Study of Reconstructed ^{39}Ar Beta Decays at the MicroBooNE Detector

Alex Flesher and Michael Mooney
Colorado State University

µBooNE

Introduction

In atmospheric argon, ^{39}Ar beta decays occur at a rate of roughly one Becquerel per kilogram [1]; as a result, large liquid argon time projection chambers (LArTPCs) see plentiful amounts of these decays in each event readout window. The ^{39}Ar beta decays allow for the study of reconstructing point-like ionization charge deposition in the detector [2], which is relevant for the reconstruction of supernova neutrino interactions. The point-like topology and well-known energy spectrum of ^{39}Ar beta decays also provides a unique handle for calibrations.

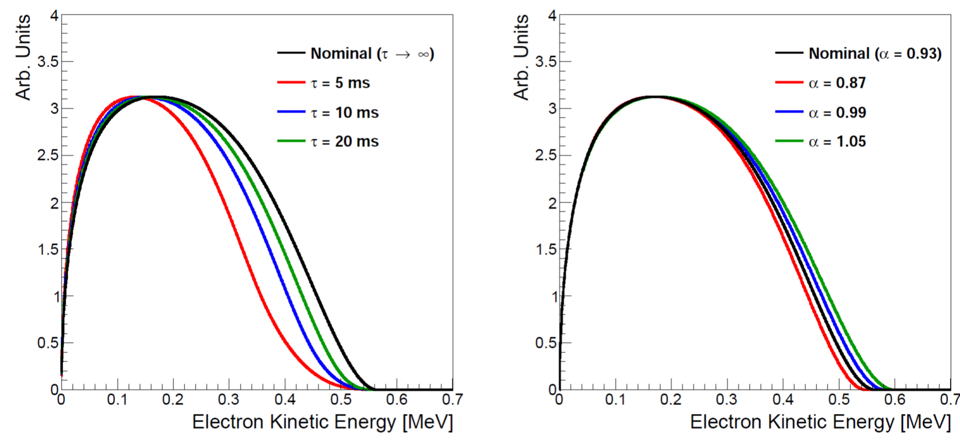

Figure 1: A demonstration of the separate effects of variations in the electron lifetime (left) or recombination factor (right) on the reconstructed ^{39}Ar beta decay energy spectrum at MicroBooNE. The recombination factor is parametrized with the α parameter of the modified Box model [3]. Decays are uniform in the drift direction, allowing calibrations to be performed without knowing the drift time of individual decays.

Beta Decay Candidate Selection and Preliminary Energy Spectrum

- Looking at only the collection plane, beta decay candidates are selected based on charge measured above threshold.
- Raw waveforms (after noise filtering) are used in this measurement.
- A window is drawn around points of charge over threshold; if any other signals or dead channels intersect this exclusion window, the candidate is rejected.
- If it passes, the charge inside the window is integrated.
- An additional algorithm is employed in order to mitigate contributions from cosmogenic sources (see Figure 3).

