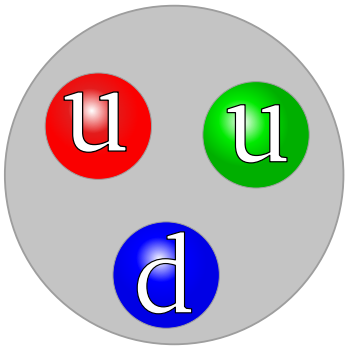
Measuring Nucleon Structure from Neutrino Interactions in MicroBooNE

Katherine Woodruff
with
Vassili Papavassiliou Stephen Pate Tia Miceli

Fermilab New Perspectives

June 13, 2016

Strange Quarks in the Nucleon

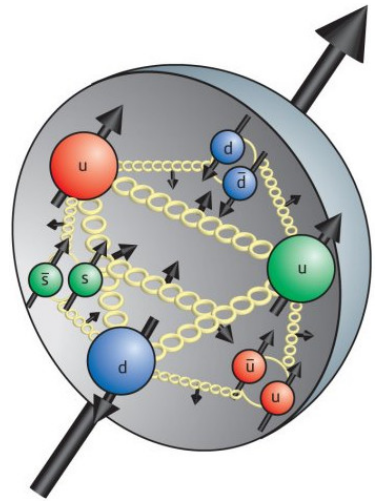


Nucleons are composed of three up and down valence quarks

- These quarks account for small percent of nucleon mass

Gluons that bind the quarks carry remainder of the mass

- The gluons can split into short lived quark-antiquark pairs (sea quarks)
- Sea quarks are mostly up and down, but there are also strange-antistrange pairs



Strange Quark Contribution to Nucleon Spin

We want to know the total contribution to the nucleon spin that comes from the spin of strange quarks and antiquarks (Δs)

$$\Delta s = (s^{\uparrow} + \bar{s}^{\uparrow}) - (s^{\downarrow} + \bar{s}^{\downarrow})$$

- The up and down quark contributions (Δu and Δd) are fairly well known

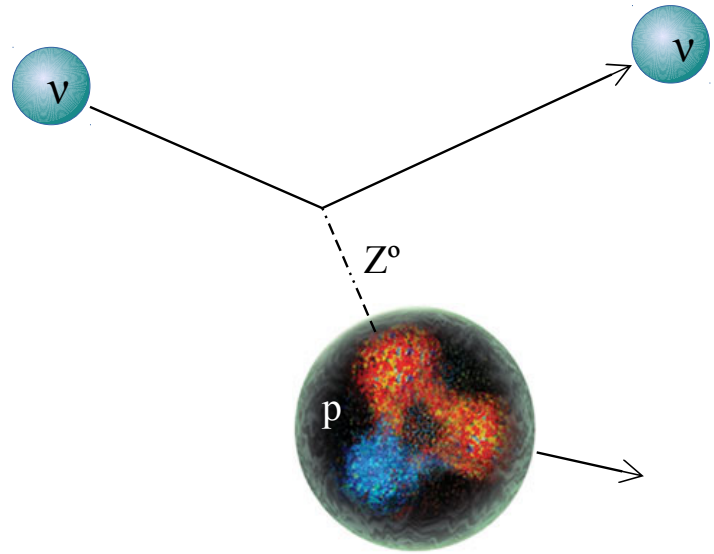
This value was expected to be zero

- Found to be negative in polarized, charged-lepton, DIS
- Analyses give range $\Delta s = -0.08$ to -0.14

Neutral-Current Elastic Scattering

The neutral-current elastic (NCE) neutrino-nucleon cross section depends on the form factors G_A^{NC}, G_E^{NC}, and G_M^{NC}

- Represent the spin, electric, and magnetic distributions of the nucleon
- Each form factor can be separated in terms of individual quark contribution



