First Results from the NOvA Antineutrino Neutral-Current Disappearance Sterile Neutrino Search

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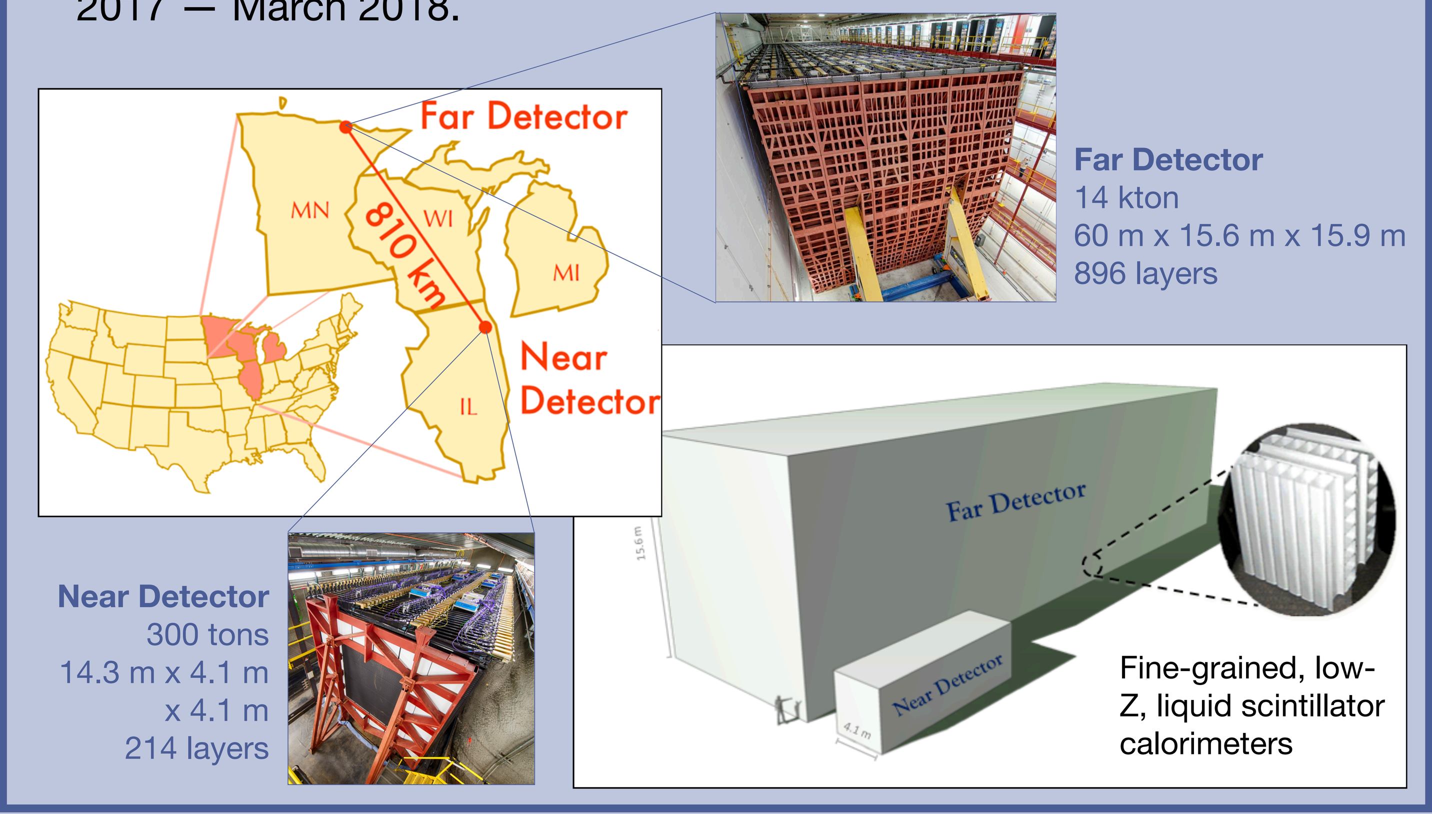
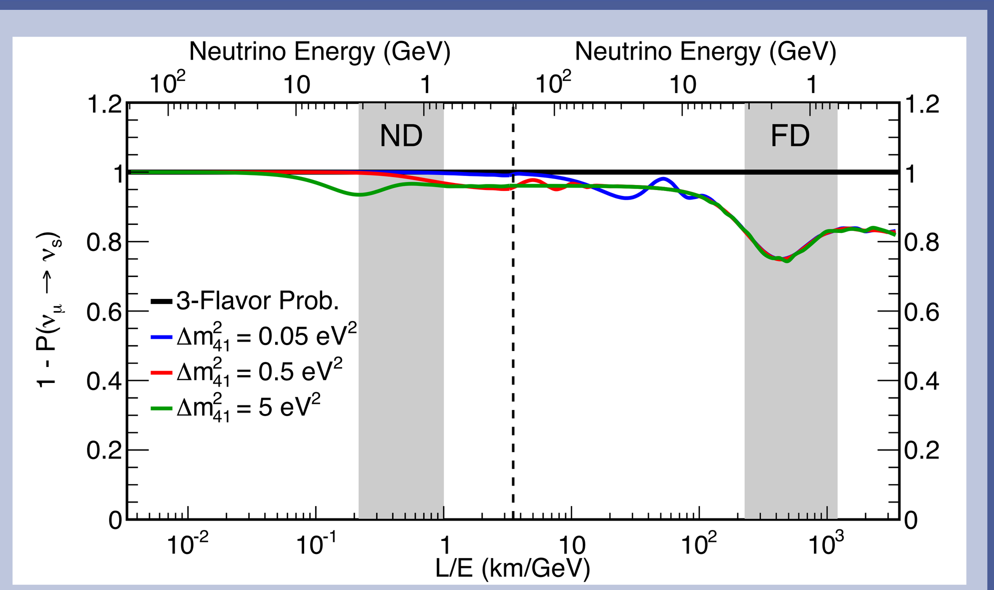
NOvA

