Reconstruction of ^{39}Ar Beta Decays at ProtoDUNE-SP

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ProtoDUNE Sim/Reco Meeting

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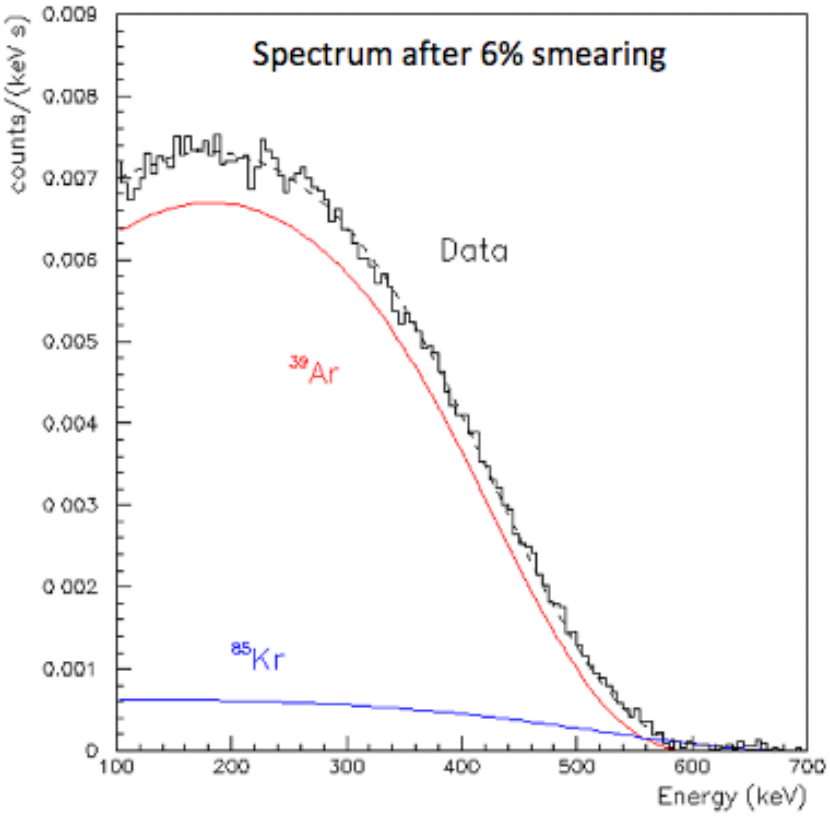
Motivation

- Many calibrations done at MicroBooNE utilize cosmic rays (e.g. electron lifetime)
  - MicroBooNE on surface → **4000 cosmics/second**
- Not a reliable option at DUNE FD due to being almost a mile underground
  - DUNE FD: **4000 cosmics/day** (and **20 Michels/day**)
  - … and this is for an entire 10 kt module!
  - Corresponds to 5 cosmics/day/m^3
- Cosmics can still help, but need alternative charge sources for calibrations
- Plenty of ^{39}**Ar beta decays** at DUNE FD (O(50000) per readout) – good option that should be explored for DUNE, studied first at MicroBooNE/ProtoDUNE

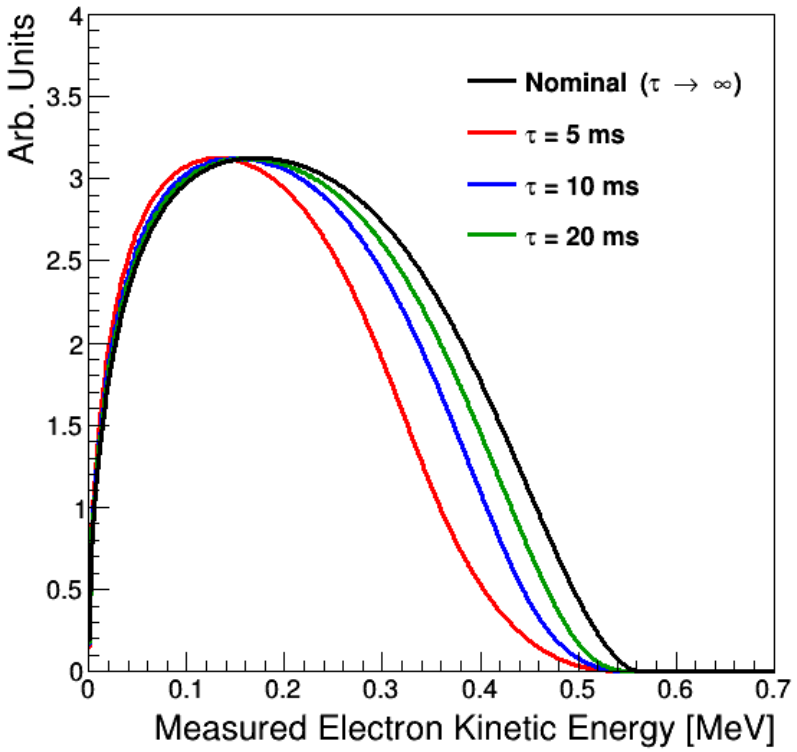
^{39}Ar Beta Decays



Benetti et al., "Measurement of the specific activity of Ar-39 in natural argon" (2006).

- ^{39}Ar beta decay cut-off energy is 565 keV
  - Roughly **half** of the energy deposited on a single wire by a MIP at DUNE
- Several things smear observed **charge spectrum**, e.g.:
  - Electronics noise
  - Recombination fluctuations
  - Unknown location of ^{39}Ar decay in drift direction
- For last point: we know decays are **uniform in x**

^{39}Ar Beta Decays



Example Use Case:
Fine-Grained Electron Lifetime Measurement

- ^{39}Ar beta decay cut-off energy is 565 keV
  - Roughly **half** of the energy deposited on a single wire by a MIP at DUNE
- Several things smear observed **charge spectrum**, e.g.:
  - Electronics noise
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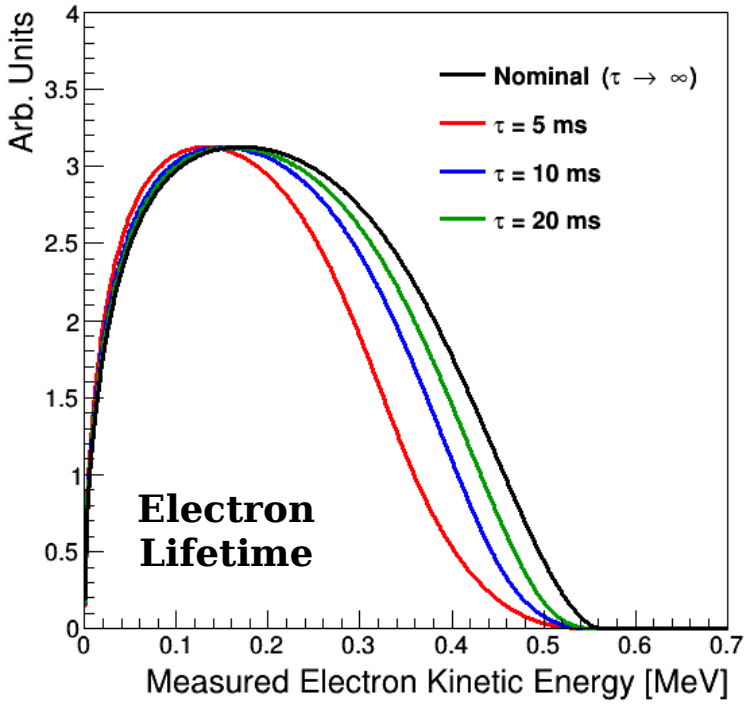
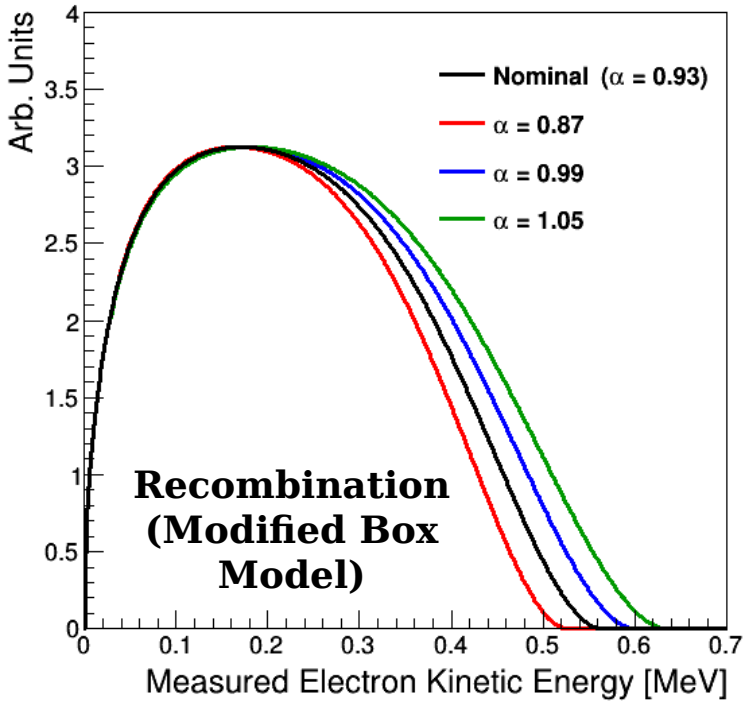
  - Unknown location of ^{39}Ar decay in drift direction
- For last point: we know decays are **uniform in x**

e^- Lifetime vs. Recomb.