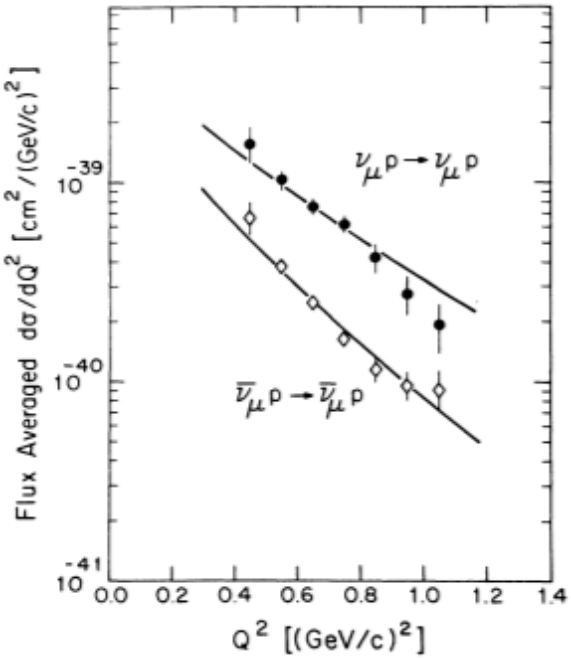
If we extrapolate G_A^{NC} to zero, we get

$$G_A^{NC}(Q^2 = 0) = -\Delta u + \Delta d + \Delta s$$

- $\Delta u - \Delta d$ has been determined in neutron decay

Experimental NCE Measurements of Δs

NCE measurement from the E734 neutrino scattering experiment at BNL



- Measured NCE $\nu - p$ interactions down to $Q^2 = 0.45$ GeV^2
- Found $\Delta s = -0.12 \pm 0.07$

NCE $\nu - p$ measurement in **MicroBooNE**

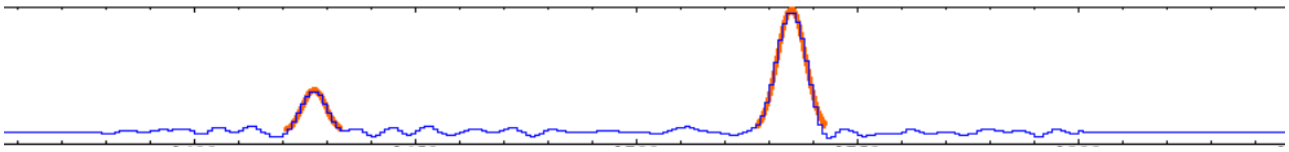
- Measure the ratio of neutral-current elastic to charged-current quasi-elastic events
  - Reduce uncertainty from beam flux, detector efficiency, nuclear effects, and final state interactions
- The signal for a NCE $\nu - p$ interaction in MicroBooNE is a single proton
  - We will be able to detect protons that traverse as few as five wires (1.5 cm)
  - Corresponds to a NCE interaction with $Q^2 = 0.08$ GeV^2

LArSoft Reconstructed Tracks

We first get reconstructed TPC tracks from LArSoft (Liquid Argon Software)

