Non-Linear Behavior in Plastic Scintillator Neutron Detectors

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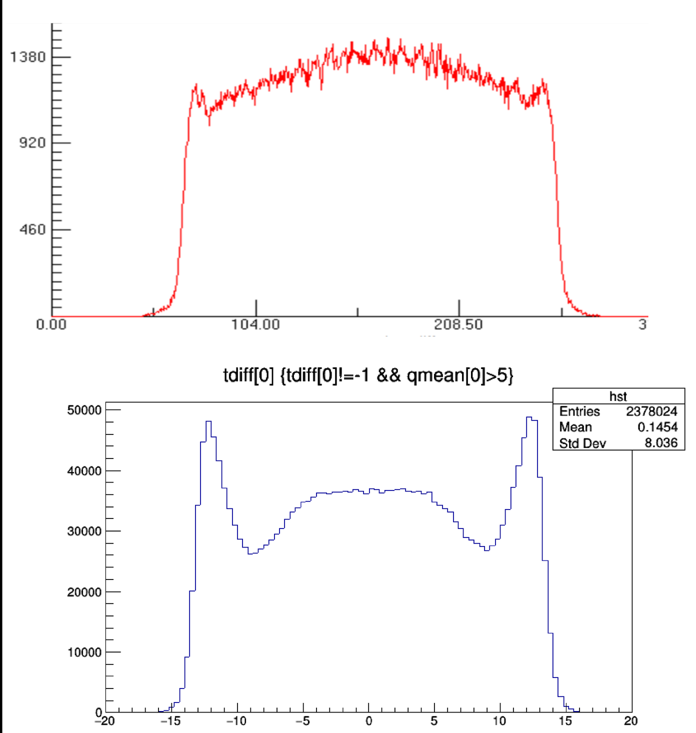
Introduction to MoNA

The Modular Neutron Array (MoNA) is a collection of 144 plastic scintillator detectors, 200cm in length and 10cm square in width and height, with 2" photomultiplier tubes attached to either end. The MoNA Collaboration has used this array with analog electronics for years, but now is investigating **digital electronics for future experiments**. This yields a different spectrum when we calculate position from the time difference between the waveforms of light in either phototube.



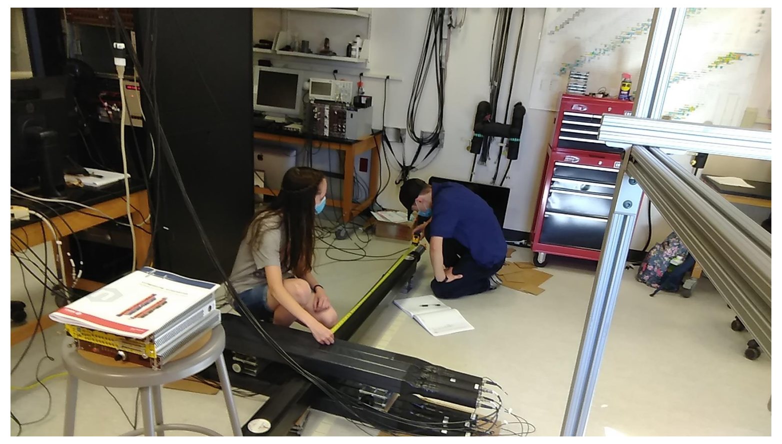
Top: An analog graph of cosmic muon position data. Light attenuation reduces counts near the ends of the bar as lower energy events drop below threshold since light has further to travel. Note a gentle slope.

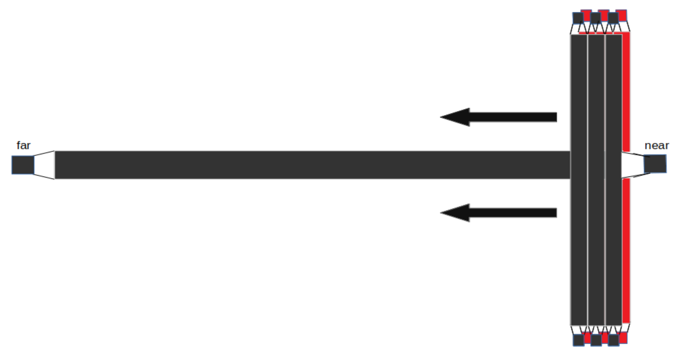
Bottom: The same position spectrum using a CAEN V1730 digitizer. Note the different shape from analog.