- Electron lifetime and recombination both impact spectrum, but in different ways → largely separable
- Noise also leads to smearing, but this can be measured very precisely with noise data

Studies at MicroBooNE

MicroBooNE Public Note

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

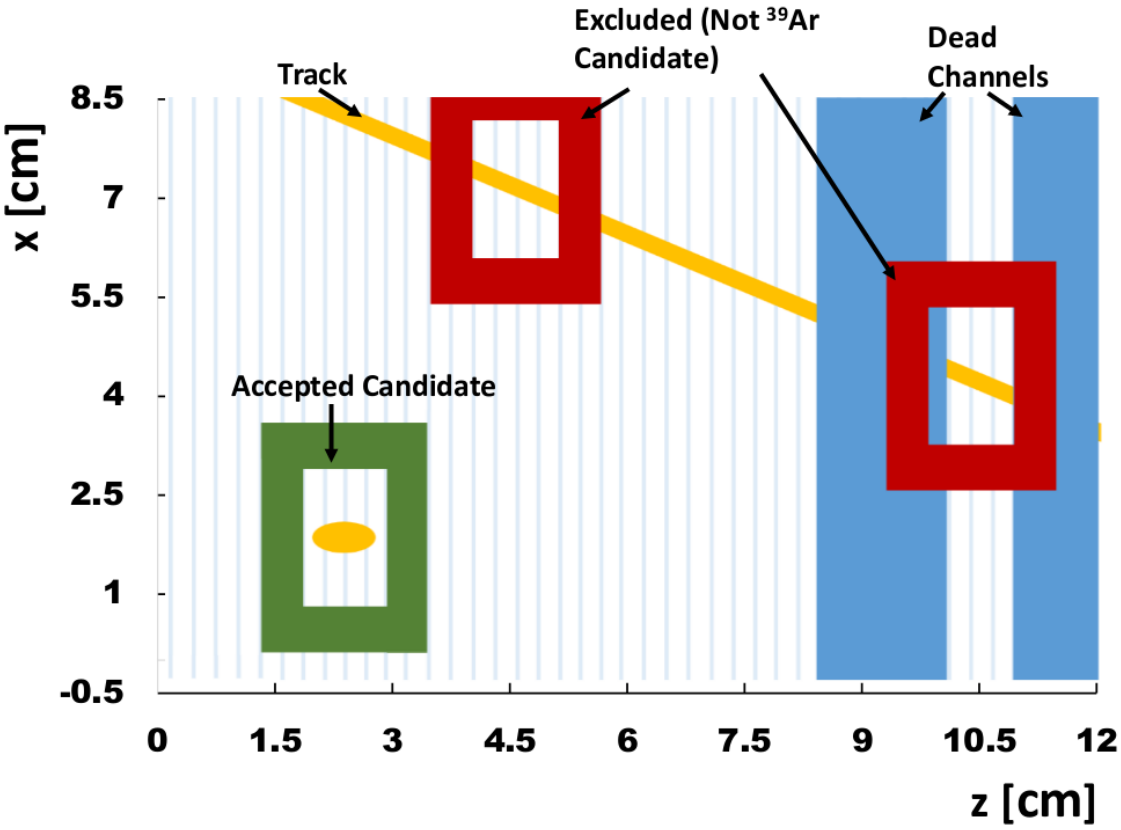
The MicroBooNE Collaboration*

June 28, 2018

In atmospheric argon, ^{39}Ar beta decays occur at a rate of roughly one Becquerel per kilogram; as a result, large liquid argon time projection chambers (LArTPCs) see plentiful amounts of these decays in each event readout window. These ^{39}Ar beta decays can provide a variety of different uses in LArTPC experiments. They allow for the study of reconstructing point-like ionization charge deposition in the detector, 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. Presented here is the first study of reconstructing ^{39}Ar beta decays in the MicroBooNE LArTPC. The spectrum of reconstructed electron energies from ^{39}Ar beta decays, measured using raw TPC waveforms, is found to have a similar end point as the predicted distribution. Additionally, the signal shapes of reconstructed ^{39}Ar beta decay candidates are used to validate the collection plane wire field response.

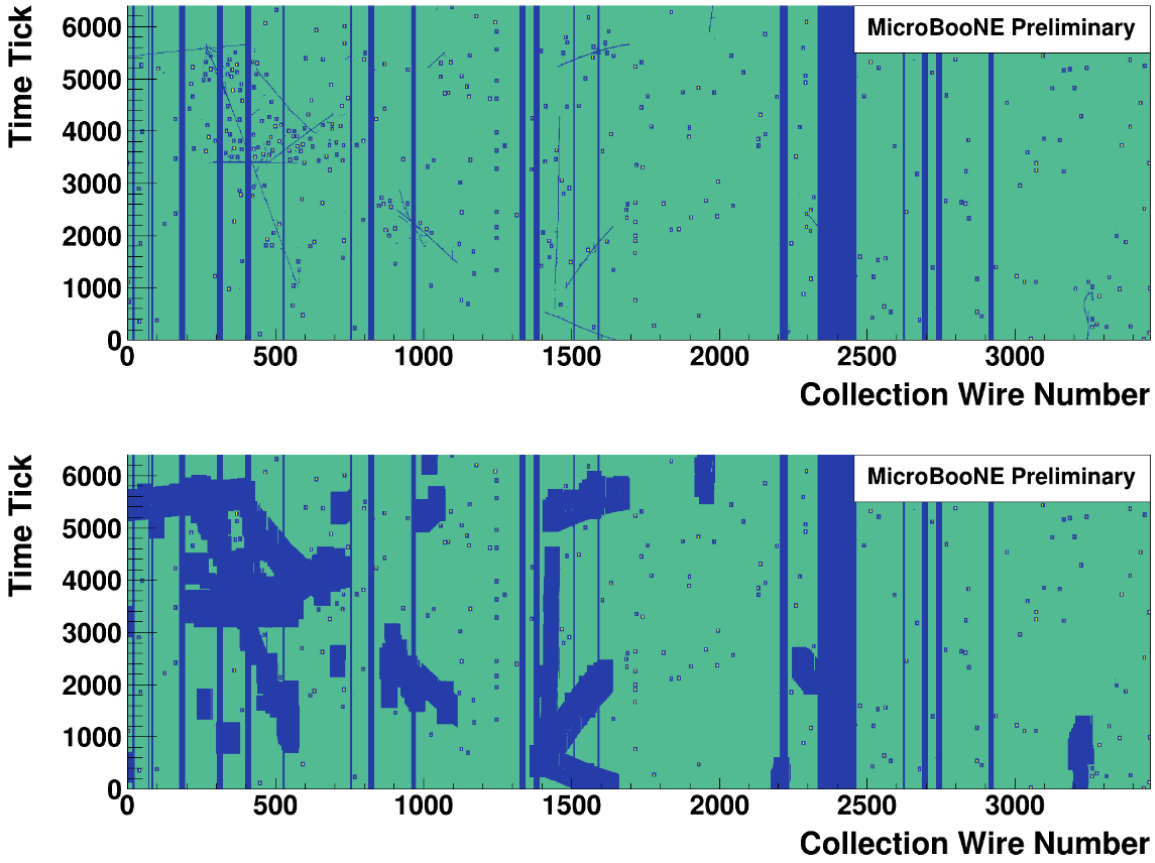
- See MicroBooNE **public note** on ^{39}Ar beta decays
- Will summarize main results in following slides