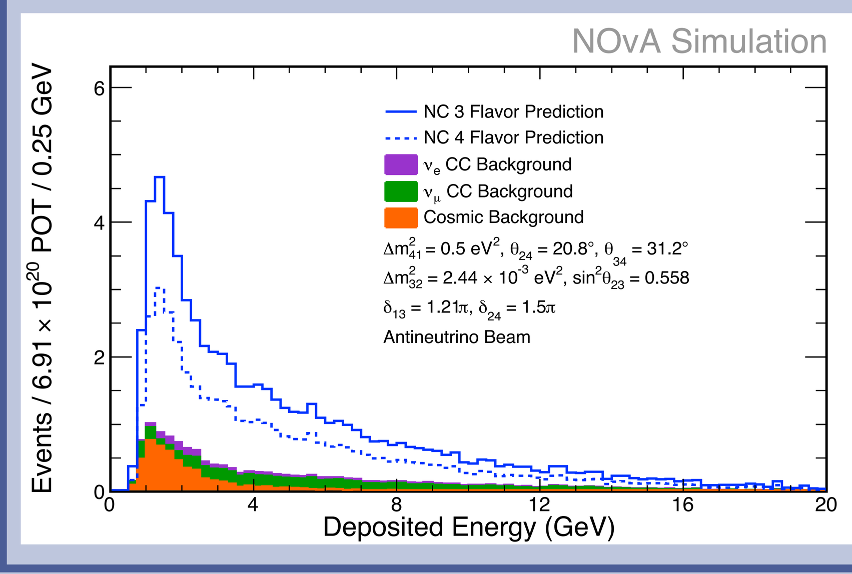
- NOvA (NuMI Off-Axis ν_e Appearance) is a long-baseline neutrino oscillation experiment based at Fermilab.
- Neutrinos from the NuMI beam are sampled 14 mrad off-axis at 1 km and 810 km by two functionally identical detectors.
- First antineutrino beam data taking, 15 months: June 2016, February 2017 — March 2018.



Neutral Current Disappearance

- Neutral Current (NC) interactions of active neutrinos are unaffected by three-flavor oscillations but mixing between active and sterile neutrinos would reduce the NC event rate.
- Two previous results of this analysis applied to neutrino data shown [1]; this is the first antineutrino NC-disappearance study.
- Consider a 3+1 model with $\Delta m^2_{41} < 0.5$eV², so the ND spectrum does not include oscillations.
- Future analysis will include joint ND oscillation fit (see Poster #141 and the corresponding NOvA neutrino NC analysis).





