PROSPECT Pulse Clipping Analysis

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Pulse clipping is an effect where a high energy signal overwhelms the photo-detectors on the ends of scintillator tubes, causing the signal pulse peak to be artificially trimmed at a threshold energy. This changes the shape of the pulse and causes calculated quantities like the arrival time and PSD value to be skewed. We present a data-based, energy-independent method to correct for the changes in arrival time induced by clipping.

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1 Introduction

Pulse clipping occurs when the energy of a event exceeds a certain detector threshold, causing the pulse signal to be artificially limited in height. This will cause the top of the pulse to be "clipped." When analyzing signals below a certain energy below which clipping applies, this is not a problem. However, for other events, the calculation of the arrival time will be skewed, because (as defined in [1]) "the pulse's arrival time t is determined by scanning backwards from the pulse's maximum sample location to the first level-crossing at 50% of the maximum ... the arrival time is linearly interpolated to the 50% point between the two samples bracketing the level crossing." Therefore, since clipping skews the pulse maximum height, the 50% point and arrival time will similarly be skewed. Figure 1 shows a comparison between a non-clipped and clipped waveform; the effect on arrival time is significant.

Naturally, clipping also causes both the pulse area and the pulse-shape discriminant (PSD) value to be altered as well. Therefore, if one were to map PSD against energy (proportional to the area of the pulse), we see a systematic deviation in PSD at higher energies, where clipping is relevant. Theoretically, if clipping were not an issue, and if the *shape* of the pulse were independent of the

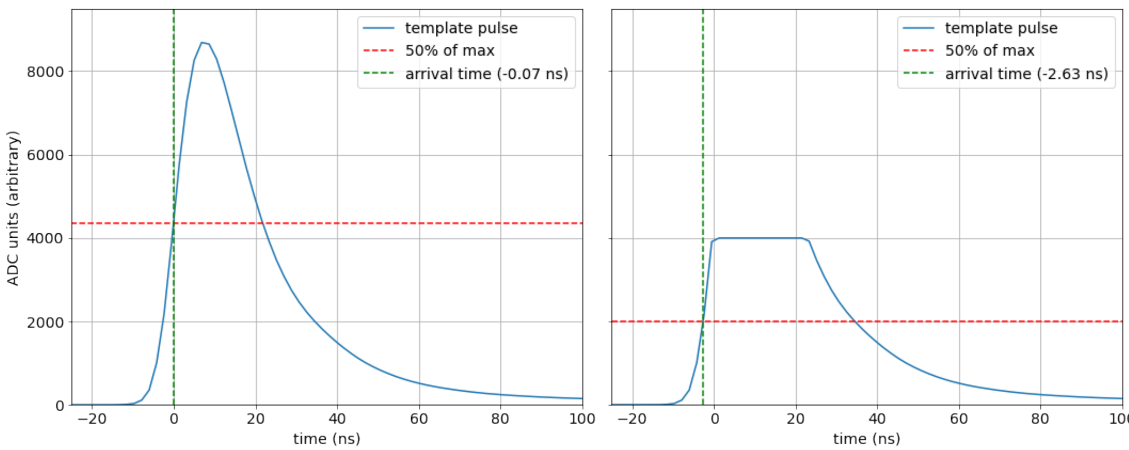

Figure 1: For a template pulse shape, we clip it at some height and demonstrate the effects that it has on the arrival time. The pulse on the left is unclipped; the pulse on the right is clipped. This skews the arrival time by close to 3 ns, which is significant given the total time length of the pulse (tens of ns).

energy, then the PSD should be completely independent of the energy. Figure 2 shows a histogram of PSD and energy. We see a tail flaring upwards; without clipping effects, the tail would be a single horizontal band.

For studies requiring accurate information about the pulse arrival time, a correction should be applied to correct for any discrepancies caused by clipping. This correction should ideally be based on a parameter that changes along with clipping, so the correction can be obtained directly from the other extracted paramters in the data. Using the PSD is a natural choice, because clipping directly affects the PSD value, and we can in turn use the PSD value to determine the correction in arrival time.

2 Template Waveforms

If we assume all pulses have a common shape, a template waveform may be a good way to characterize a universal shape for all waveforms, and generate a curve which maps PSD to a time correction. The template waveform (figure 3) we study in this section is located in `/home/awen/pulse_clipping/templates/AD_templates.root` on the Wright server at Yale Physics. It is important to note that like real waveforms, the template waveform has a limited resolution, and therefore for miniscule amounts of clipping, the arrival time and other paramters will not be affected.