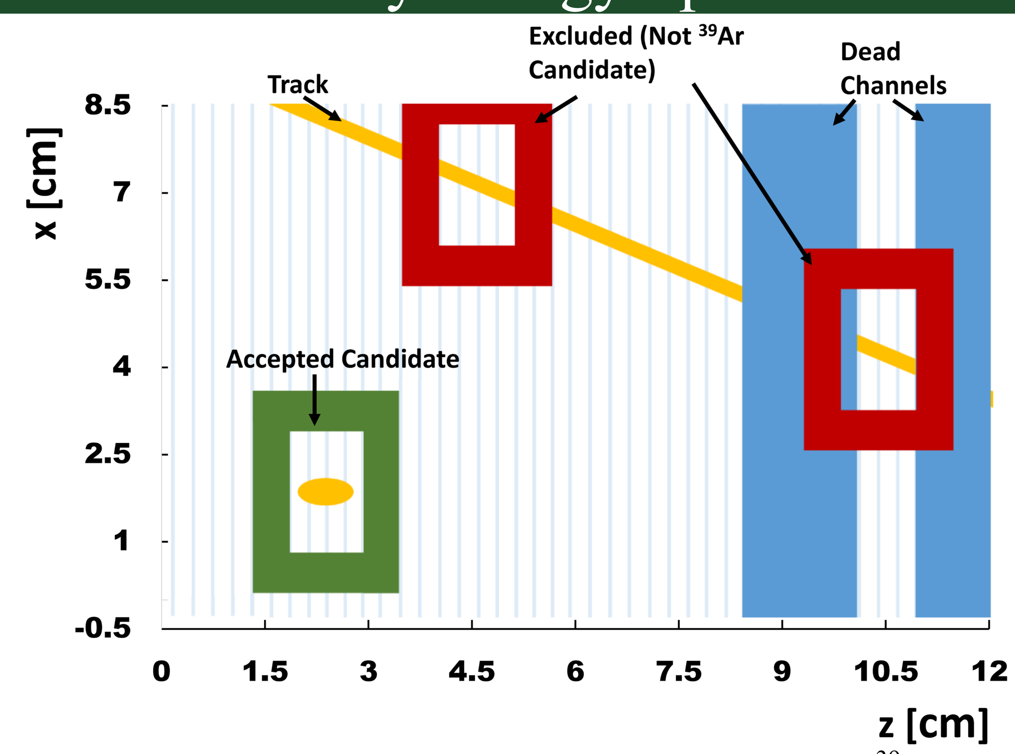

Figure 2: A cartoon illustrating the selection of ^{39}Ar candidates.

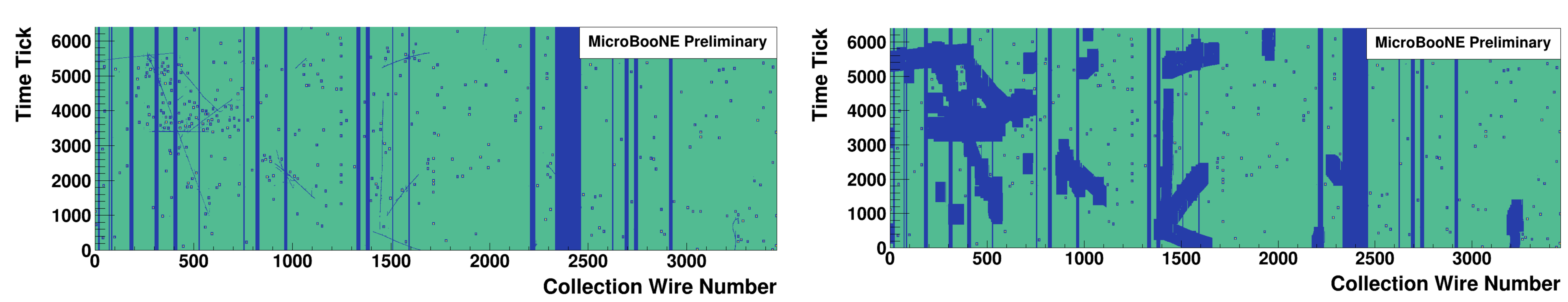

Figure 3: A demonstration of the method used to avoid point-like activity near cosmic muon tracks. The method flags all points within a certain distance from a track. These points are then removed as candidates.

- The measured charge can be reconstructed into energy with the following formula:

$$E = \frac{GI}{\mathcal{R}K} \times Q$$

Q is charge (in ADC · time ticks), E is energy (in keV), G is electronics gain (in electrons/ADC), I is the ionization energy (in keV/electron), R is the average value of the electron-ion recombination factor (unitless), and K is the electronics response area-to-amplitude ratio (in time ticks).

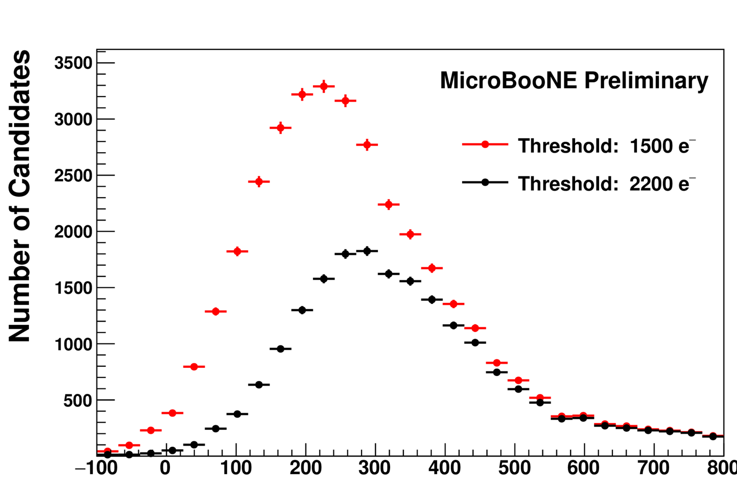

Figure 4: Preliminary ^{39}Ar beta decay energy spectrum using MicroBooNE data for two different choices of threshold.

- Reconstructed ^{39}Ar beta decay energy spectrum is shown in Figure 4; the spectrum end point (close to 565 keV) matches expectations (see Figure 1).
- Spectrum is smeared by noise (see Figure 5).
- Prominent high-energy tail is not caused by ^{39}Ar; likely due to higher-energy radiologicals and/or cosmogenic contributions.
- Understanding background contributions will be important for electron lifetime and recombination measurements using the energy spectrum.

