Selection of 1 Electron - 1 Proton Events for the MicroBooNE Deep Learning Based Low Energy Excess Search

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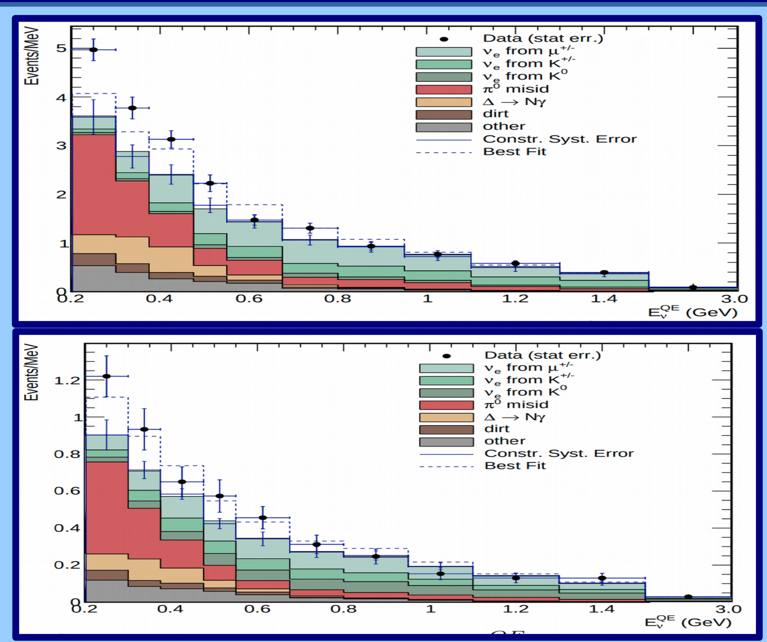
The MiniBooNE Anomaly

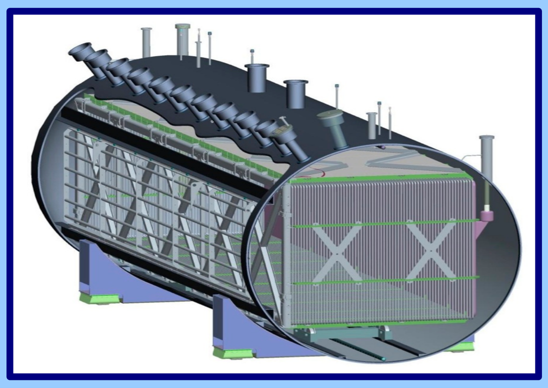
The MiniBooNE low energy excess (LEE) was an excess of low energy electron neutrino like events observed by the MiniBooNE experiment on the Fermilab Booster Neutrino Beam.[1]

Explaining this signal within an oscillation framework requires mixing parameters in tension with global fits. If confirmed, this anomaly may point toward physics beyond the standard model.

Understanding the nature of this excess is the primary goal of this analysis.

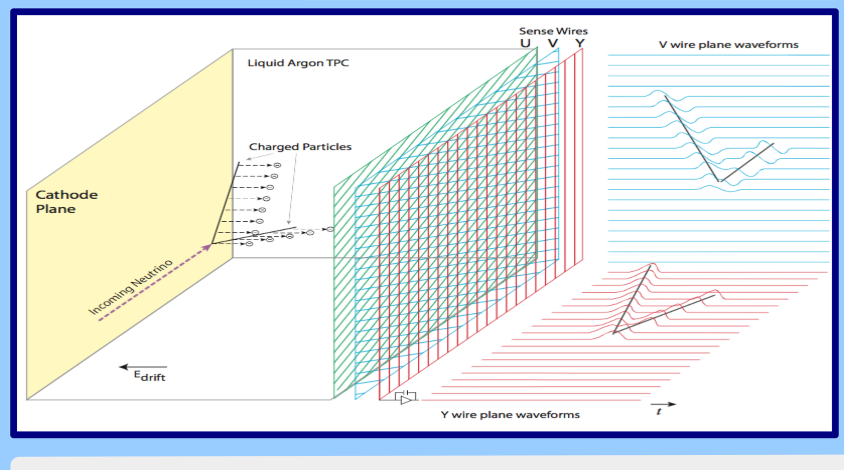


The MinBooNE result shows an excess at low energies in both neutrino (top) and antineutrino (bottom) running



The MicroBooNE detector (right)

Image formation in a LArTPC (bottom)



The MicroBooNe Experiment

MicroBooNE is an 85 ton liquid argon time projection chamber located on the Fermilab Booster beam. It probes almost identical L/E region as MiniBooNE.

