LOW ENERGY ELECTRON AND NUCLEAR RECOIL THRESHOLDS IN DRIFT-II

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For more information:
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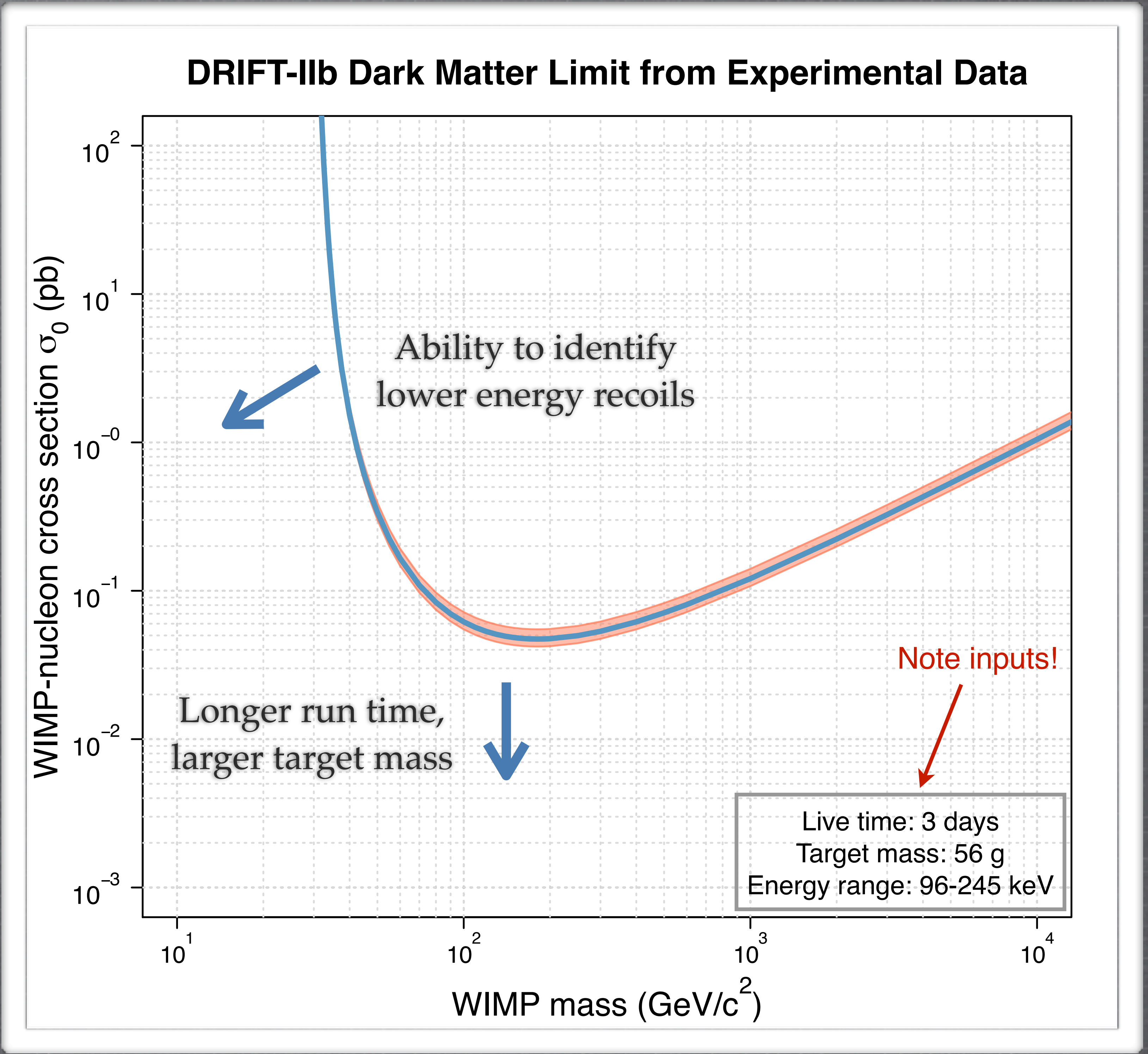
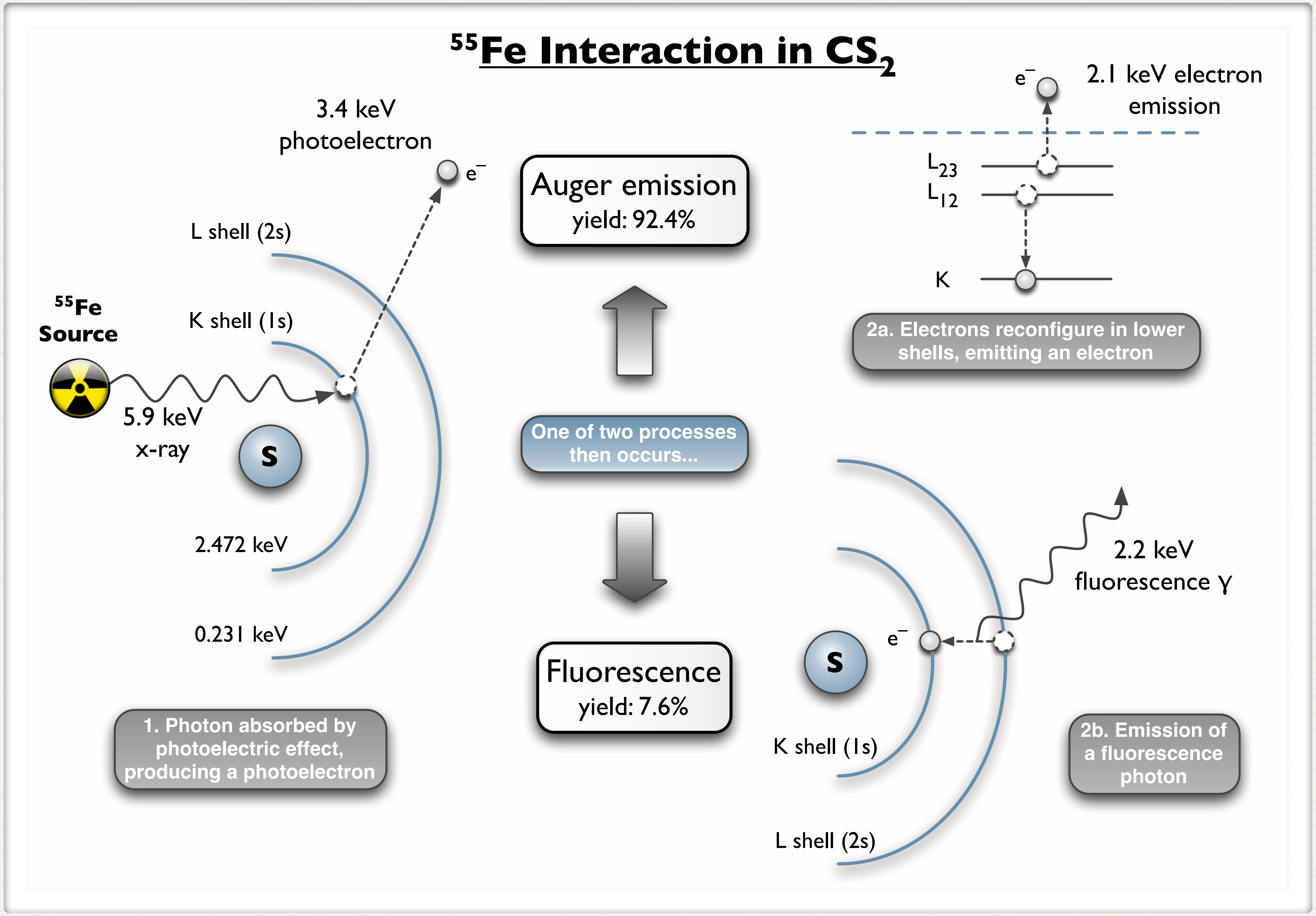
PhD Thesis: http://muna.postgrad.shef.ac.uk

