Timing Algorithms for Organic Scintillators Coupled to Silicon Photomultipliers

William M. Steinberger*, Marc L. Ruch, Sara A. Pozzi
Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109, USA
*wmst@umich.edu

Objective: Analyze combinations of silicon photomultipliers (SiPMs) and organic scintillators with varying algorithms to determine which gives the best timing resolution.

Motivation

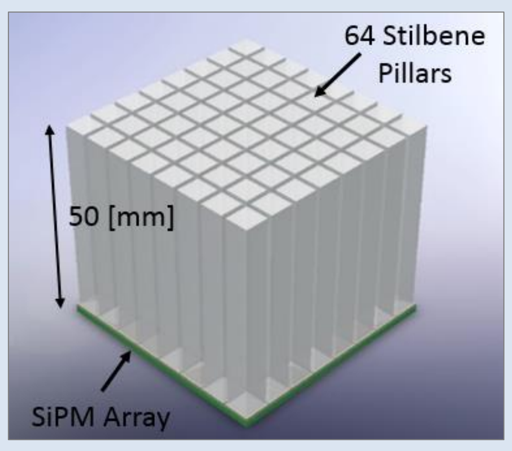

Figure 1: 3D Model of the Handheld Dual Particle Imager

- Increased need for human-portable systems that can detect and image special nuclear material (SNM)
- We propose a handheld dual particle imager to meet this need
- Composed of two SiPM arrays and 64 stilbene pillars
- Works as both a Compton and neutron camera utilizing the pulse shape discrimination capability of stilbene
- Neutron cameras work by measuring neutron time of flight (TOF)
- Decreasing uncertainty in the TOF measurement allows for a more accurate energy distribution to be determined, and improves backscatter imaging

Digitized Pulses

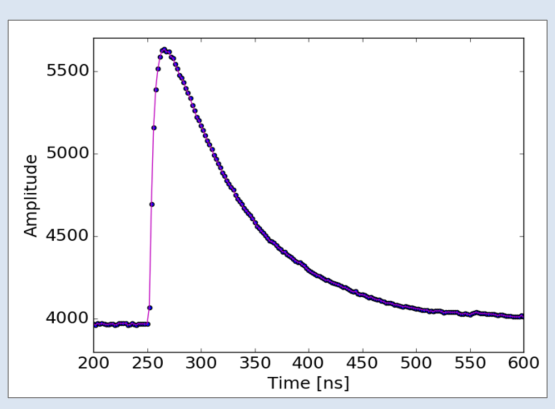

Figure 2: Pulse from the Standard Output of a SensL J-Series SiPM with Stilbene

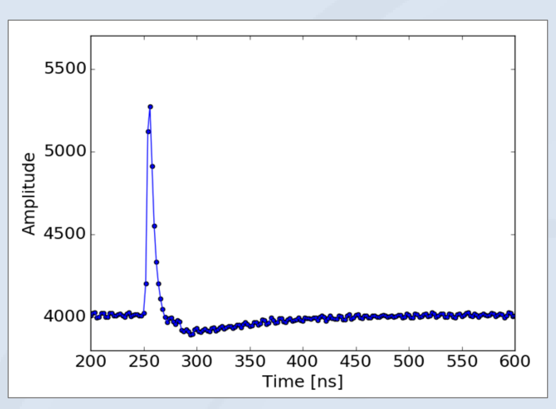

Figure 3: Pulse from the Fast Output of a SensL J-Series SiPM with Stilbene

- SensL SiPMs have a standard and fast output while KETEK SiPMs only have a standard output
  - Standard output: Used for timing resolution, PSD and energy resolution
  - Fast output: Better timing resolution, no PSD, and worse energy resolution

Constant Fraction Discrimination (CFD)

- Determining the start time of a pulse
  - Multiply the amplitude by some fraction, F, and add that value to the baseline
  - Linearly interpolate between existing points to find the time at which that value occurs