As we look forward to future array designs, it is critical to **understand how our detectors work** with digital acquisition so we can optimize them for this purpose. We conducted an experiment at the Los Alamos National Lab to test the behavior of light in our bars to learn more about them.

Testing Light Propagation Behavior

We used another MoNA bar at Indiana Wesleyan University to investigate the anomalous position spectra and learn how the bars operate.

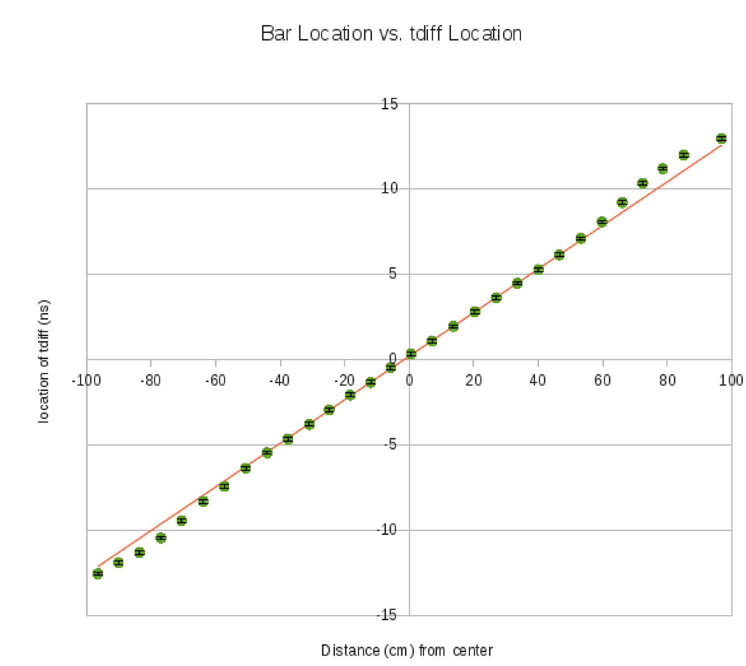


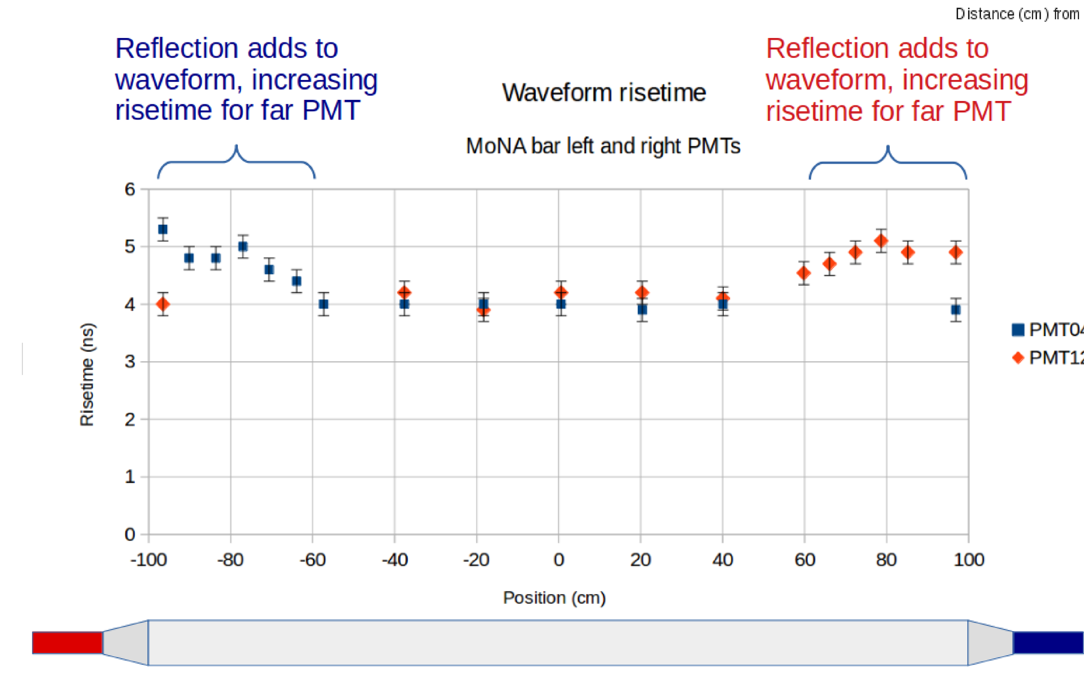


We placed half-sized scintillator bars above and below the MoNA bar, then found triple coincidences from cosmic muons across the three detectors to determine precisely where a muon hit. In total, we took muon data at 30 positions across the bar's length, in 6.5cm increments. Measuring the physical position allowed us to evaluate our **mapping from time difference (channels) to calculated position**.

