Background estimation for the electron neutrino appearance analysis in NOvA

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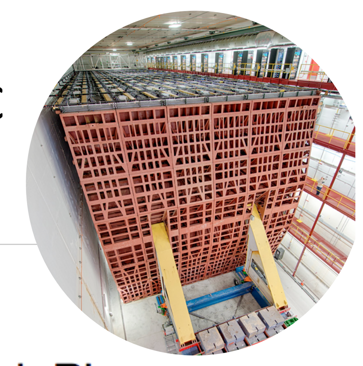
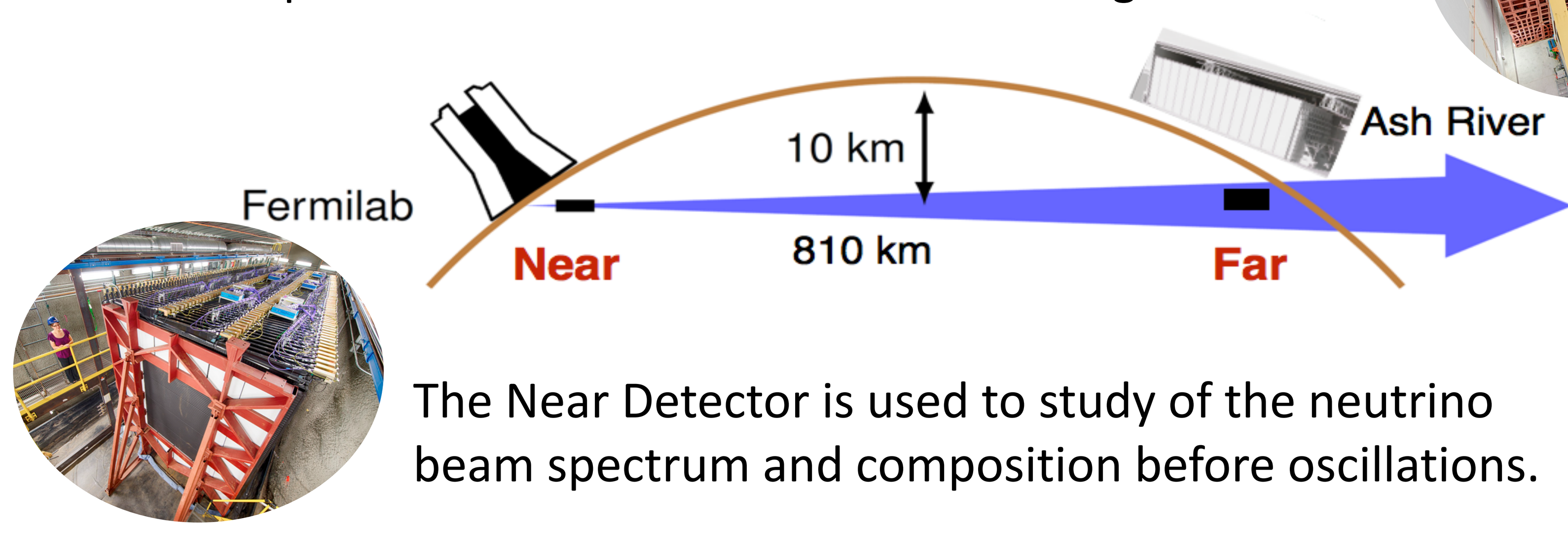
NOvA: NuMI Off-Axis ν_e appearance

NOvA is a long-baseline neutrino experiment optimized to observe the oscillation of muon neutrinos to electron neutrinos. The probability $P(\nu_\mu \rightarrow \nu_e)$ is sensitive to θ_{23}, δ_{CP}, and the neutrino mass hierarchy.