- There is a series of algorithms that create these tracks

1. Hit finding: Fit gaussians to deconvolved waveform peaks

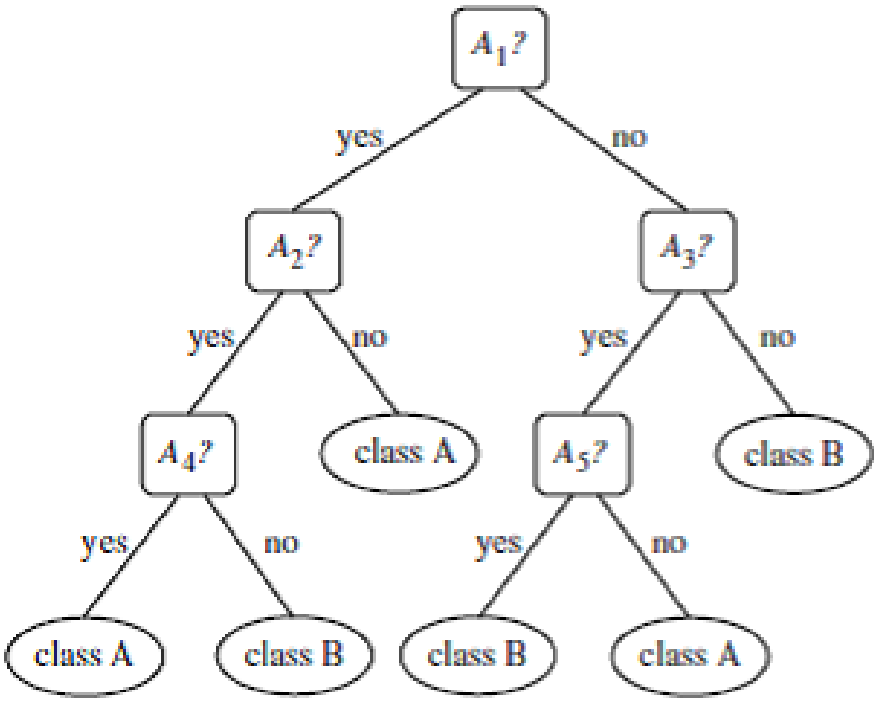


2. Cosmic track finding:
   - Combine hits from step (1) into tracks
   - Use cosmic tagging algorithm to remove cosmic-like tracks
   - Return set of hits that are not associated with cosmic tracks

3. Neutrino track finding:
   - Combine hits from step (2) into tracks
   - Return set of neutrino event-like tracks
   - The current neutrino-finding algorithm finds ∼50% of simulated proton tracks — this efficiency is rapidly improving

- The next step is to identify which tracks are protons

Gradient-Boosted Decision Trees



Decision tree:
series of if/else statements

- Input an event (collection of physical features)
- Output a class (0 or 1)

Gradient-boosting:
Each new tree trains on the the error of the previous tree

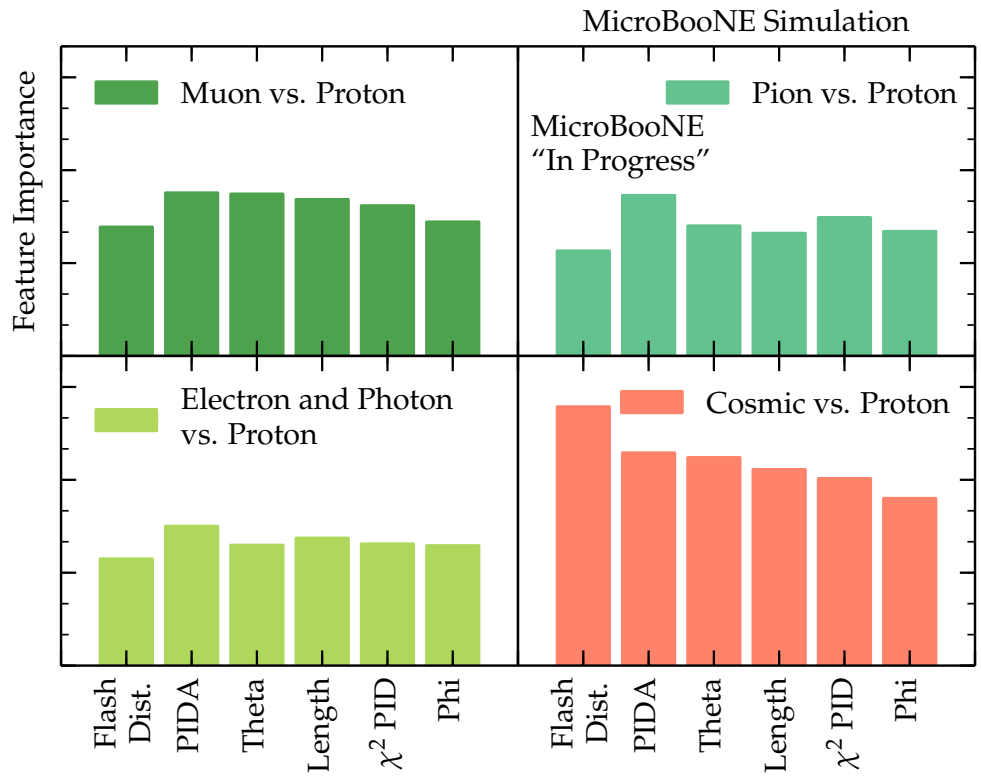
Building the Gradient-Boosted Decision Trees

We are using four classifiers

- proton vs. muon, proton vs. pion, proton vs. electron/photon, proton vs. cosmic
  - protons, muons, pions, electrons, and photons are neutrino-event like
  - cosmics are any type of cosmic induced tracks