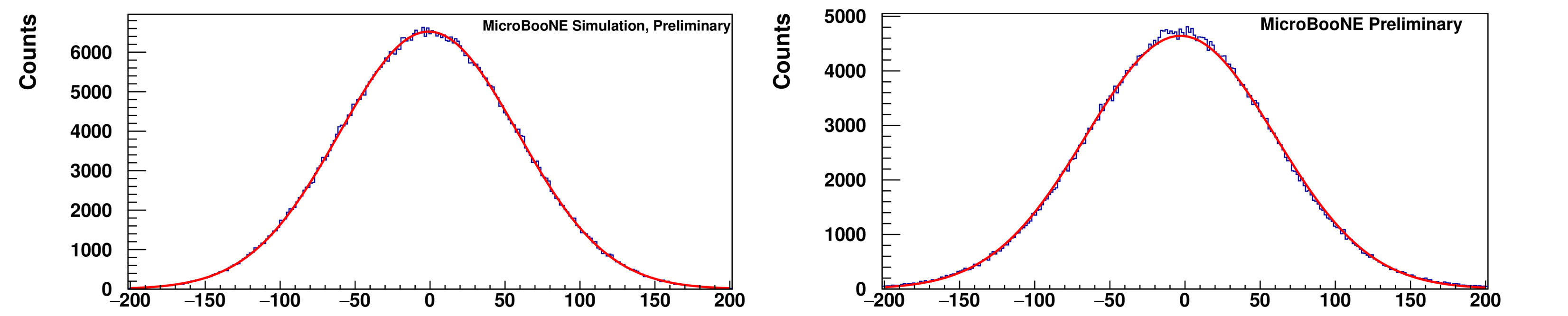

Figure 5: Noise studied in both simulation (left) and data (right) by randomly sampling the collection plane. A Gaussian is fit to both distributions. For simulation, σ = 59.5 keV, and for data, σ = 62.7 keV.

Cosmogenic and Radiological Backgrounds

- Cosmic muons create point-like activity in detector that can "fake" beta decays.
- These can be due to radiative photons near tracks or longer-range neutrons.
- Running the beta decay candidate selection on a simulation (CORSIKA [4]) of cosmic rays produces the spectrum shown in Figure 6.
- This spectrum can be modeled well with the Crystal Ball function.
- Another contribution to the high-energy tail in Figure 4 could come from radiological contaminants inside the detector.
- Use dedicated simulation to study energies of radiological contaminants (see Figure 7).
- Certain radiological contaminants have a similar energy spectrum to the cosmogenic distribution, which may introduce difficulties when separating out the two components in data.

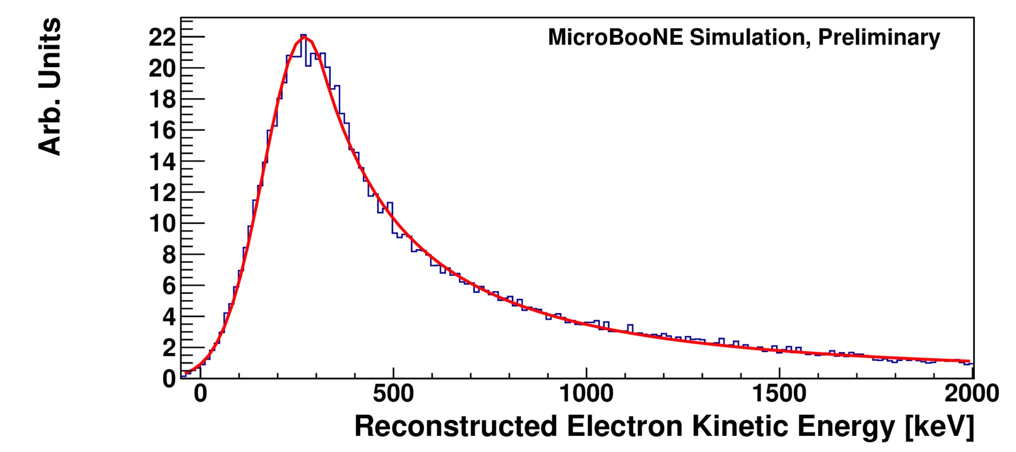

Figure 6: Reconstructed energy for the point-like "fake" beta decay candidates around tracks in a simulation of cosmics. The spectrum fits well to a Crystal Ball function (also shown).

