Sterile Neutrino Search in the NOvA Far Detector through Neutral Current Disappearance.

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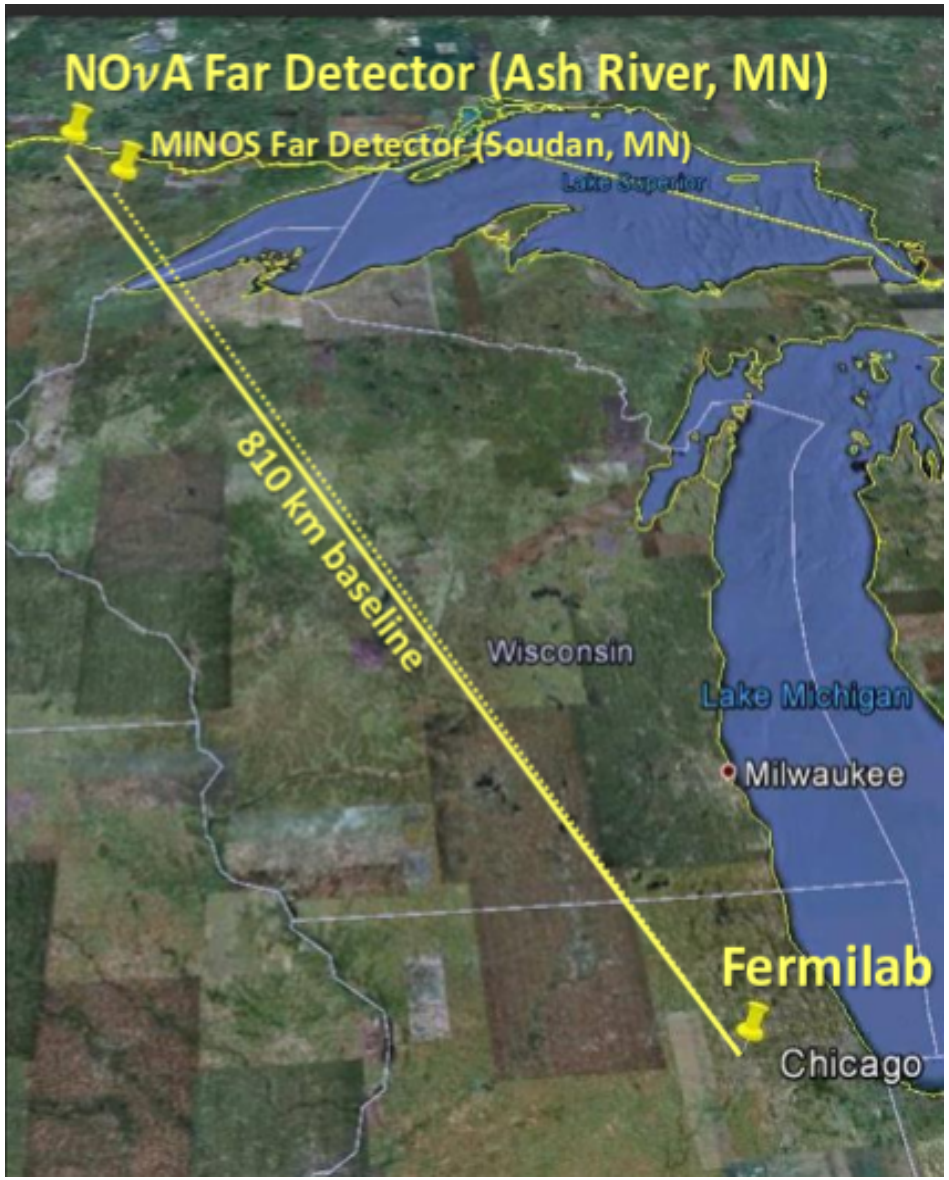
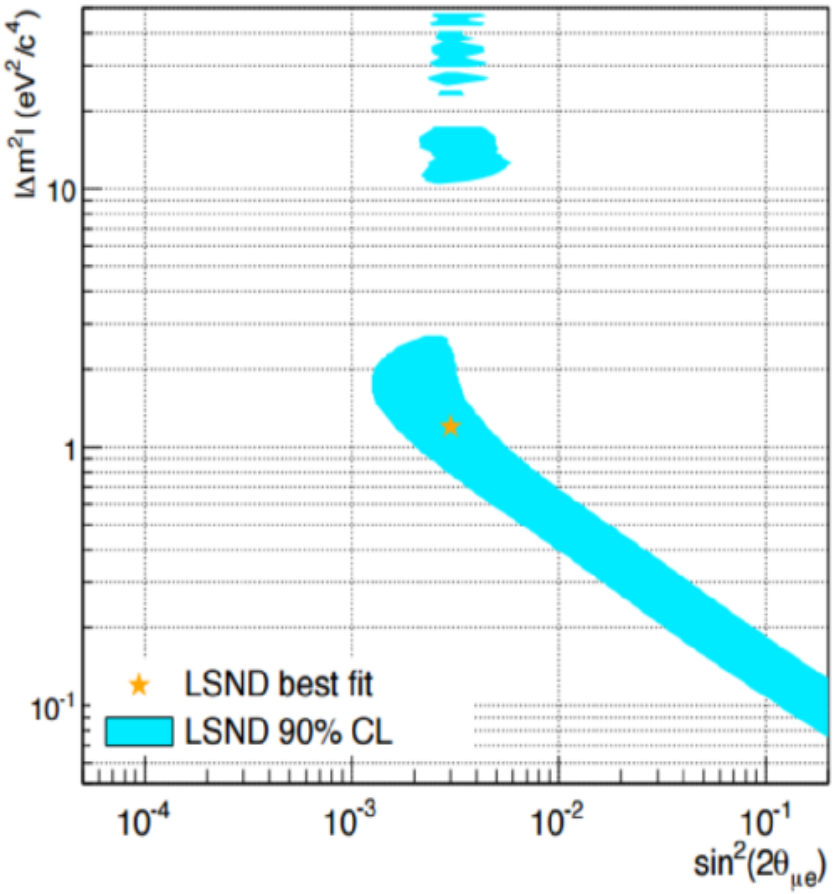
NOvA at a glance

- **NuMI Off-axis ν_e Appearance experiment**.
- A long-baseline neutrino experiment.
- Two functionally identical detectors- **Near Detector** at Fermilab and **Far Detector**, at Ash river, Minnesota.
- The detectors lie **14.6 mrad. off** from the Fermilab's NuMI (Neutrino at Main Injector) ν_μ **beam axis**, which provides a narrow-band beam **peaked at 2 GeV**



The LSND Anomaly

SBL experiment LSND measured an excess of $\overline{\nu}_e$ in $\overline{\nu}_\mu$ beam in the vicinity of $\frac{L}{E} = \frac{1m}{MeV}$. Another SBL experiment MiniBooNE also saw similar excess.

