Pulse Shape Fitting for Double Pulse Recovery

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ABSTRACT –Reliable fits of pulses from organic scintillators will greatly improve how we perform pulse shape discrimination by advancing the technique itself and allowing us to save what would normally be lost data. Piled up pulses can cause misclassification in pulse shape discrimination, so they are normally filtered out. This means that in some cases large subsets of data are effectively thrown away. The goal is to separate and extract the pulses from double pulses to be able to analyze them. Each pulse in the double pulses are fit separately and extracted. From visual inspection, the equation agrees very well with the pulse shape, including the initial rise and the fast and slow portions of the decay. Future work will include performing PSD on the extracted pulses to test the quality of the fits.

Motivation and Objectives

Motivation

- In radiation measurements, millions of pulses are acquired but we throw a lot of them away, so there is room for efficiency gains.
- When count rates are high, two pulses can occur in the same time window which is called pulse pileup or a double pulse.
- Pulse shape discrimination (PSD) allows for separation of photon and neutron interactions, but a double pulse event is likely to be misclassified as a single neutron interaction because of a secondary pulse in the tail region of the original triggered pulse.
- Current methods remove double pulses from the data set without extracting any information, so they are essentially wasted pulses.

Objectives

- To recover both pulses from double pulses
- To perform PSD on the recovered pulses

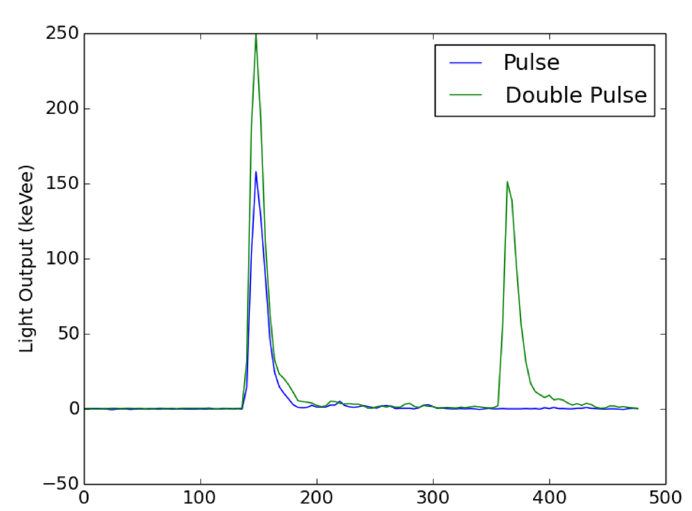

Fig. 1. Example of a pulse and double pulse

Method

Theory

- Equation 1 approximately models the shape of an organic scintillator pulse, which includes a fast component for the initial decay and a slow component for the delayed decay.
- The fast component arises from singlet excitations that decay exponentially and the slow component arises from triplet states recombining to form singlet states that decay exponentially.
- The first half of the equation corresponds to the fast component of the pulse and the second half corresponds to the slow component.
- The A constants define the amplitude terms, the λ constants define the decay terms, θ is the rise time and t0 corresponds to the start time.

$$V(t) = heaviside(t-t0) * A_f \frac{\lambda_f}{\lambda_f-\theta}\left(e^{-\theta(t-t0)} - e^{-\lambda_f(t-t0)}\right) + heaviside(t-(t0+1)) * A_s \frac{\lambda_s}{\lambda_s-\theta}\left(e^{-\theta(t-t0)} - e^{-\lambda_s(t-t0)}\right) \quad (1)$$

Pulse Fitting

- Equation 1 is used as a custom equation in Matlab's fitting algorithm to create the fit.
- The fitting algorithm outputs the constants that it determines, which are used to recreate the pulse.

Data

- To test the double pulse recovery algorithm, known neutron and gamma pulses from measured Cf data were superimposed on one another and then separated for direct comparison.
- Digitized waveforms were collected from neutron and photon pulses in crystalline stilbene detector coupled to photomultiplier tubes (PMTs).