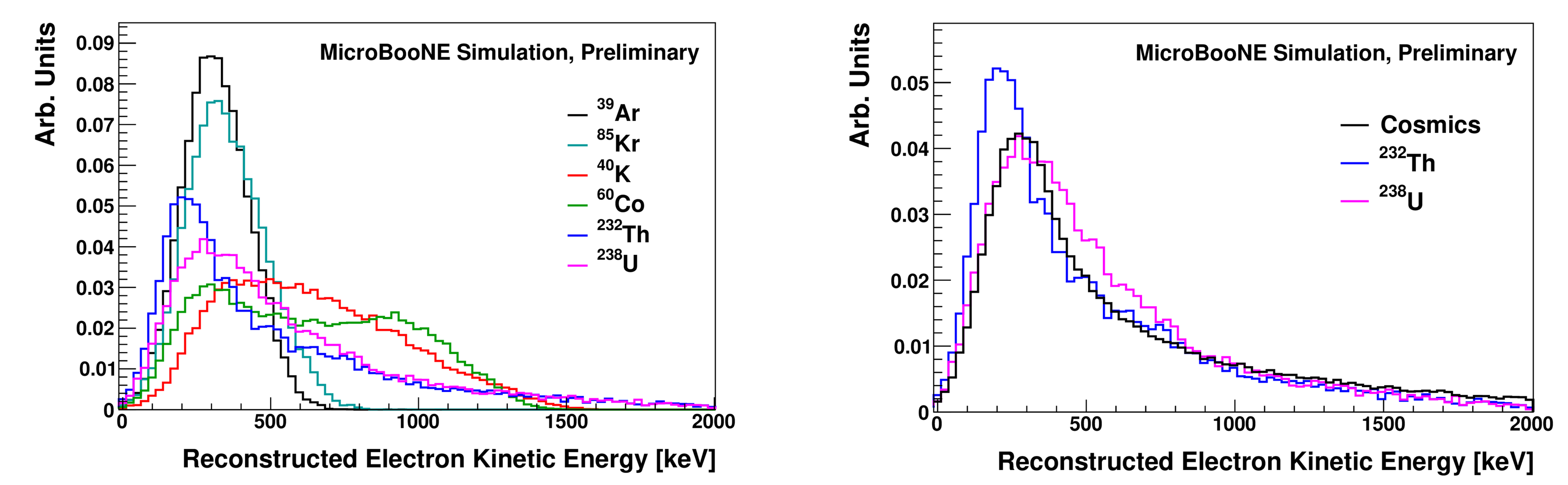

Figure 7: Various radiological sources that may be present in the MicroBooNE detector (left), and a plot demonstrating the similarities between the reconstructed energy spectra for ^{232}Th and ^{238}U and the reconstructed energy spectrum associated with cosmogenic activity (right).

Signal Shape Study

- The signals are lined up in time and wire using the point of highest charge associated with each individual ^{39}Ar beta decay candidate.
- Average signal shape (obtained from the sum of the lined-up signals) shows that even on the collection wire plane, induced charge effects are relevant: the side wires are shifted back by 1-2 time ticks (see Figure 8).
- The side wire distributions in Figure 8 can be reproduced in simulation [5] by including the effect of both charge collection and induced charge in the wire field response (see Figure 9).
- In addition to measuring the wire field response, the signal shapes of these point-like sources could have applications for longitudinal and transverse diffusion measurements.

