Reconstructing 3D Charge Depositions in LArTPCs using a Convolutional Neural Network

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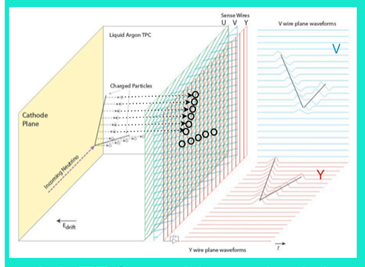
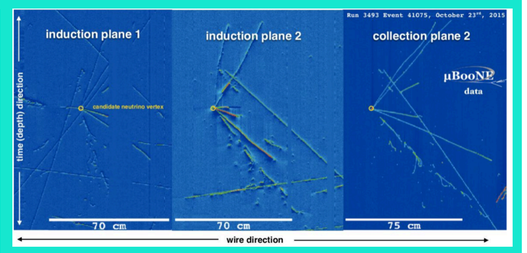
Introduction

- MicroBooNE is a Liquid Argon Time Projection Chamber (LArTPC) experiment investigating the MiniBooNE low-energy excess [1] with the Fermilab Booster Neutrino Beam (BNB)
- Wire readout LArTPCs record particle interactions as 2D images of deposited charge on a wire vs. time
- To reconstruct 3D particle trajectories one has to associate charge deposited on the 3 wire planes at the same time



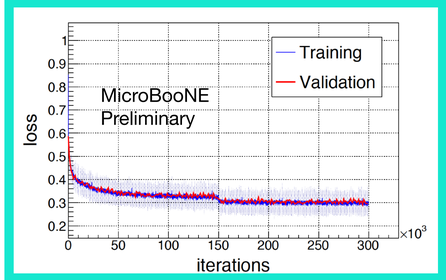
LArTPC working principle



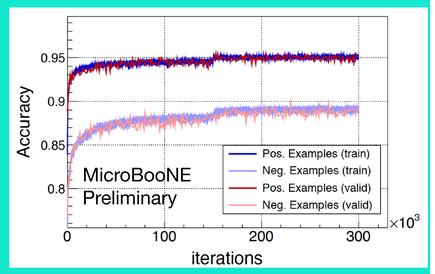
Wire plane images of charge

Network Training

- Network was trained on a sample of 40,000 simulated images of BNB neutrino interactions and multiple cosmic rays
- Using binary cross entropy loss
- For each iteration fed the network 50,000 wire triplets. Trained for a total of 300,000 iterations (3.75 epochs) without observing divergence



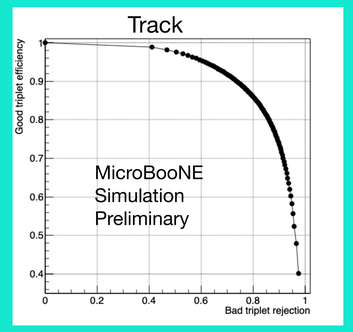
Network loss vs. # iterations

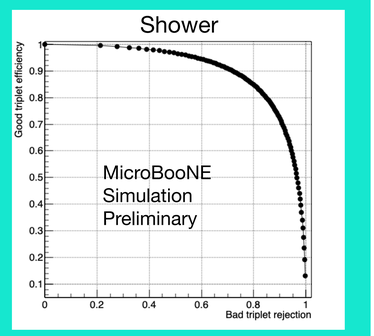


Accuracy vs. # iterations

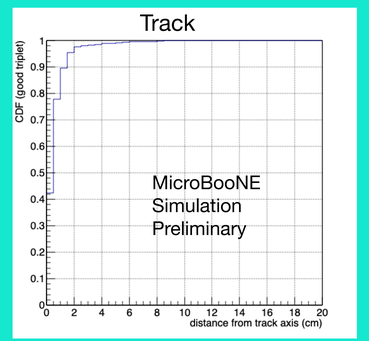
Performance

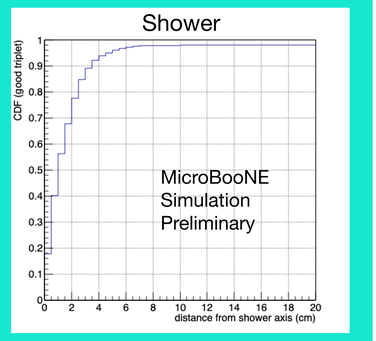
- Multiple predictions for every true simulated point. Best-match: prediction with highest network score.
- 3D point considered "good" if within 1 cm of true point