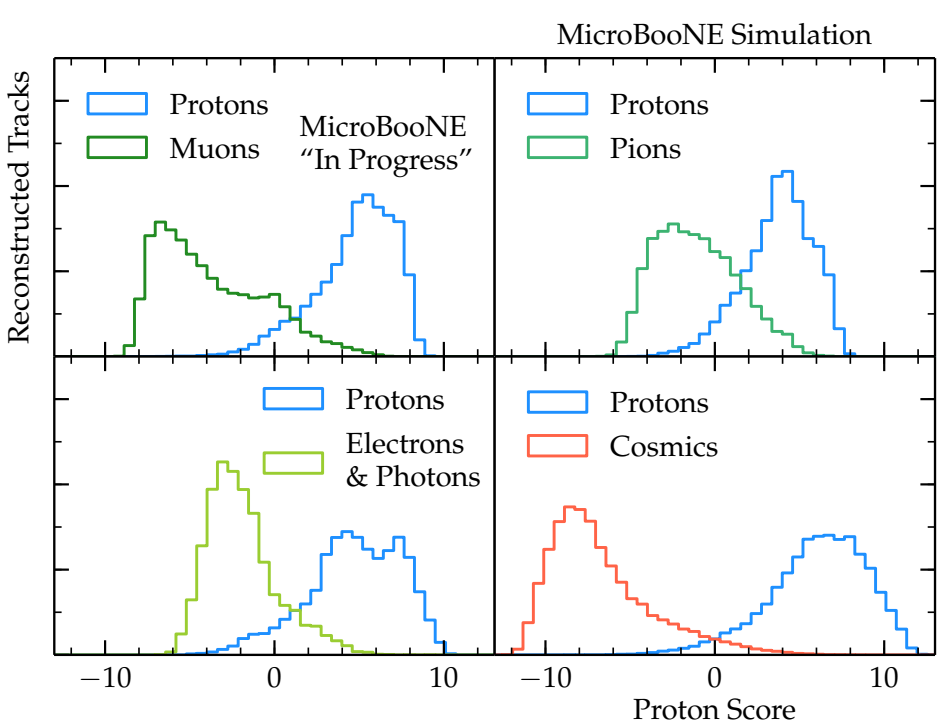
Each input is a collection of reconstructed track features:

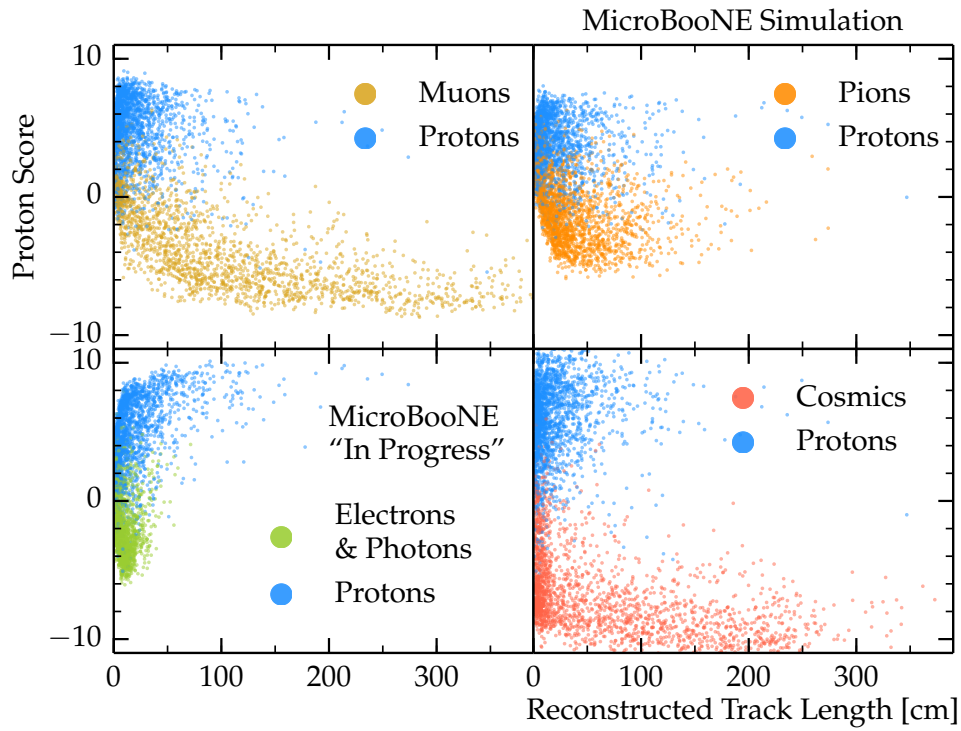
- Geometry (length, angle, ...), calorimetry (total charge, ...), light collection (distance to flash)