Discovery of Non-Linear Behavior

The plot at the right shows the nonlinear mapping between PMT time difference to physical position. In **the last 40cm** from either end of the bar, the mapping shows **especially nonlinear behavior**. Below is a graphic showing the measured rise time for waveforms across the bar.

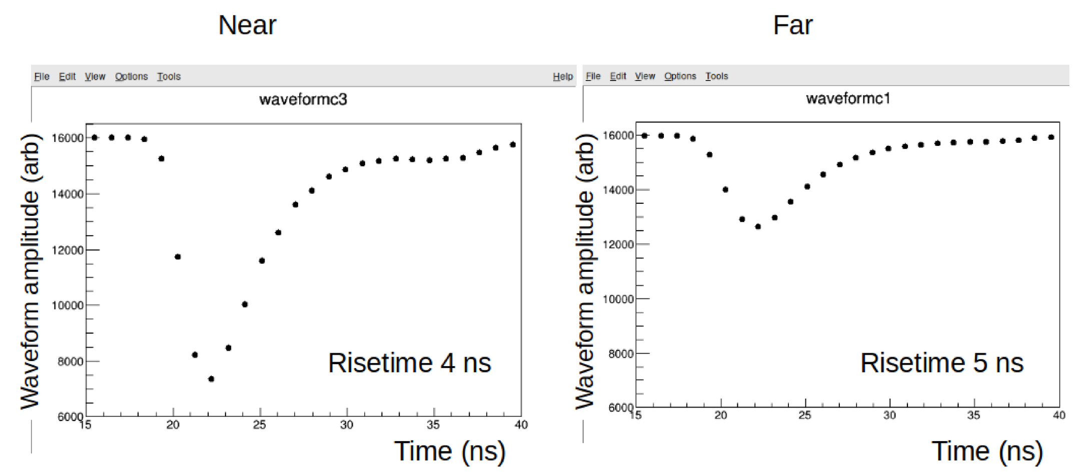




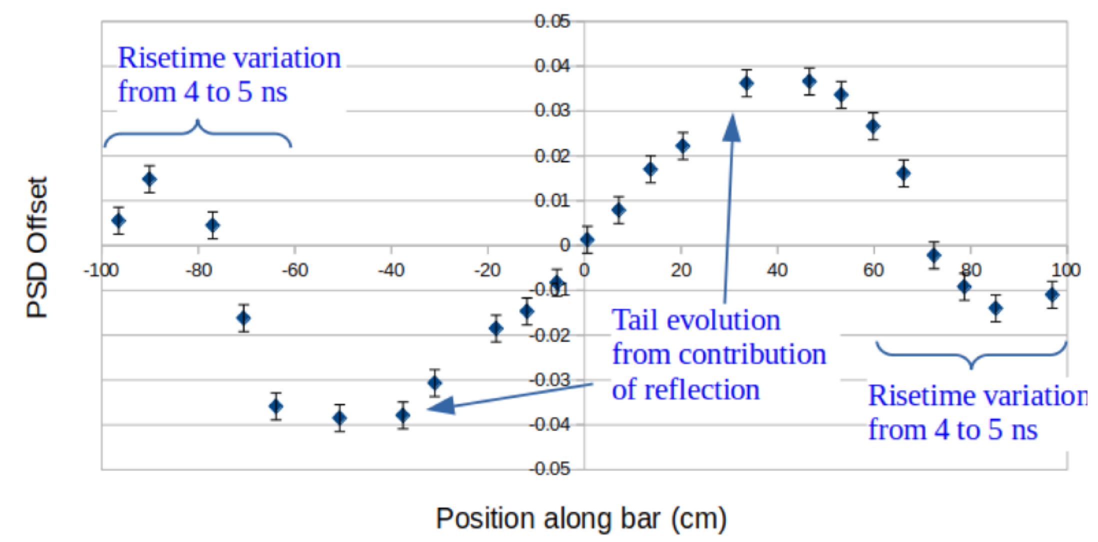
Waveform Shape Analysis

In order to understand the nonlinear behavior of our detectors, we measured the shapes of actual light waveforms across the span of the bar. We found that **light reflection from the far end of the PMT** changed the waveform rise time from 4ns near the PMT to 5 ns at the opposite end.