When a neutrino interacts with an argon, the final state particles produce ionization electrons. These are drifted by an electric field past three wire planes.

Event timing is obtained using scintillation light with a set of 32 PMTs.

This results in high resolution 3D images of the event.

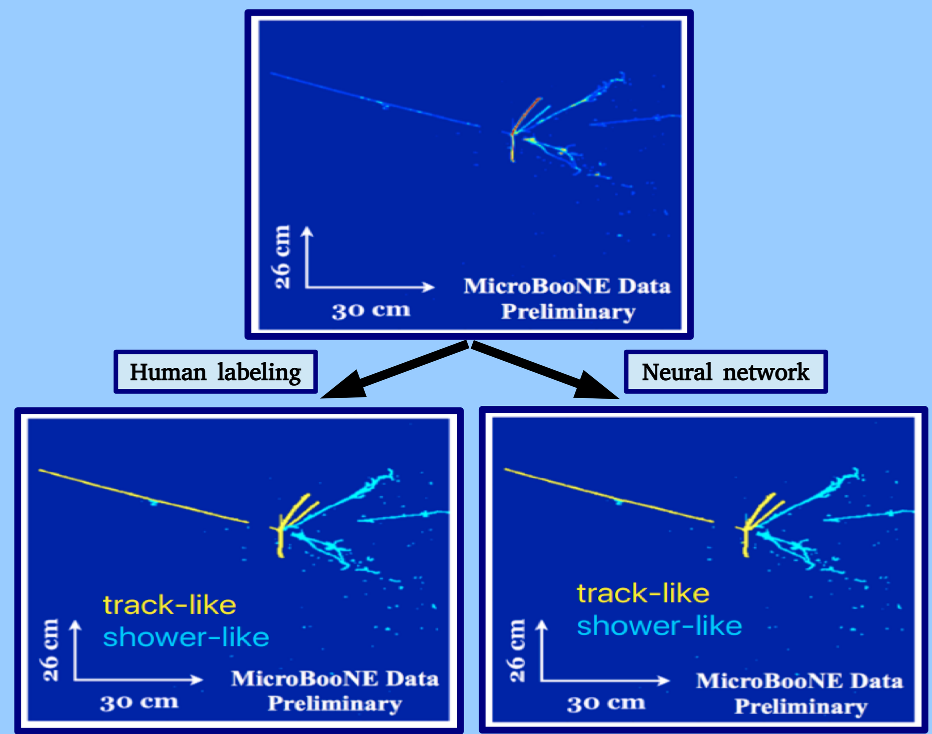
Analyzing Images With Neural Networks

Semantic Segmentation

Particles produce tracks or showers. Determining if a feature is a track or shower is a powerful event selection tool.

Visual feature analysis lends itself naturally to convolutional neural networks, a machine learning technique.

After training on simulated images, a semantic segmentation network provides the fraction of a reconstructed particle which is shower or track like.[2]



In "man vs machine" labeling trials such as this, neural networks are found to reliably produce track vs shower labeling

Multi Particle Identification

Determining which particles are present is a potent selection tool.

A Multi Particle Identification (MPID) neural network provides a score for how likely it is that a particle is present.

This network is trained to identify p, μ, $\pi^{\pm}$, e^{-}, & γ

This image contains 1 proton and 1 electron.

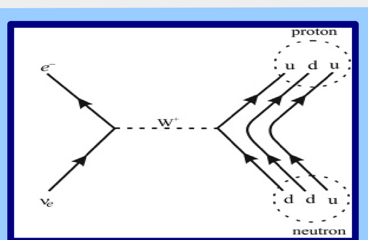
The MPID network returns the following particle probabilities:

- Proton : 97%
- Electron : 98%
- Muon: 2%
- Pion 3%
- Gamma: 10%

Our Signal: CCQE 1e1p Events

This analysis seeks to identify CCQE events with 1 electron and 1 proton (1e1p) in the final state.

This topology provides clean reconstruction handles with which to differentiate from backgrounds. Quasielastic interactions also have distinctive kinematics that we leverage to discriminate against backgrounds.