- NC disappearance at the Far Detector (FD) is approximated by

$$1 - P(\nu_\mu \to \nu_s) \approx 1 - c^4_{14} c^2_{34} \sin^2 2\theta_{24} \sin^2 \Delta_{41} - s^2_{34} \sin^2 2\theta_{23} \sin^2 \Delta_{31} - \frac{1}{2} \sin \delta_{24} s_{24} \sin 2\theta_{34} \sin 2\theta_{23} \sin 2\Delta_{31}$$

- NOvA long-baseline sterile search sensitive to θ_{24} and θ_{34}, assuming a small θ_{14} consistent with reactor experiment constraints.
- First fit of these angles with long-baseline antineutrinos.

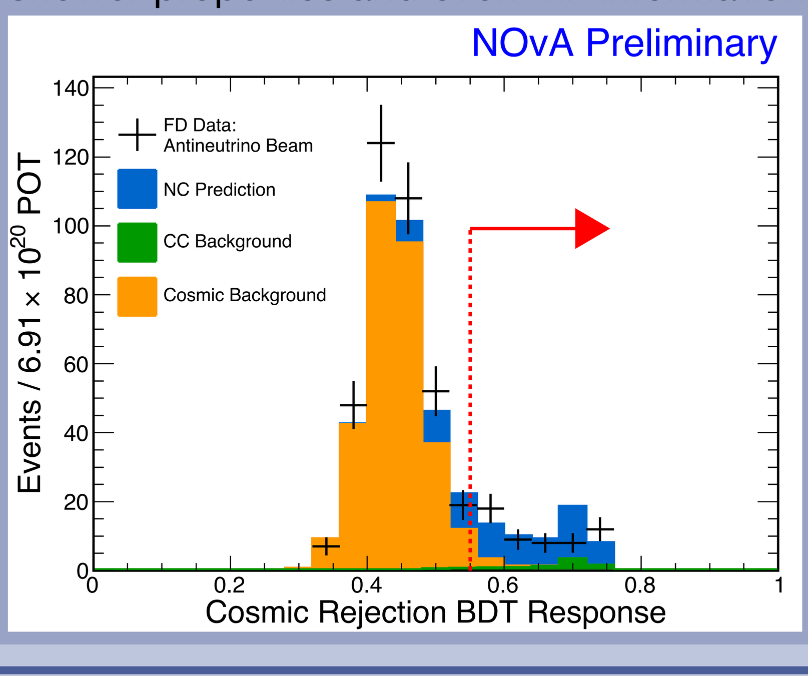
$$s_{ij} \equiv \sin\theta_{ij} \quad c_{ij} \equiv \cos\theta_{ij} \quad \Delta_{ij} \equiv \frac{\Delta m^2_{ij} L}{4E}$$

Neutral Current Event Selection

- Same selection applied at the ND and FD, with ND data used along with FD and ND simulation to produce FD prediction spectrum.
- Main backgrounds of cosmic events and beam induced Charged Current (CC) interactions (ν_μCC and ν_eCC) are reduced through a succession of cuts.