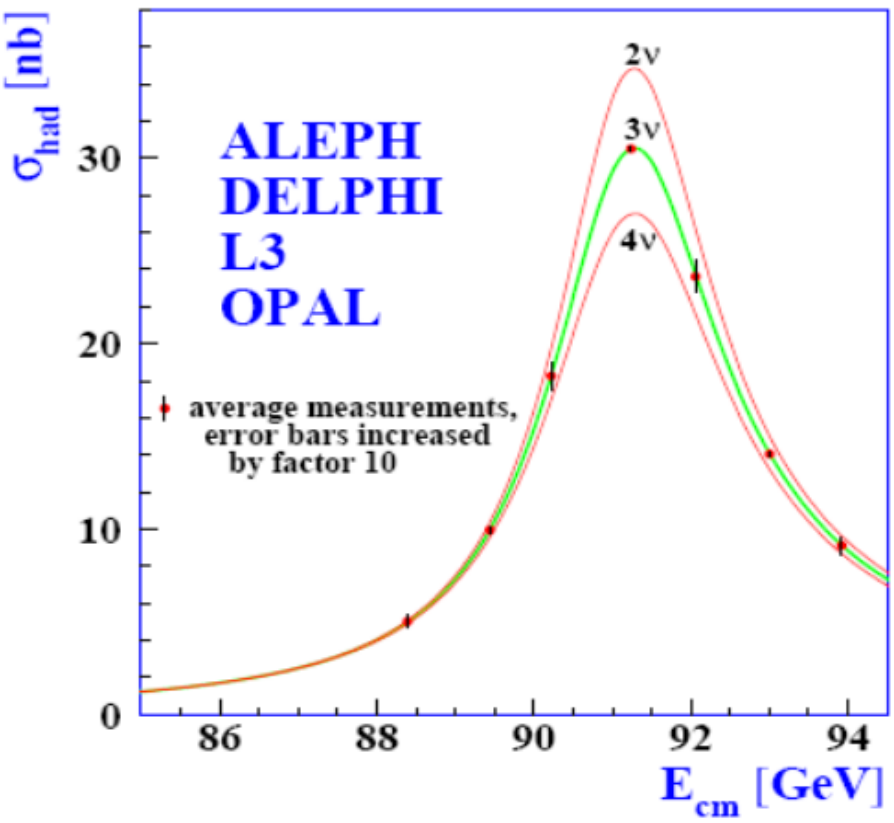


1. This can be interpreted as **a result of oscillation** at a mass squared splitting $1\ eV^2$. It is not consistent with Δm^2_{21} and Δm^2_{32}.

2. The presence of 3 Δm^2 requires the existence of at least 4 neutrinos.

The sterile neutrino

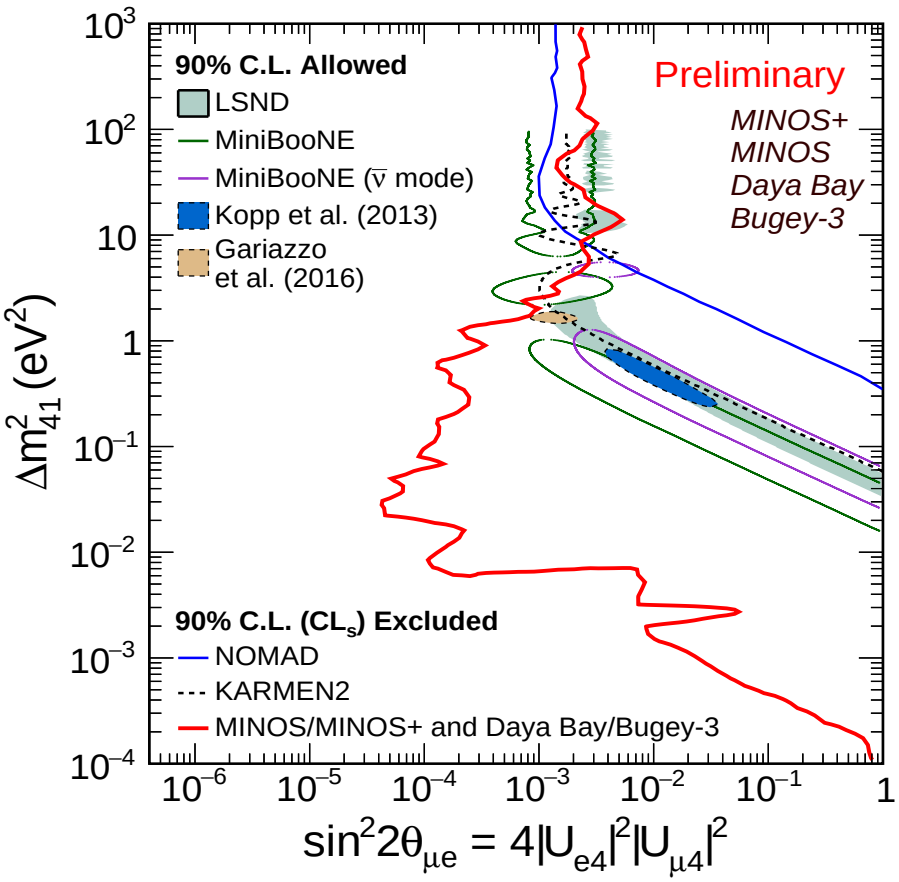
- LEP measurements of the Z^0 boson decay into neutrinos is consistent with only 3 active neutrino flavors.
- If a fourth neutrino exists, it is either heavier than $\frac{M_{z^0}}{2}$, or otherwise it does not participate in the weak interaction, a Light Sterile Neutrino.



Light Sterile Neutrinos are a potential solution to open questions ranging from the neutrino sector to cosmology.

"Tension" in sterile search.