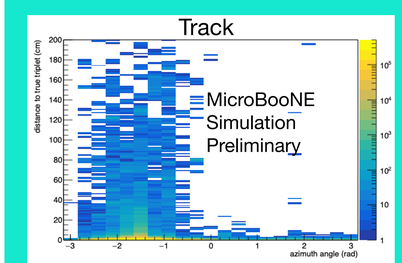


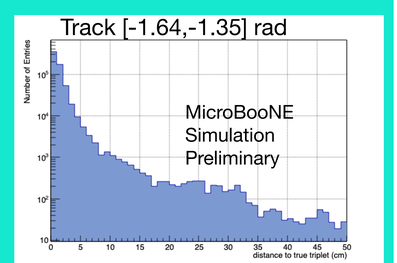
Good 3D point efficiency vs. bad point rejection as a function of network score for track (left) and shower (right) topology. ROC curve proves network score representative of actual 3D point goodness.





Integrated fraction of good reconstructed points as a function of distance to track/shower axis for neutrino-induced track (left) and shower (right) points, best-match only. Integrating within a radius of 5 cm collects >99% of good track and >95% of good shower points.

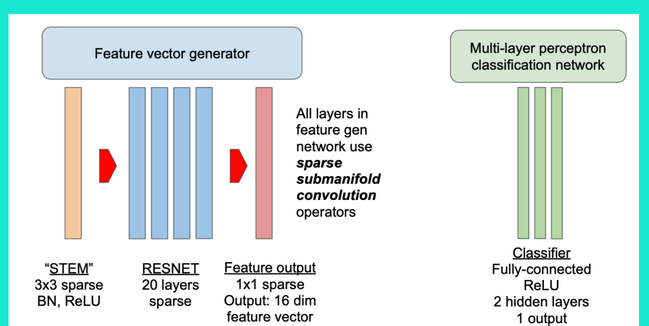




Distance from true point vs. azimuth angle for best-match reconstructed track 3D points (left). Dominated by cosmic tracks. Projection for vertical tracks (right). Performance robust in vertical tracks (hard to reconstruct).

LArMatch Algorithm

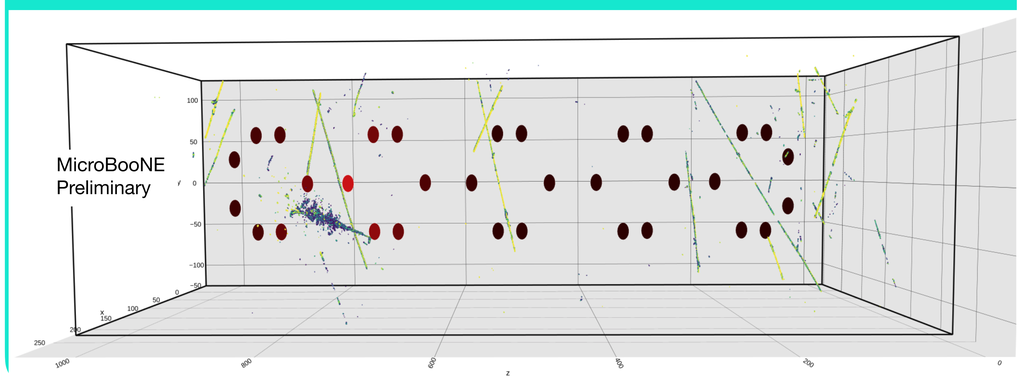
- Takes in 2D LArTPC images and outputs 3D reconstructed positions of charge deposition
- Image pre-processing: identify all geometrically possible combinations of same-time charge on the 3 wire readout planes (wire triplets)
- Inference: sparse CNN generates feature vectors for each triplet. MLP scores the probability that a triplet is a true charge deposition from 0.0 (low confidence) to 1.0 (high confidence)
- Post processing: form a 3D point for each triplet using detector geometry



Network implementation in Pytorch [2]

Example Inference on Data

- Colored points are 3D reconstructed space-points in a BNB electron neutrino event in data. Neutrino selection criteria described in [3]. BDT score between 0.5 and 0.7 required. Red circles represent light seen by PMTs. Proton track & electron shower of CCQE neutrino clearly seen.
- Color represents network score for each reconstructed point. Yellow: high score, blue: low score. Only plotting points with scores above 0.5



Future Work

- Estimate systematic uncertainty of 3D point reconstruction using simulation samples with different detector configurations and signal processing methods
- Further optimize network architecture

References

[1] "SignificantExcess of Electron-like Events in the MiniBooNE Short-Baseline Neutrino Experiment", arXiv:1805.12028
[2] Pytorch https://pytorch.org
[3] MICROBOONE-NIOTE-1086-PUB

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