Using this template waveform, we set some arbitary height for clipping, and scale the waveform up in small increments. This way, we get many waveforms with a range of clipping extents.

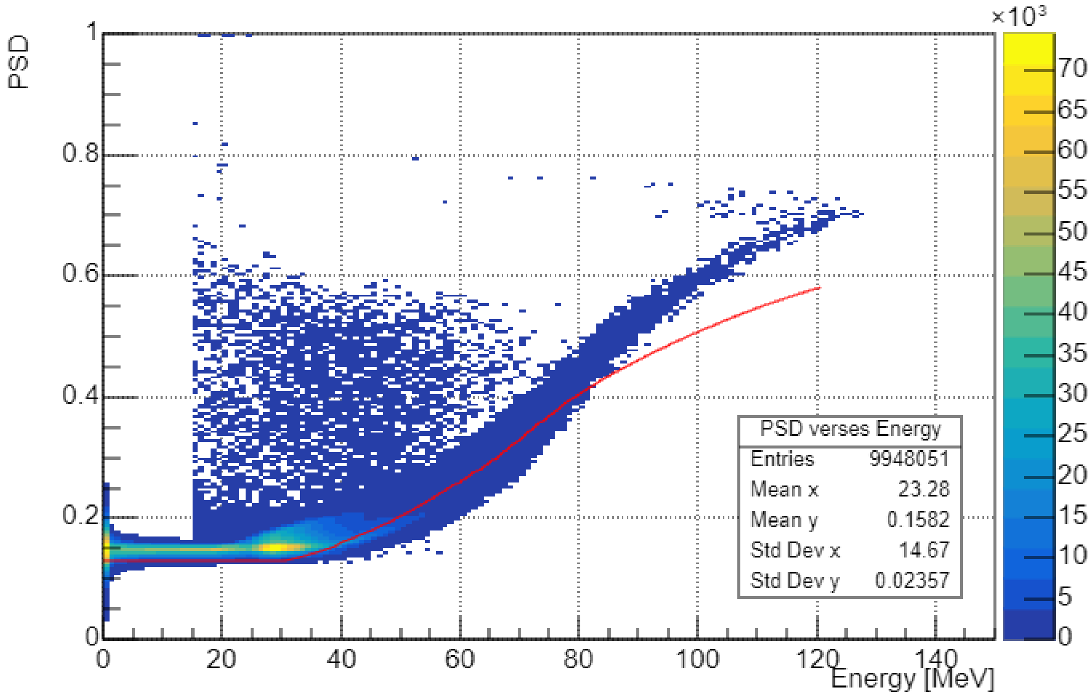

Figure 2: A histogram of PSD and energy for a collection of simulated events (with clipping). One can clearly see the flared tail caused by the clipping effect. The red line is the curve generated by the clipping correction method detailed in section 2.

To illustrate this, we define a quantity Δh which denotes the difference between the un-clipped maximum height of the pulse, and the clipped height. Since this is a template waveform, we can also determine other quantities easily, such as the real arrival time (so we know the exact time offset Δt between the real arrival time and the arrival time after clipping) and the PSD value.

We first plot Δh against Δt for our collection of progressively more clipped waveforms. Figure 4 shows this relationship. Similarly, we can also plot Δh against PSD, in figure 5. In both figures, we can see a region at low and negative Δh where clipping is almost irrelevant, since the effect is too small compared to the resolution of the pulse to affect PSD or Δt.

Having these two plots, we can then directly plot a relationship between PSD and Δt. This plot, shown in figure 6, is our "map" which produces a time correction Δt depending on the PSD value that is measured.