Motivation For Improving Detector Sensitivity

- Improve limit setting capability
- Improve detector calibration
- Improve track reconstruction
- Improve background discrimination
- Via data analysis: free!
- Via new electronics: cheap!
- New physics opportunities (e.g. KK axion search)



^{55}Fe Calibration



Energy Spectrum

Full aborption peak: 1 + 2a, 5.895 keV
Escape peak (γ escapes): 1 + 2b, 3.4 keV
Third peak: 2.2 keV fluorescence γ

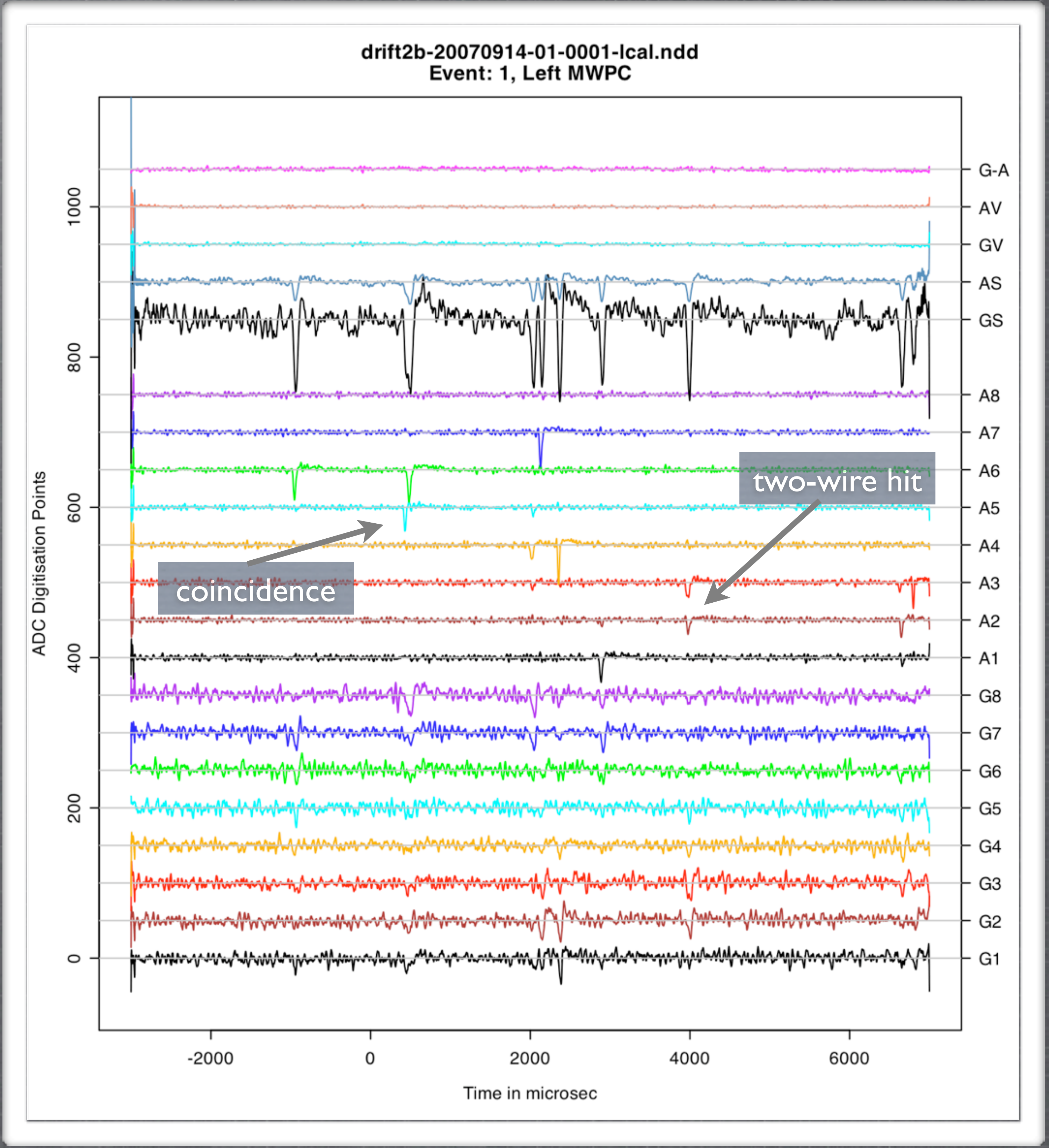
^{55}Fe Energy Spectrum

- In smaller detectors, the fluorescence γ (mean free path of 21 cm in 40 Torr CS_2) escapes, but DRIFT is large enough to capture many of these events, though at a distance and are thus uncorrelated.
- The number of fluorescence γ captured depends on the detector geometry.
- A Monte Carlo simulation indicated that the counts of the fluorescence γ peak should be 6% of the full absorption peak, i.e. 79% of the fluorescence x-rays do not actually escape.

^{55}Fe Event Record

- At least 10 events in record
- Events are ~1-2 mm in range
- ~50% fall on a single wire, ~50% register on two

- Thus, DRIFT cannot be used as a simple event counter – track reconstruction must be applied, even for calibration.