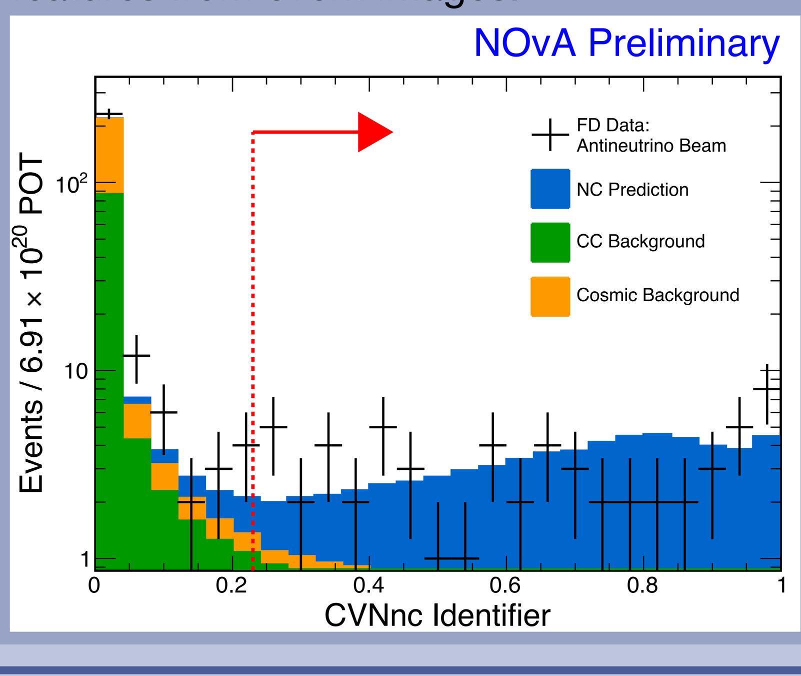
Cosmic Rejection

- Cosmic events are removed by identifying backward facing showers and possible cosmogenic neutrons in temporal and physical proximity to NC candidate events.
- Strongest cut comes from a Boosted Decision Tree trained on parameters such as shower properties and event hit information.



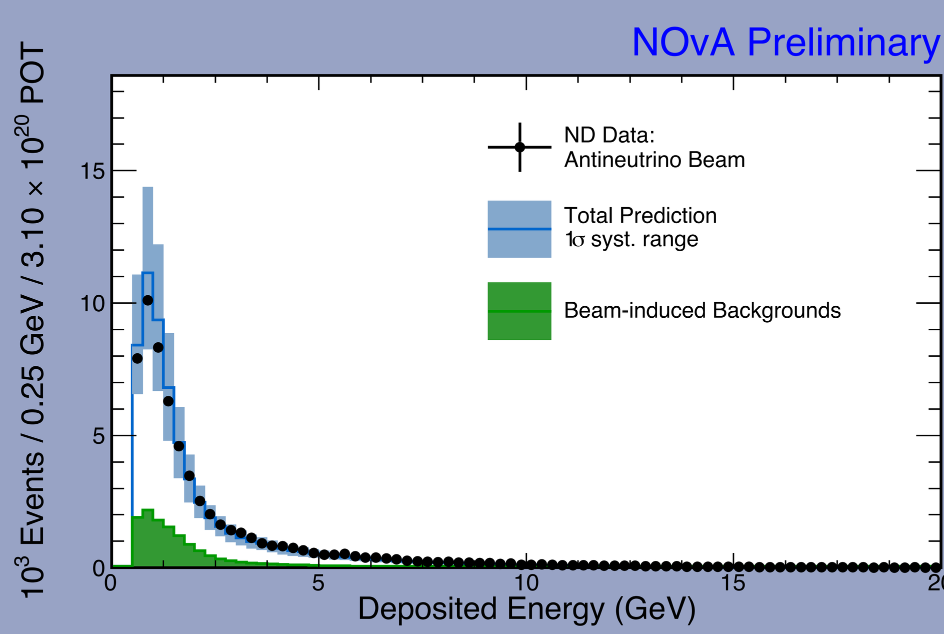
NC Selection

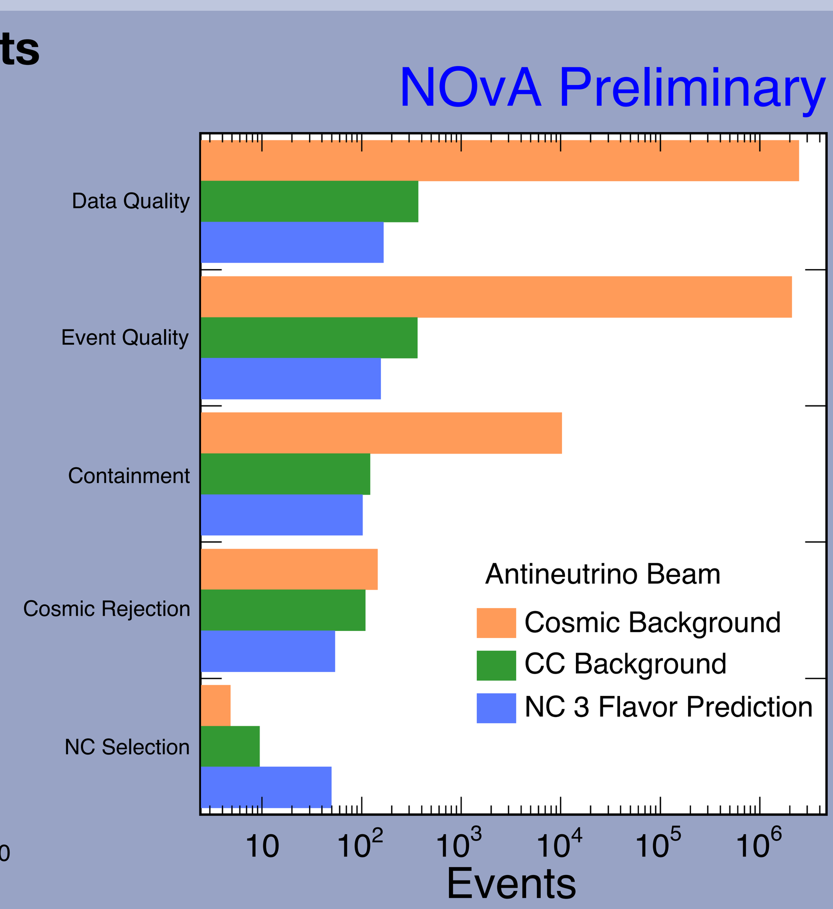
- NC and CC events have very distinct topologies in NOvA.
- A convolution neural network is used to classify event types (see Poster #79 on Wednesday) [2].
- Deep-learning algorithm designed to extract features from event images.



