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Progress Toward a Deep-Learning-Based Search for Low-Energy Electron Neutrinos in MicroBooNE

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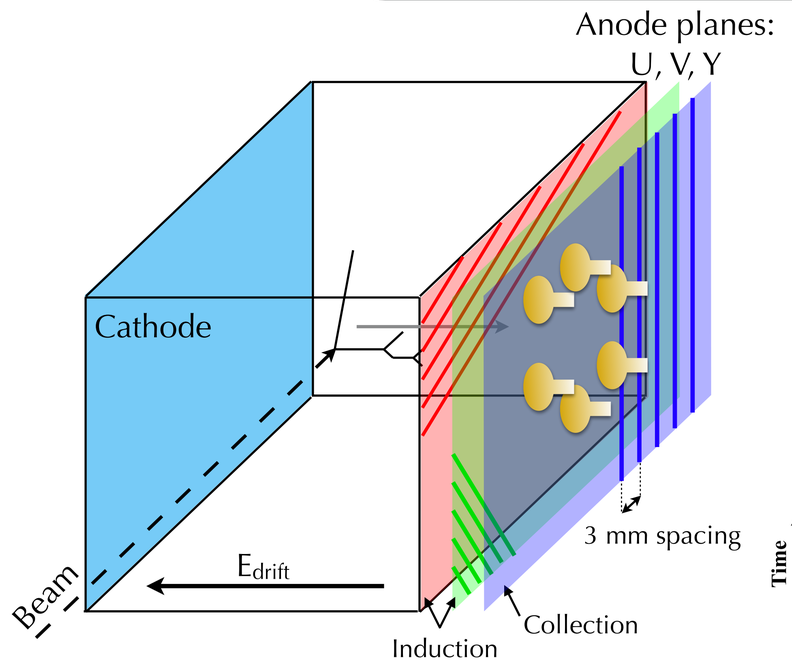
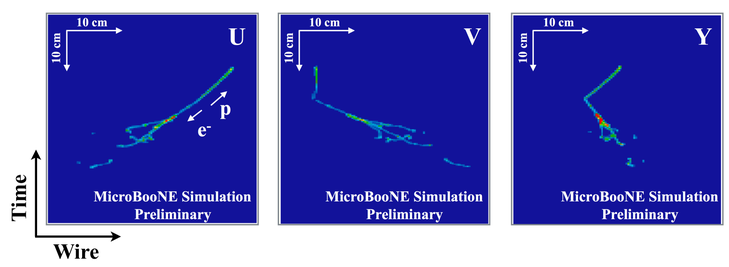
The MicroBooNE Detector



MicroBooNE is an 85-tonne liquid argon time projection chamber (LArTPC) in the Fermilab Booster Neutrino Beam [1]

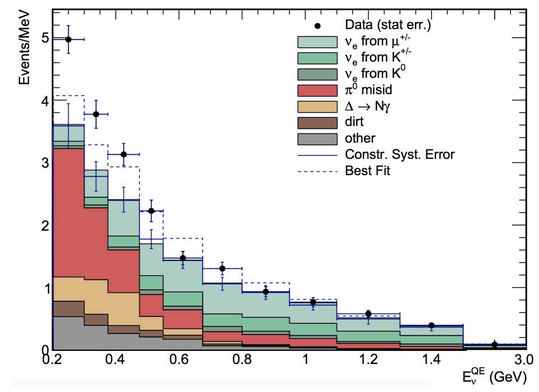
Below: MicroBooNE simulated ν_e event, showing the deconvolved wire images from each of the three planes



Low-Energy Excess

The MiniBooNE experiment observed a 4.5σ excess of ν_e-like events between 200 and 1250 MeV [2]

MicroBooNE sits in the same beam but uses different detector technology, and will determine if the excess is due to true ν_e events or something else