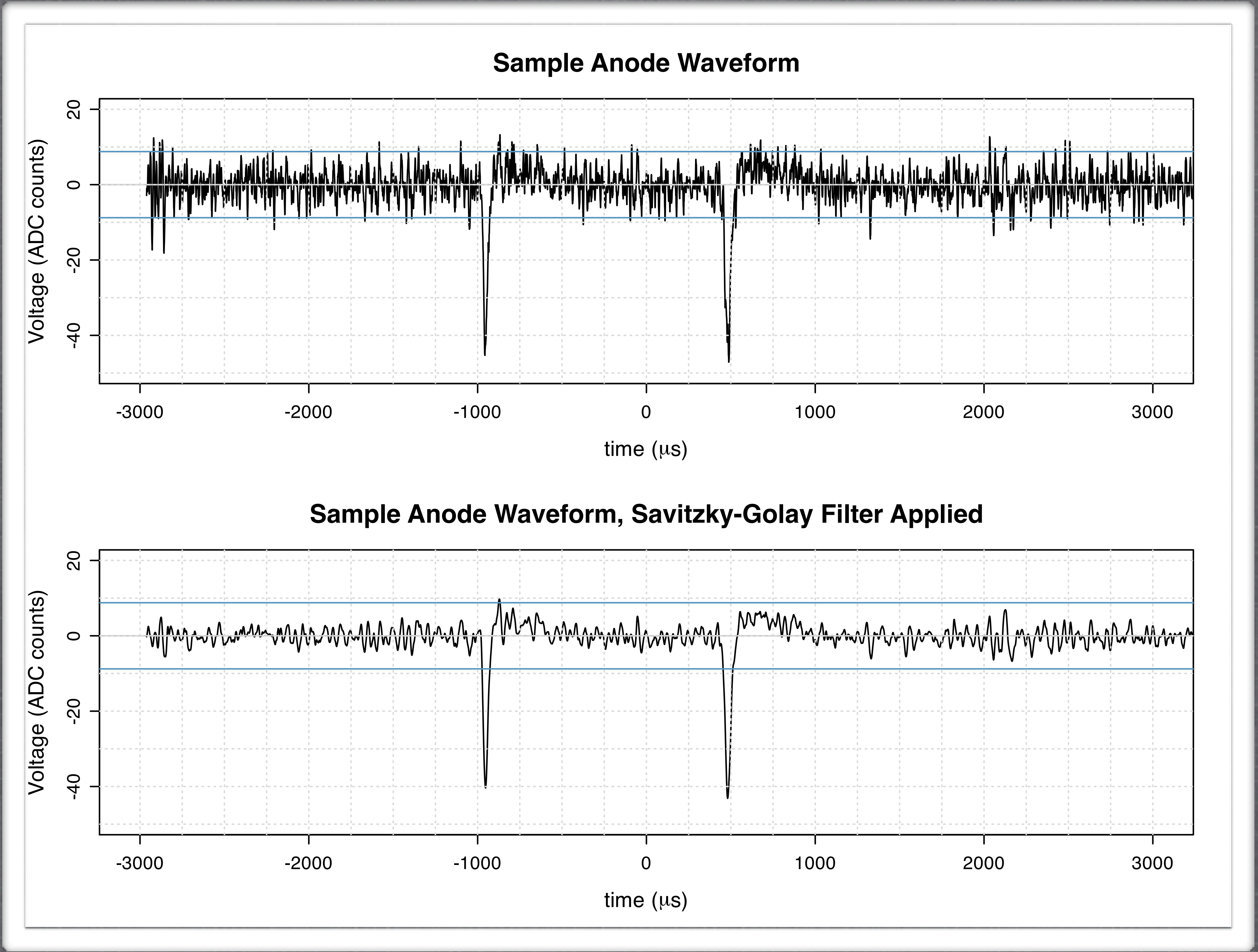


A1-A8: Anode readouts
G1-G8: Grid readouts
AS: Sum of anodes
GS: Sum of grids

Waveform Smoothing

- Detector has 55 kHz noise, easily removed in post-processing via Fourier analysis.
- However, more noise remains that limits the energy sensitivity– waveform smoothing can correct for this.
- Boxcar smoothing retains pulse area, but does not preserve height, width, etc.
- Digital polynomial smoothing (Savitzky-Golay) preserves pulse area, center of gravity, line width, and symmetry. A fourth order fit was chosen over a 65 μs (65 samples) smoothing window.
- Reduces noise level by a factor of ~5.