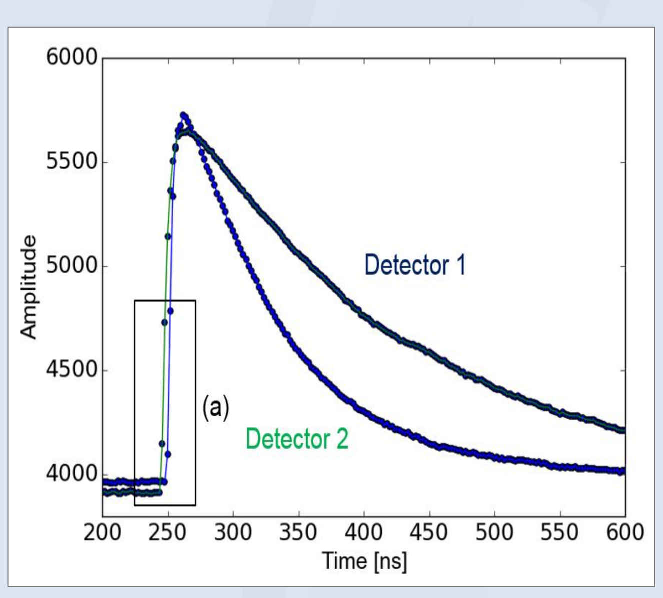

Figure 4: Coincident Pulses from the Standard Output

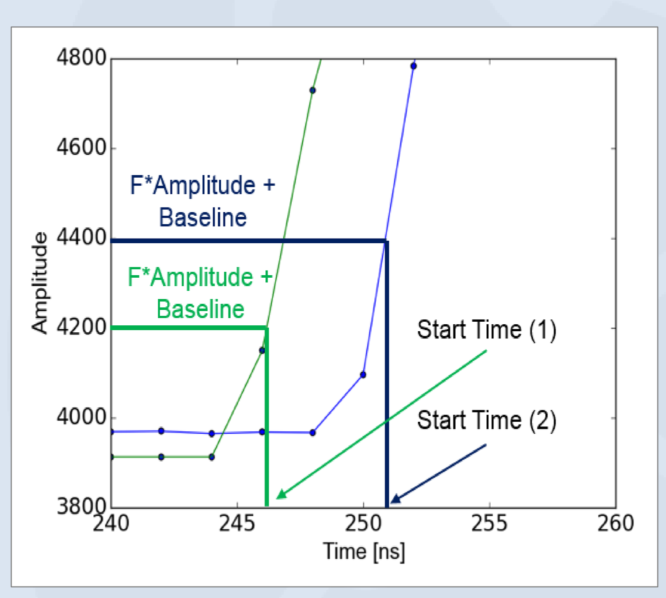

Figure 5: Section (a) of Figure 4

- Time difference = Start Time (2) – Start Time (1) = 4.15 [ns]
  - Histogram all time differences to determine the spread as shown in Figure 6
  - Minimize the spread as shown in Figure 7