Pulse Recovery

- The entire pulse window is fit with weights placed on the first pulse based on the start time, effectively fitting only the first pulse.
- At each point on the pulse, the difference between the fit and the pulse is checked.
- If the difference is greater than 50%, the point corresponds to the second pulse rather than the first.
- The separated pulses are then fit individually.

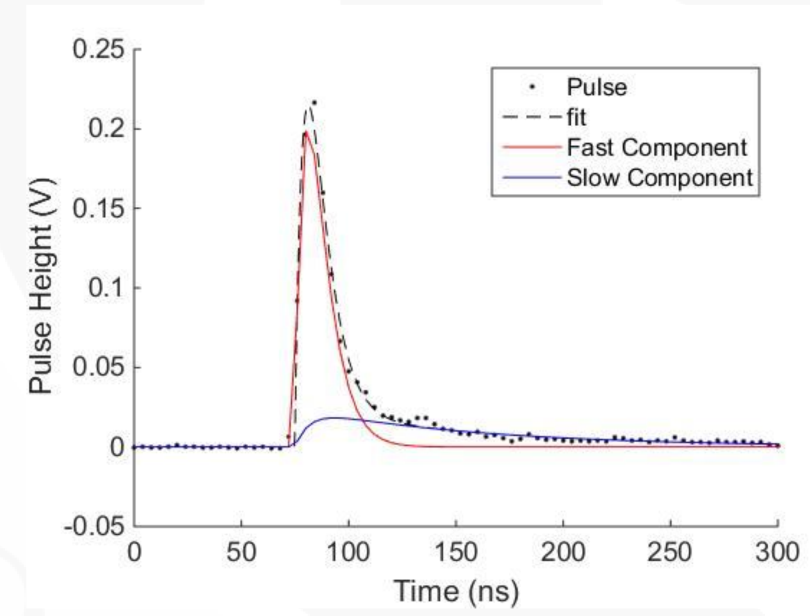

Fig. 2. Single known neutron pulse

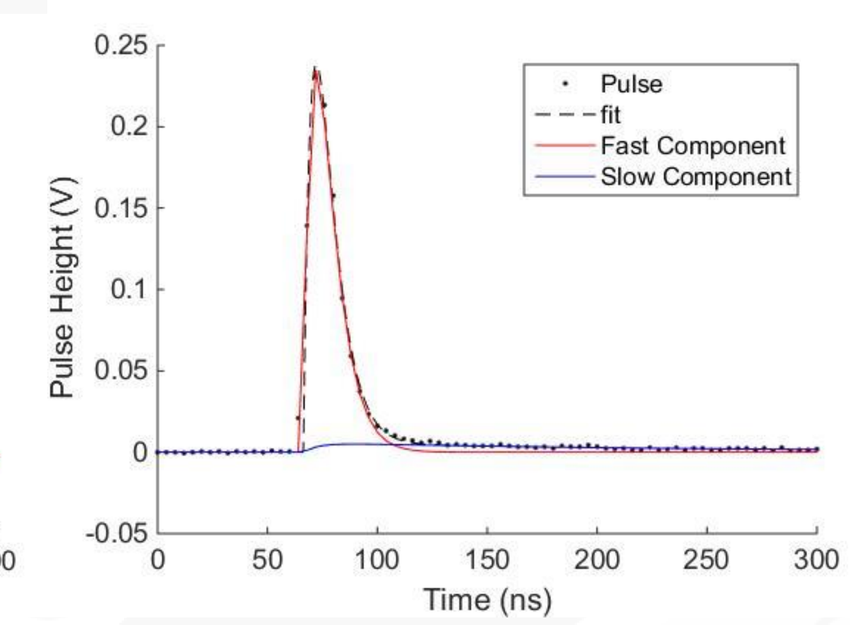

Fig. 3. Single known gamma pulse

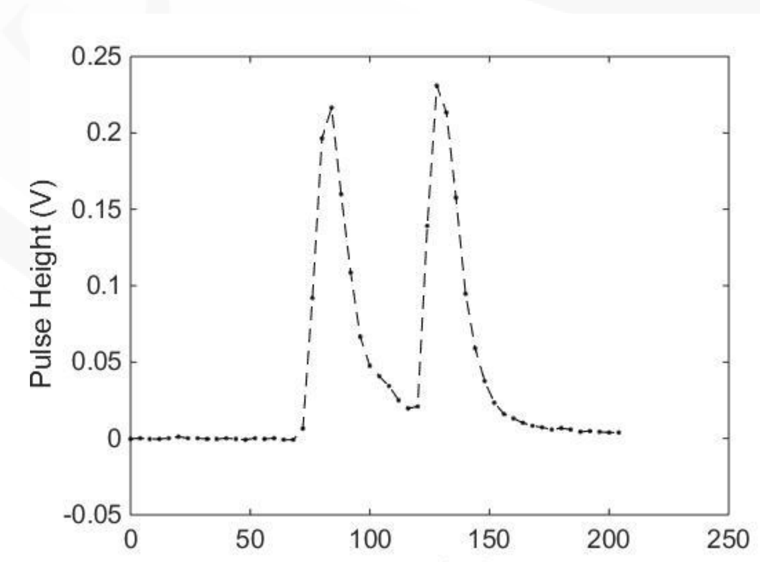