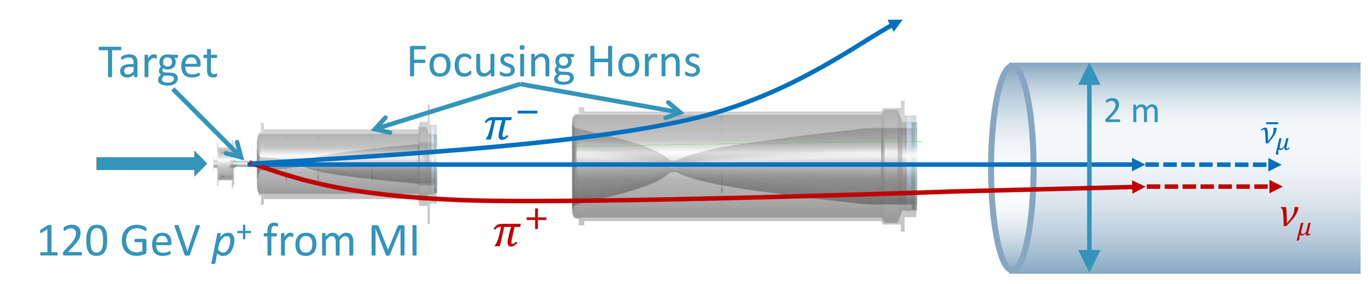
A precise measurement relies on an efficient selection of ν_eCC events in the Far Detector against a background formed by other components of the NuMI beam and cosmogenic events.



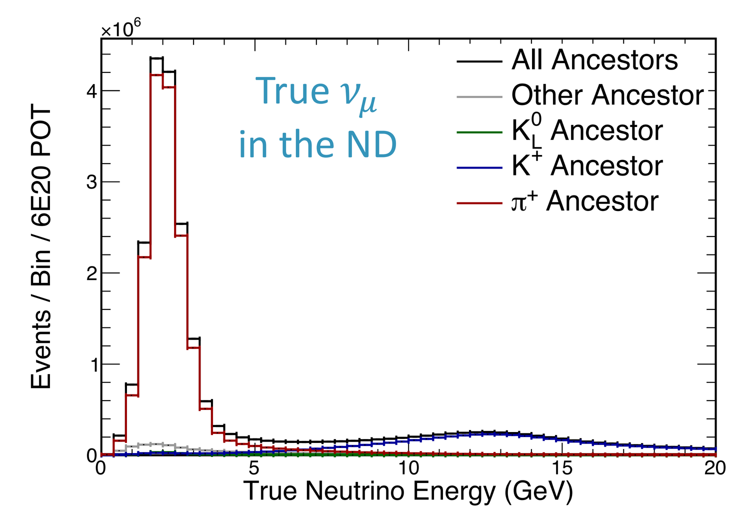


The Near Detector is used to study of the neutrino beam spectrum and composition before oscillations.

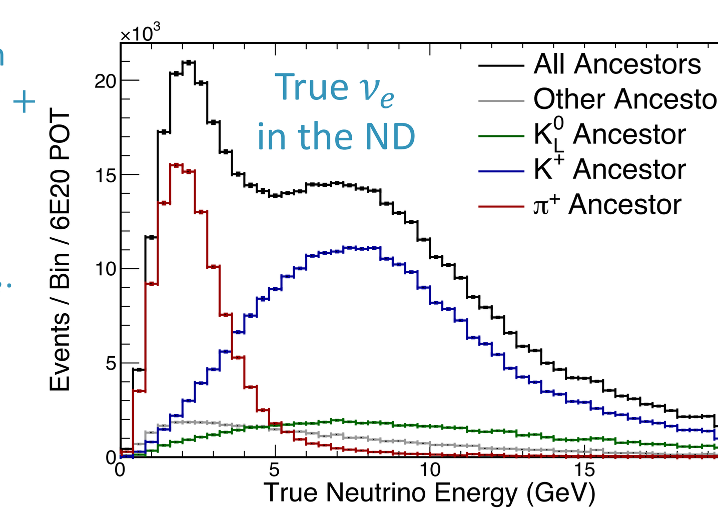
The NuMI muon neutrino beam



The NOvA detectors are located 14.6 mrad off the beam axis. The narrow-band neutrino energy spectrum peaks ~2GeV, and is composed of 94% ν_μ, 3.8% $\bar{\nu}_\mu$, 2.1% $(\nu_e + \bar{\nu}_e)$.