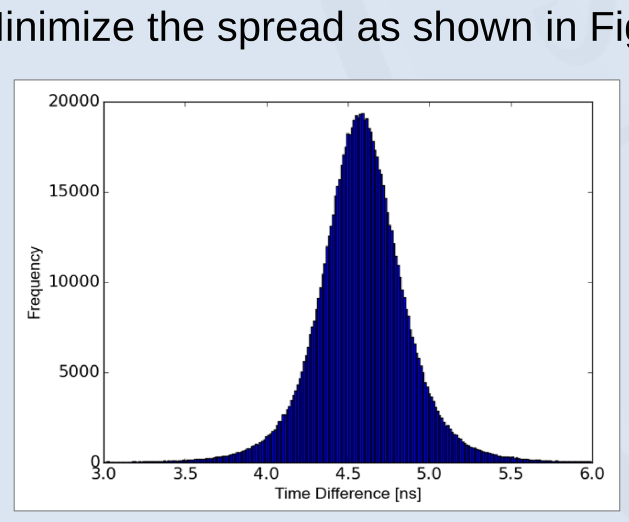

Figure 6: Time Difference Histogram (TDH) of Pulses from the Standard Output

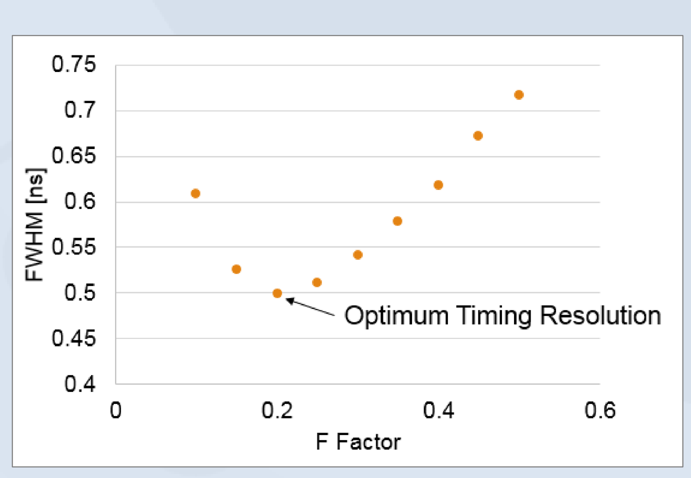

Figure 7: FWHM as a Function of the F Factor

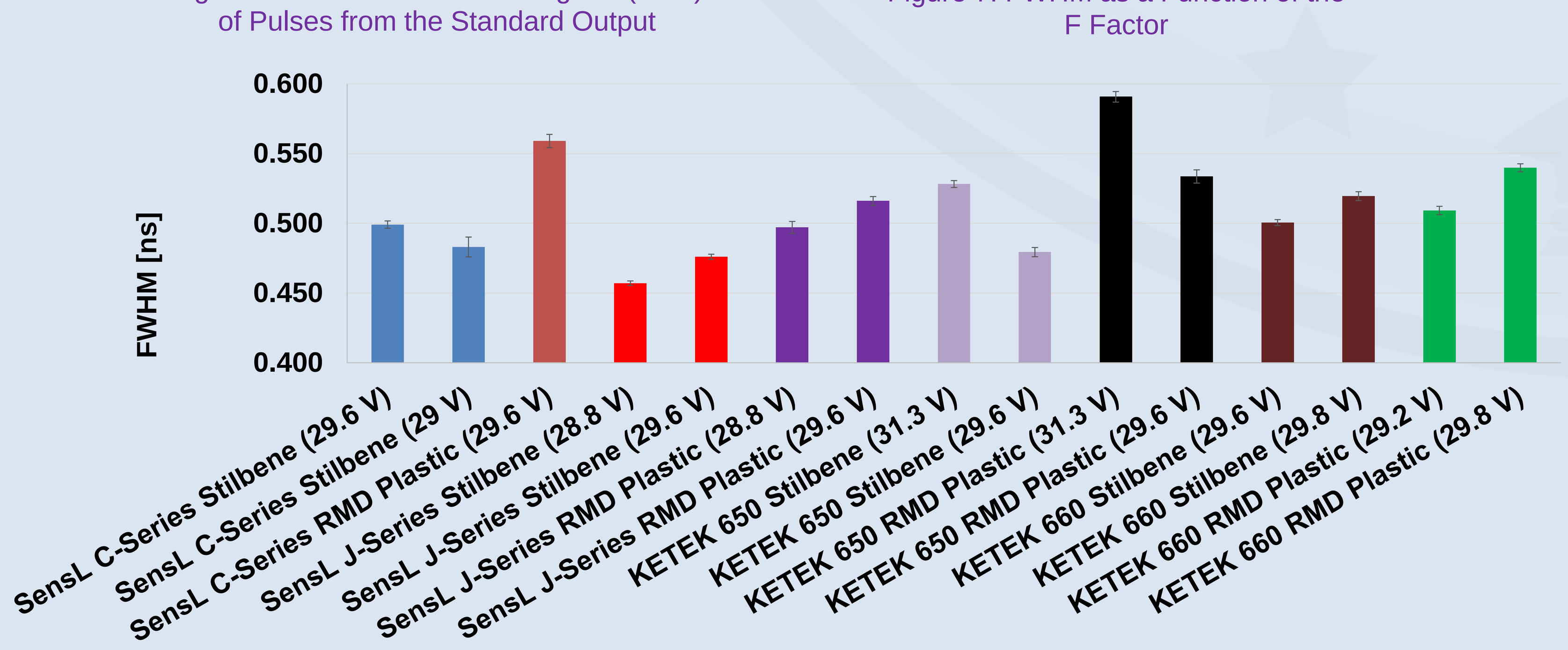

Figure 8: Optimum Timing Resolution for the Standard Output of each Detector and Scintillator Combination

Averaging Filter with CFD

Applying CFD to pulses from the fast output

- The distribution is no longer Gaussian
- FWHM is not an accurate measure of the spread
- The skew in the TDH for pulses from the fast output is due to how few points are digitized in the rising edge
- Solution is to create more points in the rising edge