Performance on Training Set

To train, we used 99,940 simulated neutrino events and 32,428 real cosmic events in MicroBooNE



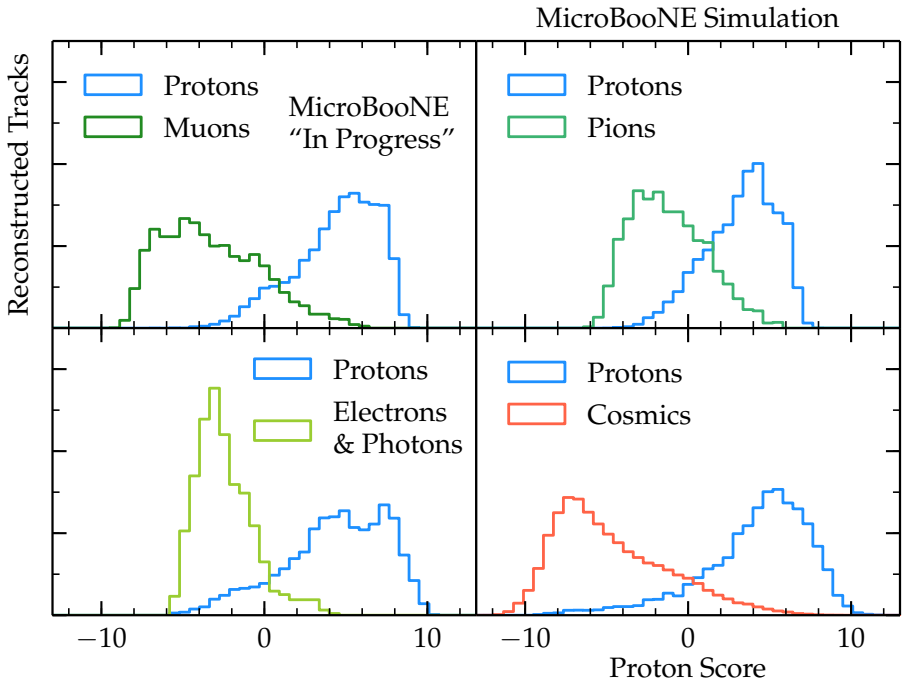


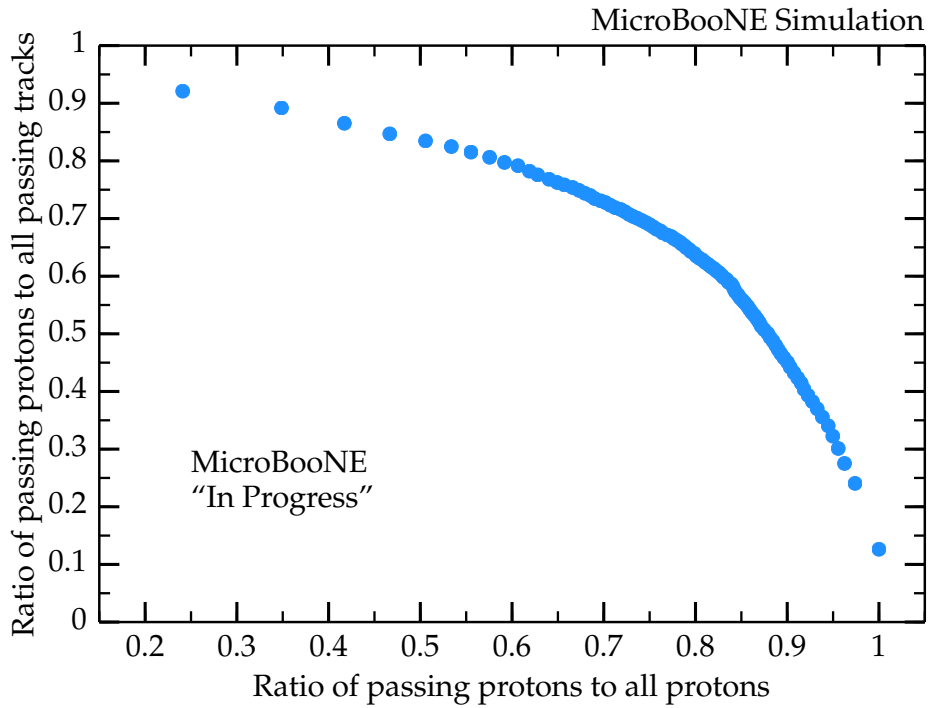
- "Proton Score" is the log-odds of a track being from a proton