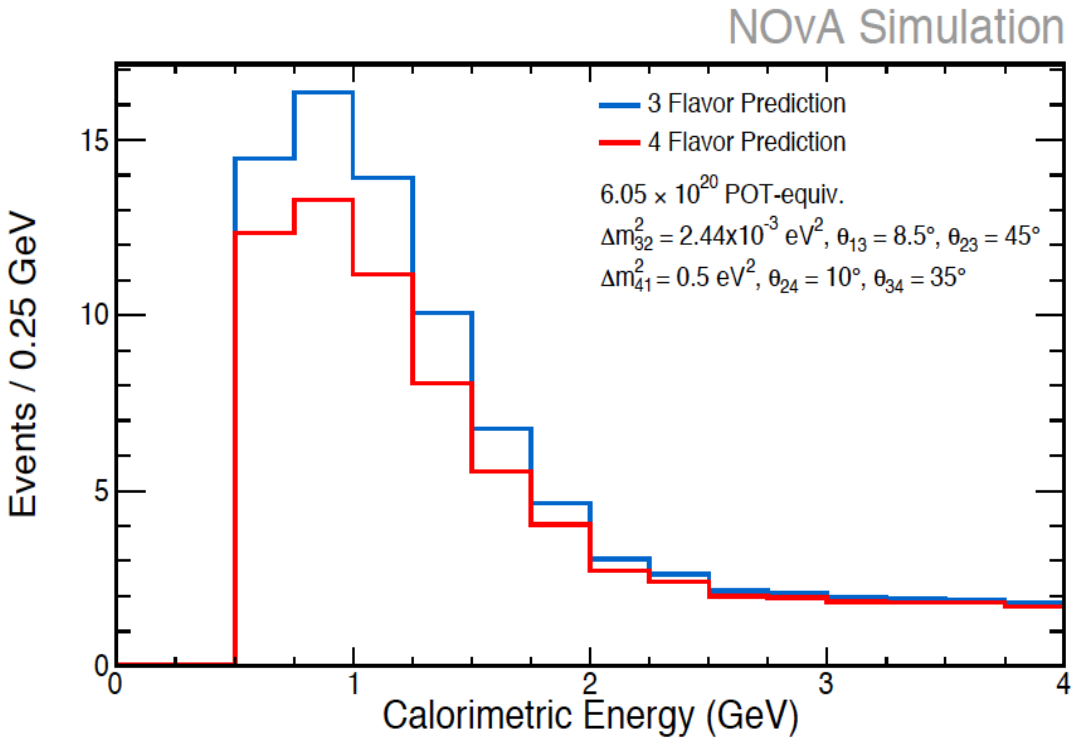
- **Potential Evidence.**
  - MiniBooNE: ν_e appearance.
  - LSND: ν_e appearance.
  - GALLEX: ν_e disappearance.
- **Null results.**
  - MINOS: ν_μ disappearance.
  - Ice Cube: ν_μ disappearance.
  - Daya Bay: ν_e disappearance
  - Bugey-3: ν_e disappearance
  - T2K: ν_μ disappearance.
  - KARMEN: ν_e appearance.
  - NOMAD: ν_e appearance.
  - MiniBooNE+SciBooNE: ν_μ disappearance.



The combined 90% C.L. limit excludes appearance allowed regions for $\Delta m^2_{41} < 0.4$ eV^2, and it excludes almost all of the 90% C.L. global allowed region.

NC Disappearance at the NOvA Far Detector.

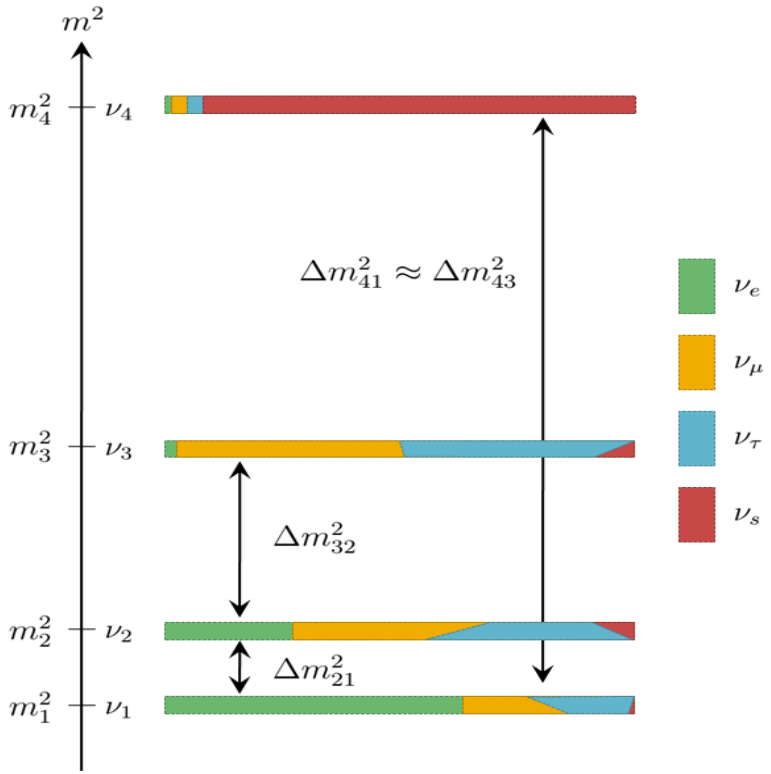
- Looking for the depletion of NC spectrum at the FD($\nu_\mu \rightarrow \nu_s$ oscillation).
- NC events are not sensitive to three flavor oscillation.



NC depletion as a function of energy.

NC Disappearance at the NOvA Far Detector.

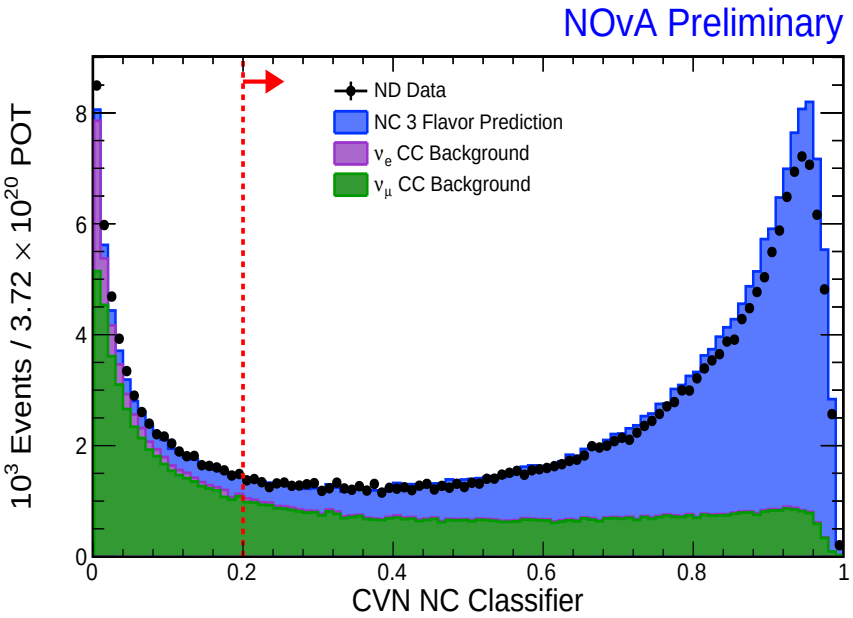
- We adopt a minimal "3+1" extension of three flavor neutrino model.
- Which adds Δm^2_{41}, θ_{14},θ_{24}, θ_{34},δ_{14} and δ_{24} along with 3 flavor parameters.
- NOvA is sensitive to the measurement of the angles θ_{24},θ_{34} and $|U_{\tau 4}|$ and $|U_{\mu 4}|$.