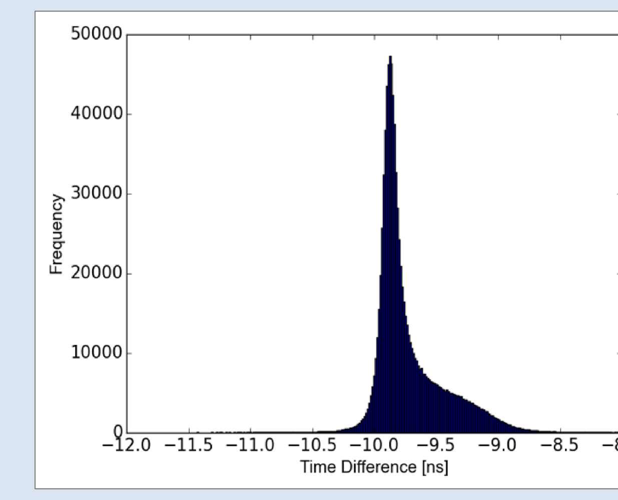

Figure 9: TDH of Pulses from the Fast Output using CFD Method

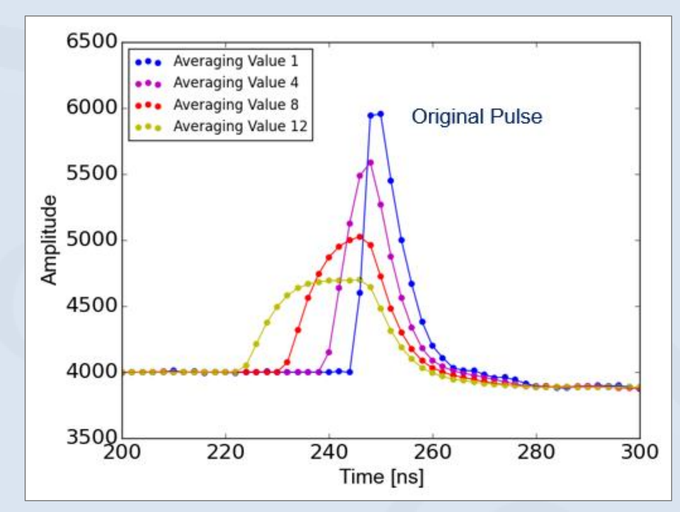

Figure 10: Applying an Averaging Filter to a Pulse from the Fast Output

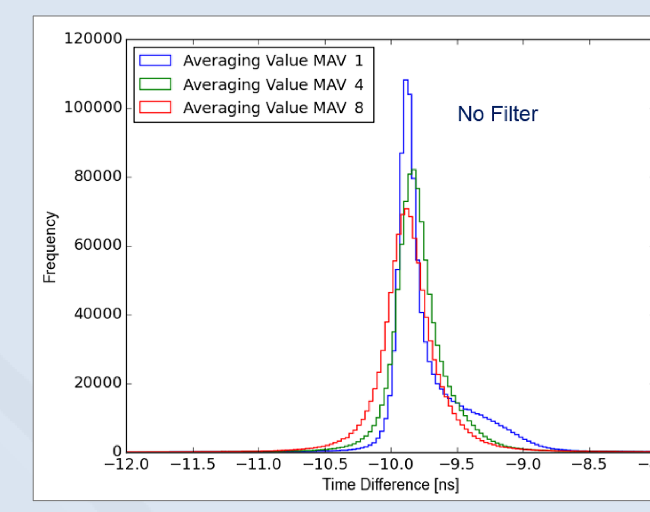

Figure 11: TDH of Pulses from the Fast Output with Applied Averaging Filter

- Applying an averaging filter to the pulses from the fast output creates more points in the rising edge
- These filters produce more Gaussian-like distributions for the fast outputs so that an optimum timing resolution can be determined

