The Mu2e experiment: STM Detector.

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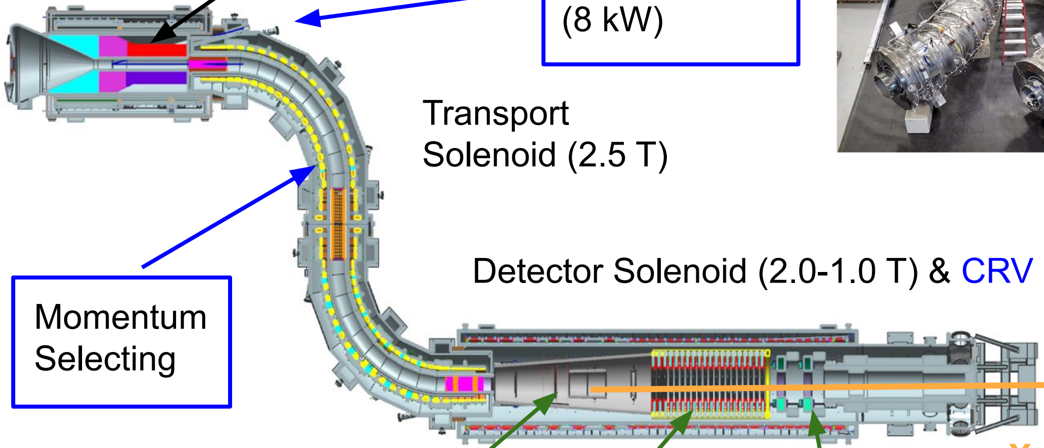
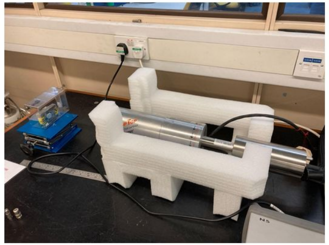
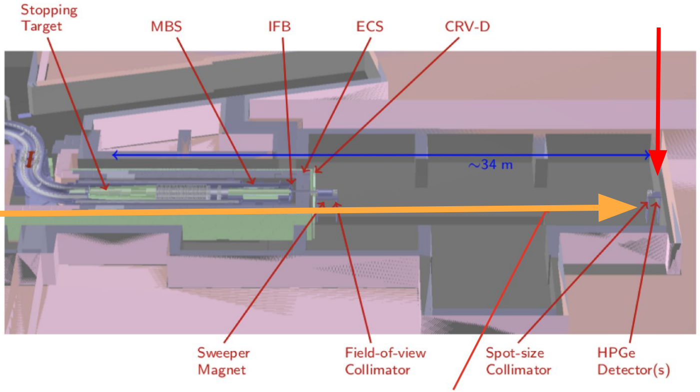
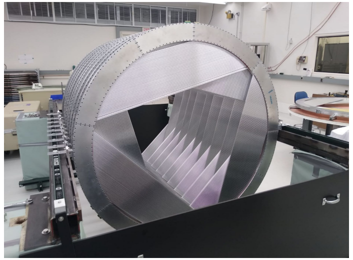




STM Detector:
HPGe and LaBr



Polyethylene Absorber



35 m

Sensitivity of 8×10^{-17} requires 10^{10} muons/s to interact with the aluminium (stopping) target.

Muons (< 75 MeV/c) are captured by the aluminium and in that process characteristic X-rays are emitted.

We detect these X-rays 35m away from the target to “count the muons”.

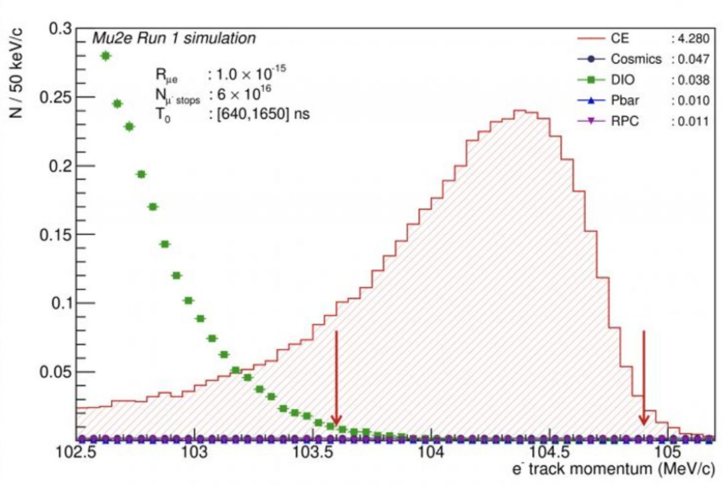
Mu2e measurement: Normalised to the number of nuclear-captured-muons.

Signal: monoenergetic electron near the muon rest energy.
The measurement is reported relative to the number of nuclear-captured muons and this number is determined measuring the X-rays emitted by Al nuclei.