Candidate Selection



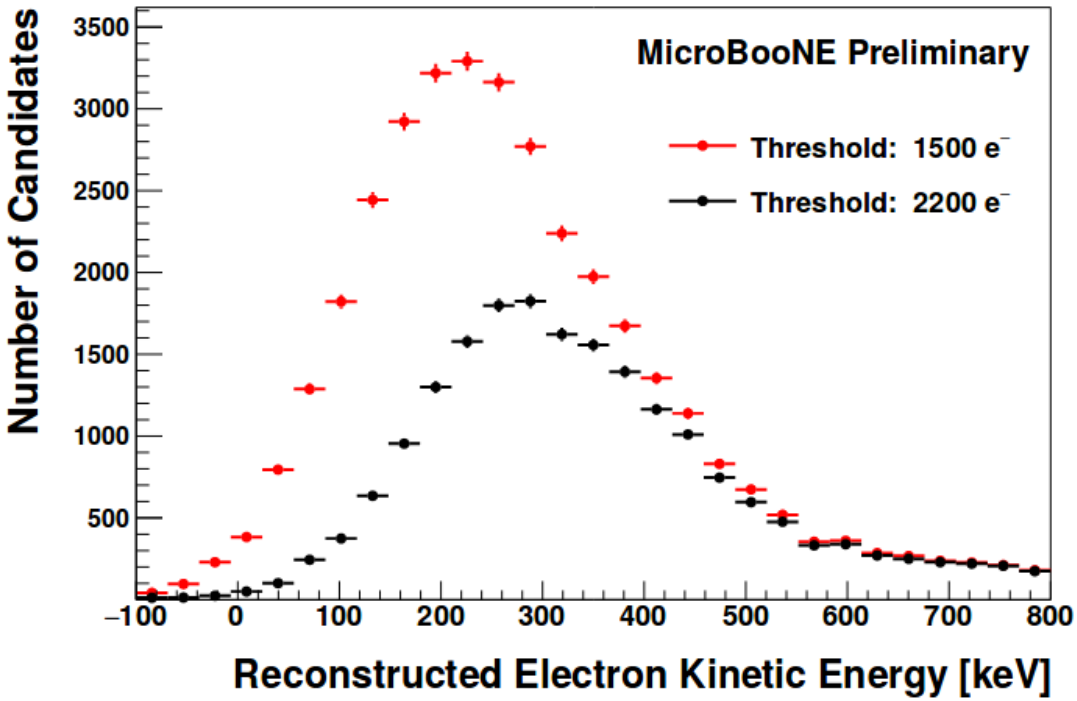
- Select point-like topology; reject track-like topology
- Account for dead channels in selection
- Only looking at collection plane (for now)

Track Proximity Veto



- Ignore point-like activity near tracks that is more likely to be cosmogenic in nature (within ~30 cm)

Energy Spectrum

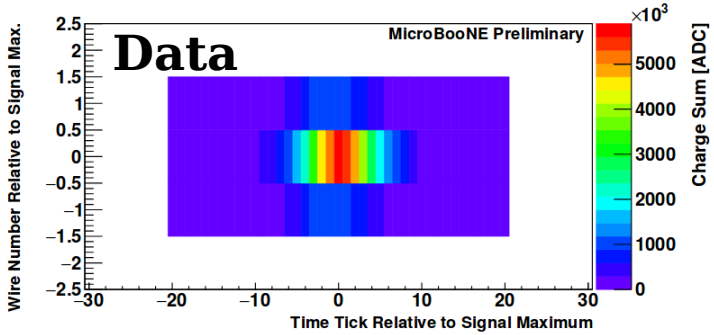


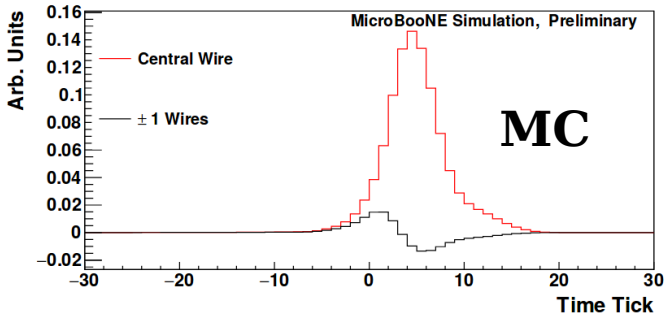
$$E = \frac{GI}{\mathcal{R}K} \times Q$$

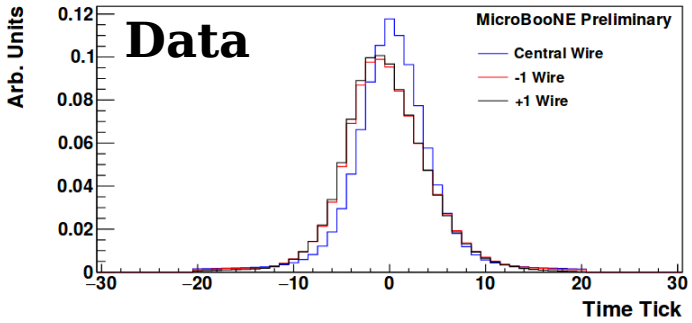
G = Gain [e^-/ADC]
I = 0.0236 keV/e^-
R = Recombination Factor
K = Elec. Response Area-to-Amp. Ratio

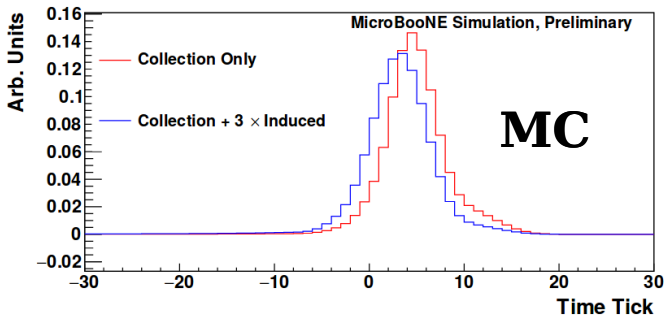
- Reconstruct energy spectrum in 3 wire by 40 time tick window around candidate peak
- Reconstructed end point in correct place (~565 keV)
- High-energy tail: cosmogenic background

