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New Baseline Algorithm for UUB Traces

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Abstract

To acquire an unbiased signal from a time trace, it is necessary to correctly identify and subtract a baseline. An improved algorithm for estimating the baselines of SD time traces has been previously developed for UB electronics. However, these electronic boards will be exchanged with the upgraded unified boards (UUB) in the course of the ongoing AugerPrime upgrade, thus making it necessary to revisit and adjust the algorithm to the new electronics.

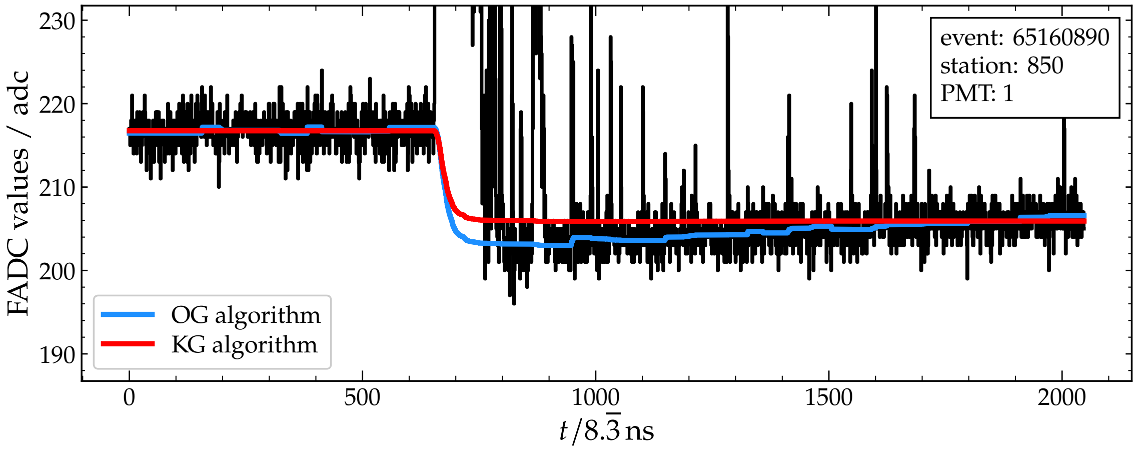

Figure 1: The KG algorithm for UBs computes a constant front and end piece of the time trace and interpolates in between both estimates the baseline. The OG algorithm tries to identify flat pieces in the trace and interpolates the baseline between these pieces, resulting in a varying baseline.

1 Introduction

The KG baseline algorithm was developed on a physically motivated trace model. Without any signal present in a trace, the baseline of this trace can be assumed to be constant. After significant signal, the output of photomultipliers is visibly reduced, resulting in an undershoot of the baseline that recovers exponentially with a characteristic decay constant τ. For the UB the recovery of the undershoot takes about 300 µs, which is followed by a systematic overshoot of the trace. This overshoot then slowly decreases over a time span of up to 1 to 1.5 ms [1]. The total trace length of UB time traces is 19.2 µs and thus, the baseline after the undershoot can be assumed constant. In the UUB the recovery of the undershoot is visible due to shorter decay constants, as can be seen in Fig. 1. The nominal decay times for high gain traces are around 100 µs and around 270 µs for low gain traces. However, this excludes the AC coupling at the PMT base and thus diverging results are to be expected [2]. The KG baseline algorithm for UBs is not able to take the recovery of the undershoot into account. A constant front and end baseline estimate, based on the truncated mean of the first and last 100 bins of the trace, is calculated. Depending on the absolute difference ΔB of these estimates, a baseline is interpolated between the front and end estimate. The OG baseline algorithm identifies various flat pieces and interpolates in between them, resulting in a varying baseline estimate that roughly follows the recovery. However, it has been shown that the baseline estimates of the OG baseline algorithm result in false estimates due to the flat piece determination and should not be used [3]. Therefore, a modification of the current KG baseline algorithm is needed in order to take the shorter decay times of the UUB into account.

2 Determination of the decay constant

As a first step, the decay constants of multiple traces of events between November 2021 and June 2022 are determined. The recovery of the undershoot is related to the size of the signal. Since the undershoot is linearly dependent on the signal size, a small signal will not produce a significant undershoot and thus no decay constant can be determined. A cut on the charge is applied to select events with significant undershoot, such that a decay constant can be fitted. A detailed description on how this cut is chosen is explained in Appendix A. This gives a set of 39235 high gain traces. Since the data set is too small to include a sufficient number of low gain traces with a significantly large undershoot, the following analysis is performed purely on high gain traces.