$$S_i = ln\left(\frac{p_i}{1-p_i}\right)$$

Performance on Test Set

Tested the trained classifiers on a set of 40,864 simulated neutrino and simulated cosmic events



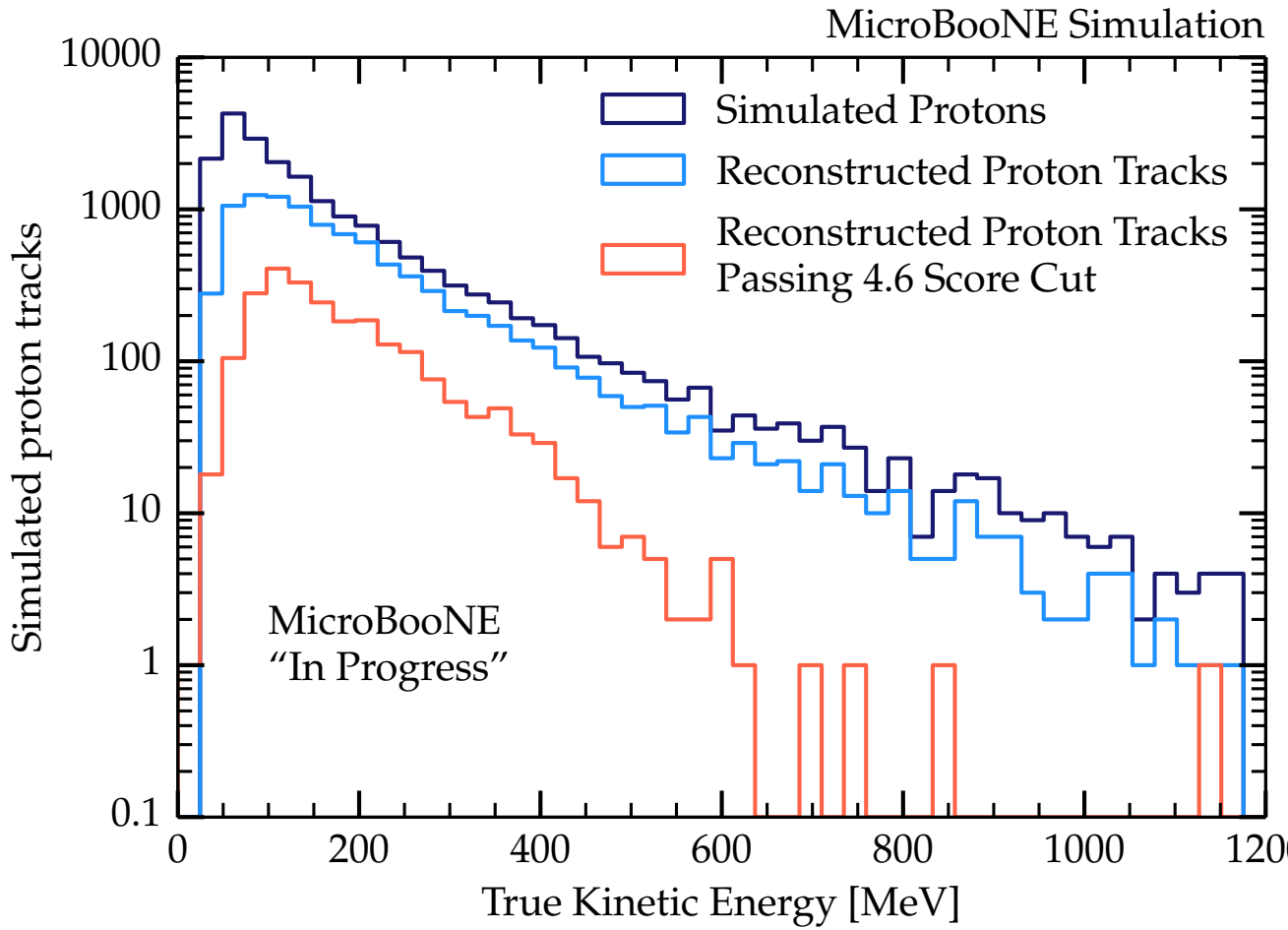


- Can choose a score cut to optimize efficiency or purity
- As an example, we chose a score cut of 4.6 to get a high-purity set

