# ZnWO4 PSD study

Denys Klekots

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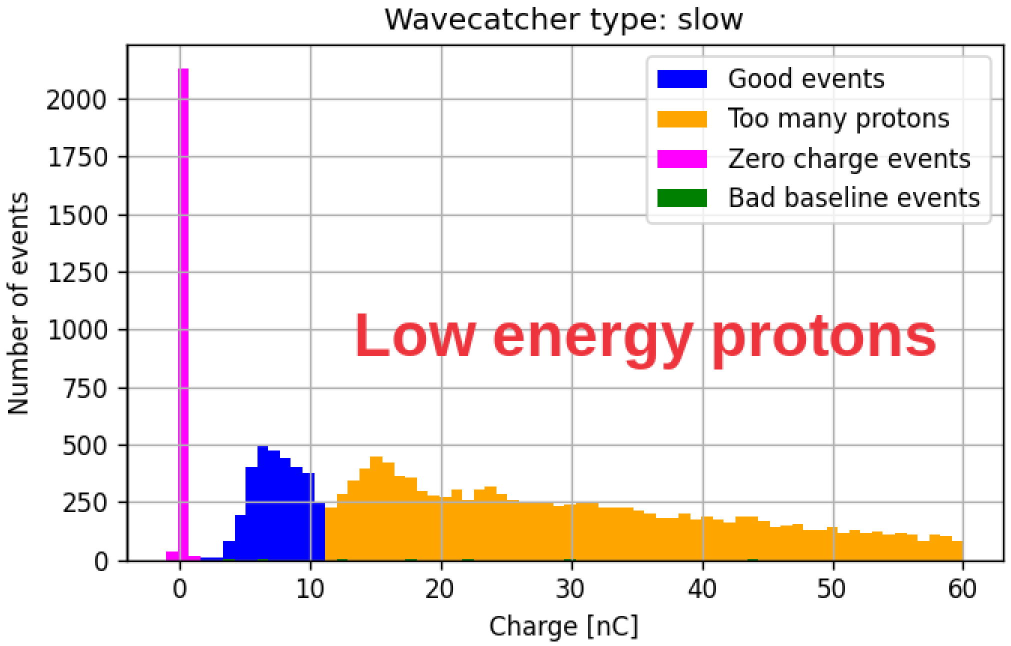
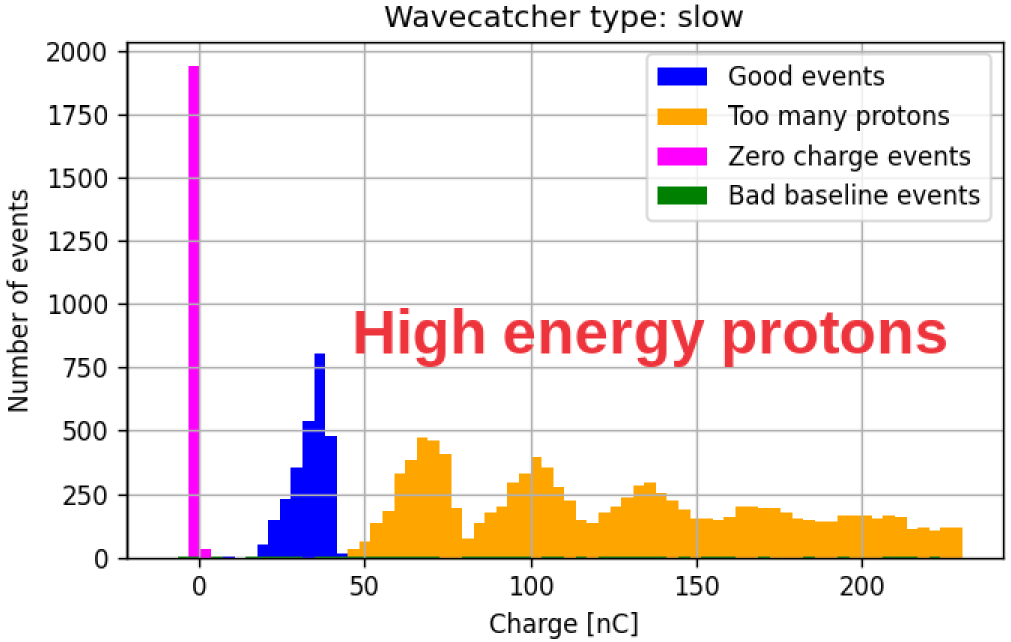
# Preprocessing setup

- Average pulse curves are calculated for an order of 1000 events.
- The events individually undergo some preprocessing to ensure good quality of events.
- Data measured with fast and slow wavecatchers.
- The events with one proton were selected for analysis. For electrons, it's already one electron.





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# Normalised average pulse shapes.

❑Considered the following cases:

- Electrons (measured)
- Protons 6 MeV, low energy (measured)
- Protons 15 MeV, high energy (measured)
- Alphas, pulse builds on values from publication.

Pulse parameters from publication

| Type of irradiation | Decay constants, μs | | |
|---|---|---|---|
| | $\tau_1$ ($A_1$) | $\tau_2$ ($A_2$) | $\tau_3$ ($A_3$) |
| γ ray | 0.7 (2%) | 7.5 (9%) | 25.9 (89%) |
| α particles | 0.7 (4%) | 5.6 (16%) | 24.8 (80%) |

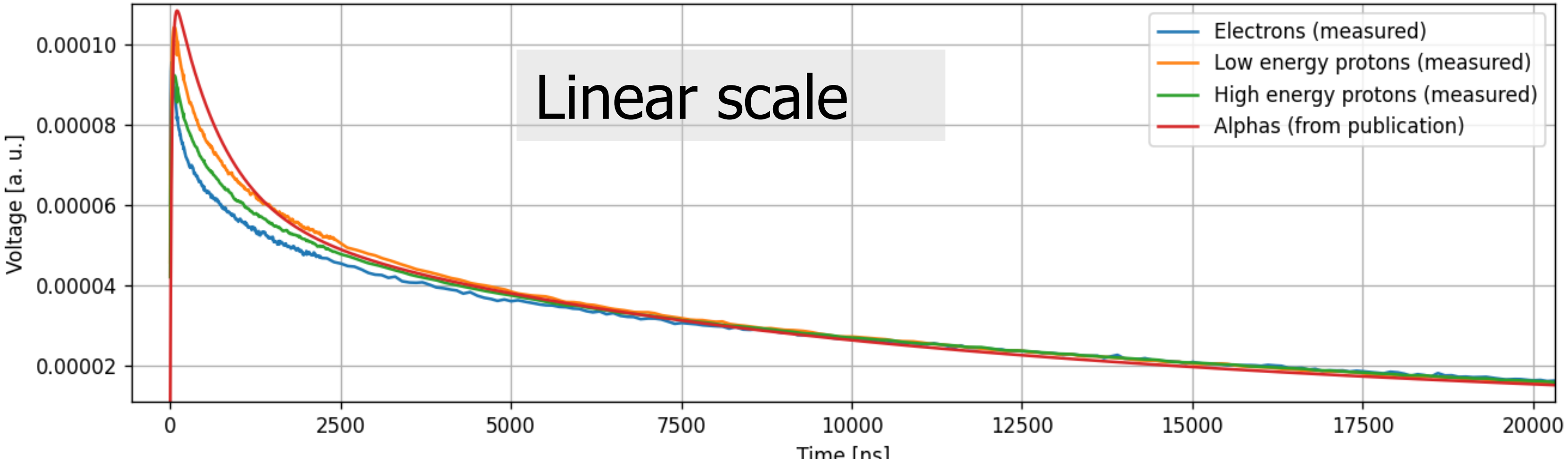
Measured pulses for protons compared against measured electrons.

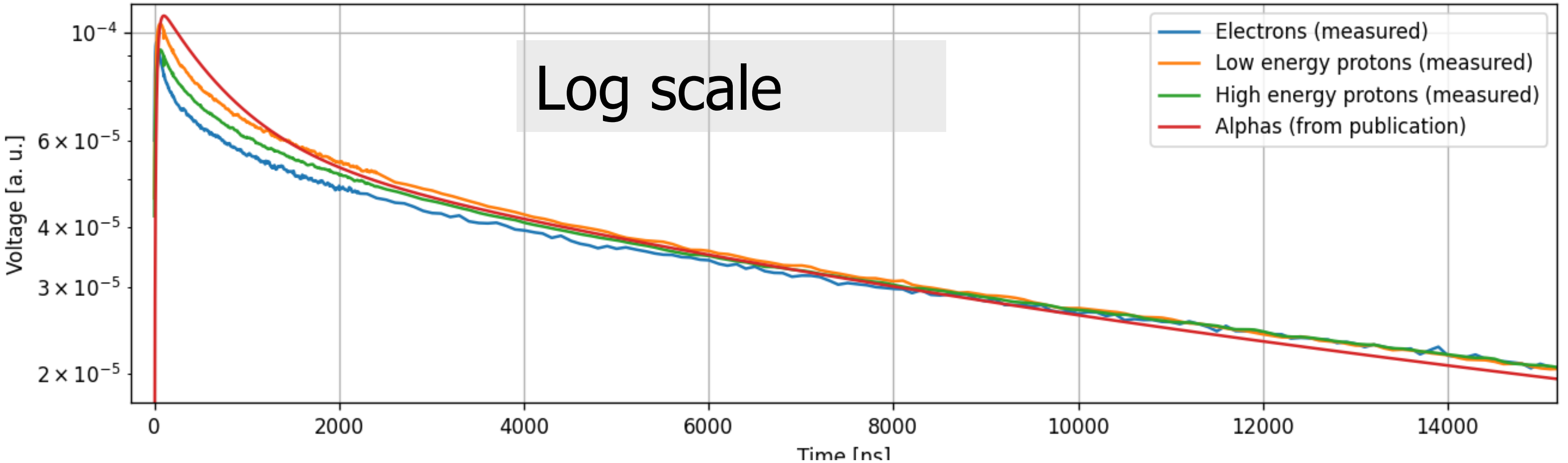
Built pulses for alphas compared against the built for gammas.

# Normalised average pulse shapes.

## Normalisation

$$\int_0^\infty V(t)dt = 1$$



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# Ratio of normalised curves

- Here curves represent the ratio of the handrons and corresponding electron pulses for each point in time.