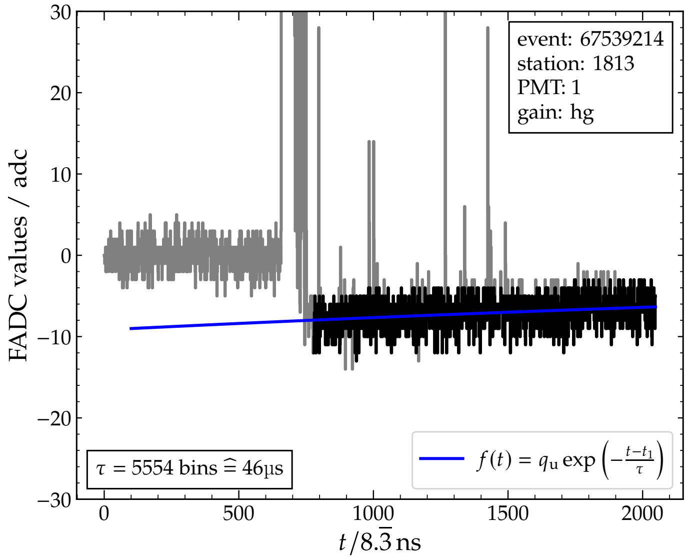

Figure 2: Example final fit of the decay constant and undershoot of a trace. After an initial fit, all signal contributions in the trace, that do not belong to the baseline are removed (in grey) and a final fit of the decay function is performed.

An exponential decay of the form of

$$f(t) = q_\mathrm{u} \exp\left(-\frac{t-t_1}{\tau}\right) \tag{1}$$

is used, where τ is the decay constant and q_u denotes the undershoot after the signal at the time t_1. First, a robust baseline estimate of the front baseline is estimated. A detailed description of this procedure is given in [3]. This estimate is then subtracted from the trace for the following fit of the trace. As a rough approximation for t_1, the first bin after the trace maximum, where the trace becomes negative, is chosen and half a microsecond is added to avoid signal of the shower. The undershoot q_u and the decay constant τ are determined during the initial fit. After the first fit has been performed, the trace can be cleaned from unwanted signal contributions to improve the quality of a second fit. Using the results from the initial fit, the decay term is subtracted from the trace. Similar to the estimation of the robust baseline at the beginning of the trace, the mode of the trace is determined and all signal, exceeding a threshold of 2σ relative to the mode is removed. The fit of the decay constant and the undershoot is then repeated with the cleaned trace. The resulting fit can be seen in Fig. 2.

The distribution of all fitted decay constants is shown in Fig. 3-left. The maximum of this distribution is around $\tau = 42\,\mu\mathrm{s}$, with 95 % of the decay times being in the interval of 28 µs to 73 µs. For each station and PMT, the mode of τ is determined, if at least 50 fits were performed. In Fig. 3-right the histogram and the mode is shown for a specific station and PMT.

Fig. 4 shows the estimated decay constants for a total of 110 PMTs from 44 different stations. The mean of the distribution is at $\tau = 41\,\mu\mathrm{s}$ with a standard deviation of $\sigma = 2\,\mu\mathrm{s}$.

In order to test the variance of this estimated average decay constant, the full procedure is repeated for different cuts on ??? Since the standard deviation of τ from the different PMTs is small, the average of the distribution can be assumed as universal decay constant for the further development of the UUB update of the KG baseline algorithm.