In a CCQE interaction the incoming neutrino exchanges a W+ with a neutron, producing a proton and lepton

A typical 1e1p interaction

Using Kinematics

Ignoring nuclear interactions, our signal amounts to relativistic 2-body scattering. This provides concrete kinematic expectations.

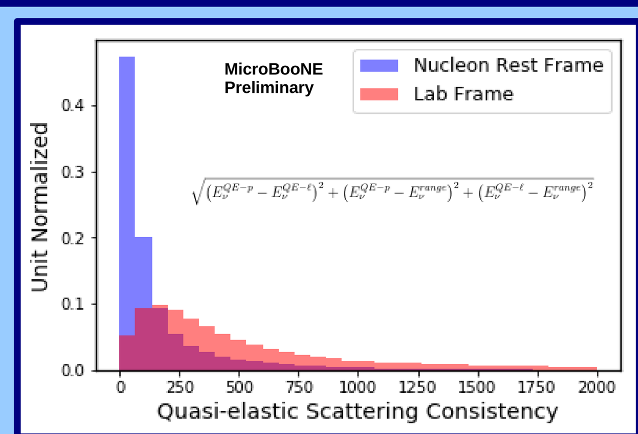
For instance, E_{ν} in a QE interaction can be reconstructed using the proton, lepton, or both. The degree of simultaneous agreement between these formulae picks out events with QE like behavior.

Reconstructing all final state momenta permits an estimate of the Fermi momentum of the struck nucleon which allows us to boost into a reference frame in which the struck nucleon is at rest, strengthening these patterns.

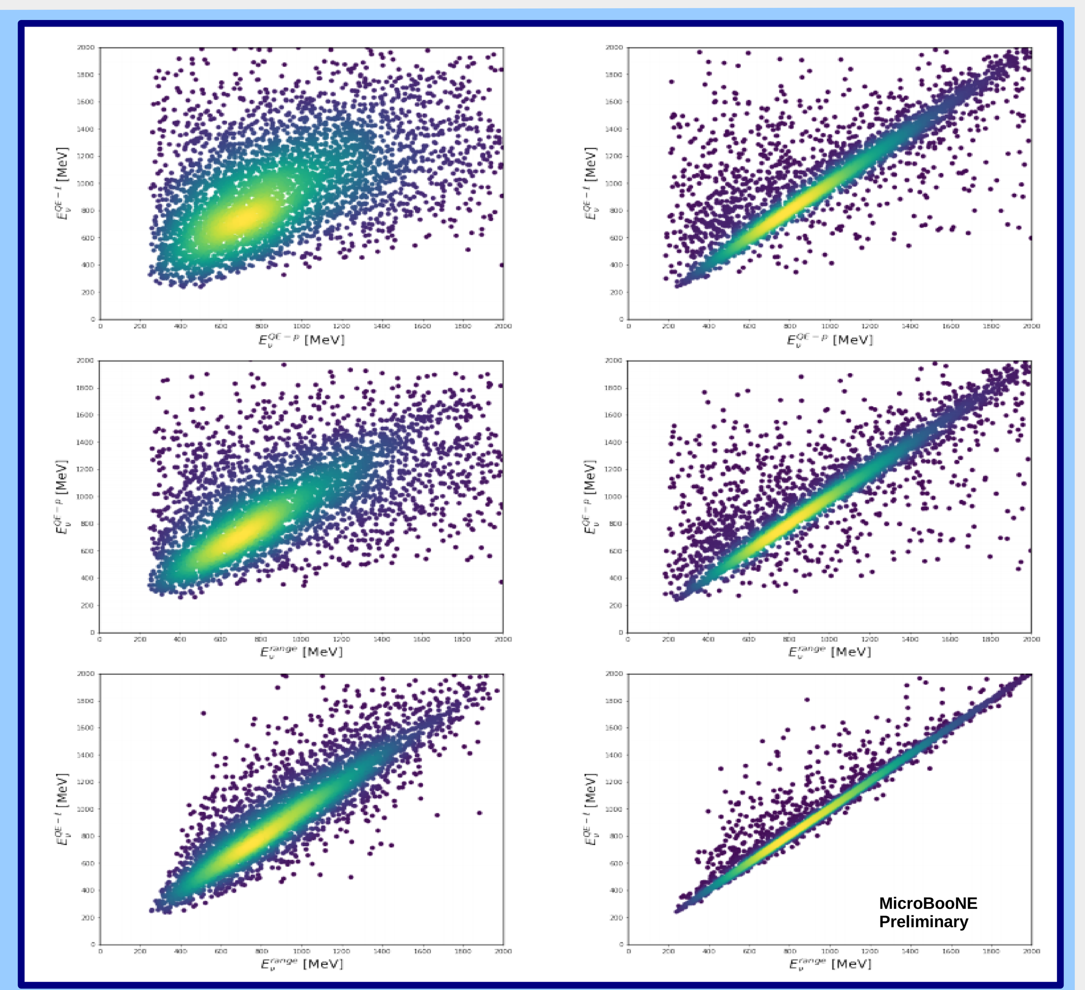
Other kinematic parameters are also useful:

P_T & α_T compare the transverse momentum profile to an ideal QE scatter from a longitudinal beam.

The four momentum transfer components (Q_0 & Q_3) have a distinct shape for QE scatters.



Casting the E_{reco} agreement as a 1D variable built from the differences of the three E_{reco} formulae added in quadrature shows the power of boosting to nucleon rest frame.



In simulated true 1l1p CCQE interactions, each of the three energy reconstruction methods are well correlated (left). This will not typically be true of backgrounds.

This correlation is strengthened if the energies are reconstructed in the boosted reference frame (right).

Event Selection

Selection of the signal sample comprises a set of preliminary cuts followed by a cut on a boosted decision tree.

Preliminary Cuts:

- 2 contained particles above energy thresholds
- Fiducialization volume cuts
- Rejection of detached π^0 showers
- A shower-like particle must be found
- Require a physical boost
- MPID predicts muon probability < 20%

Boosted Decision Tree:

Trained using MC and cosmic data to distinguish CCQE 1e1p events backgrounds

Takes advantage of kinematic variables discussed above as well as patterns in ionization density & angular info

Final selection yields a sample which is 60% pure CCQE 1e1p and 73% pure 1e1p of any kind.

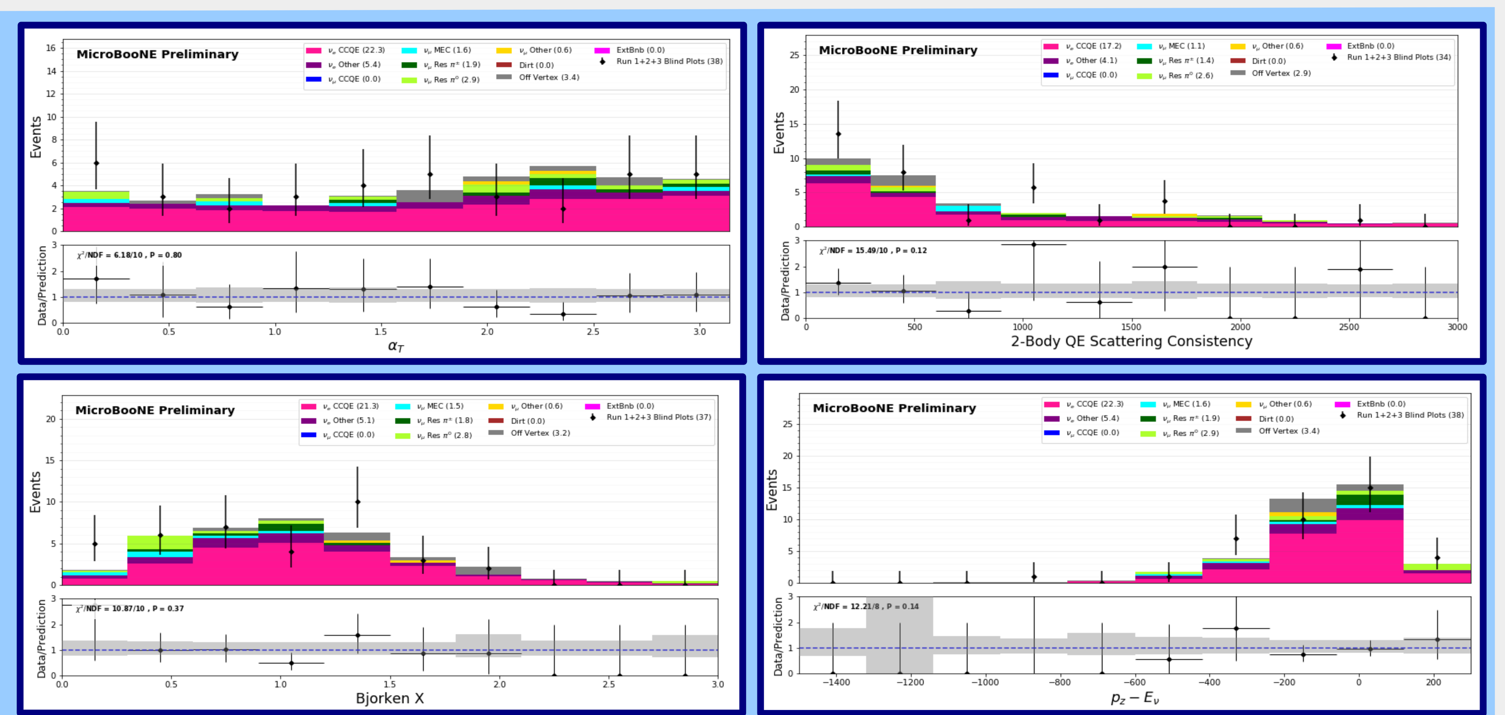
Current Status

We have done validations using several samples

- 5.3 x 10^{19} open POT (<5% of all data)
- 4.8 x 10^{20} POT high energy sideband (E > 700 MeV)
- 4.8 x 10^{20} POT blindness-safe histograms

These data sets enable us to validate our selection, without having sensitivity to the LEE signal.

Observations are compared to a POT normalized prediction using GENIE G18_10a_02_11a[4]



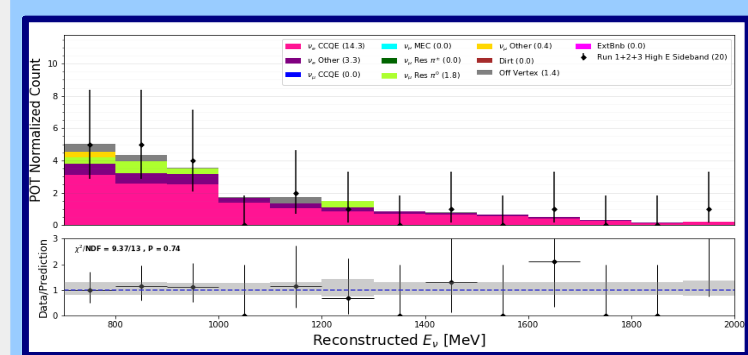
Selection of blinded histograms. These provide higher statistics validation of reconstruction variables without giving LEE signal sensitivity.

α_T (upper left): Illustrates that we have modest FSI

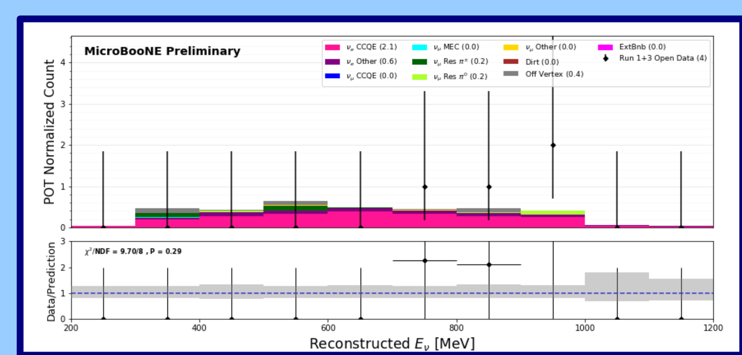
QE-consistency (upper right): Illustrates the preference for QE-like values

Bjorken x (lower left): Evaluated in the boosted frame, peaks near 1 as anticipated for QE-like interactions

$P_z - E$ (lower right): Peaks near zero, indicating that the reconstructed neutrino momentum matches it's energy well as anticipated for m ~ 0



Reconstructed neutrino energy for the high energy sideband



Reconstructed neutrino energy for the partial open data set

References:

[1] Phys. Rev. Let. 110, 161801 (2013)
[2] Phys. Rev. D 99, 092001 (2019)
[3] MicroBooNE Public Note 1086
[4] MicroBooNE Public Note 1074