Graph to the right shows near and far waveforms. Rise time varied from 4ns (near) to 5ns (far).

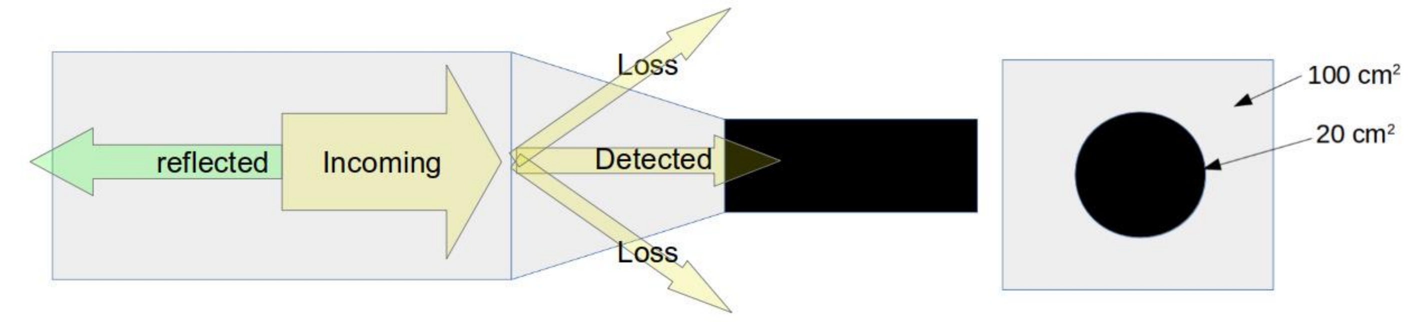


A plot showing the evolution of the waveform shape via its PSD spectrum. The nonlinearity is evident in this plot for the outer 40cm of each end.



Reflection

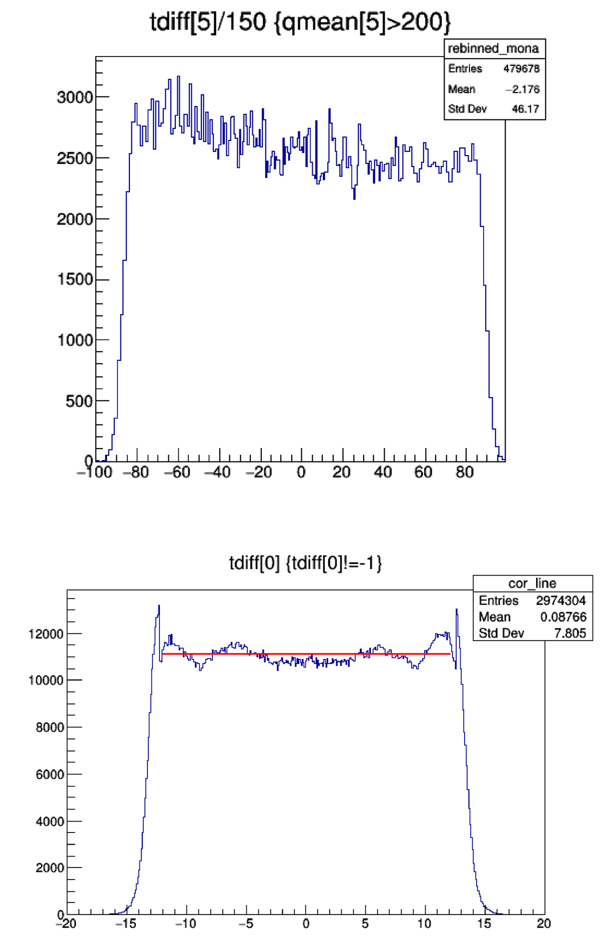
- The diagram below shows how the scintillator is joined to the PMT with a tapered light guide.
- We concluded that reflection of light from the light guides at each end was responsible for the nonlinear behavior in time to position mapping.
- From Liouville's theorem, we know that a large scintillator coupled to a small PMT will always involve some of the light being reflected.



Looking Forward

Next Generation:

We will minimize nonlinearity on future bars by addressing reflection. Our next generation of detectors will eliminate reflection at the ends by matching the cross-sectional area of the scintillator to the PMT.



In the meantime:

For analyzing data from our current bars, we can either choose to:

1.) use the center (linear) part of the bars only

or

2.) apply a position correction

Left shows 2 approaches to position spectra correction.

- Correction algorithm from mapping nonlinearity (rough example, top)
- Correction algorithm from shape matching (rough example, bottom)

Acknowledgements

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