Signal of conversion electron (CE) at 104.5 MeV

$$\mathrm{BR} = \frac{\Gamma\left(\mu^- + \mathrm{N} \rightarrow e^- + \mathrm{N}\right)}{\Gamma\left(\text{nuclear}\ \mu^-\ \text{captures}\right)}$$

X-rays measured by STM



Stopped/Captured muons.

$$\mathrm{BR}^{\mathrm{Al}} = \frac{\Gamma\left(\mu^- + \mathrm{Al} \to e^- + \mathrm{Al}\right)}{\Gamma\left(\mu^- + \mathrm{Al} \to \nu_\mu + \mathrm{Mg}\right)} < 8 \times 10^{-17} \ (90\% \ \mathrm{C.L}).$$

Ordinary muon capture on the nucleus

- Capture rate for Al is well-known from literature: 60.9% of stops.
- Stop rate:
  - 80% of stops emit 347 keV X-rays 2p-1s (1s orbit lifetime= 864 ns).
  - 31% of stops/ 51% of captures emit 1809 keV gammas.

$$\mu^- + ^{27}_{13}Al \to \nu_\mu + ^{26}_{12}Mg^* + n$$

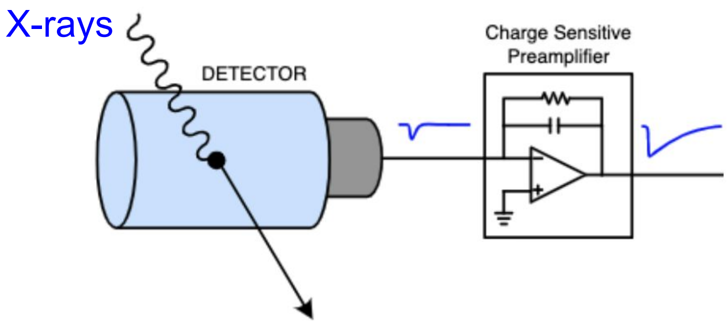
$$\to {}^{26}_{12}Mg + \gamma$$

  - 5.7% of stops/ 9.2% of captures emit 844 keV gammas.

$$\mu^- + ^{27}_{13}Al \to \nu_\mu + ^{27}_{12}Mg \xrightarrow{\beta^-\ (9\ \mathrm{min})} {}^{27}_{13}Al + e^- + \bar{\nu}_e + \gamma$$

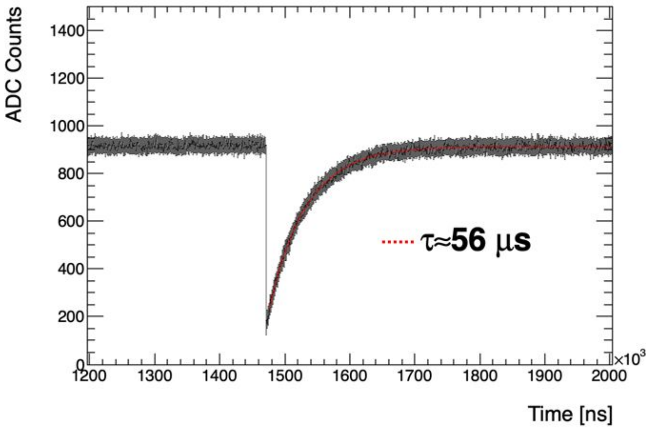
Measuring the energy deposited.

Detector: HPGe+preamplifier.



+

FPGA+ADC.



Signal measured from ADC:

- ADC Counts range from (−32768, +32767) and it's equal to a range voltage of -0.85 - 0.85 V peak to peak.
- The sampling rate of the ADC is 370 MHz i.e. one sample every T_0=2.7 ns. Figure in the right shows a typical pulse from the ADC with a time decay constant of τ≈56 μs.

MWD + Pulse Finding Algorithm.

- Signal.
- Deconvolution:

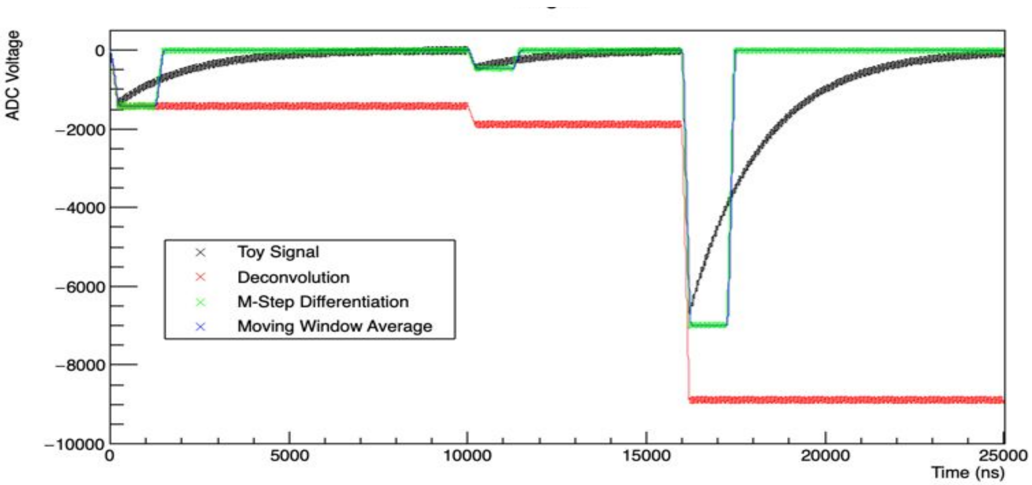
$$A[i] = V[i] - \left(1 - \frac{T_0}{\tau_{decay}}\right) V[i-1] + A[i-1]$$