Fig. 4. Gamma pulse superimposed on neutron pulse to simulate double pulse

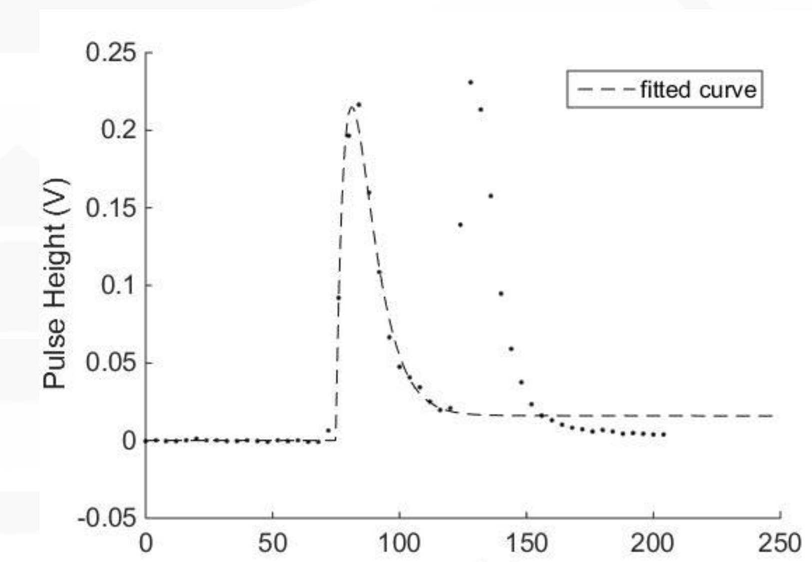

Fig. 5. Pulse is fit with a focus on the first pulse

Results

Pulse Recovery Results

- The double pulses can be separated with this method and the decaying edge of the first pulse that was originally cut off by the second pulse is filled in with the predicted pulse shape from the fit function.
- From visual inspection, the fits reflect close to the true nature of the pulses themselves and the constants stayed relatively the same.