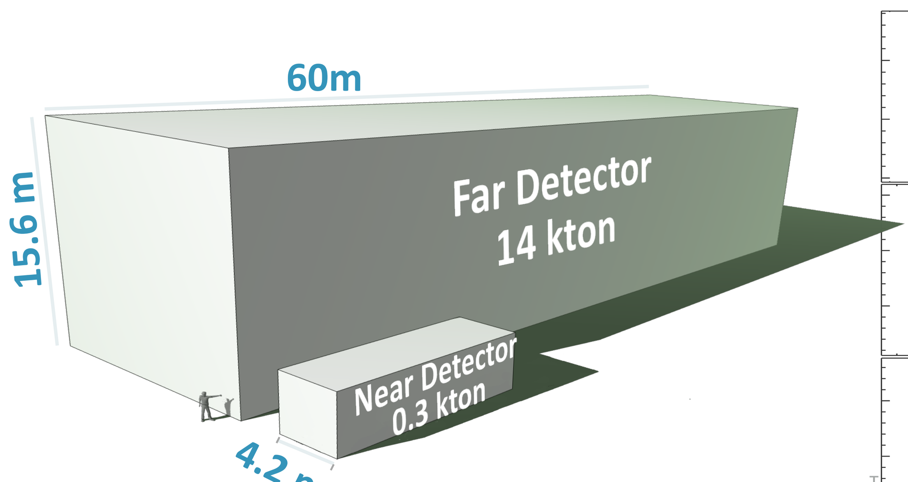


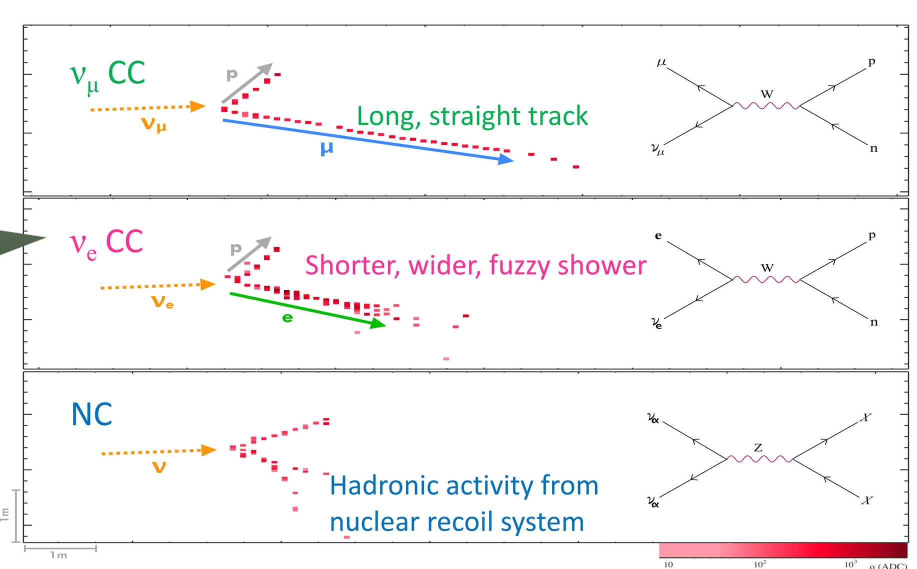
Most ν_μ result from the decay $\pi^+ \rightarrow \mu^+ + \nu_\mu$, and most low-energy ν_e from the subsequent decay $\mu^+ \rightarrow \bar{\nu}_\mu + e^+ + \nu_e$. Contributions from kaons dominate at high energy.

