Neutrino Energy Reconstruction in NOvA

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for the NOvA Collaboration

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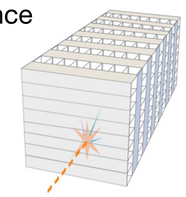
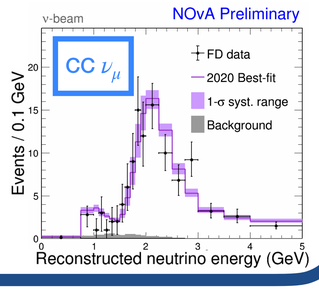
http://novaexperiment.fnal.gov

The NOvA Experiment

- Long-baseline neutrino oscillation experiment utilizing the Fermilab NuMI beam
- Observing ν_e appearance and ν_μ disappearance

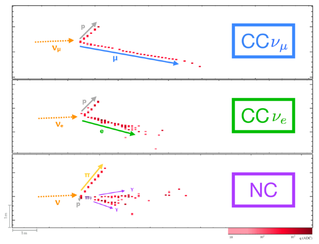


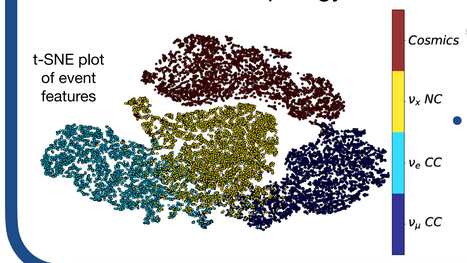
- Two functionally identical segmented liquid scintillator calorimeters
  - Low-Z material (mineral oil, PVC)
  - 6X cell depth ~ 1 radiation length
- Utilize both track length and calorimetric information to estimate neutrino energies
- More precise fits by utilizing spectrum shape. Requires good energy resolution



Particle Identification (PID)

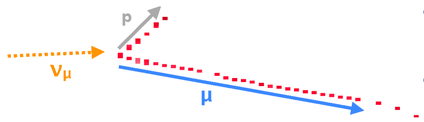
- Convolutional Visual Network (CVN)
  - Event maps are input to a convolutional neural network
  - Convolve the event maps with various filters to extract features
  - Identify event and particle types based on event topology





- Combine with traditional BDTs to reject cosmics and identify muons

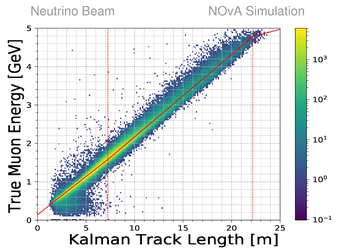
ν_μ Energy Estimation

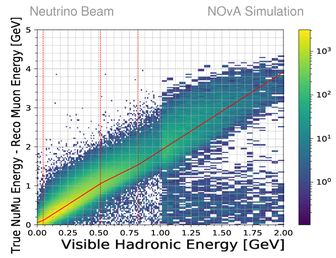


- Muons leave long straight tracks
- Tracks are made using a modified Kalman filter

$$E_\nu = E_\mu + E_{Had}$$

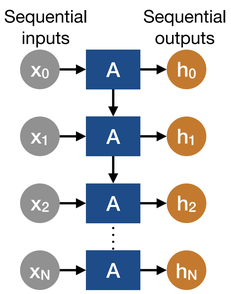
- Muon energy:
  - Spline fit to track length
  - Energy resolution ~ 3%
- Hadronic energy:
  - Sum calorimetric energy of hits not associated with muon track accounting for possible overlap
  - Spline fit to calorimetric energy
  - Energy resolution ~ 26%
- Yields an overall neutrino energy resolution of ~ 9%

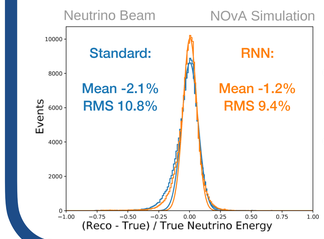




ν_μ Energy - In Development

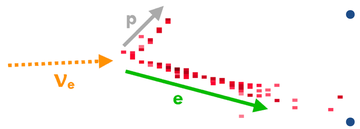
- Relying only on the track and remaining calorimetric energy may miss important information
- Recurrent neural networks (RNNs) can utilize more information and expand to a variable number of particles



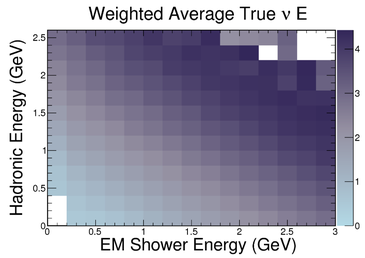


- Improved bias and resolution
- Implemented via a Long short-term memory (LSTM) network

ν_e Energy Estimation

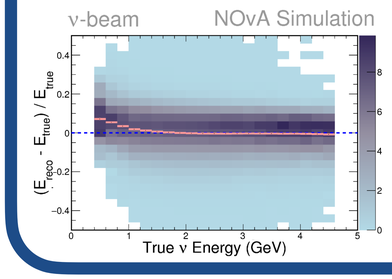


- EM (e, γ, π^0) and hadronic (p, $\pi^\pm$, etc) particles have different detector responses
- Use CVN-PID to separate particle types



- Simulated flux is peaked at about 2 GeV
- Re-weight events to a flat flux to avoid bias

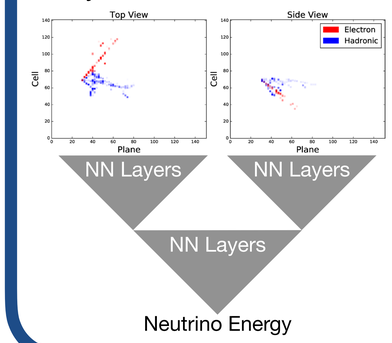
$$E_\nu = A \cdot E_{EM} + B \cdot E_{Had} + C \cdot E_{EM}^2 + D \cdot E_{Had}^2$$



- The resulting resolution is fairly flat across the energy spectrum
- Energy Resolution ~ 10%

ν_e Energy - In Development

- Feed event images into a CVN with a linear regression applied to the output layer to estimate event energy



- Minimizes dependency on "classical" reconstruction
- Shows better performance