Neutrino Energy Reconstruction with Recurrent Neural Networks at NOvA

Dmitrii Torbunov, University of Minnesota
torbu001@umn.edu

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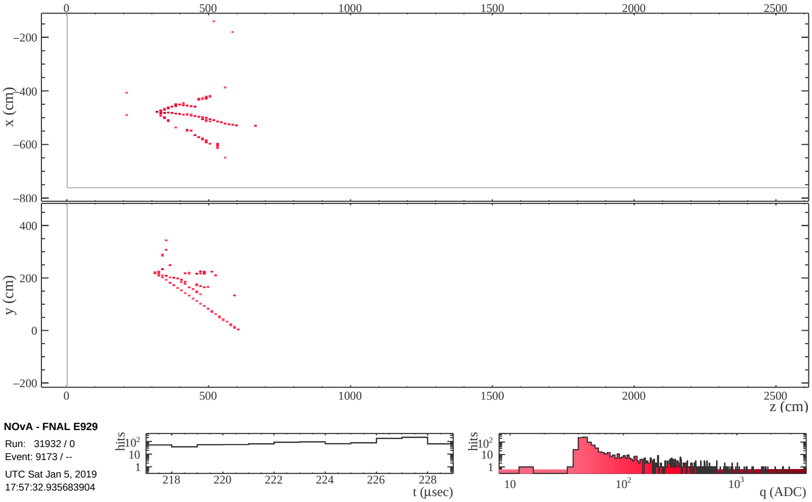
Introduction

- NOvA is a long-baseline accelerator based neutrino oscillation experiment aimed at making precise measurement of oscillation parameters.

- To make precise estimations of the oscillation parameters we need a good neutrino energy reconstruction algorithm.

- In this talk I will discuss development of a energy reconstruction algorithm based on a Recurrent Neural Network for the ν_μ CC events: $\nu_\mu \rightarrow \mu +$ hadrons.

ν_μ CC Event Topology



Find Energy of a fully contained ν_μ CC Event?

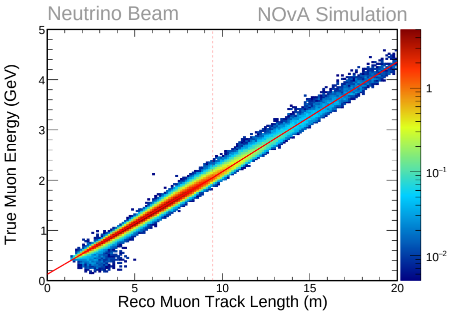
The Standard NOvA ν_μ CC Energy Estimator

- The standard ν_μ energy reconstruction in ν_μ CC events ($\nu_\mu \to \mu +$ hadrons) has 3 steps:
  1. Identify muon and estimate its energy E_μ.
  2. Estimate energy of the remaining hadronic activity E_{had}.
  3. $E_{\nu_\mu} = E_\mu + E_{\text{had}}$

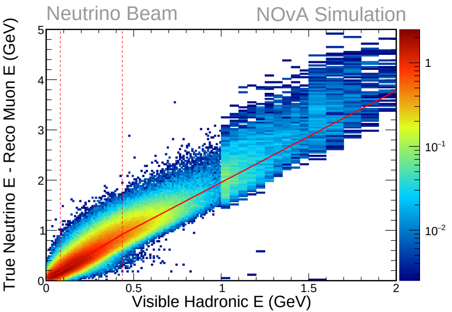
- Muons deposit energy at a fairly constant rate and leave long narrow tracks. Muon energy is reconstructed as a piecewise linear function of its length L.

- Hadronic energy is estimated from a calorimetric energy of hadronic activity using another piecewise linear function.

The Standard NOvA ν_μ CC Energy Estimator 2



(a) E_μ vs Muon Track Length



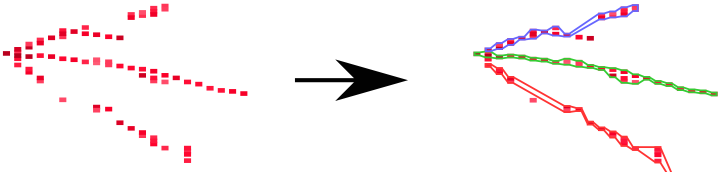
(b) E_{had} vs Calorimetric Energy

Hadronic Energy component has large variance not explained by a calorimetric energy.

Can We Do Better?

- The standard ν_μ energy estimator performs reasonably well, but is it possible to further improve its performance?
- NOvA is able to reconstruct cluster of hits (prongs) for individual particles in event.
- For prongs we reconstruct their dimensions, directions, energies, number of hits, particle type etc.