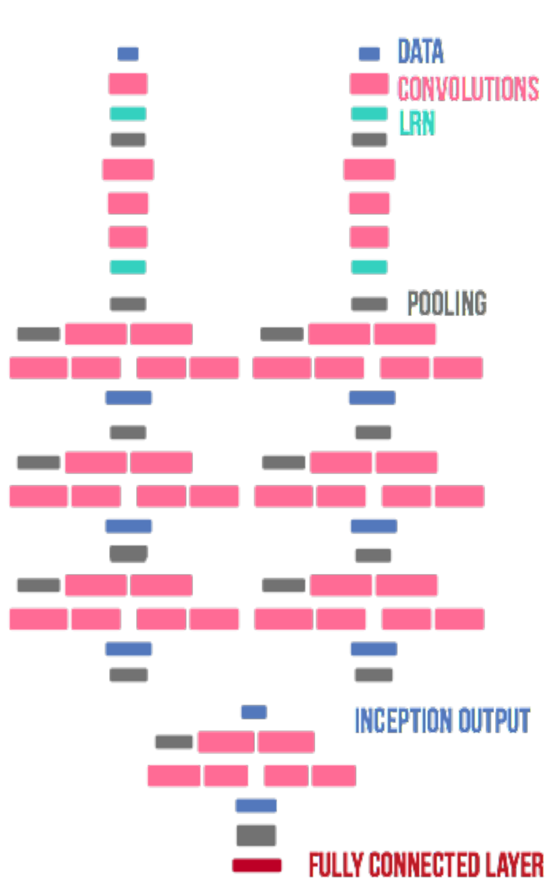


Event topologies and classification

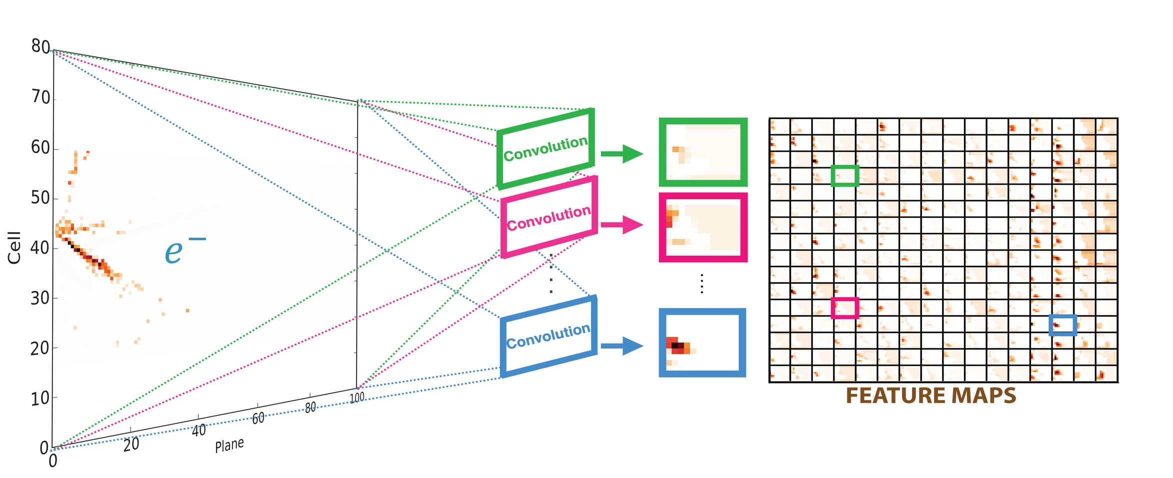
The two functionally equivalent detectors are segmented, tracking calorimeters. PVC cells filled with liquid scintillator are arranged in planes that alternate between vertical and horizontal orientations to allow 3D reconstruction.