Score Cut to Maximize Purity

Required a track score of at least 4.6 for all four classifiers

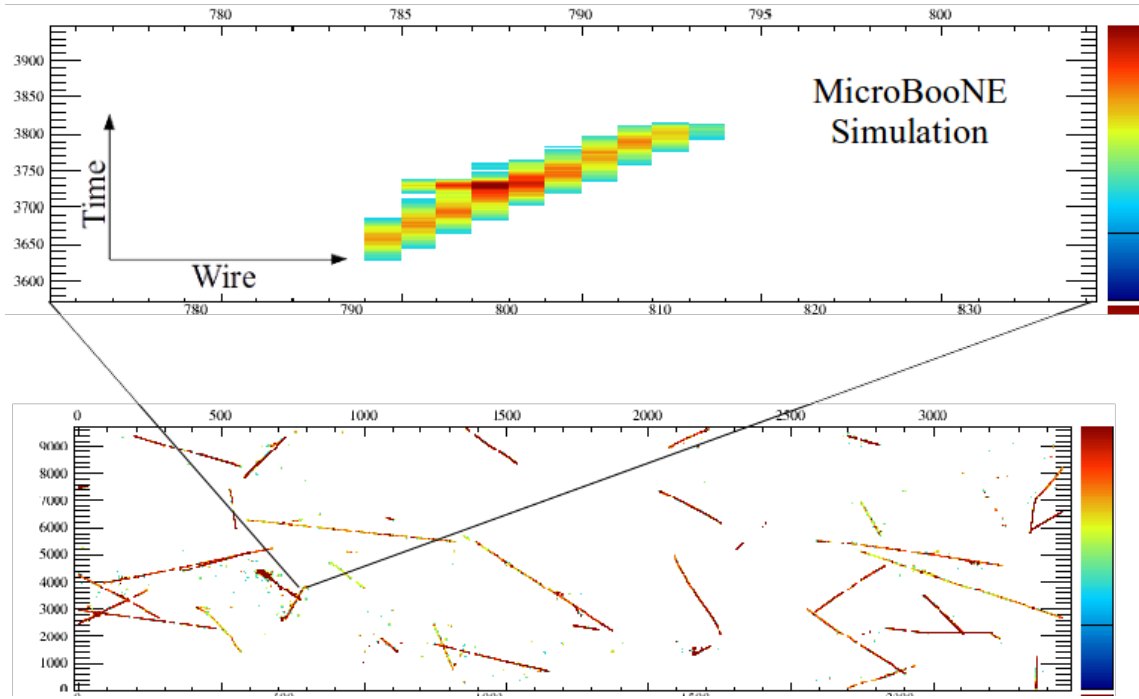
- Purity of BNB protons: 60%
  (91% total proton purity — including cosmic)



- Efficiency of BNB protons: 10%
  (20% BDT efficiency 50% reconstruction efficiency)