Signal Shape





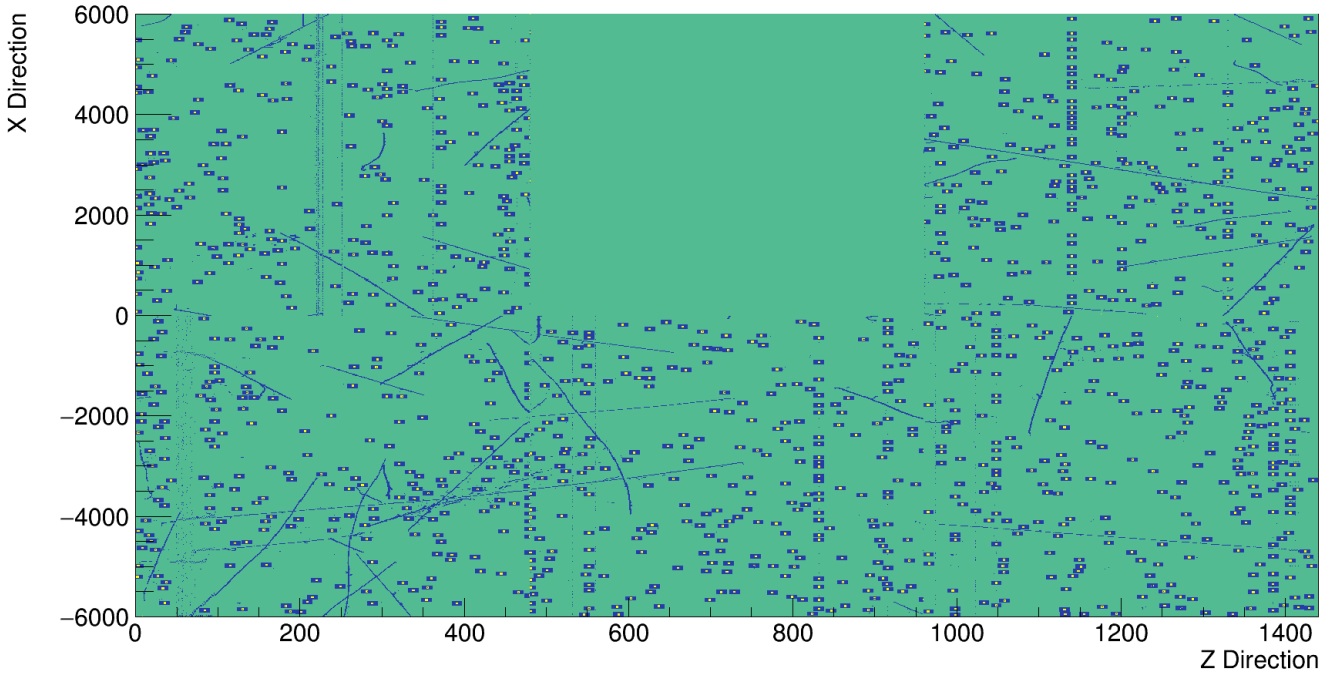




- Average signal shape reconstructed by lining up signals in time; include central **and** side wires
- Signs of induced charge effects on collection plane
- Use to study diffusion, wire field response variations

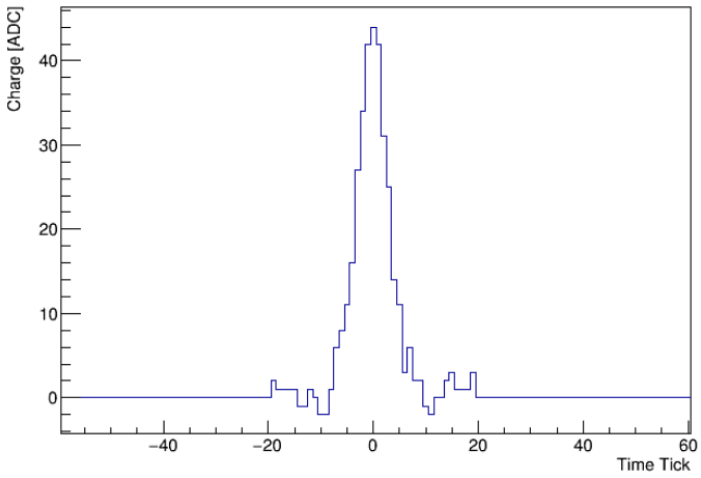
Studies at ProtoDUNE-SP

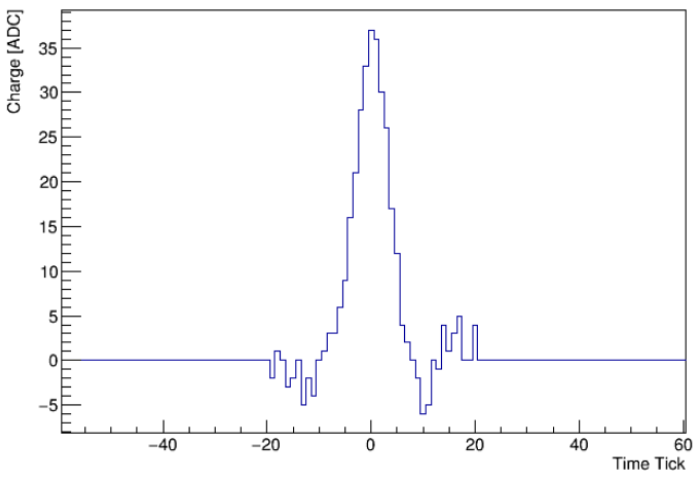
Preliminary Selection

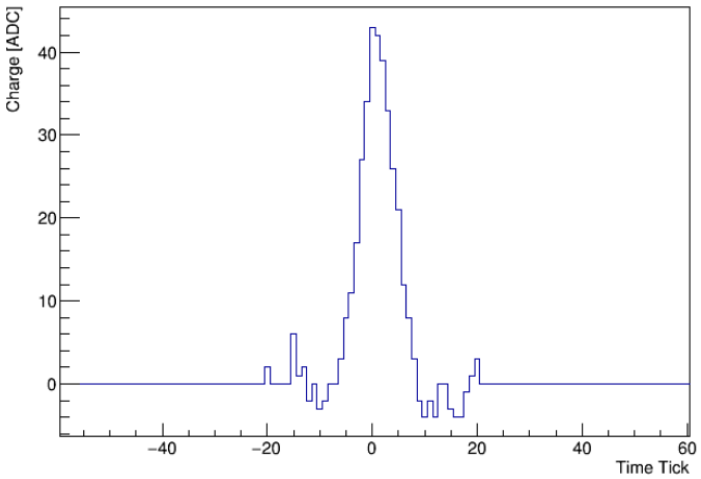


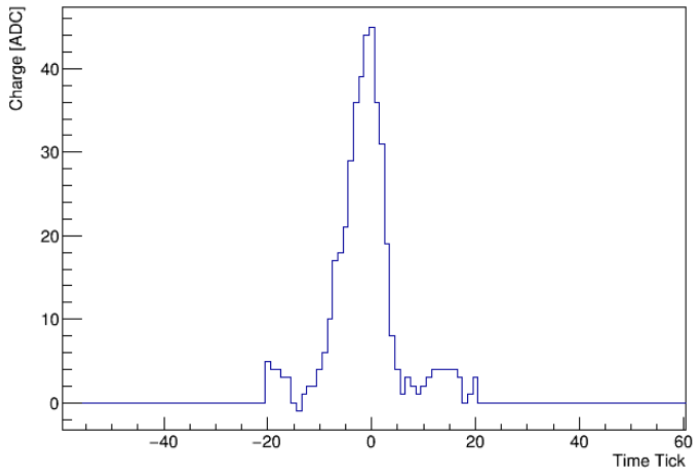
- Largely use same methodology as at MicroBooNE
- For now, not vetoing regions near tracks (next step)
- Run 5451 (missing one APA); study 150 events
- Signs of noisy wires contributing fakes (minor)

