Identifying Neutrino Final States and Energies in MicroBooNE with New Deep-Learning Based LArTPC Reconstruction Frameworks

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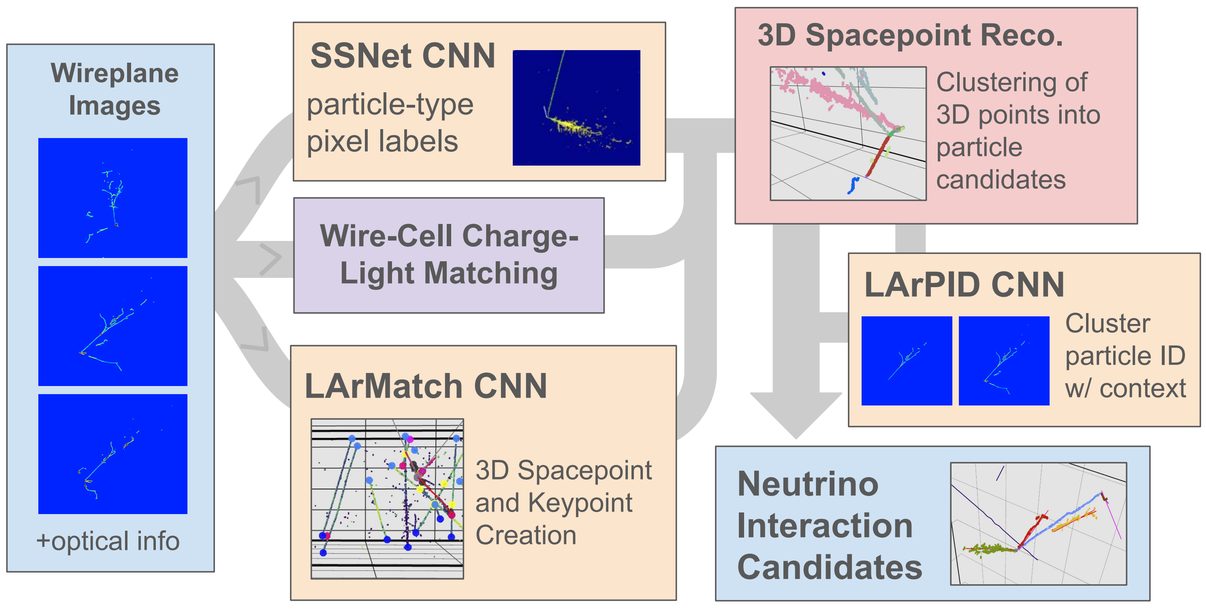
Overview of MicroBooNE's New CNN-Based LArTPC Reconstruction



1) Pixel processing

A) SSNet CNN tags pixels as track or shower pixels

B) Use cosmic-background tagging from Wire-Cell reconstruction [1]

C) LArMatch UNET CNN takes 3D-consistent wire intersections and:

- Finds true 3D energy deposition points (spacepoints)
- Locates keypoints (neutrino vertices, track start/end points, etc.)

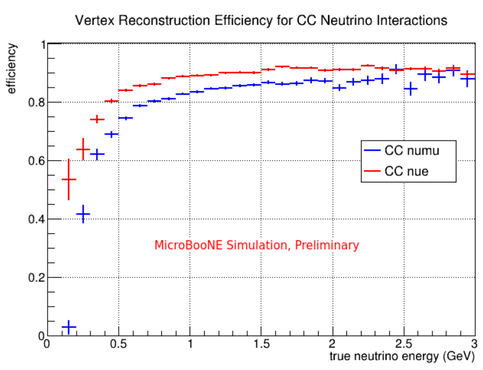
2) 3D spacepoint clustering:

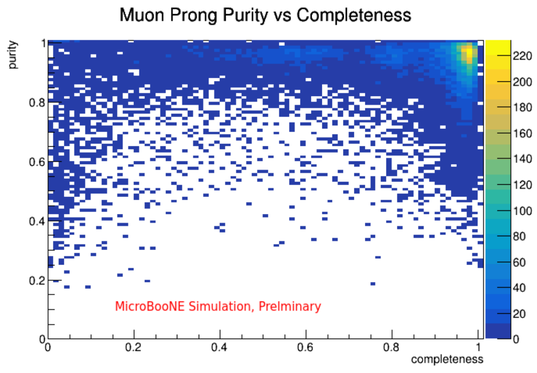
- Partition spacepoints using SSNet and Wire-Cell cosmic tags
- Density-Based Scan algorithms cluster spacepoints
- Attach clusters to neutrino keypoints to form interaction candidates