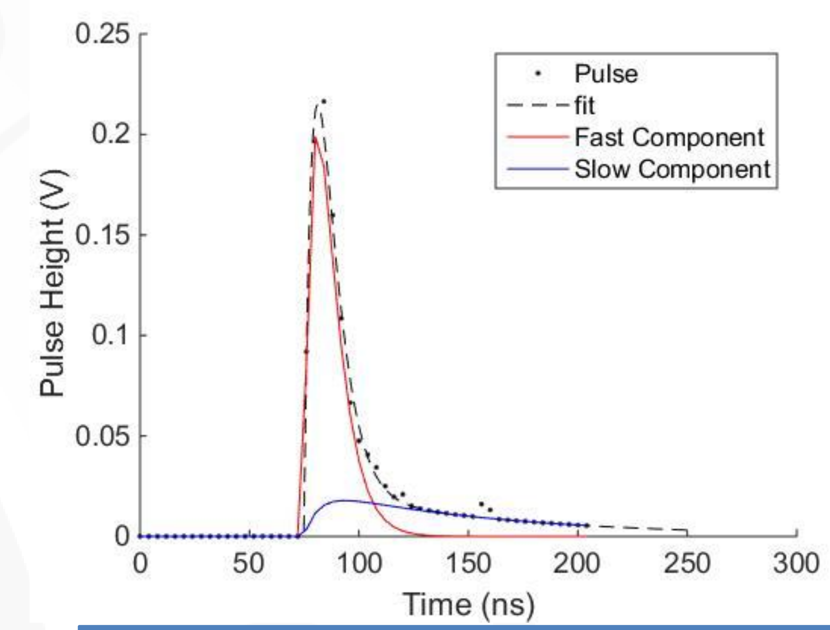

Fig. 6. Extracted neutron pulse

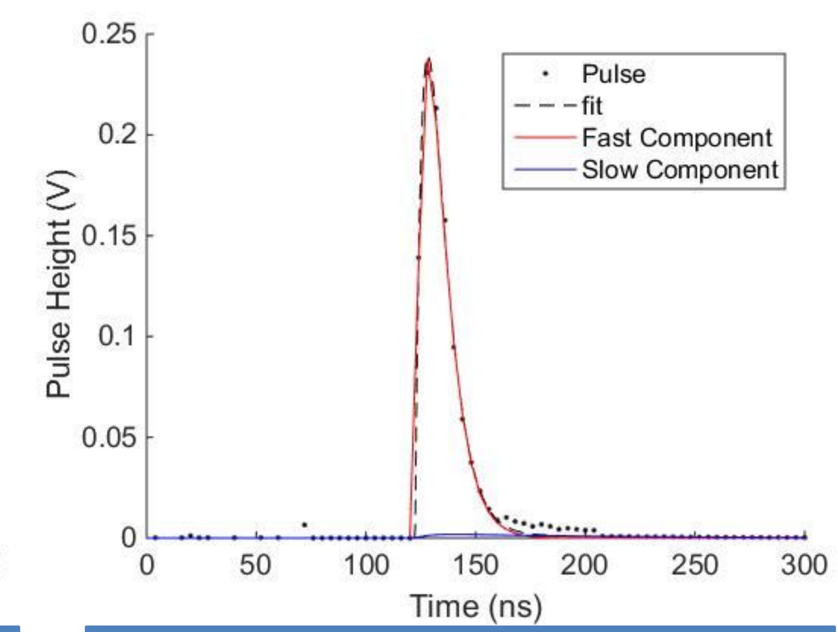

Fig. 7. Extracted gamma pulse

Constant	Single neutron	Extracted neutron	Single gamma	Extracted gamma
A_f	0.5045 V	0.506 V	0.50646 V	0.5739 V
λ_f	0.178 ns^{-1}	0.1774 ns^{-1}	0.1942 ns^{-1}	0.1925 ns^{-1}
A_s	0.2915 V	0.2877 V	0.1569 V	0.02624 V
λ_s	0.01167 ns^{-1}	0.01154 ns^{-1}	0.005428 ns^{-1}	0.01306 ns^{-1}
θ	0.15 ns^{-1}	0.15 ns^{-1}	0.15 ns^{-1}	0.15 ns^{-1}
t0	74.85 ns	74.85 ns	66.35 ns	122.4 ns

Conclusion and Future Work

- The ability to separate double pulses using pulse fitting has been demonstrated.
- Future work:
  - Testing PSD techniques on the fitted pulses to determine if the extracted pulses are useful
  - There will be a limit to how close together pulses can be before this method breaks down, which also needs to be investigated
  - Double pulse recovery is computationally expensive, so optimization methods need to be investigated

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