Improvement From Smoothing

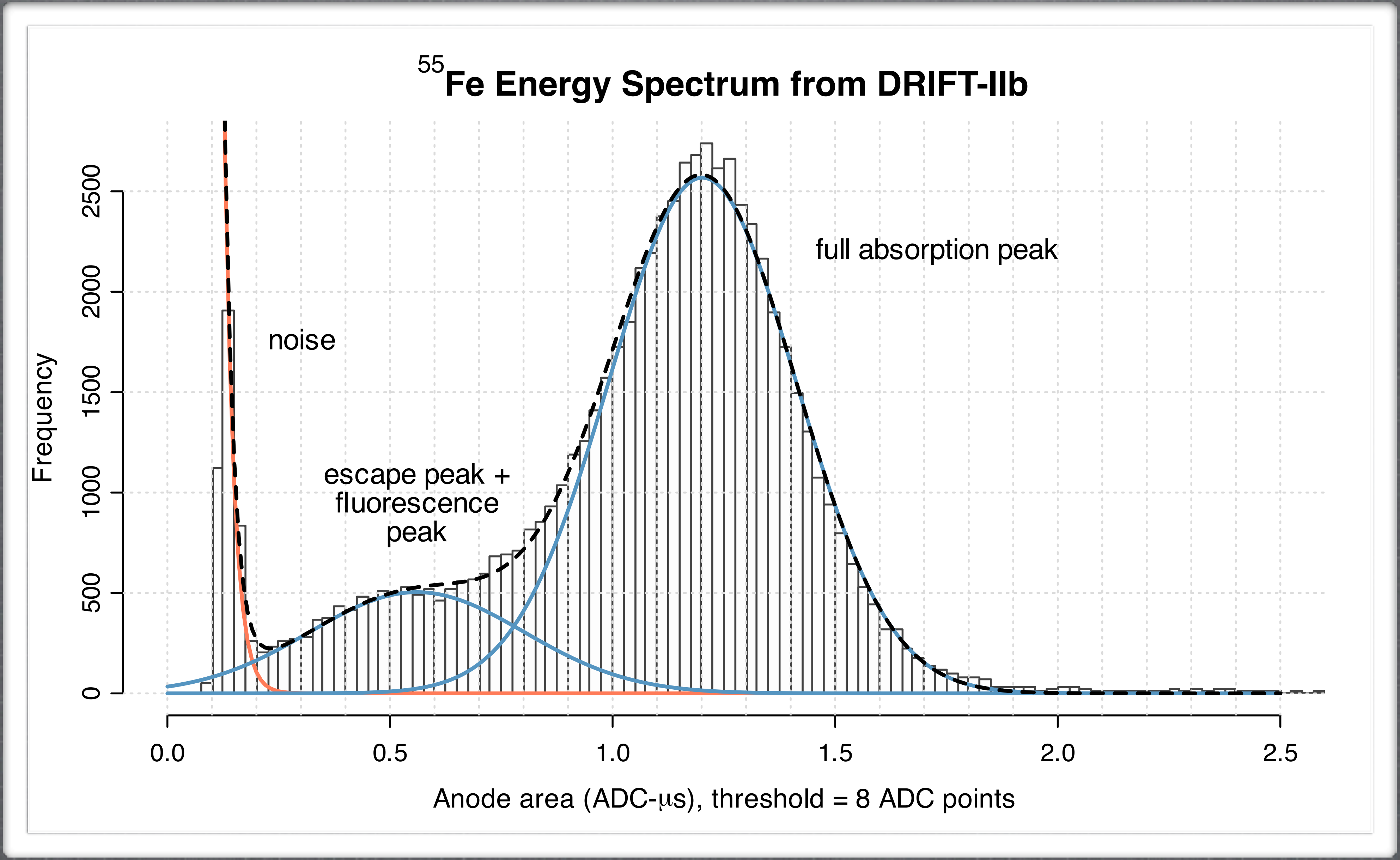


These signals are obvious, but we're interested in ones that are as close to the noise as we can get. Threshold shown is 4σ above the noise.