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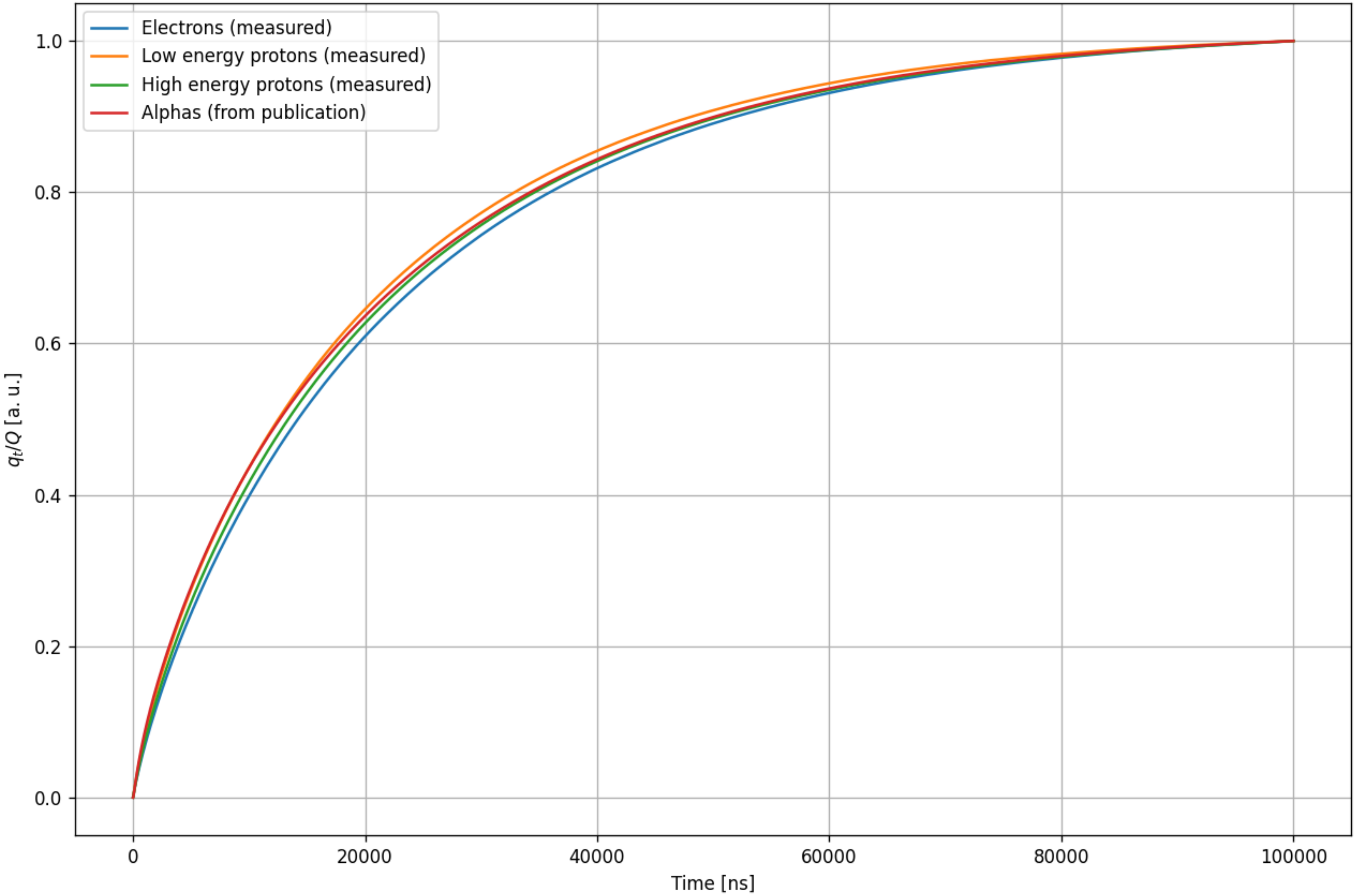
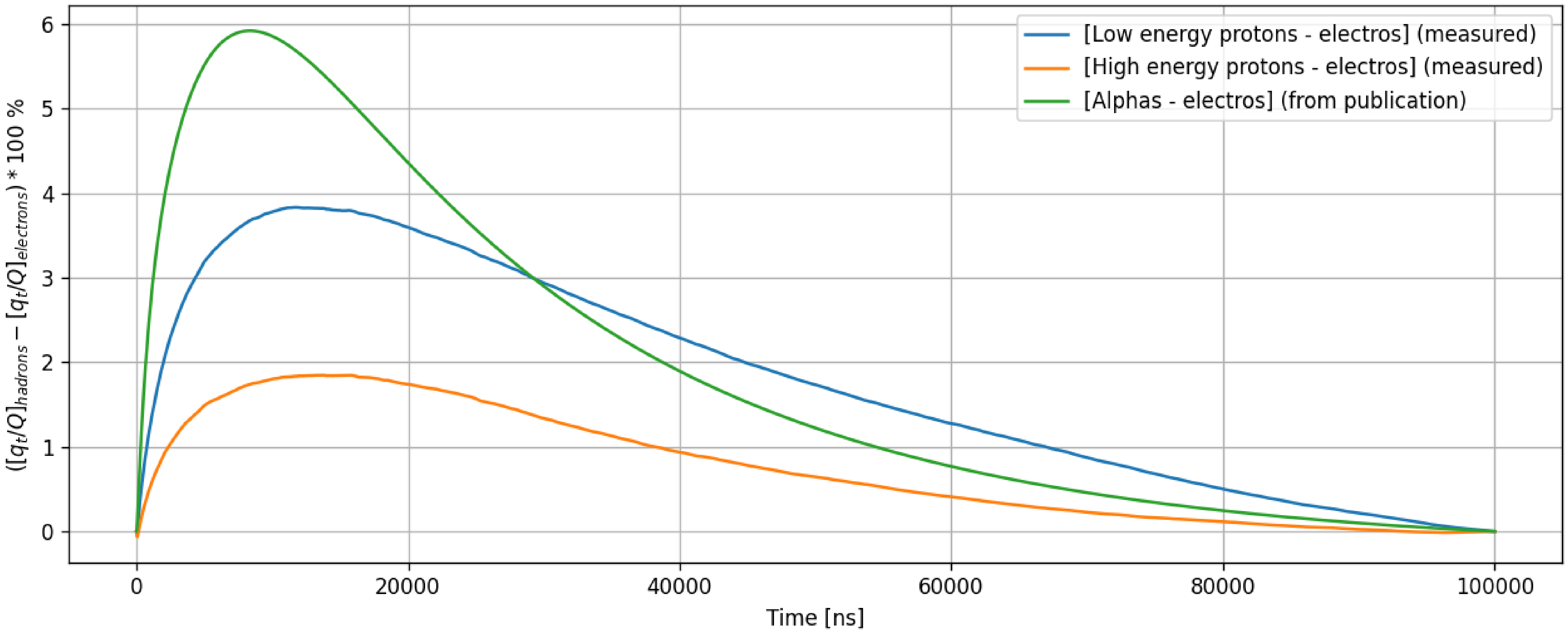
# Comparison of charge integrals

$$q_t = \int_0^t V(\tau)d\tau$$



# Difference between charge integrals



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# Summary

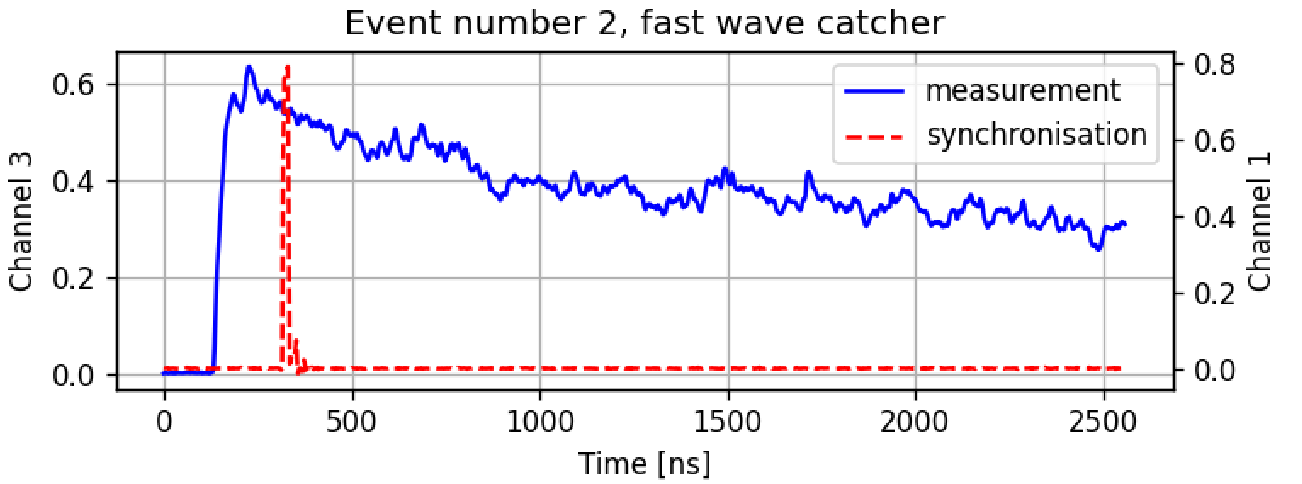
| Hadronic particle | Max $V_h/V_e$ | Max $q_t$ difference (% of total charge) |
| --- | --- | --- |
| High energy protons | 1,12 | 1,85 % |
| Low energy protons | 1,24 | 3,85 % |
| Alphas | 1,55 | 5,95 % |

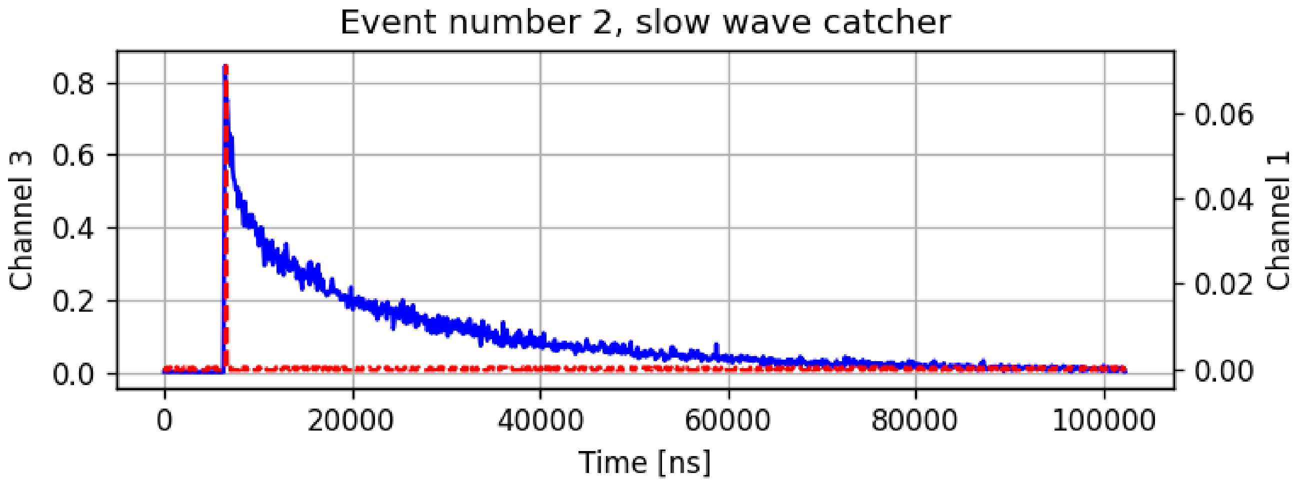
Thank you for your attention

Backup slides.