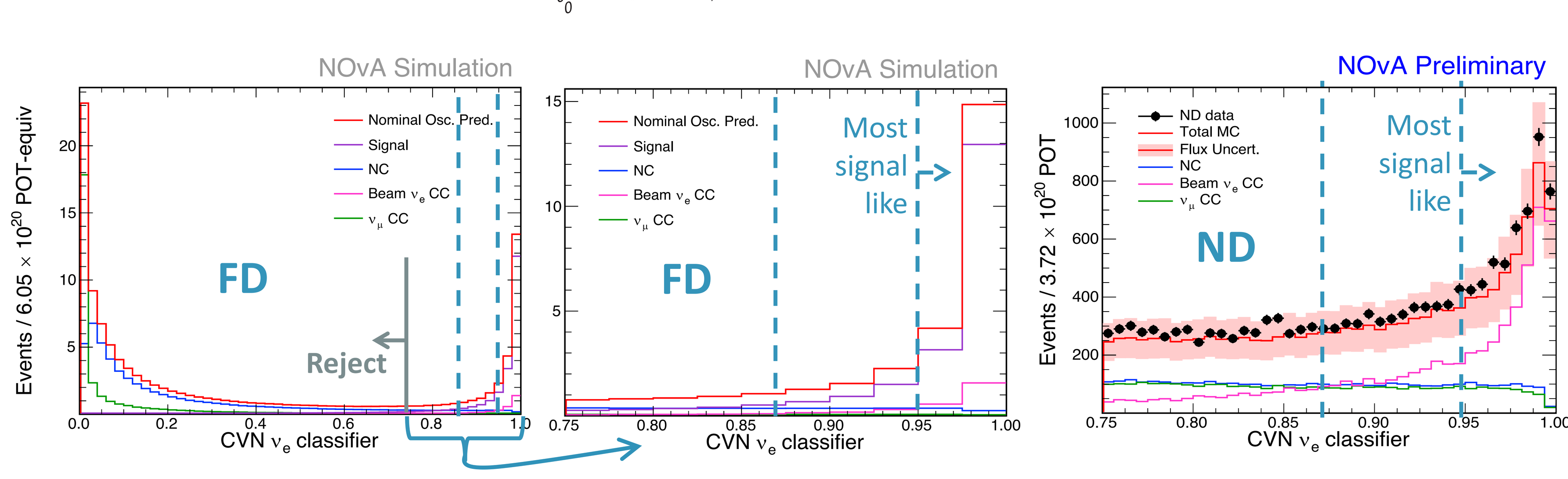






Signal identification is done by CVN (Convolutional Visual Network). CVN is an event classifier which employs a Deep Convolutional Network in the "image recognition" style. The network is trained on two-dimensional views of the event's calibrated hits. The information of each view is then combined in the final layers of the network.





The signal $\nu_\mu \rightarrow \nu_e$ is negligible in the ND. The 3 components selected in the ND correspond to the 3 beam backgrounds in the FD:

- Beam ν_eCC: intrinsic ν_e component in the beam
- ν_μCC, NC: events that are misidentified as ν_eCC in either detector

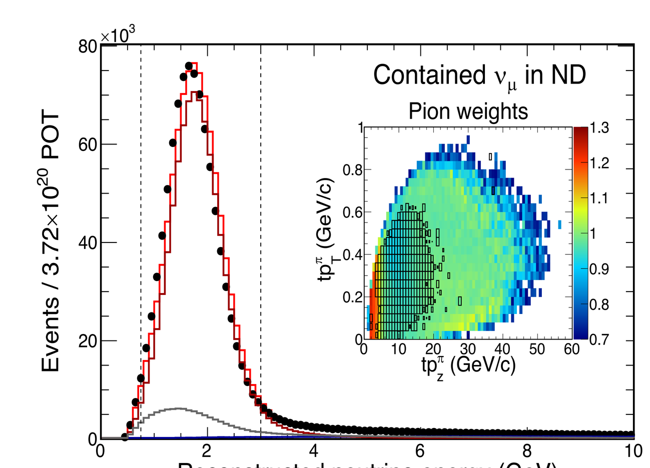
Data-driven background estimation

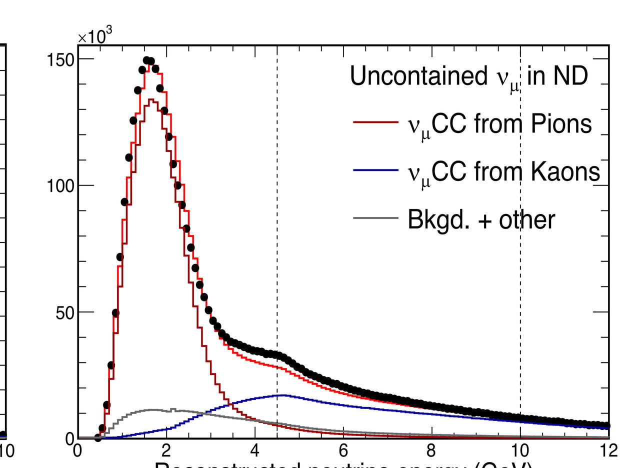
The ND data is translated to a FD bkgd. expectation in reconstructed energy x PID bins using Far/Near ratios from the simulation.

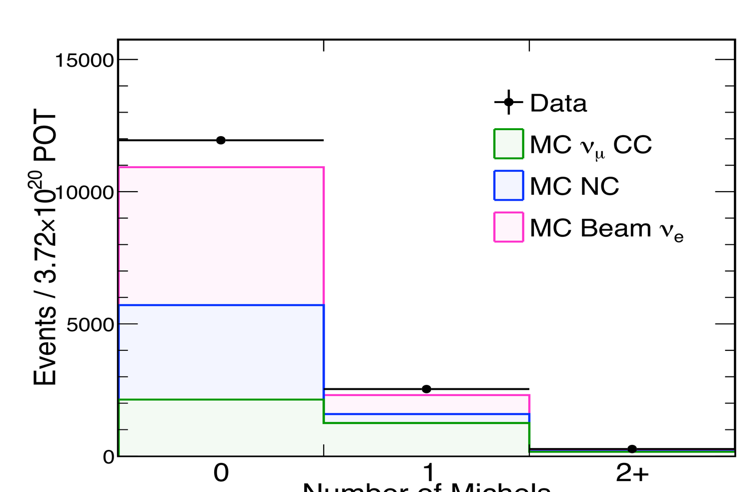
Since the NC, ν_μCC and beam ν_eCC background components are affected differently by oscillations, the total background selected in the ND data is broken down into these components.

