KamLAND Waveform Analysis

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KamLANDs electronics are unique. Their job is to digitize signals coming from the photo-multiplier tubes (PMTs) during an event of interest. To do so, they sample and record the PMT signal 128 times at 1.5 ns intervals, generating a waveform (see Fig. 1). The first step in analyzing KamLAND data is the extraction of times and charges of photo-electron hits from these waveforms.

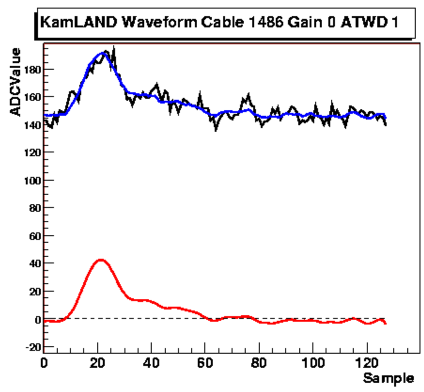

FIG. 1: An example KamLAND waveform. The black line is the raw waveform. The blue line is the pedestal subtracted waveform. The red line is the renormalized and smoothed waveform.

The waveform analysis has four steps. In step 1, Pedestal Subtraction, background waveforms taken at the beginning of the run are subtracted from the waveform to remove any structure intrinsic to an individual channel. Steps 2 and 3, Renormalization and Smoothing, remove electronic jitter in the waveform, force the baseline to zero and smooth the remaining waveform. In step 4, Pulse Finding, the waveform is fed to a pulse-finding algorithm that returns times and charges of any pulses present.

For the first analysis algorithms for calculating Pedestals, Renormalization, Smoothing, and Pulse finding were developed for single photo-electrons in the 17″ PMTs. The algorithms were tested and those used to process the data were chosen for performance and computing efficiency.

In addition to the 17″ PMTs, KamLAND has five hundred 20" PMTs, which are older than the 17" tubes and have very different timing characteristics. Their longer pulse shape does not affect the pedestal or smoothing steps, but it does impact renormalization and pulse finding algorithms. Testing showed that the performance of all of the pulse-finding algorithms was deteriorated equally by the longer pulses from the 20″ tubes. It also showed that the current renormalization method fails more often: since more of the waveform is occupied by the pulse, the algorithm tends to over-renormalize. An algorithm which calculates the average baseline by requiring that all samples used in the calculation deviate equally from the mean is less susceptible to over-renormalization.

Processing algorithms have also been developed for waveforms that are the result of muons passing through the detector. These events are comprised of thousands of photoelectrons and are therefore fundamentally different from single photo-electron waveforms. The standard pedestal and smoothing algorithms work well for muon events, but the pulse-finding and renormalization algorithms need alteration. Since the muon signal occupies all 128 samples, the best approximation for the baseline is the first few samples. The time of the pulse is the time of the arrival of the first photo-electron, which travels the shortest path. A threshold which extrapolates back to the zero crossing was found to be the most accurate method of calculating this time.

Recently, a new step has been added to waveform analysis for single photo-electron events. After the pulses are found and time and charge are assigned, another algorithm evaluates the first and second derivatives of the waveform to see if it contains sub-pulses. It then assigns an error to the pulse based on the shape and likelihood of these sub-pulses.

The improvements in waveform analysis are now being applied to the algorithms that reconstruct the position and energy of events in the detector. The inclusion of data from the 20″ tubes will increase the amount of charge information available and therefore improve the resolution of the energy estimator. The muon waveform analysis will streamline the muon-tracking algorithm. Error estimates on the single photo-electron data will provide more timing information for the vertex fitters and are being used to improve fitting far from the detector center.