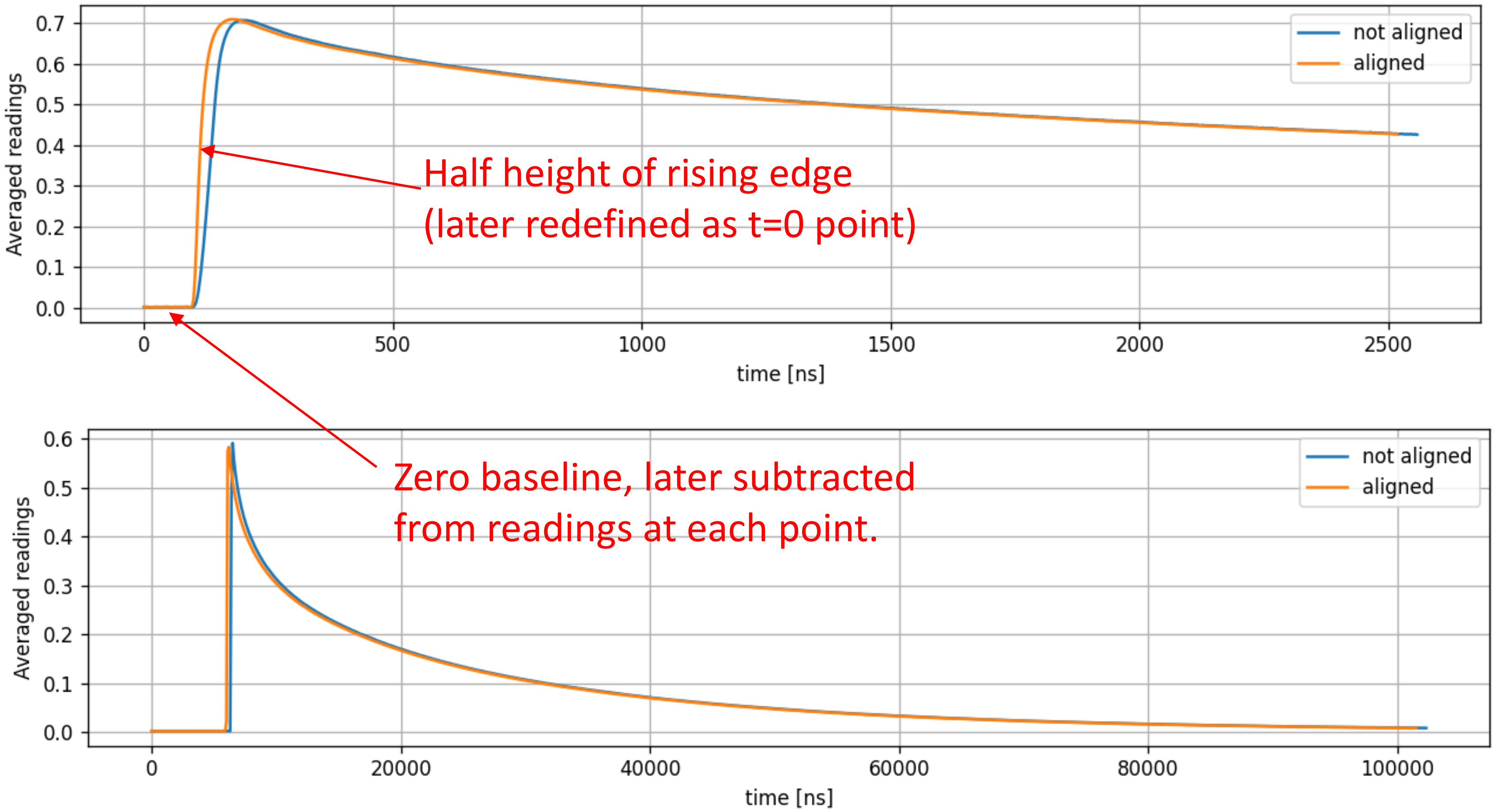
# Single event readings and synchro signal

- Reference time is half the height of the rising edge of the channel 1 pulse.
- All of the event readings were shifted to the left to align the reference time to the most left one.
- Readings were averaged to get the final pulse shape



# Effect of event alignment by the synchro signal



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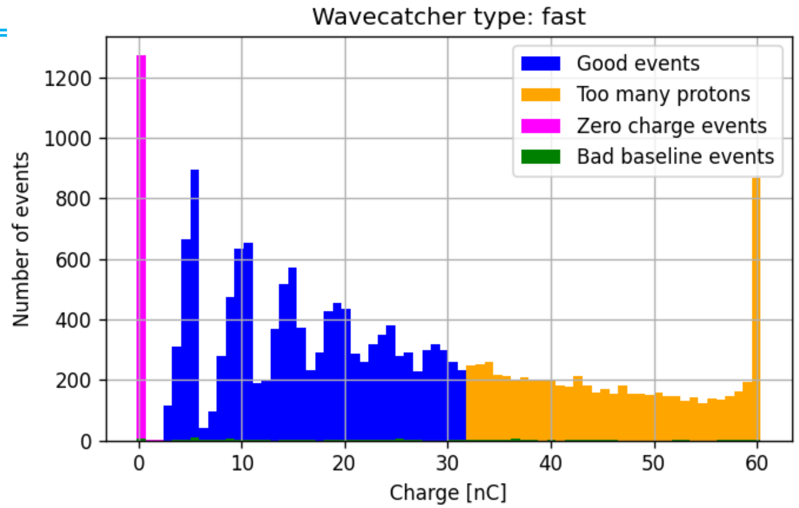
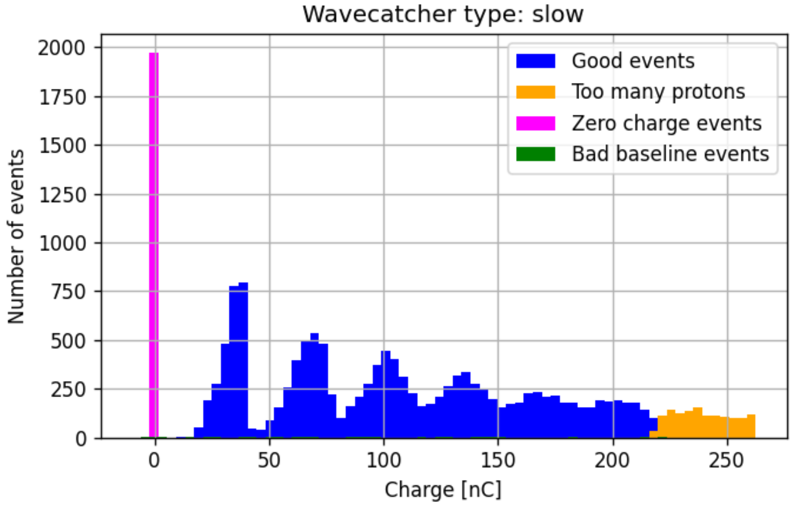
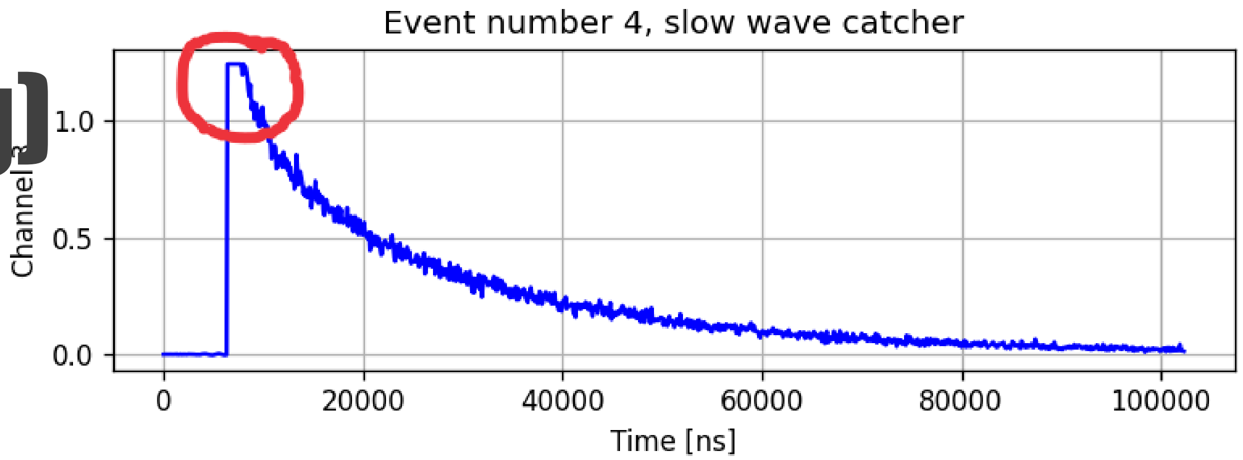
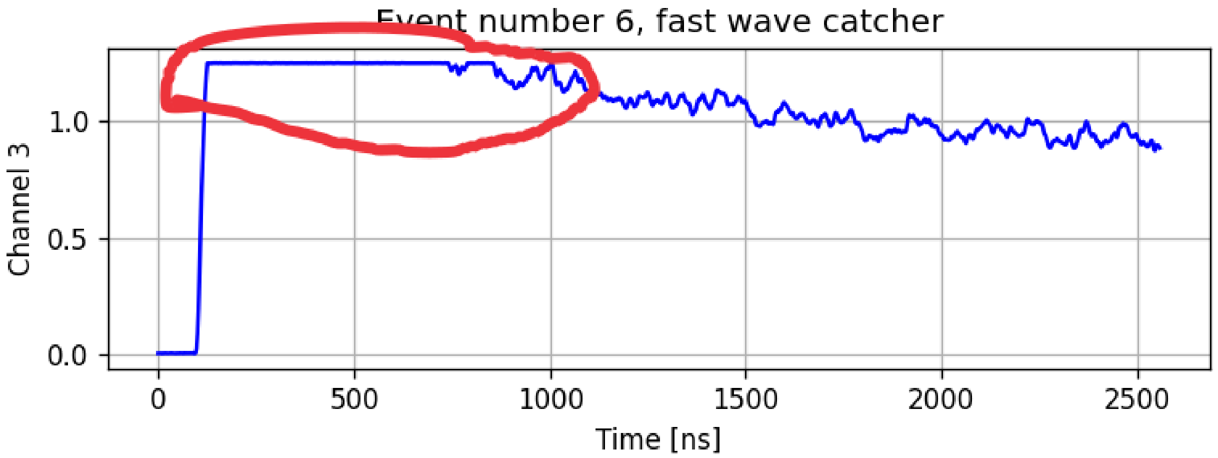
# Event selections (clearing)




Example of events with too many protons

- Events were selected based on integrated charge over all wavecatcher time.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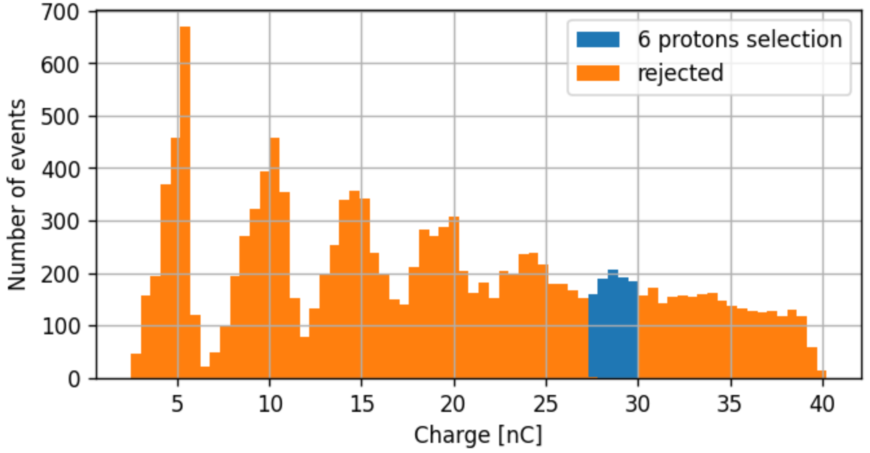
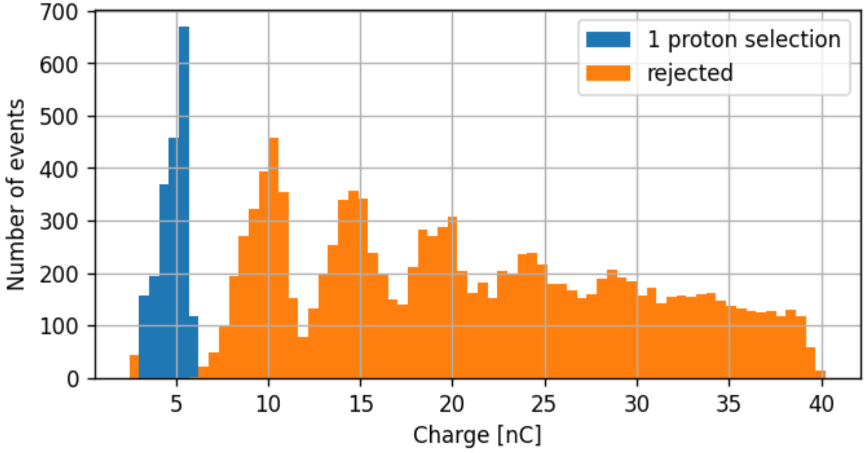
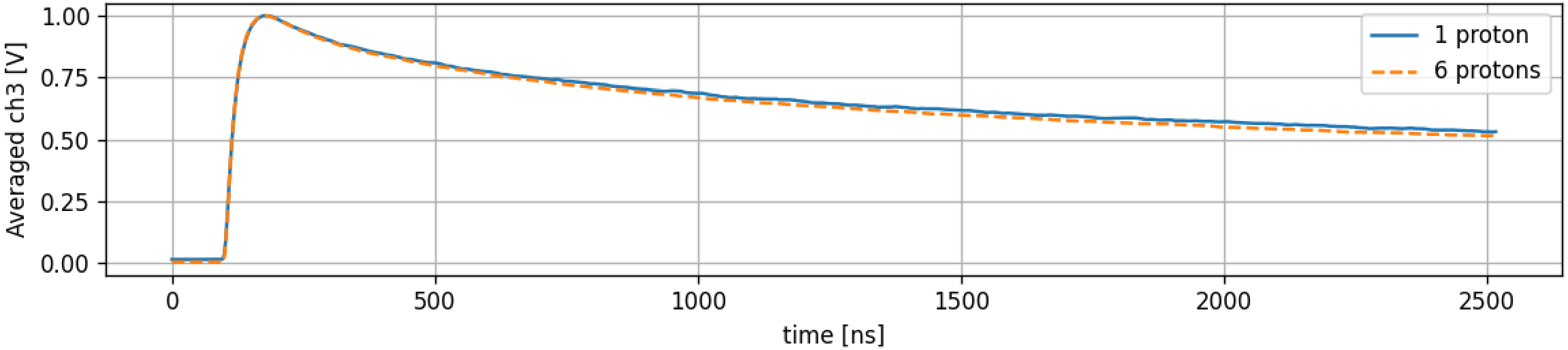
# 1 proton vs 6 proton events comparison