All Cuts

Cut Level	Efficiency	Purity
Containment	100%	3.3%
All	50.4%	76.7%





- Additional cuts include quality assurance (such as requiring a minimum detector activity and reconstructed information), and containment cuts to isolate beam events.
- Backgrounds are significantly reduced whilst selecting an excellent NC sample.

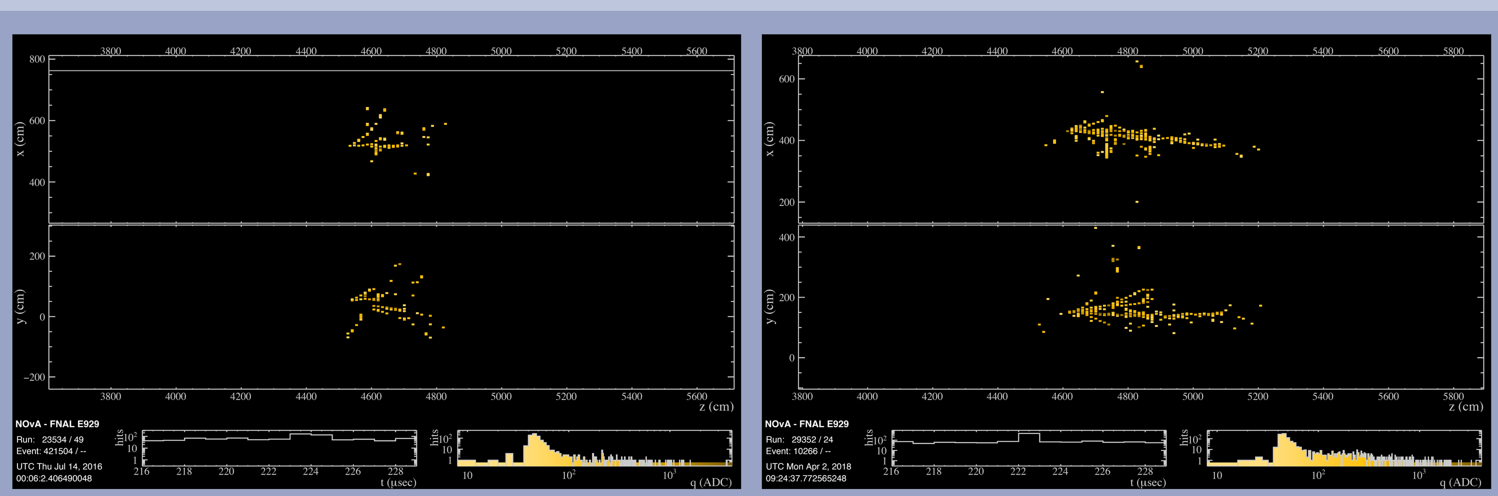
Results

- Select 61 events with a prediction of 69 events.