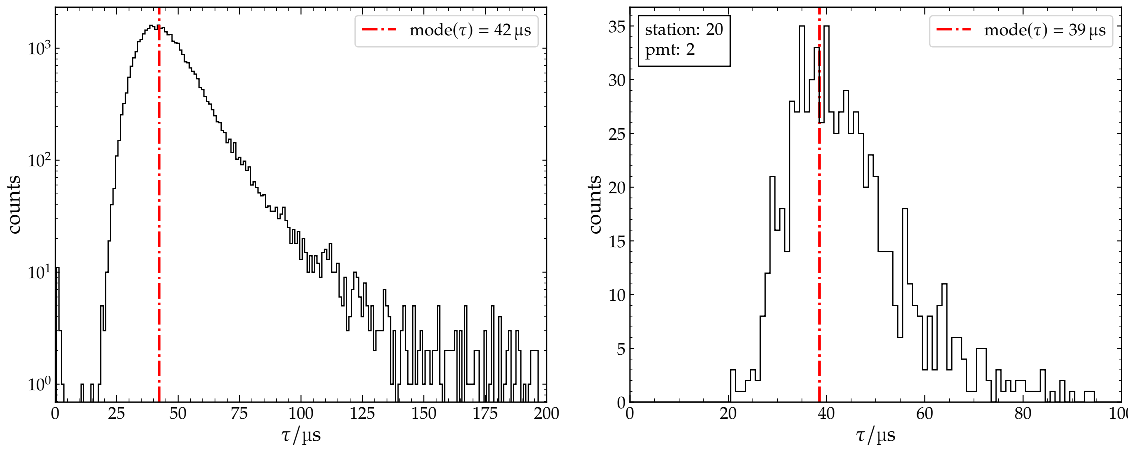

Figure 3: The distribution of τ for all stations (left) and specific PMTs (right) covers a wide range of decay constants.

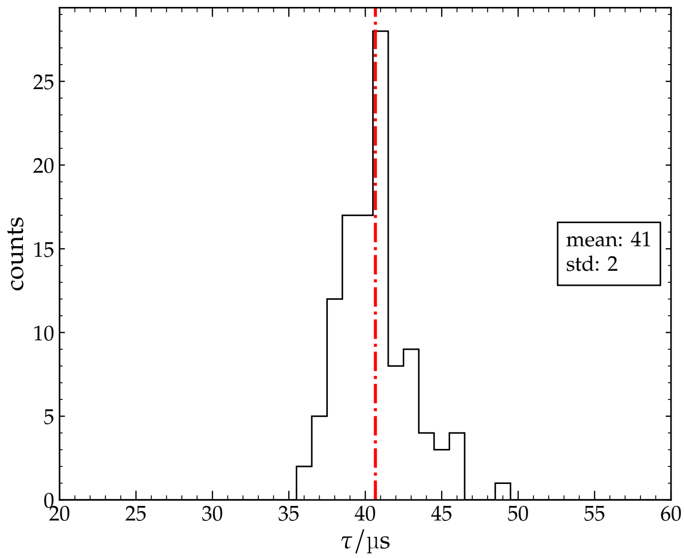

Figure 4: By calculating for each individual PMT of each station the most likely decay constant a universal constant can be estimated if the spread between the single PMTs is small enough. For 110 PMTs from 44 different stations the average decay constant is at $\tau = 41\,\mu\text{s}$ with a standard deviation of $\sigma = 2\,\mu\text{s}$, thus an universal decay constant can be assumed for all PMTs.

3 Extension of the UB algorithm

A few changes have to be implemented in the KG baseline algorithm, in order to correctly estimate the baselines of time traces of UUBs. The full procedure of the KG algorithm for UB baseline estimation has been explained in detail in [3]. With the UUB some properties of the traces change. While the total time of the trace remains approximately the same, the bin width is decreased from a binning of 25 ns down to $8.\overline{3}$ ns, which results in an increase of the number of bins from 768 up to 2048. The sample window for the estimation of the front and end baseline is thus increased from 100 up to 300 bins. After both estimates have been determined, the undershoot ΔB and baseline error $\sigma_{\Delta B}$ are determined and an interpolation method is chosen. In the case of a significant undershoot with $0 > \Delta B \geq -1\sigma_{\Delta B}$ a minimum difference of 200 adc counts between the trace maximum and the front baseline estimate B_{front} is needed to execute the charge-linear

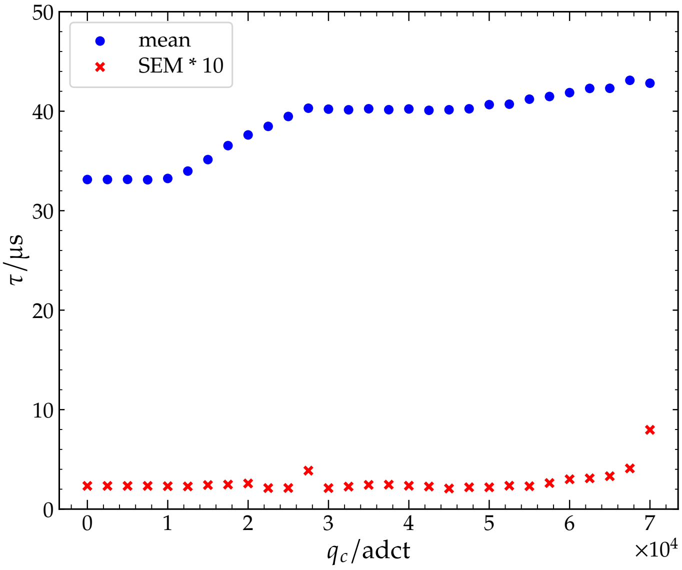

Figure 5: Text.