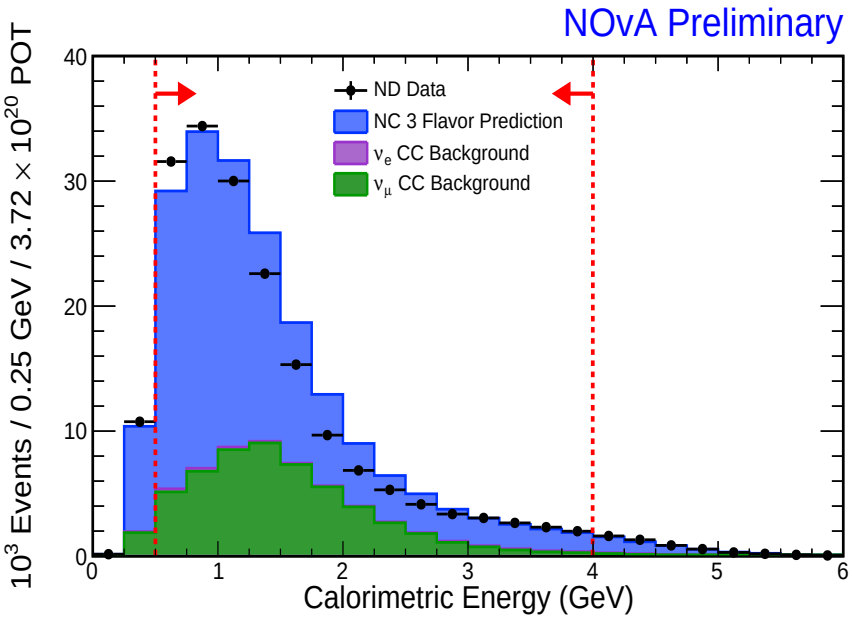
Minimal 3+1 model.

NC Event selection in both detectors

1. A computer vision based particle identifier, the Convolutional Visual Network (CVN) is used as primary selector for NC signals.
2. Selected events should be well reconstructed, contained and in the fiducial volume of the detector.
3. Along with CVN, a specific set of selection cuts and a boosted decision tree are employed for cosmic background rejection.



CVN NC classsifier for ND data and MC.



ND NC Calorimetric Energy spectrum.

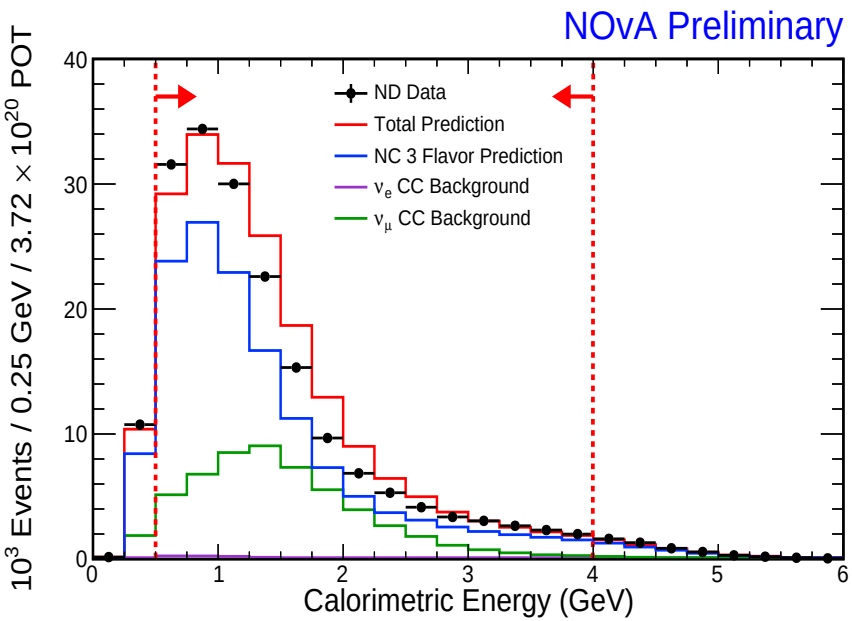
Extrapolating ND prediction to the Far Detector

The process of predicting the FD Calorimetric energy spectrum using ND energy spectrum can be summarized as,

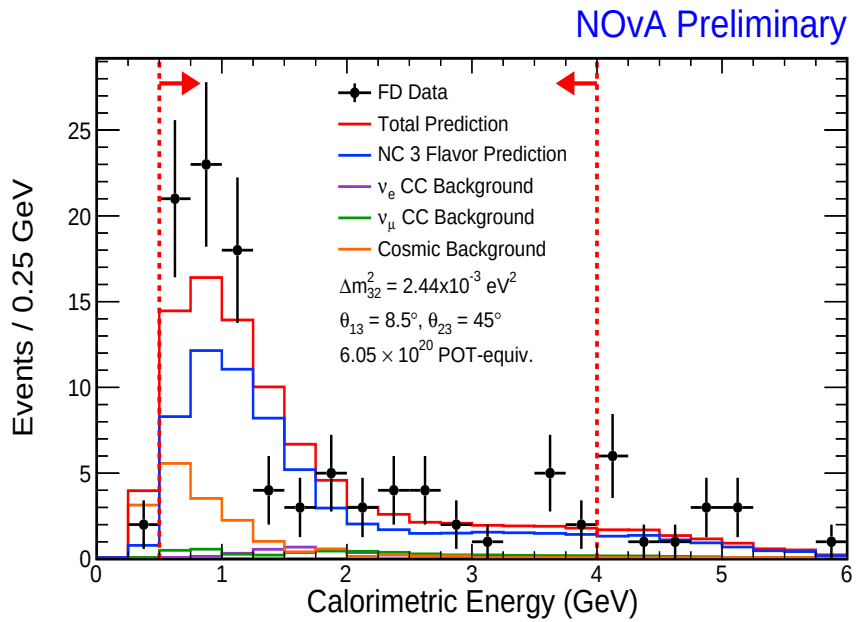
1. ND data is decomposed into different interaction types.
2. Each component is extrapolated to FD by