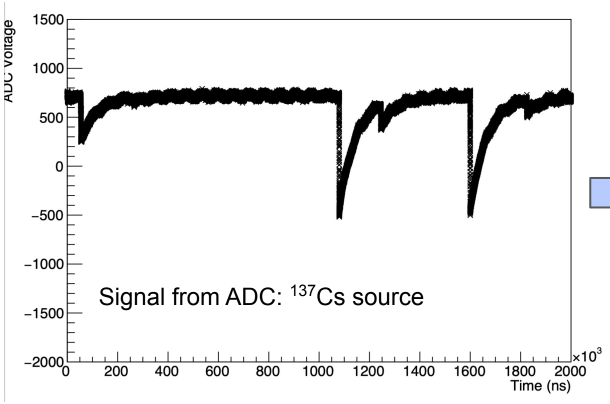
- Differentiation:

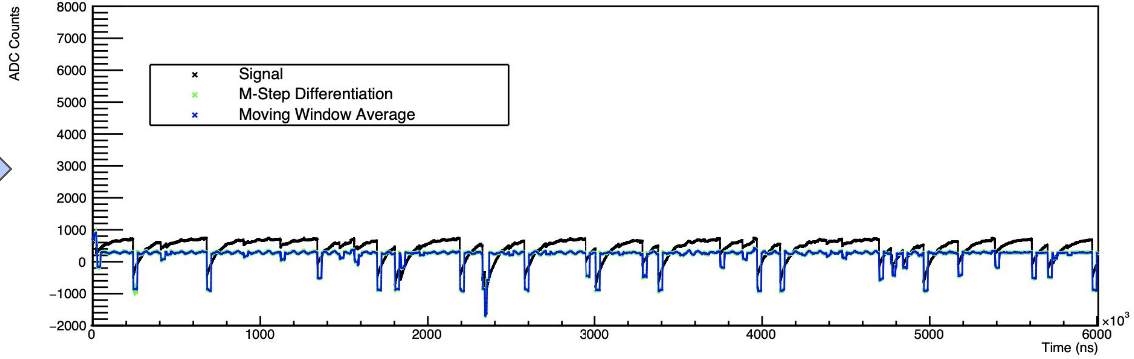
$$D[i] = A[i] - A[i-M]$$

- Averaging:

$$l[i] = \frac{1}{L} \sum_{k=i-L}^{i-1} D[k]$$



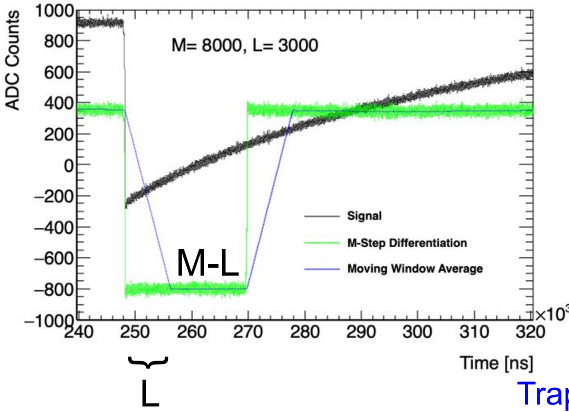


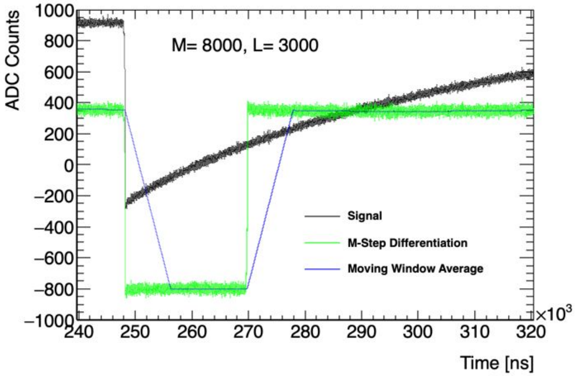


MWD parameters: Output shape.

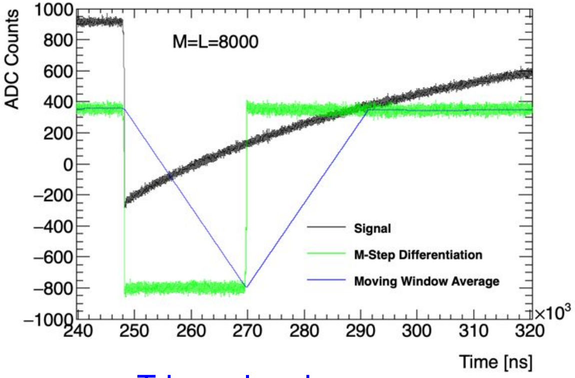
Shape of the signal: Trapezoid or triangle output.

The average is taken over L points resulting in a plateau for (M − L) time bins until the end of the M window is reached. Trapezoidal pulse shapes are generated for L < M, and a triangular one for L = M.