Example Candidates



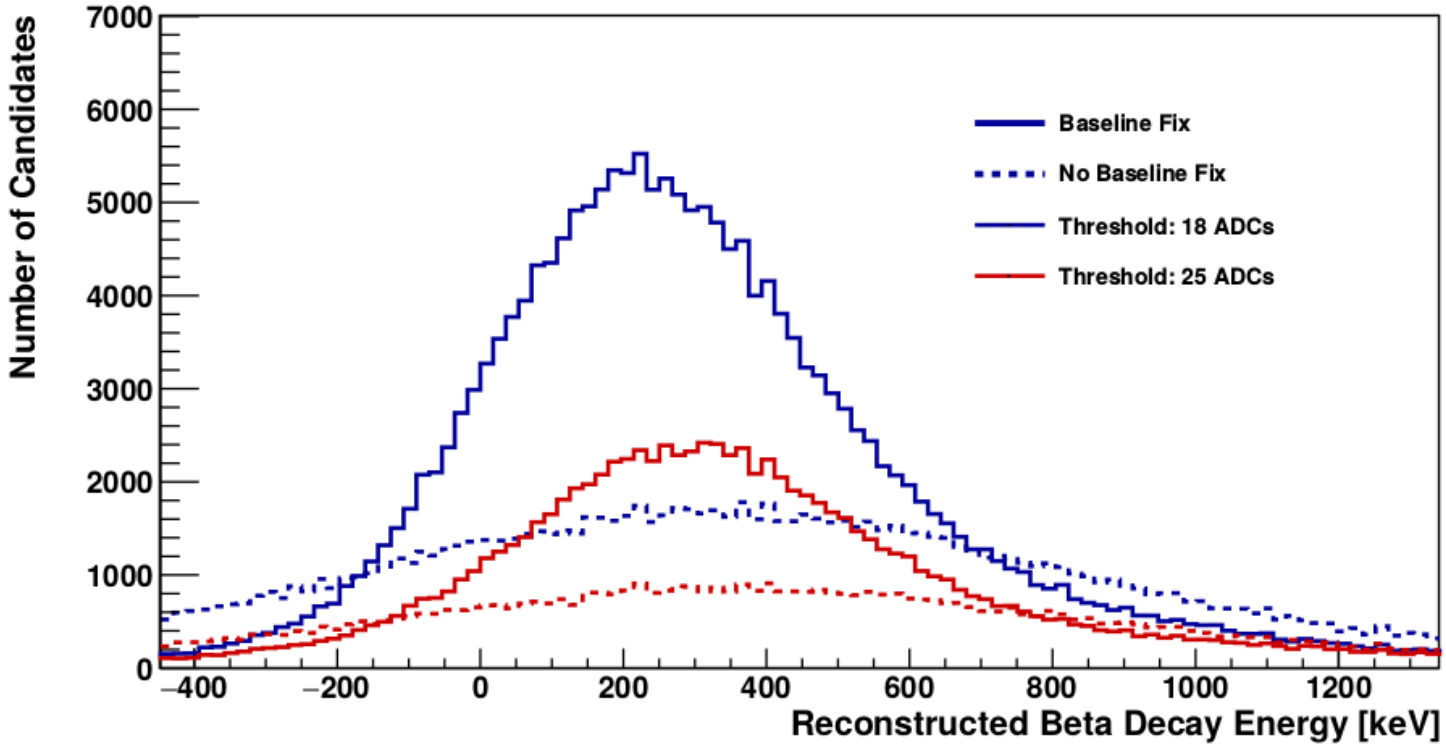






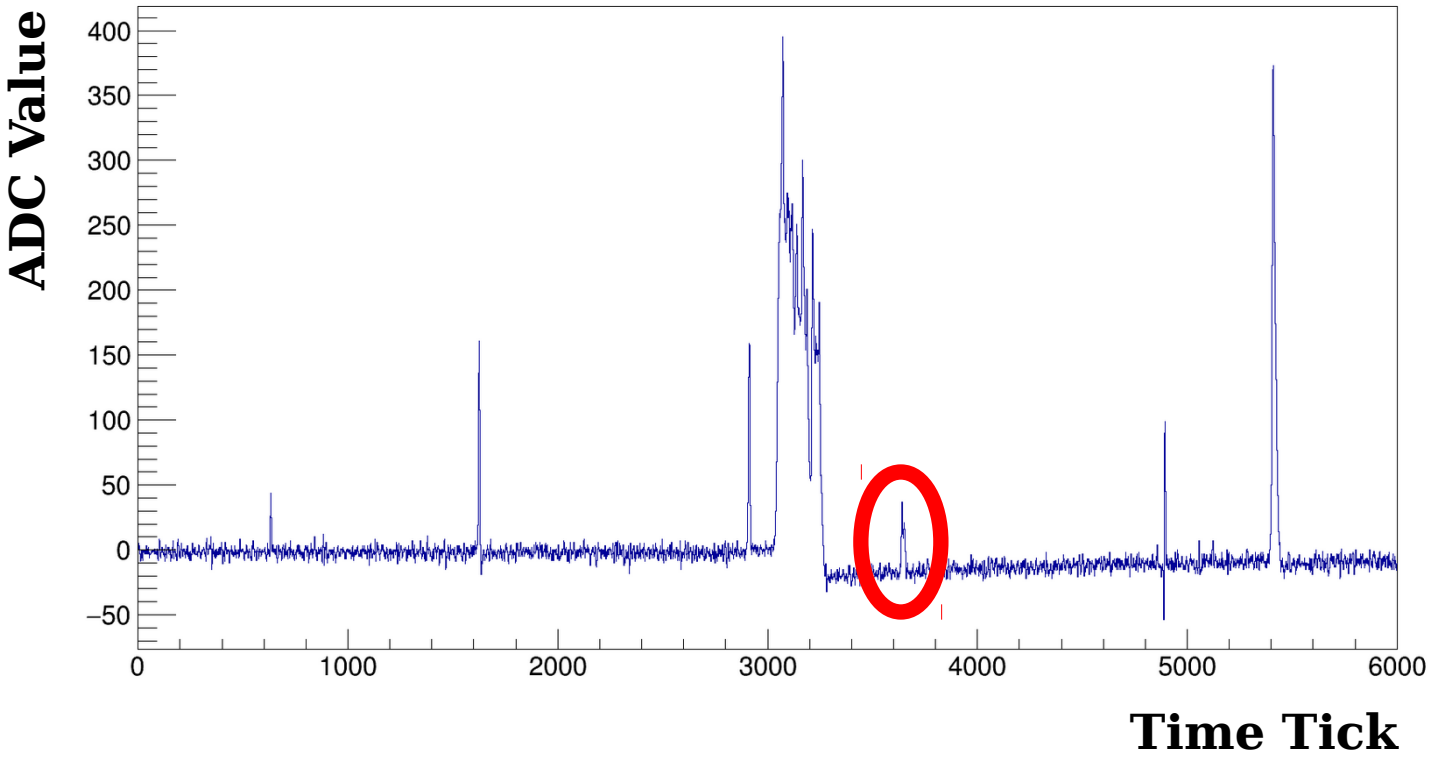
- Example ^{39}Ar beta decay candidates (300-600 keV)

First Spectrum



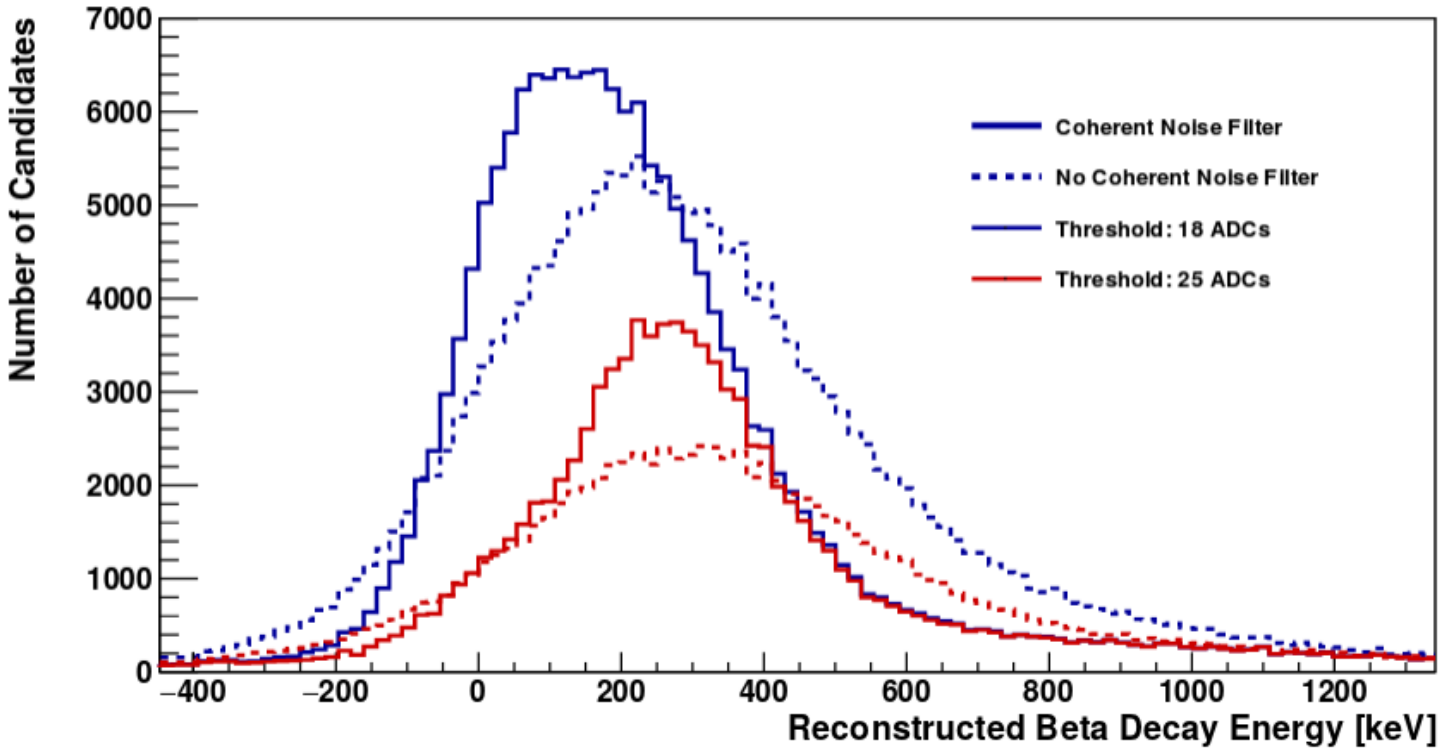
- First spectrum **looked really bad**
- Ended up being due to sagging waveforms after larger ionization signals (AC-coupled electronics)
- Moved to local baseline estimate w/ sidebands