Data Run

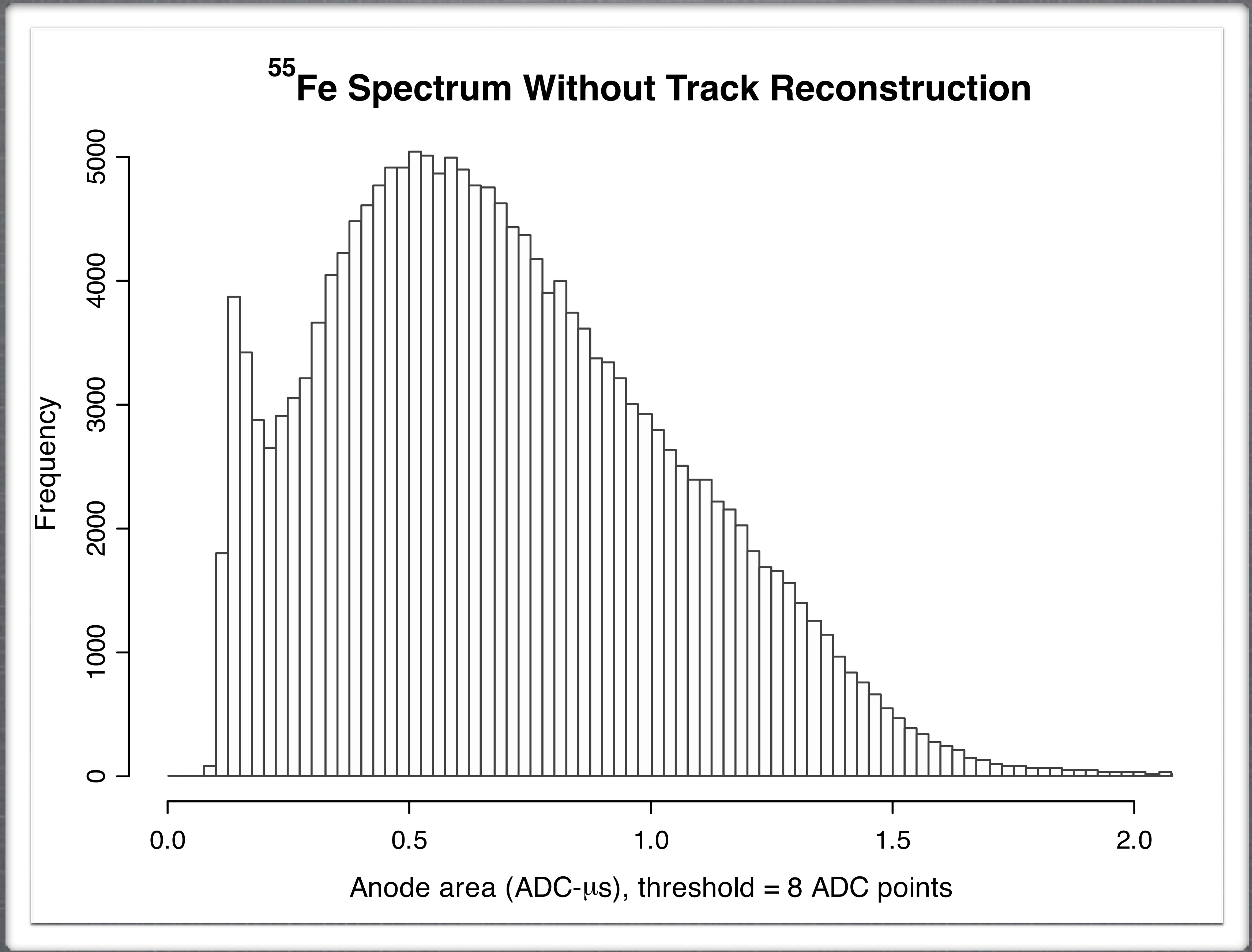
- The data used in this analysis was collected continuously over an hour to produce high statistics (a typical ^{55}Fe calibration is a couple of minutes).
- The detector was run in a triggerless mode.
- The resulting spectrum is modeled as the sum of three functions:
  - noise peak (an exponential function)
  - full absorption peak (Gaussian)
  - the escape peak + the fluorescence peak (Gaussian) - these are too close together (2.2 keV, 3.4 keV) to be expected to be resolved.

