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Abstract. Three-flavor neutrino oscillations have successfully explained a wide range of neutrino oscillation experiment results. However, anomalous results, such as the electron-antineutrino appearance excess seen by LSND and MiniBooNE, do not fit the three-flavor paradigm and can be explained by the addition of a sterile neutrino at a larger mass scale than the existing three flavor mass states. This paper will present a novel method for selecting tau-neutrino interactions with high purity at the NOvA Near Detector using a convolutional neural network. Based on this method, the sensitivity to anomalous short-baseline tau-neutrino appearance due to sterile neutrino oscillations will be shown.

1. Introduction
The NOvA experiment consists of two finely segmented, liquid scintillator detectors operating 14 mrad off-axis from the upgraded NuMI muon-neutrino beam. The Near Detector (ND) has a 0.3 kton mass and is located at the Fermilab campus, 1 km from the NuMI target. The Far Detector has a 14 kton mass and is located at Ash River, MN, 810 km from the NuMI target. The NOvA experiment is primarily designed to measure electron-neutrino appearance at the Far Detector using the Near Detector to control systematic uncertainties; however, the Near Detector is well suited for searching for anomalous short-baseline oscillations.

2. Searching for Sterile Neutrinos using Tau Neutrino Appearance
The electron-antineutrino and neutrino excesses seen by LSND [2] and MiniBooNE [3,4] do not fit the three-flavor paradigm. These excesses can be explained by adding a sterile neutrino at a larger mass scale than the three active neutrinos.

If sterile neutrinos exist, significant tau-neutrino appearance is possible over the short baselines. Charged-current (CC) tau-neutrino interactions are only possible above the $\tau$ production threshold of 3.4 GeV. Therefore, the primary source for potential short-baseline tau-neutrino appearance in the NOvA beam results from decays of high-energy kaons. The probability for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the two-flavor approximation is:

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2 2\theta_{\mu\tau} \sin^2(\Delta m^2_{41} L/4E)$$

$$\sin^2 2\theta_{\mu\tau} = |U_{\mu 4}|^2 |U_{\tau 4}|^2$$

$$= \cos^4 \theta_{14} \sin^2 2\theta_{24} \sin^2 \theta_{34}$$
3. Selecting Tau Neutrino Events
CC tau-neutrino interactions in the ND occur primarily between 10 and 20 GeV, so they typically have high multiplicity hadronic systems originating from nuclear scattering in addition to the decay products of the outgoing tau-lepton in the final state. Hence we can categorize CC tau-neutrino interactions as either hadronic with one outgoing neutrino and typically one or three pions, or leptonic with two outgoing neutrinos and an electron or muon. An example hadronic CC tau-neutrino interaction is shown in Fig. 1.

![Figure 1. A simulated $\nu_\tau$ CC event in the ND.](image)

We use the tools from the computer vision community to classify neutrino interactions. We developed the Convolutional Visual Network (CVN) [1], which is based on the GoogLeNet convolutional neural network (CNN) architecture. CNNs treat each event as an image, and pass these images through layers consisting of banks of learned filters to extract powerful features. These features are then used to classify events according to neutrino flavor and interaction type. Currently CVN is also used in the electron neutrino appearance and neutral-current (NC) disappearance analyses in NOvA.

We use the CVN tau-neutrino output as the primary classifier for the signal selection and use a muon/pion separator to further improve the rejection of muon-neutrino events. Fig. 2 shows the efficiency and purity after applying the tau-neutrino selection at the point $\Delta m^2_{24} = 22$ eV$^2$, $\theta_{24} = 0.15$, and $\theta_{34} = 0.6$. The total efficiency for selecting tau-neutrinos is 13%. The purity before signal selection is 0.14%, and after signal selection, it increases to 51%.

![Figure 2. Signal purity and selection efficiency for $\nu_\tau$ CC events.](image)

4. Predicted Sample
As shown in Fig. 3, the signal is maximized for $\Delta m^2_{41} = 22$ eV$^2$ corresponding to a small L/E for muon neutrinos originating from kaon decays. For this point, we show the signal and background prediction in Fig. 4. The dominant backgrounds are $\nu_\mu$ CC-and NC events.

5. Sensitivity to Sterile Neutrinos
As shown in Fig. 5, NOvA will be competitive with previous experiments [2–9] after 3 years of running. Future work will include improving CVN by categorizing tau-neutrinos according to...
their τ decay mode and developing a version of CVN specifically tuned for the ND.

Figure 3. Predicted events as a function Δm^2_{41} for the selected sample.

Figure 4. Stacked histograms showing the signal prediction and background for maximum 3+1 νμ → ντ appearance allowed by existing and previous experiments.

Figure 5. The sensitivity to tau-neutrino appearance in the two-flavor model. The solid black line shows NOvA sensitivity to tau neutrino appearance using rate only fit to the two flavor model.

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