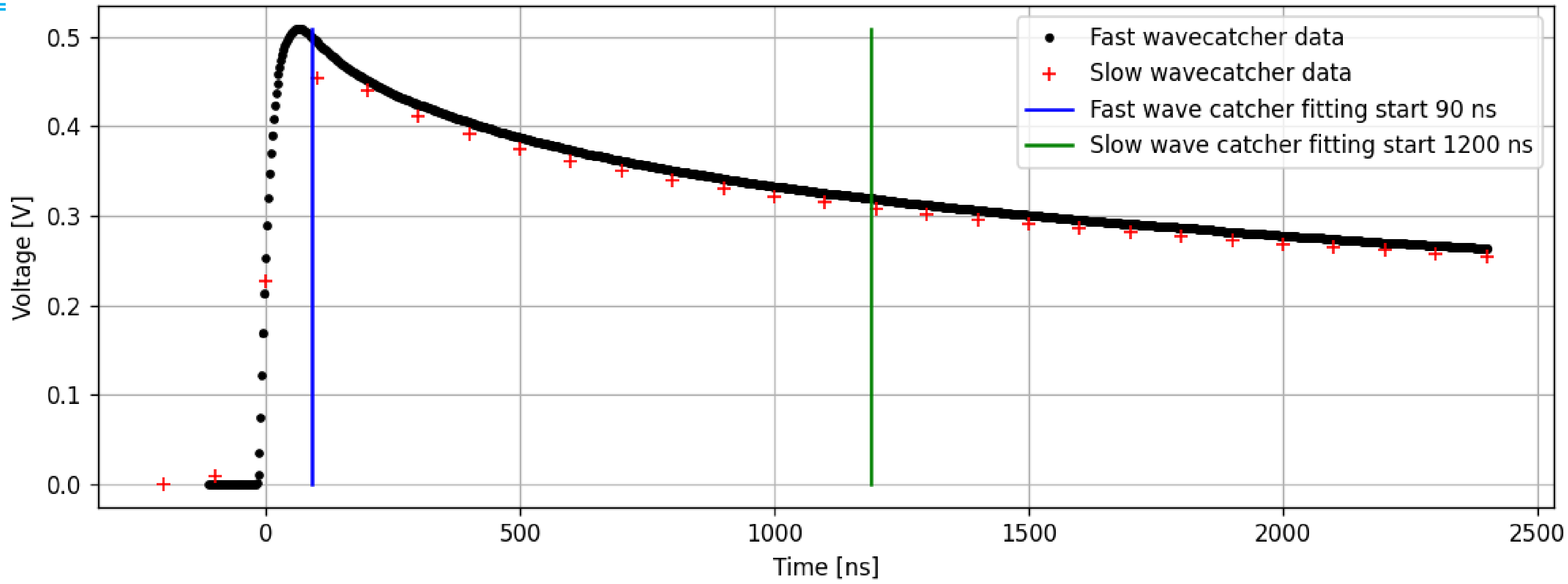




- Averaged curves look the same



# Preprocessed data before fit

- ❑Curve averaged over events that pass selection.
- ❑Zero baseline removed (subtracted from all readings)
- ❑Zero time (x-axis) redefined.




- ❑Fast wave catcher pulse fit starts from 90 ns
- ❑Slow wave catcher pulse fit starts from 1,2 microsecond.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# Fit methodology

$$F_f(t|A_{1-4}, \lambda_{1-4}) = A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t} + A_3 e^{\lambda_3 t} + A_4 e^{\lambda_4 t}$$

$$F_s(t|C, A_{1-4}, \lambda_{1-4}) = C\left(A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t} + A_3 e^{\lambda_3 t} + A_4 e^{\lambda_4 t} + A_{5s} e^{\lambda_{5s} t}\right)$$

- $A_1$ - $A_4$ amplitudes, shared for slow and fast wave cathers
- $\lambda_1$ - $\lambda_4$ the exponential decrements. They related to the $\tau$ parameters by $\lambda_i = \frac{1}{\tau_i}$. Also shared between the slow and fast dataset measurements
- $C$ - the parameter for matching the voltage between different wave catchers.

- 5th exponent introduced to correct electronics

- The fit is performed by finding the minimum of the loss function. Two loss functions considered.

**MSE fit**

$$L_k(C, A_{1-4}, \lambda_{1-4}) = \sqrt{\frac{\sum_{i=1}^{N} \left[y_i - F_k(t_i|C, A_{1-4}, \lambda_{1-4})\right]^2}{N}}$$

**CHI2 fit**

$$L_k(C, A_{1-4}, \lambda_{1-4}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \frac{\left[y_i - F_k(t_i|C, A_{1-4}, \lambda_{1-4})\right]^2}{y_i}}$$

The final loss function to minimize is as follows

$$L(C, A_{1-4}, \lambda_{1-4}) = L_f(A_{1-4}, \lambda_{1-4}) + 1.1 \cdot L_s(C, A_{1-4}, \lambda_{1-4})$$

- The dual annealing minimization was used. I tend to be safe from falling into a local minimum, and the fit does not depend on the initial parameter guess.

# 5th exponent explanation

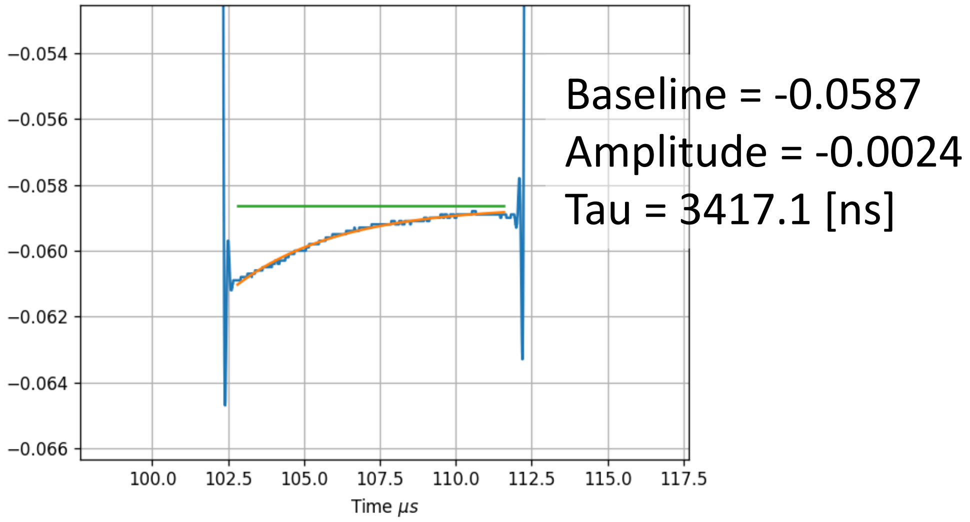
- Solving the circuit for a pulse by applying Kirchhoff's rules would get something like