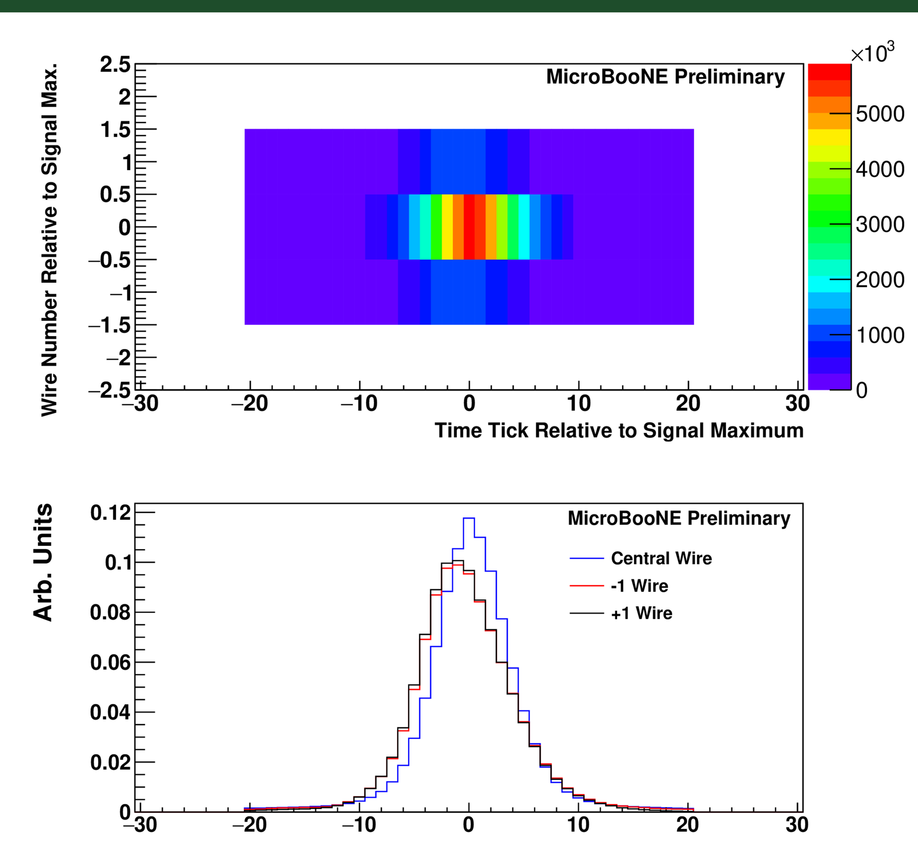

Figure 8: Two-dimensional display of the average ^{39}Ar candidate signal shape (top). One-dimensional view of the average signal shape for central wire and both side wires, normalized (bottom).

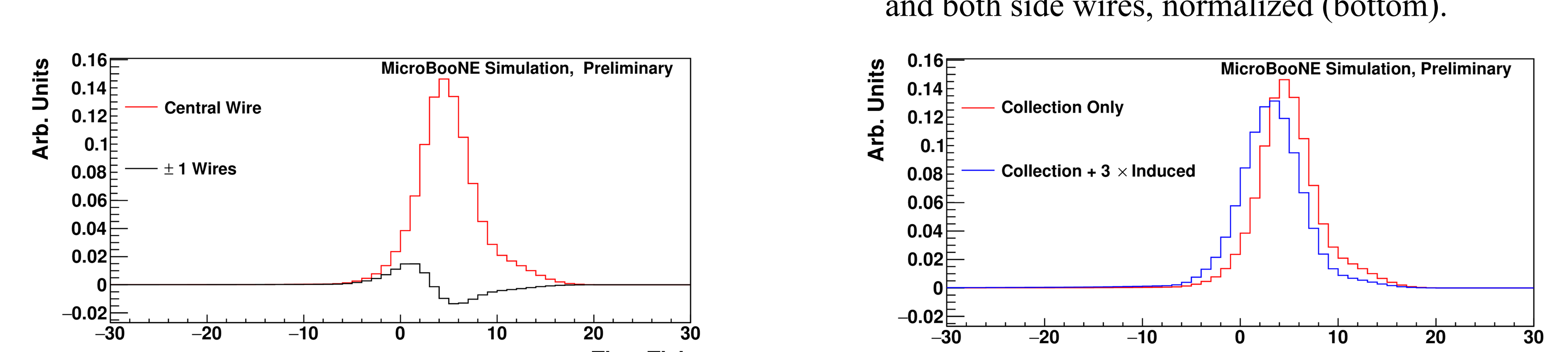

Figure 9: A demonstration of a pure collection signal and associated induced signal (left), and a demonstration of how a combination of induced signal and collection signal can produce the effect observed in data (right).

References

[1] P. Benetti, "Measurement of the specific activity of Ar-39 in natural argon," Nucl. Instr. And Meth.A 574, (2007) 83.
[2] C. Adams et al., "Study of Reconstructed ^{39}Ar Beta Decays at the MicroBooNE Detector," MicroBooNE Public Note, http://microboone.fnal.gov/public-notes/ (see MICROBOONE-NOTE-1050-PUB).
[3] ArgoNeuT collaboration, R. Acciarri et al., "A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC," JINST 8 (2013) P08005, [arXiv:1306.1712].
[4] D. Heck, G. Schatz, T. Thouw, J. Knapp and J. N. Capdevielle, "CORSIKA: A Monte Carlo code to simulate extensive air showers," FZKA-6019, 1998, https://www.ikp.kit.edu/corsika/70.php.
[5] C. Adams et al., "Ionization Electron Signal Processing in Single Phase LArTPCs II. Data/Simulation Comparison and Performance in MicroBooNE," Submitted to JINST, arXiv:1804.02583 [physics.ins-det] (2018).

Fermilab · U.S. Department of Energy Office of Science · NSF · FNSNF Swiss National Science Foundation · Science & Technology Facilities Council · The Royal Society