Baseline Deviations



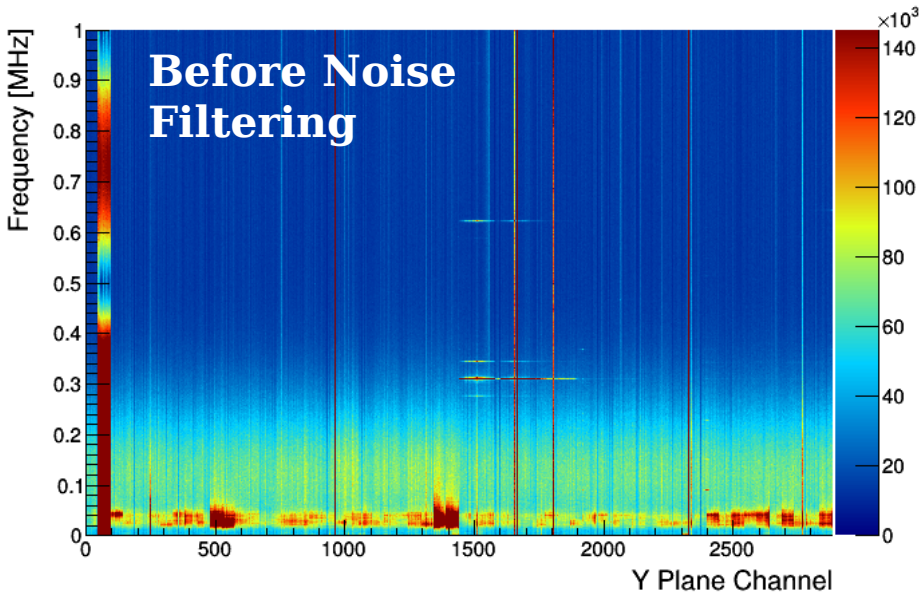
- Some ^{39}Ar beta decay candidates hidden in sag of waveform – local baseline correction (sidebands of integration window) fixes energy estimate
- Really should correct **before** selecting candidates

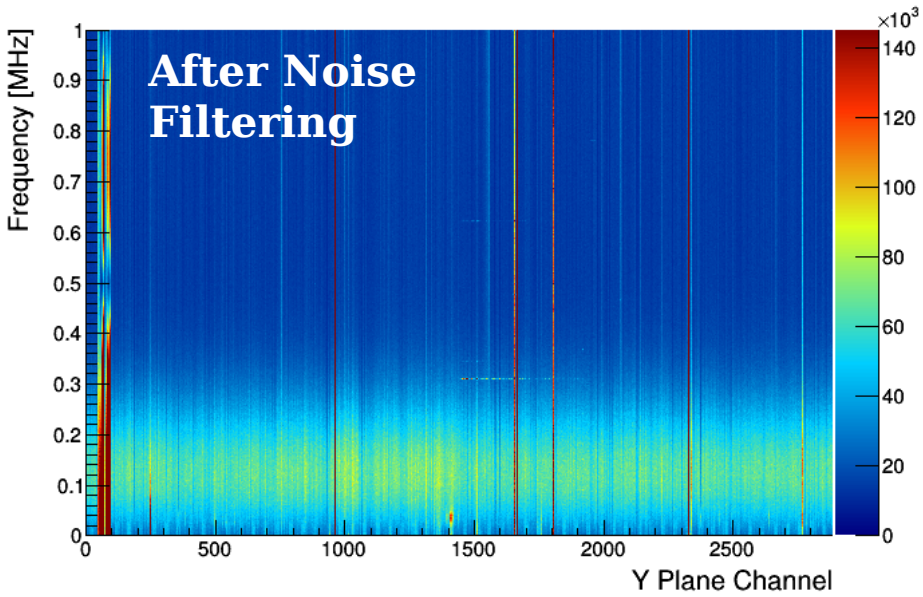
Better Spectrum

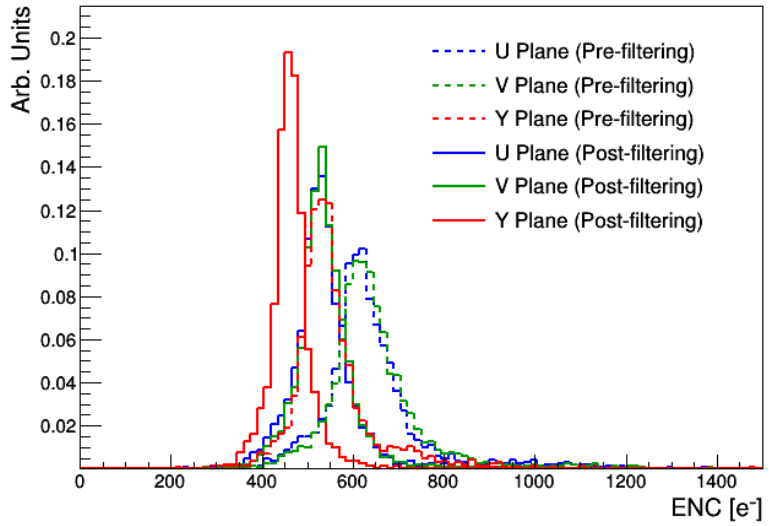


- Spectrum more narrow, but still much more broad than seen in MicroBooNE
- Can be improved further with coherent noise removal – see next slide