$$a\ddot{I} + b\dot{I} + cI = F(x)$$

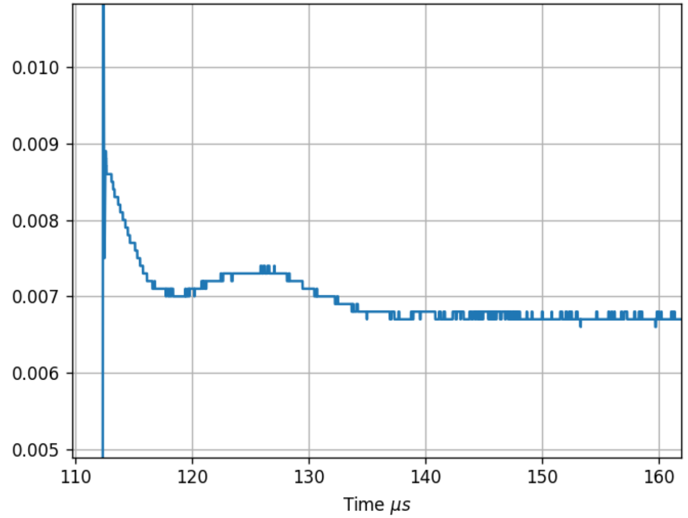
- Standard solution is

$$I = C_1 e^{\gamma_1 t} + C_2 e^{\gamma_1 t} + \tilde{F}(x)$$

- Generally, it introduces more exponents




Plateau




Falling edge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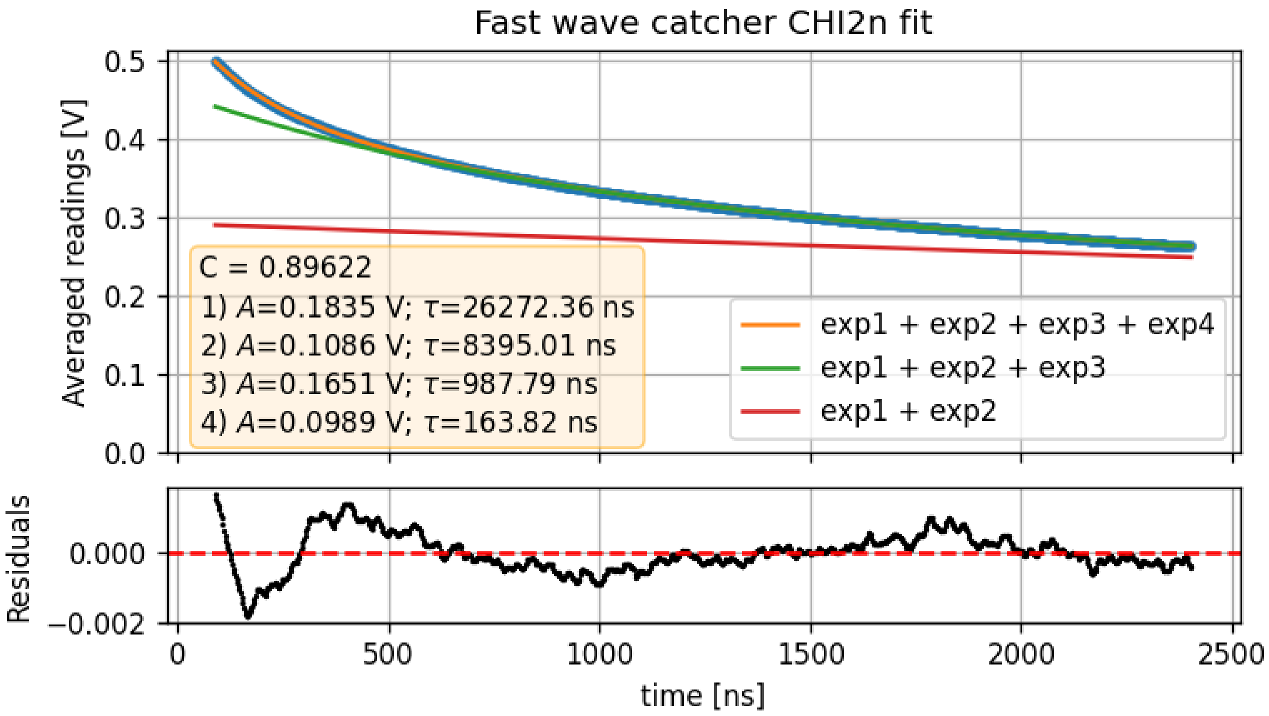
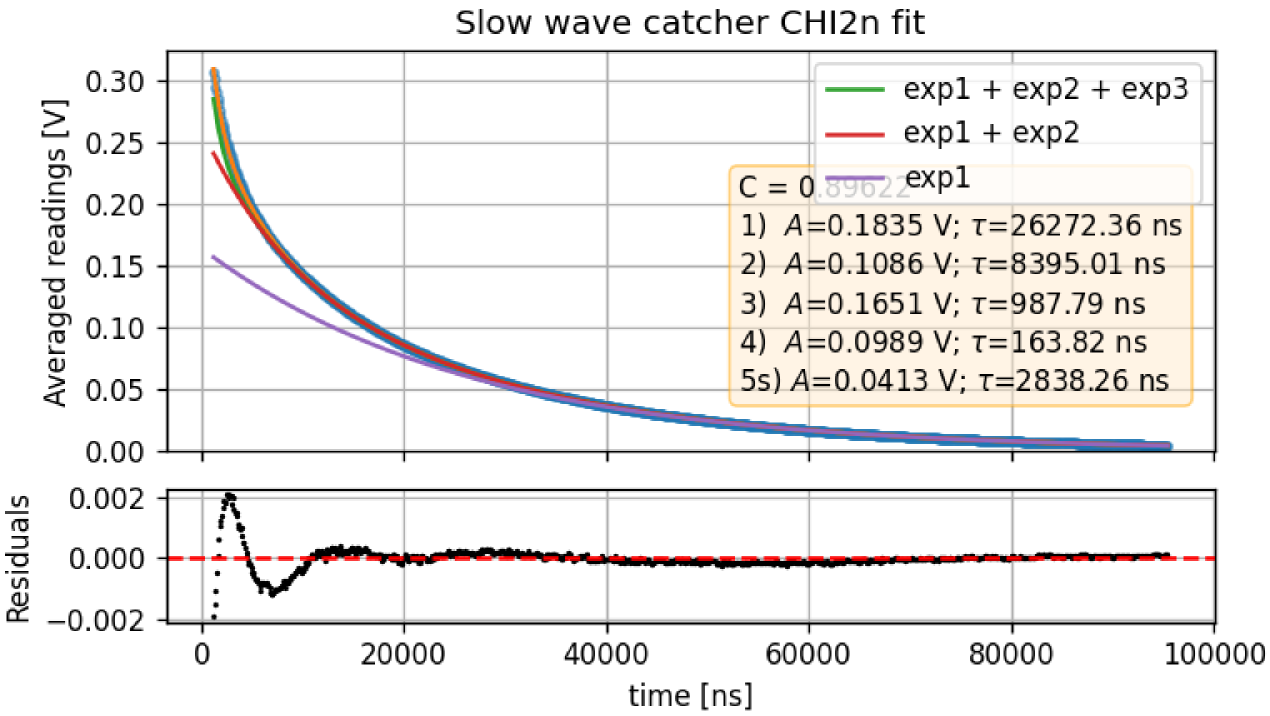
# Fit results visualisation




- Fit results for different methods of fitting (MSE) look alike.



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# Comparing numbers

| Component | Electrons (C = 0.928) | | | Protons MSE (C = 0.899) | | | Protons CHIn (C = 0.896) | | |
|---|---|---|---|---|---|---|---|---|---|
| | tau [ns] | A [V] | Charge | tau [ns] | A [V] | Charge | tau [ns] | A [V] | Charge |
| 1 | 26625,35 | 0,076 | 82,72% | 25699,73 | 0,192 | 82,31% | 26272,36 | 0,184 | 79,97% |
| 2 | 8303,82 | 0,039 | 13,20% | 7420,74 | 0,105 | 13,03% | 8395,01 | 0,109 | 15,12% |
| 3 | 823,71 | 0,056 | 1,89% | 926,87 | 0,165 | 2,54% | 987,79 | 0,165 | 2,70% |
| 4 | 83,03 | 0,061 | 0,21% | 152,07 | 0,096 | 0,24% | 163,82 | 0,099 | 0,27% |
| 5s | 2796,77 | 0,017 (6,96%) | 1,98% | 2799,26 | 0,040 (6,72%) | 1,87% | 2838,26 | 0,041 (6,92%) | 1,95% |

| Type of irradiation | Decay constants, μs | | |
|---|---|---|---|
| | $\tau_1$ ($A_1$) | $\tau_2$ ($A_2$) | $\tau_3$ ($A_3$) |
| γ ray | 0.7 (2%) | 7.5 (9%) | 25.9 (89%) |
| α particles | 0.7 (4%) | 5.6 (16%) | 24.8 (80%) |

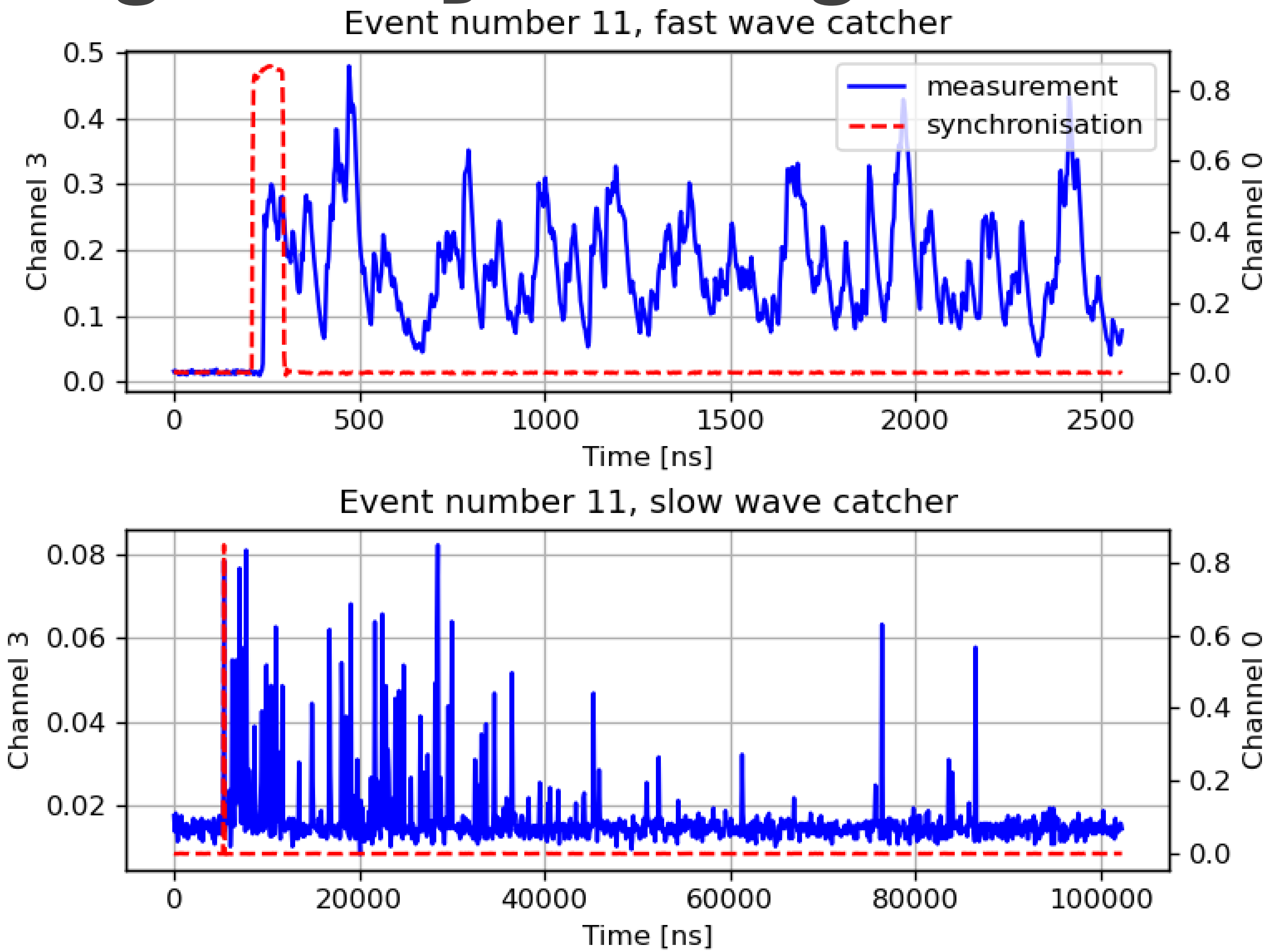
# Electrons PSD presentation

# Single event readings and synchro signal

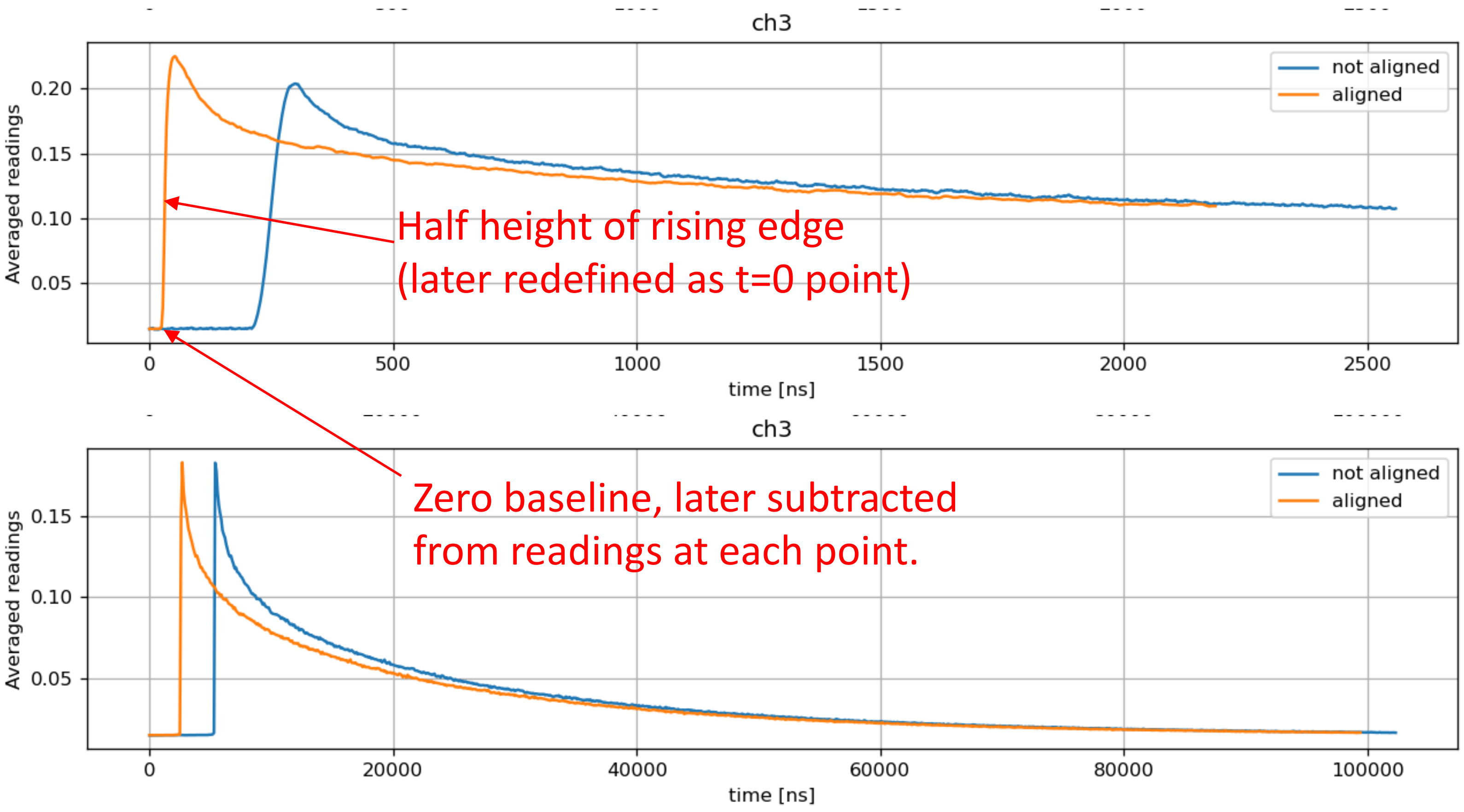
- Reference time is half the height of the rising edge of the channel 0 pulse.