approximation of the baseline. After a time-linear interpolation of the baseline has been performed the baseline of the charge-linear interpolation can be calculated as

$$b_i = B_{\text{front}} + \epsilon_i \Delta B \tag{2}$$

with ϵ_i as the cumulative current charge

$$\epsilon_i = \frac{q_i}{q_{\text{ref}}}. \tag{3}$$

q_{ref} is the integrated total charge of the baseline subtracted trace up to the center bin of the end baseline estimate, which is at 1898 bins. Since there is a decay of the undershoot after the signal, an exponential kernel has to be added when calculating q_i

$$q_i = \sum_{j=0}^{i} (T_j - b_j) \exp\left(-\frac{\Delta t(i-j)}{\tau}\right) \tag{4}$$

with the previously determined universal decay constant $\tau = 41\,\mu\text{s}$. In the case of large decay times, the exponential term becomes 1 and the equation is the same as for the UB baseline estimation.

4 Evaluation

As shown in the previous section, the decay constant varies on the PMT level. By using an universal decay constant, systematic errors have to be checked. For a set of 114484 traces the baseline is estimated multiple times for a varying τ. The total charges $q_{\text{tot}}(\tau)$ of the traces are then calculated and compared to the trace with the baseline estimate that is performed with the universal decay constant $\tau = 41\,\mu\text{s}$. The resulting bias relative to $q_{\text{tot}}(41\,\mu\text{s})$ is shown in Fig. 6. For decay times, that are larger than the estimated universal decay constant, the bias reaches a limit of -2%. If the decay times are smaller the bias increases exponentially. At approximately $\tau = 20\,\mu\text{s}$, the bias relative to the the universal decay constant is at around $+2\%$.

Fig. 7 shows a comparison of estimated baselines between the OG algorithm, the KG algorithm and the updated version of the KG algorithm.

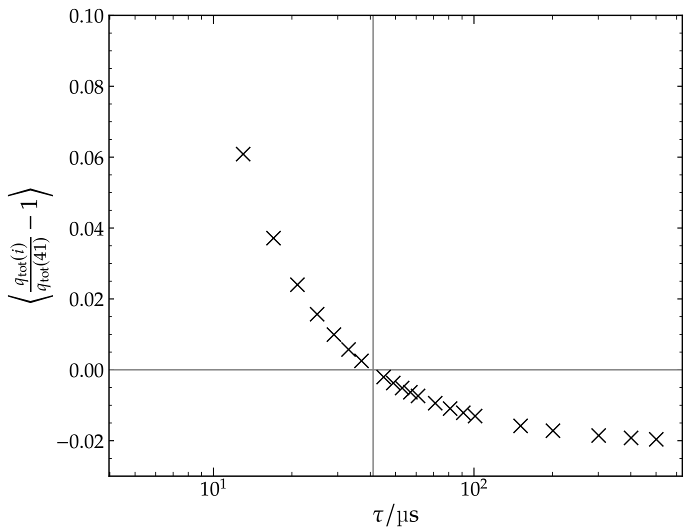

Figure 6: Bias of the total charge $q_{\mathrm{tot}}(\tau)$ relative to the total charge, estimated with an universal decay constant of $\tau = 41\,\mu s$.