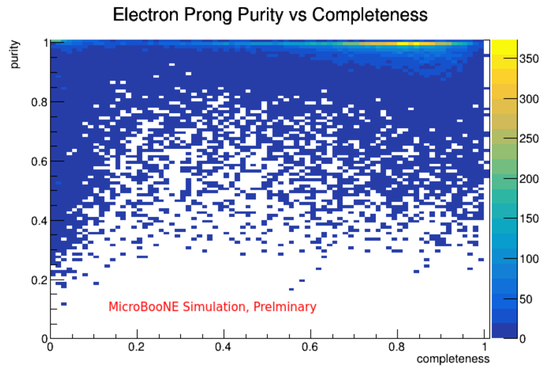
3) Particle classification with LArPID CNN:

- Inputs: 2D pixels associated with 3D cluster and full context image
- Outputs: particle label, primary or secondary classification, and purity and completeness reconstruction quality metrics

CNN-Based Reconstruction Performance







92% of clusters are assigned the correct particle label

LArPID Particle Classification Performance

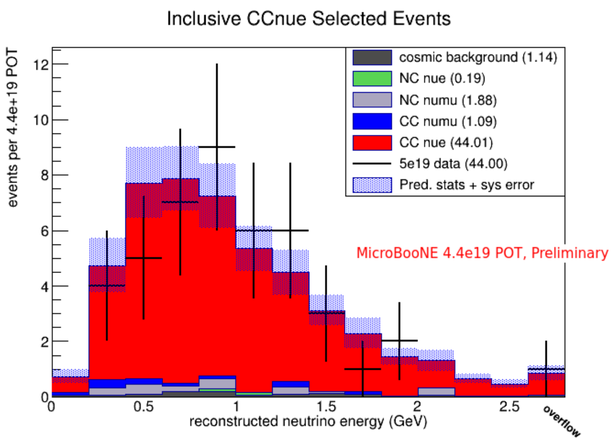
	True $e^{\pm}$	True γ	True $\mu^{\pm}$	True $\pi^{\pm}$	True p
Fraction classified as $e^{\pm}$	**84.5%**	5.2%	0.1%	0.5%	0%
Fraction classified as γ	12.7%	**94.3%**	0.2%	0.2%	0.1%
Fraction classified as $\mu^{\pm}$	0.4%	0.1%	**93.9%**	11.5%	0.3%
Fraction classified as $\pi^{\pm}$	2.3%	0.3%	5.6%	**86.5%**	1.6%
Fraction classified as p	0.1%	0.1%	0.2%	1.4%	**97.9%**

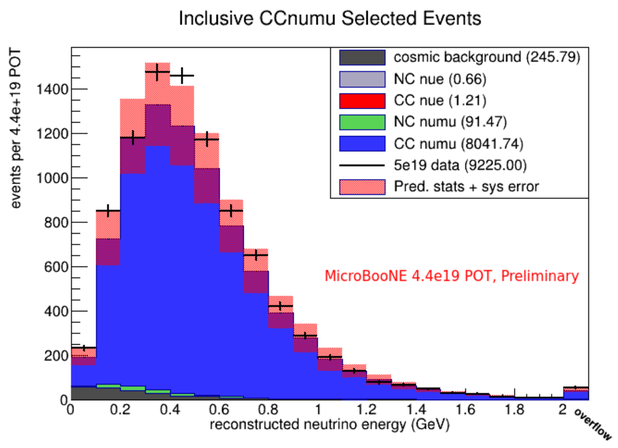
In simulation, 68% of reconstructed neutrino vertices are within 9mm (3 wires) of true interaction and clusters are reconstructed with high purity and completeness

Inclusive CC Event Selections with CNN-Based Reconstruction

Method:

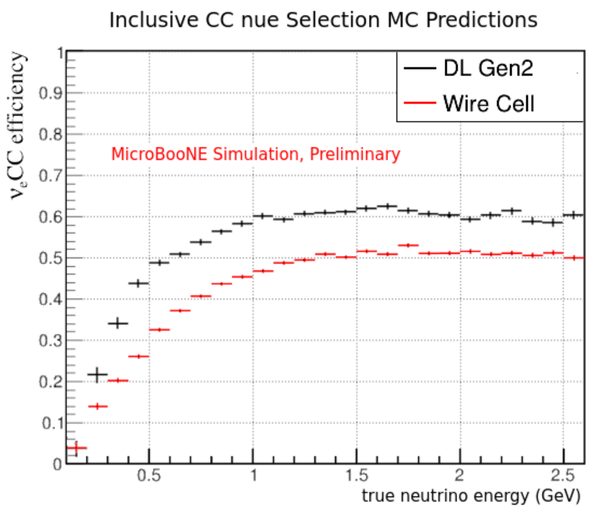
1) Take neutrino interaction candidates from LArMatch and clustering reco
2) Check LArPID outputs of attached tracks and showers to:
   - Find events with primary electron (for inclusive CC ν_e selection)
   - Find events with primary muon (for inclusive CC ν_μ selection)