Observed	Predicted					
	All	NC	ν_μCC	ν_eCC	ν_τCC	Cosmic
61	68.9	53.4	6.8	1.9	1.5	5.3

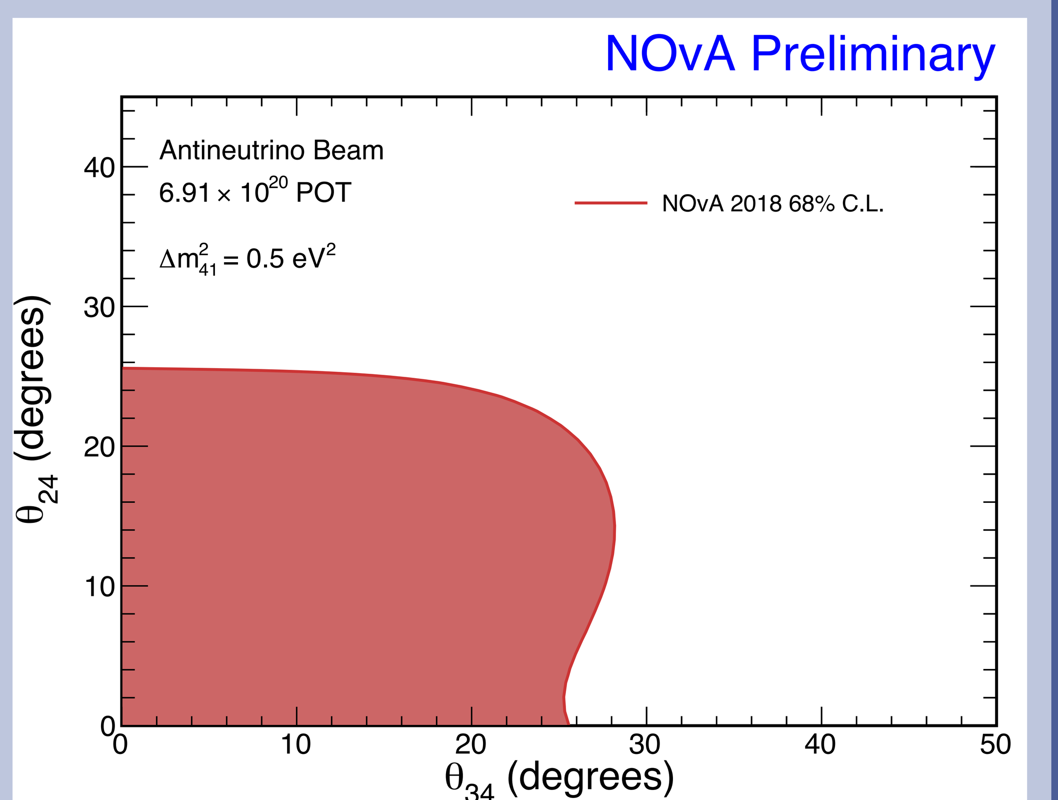
- **Consistent with oscillation in a 3-neutrino framework.**

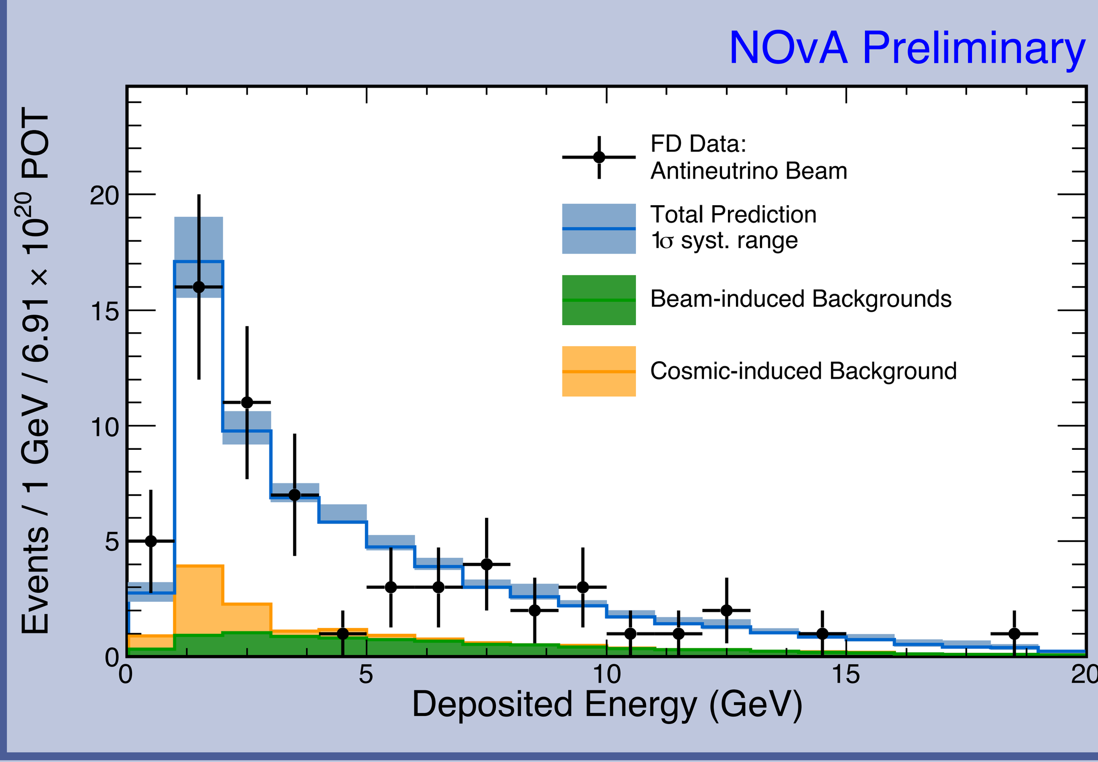
$$R_{NC} \equiv \frac{N^{Data} - \sum N^{Pred}_{Bkg}}{N^{Pred}_{NC}} = 0.86 \pm 0.15(\text{stat.})^{+0.09}_{-0.12}(\text{syst.})$$