Trapezoidal shape



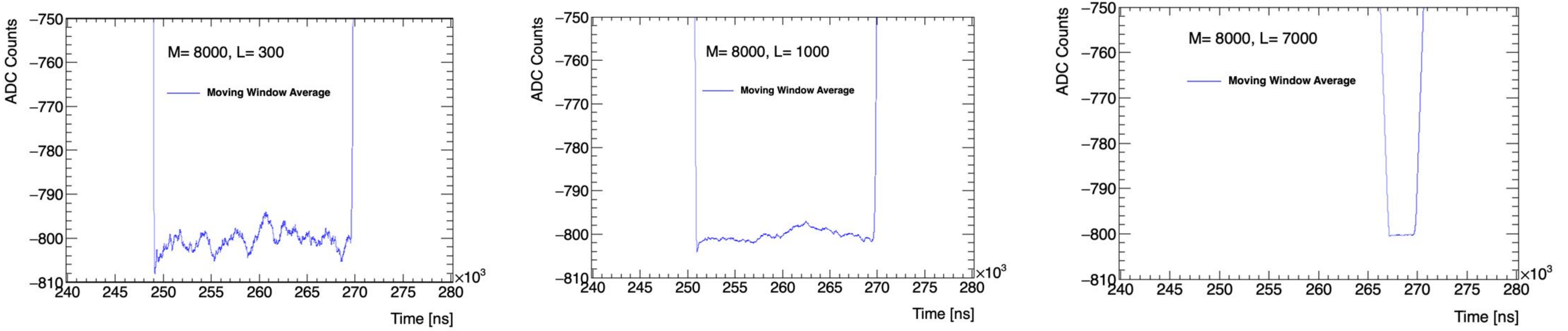
Triangular shape

For the trapezoidal pulse, the moving average leads to a signal with a flat plateau of size M − L, while the decreasing and increasing side of the trapezoid have a size L.

Study the optimal values for M and L.

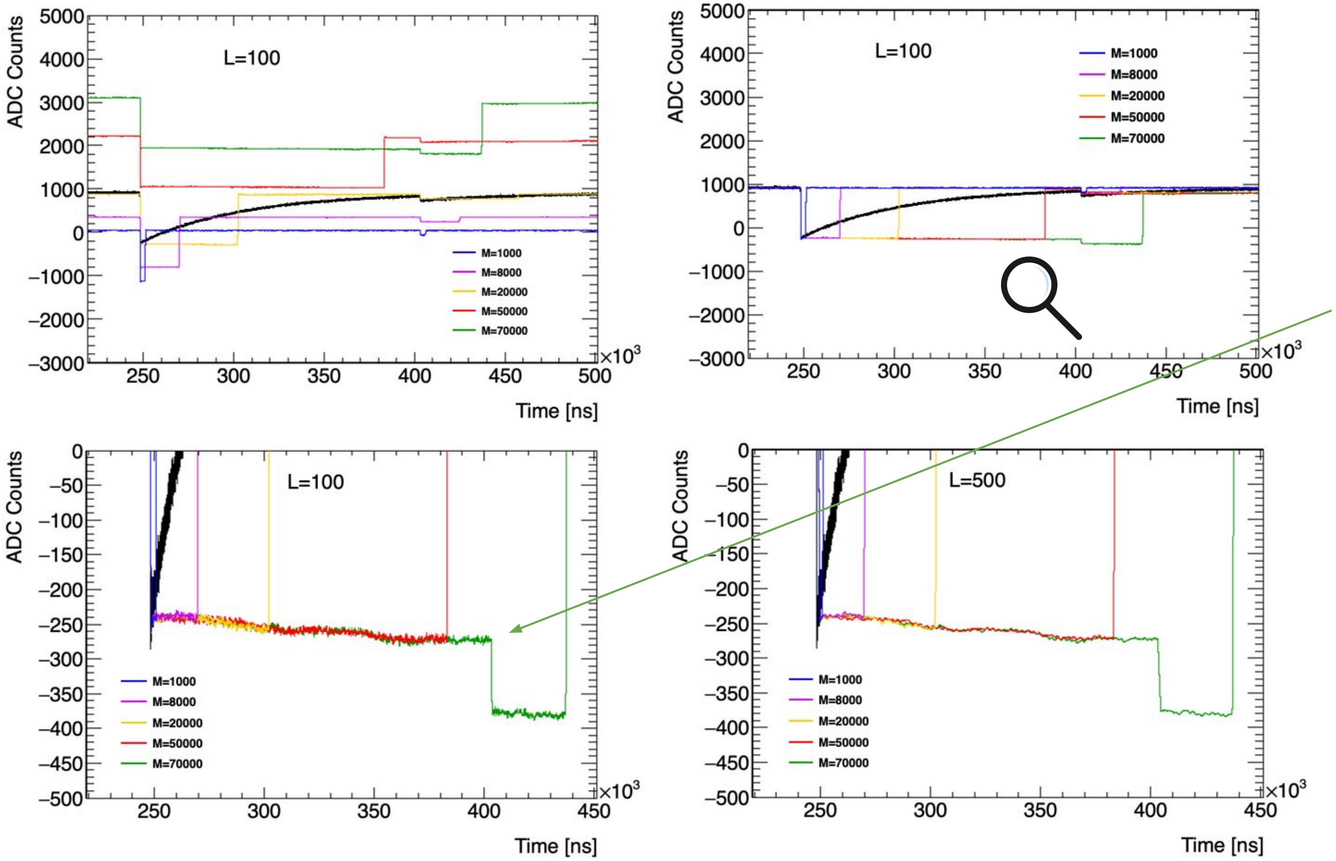
MWD parameters: L size.

If L is chosen such that L≪M then the MWD output is more strongly affected by the noise. But if L∼M is chosen then fewer plateau values are included in the average determining the pulse-height.



The Pulse Finding algorithm takes the minimum value to determine the height of the pulses.