A sanity check that can be performed is to use our collection of artifically clipped waveforms to reproduce a plot of PSD against energy (area). This is shown as a red line in figure 2, along with appropriate horizontal scaling to overlay the curve onto the histogram (we do not know the area-energy conversion). The shapes do agree, but there is still some disagreement in the curve and histogram. This is possibly due to potential discrepancies between the template waveform

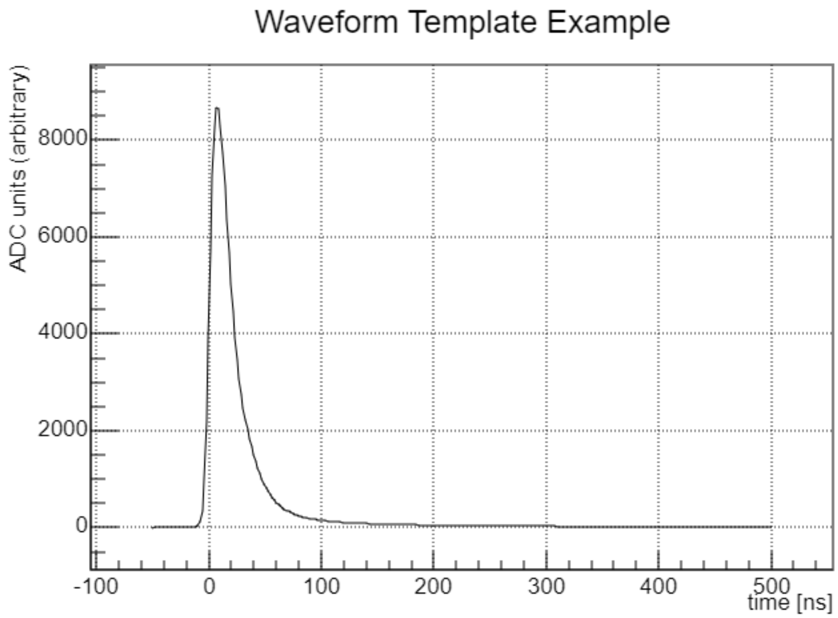

Figure 3: The template waveform that we use in section 2.

(used to generate the curve) and simulation (used to generate the histogram).

3 Data Waveforms

Questions may be raised about the template waveform, so the same analysis was done on a waveform that isn't a template, but instead generated with real pulse data from the PROSPECT detector. Some examples of events are shown in figure 7; each event features multiple energy deposits over several detectors, so each event consists of multiple pulses (displayed in the different colors).

Raw pulses are processed by Blaine Heffron's PulseCruncher plugin code, which itself is located at `https://github.com/BlaineHeffron/PROSPECT2x_Analysis`. This modification, in contrast to the master code, has an additional ability to extract the raw waveforms from the data pipeline; these raw pulses (see the examples in figure 7) are need to generate the data waveform.

An example command is

```
./PulseCruncher ~/PROSPECT2x_Analysis/PulseCruncher/Config/
   Crunch_AD1_Production.cfg /projects/prospect/converted_data/
   Unpacked/AD/WetCommissioning/series023/
   s023_f00027_ts1520890824_Unpacked.root s023_f00027_ts1520890824.
   h5 wf
```

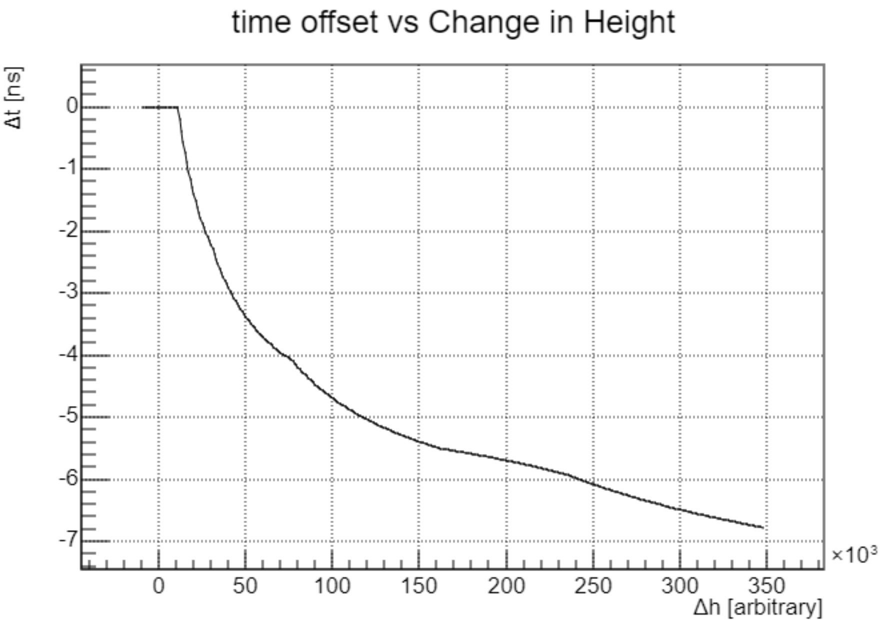

Figure 4: A plot of Δt against Δh. Notice that at small and negaive Δh, we have no time offset because clipping was minimal.

where the first argument is a .cfg configuration file, the second argument is a .root data file, the third argument is the output .h5 file with the raw pulses, and the fourth argument simply needs to be nonempty to flag the program to output raw pulses.