^{55}Fe Energy Spectrum From Experiment



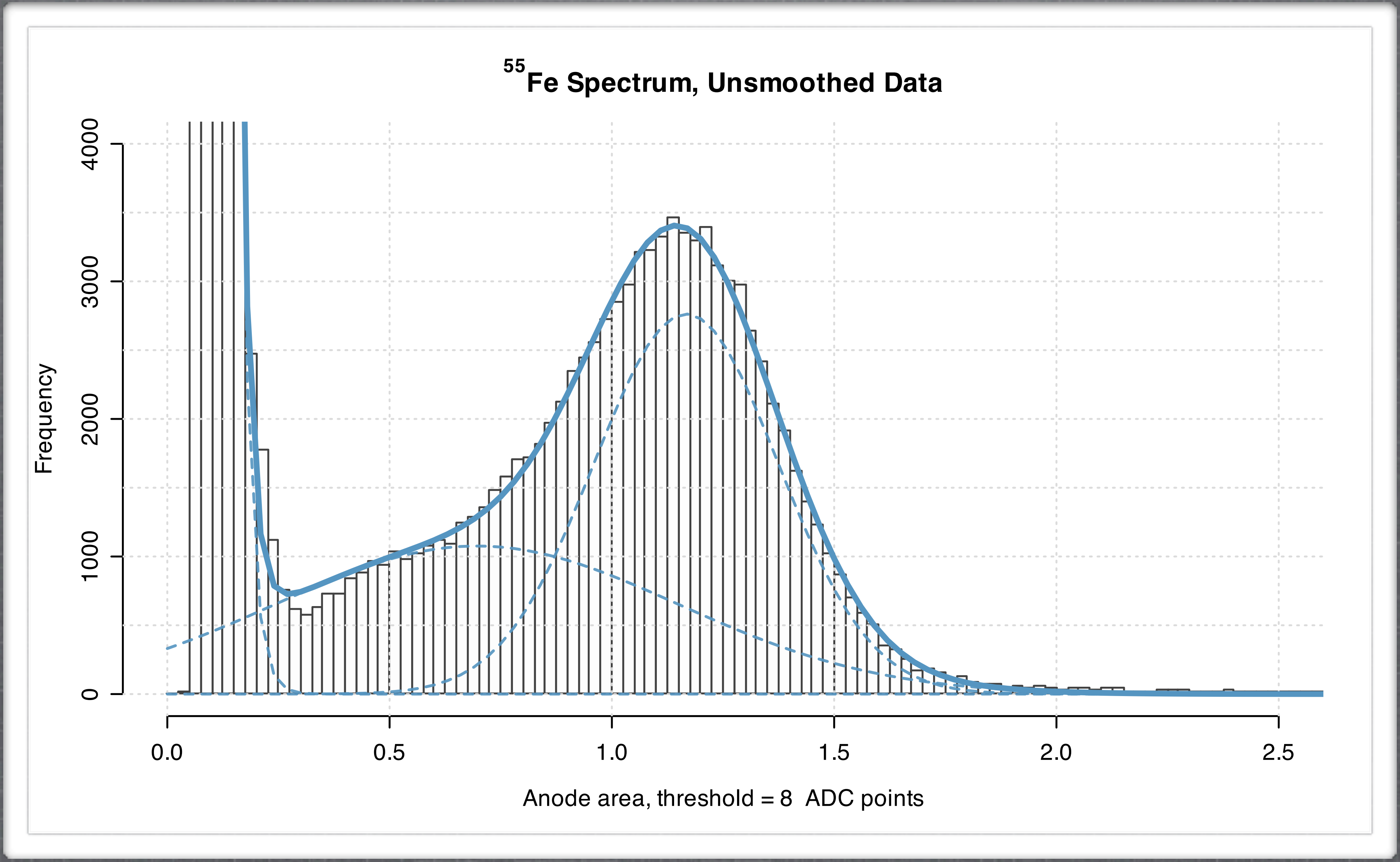
Clear separation between full absorption peak and escape + fluorescence peak.
Also clear separation from noise peak.
This plot yields a detector resolution of 17.5 ± 0.1% at 5.895 keV.

^{55}Fe Energy Spectrum From Experiment



Same data as before, but treating all events as uncorrelated i.e. no track reconstruction performed. An excess appears at lower energies, the full absorption peak is not significantly separated from the noise, and the calibration is not accurate.

^{55}Fe Energy Spectrum From Experiment



What did the smoothing alone do for us? The mean position of the full absorption peak is nearly the same, but the resolution is noticeably worse, and lower energy features are washed out.

Energy Sensitivity

- Given $W = 21$ eV, full absorption peak = 280 NIPs
- Lowest energy of physics event (i.e. above noise) is ~58 NIPs. Use this value to convert to eV scale for other particles.
- *W* value depends on the incident particle and its energy.
- This experiment sets the lowest energy bounds that the DRIFT-IIb technology can attain.

$$N = E / W(E)$$

N: number of ion pairs (NIPs)
E: energy of incident particle
W: *W*-value (taken as 21 eV)

Best Energy Sensitivity

Source of Track	Energy (keV)
Electron	1.22
Alpha particle	1.10
Carbon nuclear recoil	1.93
Sulphur nuclear recoil	2.90

Energy Sensitivity – *Should* We Go That Low?