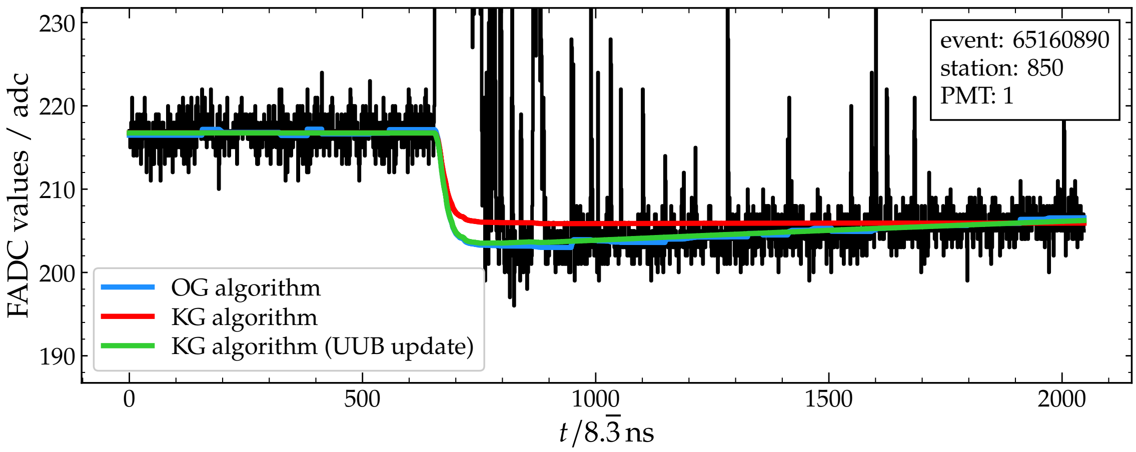

Figure 7: Text.

5 Conclusions

Here come some nice conclusions.

References

[1] B. Genolini, T. Nguyen Trung and J. Pouthas, "Base line stability of the surface detector pmt base." 2003.

[2] D. Nitz.

[3] T. Schulz, M. Roth, D. Schmidt and D. Veberič, "New baseline algorithm for sd traces of the ub." 2022.

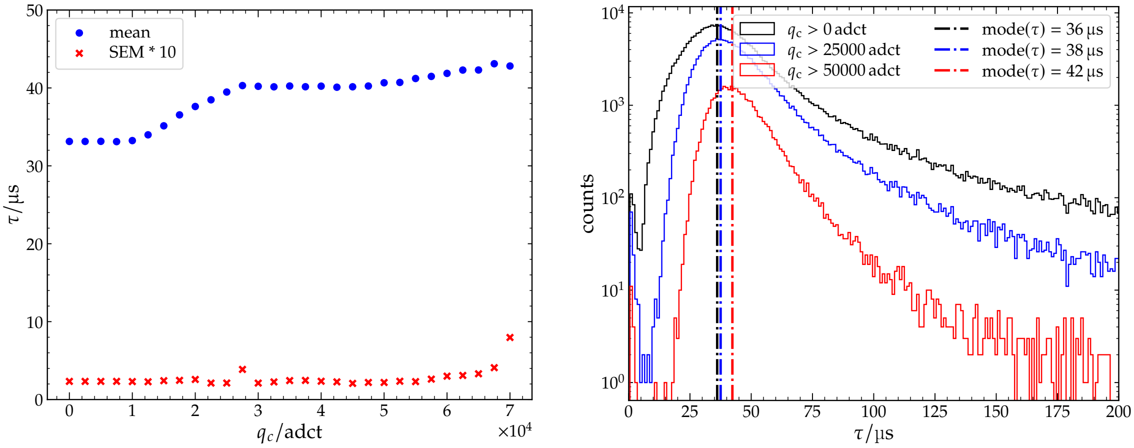

Figure 8: Text.

A Signal Cut

In order to determine a reasonable cut on the minimal trace charge, the full analysis of Section 2 is repeated. At first, for all traces the signal charge q_c of the trace is approximately determined as

$$q_c = \sum_{i=0}^{t_1} (T_i - B_{\text{front}}). \tag{5}$$

t_1 is chosen as the first bin after the trace maximum, where the trace becomes negative with half a microsecond added to include further signal contributions of the shower. q_c is then used as minimal cut to select traces by their charge. The most probable decay constant is then estimated for each distribution of fits from a single PMT. In the last step the average of the single PMT decay constants is calculated. Fig. 8-left shows the calculated average decay constants as well as their standard error of the mean (SEM) for increasing cuts on q_c. With increasing signal size and q_c the mean increases from $\tau = 33\,\mu\text{s}$ up to approximately $\tau = 43\,\mu\text{s}$. Explain why the decay time is increasing and then flat again. For this analysis, the cut on q_c has been chosen at a minimum of 50000 adct. In Fig. 8-right the distribution of all fitted decay constants is shown for three different cuts on q_c. With increasing minimal q_c, the amount of fits with very long decay times reduces. Since the undershoot correlates with the signal size, the decay of the undershoot becomes more visible.