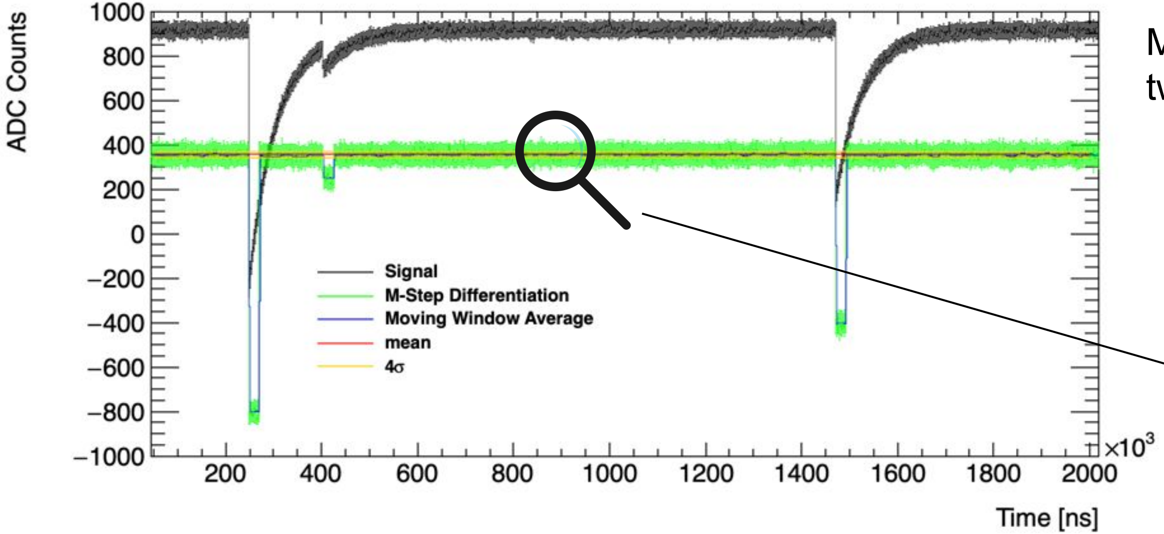
Optimizing MWD parameters.



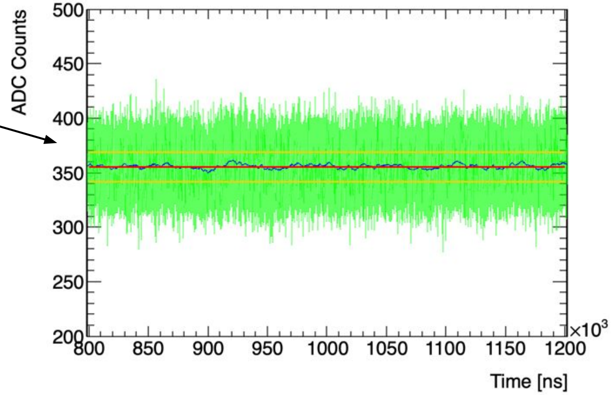
- The larger the M value, the larger the size of the step after deconvolving the signal but the Pulse Finding algorithm becomes less efficient for resolving overlapping pulses.
- For M=70,000, the two pulses are treated as a single pulse by the Pulse Finding algorithm because the trapezoid doesn't return to baseline after deconvolving the first peak.
- For increasing values of L, the average is taken over a larger number of ADC values and is less affected by noise.

MWD + Pulse Finding algorithms.

Pulse Finding algorithm input parameters: Baseline and threshold x st.dev of noise from MWD output.



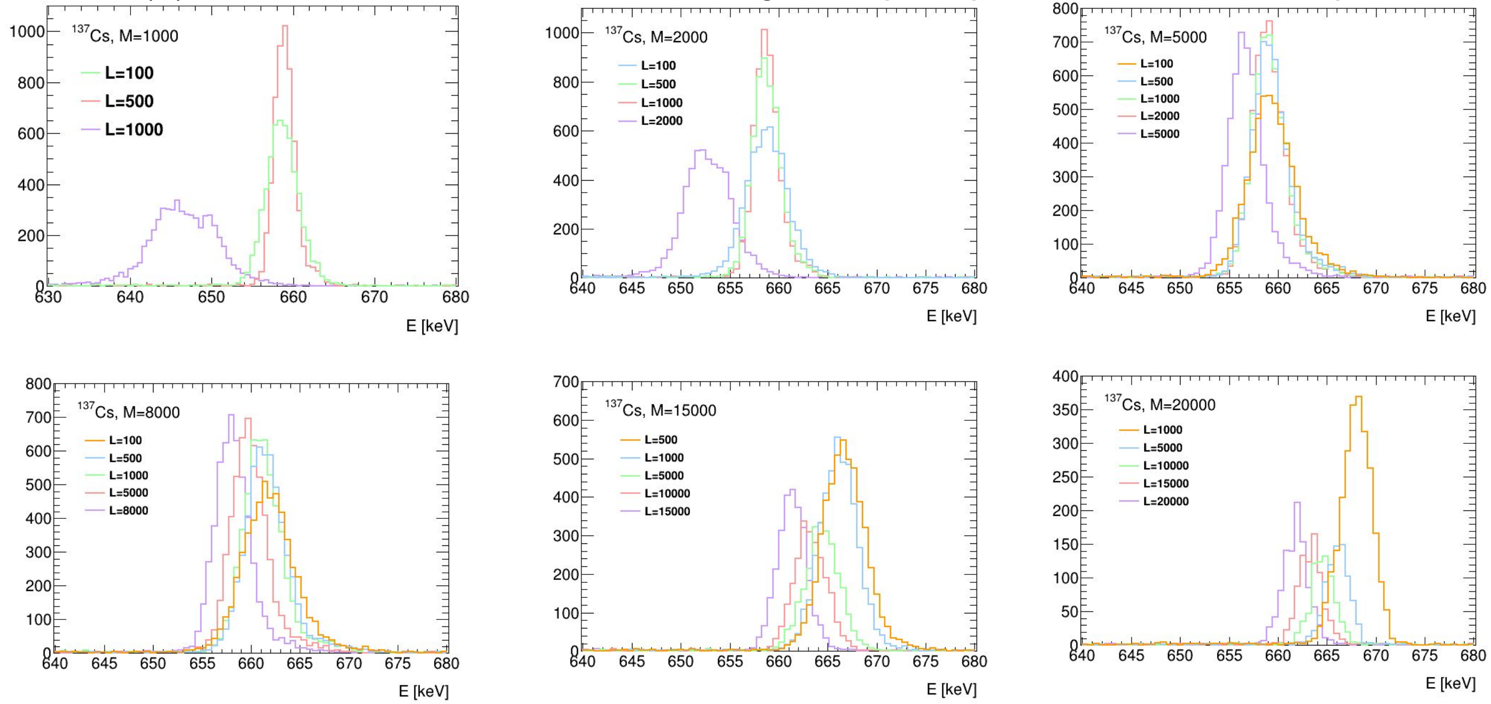
M is low enough so that we can resolve two overlapping pulses.