The file containing the raw pulses is located at `/home/awen/pulse_clipping/templates/AD_templates.root`; to generate the data waveform, we take the pulses with a peak height between 2000 and 15500, along with other cuts to remove pulses with more than one significant peak. This data waveform, which is the normalized by the maximum height and averaged to create a data waveform, with an uncertainty. This is shown in figure 8.

With this pulse we reproduce the same process as in section 2. Due to the discrete number of data points, we conducted a coarse version where the arrival time was only defined (and corrected) up to the midpoint between two successive pairs of pulse data points. This results in a coarser correction to the arrival time. A plot of arrival time against PSD is featured in figure 9. This gives a corresponding correction to be made to the arrival time, depending on the PSD value.

4 Further Work

Currently a small discrepancy exists in the calculation of PSD. The calculation of PSD for the present study and the calculation of PSD for the main PROSPECT processing code appears to be slightly different; for the same set of pulses used to construct the data template in section 3,

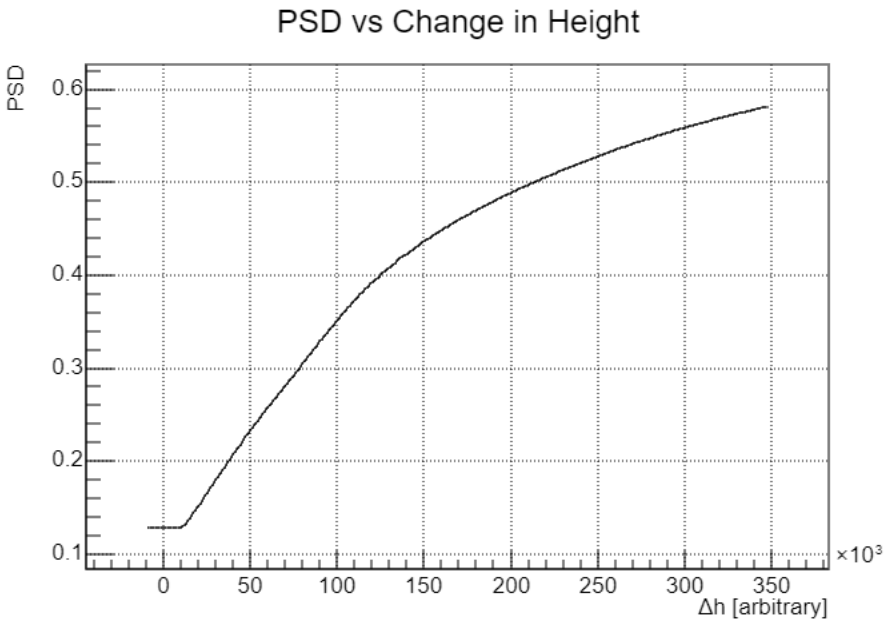

Figure 5: A plot of PSD against Δh. Notice that at small and negaive Δh, we have no effect because clipping was minimal.

the distribution of PSD values is different, as seen in figure **??**. The source of this is unclear, and should be investigated further.

Furthermore, another study that permits a finer resolution between data points, with the data template, should be done; currently, we have only defined arrival time up to 4 ns increments between two successive data points; if we used a linear interpolation to permit a better definition of arrival time, that will eliminate the qauntized nature of the time correction as seen in figure 9.

Finally, there should be a test done with separate simulation results to verify the time correction done with either the data waveform or template waveform.

The code for this study is located at `https://github.com/alexwenym/PROSPECT_pulse_clipping_analysis`, along with the template and raw data files located at `/home/awen/pulse_clipping` on the Wright server at Yale physics.