$$ND^{Data} x \frac{FD^{MC}}{ND^{MC}} = FD^{Pred} \quad (1)$$

3. Oscillation weights are applied to each FD predicted components. The MC prediction is compared with the FD data.



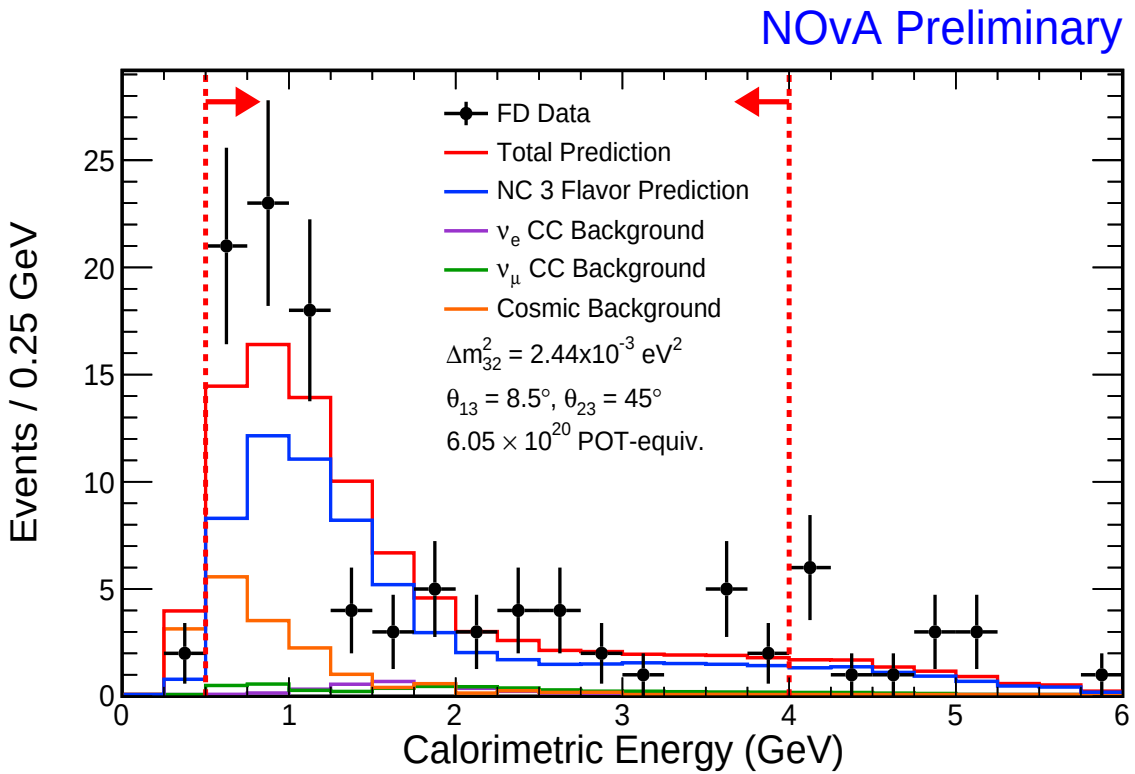
ND NC Calorimetric Energy spectrum.



FD NC Calorimetric Energy spectrum.

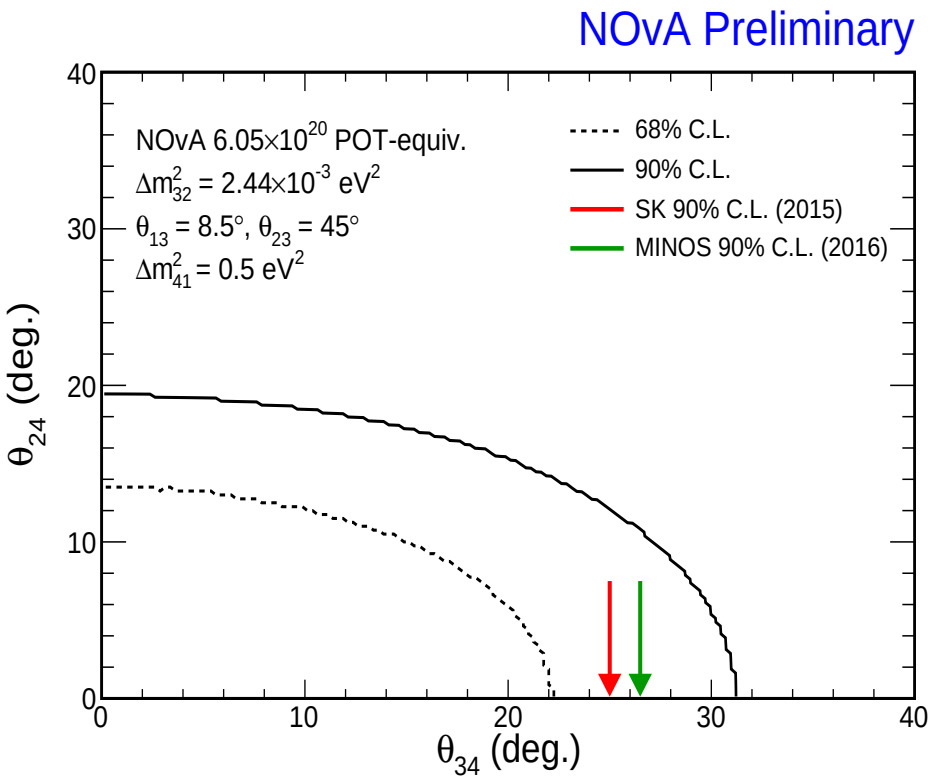
Current NC Disappearance analysis results.

- Selected **95 ±9.7 NC** candidates at FD, where as predicted events are **83.5±0.8**$(stat.)^{+10.9}_{-7.2}$**(syst.)**.
- **No sterile neutrino oscillation is observed**
- Measured 1.03 sigma excess of NC events is consistent with standard 3-flavor oscillations.



Current NC Disappearance analysis results.

1. The table compares the 90% C.L. upper limits of sterile mixing angles and matrix elements of NOvA with other experiments.
2. The limits are shown for $\Delta m^2_{41} = 0.5 eV^2$, for all experiments.
3. The plot shows the Feldman-Cousins corrected 2D allowed regions.
4. It is a counting experiment, fitted for the total event count.