- Beam ν_eCC: use ν_μ-selected data to correct pion and kaon hadron yields
- ν_μCC, NC: use the distribution of number of Michel e- for ν_e-selected data

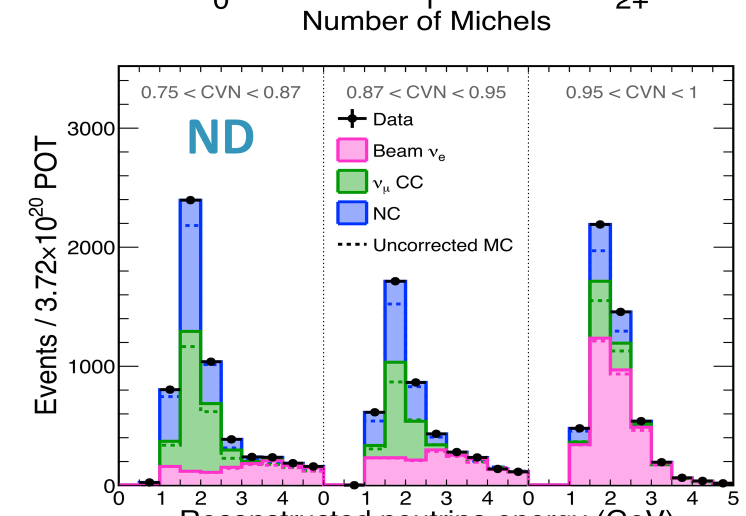
The pion and kaon hadron yields can be derived from the low and high-energy ν_μCC rate in the ND data and are used to correct the ν_e CC rate in the simulation. From this method, it is inferred that the kaon yield is higher by 17% and the pion yield lower by 3% than predicted by the simulation.



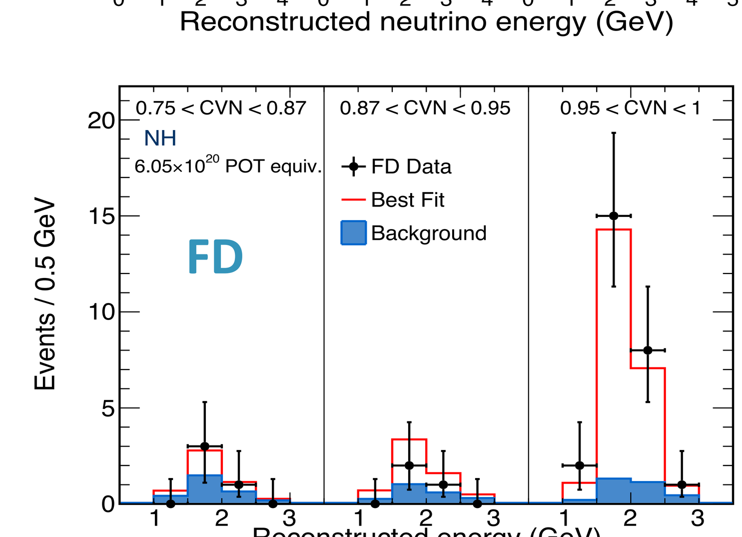




Some of the ν_μCC interactions that are a background to the ν_eCC selection have a muon hidden in the shower associated with the hadronic recoil. In these events, the time-delayed electron from muon decay (Michel electron) may often be found. The ν_μCC and NC background components are varied to obtain the best match to the distribution of the number of Michel electron candidates in data. This method leads to an integrated increase of 17.7% and 10.4% in the ν_μCC and NC background rates relative to those predicted by the ND simulation.



The data-driven corrections are applied to the background spectra in the FD simulation in the analysis bins. The spectra are then weighted by the appropriate 3-flavor oscillation probability to obtain the final estimates of the beam backgrounds in the FD.



Signal expectation	28 – 11 events				
(±5% syst. unc.)	(NH, 3π/2 – IH, π/2)				
Bkgd. expectation	8.2 events				
(±10% syst. unc.)	NC	beam	ν_μ CC	ν_τ CC	Cosmics
	3.7	3.1	0.7	0.1	0.5
Observation	33 events				

Learn more about NOvA and the electron neutrino appearance analysis

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