MWD and Pulse Finding have been run changing M and L values over all the ^{137}Cs sample to determine the impact on the resolution achieved for the 661.7 keV peak.

Resolutions for ^{137}Cs peak at 661.7 keV.

Two values should be taken into account when optimizing the output of the algorithm: The energy resolution (σ) and the number of counts contributing to the photopeak i.e. the number of pulses found.

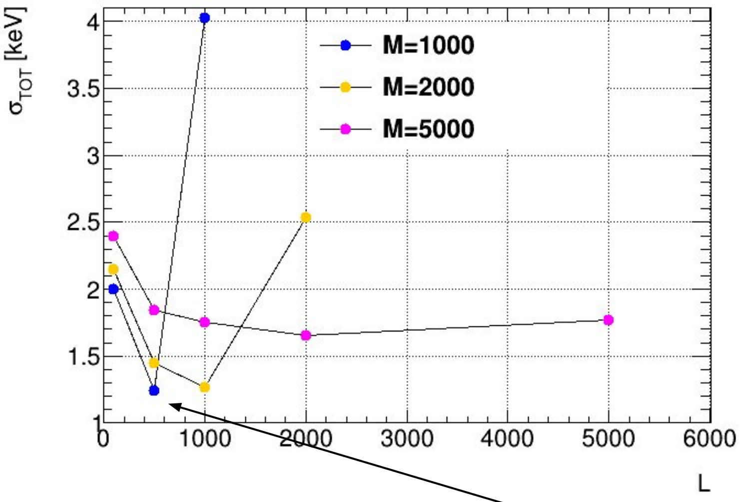


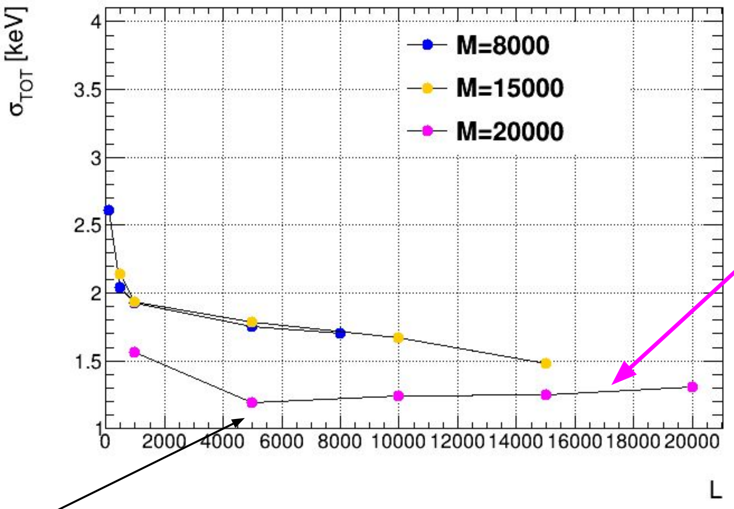
For higher M values the efficiency is worse as expected due to the inability to resolve overlapping pulses.

For higher L values, the resolution is worse, implying that he trapezoidal shape is more optimal than the triangular.

Resolutions for ^{137}Cs peak at 661.7 keV.

Resolutions achieved in the photopeak as a function of L value.