Predicted Inclusive Selection Results with Comparison to Wire-Cell Reconstruction [1]

	DL Reco	Wire Cell
CC ν_e Efficiency	57%	46%
CC ν_e Purity	91%	82%
CC ν_μ Efficiency	68%	68%
CC ν_μ Purity	96%	92%

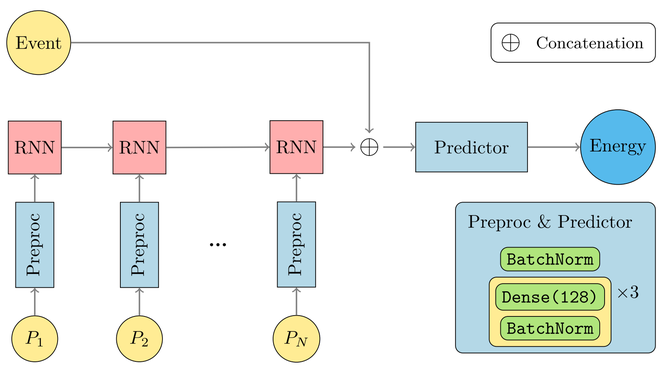


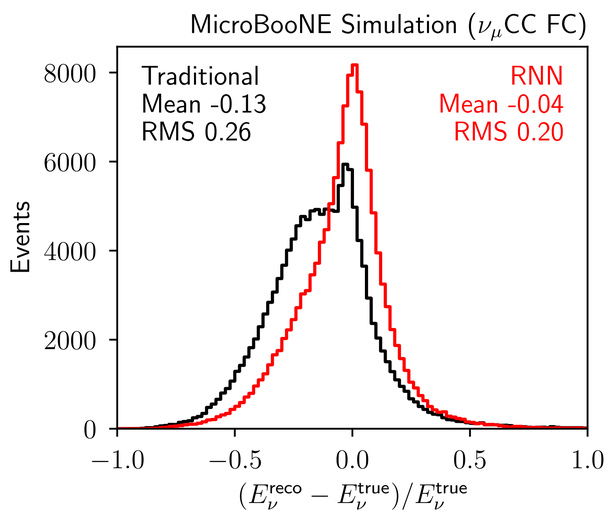
Data Validation:

- Hand scan results of selected CC ν_e events are consistent with efficiency and purity predictions and predicted improvements over Wire-Cell selection [2]
- High p-values for χ^2 data/MC consistency tests of kinematic distributions

An RNN Neutrino Energy Estimator in MicroBooNE's Wire-Cell Reconstruction

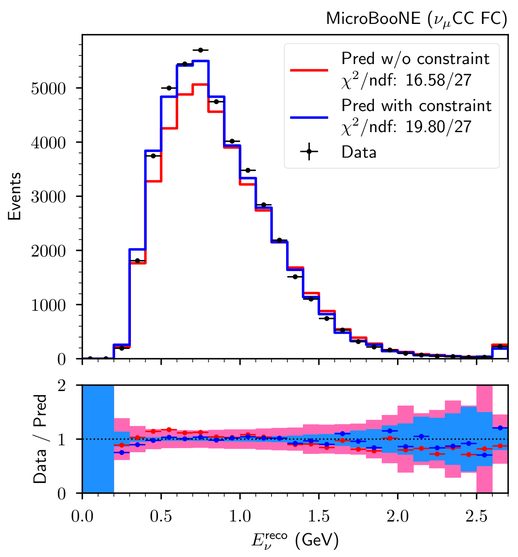
RNN takes reconstructed particles as input tokens and concatenates with event-level info to estimate neutrino and lepton energy

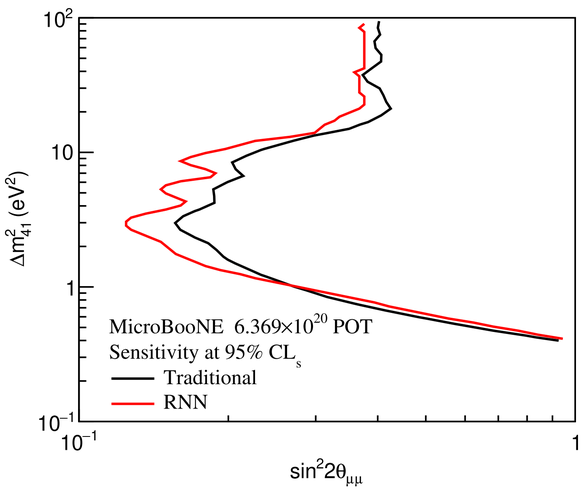




Substantial improvements in resolution and bias over traditional approach [1]

Results are consistent with data (high p-values from χ^2 tests)





Increases sensitivity to oscillation parameters in example ν_μ disappearance search

[1] Abratenko, P., et al. (MicroBooNE Collaboration). Physical Review D 105.112005 (2022)