- All of the event readings were shifted to the left to align the reference time to the most left one.

- Readings were averaged to get the final pulse shape

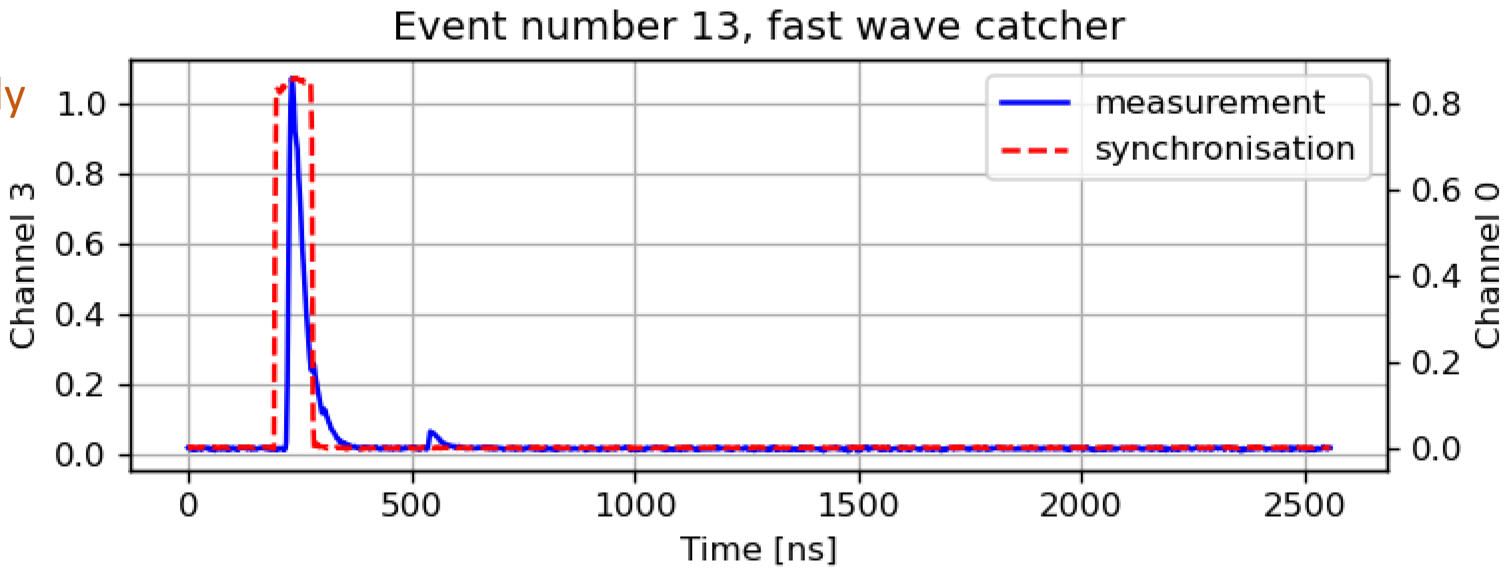


# Effect of event alignment by the synchro signal

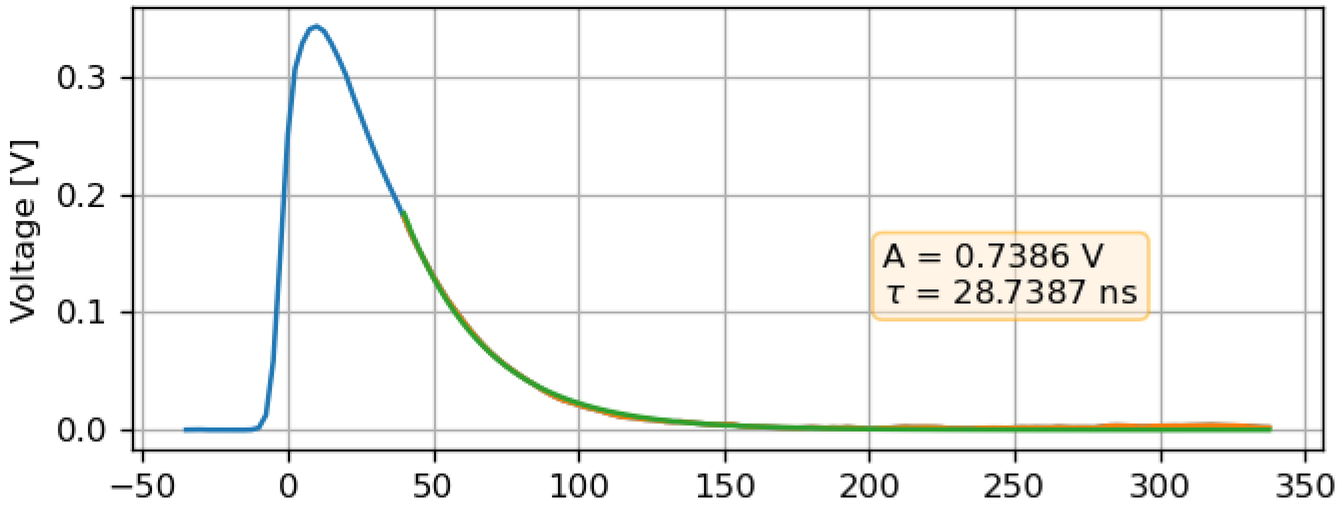


# Purely Cherenkov Events

Example of a purely Cherenkov event




- Some of the events contain only Cherenkov light, they were excluded from the analysis.




Average curve of purely Cherenkov events (excluded from analysis). t0 redefined



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# Purely Cherenkov/Scintillation event discrimination

- Discrimination is performed based on the relationship between charges accumulated:
  - Fast wave catcher:
    - Qc by pulse from 0 to 90 ns
    - Qs by pulse from 90 to 1200 ns
  - Slow wave catcher:
    - Qc by pulse from 0 to 200 ns
    - Qs by pulse from 200 to 1200 ns
- Charges Q are calculated by integrating readings over time.
- Ohm's law applied. $I = \frac{U}{R}$, R=50 Ohm.