Noise Filtering

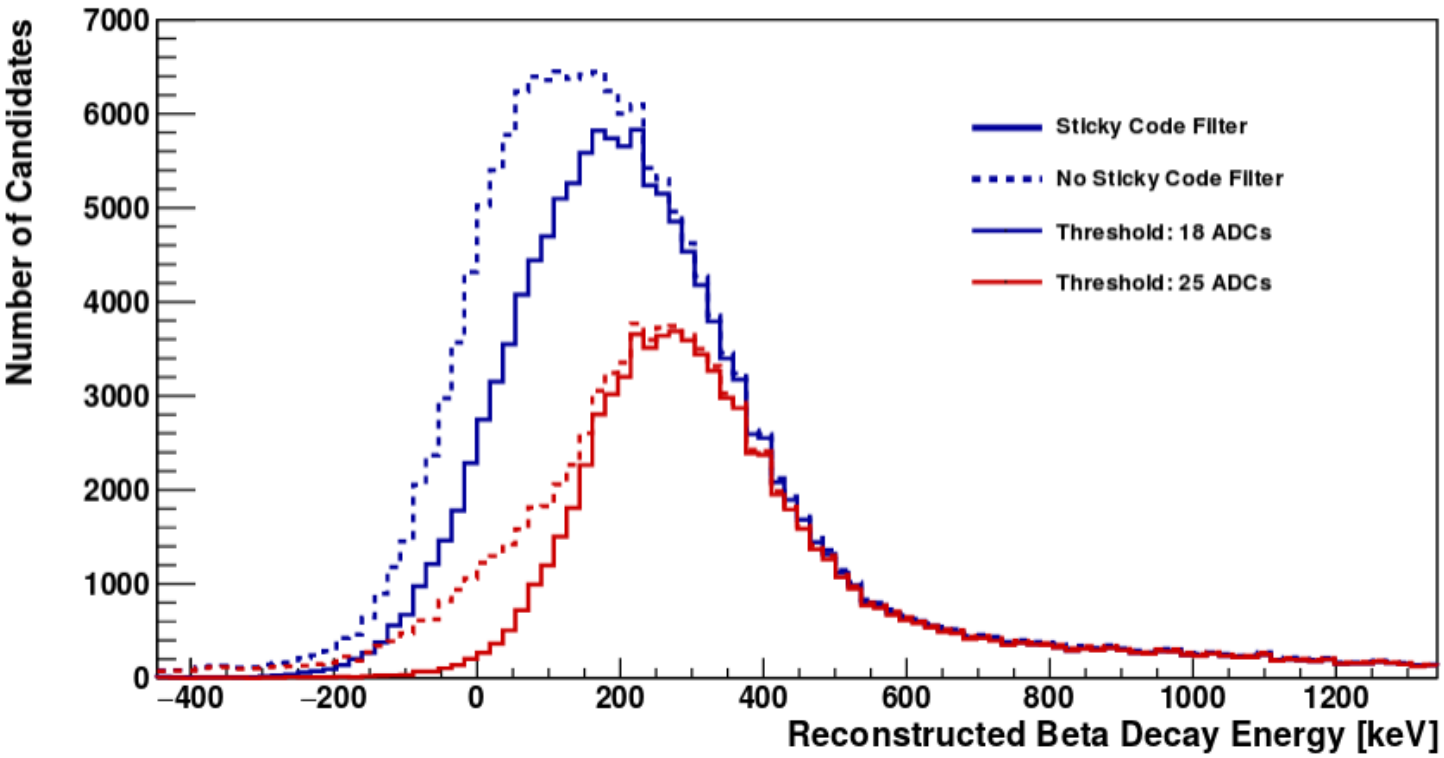






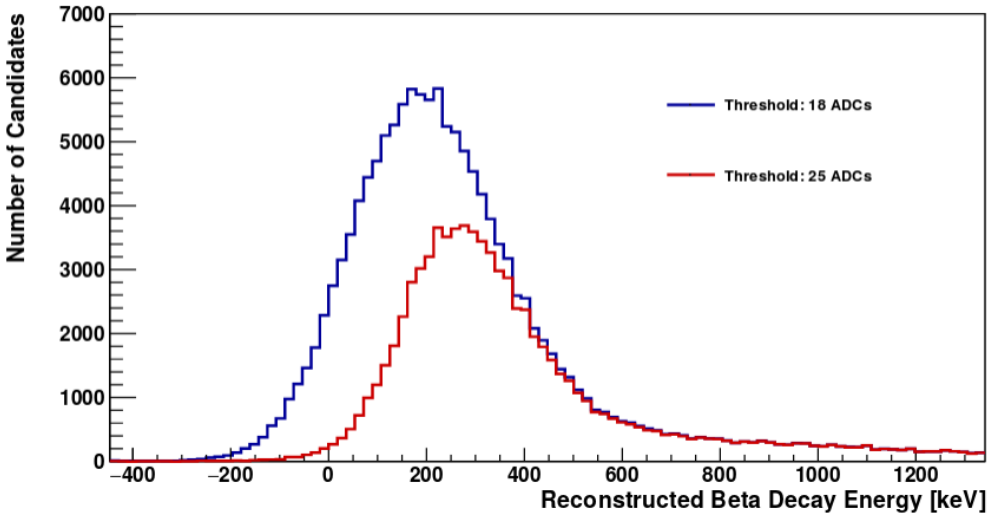
- Coherent noise @ 10-40 kHz
- Remove by subtracting median ADC value across every 16 channels, independently for each tick
- ENC: ~100 e^- effect

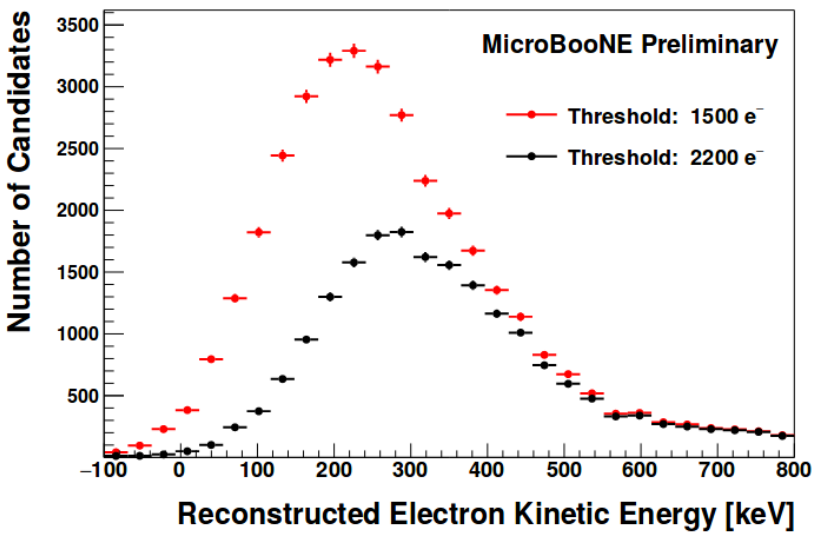
Even Better Spectrum



- Much better, but strange low-energy features
- Largely a result of **sticky codes** (ADC issues); can filter out with pulse shape discrimination
  - Reject candidates with abrupt jump in ADC across time

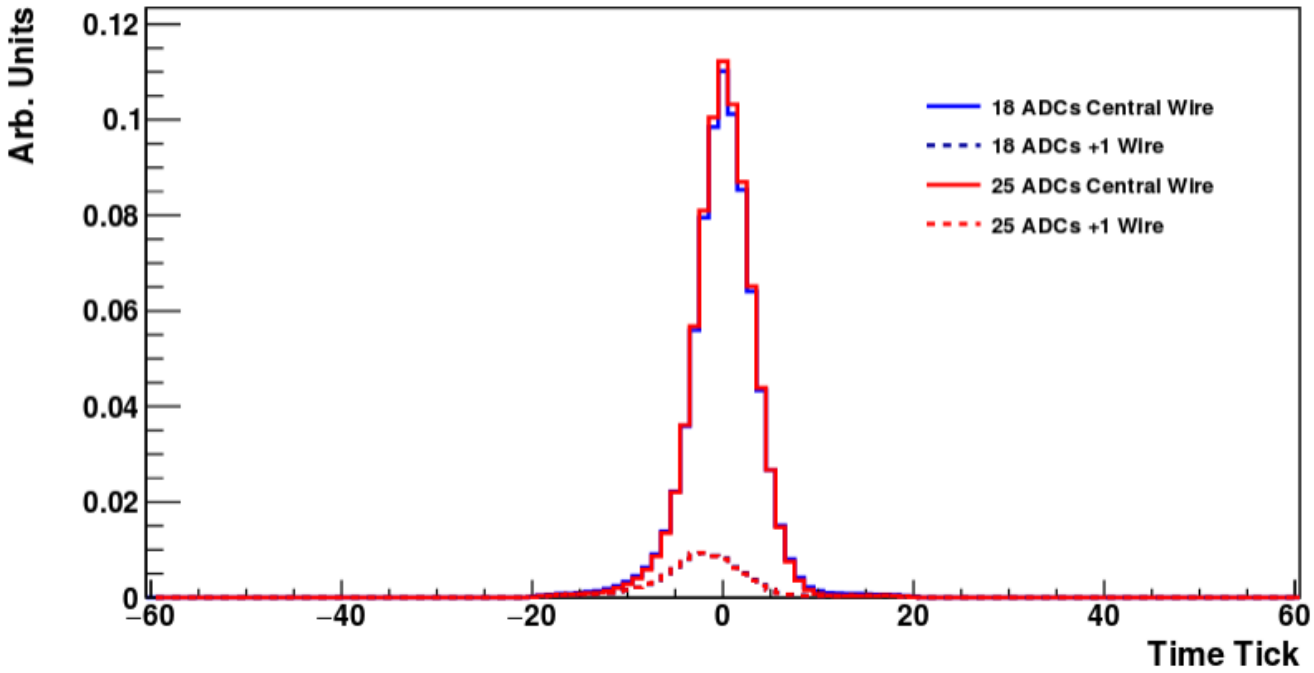
Final Spectrum





- After the three fixes, spectrum looking much closer to that observed at MicroBooNE
  - Still broader due to longer wires, thus higher noise
  - Lower energy reach due to less recombination at 500 V/cm (MicroBooNE runs at 273 V/cm)
- Next: fit to MC templates and extract **rate**