Feldman-Cousins corrected 2D allowed regions

Parm.	NOvA	SuperK	MINOS
θ_{34}	30^0	25^0	28^0
θ_{24}	19^0	12^0	8^0
$\lvert U_{\mu 4}\rvert^2$	0.25	0.18	0.38
$\lvert U_{\tau 4}\rvert^2$	0.10	0.04	0.02

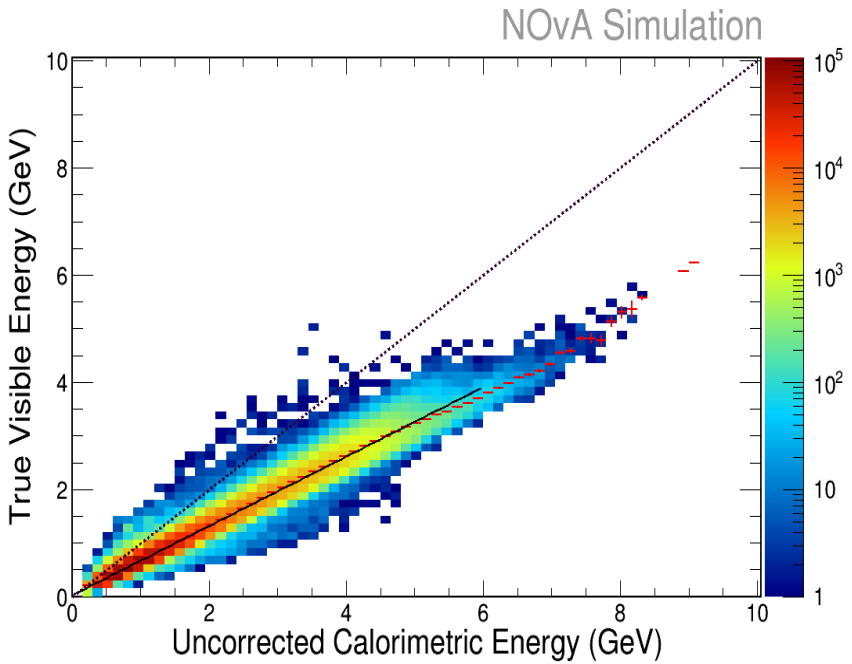
- MINOS: Phys. Rev. Lett. 117, 151803(2016)
- SuperK: Phys. Rev. D 91, 052019(2015)

Improvements for Future Analyses

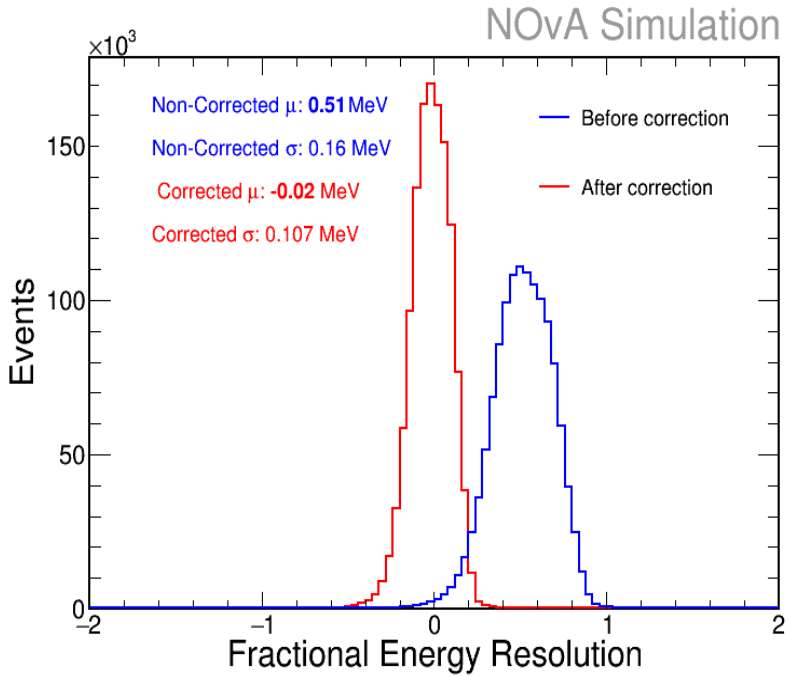
- Improved Calorimetric energy resolution of the detectors.
- Shape fit of the FD energy spectrum.
- Joint fit of Near and Far Detectors.

Improved calorimetric energy resolution of the detectors.

1. The true visible energy vs uncorrected calorimetric energy plot is fitted with a line.
2. The true visible energy is the true energy deposited in the detector. Which is the true energy of the NC event minus energy of outgoing neutrino.
3. The calorimetric energy is corrected with the slope of the fitted line.



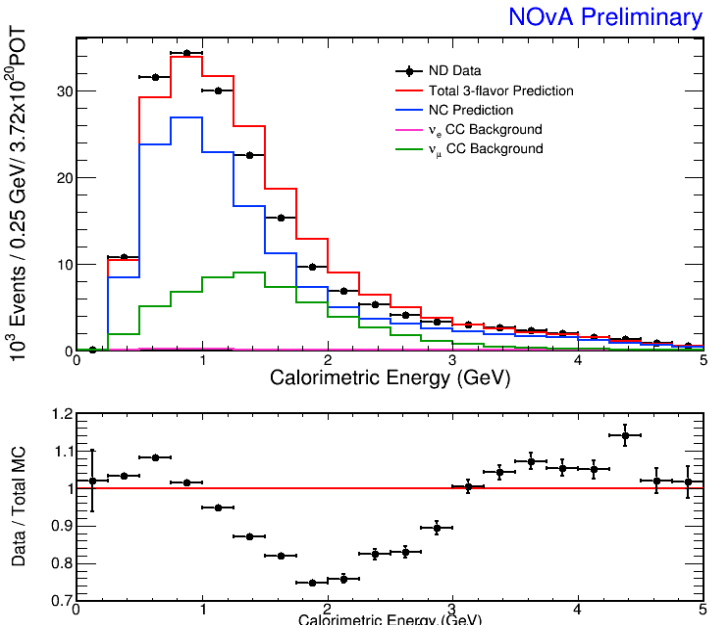
True visible energy vs Uncorrected calorimetric energy log-Z plot.