References

[1] M. Andriamirado, A. B. Balantekin, H. R. Band, C. D. Bass, D. E. Bergeron, D. Berish, N. S. Bowden, J. P. Brodsky, C. D. Bryan, T. Classen, A. J. Conant, G. Deichert, M. V. Diwan, M. J. Dolinski, A. Erickson, B. T. Foust, J. K. Gaison, A. Galindo-Uribarri, C. E. Gilbert, B. W. Goddard, B. T. Hackett, S. Hans, A. B. Hansell, K. M. Heeger, D. E. Jaffe, X. Ji,

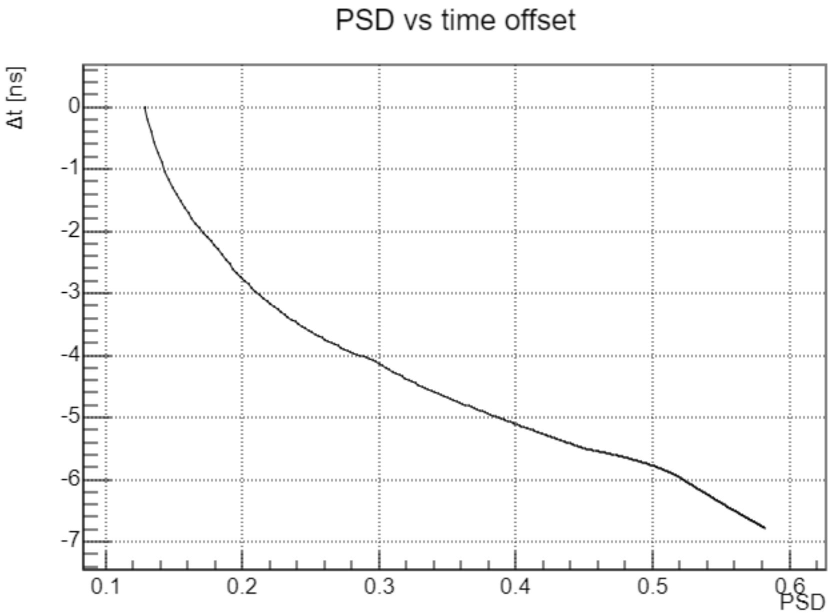

Figure 6: A plot of Δt against PSD. This serves as a mapping that produces a time offset correction Δt depending on the extent of clipping (as indicated by the PSD value).

D. C. Jones, O. Kyzylova, C. E. Lane, T. J. Langford, J. LaRosa, B. R. Littlejohn, X. Lu, J. Maricic, M. P. Mendenhall, A. M. Meyer, R. Milincic, I. Mitchell, P. E. Mueller, H. P. Mumm, J. Napolitano, C. Nave, R. Neilson, J. A. Nikkel, D. Norcini, S. Nour, J. L. Palomino, D. A. Pushin, X. Qian, E. Romero-Romero, R. Rosero, P. T. Surukuchi, M. A. Tyra, R. L. Varner, D. Venegas-Vargas, P. B. Weatherly, C. White, J. Wilhelmi, A. Woolverton, M. Yeh, A. Zhang, C. Zhang, and X. Zhang. Improved short-baseline neutrino oscillation search and energy spectrum measurement with the prospect experiment at hfir. *Phys. Rev. D*, 103:032001, Feb 2021.