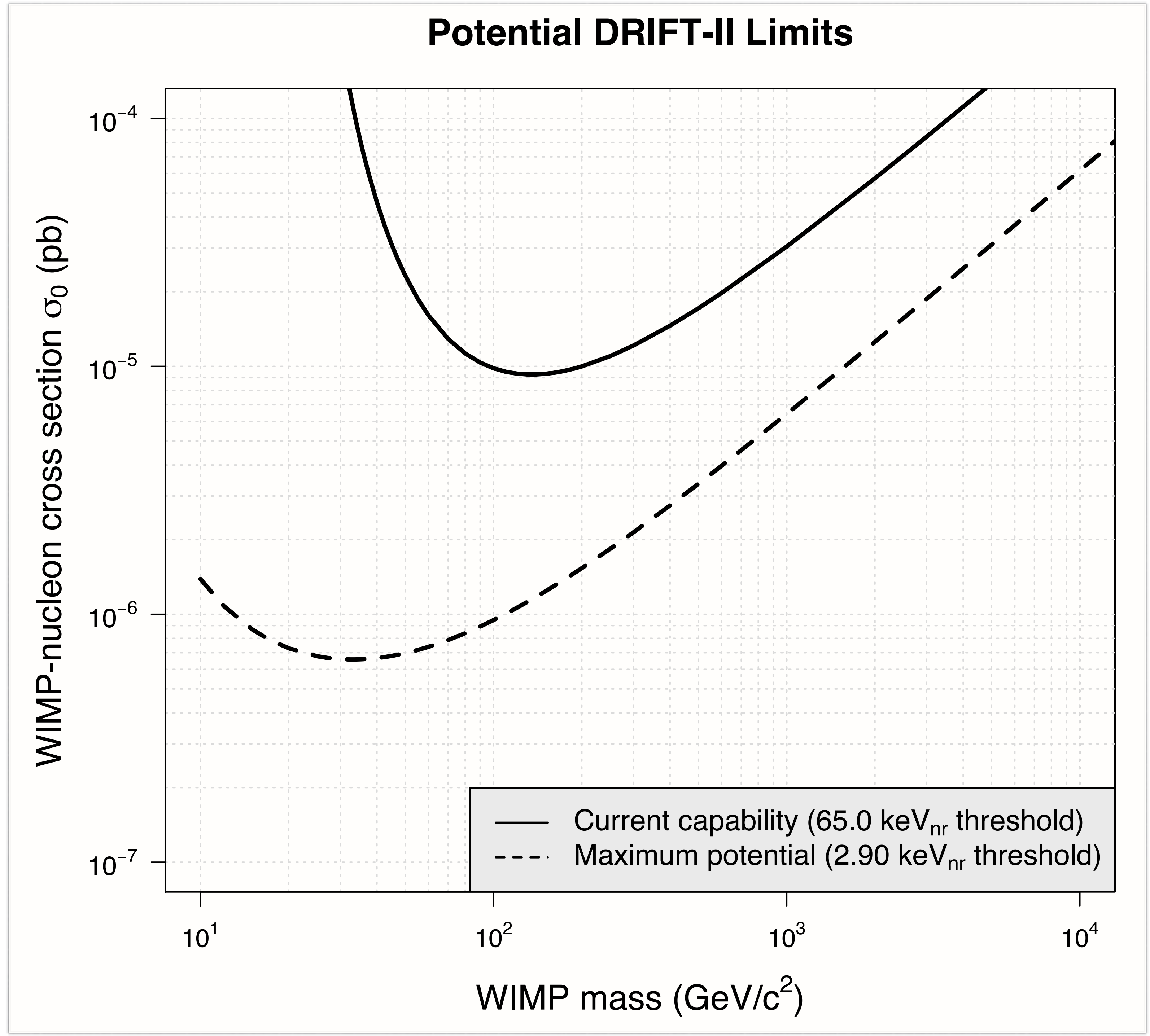
- From Anne Green's talk, we know below a certain energy there is minimal benefit (and we're well past that energy).
- There is certainly no directionality on this energy scale – events are isotropic.
- The answer is *yes* – there are benefits to be had:
  - better track reconstruction for range measurement
  - better energy measurement
  - both contribute to better background discrimination
  - better limit setting for low WIMP masses (but mainly the points above)
- OK, not *that* low, but we can go much lower...

Implementing In A Real Time Trigger

- Many of the signals used here fall well within the raw data.
- All improvements shown involve a fair amount of post-processing.
- However, the noise removal and smoothing can be done in real time. The DAQ can trigger on this smoothed data, but record the raw data to disk.
- Improvements to the electronics to remove known noise (e.g. the 55 kHz signal) can simplify things further.
- Caveat: Most of the events recorded occur within ~25cm of the MWPC, or half the drift distance. Events that occur further will undergo greater diffusion, and the minimum energies measurable will be higher.

Effect Threshold Improvement On The Limit

Reality is somewhere in the middle...



Limit Assumptions
Target: CS_2
Live time: 1 year
Zero background
Target mass: 113 g (S)
Detector Efficiency: 80%