Analysis Path

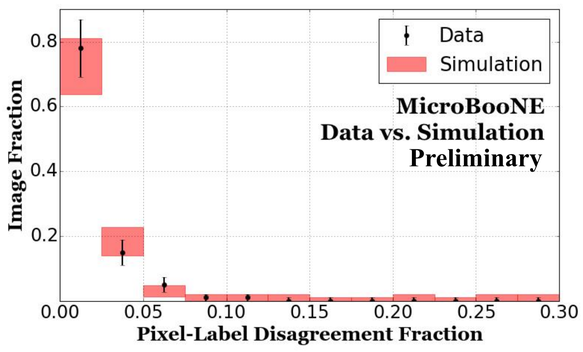
- PMT Pre-Cuts — Remove cosmic-only events
- ↓ Cosmic Tagging & ROI Finding — Tag and reject cosmics, find clusters of fully contained charge
- ↓ Semantic Segmentation — Label each pixel as part of a track or a shower
- ↓ Candidate Vertex Finding — Identify candidate neutrino vertices and match them across planes
- ↓ 3D Reconstruction — Reconstruct candidate vertices and associated tracks and showers
- ↓ ν_μ Selection | ν_e Selection
- ↓ Particle Identification — Identify particle types present in the region of interest
- ↓ E_{reco} spectrum for ν_μ, ν_e

Deep Learning Techniques

Semantic segmentation network (U-ResNet) labels pixels in region of interest as "track", "shower", or "background"

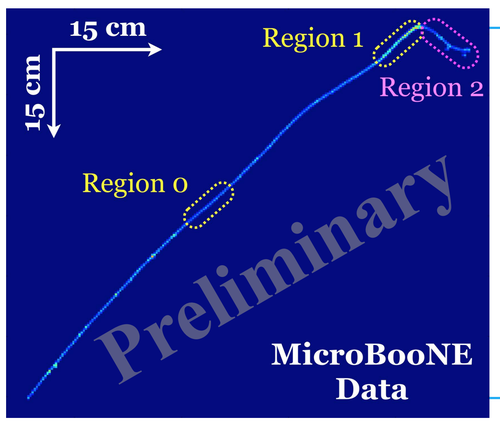
Helps us separate tracks and showers to make the vertex reconstruction and track/shower clustering more efficient

Find good agreement between pixel labels by U-ResNet and by a human physicist in data and simulation



To study U-ResNet's use of inter-pixel correlations, we consider three regions of the cosmic muon data event to the right

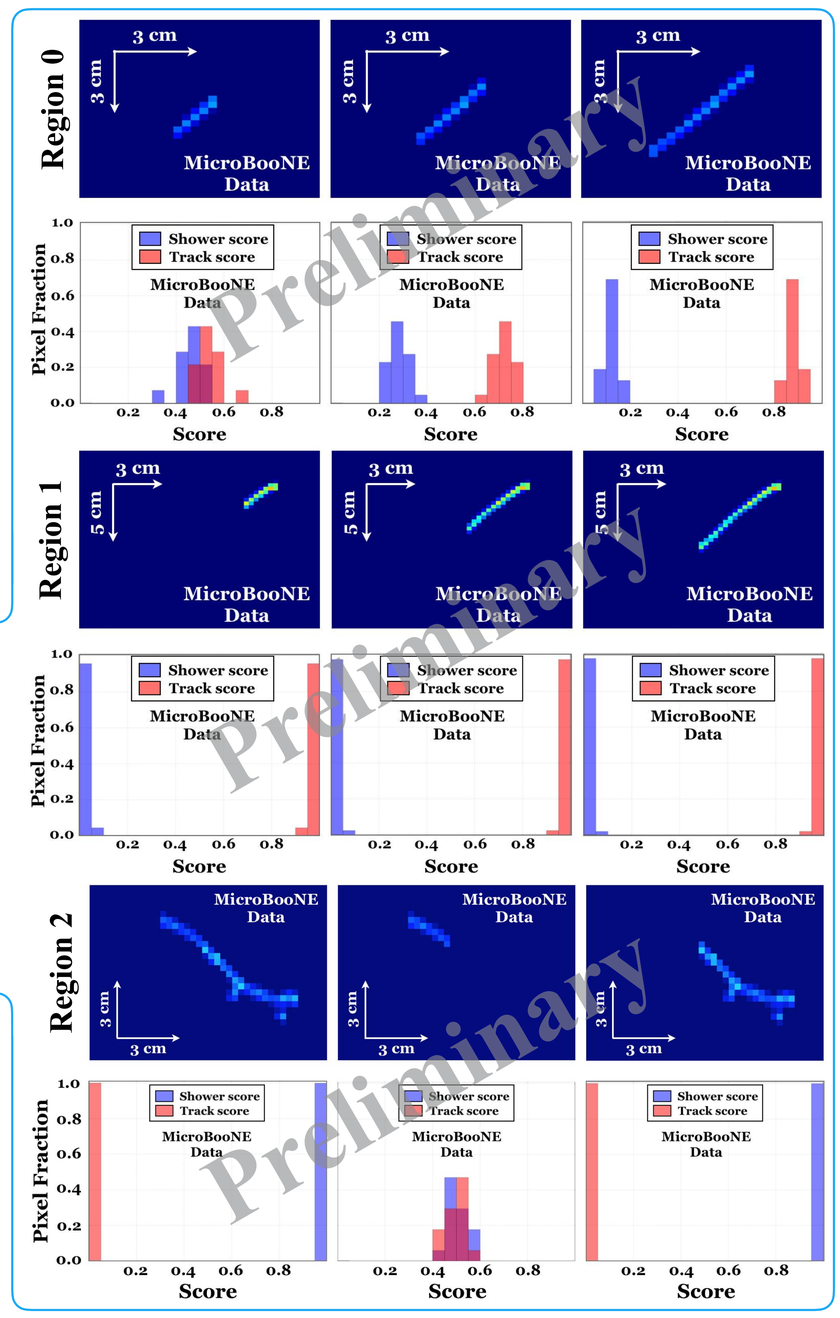
- Region 0: MIP
- Region 1: Bragg peak
- Region 2: Michel