Representative event displays

Both detector views (*x-z*, *y-z*). Brightness ~ charge deposited.

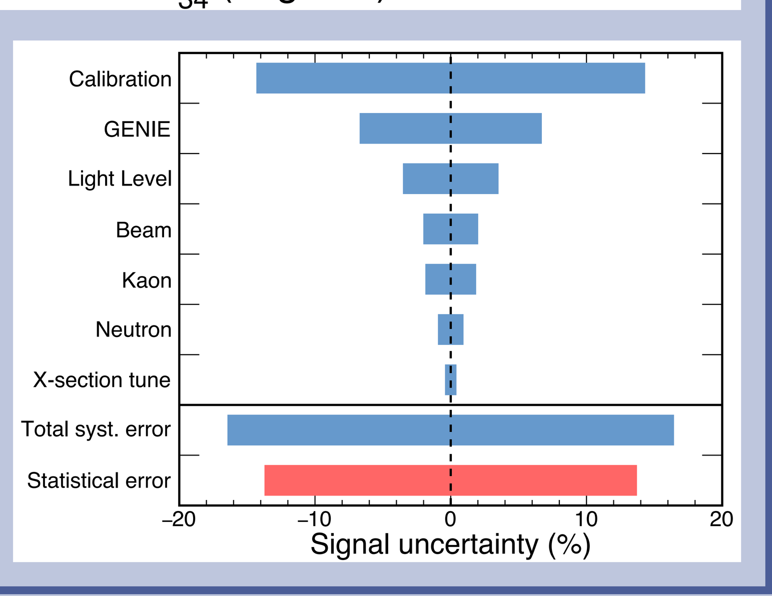




- Produce FD prediction by using simulation to constrain the ND data and extrapolating these spectra to the FD by convolving with the predicted ratio of the FD and ND distributions, taking into account geometrical differences of the detectors, beam dispersion and the effects of oscillation.
- This prediction may be compared directly to the spectrum of observed FD events.
- Perform fit to 3+1 model, scanning over the mixing angles θ_{24} and θ_{34} for Δm^2_{41} fixed at 0.5 eV². (A joint ND-FD fit to account for ND oscillations, and therefore larger values of mass splitting, will be included in the next analysis.)
- Results consistent but not yet competitive with global limits [3].
- Future analyses, including joint fits with neutrino data, will improve these limits.

Upper limits from 1D fit (68% C.L.)

θ_{24} (°)	θ_{34} (°)
25.5	31.5



References

[1] NOvA Collaboration, Search for active-sterile neutrino mixing using neutral-current interactions in NOvA, Phys. Rev. D **96**, 072006 (2017).
[2] A Aurisano *et al.*, A convolutional neural network neutrino event classifier, JINST **11** P09001 (2016).
[3] M Dentler *et al.*, Updated global analysis of neutrino oscillations in the presence of eV-scale sterile neutrinos, arXiv:1803.1066 (2018).

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http://novaexperiment.fnal.gov