Performance of Stilbene Bars Coupled to Silicon Photomultipliers Using Different Reflectors

William M. Steinberger[1], Marc L. Ruch[2], Sara A. Pozzi[1]
[1]Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109, USA
[2]Nuclear Engineering and Nonproliferation Division, Los Alamos National Laboratory, Los Alamos, NM 87544, USA

Objective

Analyze stilbene crystals coupled to silicon photomultipliers (SiPMs) with various reflectors coating the stilbene to potentially increase the performance of neutron scatter cameras.

Motivation

- Increased need for systems that can detect and image special nuclear material (SNM)
- SNM has the characteristic of emitting both neutrons and gamma rays
- Neutron scatter cameras work by measuring neutron time of flight (TOF) and deposited energy to reconstruct the event
- Most neutron scatter cameras such as the dual particle imager (DPI) shown in Figure 1 use diffuse reflectors

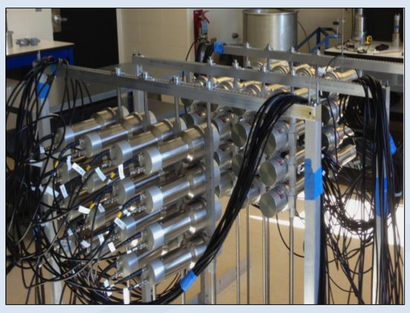

Figure 1: DPI that uses liquid organic scintillators to detect and image neutrons

Diffuse and Specular Reflection

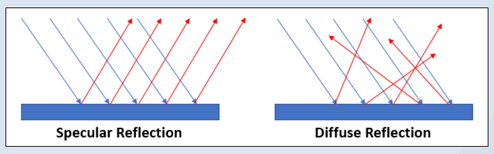

Figure 2: Visualization of the difference between a diffuse and specular reflector

- Specular reflectors scatter incident light at the same angle relative to the normal of the surface
  - Specular reflectors tested: Mylar and 3M SFP D50F
- Diffuse reflectors have some probability of reflecting incident light at any angle
  - Diffuse reflectors tested: PTFE (Teflon tape)

Digitized Pulses

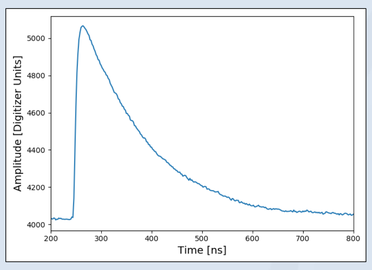

Figure 3: Pulse from the standard output of a SensL C-Series SiPM with stilbene

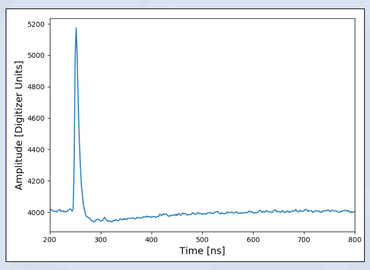

Figure 4: Pulse from the fast output of a SensL C-Series SiPM with stilbene

- SensL SiPMs have a standard and fast output
  - Standard output: Used for timing resolution, pulse shape discrimination (PSD) and energy resolution
  - Fast output: Better timing resolution, no PSD, and worse energy resolution

Signal to Noise Ratio (SNR)

- Determining the SNR for the various reflectors
  - Measured the stilbene coated with each reflector with a Cs-137 source
  - The signal was chosen to be the Compton Edge of the Cs-137 spectrum while the noise was chosen to be the average root mean square of the baseline of the pulses making up the pulse height distributions (PHDs)