In addition, R&D is ongoing on a convolutional neural network for **multiple particle identification (Multi-PID)**

Looks at ROI with a neutrino candidate and outputs a probability it has: proton, muon, electron, photon, pion

Will be used in final decision on candidate selection



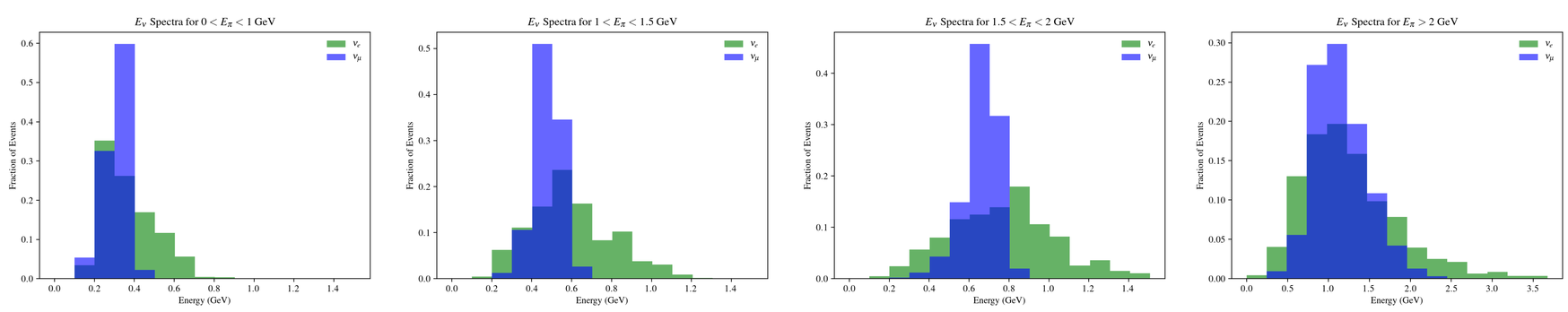
Muon Neutrino Constraints on Electron Neutrinos

Systematic uncertainties for this analysis can be separated into three main components: flux, cross-section, and detector response — and for each of these, a ν_μ sample will help us constrain uncertainties on the ν_e

For example, how do ν_μ constrain ν_e flux? Consider CCQE events in the fiducial volume that come from

- Primary (beam) proton that undergoes an inelastic scatter and produces a π^+
- For ν_μ events, the π^+ decays via $\pi^+ \rightarrow \nu_\mu + \mu^+$
- For ν_e events, the μ^+ resulting from the π^+ decay subsequently decays via $\mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$

Using simulations, we can study ν_μ and ν_e events descended from pions with E_π in the same energy range



Future Work

Leverage the Multi-PID network to optimize neutrino candidate selection

Continue to study the flux, cross-section, and detector response systematic uncertainties for both ν_e and ν_μ samples

Expand our understanding of how the ν_μ can constrain the ν_e, including kaon-ancestry neutrinos and cross-sections

Incorporate the results of this work into our measurement of the low-energy excess

References: [1] JINST 12, P02017 (2017)
[2] arXiv:1805.12028 [hep-ex]

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