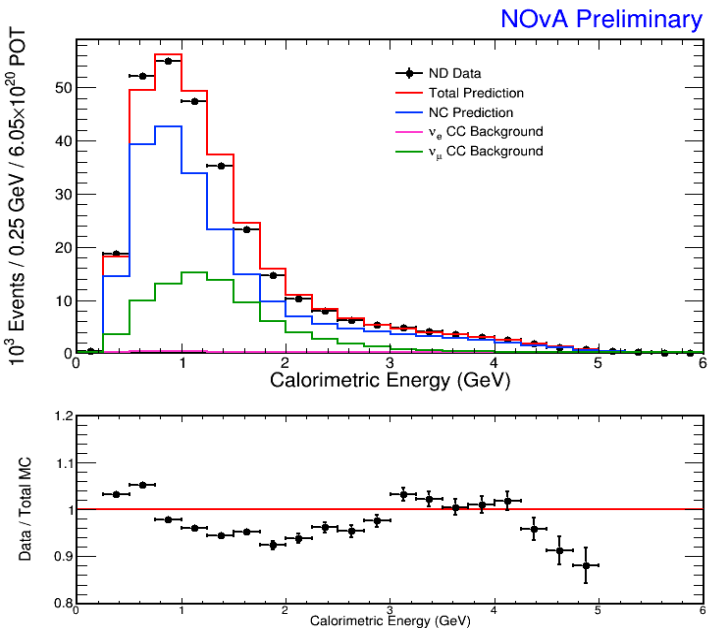
6% increase in resolution after correction.

Shape fit of the FD energy spectrum.

- Improved modeling of detector and neutrino interaction cross-section will enable for a shape fit.
- These improvements includes,
  - Improved detector modeling.
  - Threshold energy correction from data.
  - Cherenkov light modeling.
  - The 2p2h interaction modeling of the NC events



Current analysis Calorimetric energy plot.

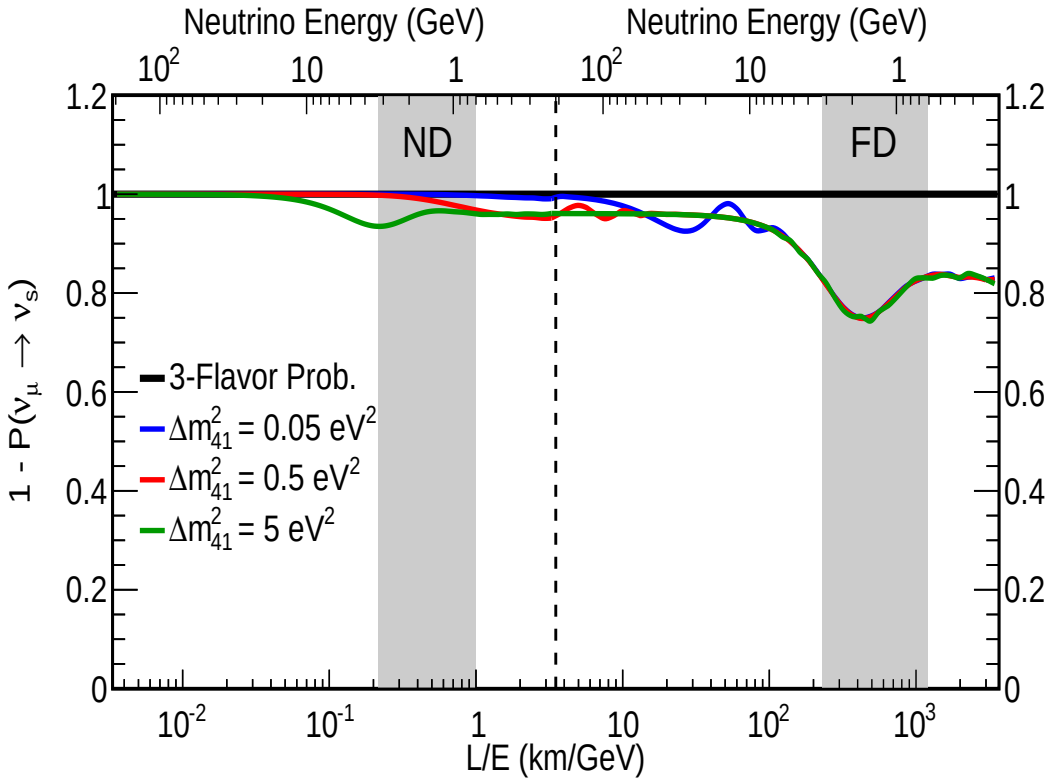


Next analysis Calorimetric energy plot.

Joint fit of Near and Far Detectors.

- The current analysis did not consider the sterile oscillation in the Near Detector. Δm^2_{41} is in the range from $0.05eV^2$ to $0.5eV^2$

- Considering the ND sterile oscillation enables us to extend the sterile mass square splitting that NOvA can probe.



The probability of sterile neutrino oscillations.

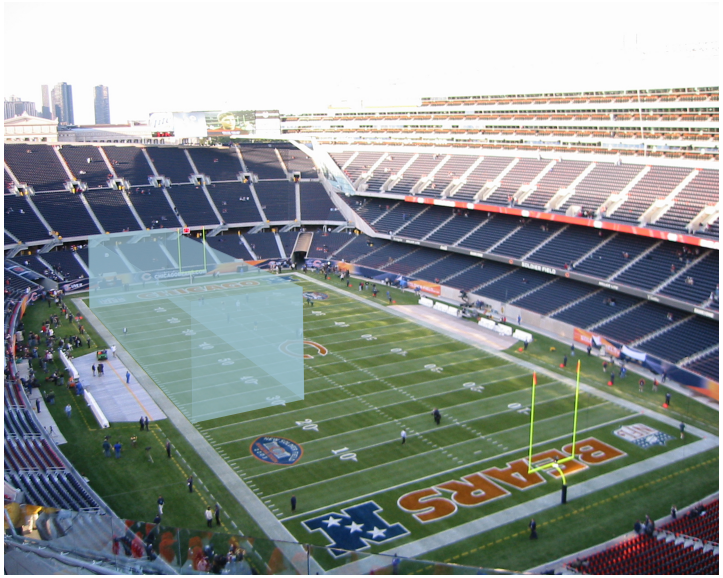
Conclusion

- **No evidence for sterile neutrinos from the current analysis.**
- **The next analysis will have 50% more data.**
- **And several analysis improvements.**
- **Stay tuned for the exciting beyond standard model results!**