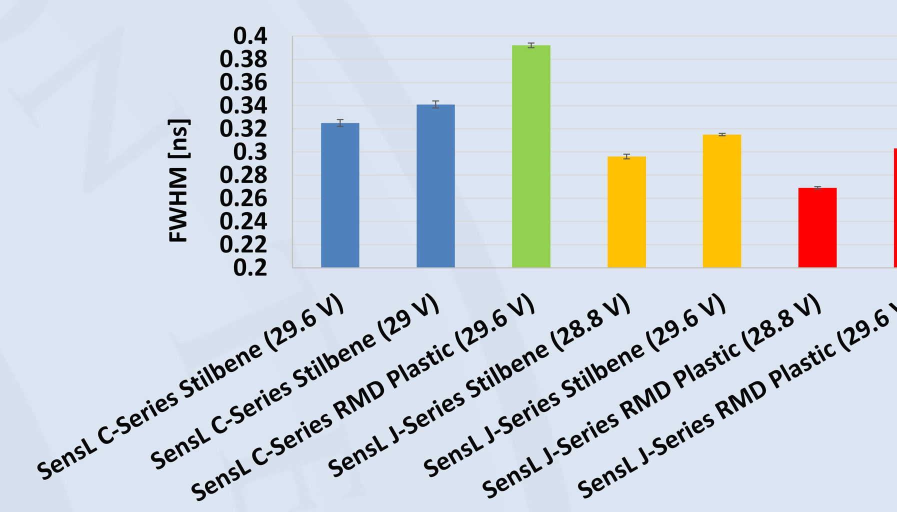

Figure 12: Optimum Timing Resolution for the Fast Output of each Detector and Scintillator Combination

Bipolar Pulse Transformation (BPT)

- A pulse is split into two pulses
  - One of the pulses is multiplied by some fraction, F
  - The other pulse is delayed and inverted
- The two pulses are summed to create a new pulse, where the zero-crossing between the max and min is the start time

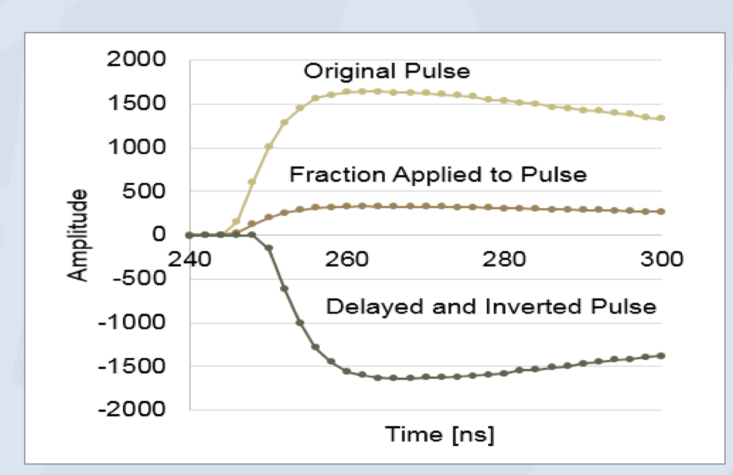

Figure 13: Transforming a Pulse into Two Separate Pulses

Figure 14: Sum of the Two Transformed Pulses in Figure 11

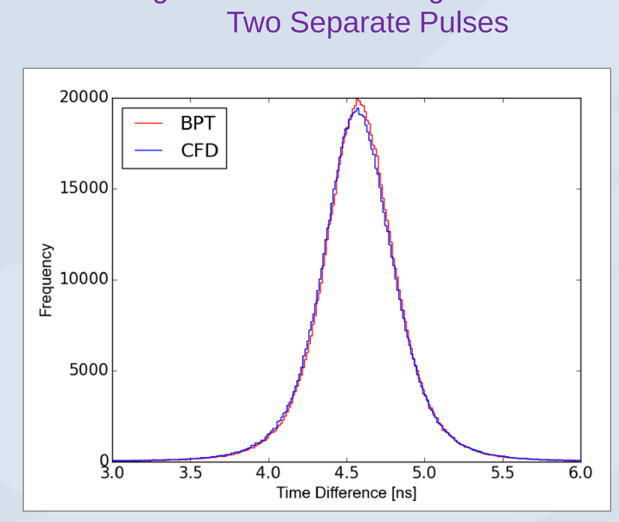

Figure 15: Comparison of TDHs of Standard Pulses Created from Both Algorithms

- Comparing optimum results of CFD and BPT analysis on pulses from the standard output
  - Improvement in FWHM from 0.499 ± 0.003 [ns] to 0.488 ± 0.002 [ns]
  - Reduction in variance from 0.131 [ns^2] to 0.095 [ns^2]
  - Reduction in skew from -0.157 to 0.037

Conclusion

Detector and Scintillator Combination

- SensL J-Series SiPM with stilbene had the lowest FWHM of 0.457 ± 0.002 [ns] for pulses from the standard output
- SensL J-Series SiPM with RMD plastic had the lowest FWHM of 0.269 ± 0.001 [ns] for pulses from the fast output

Algorithms

- Using an averaging filter on the fast output provides a more Gaussian distribution
- Using BPT on the standard output provides a more Gaussian distribution

This work was funded in-part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534

National Nuclear Security Administration