Example Event from Test Set

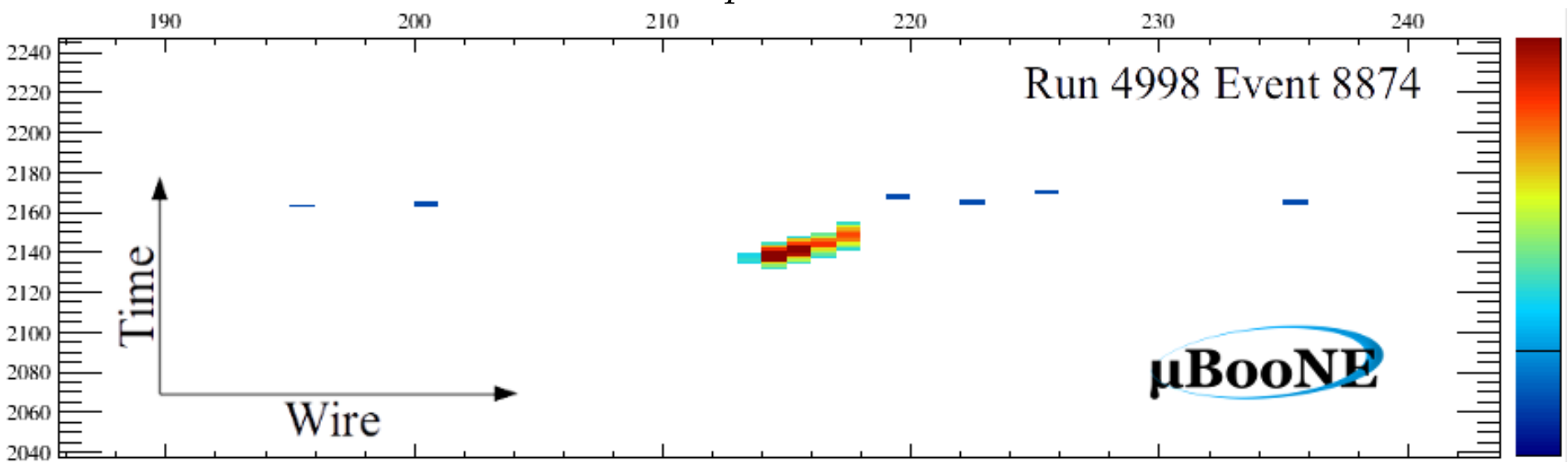
- Event display of simulated neutral-current elastic proton from test set that passed the cuts
- This is a 120 MeV kinetic energy simulated proton
- Reconstructed length is 11 cm



Running on Data

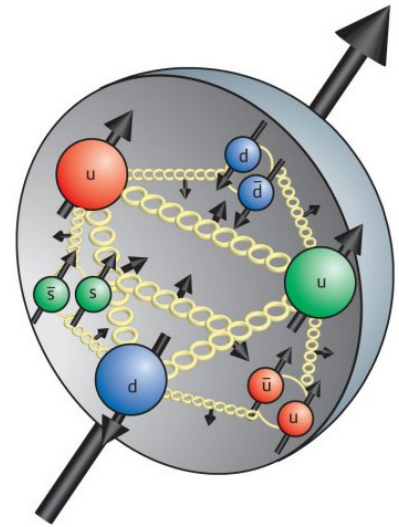
- Examples of proton candidates in real BNB data
  - Chose a run with 3,903 triggered events
  - Used the same 4.6 score cut to get pure sample
  - Five tracks passed all cuts

Possible NCE $\nu - p$ event in MicroBooNE



Conclusion

- The polarization of the strange quarks in the nucleon is an open question
- MicroBooNE has the ability to measure Δs in neutral-current elastic scattering
  - The signal is a single short proton track

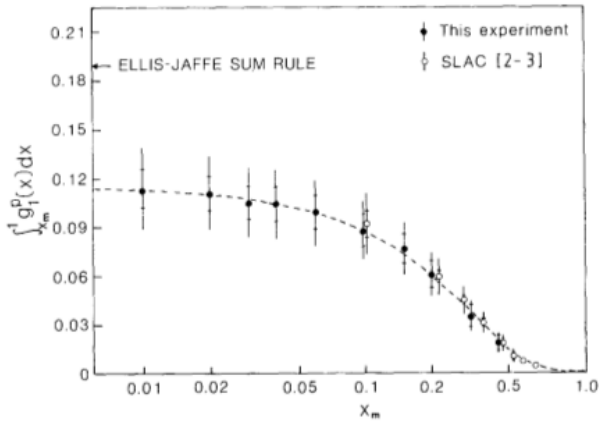


- A combination of LArSoft algorithms for track reconstruction and boosted decision trees for particle I.D. is a promising route
- We will soon be able to use this method to identify neutral-current elastic events (and others) in MicroBooNE

Thank you!

Back up slides

- Plot shows 1987 EMC results that Ellis-Jaffe sum rule is violated
  - Ellis-Jaffe sum rule assumes $\Delta s = 0$ and SU(3) flavor symmetry is valid
  - Δs should be checked using alternate methods not assuming SU(3)



- Attempts to measure Δs in semi-inclusive DIS scattering of charged-leptons off of protons gave results consistent with zero