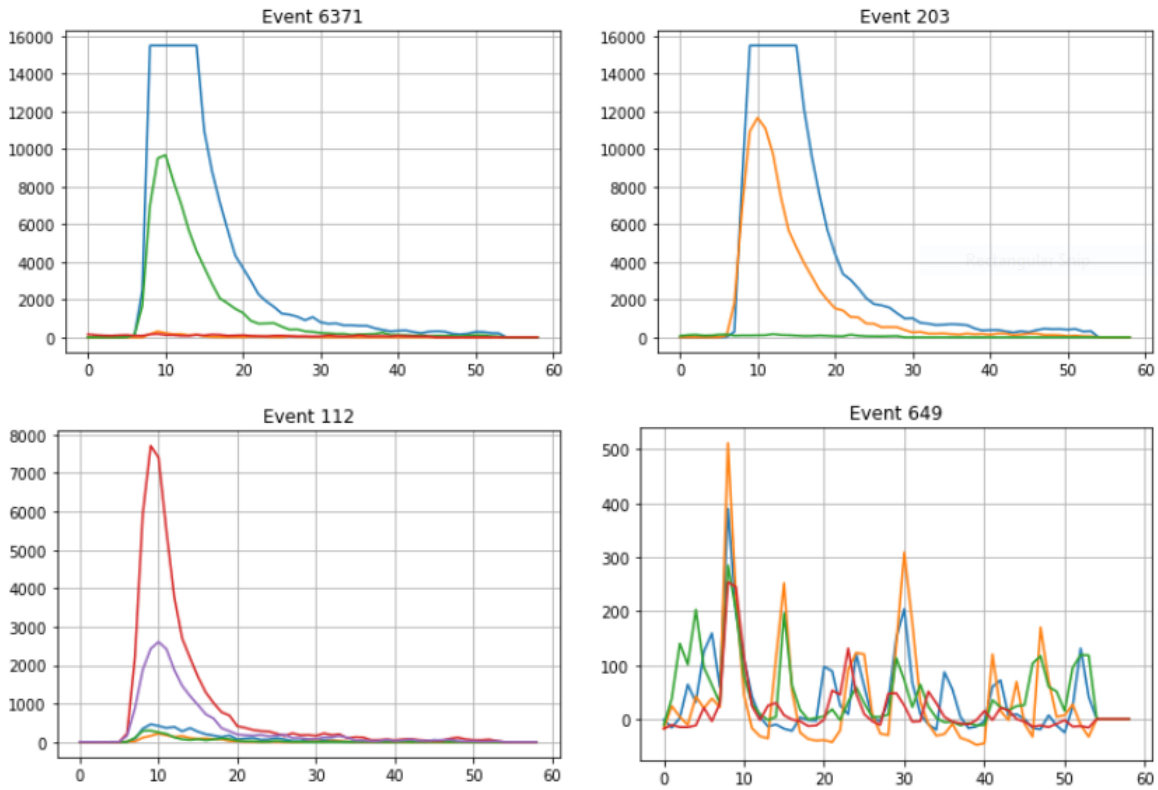

Figure 7: Examples of data pulses. Each event consists of multiple energy deposits in different detectors (different colors); clipping can clearly be seen on certain pulses greater than a certain height threshold. Some events do not have a clearly defined pulse (like event 649).

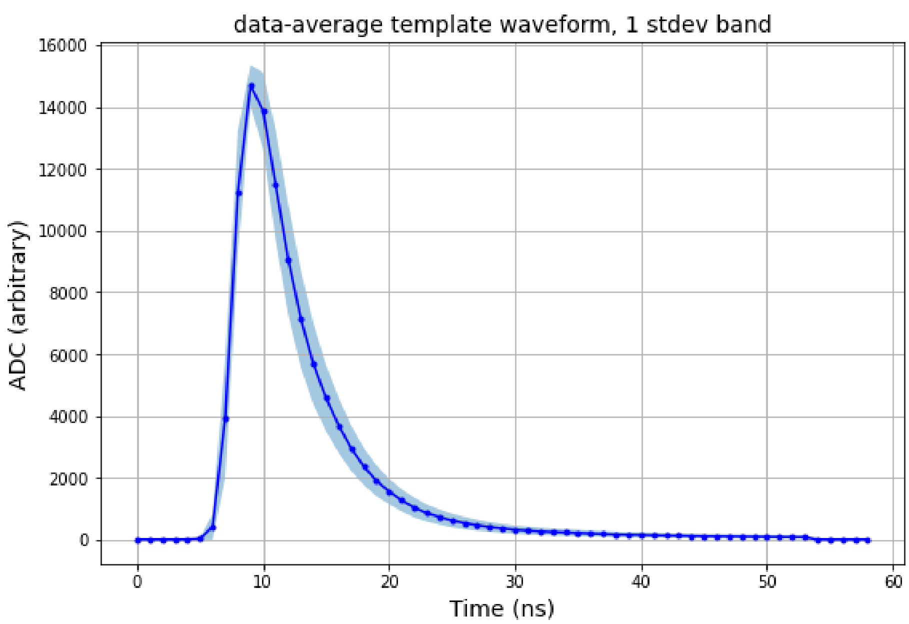

Figure 8: The data waveform generated by averaging over many data pulses. The standard deviation uncertainty is shown as the light blue band.