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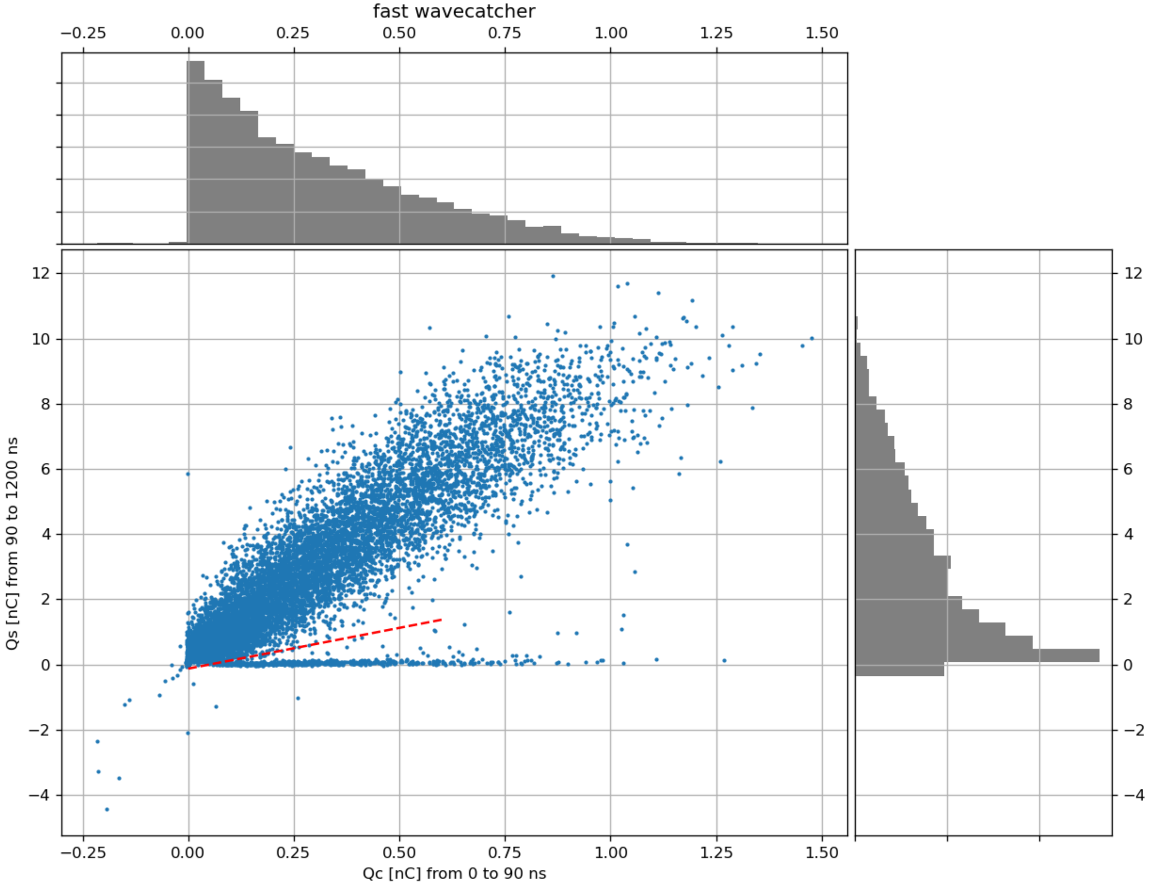
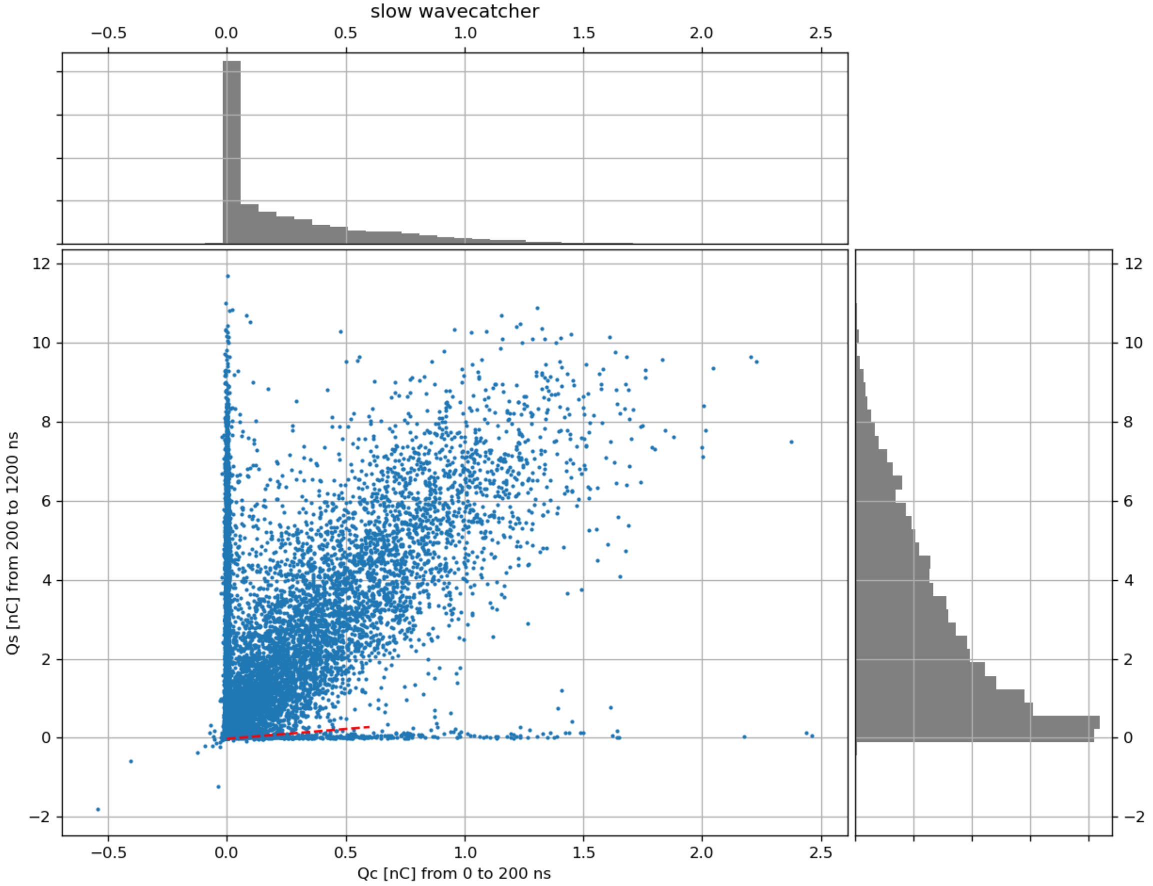
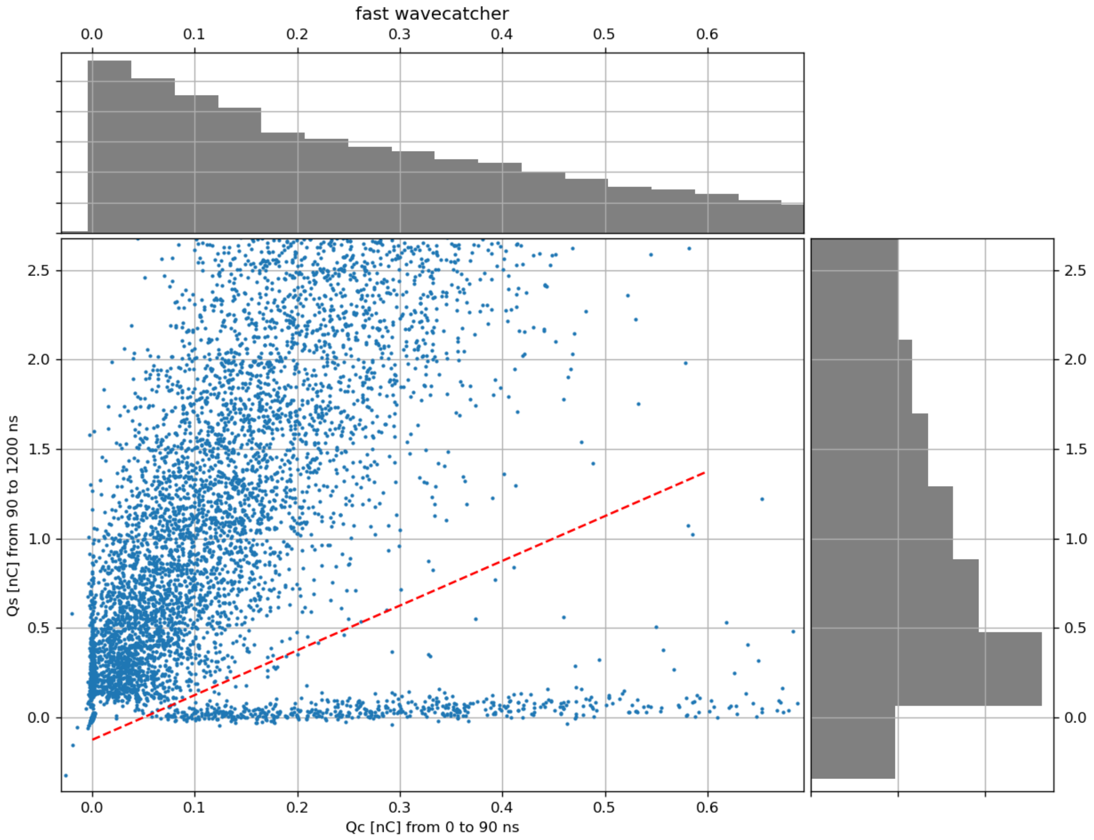
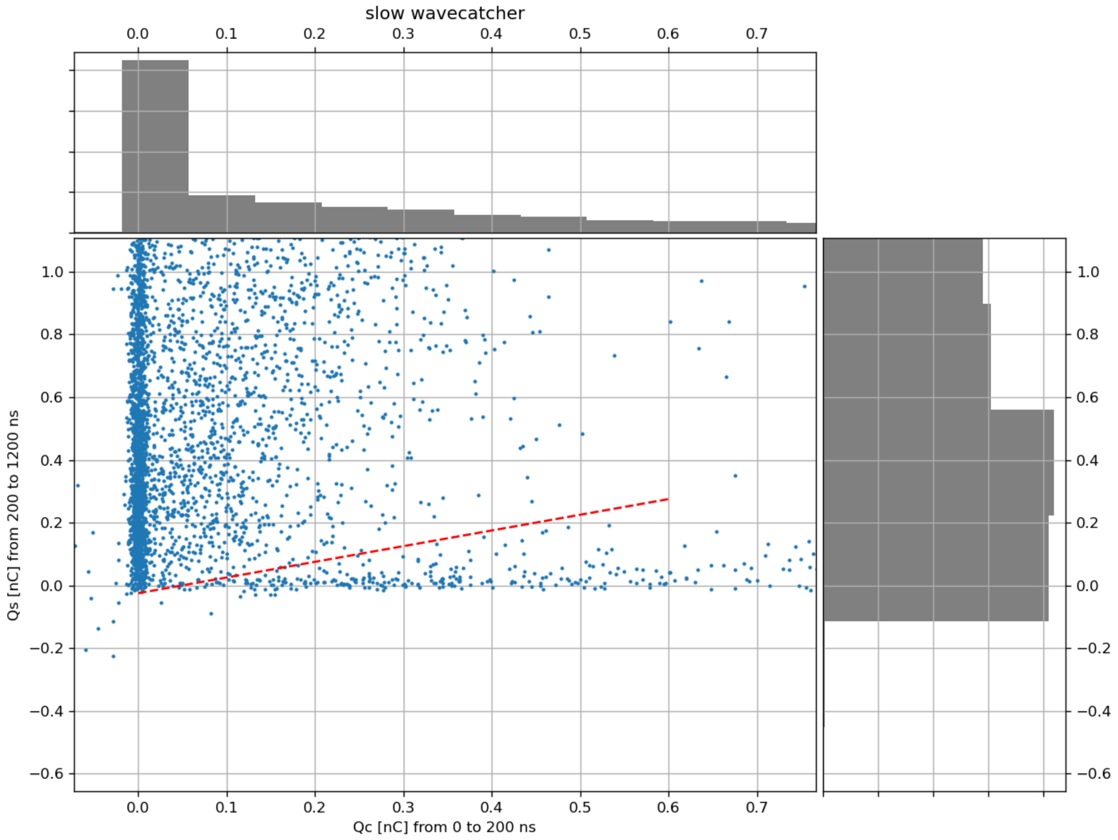
# Qc vs Qs 2D plots



# Qc vs Qs 2D plots Zoomed in

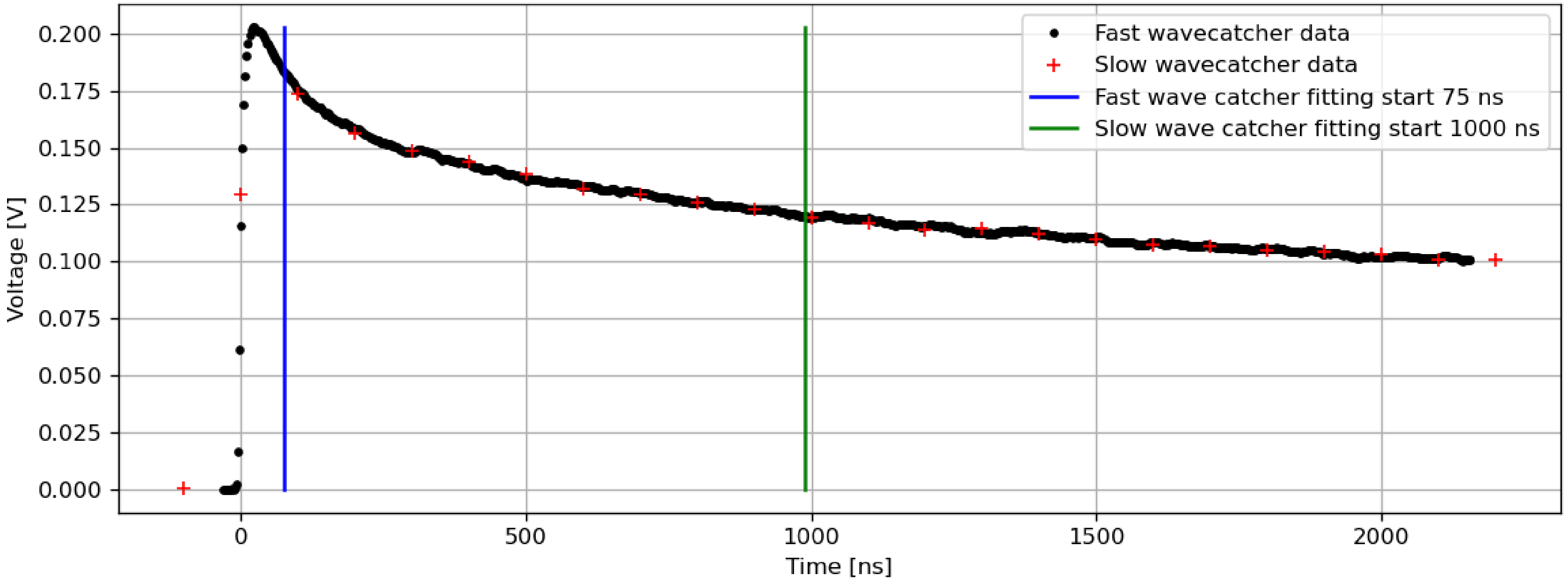



Events below the red line are considered purely Cherenkov.

# Preprocessed data before fit

- Curve averaged over events that pass Cherenkov selection.
- Zero baseline removed (subtracted from all readings)
- Zero time (x-axis) redefined.




- Fast wave catcher pulse fit starts from 75 ns
- Slow wave catcher pulse fit starts from 1 microsecond. The test of start from 5 microseconds was performed as well.

# Fit methodology

$$F_f(t|A_{1-4}, \lambda_{1-4}) = A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t} + A_3 e^{\lambda_3 t} + A_4 e^{\lambda_4 t}$$

$$F_s(t|C, A_{1-4}, \lambda_{1-4}) = C\left(A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t} + A_3 e^{\lambda_3 t} + A_4 e^{\lambda_4 t}\right)$$

- $A_1$ - $A_4$ amplitudes, shared for slow and fast wave cathers
- $\lambda_1$ - $\lambda_4$ the exponential decrements. They related to the $\tau$ parameters by $\lambda_i = \frac{1}{\tau_i}$. Also shared between the slow and fast dataset measurements
- $C$ - the parameter for matching the voltage between different wave catchers.

