Hunting Muon Neutrinos in MicroBooNE with Deep Learning Techniques

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Introduction to MicroBooNE

- Liquid Argon TPC (LArTPC) at Fermi National Lab
  - 85 ton LAr active mass
  - 470 m baseline
  - 3 wire planes
- Major goals
  - Investigate MiniBooNE low energy excess in \( \nu_e \) appearance
  - Measure \( \nu_e \)-Ar cross sections
  - R&D for future LArTPC technology (SBN program and DUNE)

Image Analysis With Deep Learning

- Physics is embedded in the details of the wire readout, essentially images with pixels as fine as our wires are spaced
- We use two types of neural networks to extract information from images

The MiniBooNE Excess

- MiniBooNE is an oil Cherenkov detector situated on the same beam at similar baseline
- Observed a 3\( \sigma \) excess in \( \nu_e \) appearance
- MiniBooNE had limited ability to distinguish e/\( \gamma \)
- MicroBooNE has sufficient spatial resolution to observe the first cm near a vertex, providing superior e/\( \gamma \) separation

Our Signal: 1 Lepton + 1 Proton Events

Signal Definition:
- 1 lepton with KE >35 MeV
- 1 proton with KE >60 MeV
- Particles remain contained

Motivation:
- V shape makes cosmic rejection easier
- Energy requirements ensure tracks are long enough to be reconstructable
- Topology helps distinguish CCQE from other CC modes which are more difficult to reconstruct

Selection of 1\( \mu p \) Vertices

- Significant number of candidate vertices are spurious cosmic vertices, or vertices from non-signal neutrino interactions
- Use the topology and kinematics of 1\( \mu p \) events to select events
  We require:
  1) Two reconstructed 3D tracks
  2) Vertex is inside a fiducial volume > 10 cm from edge
  3) Vertex must pass two likelihoods - one comparing signal to cosmic, one comparing signal to non-signal neutrinos.
  These are built from the following variables:
  - Ionization difference between tracks (called \( n \))
  - 3D Opening angle between tracks
  - How close to exiting is the event
  - Angular profile relative to beam direction (\( \delta \))
  - These form our selected and reconstructed 1\( \mu p \) sample

Our residual background is dominated by neutrinos, >99.9\% cosmic elimination

Efficiency = 18\%
Purity = 47\%

Analysis Chain

- We have developed a fully automated analysis to selection and reconstruction
- Makes use of a hybrid of CNN and traditional algorithms

PMT PreCuts
- Cosmic Tagging / ROI Finding

SSNet: Track / Shower Labels
- Candidate Vertex Finding
- 3D Reconstruction

Select 1\( \mu p \) Select 1\( \mu p \)

Comparisons of the 7 variables used to build the likelihood for selecting 1\( \mu p \) events

Comparing the reconstructed vertex position

Reconstructed Candidate Proton Length

References: