ProtoDUNE-SP Argon-39 Analysis Update

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ProtoDUNE Sim/Reco Meeting

August 26, 2020

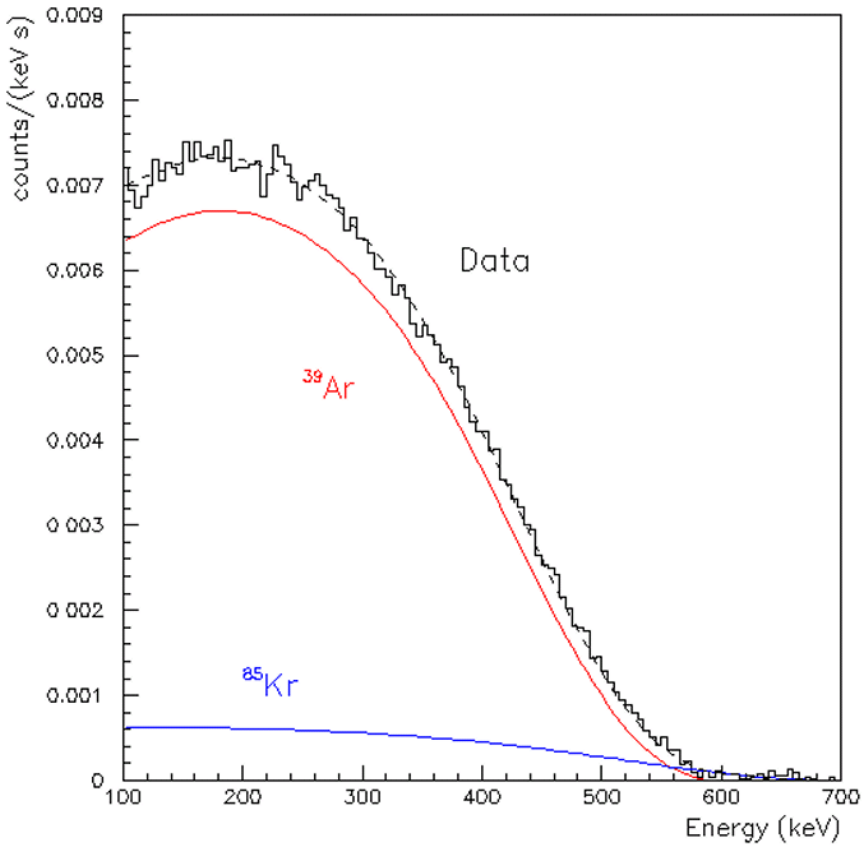
Outline:

- Quickly recap ^{39}Ar beta decay studies
- Experimental “proof-of-concept” electron lifetime measurement
- Improvements to ^{39}Ar beta decay reconstruction (and a bonus study of noise at ProtoDUNE!)

Summary of ^{39}Ar Beta Decay Studies:

- Presently, calibrations (e.g. electron lifetime) in large LArTPCs utilize cosmic rays
- DUNE Far Detector?
    - 4000 cosmics / day compared to MicroBooNE's 4000 cosmics / second
    - ~ 5 cosmics / day / m^3 (for each 10 kiloton module)
- ^{39}Ar beta decays could help supplement the low cosmic rate for calibrations
    - Expect 50000 decays on any DUNE FD readout

Summary of ^{39}Ar Beta Decay Studies:

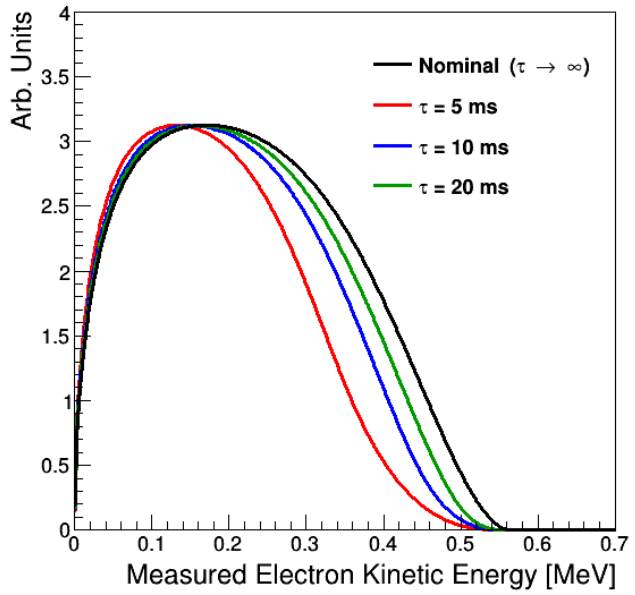


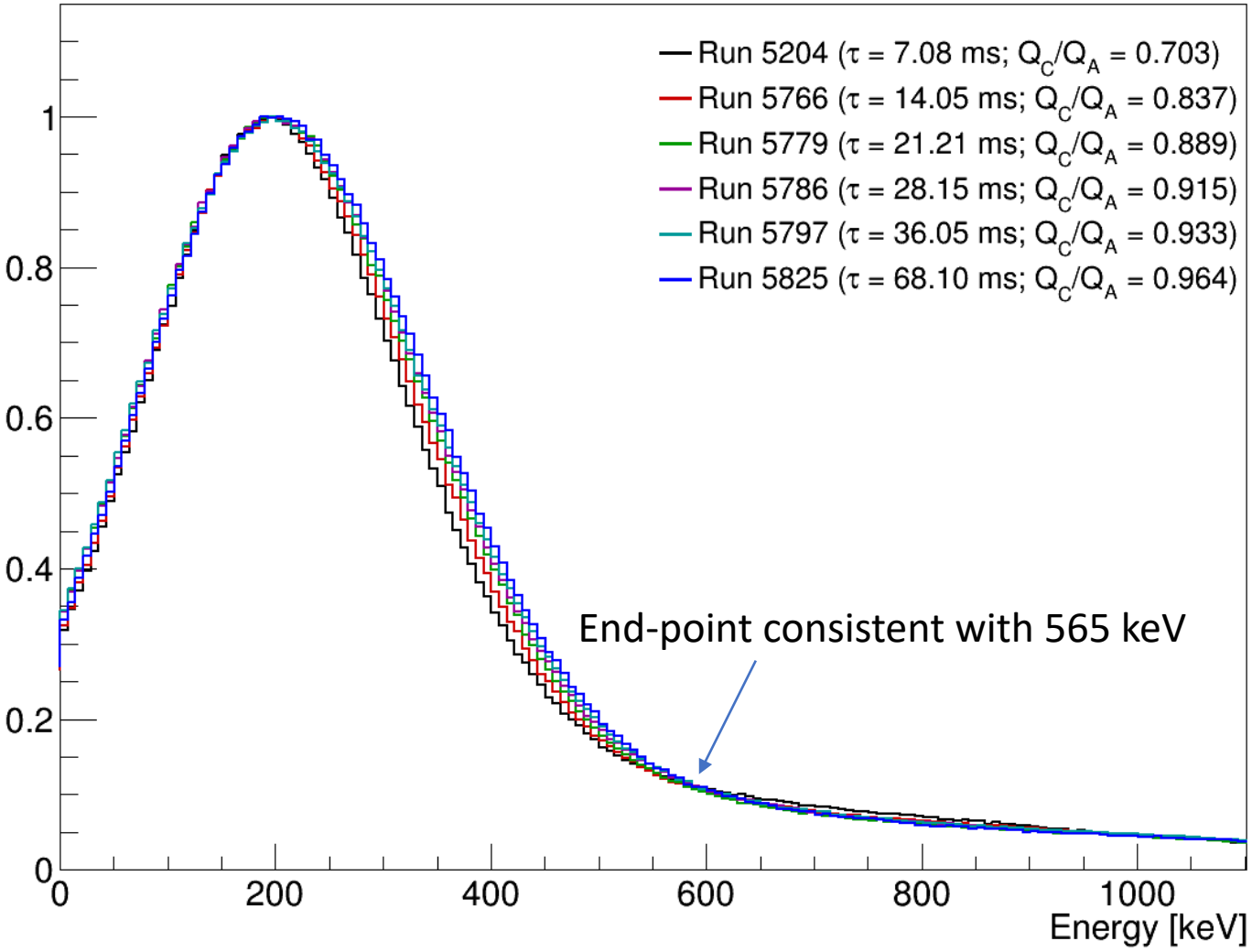
- ^{39}Ar beta decay cut-off at 565 keV (about half of the energy deposited by a MIP on a single wire at DUNE)
- Decay events should be uniform in x
  - Can make measurement without knowing t_0 of individual Ar-39 decay events

Credit: Benetti et al (2007). Measurement of the specific activity of Ar-39 in natural argon.

Summary of ^{39}Ar Beta Decay Studies:

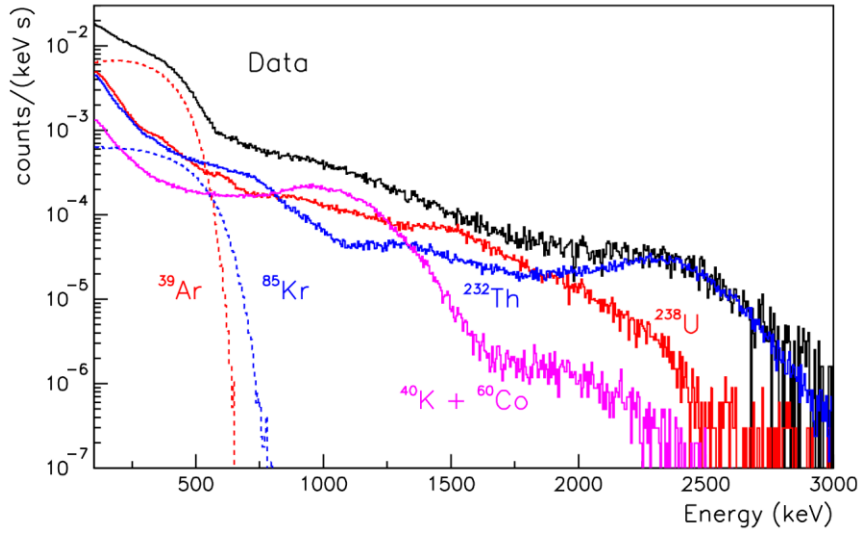
- See ^{39}Ar beta decay update from July 8 Sim/Reco meeting for more details
- Spectra normalized to the same height

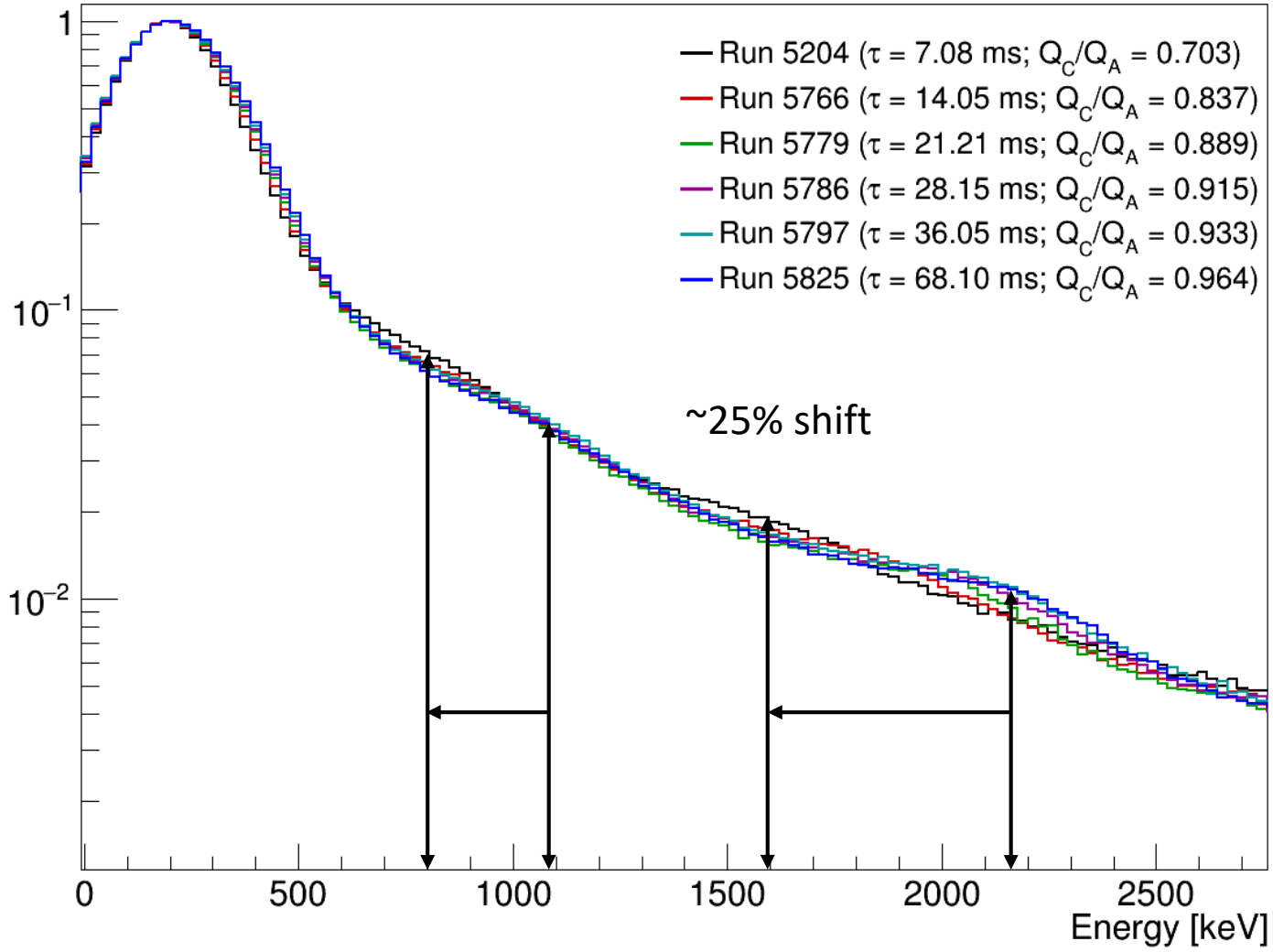




Summary of ^{39}Ar Beta Decay Studies:

- Portions of spectra could show effects from other radiological sources
- Other radiological sources show effects of electron lifetime differences

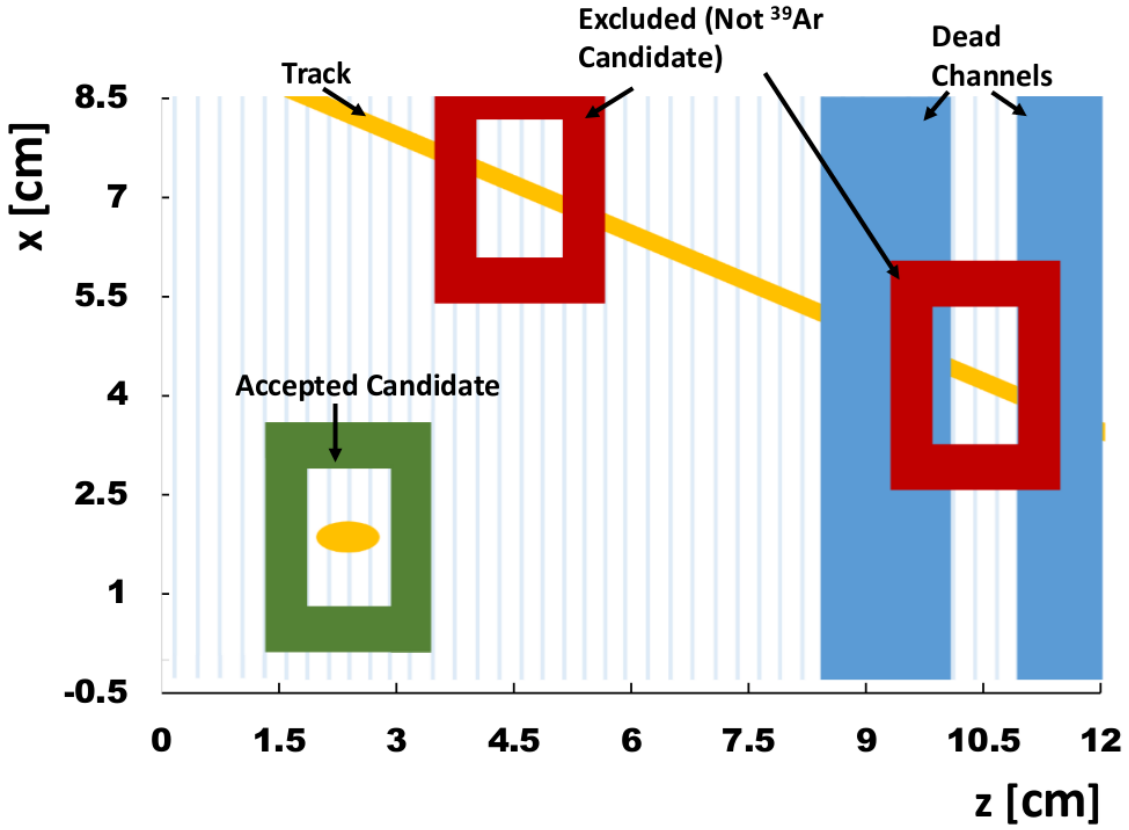




Credit: Benetti et al (2007). Measurement of the specific activity of Ar-39 in natural argon.

Summary of ^{39}Ar Beta Decay Studies:

- Only studying the collection plane in the present results
- ^{39}Ar beta decays will look point-like
- Reject tracks, being careful of dead channels (that might fake a point-like signal)
- Record charge in a window of 3 wires by 40 time ticks around accepted candidates
- See MicroBooNE Public Note 1050



Summary of ^{39}Ar Beta Decay Studies:

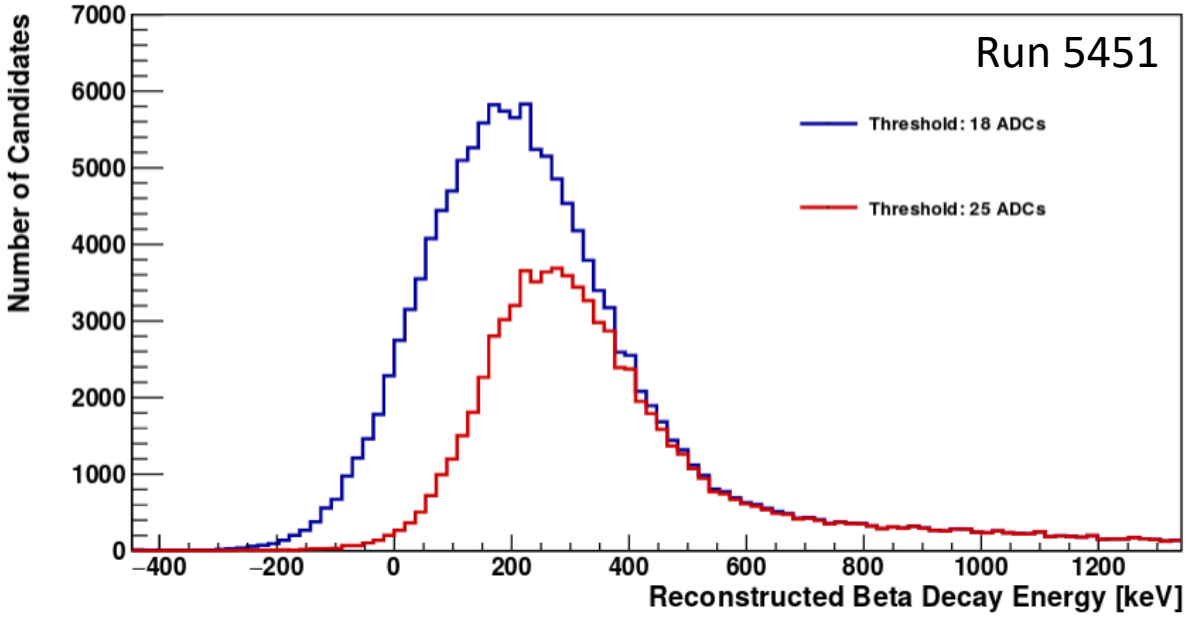
- Reconstruct candidate charge into energy via

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

G = Gain [e^-/ADC]
I = 0.0236 keV/e^-
R = Recombination Factor (calculated near the end-point for now)
K = Electronics response Area-to-Amplitude Ratio

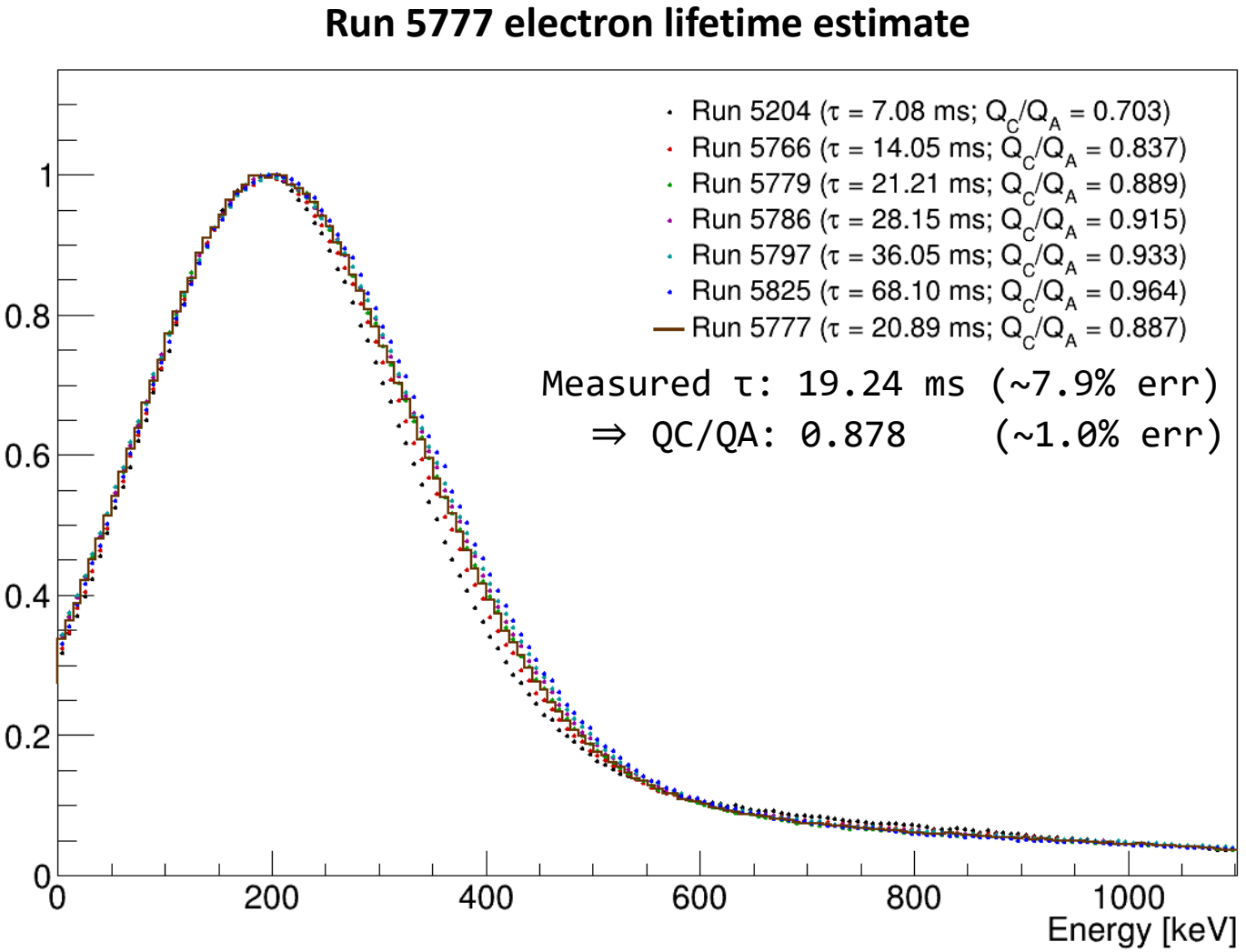
- High energy tail is due to cosmogenic background

- Minus the tail, the reconstructed end-point is in the correct place (~ 565 keV)



Electron Lifetime Proof of Concept:

- Very rough proof-of-concept
  - Measured τ from purity monitor; enhanced by cosmic ray data
  - Script automatically estimates electron lifetime for selected runs (5777 and 5785) based on measurements from other data
  - Linearly Interpolate τ from the area of the difference of the spectra between 200 and 500 keV
- With rectangular window and rough method, QC/QA error around 1%



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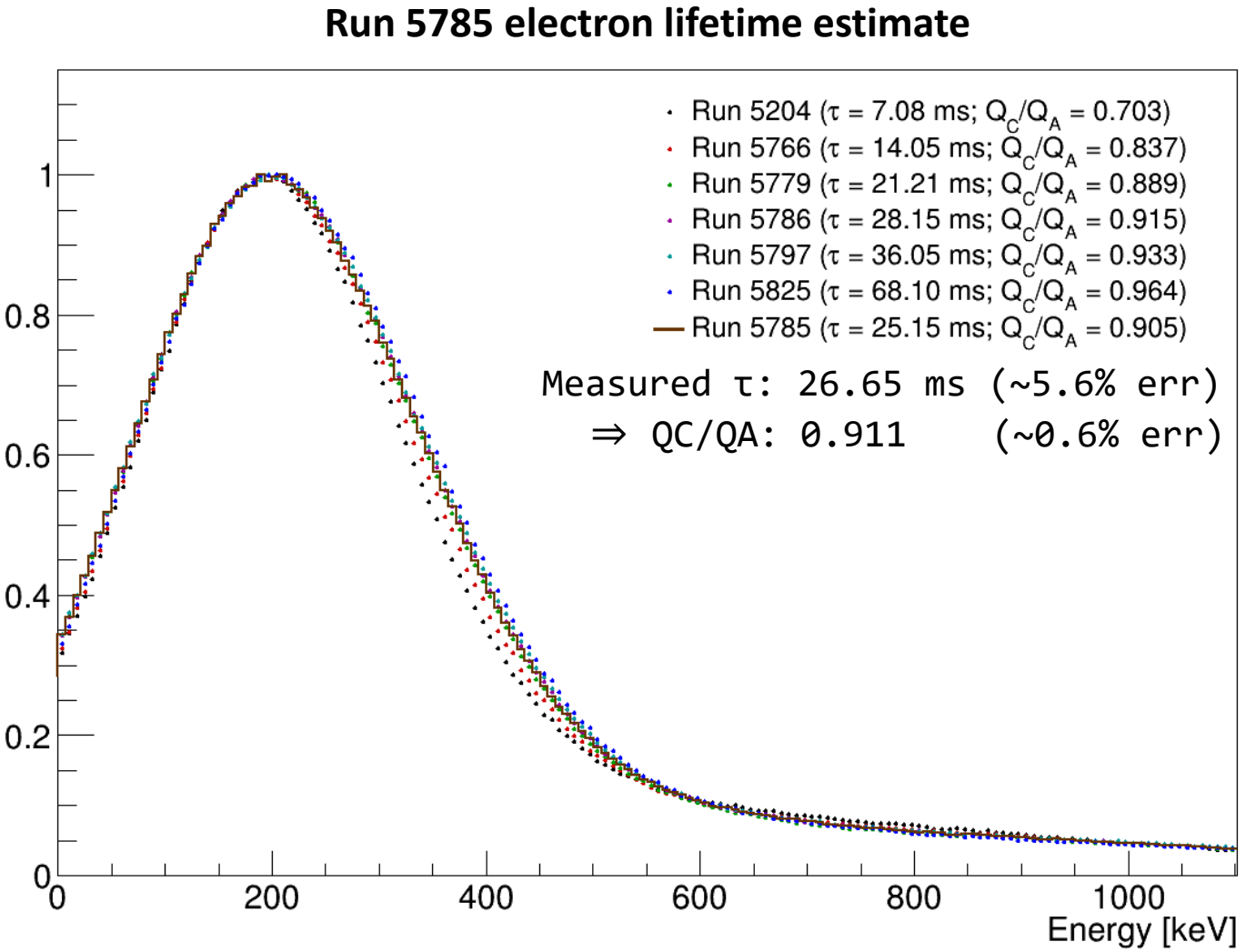
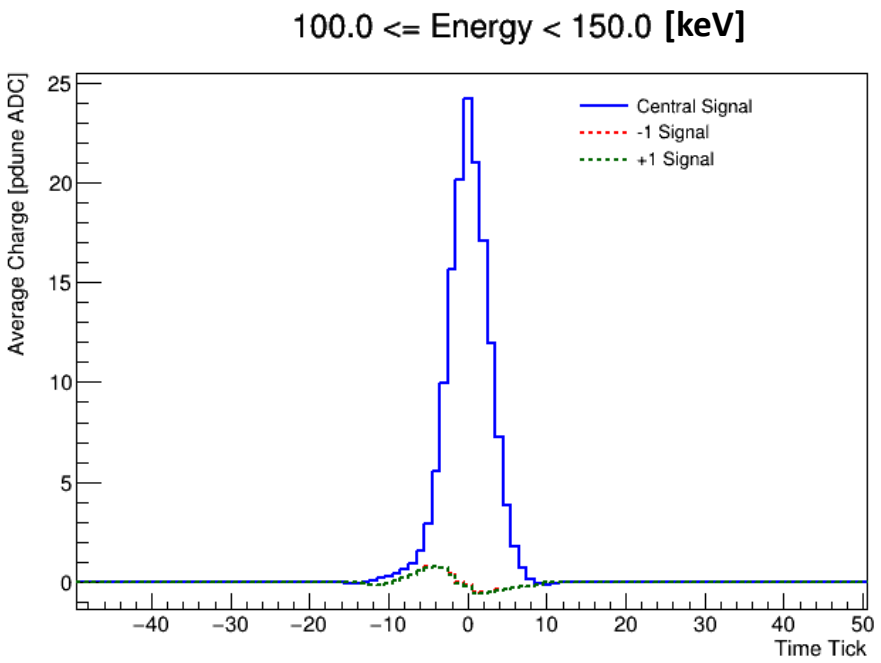
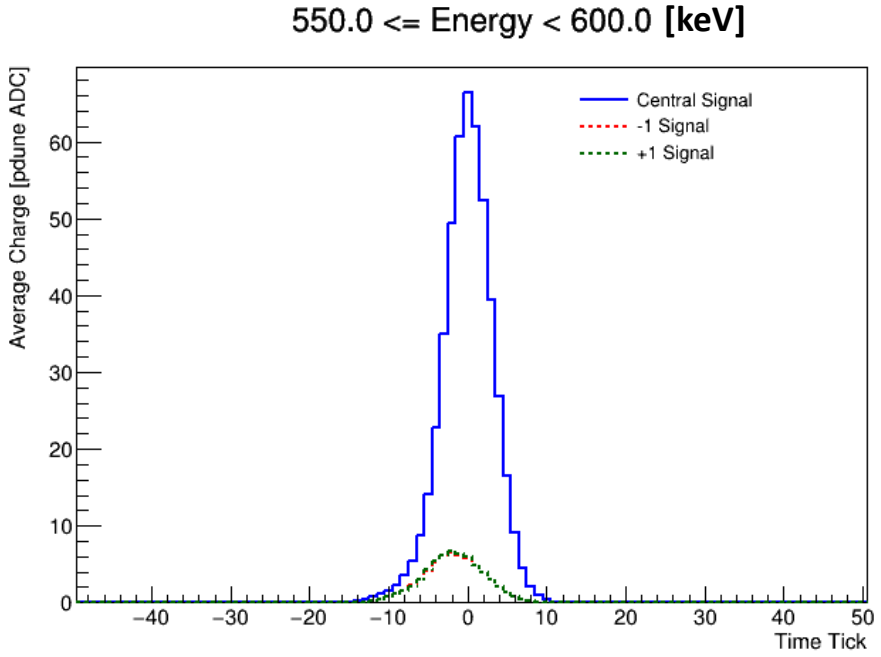


Improvements to ^{39}Ar Beta Decay Selection:

- Improve the integration window:
  - Asymmetric window allows tighter energy resolution, while keeping most of the charge
  - Integrate time ticks [-14, 10] on side wires; [-16, 12] on central wires
- Improve selection by excluding noisy channels
- Small improvements to stuck bit and electronics response mitigation
- Utilize energy-dependent recombination factor





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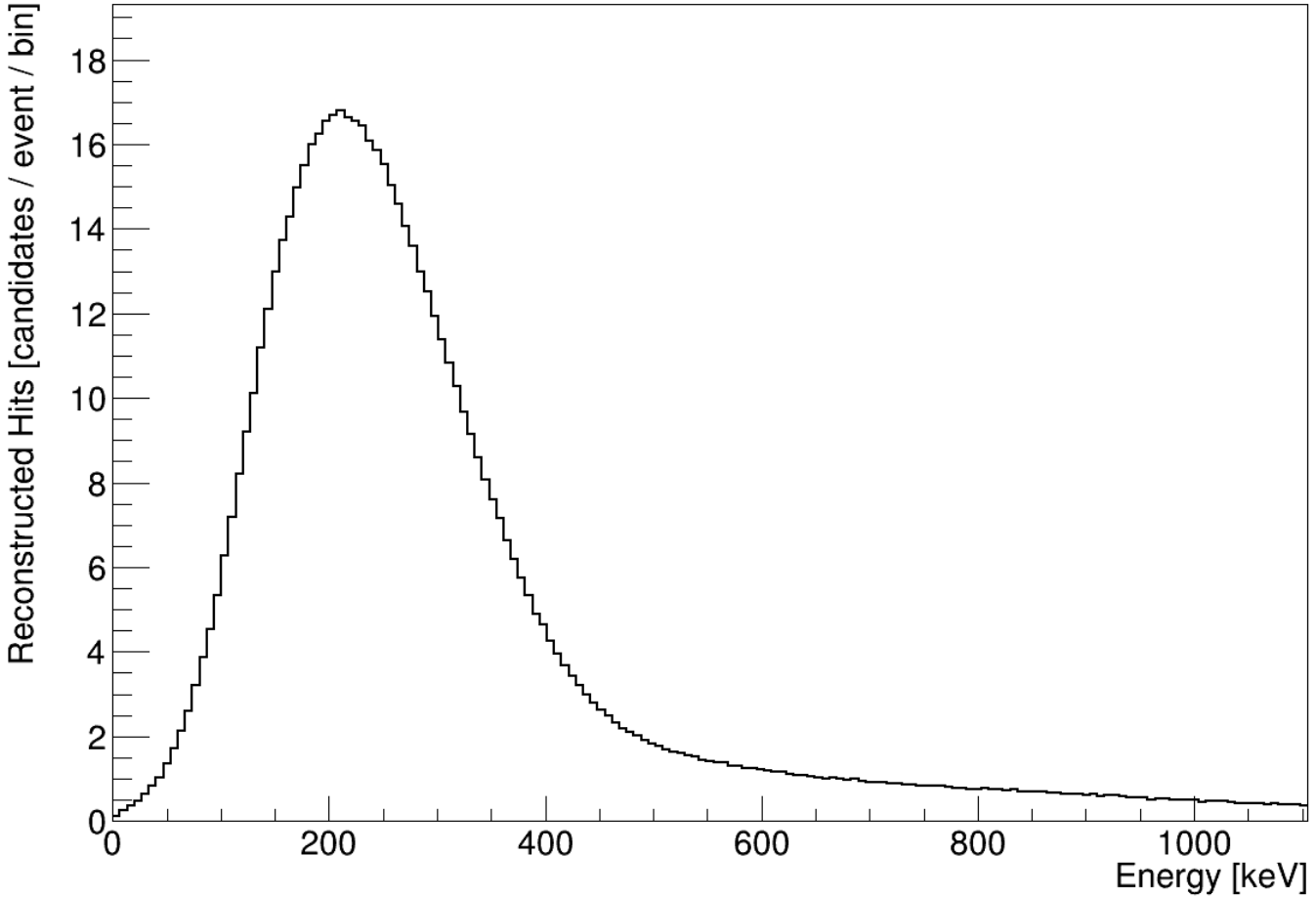
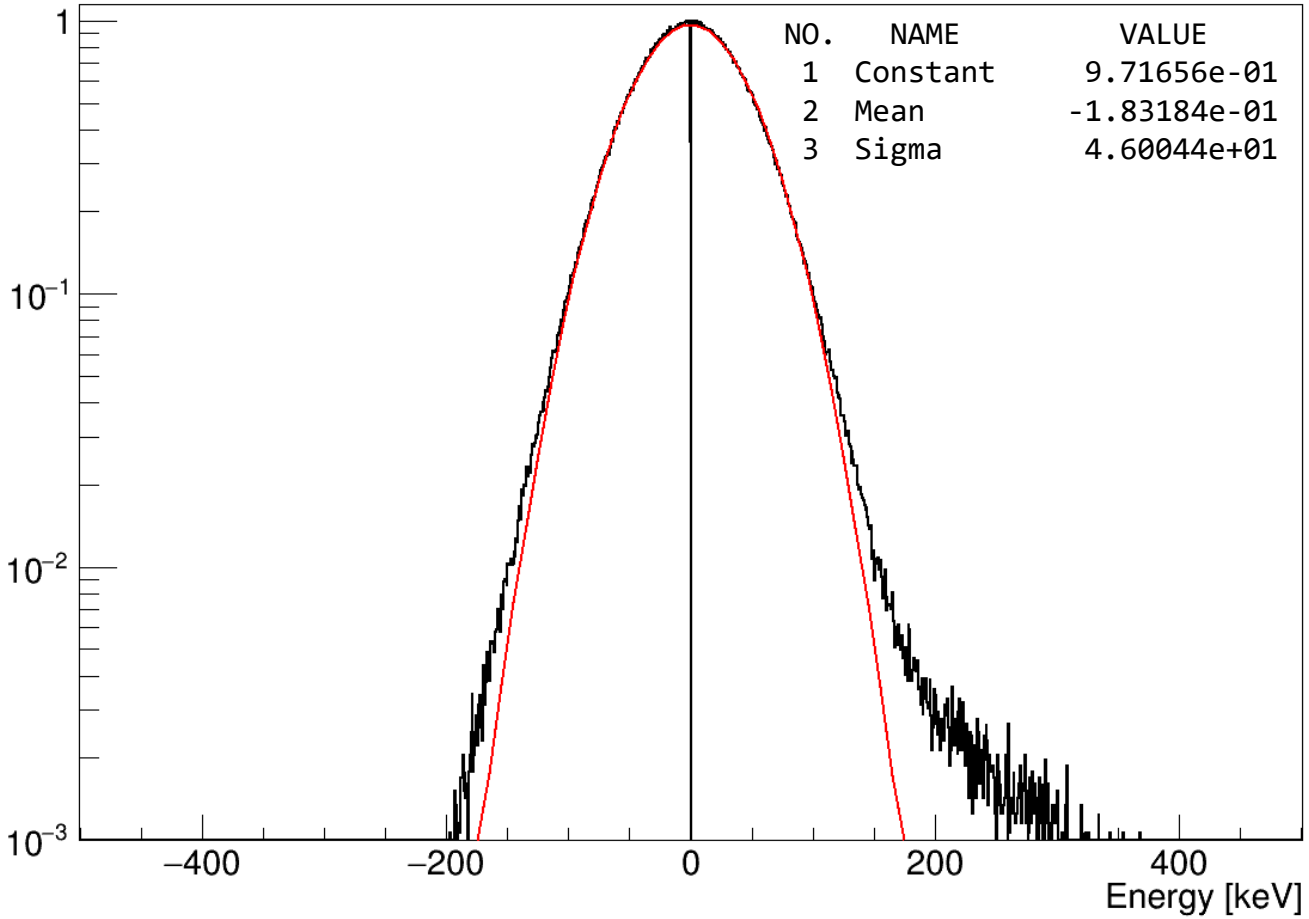


Improvements to ^{39}Ar Beta Decay Selection:

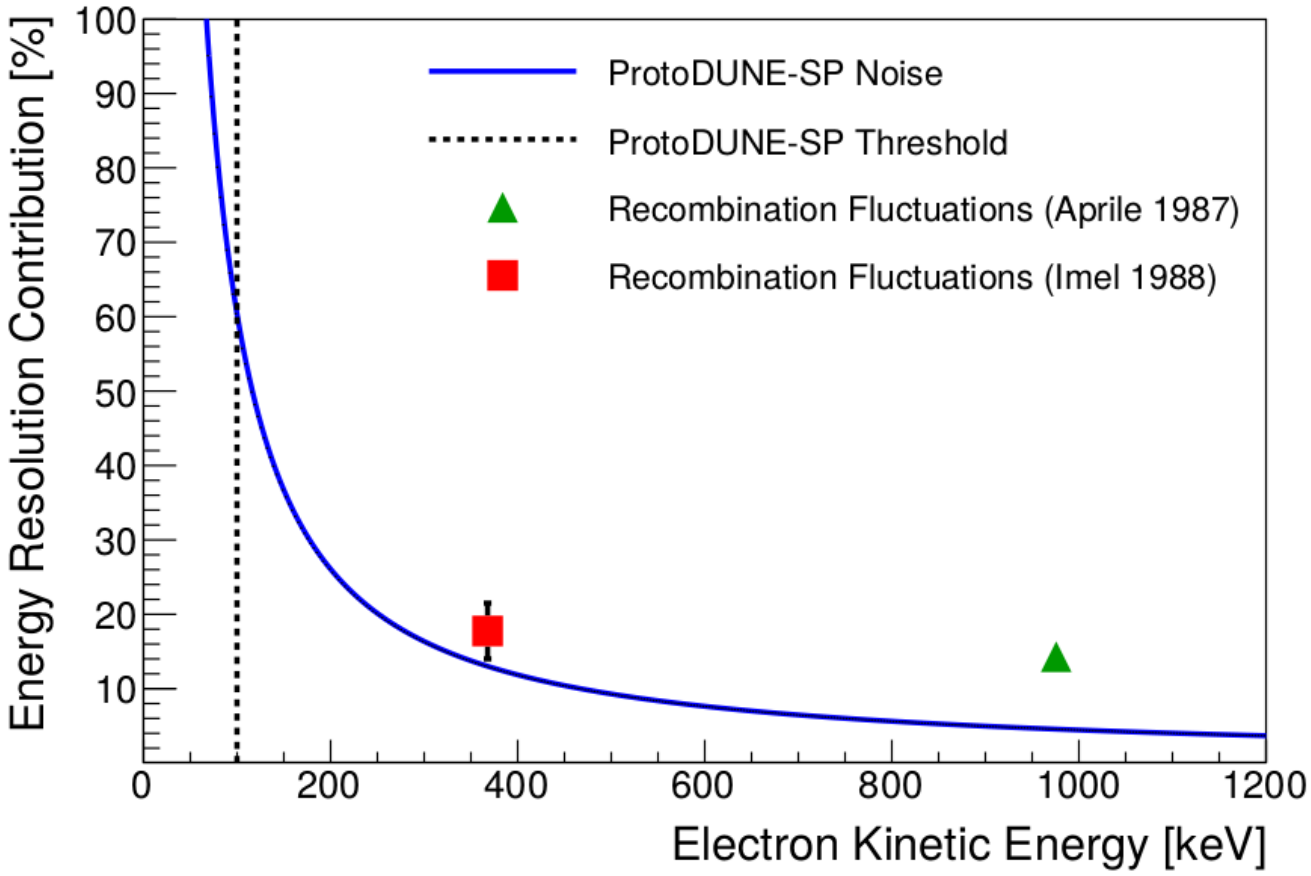
- After improving selection methods, studied noise
  - Sample random points in the detector, and reconstruct them as if they were beta-decay hits (no threshold)
  - Noise fits a gaussian distribution reasonably well; high tail due to occasional reconstruction of positive charge
- Estimate a limit on <u>energy resolution of 46 keV only due to noise at the ^{39}Ar beta decay end-point</u>



Improvements to ^{39}Ar Beta Decay Selection:

- At 46 keV, noise is not the main limit on energy resolution
- Expect ~16% (or ~90 keV) smearing at ^{39}Ar beta decay end-point from recombination fluctuations

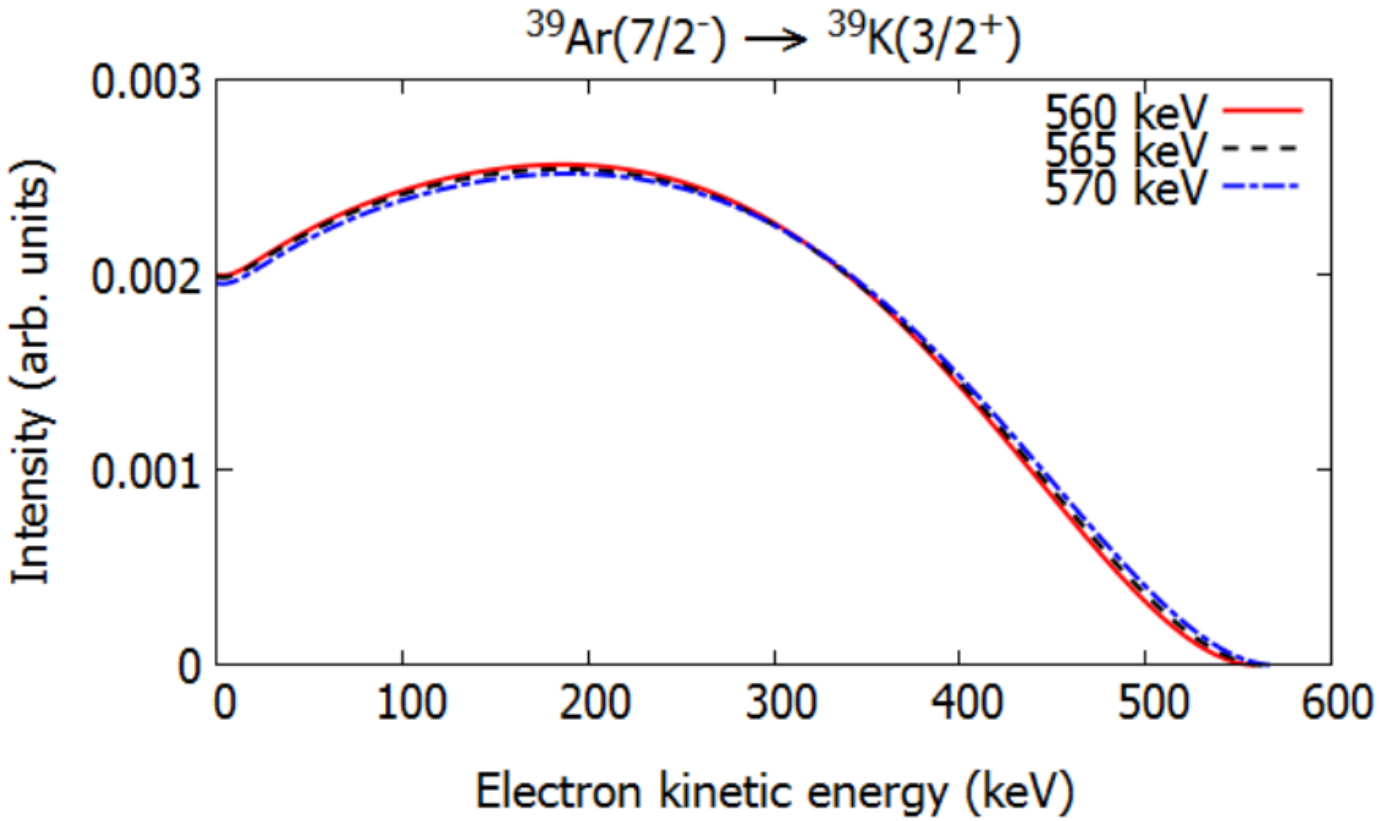
J. Thomas et al. *Statistics of charge collection in liquid argon and liquid xenon.* Phys. Rev. A 38, pg. 5793. (1988) https://journals.aps.org/pra/abstract/10.1103/PhysRevA.38.5793



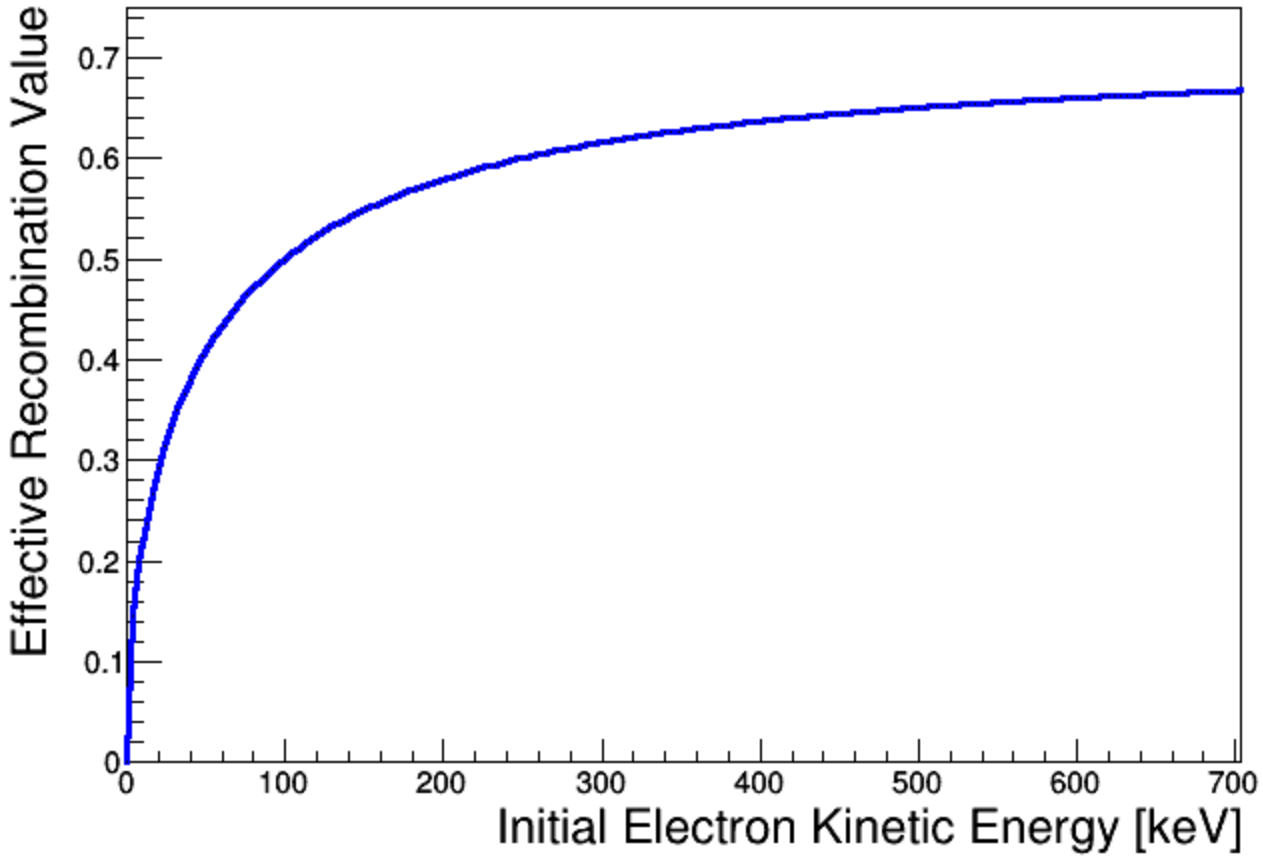
Conclusion:

- Showed a more quantitative estimate of electron lifetime utilizing reconstructed ^{39}Ar beta decays
- As we move closer to publishing, polished up the selection and reconstruction code for beta decays and other point-like activity in raw digits
- Estimated a 46 keV smearing due to noise, demonstrating that noise is not the dominant restraint to energy resolution for measurement of electron lifetime or ^{39}Ar beta decay rate

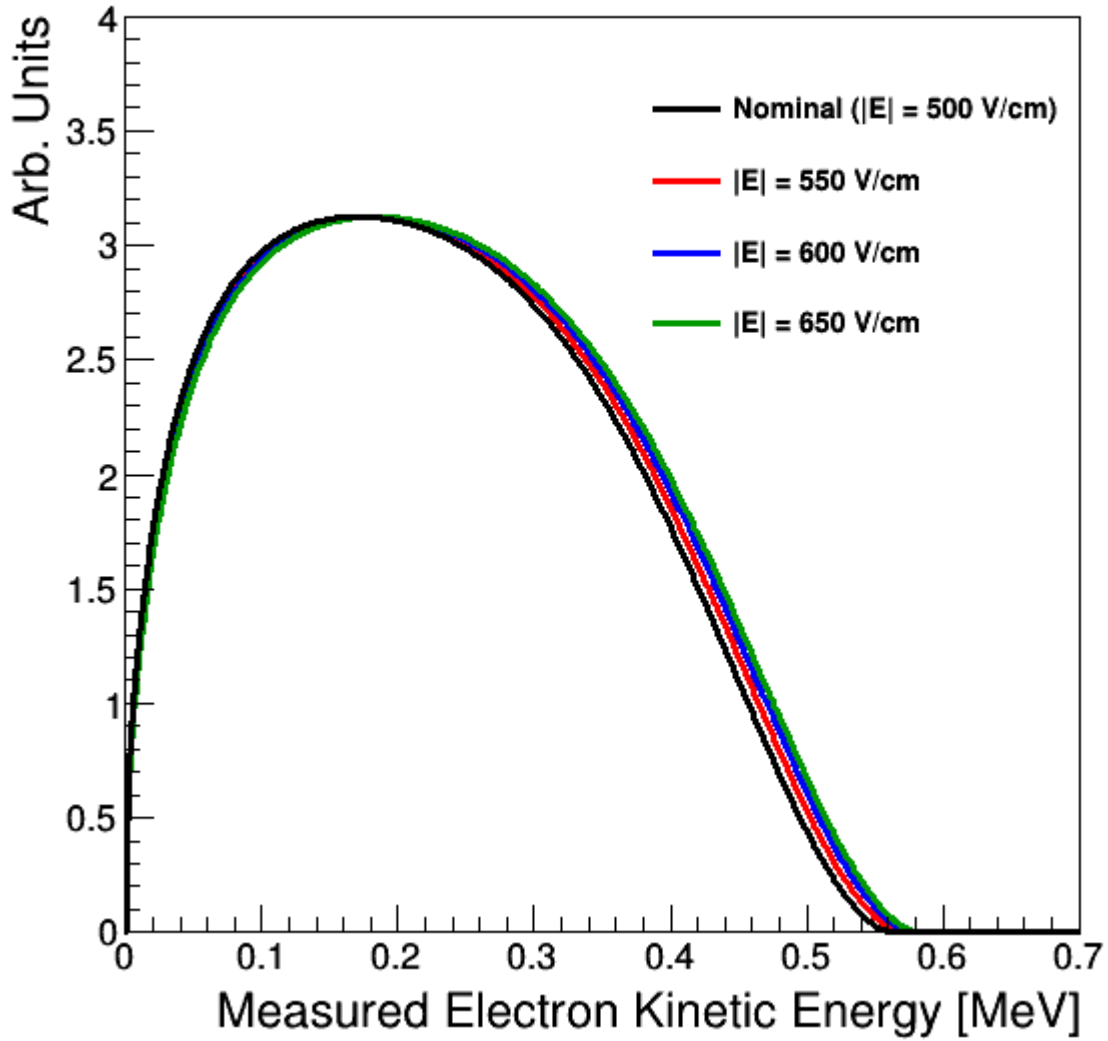
Theory uncertainties

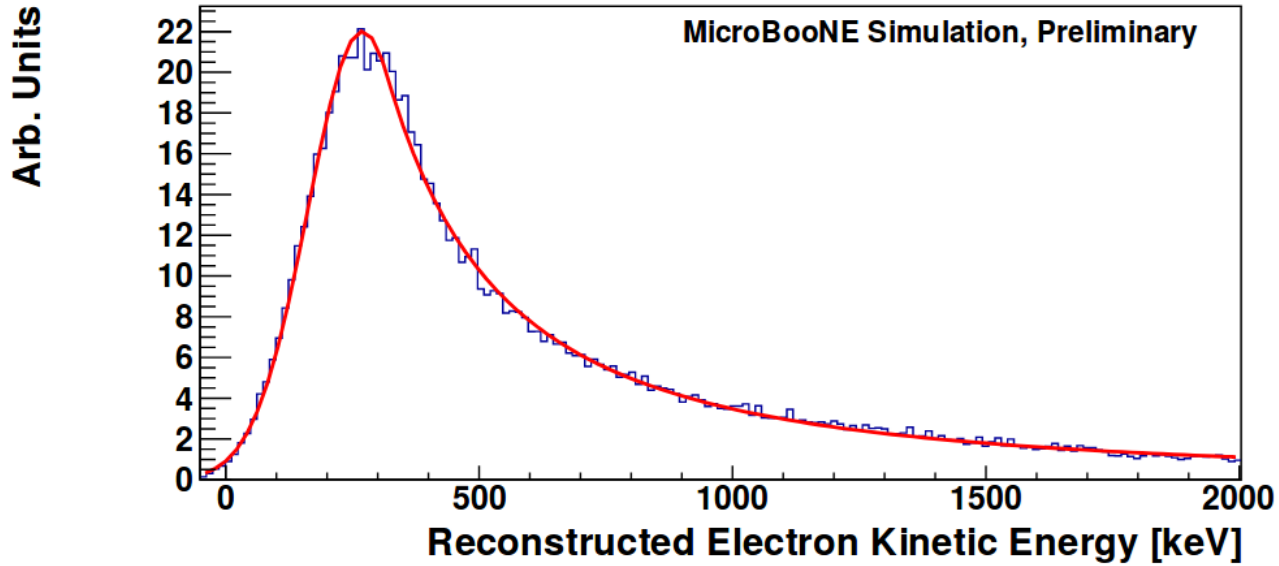


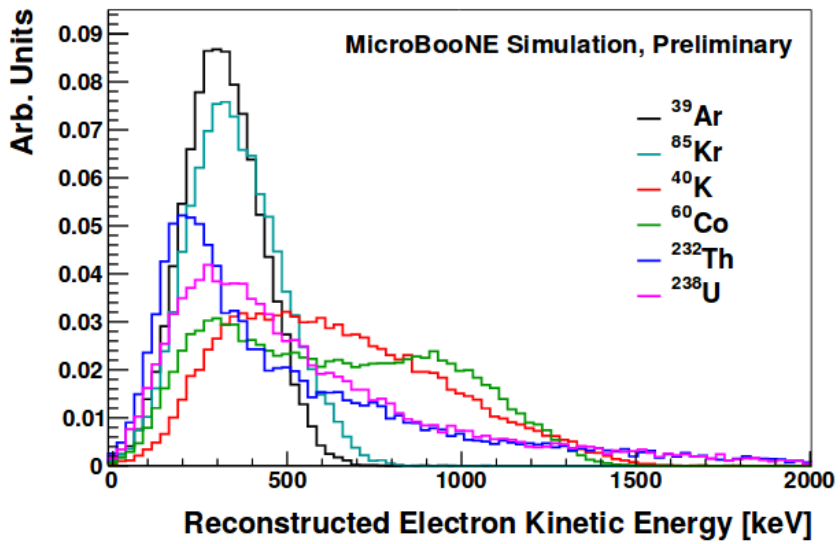
Credit: Kostensalo et al (2017). https://arxiv.org/pdf/1705.05726.pdf

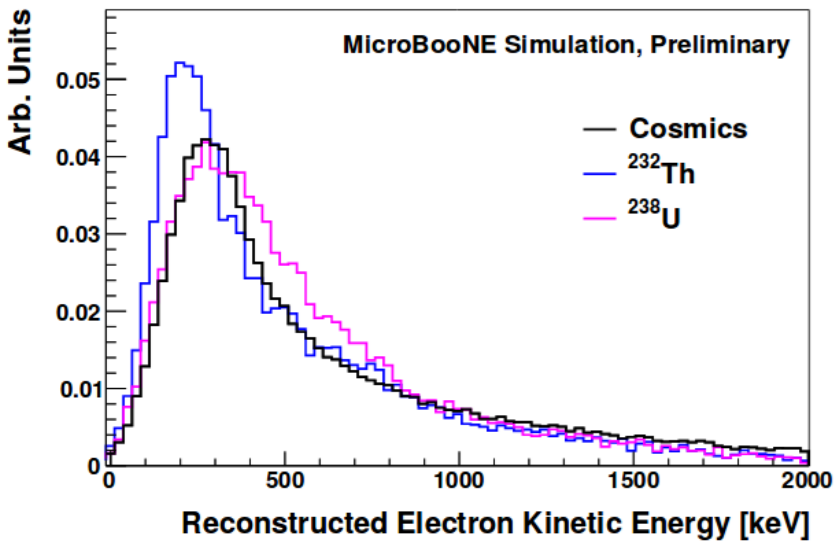

Effective Recombination Value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
100
200
300
400
500
600
700
Initial Electron Kinetic Energy [keV]

Effective E field distortions




MicroBooNE Simulation, Preliminary
Arb. Units
Reconstructed Electron Kinetic Energy [keV]


MicroBooNE Simulation, Preliminary
Arb. Units
^{39}Ar
^{85}Kr
^{40}K
^{60}Co
^{232}Th
^{238}U
Reconstructed Electron Kinetic Energy [keV]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