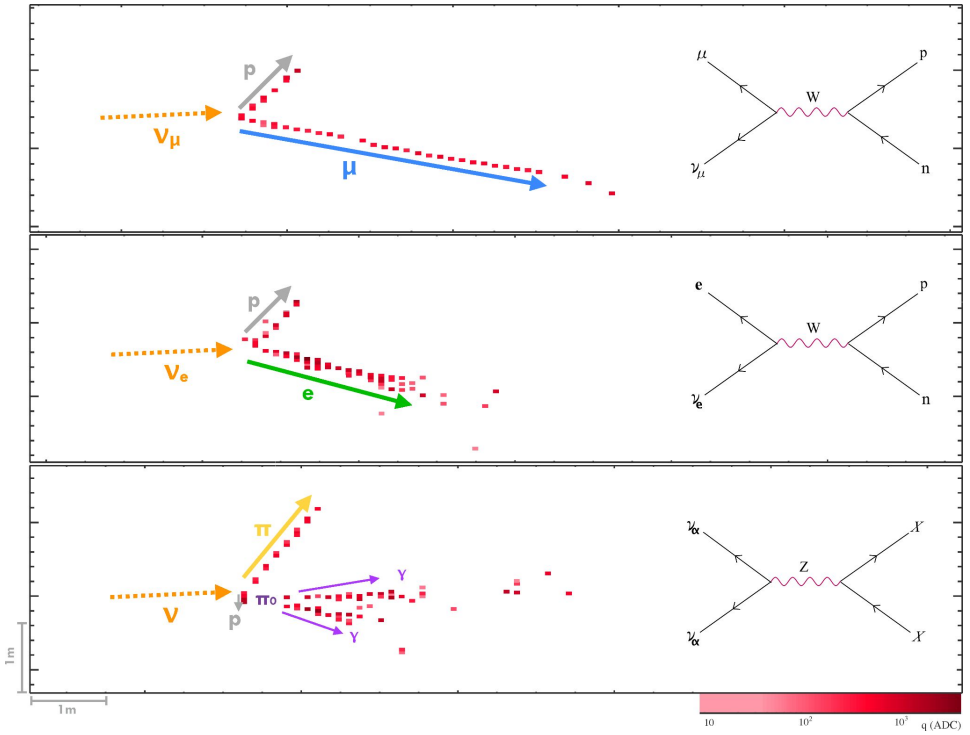




Event identification

Use convolutional neural network to distinguish between interaction types

- Muons tend to leave long straight tracks
- Electrons tend to leave EM showers
- NC events do not have outgoing charged lepton



Predictions with no oscillations