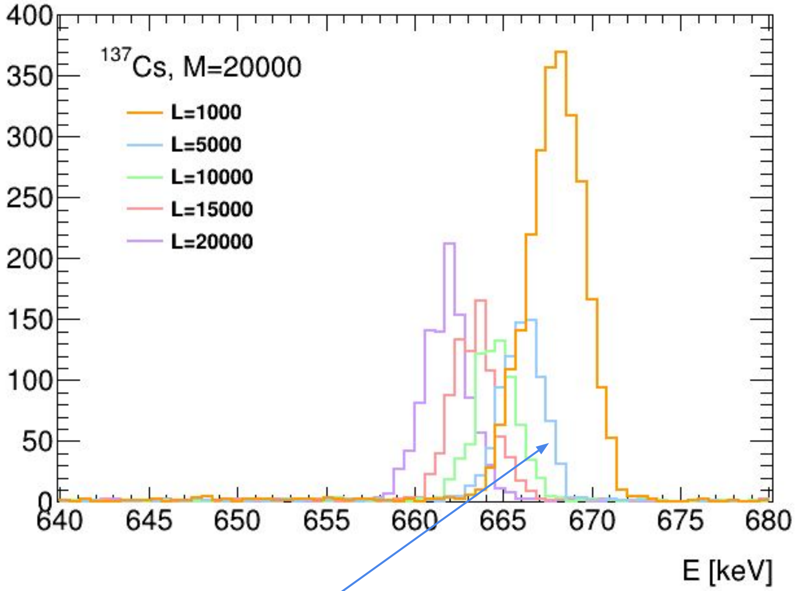


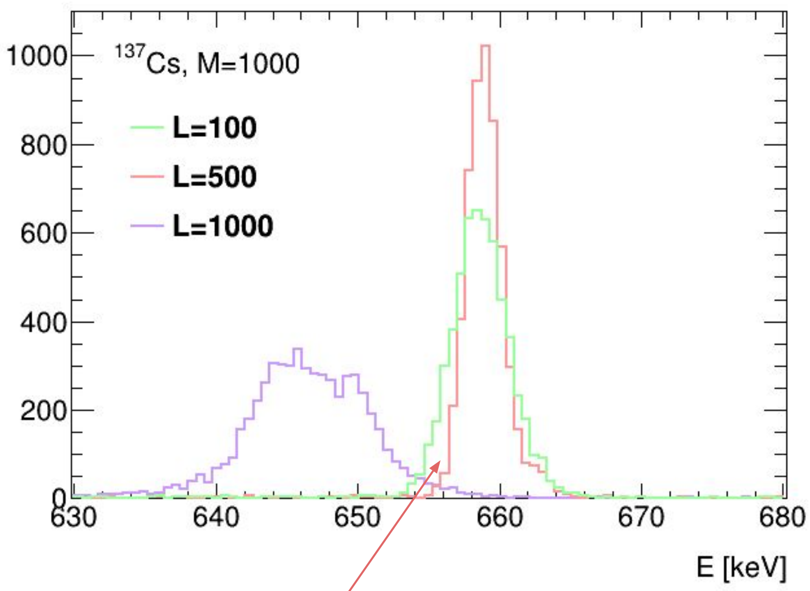
Good resolutions but very little number of peaks contributing to the photopeak.

Best resolutions achieved: M=1,000; L=500 and M=20,000; L=5,000.

Resolutions for ^{137}Cs peak at 661.7 keV.

The optimal values are: M=1,000 and L=500 and therefore the total resolution achieved is: 1.238 keV.





$\sigma_{\mathrm{TOT}}(661.7\ \mathrm{keV}) = 1.19 \pm 0.03\ \mathrm{keV}.$

$\sigma_{\mathrm{TOT}}(661.7\ \mathrm{keV}) = 1.238 \pm 0.014\ \mathrm{keV}.$

Algorithm contribution to the resolution.

$$\sigma^2_{\text{TOT}} = \sigma^2_{\text{HPGe}} + \sigma^2_{\text{ADC}} + \sigma^2_{\text{algorithms}} = \sigma^2_{\text{electronic noise}} + \sigma^2_{\text{cc}} + \sigma^2_{E} + \sigma^2_{\text{ADC}} + \sigma^2_{\text{algorithms}}$$

At 1330 keV (manufacturer: ORTEC):

$$\sigma_{\text{HPGe}}(1330\,\text{keV}) = 1\,\text{keV} \quad \begin{cases} \sigma_{\text{electronic noise}}(1330\,\text{keV}) = 0.45 \\ \sigma_{\text{cc}}(1330\,\text{keV}) = 0.63 \end{cases}$$

Scaling as in the figure

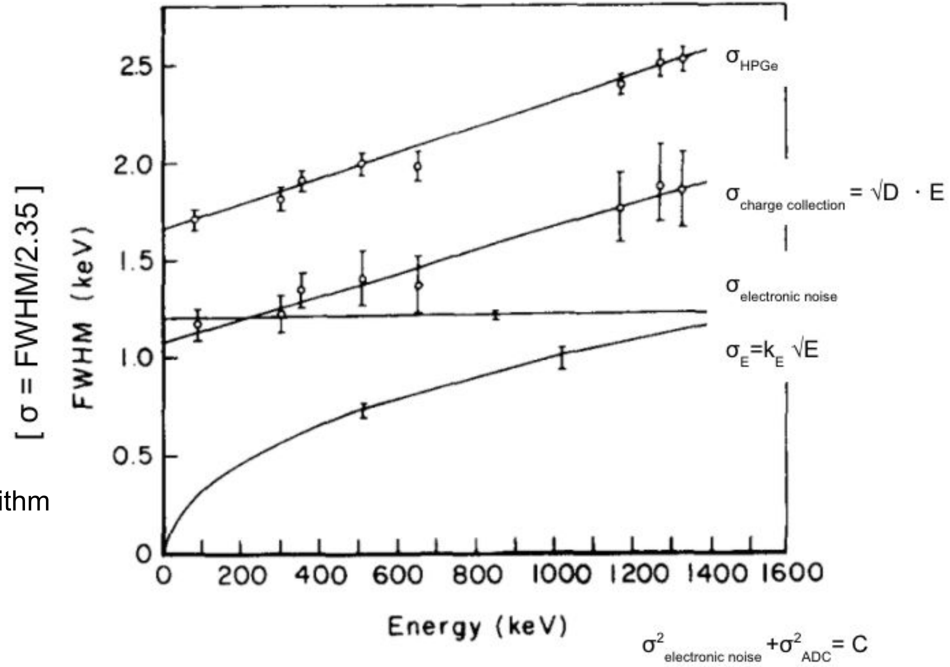
At 661.7 keV (data):

