

Reconstructing ^{39}Ar Beta Decays at the MicroBooNE Detector

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Michael Mooney

DUNE Calibration Task Force Meeting

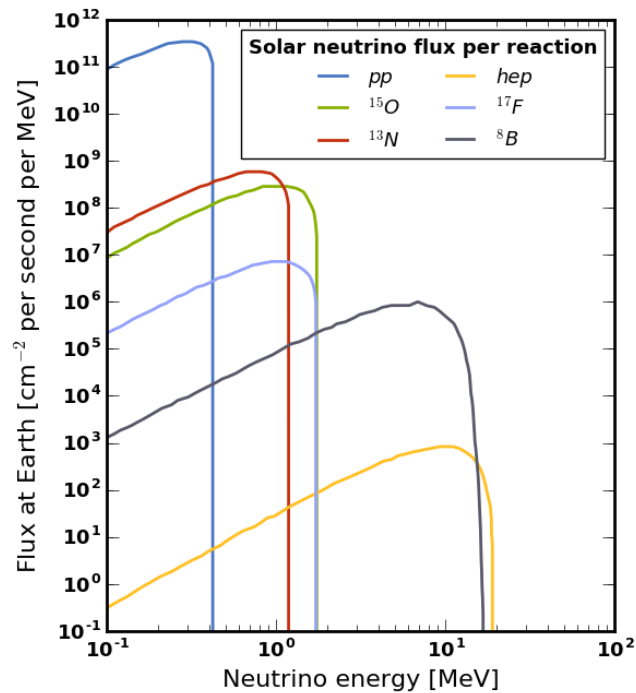
July 10, 2018

Outline:

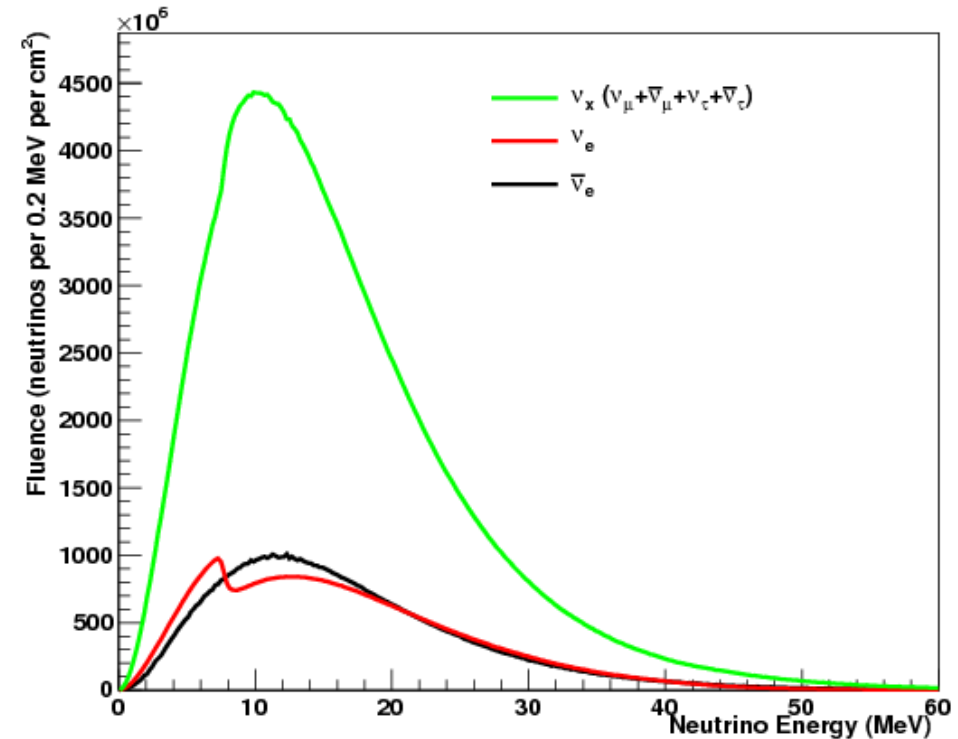
- **Motivation**
- ^{39}Ar Candidate Selection
- Preliminary Results
- Cosmogenic Backgrounds
- Radiological Backgrounds
- Point-like Signal Shape

Motivation for Studying ^{39}Ar beta-decays:

- ^{39}Ar beta-decays lie on an energy spectrum between 0 and 565keV
- This energy scale is very relevant to the study of solar and supernova neutrinos



Credit: Wikipedia, "Solar neutrino".

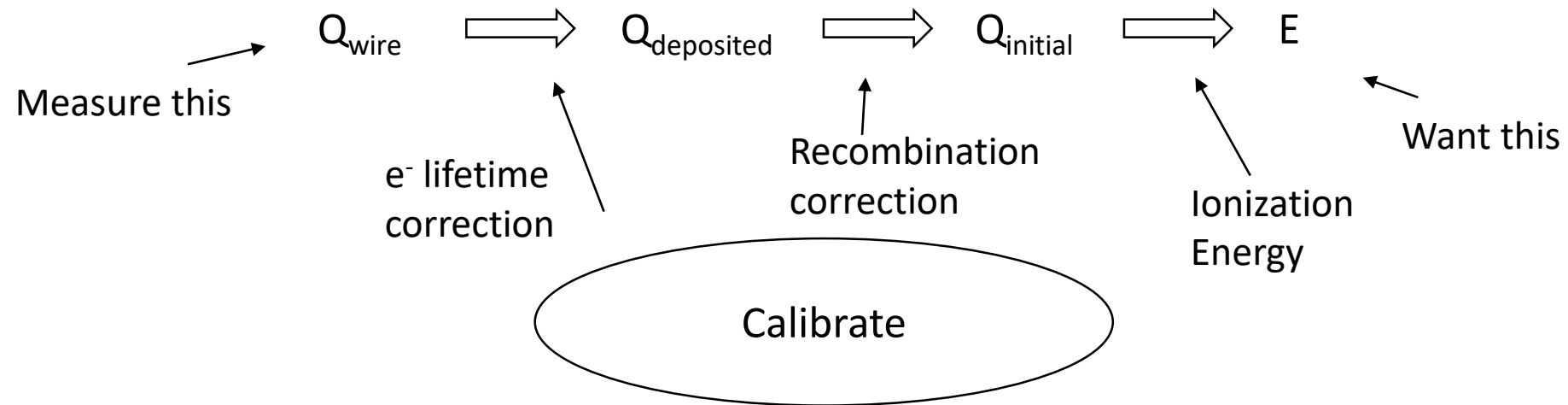


Credit: Kate Scholberg, "Supernova Neutrino Detection". (2012)

Motivation for e^- Lifetime Measurement:

- ^{39}Ar beta decays are also useful for calibrating out detector effects, such as electron lifetime

Why calibrate electron lifetime?

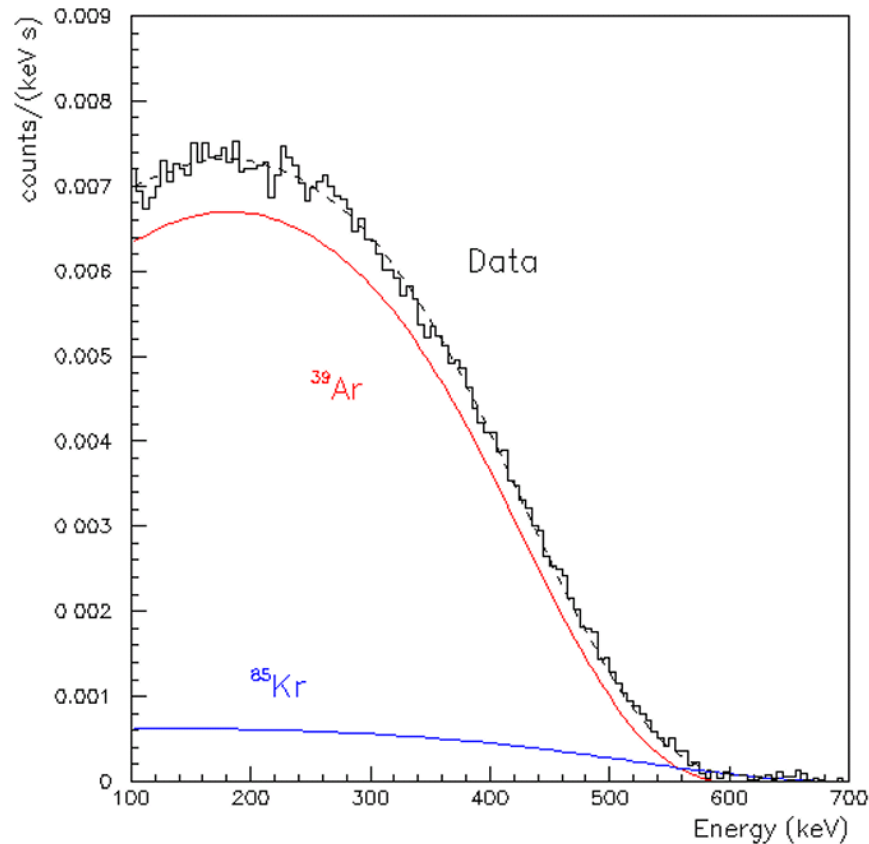


- Electron lifetime correction is an important step for accurate calorimetry

Motivation for e^- Lifetime Measurement:

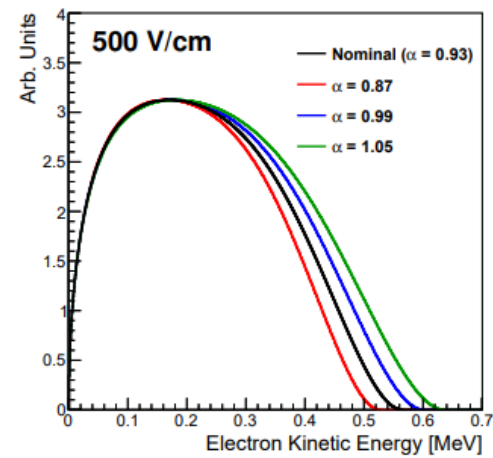
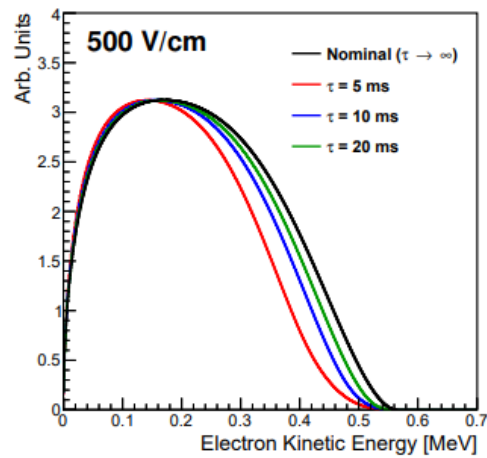
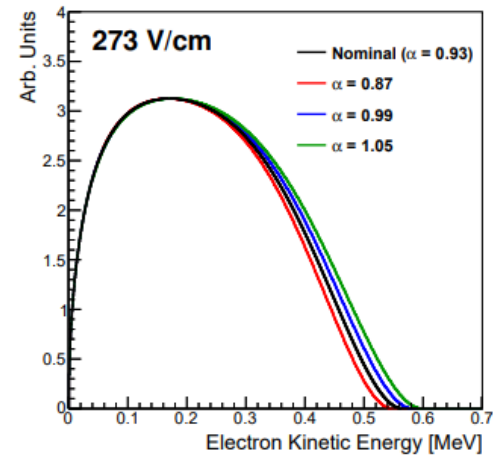
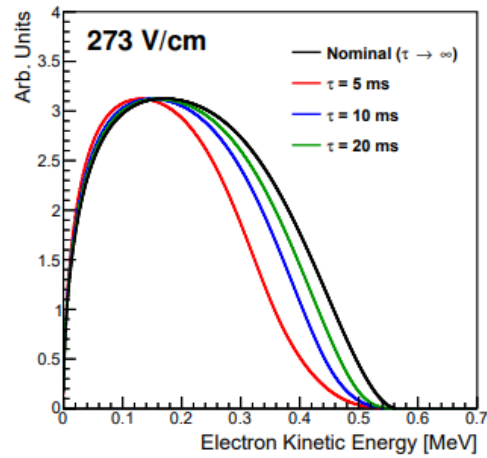
- Current calibration of electron lifetime at MicroBooNE achieved via cosmic rays
 - <https://www-microboone.fnal.gov/publications/publicnotes/MICROBOONE-NOTE-1026-PUB.pdf>
- DUNE Far Detector?
 - Deep underground -> fewer cosmics
 - 4000 cosmics / day compared to MicroBooNE's 4000 cosmics / second
 - ~ 5 cosmics per day per m^3 (for each 10 kiloton module)

^{39}Ar Beta Decay Properties:

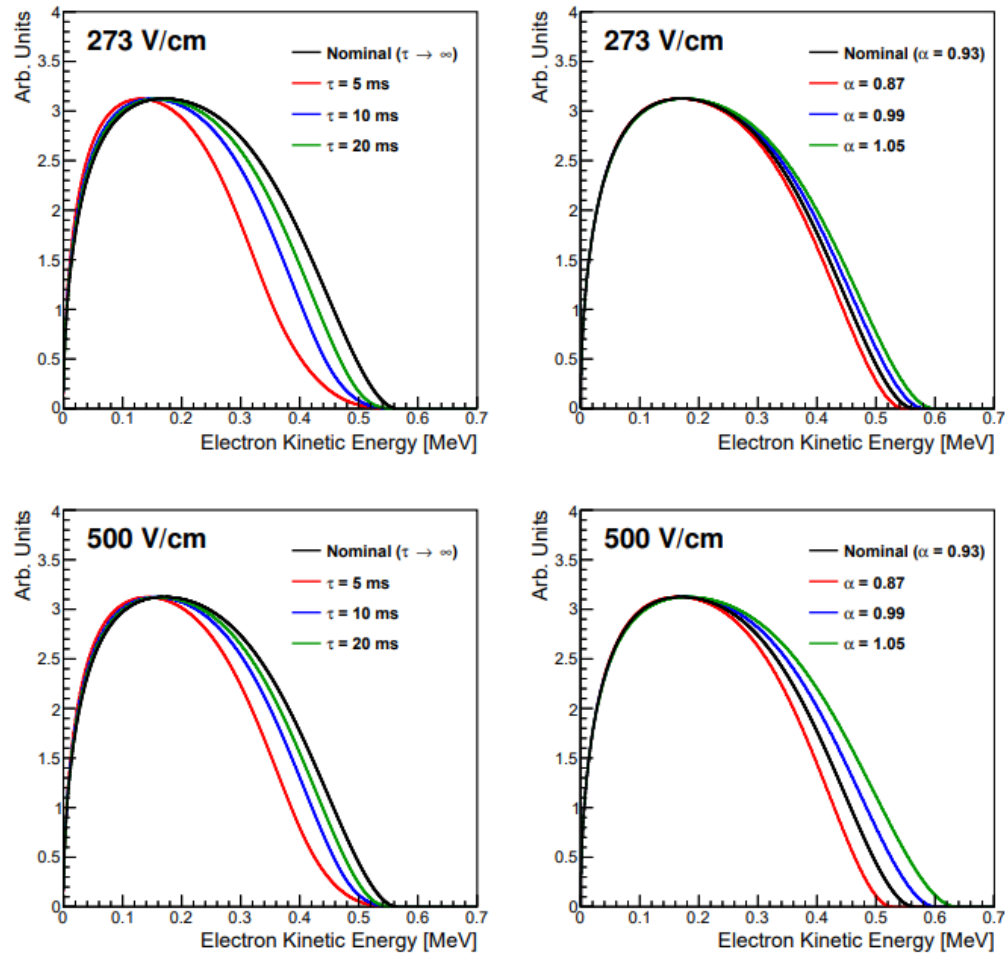


- ^{39}Ar beta decay energy spectrum is well known
- ^{39}Ar decay is frequently observed in LArTPC
 - Expect 1 Bq/kg
 - ~400 per MicroBooNE readout event
- Decay events should have a uniform distribution across the detector in drift direction
 - Can make measurement without knowing t_0 of individual ^{39}Ar decay events

Motivation for e^- Lifetime Measurement:

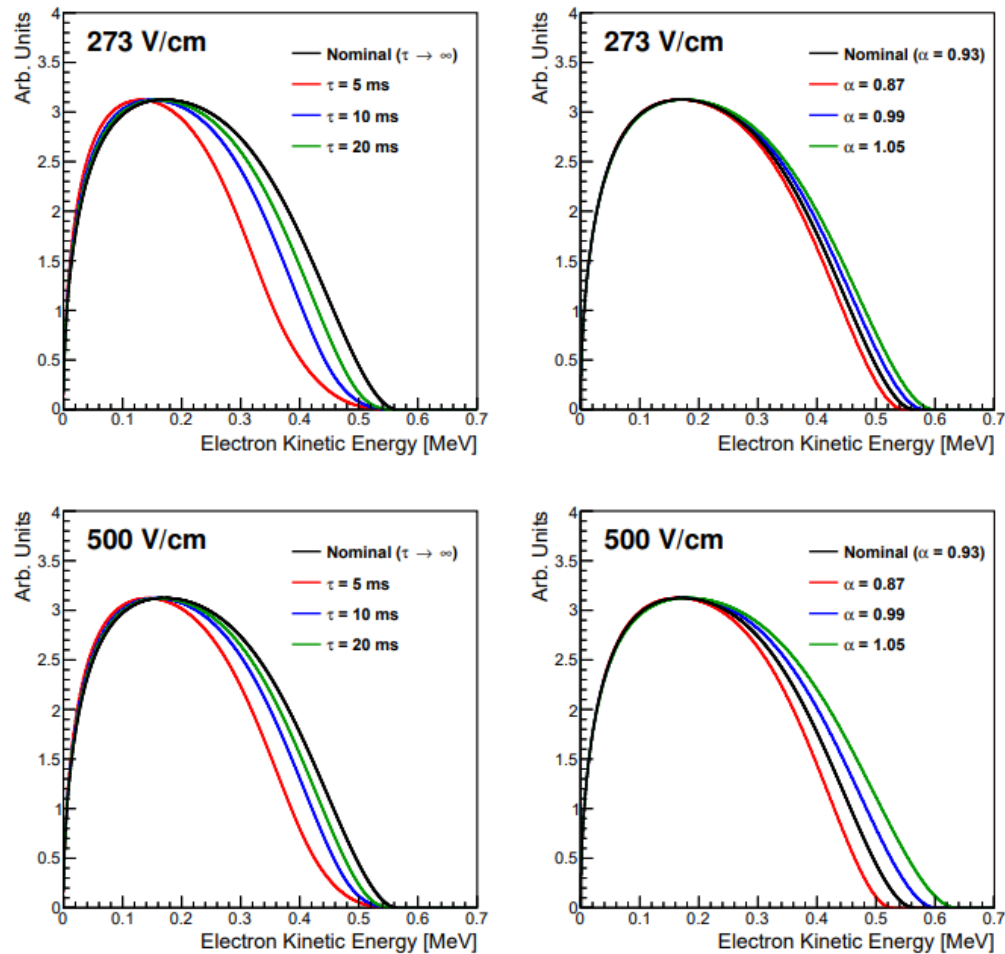


Motivation for e^- Lifetime Measurement:



- The effects of electron lifetime and electron-ion recombination are distinctly different on the ^{39}Ar Spectrum

Motivation for e^- Lifetime Measurement:

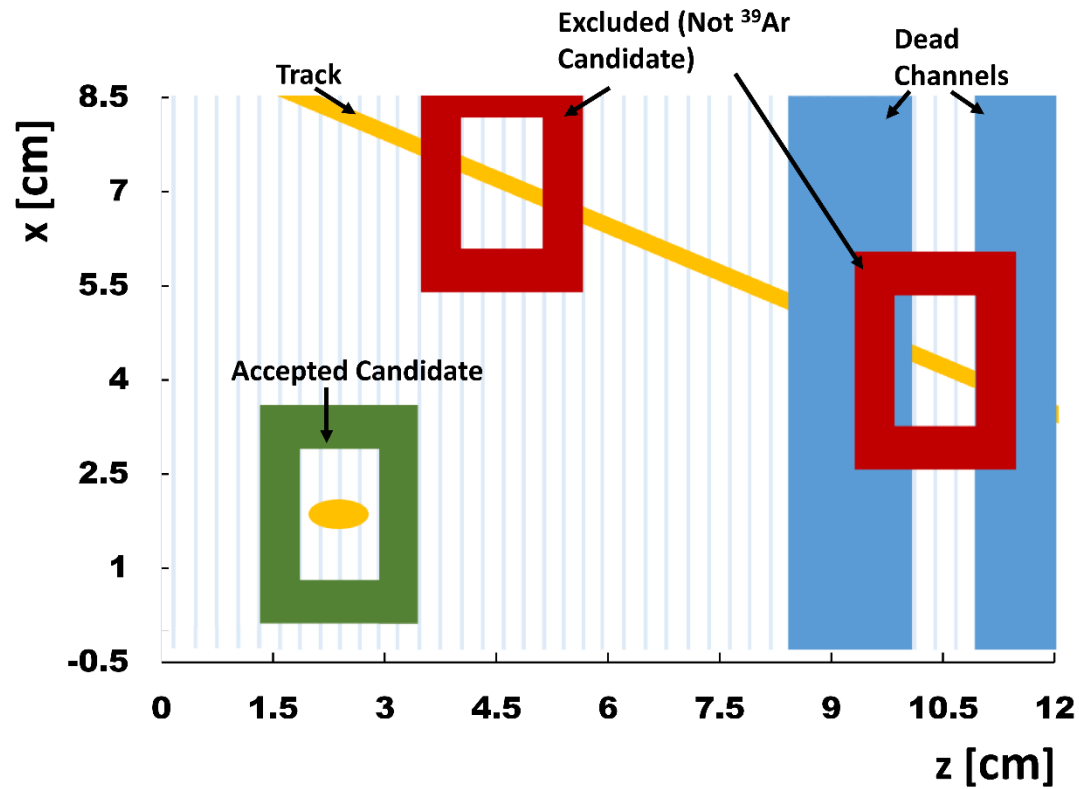


- The effects of electron lifetime and electron-ion recombination are distinctly different on the ^{39}Ar Spectrum
- Mostly affect higher energies

Outline:

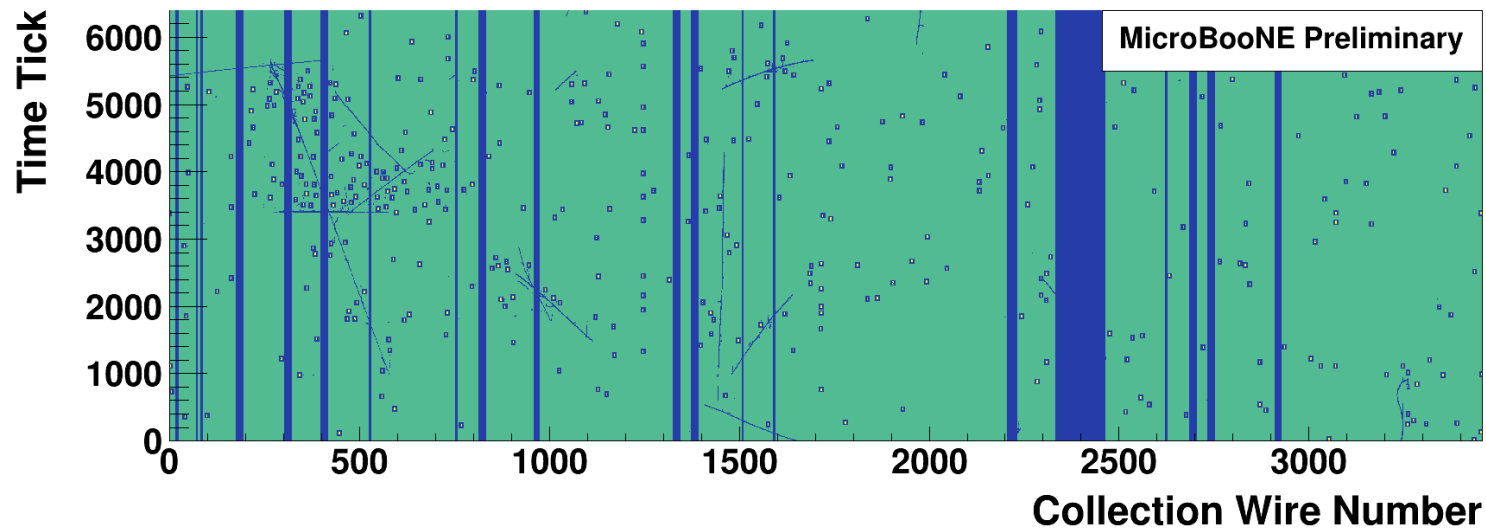
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^{39}Ar Beta Decay Selection:

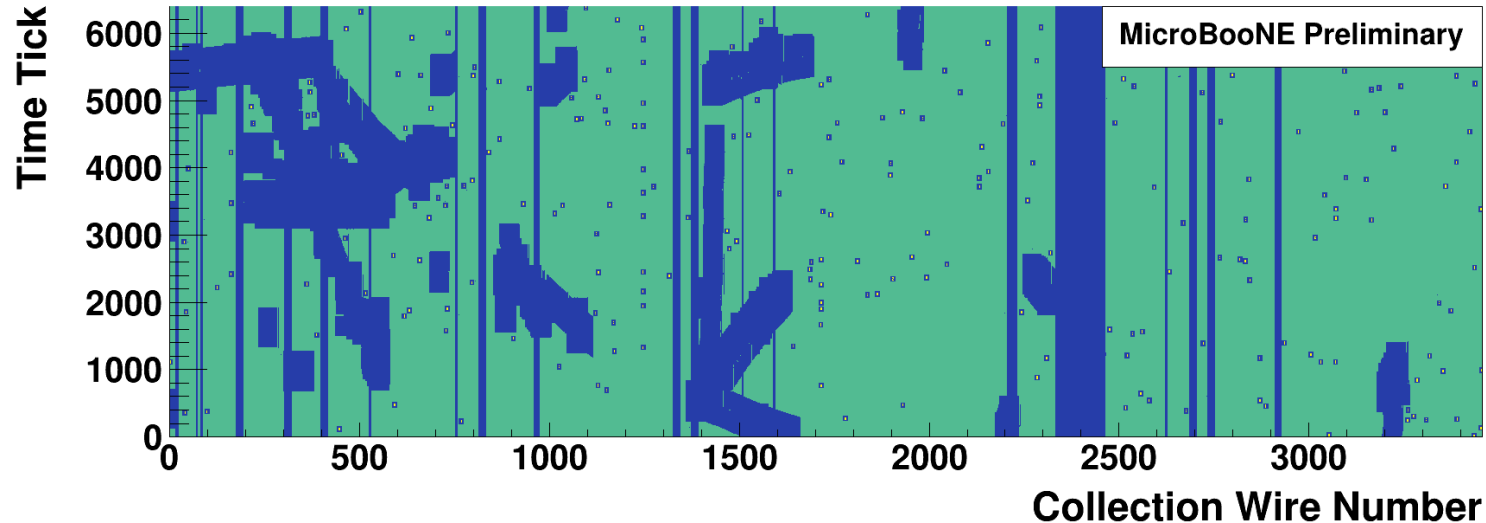


- Attempt to verify point-like activity over threshold by checking for tracks and dead channels
- If point-like, integrate charge
- Integration window is 3 wires by 40 time ticks
- Threshold is $> 1500\text{ e}^-$

^{39}Ar Beta Decay Selection:



- An additional algorithm is employed to mitigate contributions from point-like activity near cosmic tracks
- Track “bubble” has a 15cm radius



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Results with Data:

- After measuring the charge, energy can be reconstructed using this formula:

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

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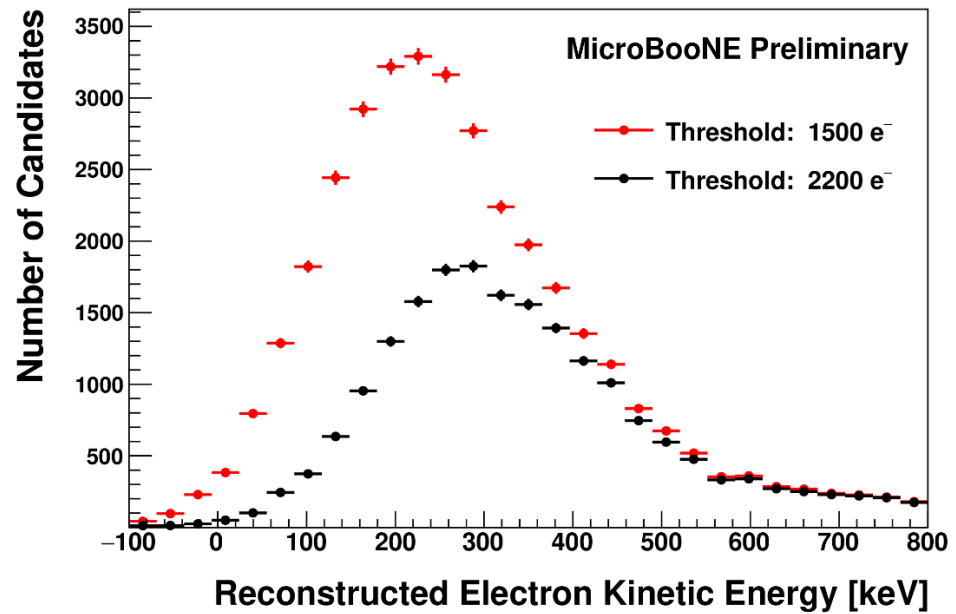
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- K is the electronics response area-to-amplitude ratio (in time ticks)

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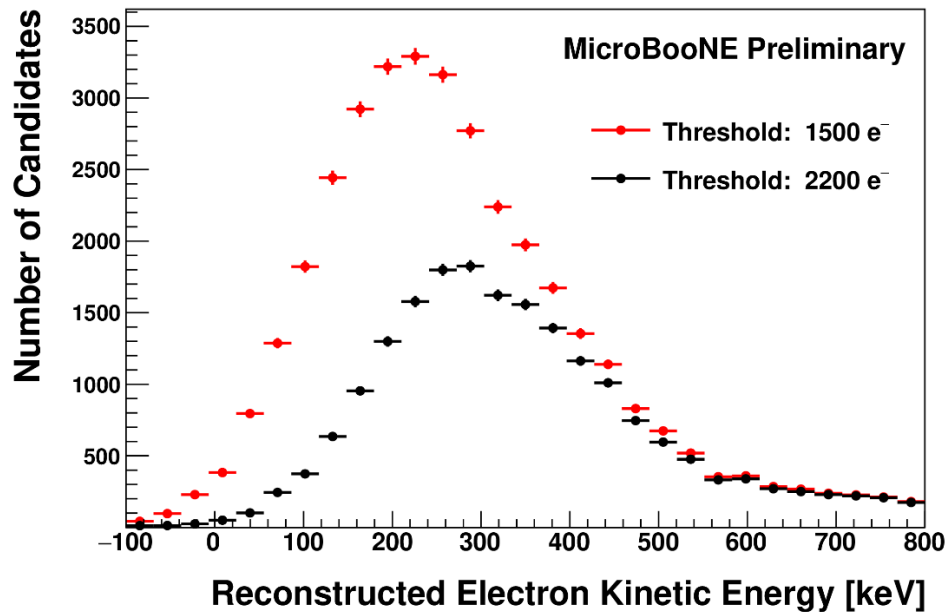
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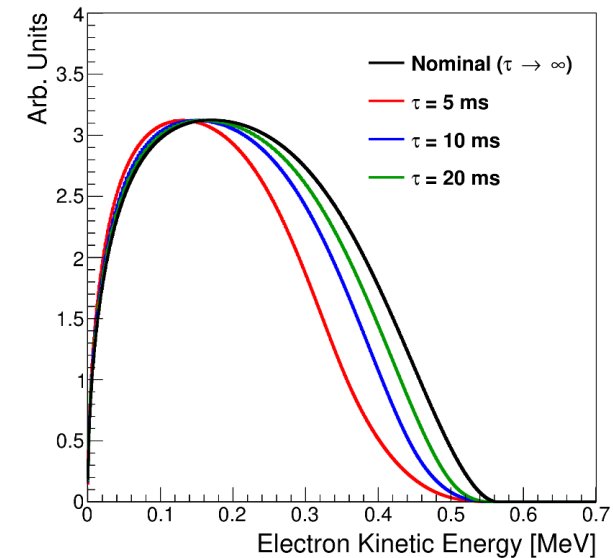
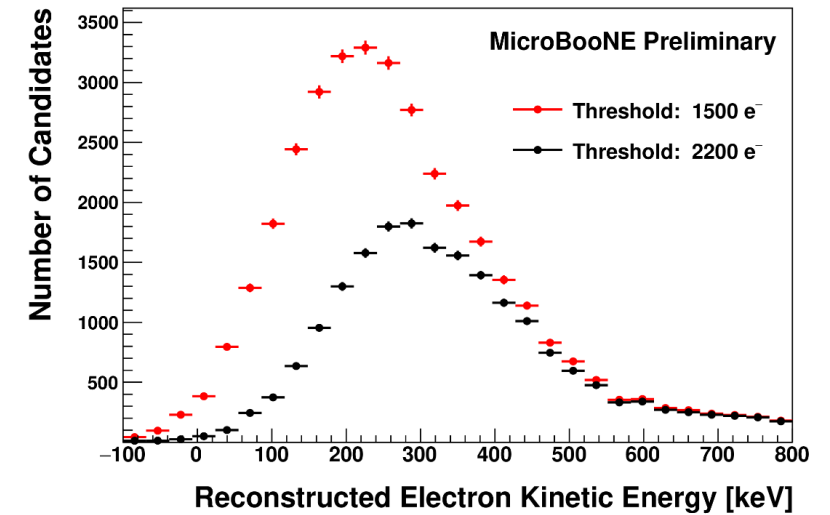
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- Seen in **red** is the threshold used for MicroBooNE
- In **black** is the threshold that should be used for DUNE, to mitigate the greater noise contribution

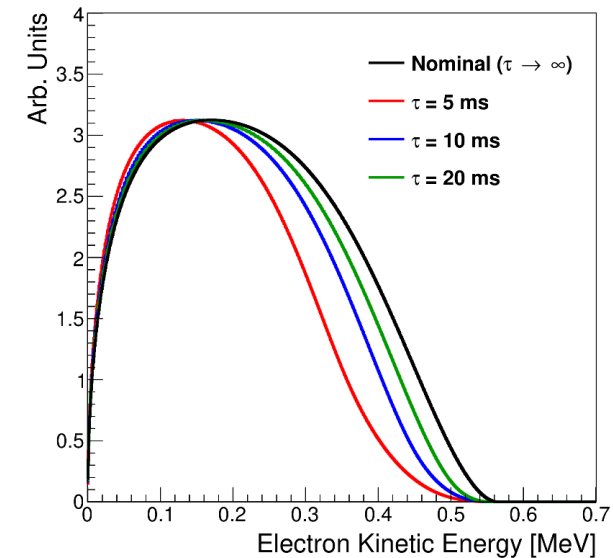
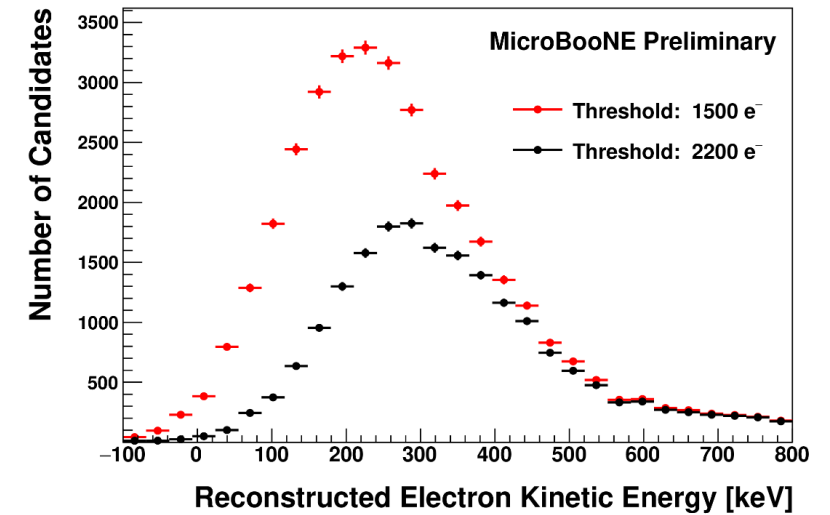
Results with Data:

- Differences between preliminary reconstructed spectrum and true spectrum



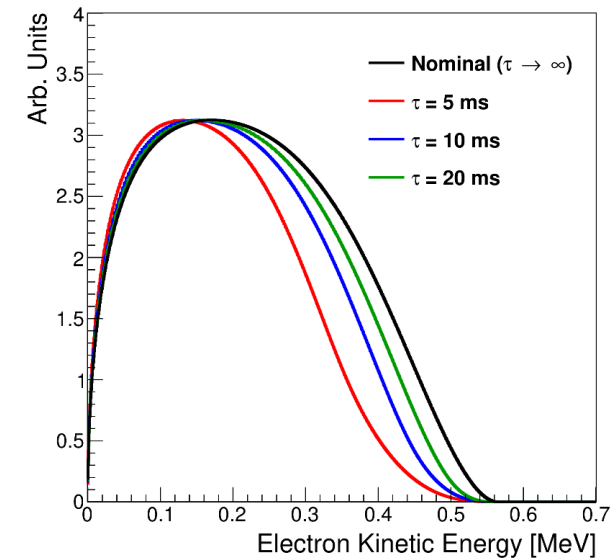
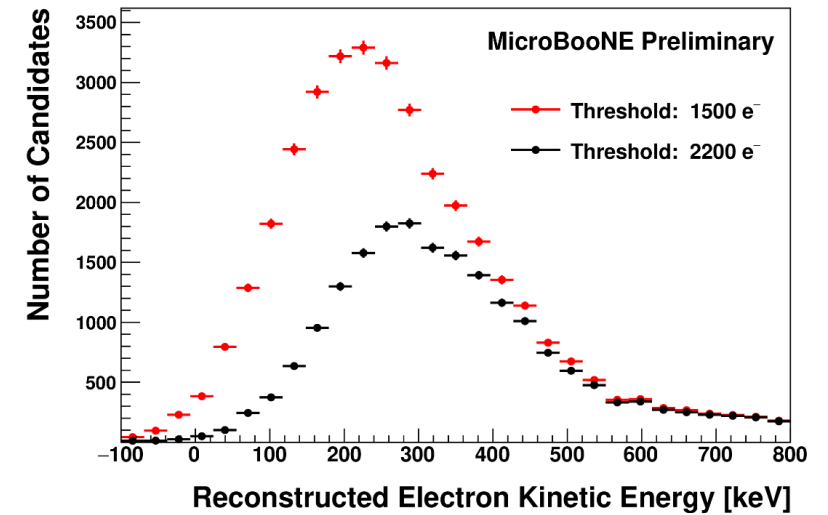
Results with Data:

- Differences between preliminary reconstructed spectrum and true spectrum
 - Thresholding effect at low energies



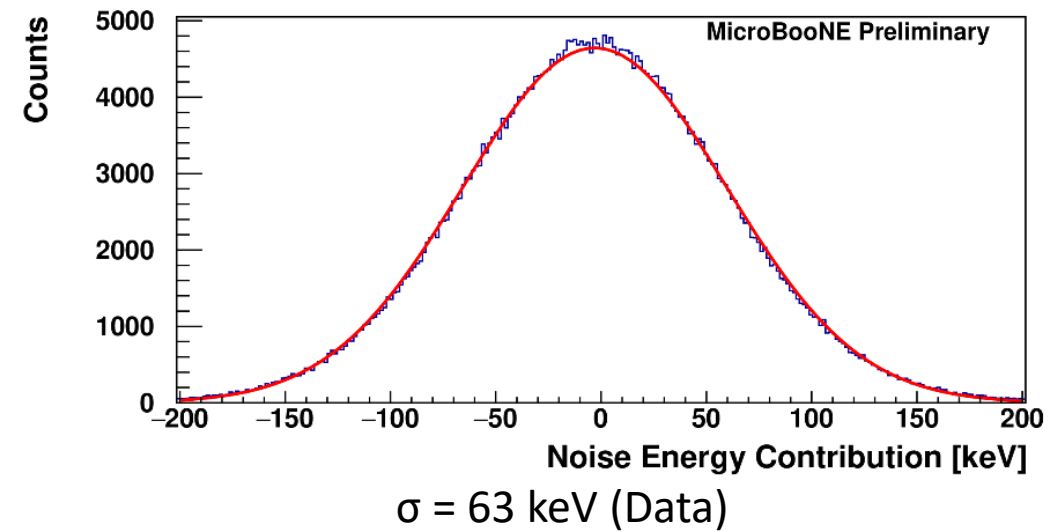
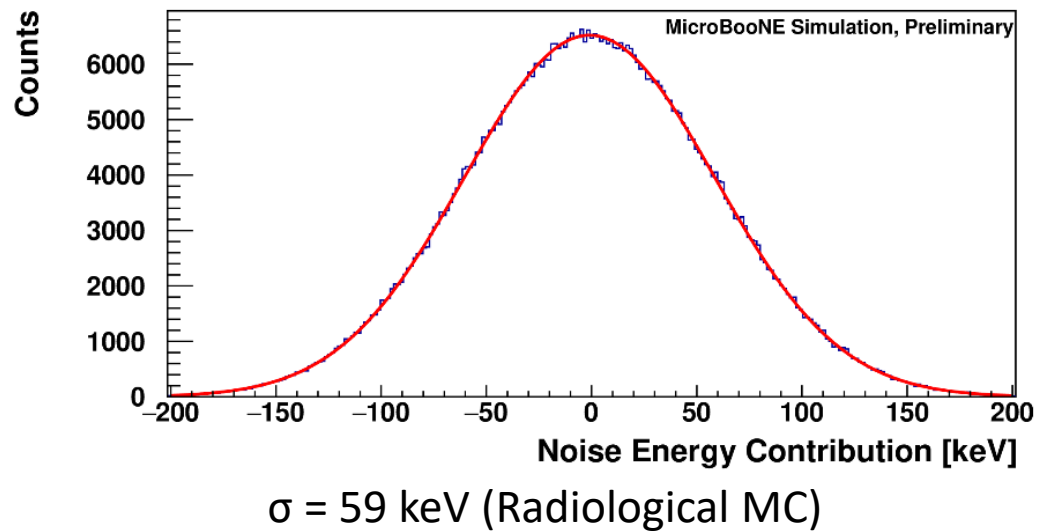
Results with Data:

- Differences between preliminary reconstructed spectrum and true spectrum
 - Thresholding effect at low energies
 - Broadening due to noise



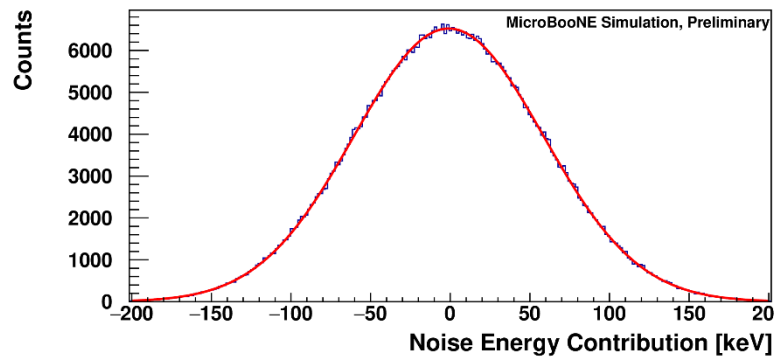
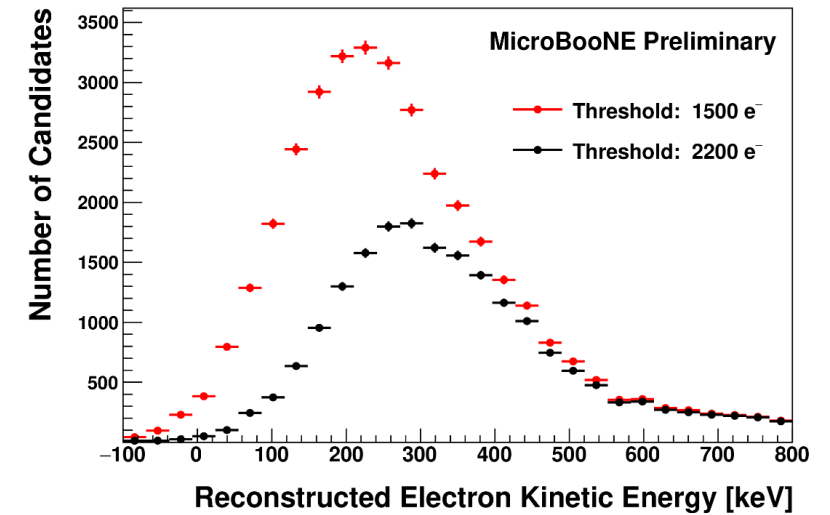
Results with Data:

- Noise studied by using the same reconstruction method on randomly selected points
- This estimates the contribution of energy smearing due to noise

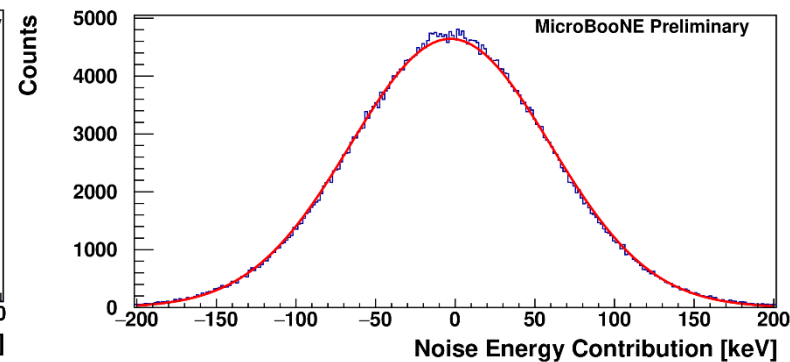


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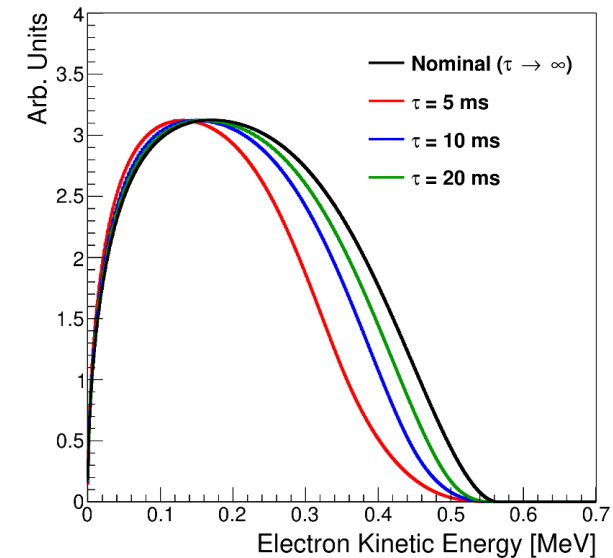
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$\sigma = 59$ keV (Radiological MC)

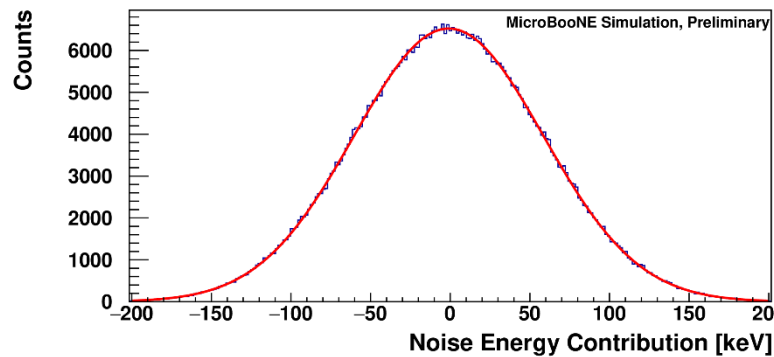
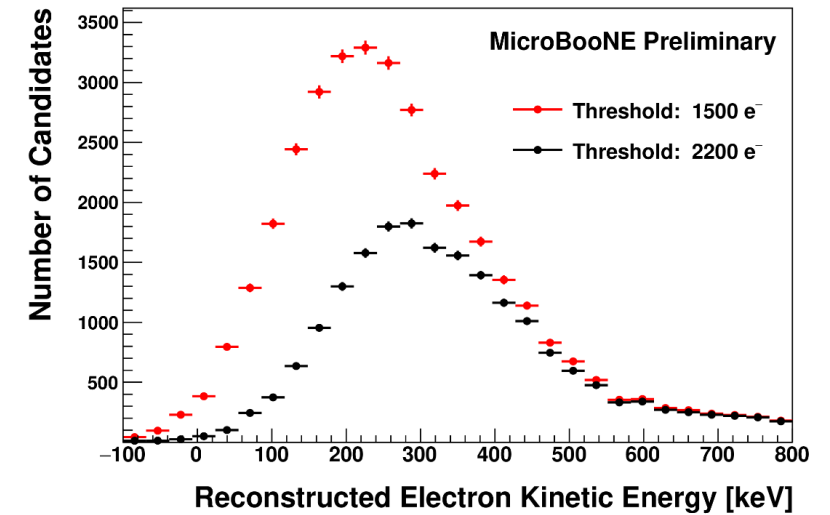


$\sigma = 63$ keV (Data)

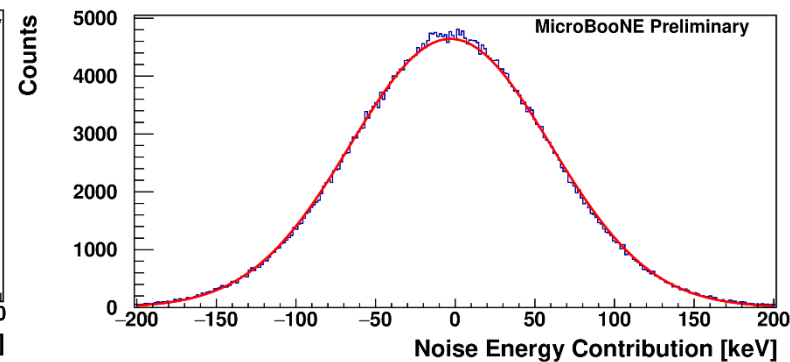


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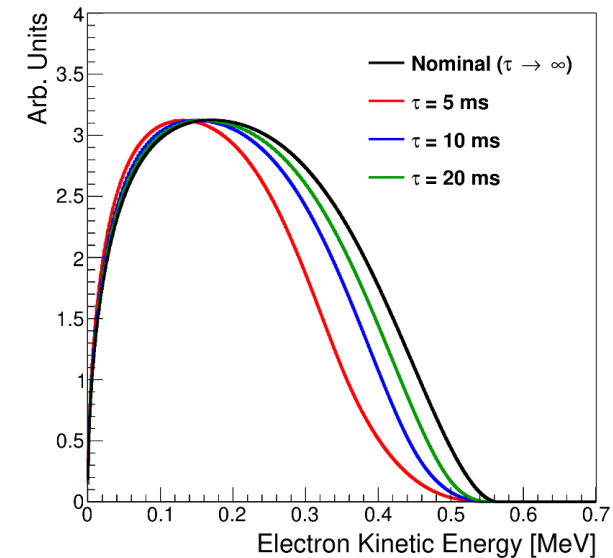
- Differences between preliminary reconstructed spectrum and true spectrum
 - Thresholding effect at low energies
 - Broadening due to noise
 - High energy tail



$\sigma = 59$ keV (Radiological MC)



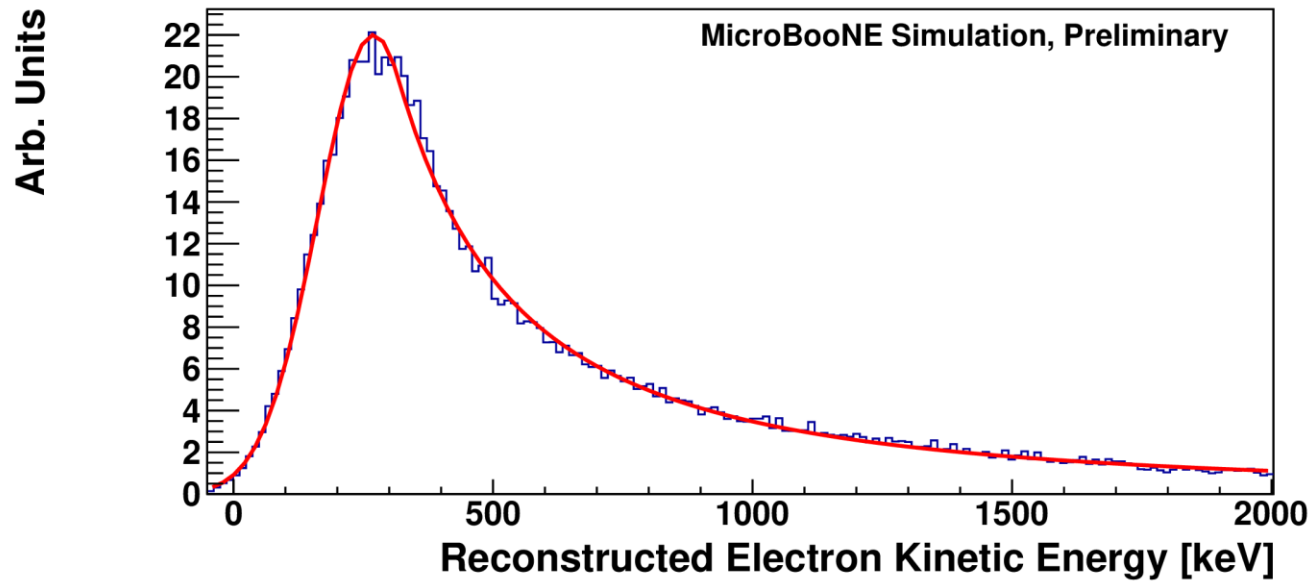
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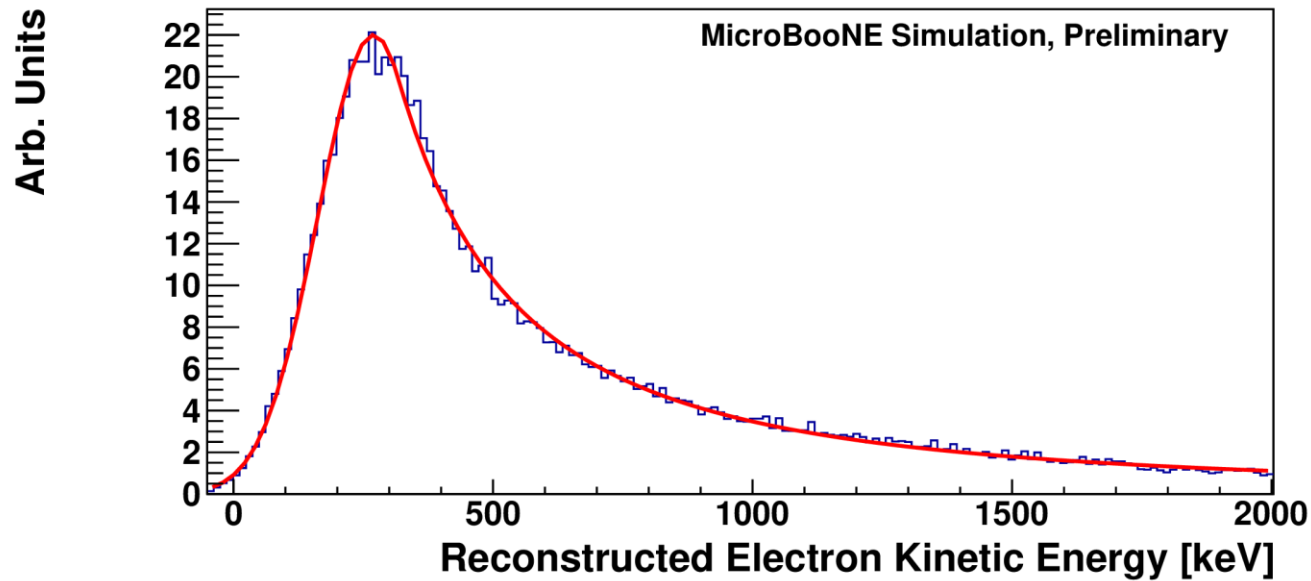
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Cosmogenic Background:



- This is a dedicated simulation of muon showers (CORSIKA)
 - No radiological sources simulated here
- Same method for finding point-like activity used near simulated cosmic tracks

Cosmogenic Background:



- “Crystal Ball” function

$$f(x; \alpha, n, \bar{x}, \sigma) = N \cdot \begin{cases} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{x-\bar{x}}{\sigma}\right)^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leq -\alpha \end{cases}$$

where

$$A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

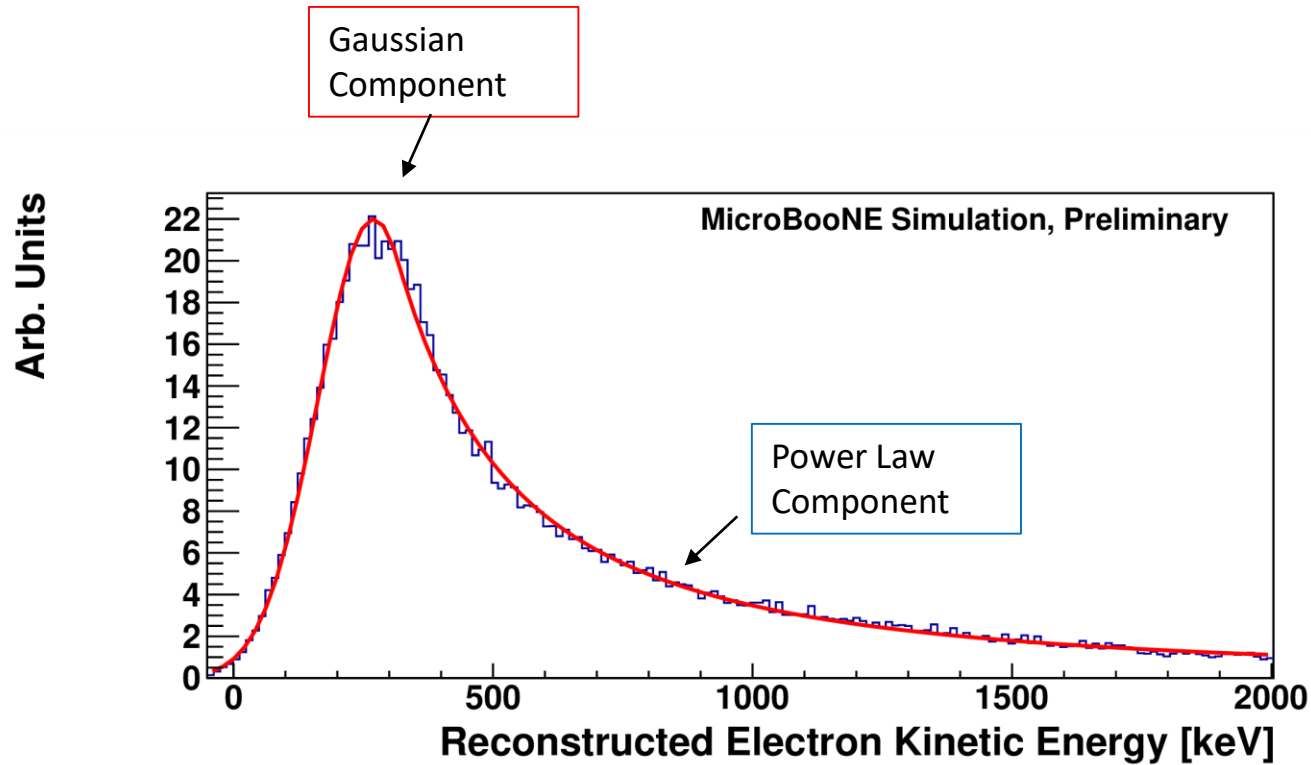
$$B = \frac{n}{|\alpha|} - |\alpha|,$$

$$N = \frac{1}{\sigma(C + D)},$$

$$C = \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right),$$

$$D = \sqrt{\frac{\pi}{2}} \left(1 + \operatorname{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right).$$

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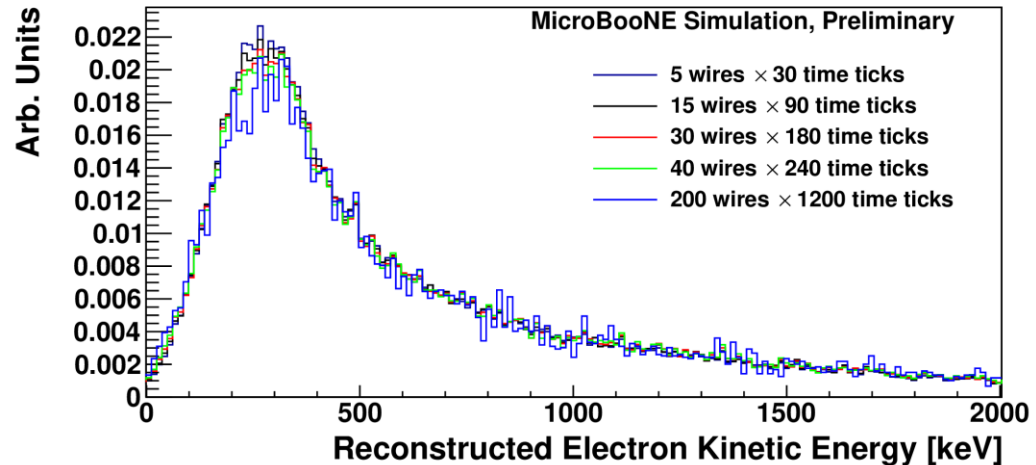
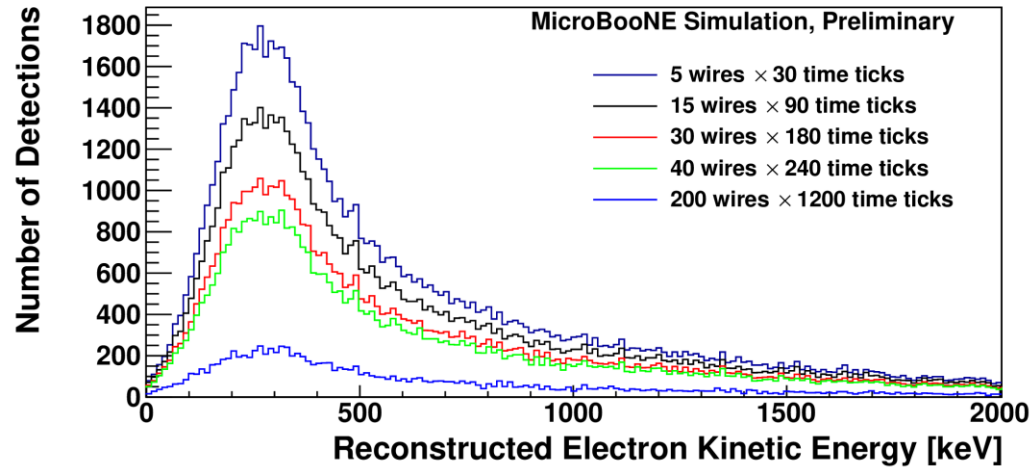
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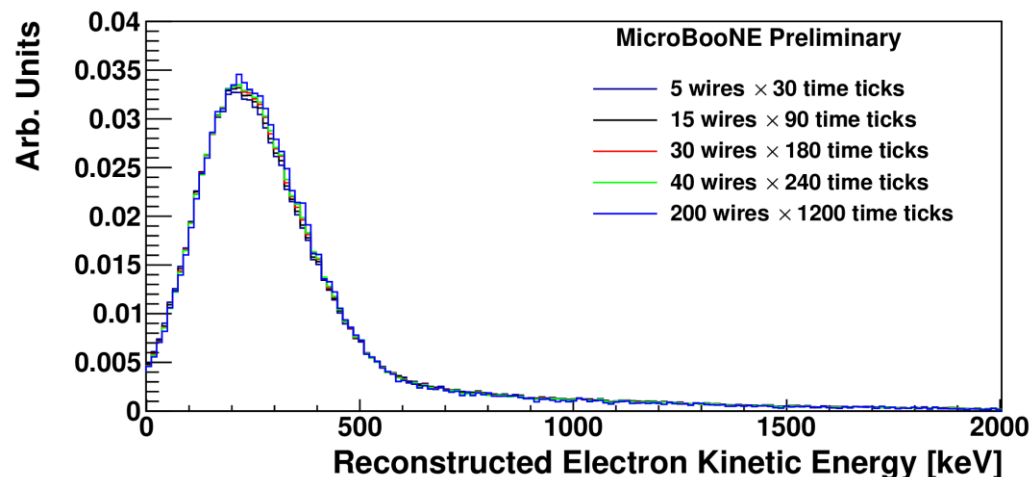
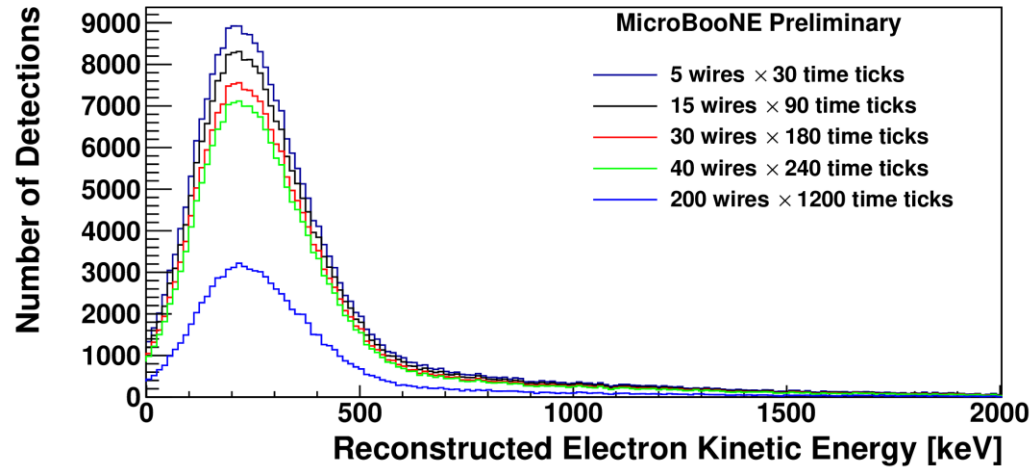
$$D = \sqrt{\frac{\pi}{2}} \left(1 + \operatorname{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right).$$

Cosmogenic Background:



- MC cosmic background with different track exclusion windows
- This shows the track exclusion significantly cuts down on cosmic contribution

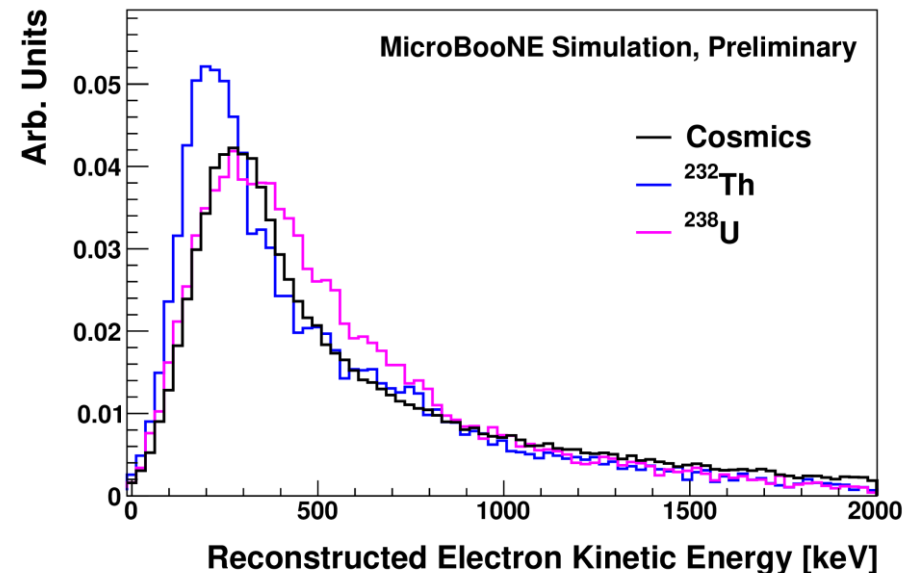
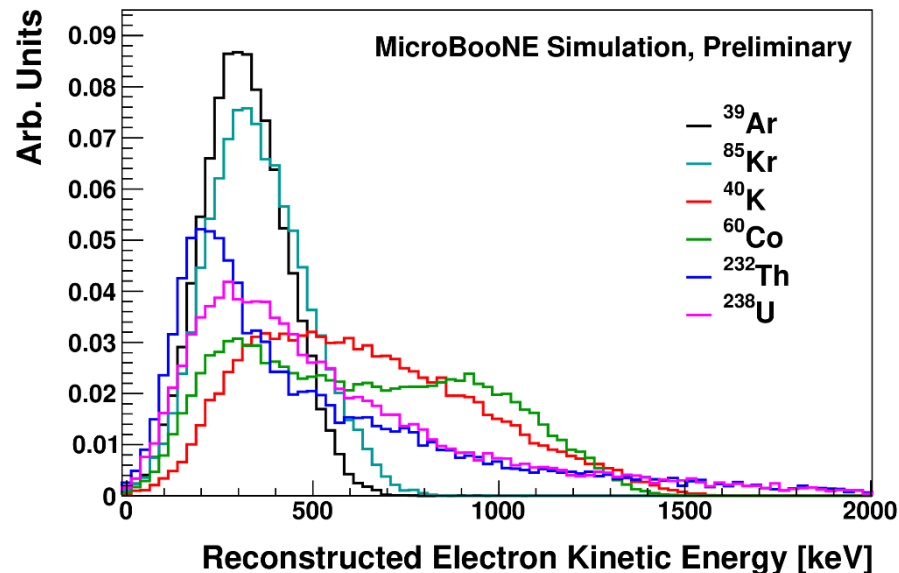
Cosmogenic Background:



- Same track exclusion method run on data
- Non-normalized distributions show cutting cosmic contribution by larger factor than ^{39}Ar
- High energy tail could be other radiological contaminants (probably ^{40}K , ^{232}Th and ^{238}U decay chains, for example)

Radiological Background:

- Dedicated simulation of radiological sources
- Some radiologicals produce a spectrum similar to the cosmogenic activity, which makes their contributions difficult to separate
- Spectra are area-normalized to unity

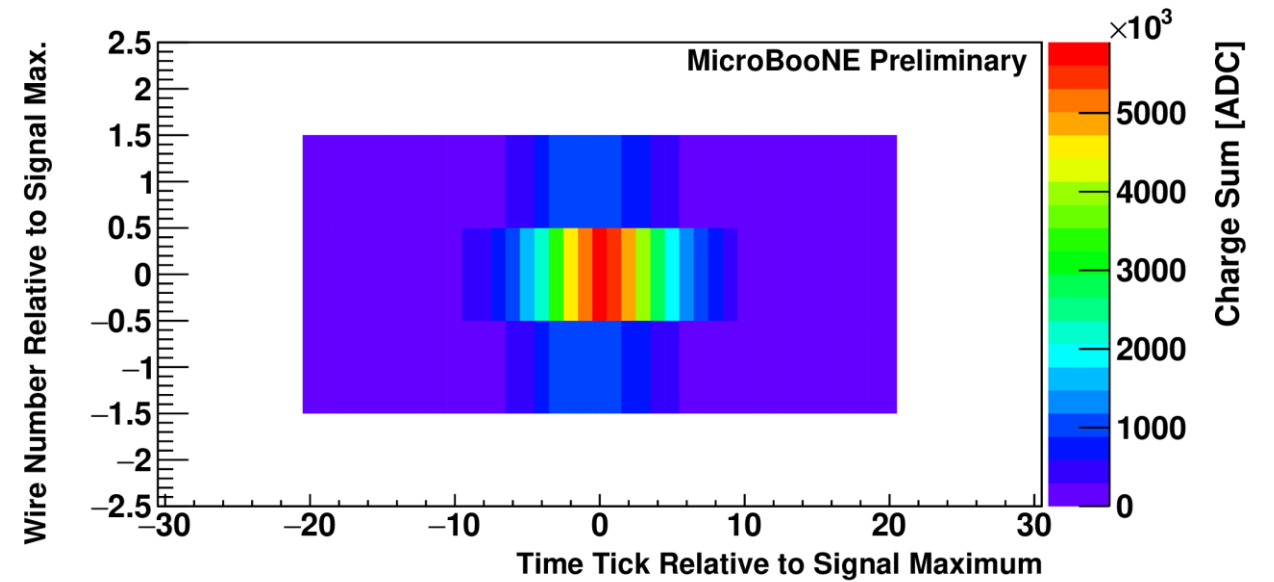


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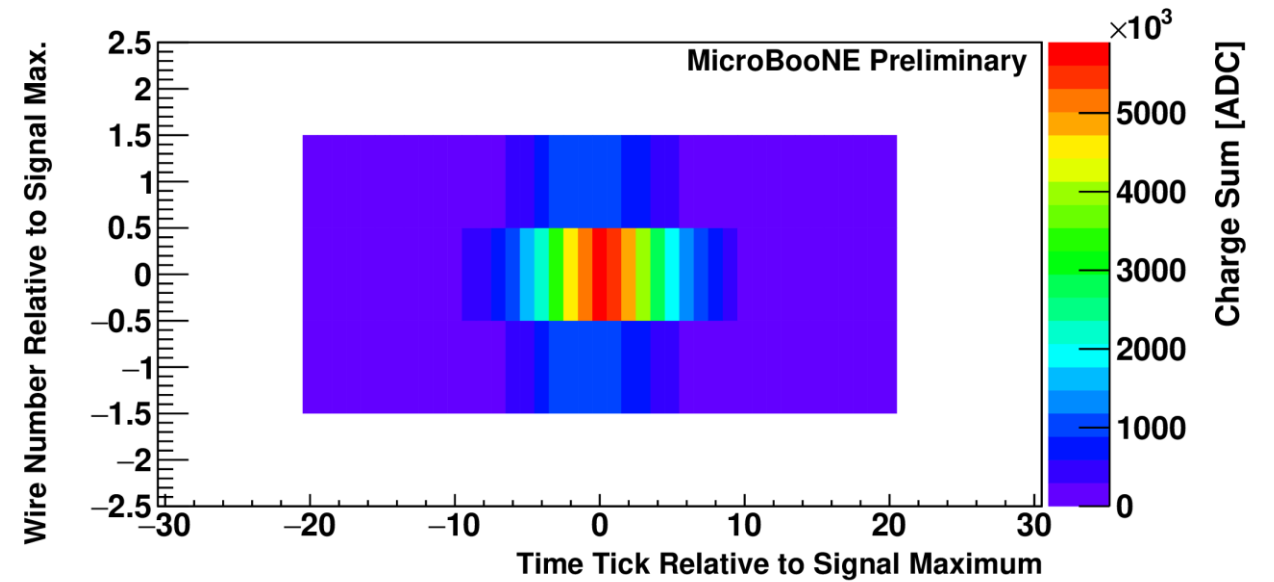
^{39}Ar Signal Shape:

- Point-like signal has applications outside of measuring electron lifetime



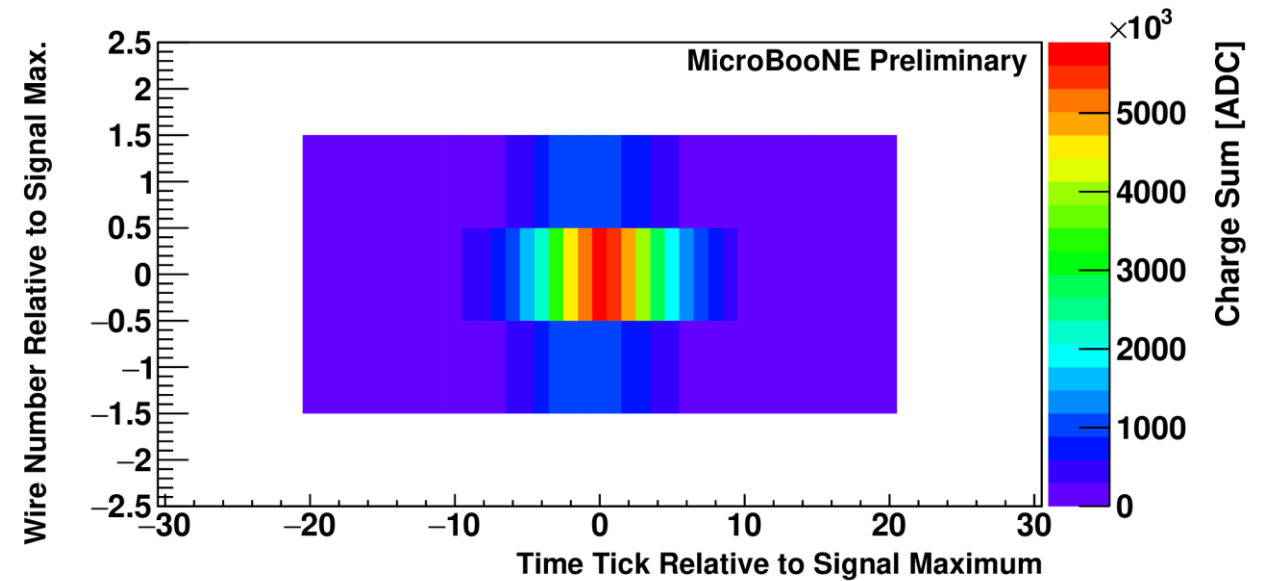
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- Diffusion measurements (longitudinal and transverse)



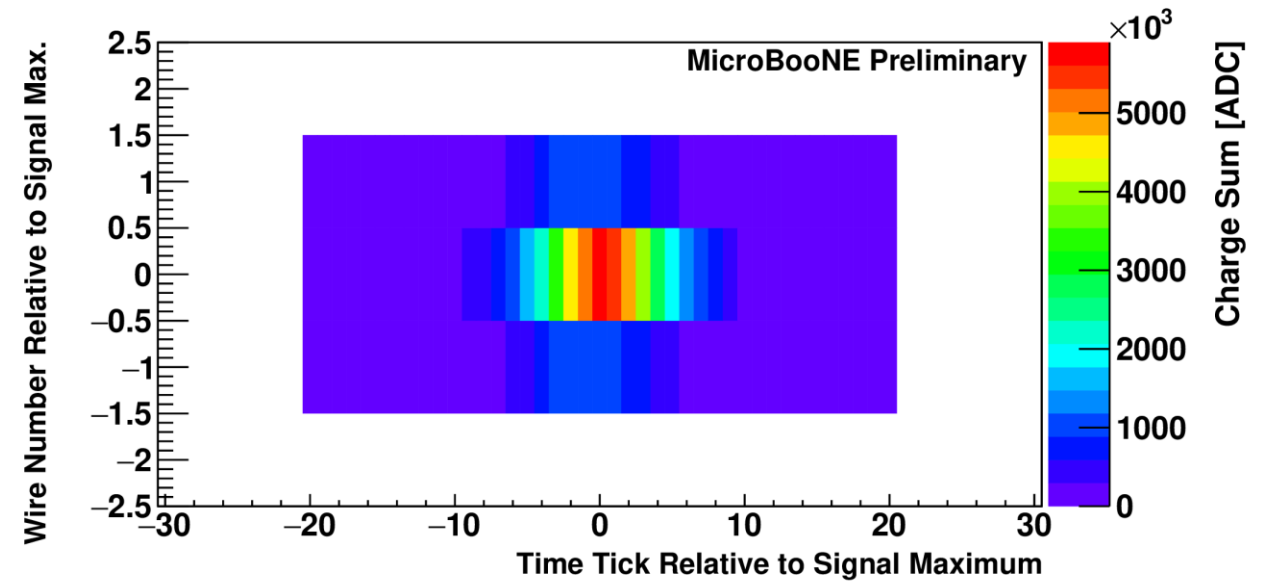
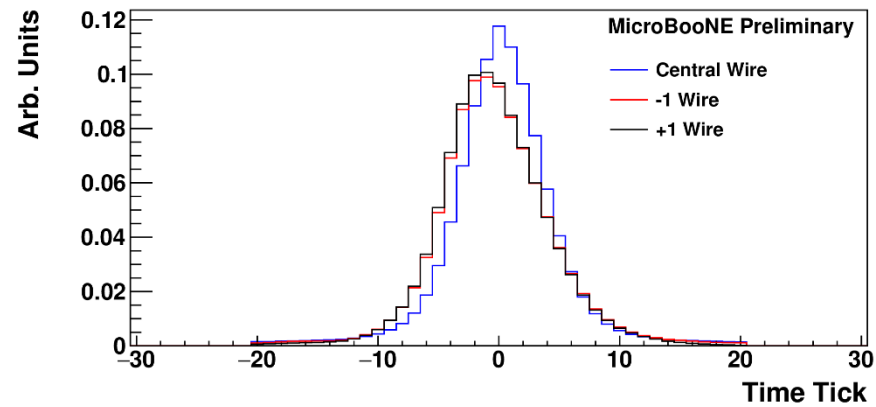
^{39}Ar Signal Shape:

- Point-like signal has applications outside of measuring electron lifetime
- Diffusion measurements (longitudinal and transverse)
- Measurement of wire-to-wire variations in the field response function



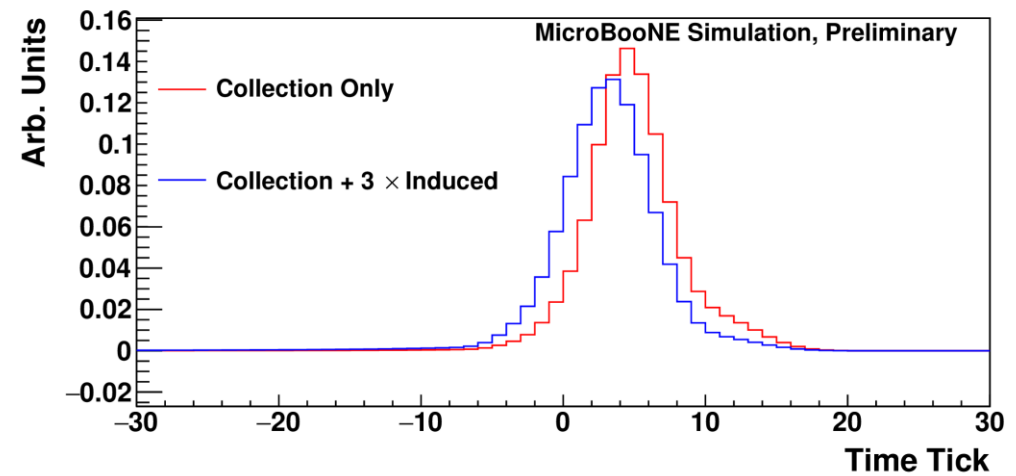
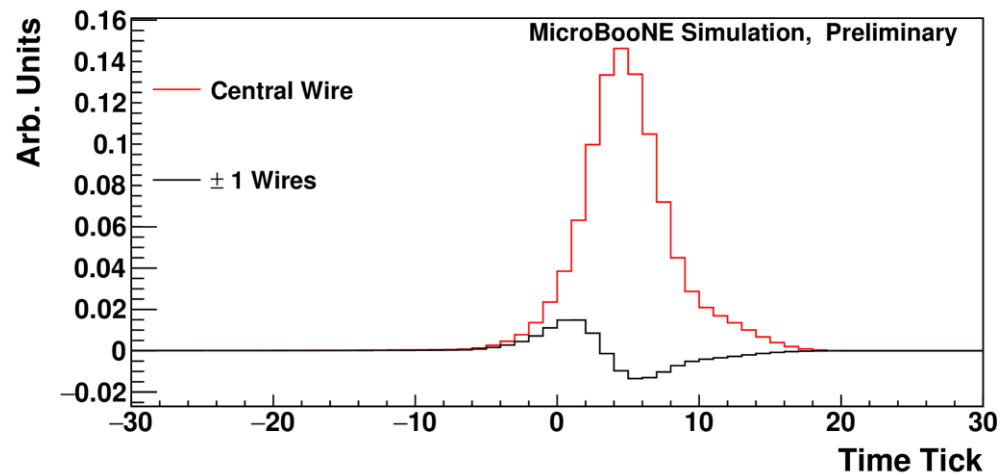
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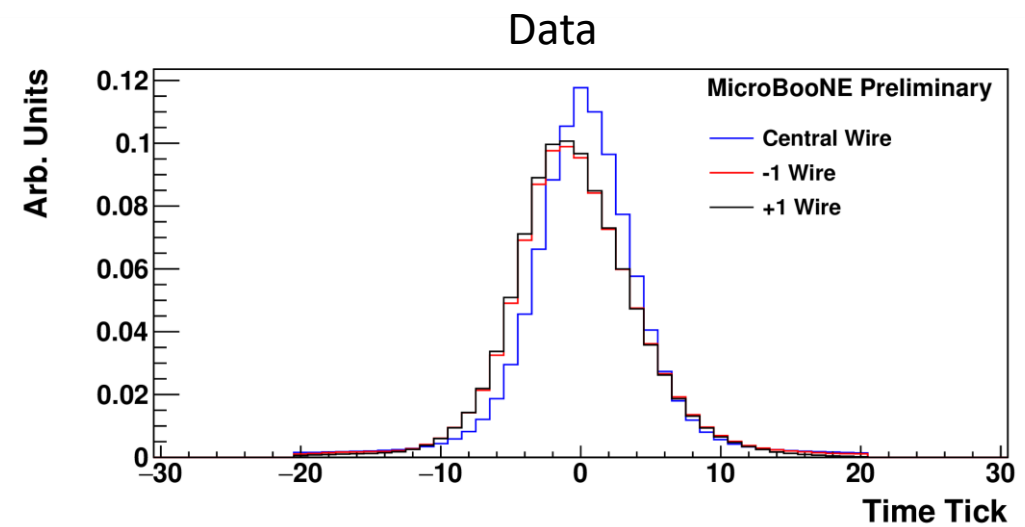
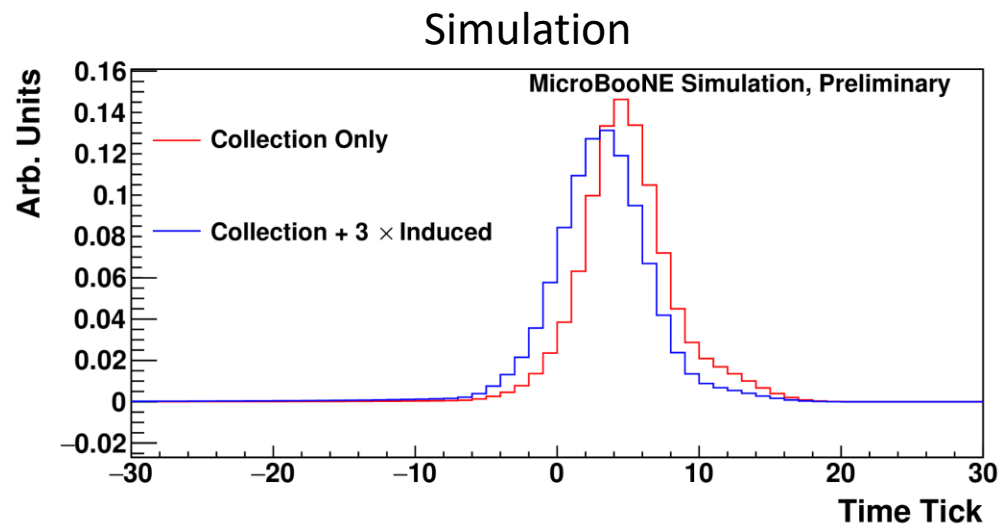
- The observed effect is explained by simulating induced charge effects (even on collection plane)



(Wire field response only)

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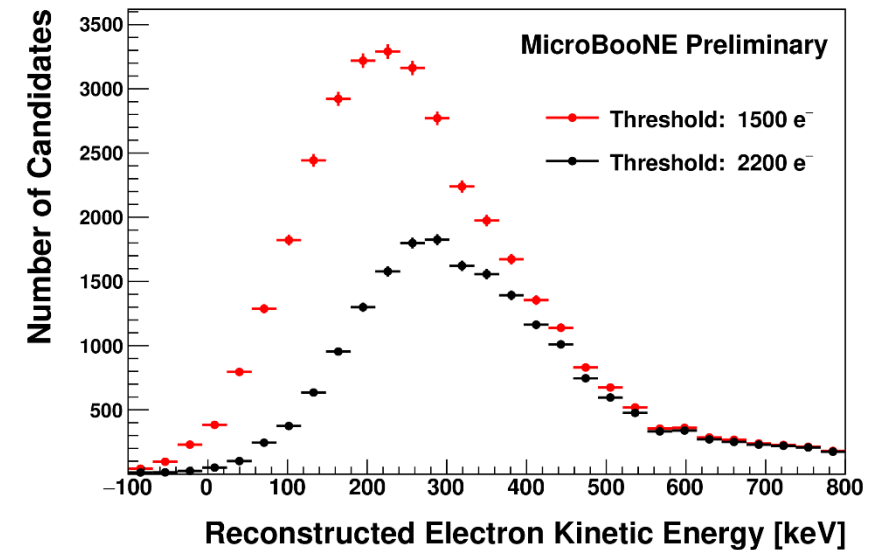
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Conclusion:

- In large LArTPCs, reconstructed ^{39}Ar beta decays have the following potential uses:
 - Study of energy scale at lower energies relevant for solar/supernova neutrino reconstruction
 - Measurement of electron lifetime
 - Measurement of electron-ion recombination
 - Diffusion measurement (longitudinal and transverse)
 - Measuring wire-to-wire variations in field response
- We have shown for the first time that it is possible to reconstruct ^{39}Ar decays in a large LArTPC



Conclusion:

- For a more detailed discussion of this study, see MICROBOONE-NOTE-1050-PUB
- <http://microboone.fnal.gov/public-notes/>
- We plan on putting out a publication on this later this year to come out before the DUNE TDR