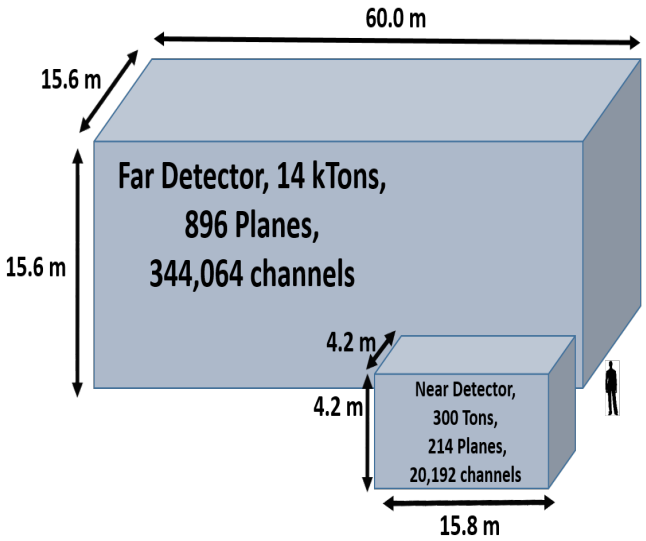

220+ members, 20+ institutions, 7 countries

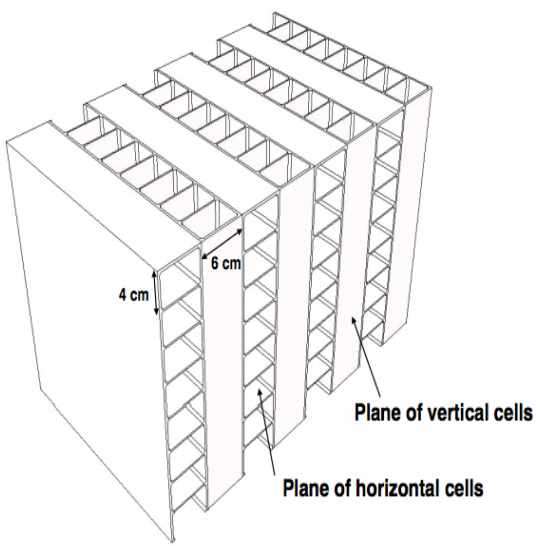
BACKUPS

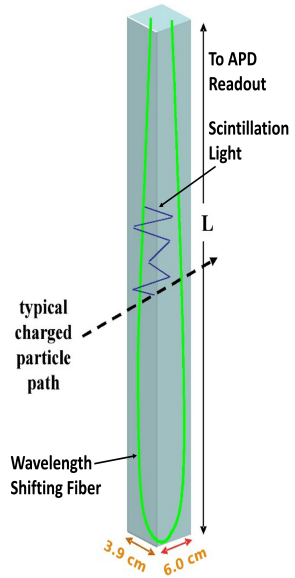
NOvA Detectors



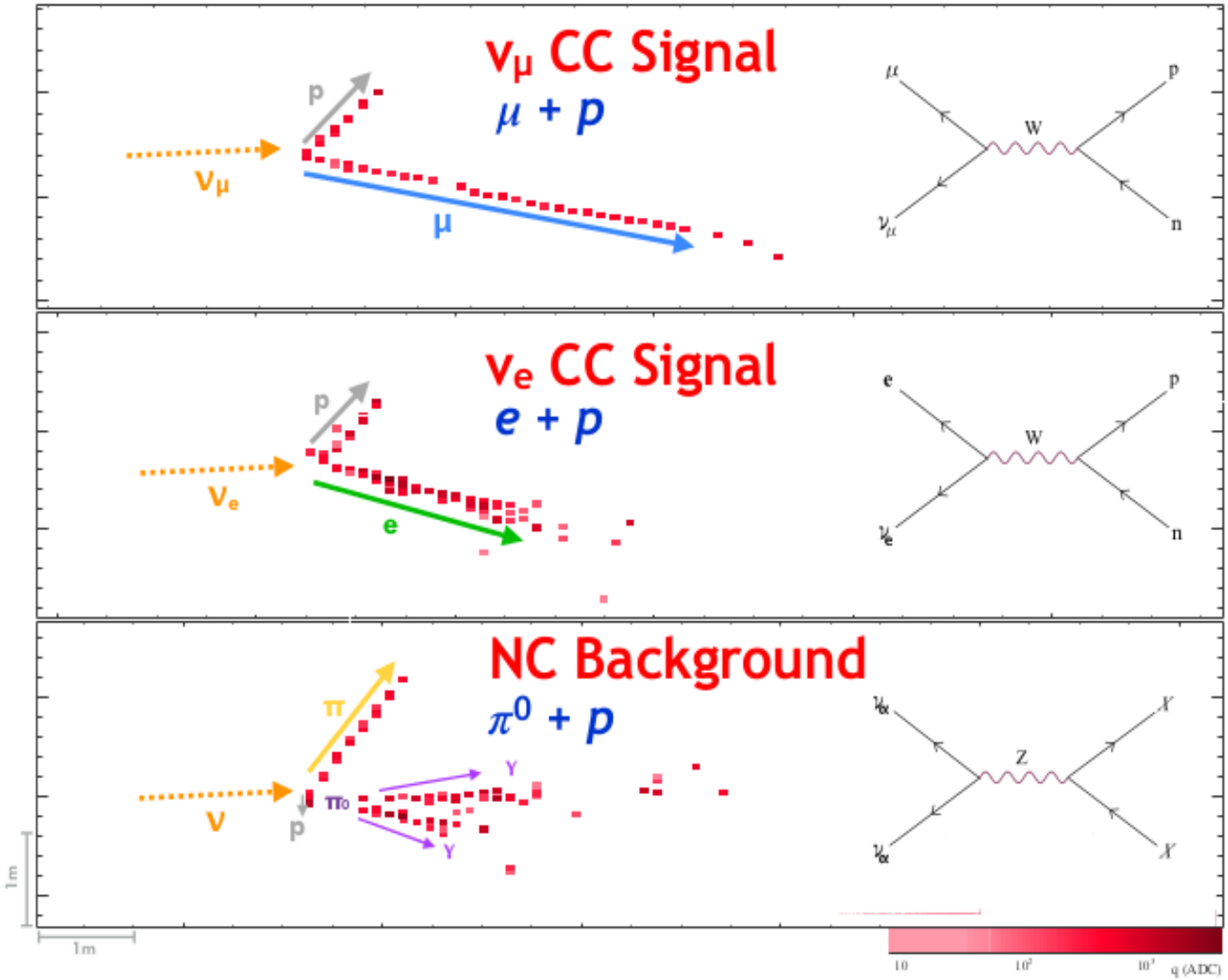
- **Far Detector**
  - 14 kton detector at the surface.
- **Near Detector**
  - Structurally identical to FD
  - 0.3 kton underground detector.







The event topology in the NOvA detector



THANKS