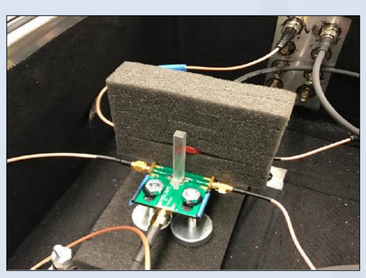

Figure 5: Experimental setup

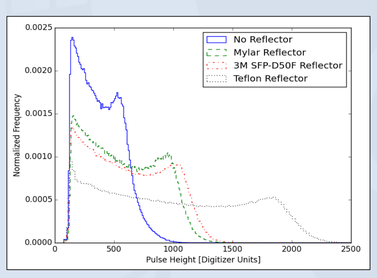

Figure 6: PHDs for the various reflector coatings measuring a Cs-137 source

Table 1: Measured average SNR values

Reflector	Average SNR
No Reflector	108 ± 10
3M SFP D50F	170 ± 10
Mylar	161 ± 3
PTFE	258 ± 2

Time Resolution

- A coincident measurement was setup using a Na-22 source
- Determining the start time of a pulse
  - Multiply the amplitude of each pulse by some fraction (F)
  - Linearly interpolate between existing points to find the time at which that value occurs

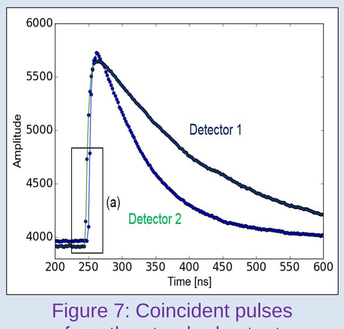

Figure 7: Coincident pulses from the standard output

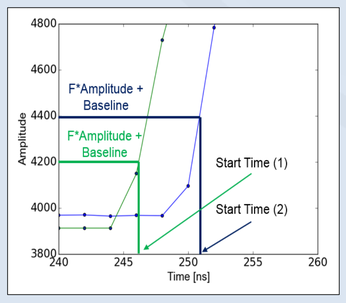

Figure 8: Section (a) of Figure 7

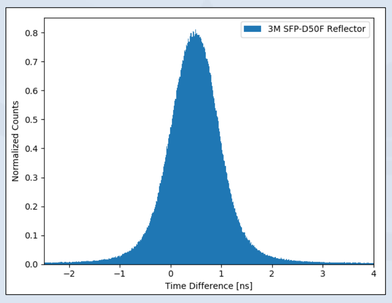

Figure 9: Time difference histogram (TDH) of pulses from the standard output

- Time difference = Start Time (2) – Start Time (1) = 4.15 [ns]
  - Histogram all time differences to determine the spread as shown in Figure 9
  - Vary the F factor to optimize the time resolution as shown in Figure 10

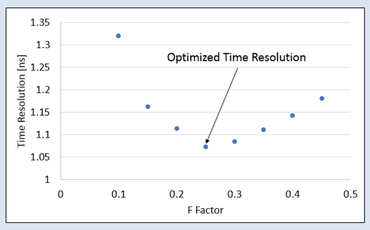

Figure 10: FWHM as a function of the F factor

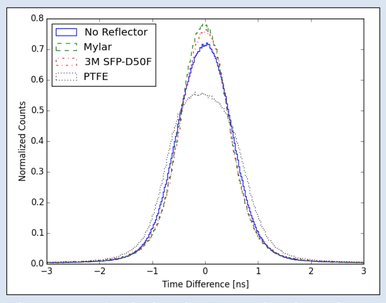

Figure 11: Optimized TDHs of pulses from the standard outputs

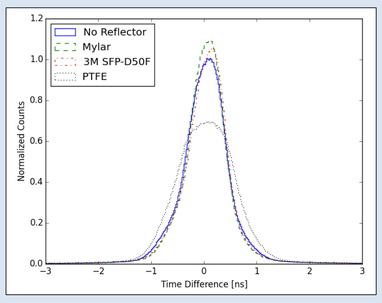

Figure 12: Optimized TDHs of pulses from the fast outputs

- Replacing a diffuse reflector with a specular reflector in this setup:
  - Improves timing performance by 32% for standard output
  - improves timing performance by 40% for fast output pulses

Table 2: Measured time resolution for each reflector coating

Reflector	Standard FWHM [ns]	Fast FWHM [ns]
No Reflector	1.211 ± 0.007	0.811 ± 0.003
3M SFP D50F	1.073 ± 0.036	0.761 ± 0.004
Mylar	1.071 ± 0.014	0.730 ± 0.003
PTFE	1.574 ± 0.005	1.260 ± 0.003