Signal Shape



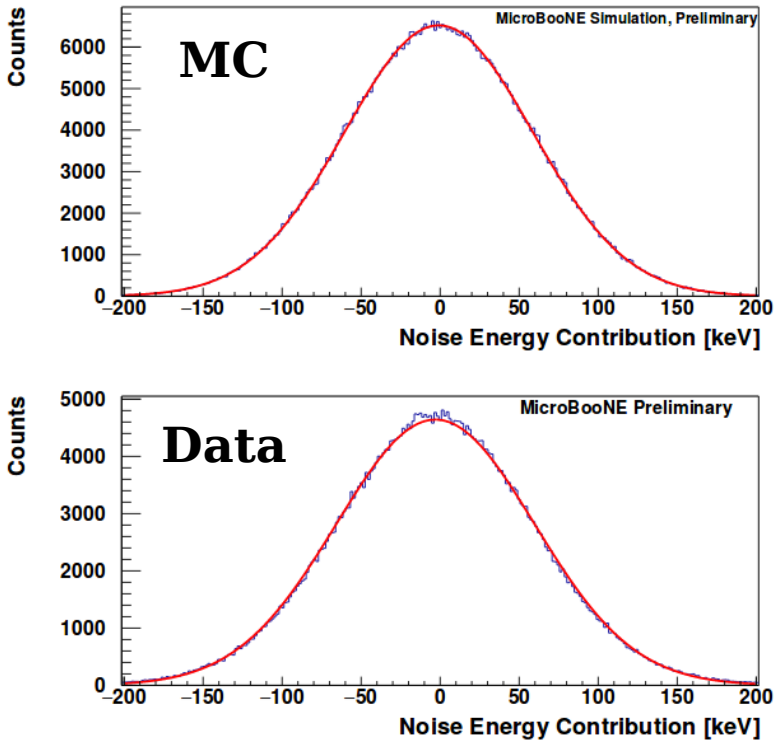
- Also looked at average signal shape
- Side wires see very little relative signal – diffusion is not too significant of an effect, on average
  - Helps that wire spacing is 5 mm (3 mm at MicroBooNE)
- Can see hints of induced charge here as well

Summary/Discussion

- ^{39}Ar beta decay could be very useful for calibrations at DUNE FD (in lieu of cosmics)
- First studied at MicroBooNE; now at ProtoDUNE-SP
  - Reconstructed energy spectrum looks reasonable
  - Signal shape consistent with point-like ionization
- Need to compare to MC as next step
  - Use MC templates to fit to data, extract rate (~1 kg/Bq)
- DAQ will be a challenge with nominal approach to forming trigger primitives – rate very high!
  - Instead: consider doing prompt analysis on FPGA, and read out only shape/energy “histogram” (one per wire)
  - Use round-robin approach to decrease bandwidth

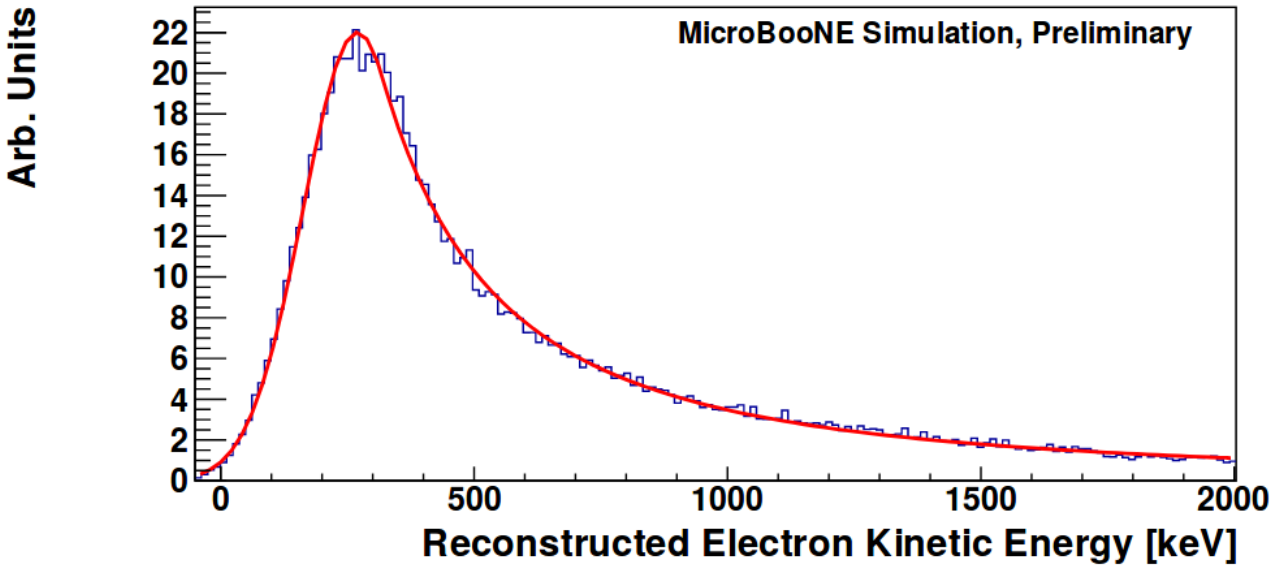
Backup

Noise Comparison



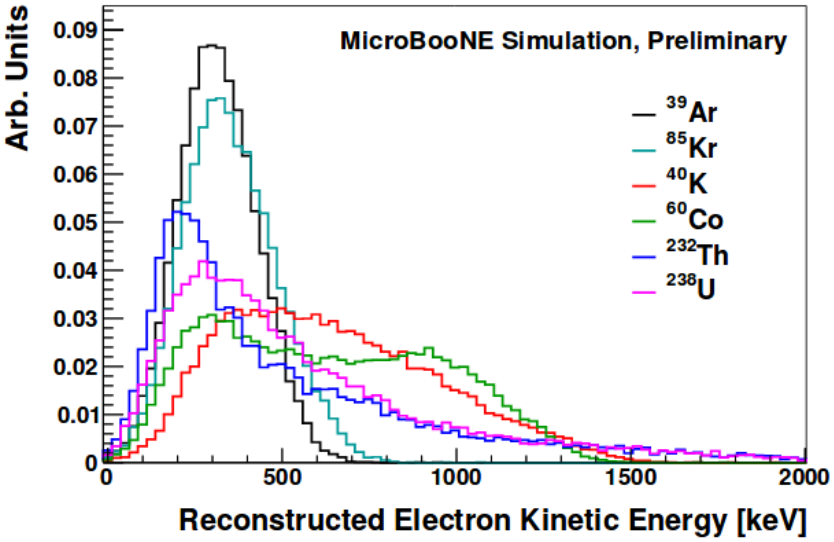
- From MicroBooNE public note
- Compare spectrum in data and MC, selecting windows randomly across readout window
  - Data and MC very similar (~60 keV RMS)

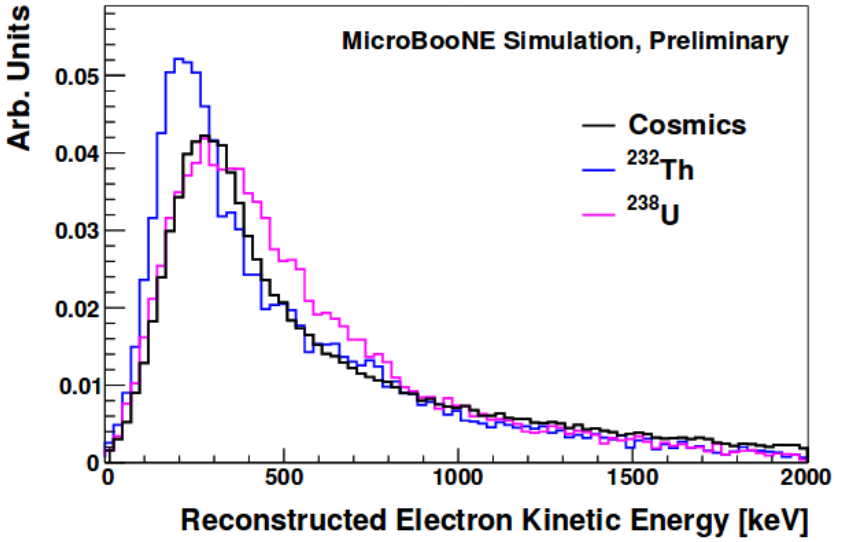
Cosmic Background (MC)



- From MicroBooNE public note
- Spectrum fits well to Crystal Ball function

Radiologicals (MC)





- From MicroBooNE public note
- Similar shapes from cosmic background, ^{232}Th, and ^{238}U → simpler to separate underground