Particle Reconstruction



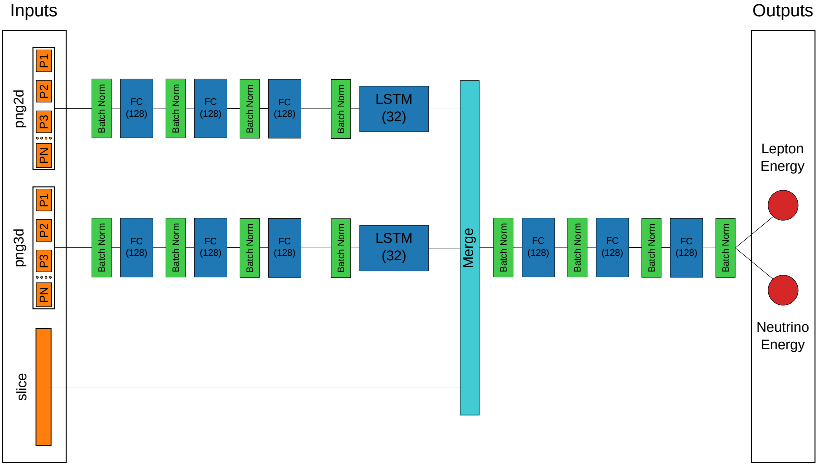
NOvA can reconstruct clusters of hits of individual particles:

- Find number of hits and calorimetric energies
- Estimate dimensions and directions
- Predict type of the particle
- Estimate energies and momenta of particles

RNNs to the rescue

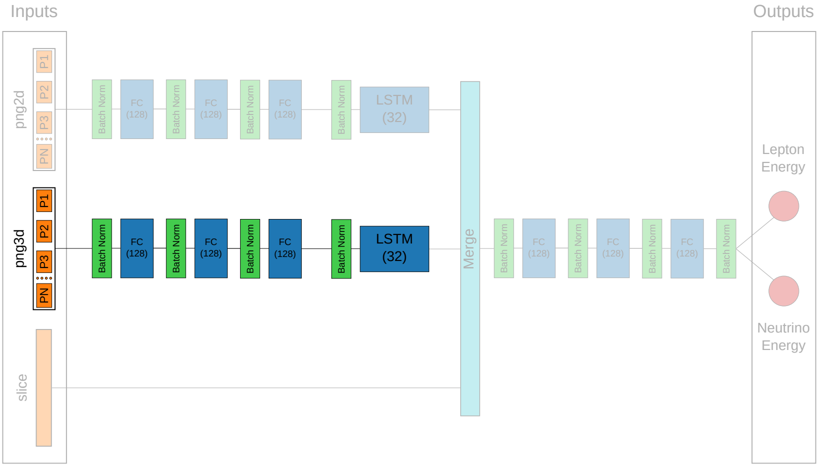
- The standard NOvA energy estimator ignores this potentially relevant information about each individual particle in event.
- To use information about individual particles we need a model that is capable of working with inputs of variable lengths (number of particles varies between events).
- Fortunately, Recurrent Neural Networks have distinctive ability to handle inputs sequentially.

Architecture of the Recurrent Energy Estimator, Overview



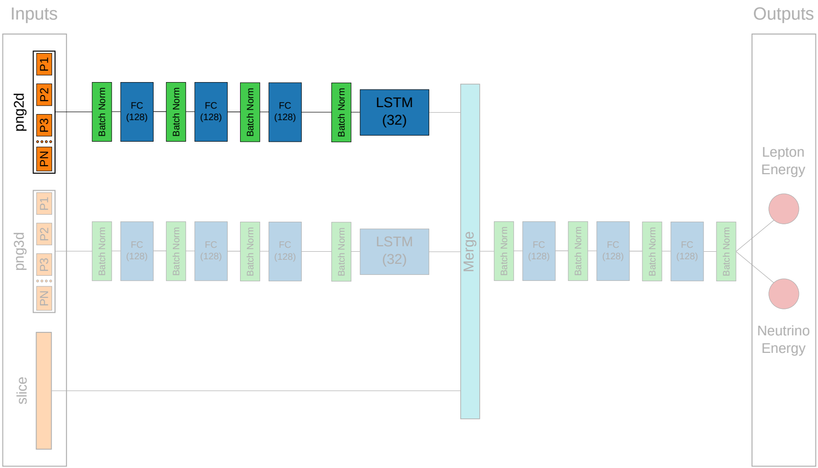
Long Short-Term Memory Cells are used to process fully reconstructed prongs (3D) and partially reconstructed prongs (2D)