Pulse Shape Discrimination

- To determine if an event was due to a neutron or gamma ray interaction, pulses are analyzed by comparing the tail integral to the total integral of the pulse as shown in Figure 13
  - Neutron interactions produce more light later in the pulse relative to gamma rays
  - A histogram of ratios, shown in Figure 14, can then be made and analyzed using a Figure of Merit (FOM) to determine how well the PSD parameters work

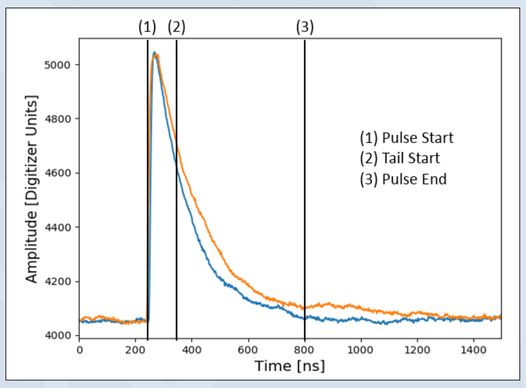

Figure 13: PSD parameters marked on measured pulses

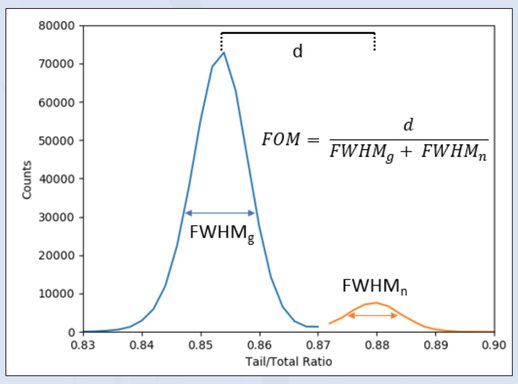

Figure 14: Histogram of the tail to total ratio based on specified PSD parameters

Table 3: Optimized PSD parameters and FOM for each reflector coating in the light output range of 100 – 200 [keVee]

Reflector	Average SNR	Optimized FOM	Pulse Start [ns]	Tail Start [ns]	Pulse End [ns]
No Reflector	108 ± 10	-*	-*	-*	-*
3M SFP D50F	170 ± 10	0.863	0	14	270
Mylar	161 ± 3	0.785	0	14	310
PTFE	258 ± 2	1.170	0	18	290

No separation between the gamma ray and neutron distributions was found

- While the FOM gives an idea of how good the PSD is, it does not give us any directly applicable information
- An additional parameter that can be analyzed is the neutron false positive (FP) rate and gamma false negative (FN) rate
  - This is visualized in Figure 15, and data is contained in Table 4

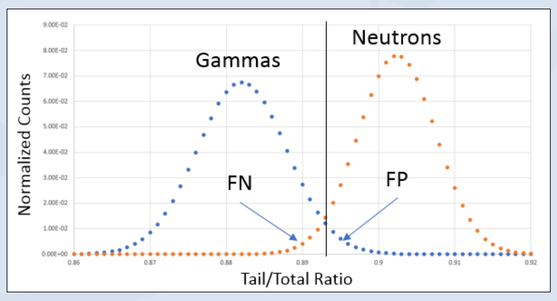

Figure 15: Normalized ratio distributions to determine FN and FP rates

Table 4: Measured FP and FN rates

Reflector	FP Rate [%]	FN Rate [%]
No Reflector	-*	-*
3M SFP D50F	3.03	2.20
Mylar	3.83	4.02
PTFE	0.32	0.49

No separation between the gamma ray and neutron distributions was found

Conclusion

- How well gamma-rays and neutrons can be discriminated is a strong function of the SNR
- While time resolution significantly increases by 32% for standard outputs and 40% for fast outputs when using a specular reflector, the misclassification rate increases by nearly a factor of 10
- This work demonstrates that diffuse reflectors are optimal for neutron scatter cameras

Acknowledgements:
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