$$\sigma_{\text{TOT}}(661.7\ \text{keV}) = 1.238 \pm 0.014\ \text{keV}.$$

ADC resolution is fixed: $\sigma_{\text{ADC}} = 0.57\,\text{keV}$

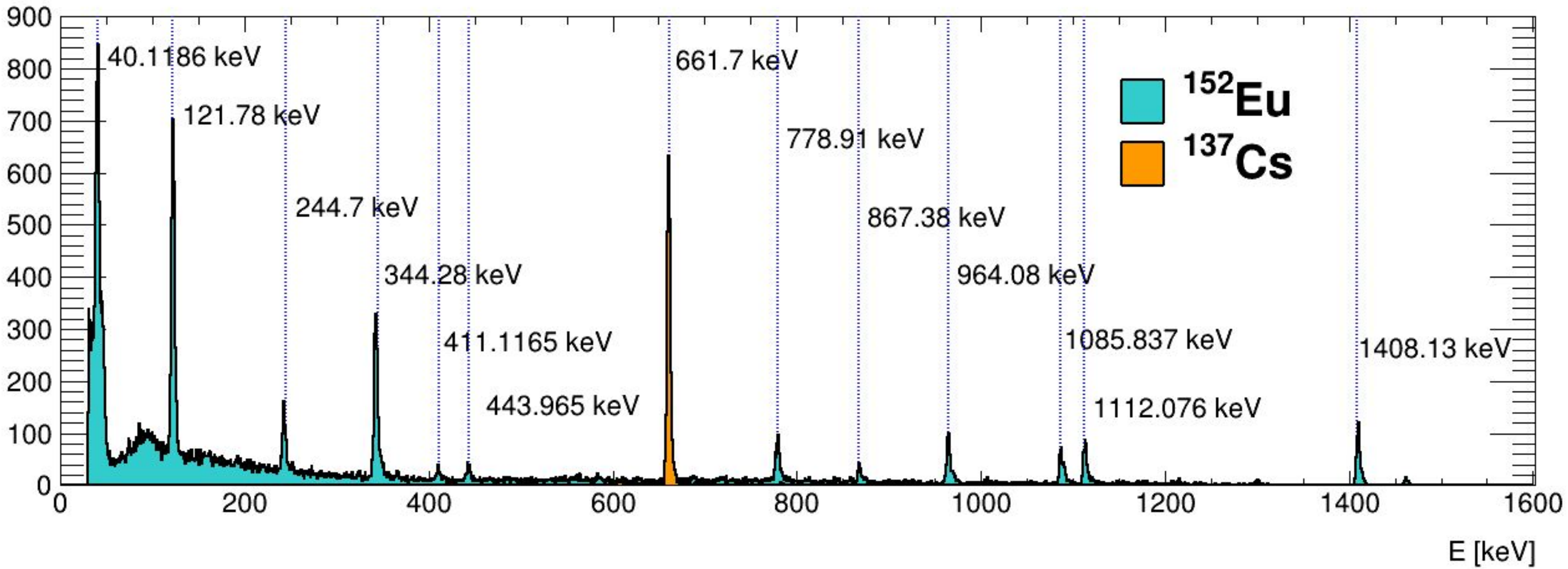
Assuming $\sigma_{\text{electric noise}}$ is constant and σ_{cc} scales with E, the algorithm contribution to the total resolution is:

$$\sigma_{\text{algorithms}}(661.7\,\text{keV}) = 0.84\,\text{keV}$$



Energy Spectrum.

Calibrated energy spectrum obtained from the ^{137}Cs and ^{152}Eu source data.



Achieve the best resolution so that we can resolve the aluminium X-rays at the Mu2e experiment.

Conclusions.

- STM DAQ for HPGe: Optimizing MWD + Pulse Finding algorithms.

    - Define M and L values to increase the resolution achieved for the energy spectrum after the offline analysis.
    - Both algorithms have been run over a ^{137}Cs data sample to determine the impact on the resolution achieved for the 661.7 keV peak.
    - High values of M provide good resolution but very bad efficiencies due to overlapping pulses.
    - Low values of L produce an output strongly affected by noise fluctuations.
    - The best resolution is found for M=1,000 , L=500, with a value = 1.238 keV at 661.7 keV.
    - An in-depth study based on assumptions of the terms contributing to this resolution allows to define the algorithm contribution to the resolution at 661.7 keV, with a value = 0.84 keV.

- Near future:
- Optimize the zero suppression code.
- Participate and then analyse the data from an upcoming beamtest at HZDR and quantify the performance of the detector as a function of rate and radiation dose.