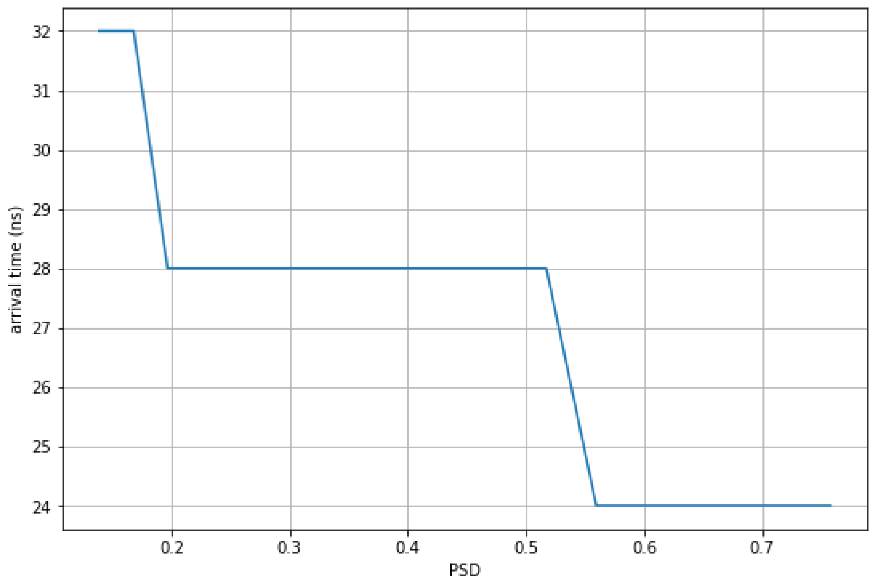

Figure 9: A plot of arrival time against PSD, generated using the data waveform. The correction, up to 4 ns, should be clear; a corresponding correction is to be applied to any event with an arrival time before 32 ns.

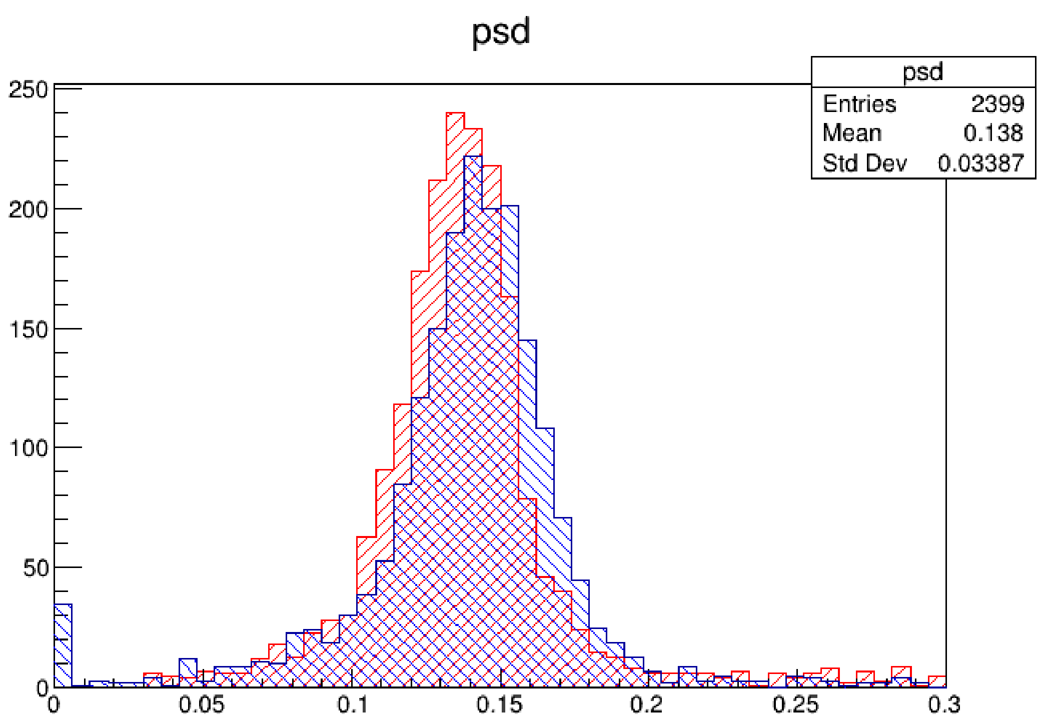

Figure 10: Distributions of PSD. For the same set of data pulses (see section 3), the distribution of PSD calculated for the present study (blue) and the distribution calculated by the main PROSPECT processing code (red) has a clear deviation. The source of this is unclear, and should be investigated further.