Architecture of the Recurrent Energy Estimator, 3D Prong



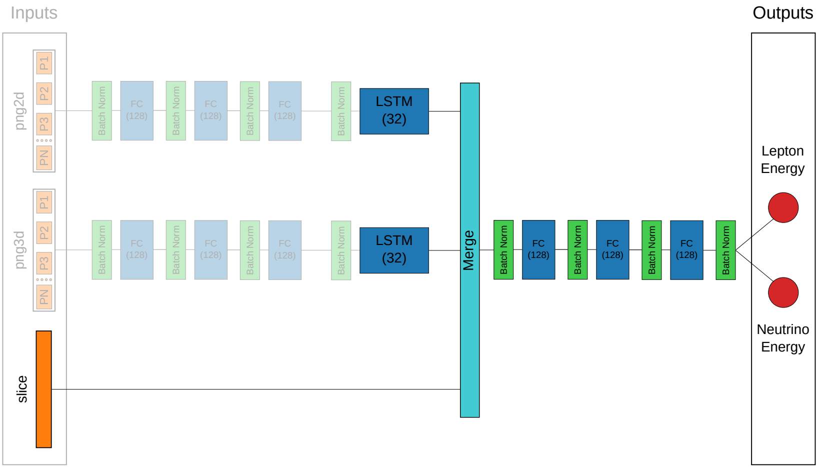
Information from fully reconstructed prongs (3D) is preprocessed through a set of Dense layers and fed to a LSTM Cell.

Architecture of the Recurrent Energy Estimator, 2D Prong



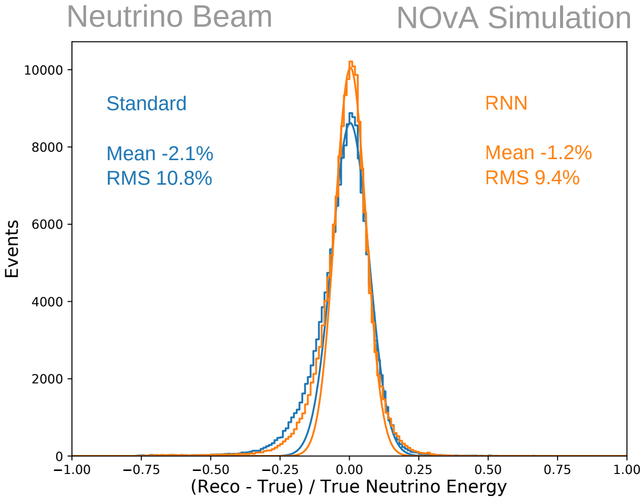
Information from partially reconstructed prongs (2D) is fed through another branch of Dense layers and LSTM Cell

Architecture of the Recurrent Energy Estimator, Output



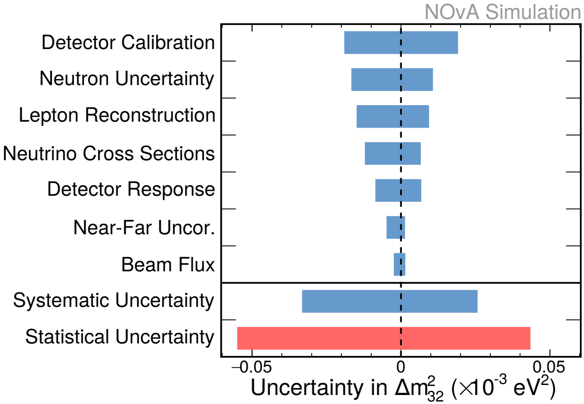
Outputs of LSTM Cells are combined with global information about event and used to predict μ and ν_μ energies.

Performance of the Recurrent Energy Estimator



RNN energy estimator is better than the standard in term of RMS 9.4% vs 10.8%.

Part 2, Systematic Uncertainties

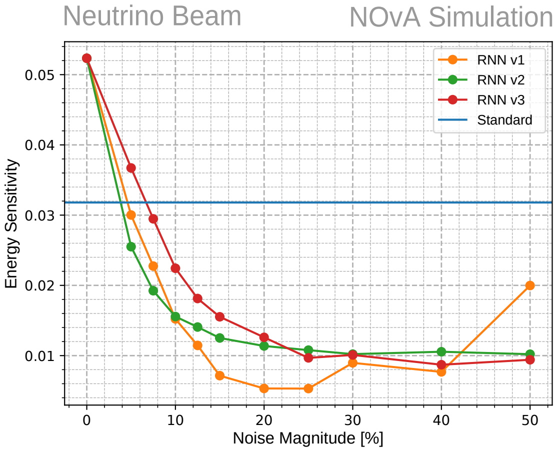


Precision of measurements of oscillation parameters is limited by systematic uncertainties.

Systematic Uncertainties

- The standard NOvA energy estimator is rather sensitive to the uncertainty in calorimetric energy.
- We would like to reduce this sensitivity in the new energy estimator.
- The solution is well known – add noise during training to inputs that are uncertain.

Calorimetric Energy Uncertainty vs Noise



RNN energy estimator can be made 5 times less sensitive to the calorimetric energy uncertainty than the standard energy estimator

Conclusions

- We have developed a new energy estimator that is based on a Recurrent Neural Network.
- It achieves about 15% better energy reconstruction and about 5 times less sensitive to the major NOvA systematic uncertainty.
- Pending further testing, new energy estimator may significantly improve NOvA measurements of oscillation parameters.

Backups