- The fit is performed by finding the minimum of the loss function. Two loss functions considered.

MSE fit

$$L_k(C, A_{1-4}, \lambda_{1-4}) = \sqrt{\frac{\sum_{i=1}^{N}\left[y_i - F_k(t_i|C, A_{1-4}, \lambda_{1-4})\right]^2}{N}}$$

CHI2 fit

$$L_k(C, A_{1-4}, \lambda_{1-4}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\frac{\left[y_i - F_k(t_i|C, A_{1-4}, \lambda_{1-4})\right]^2}{y_i}}$$

The final loss function to minimize is as follows

$$L(C, A_{1-4}, \lambda_{1-4}) = L_f(A_{1-4}, \lambda_{1-4}) + 1.1 \cdot L_s(C, A_{1-4}, \lambda_{1-4})$$

- The dual annealing minimization was used. I tend to be safe from falling into a local minimum, and the fit does not depend on the initial parameter guess.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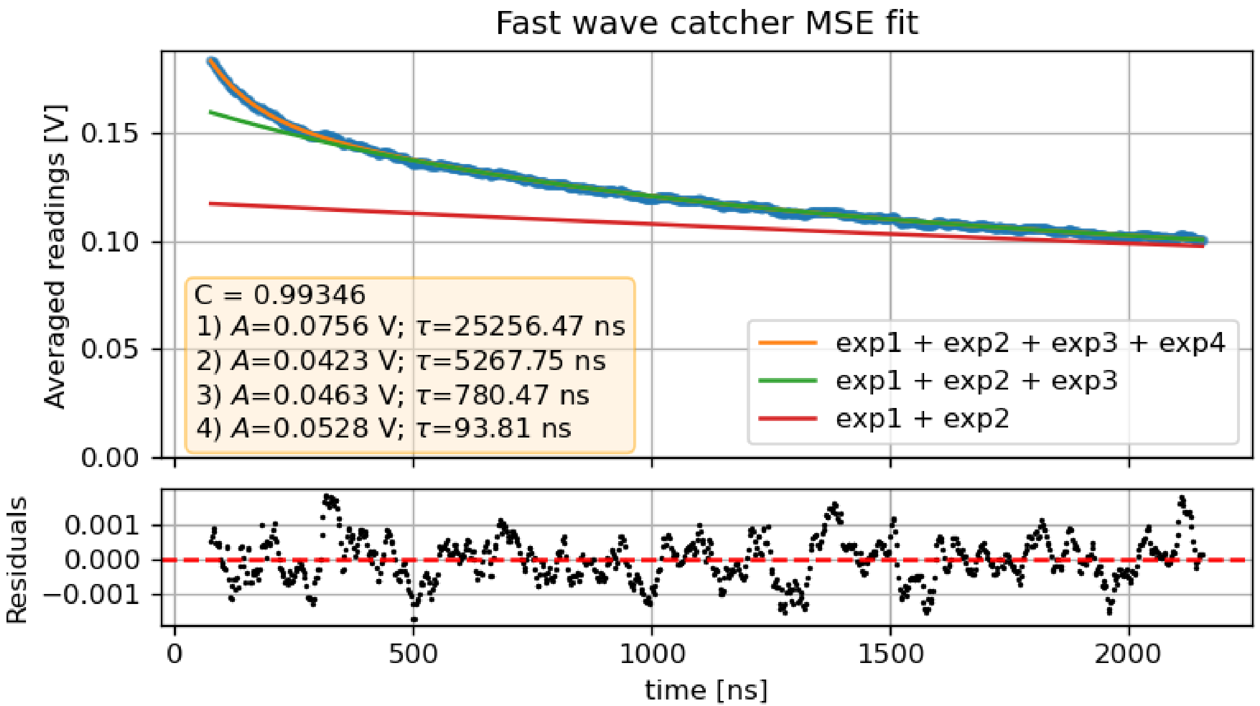
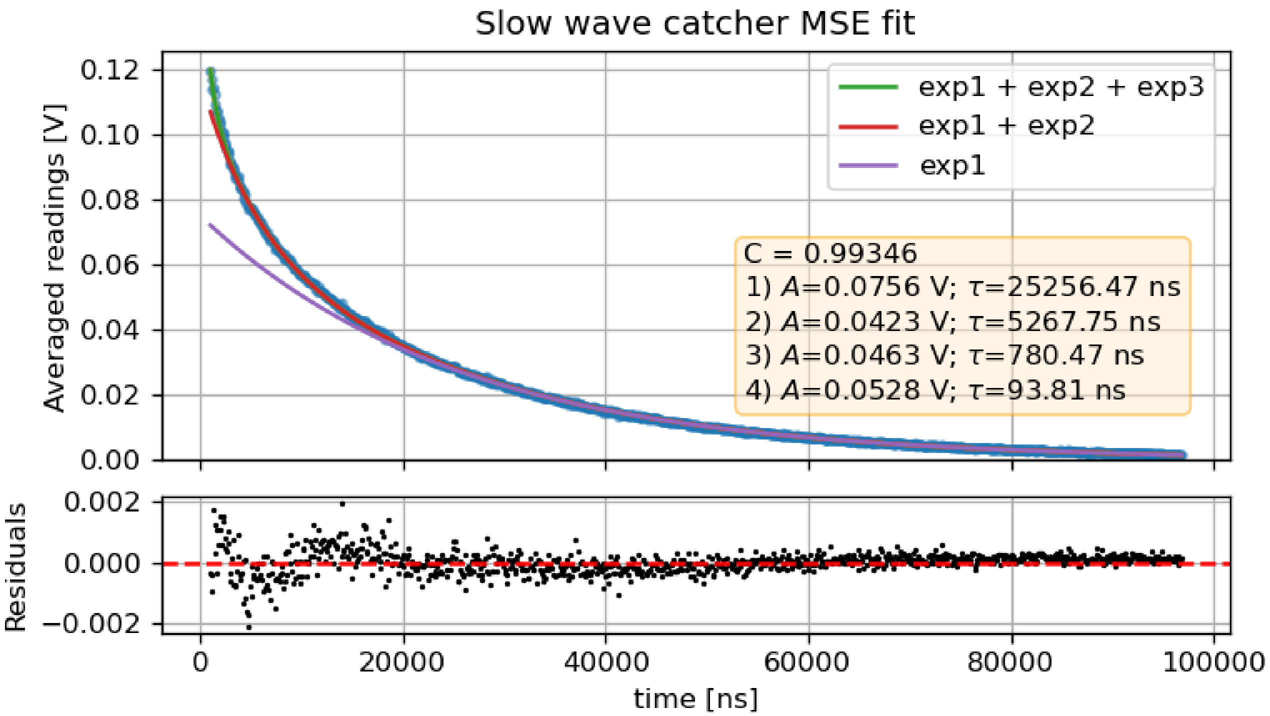
# MSE fit results





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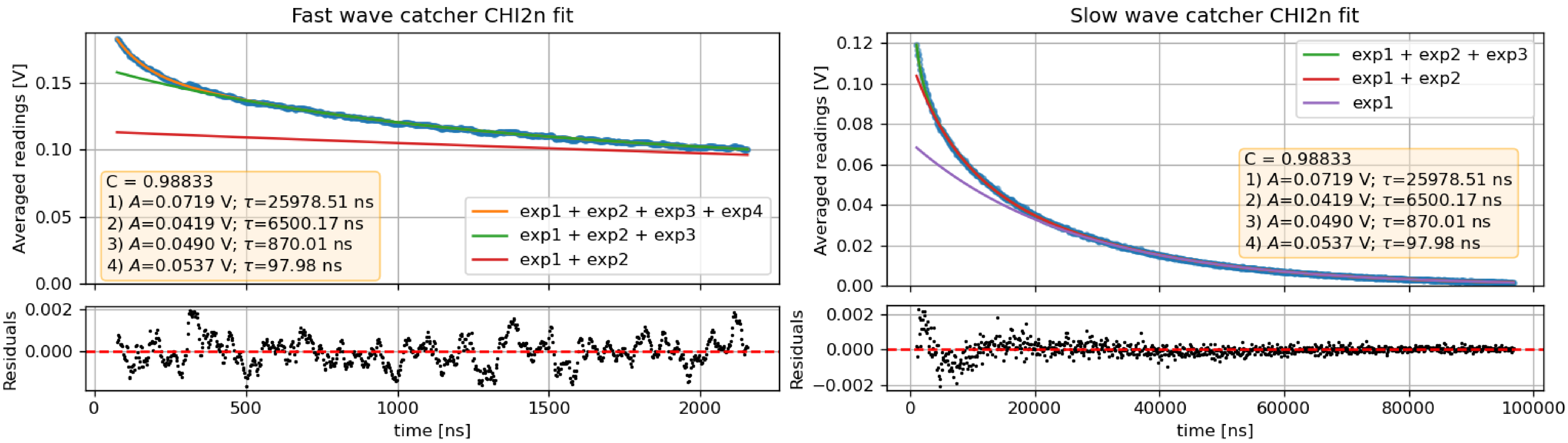
# CHI2 fit results





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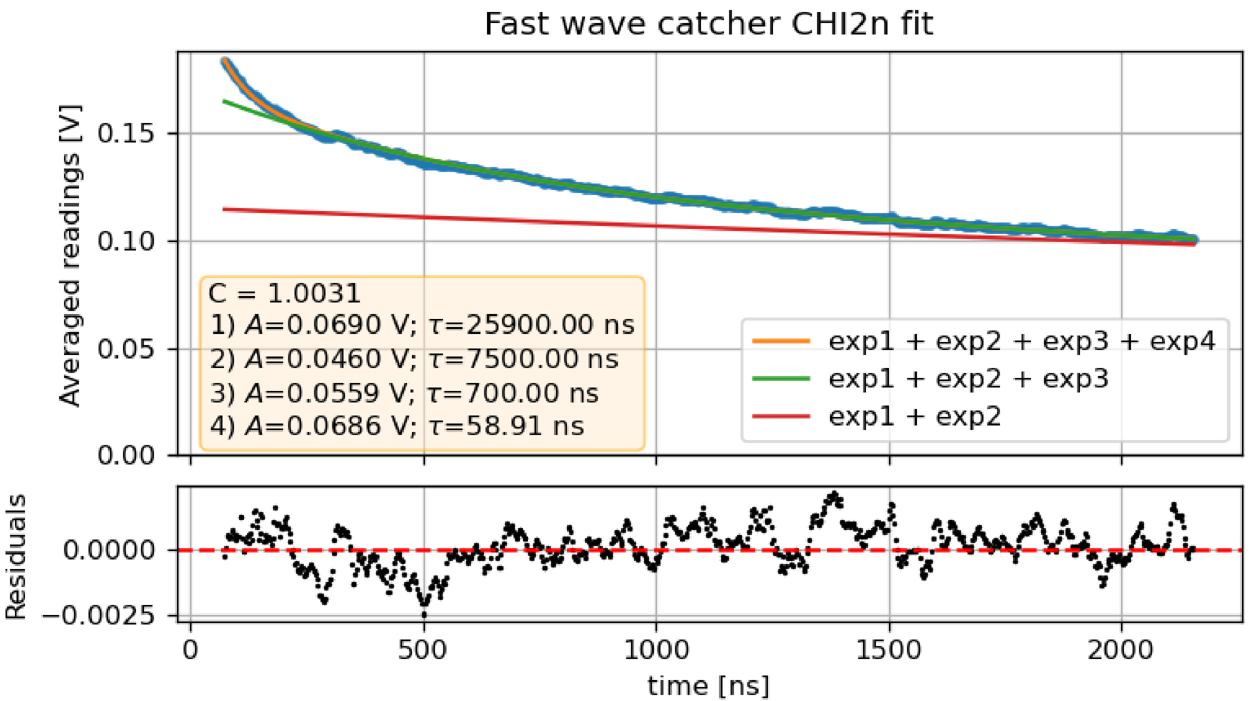
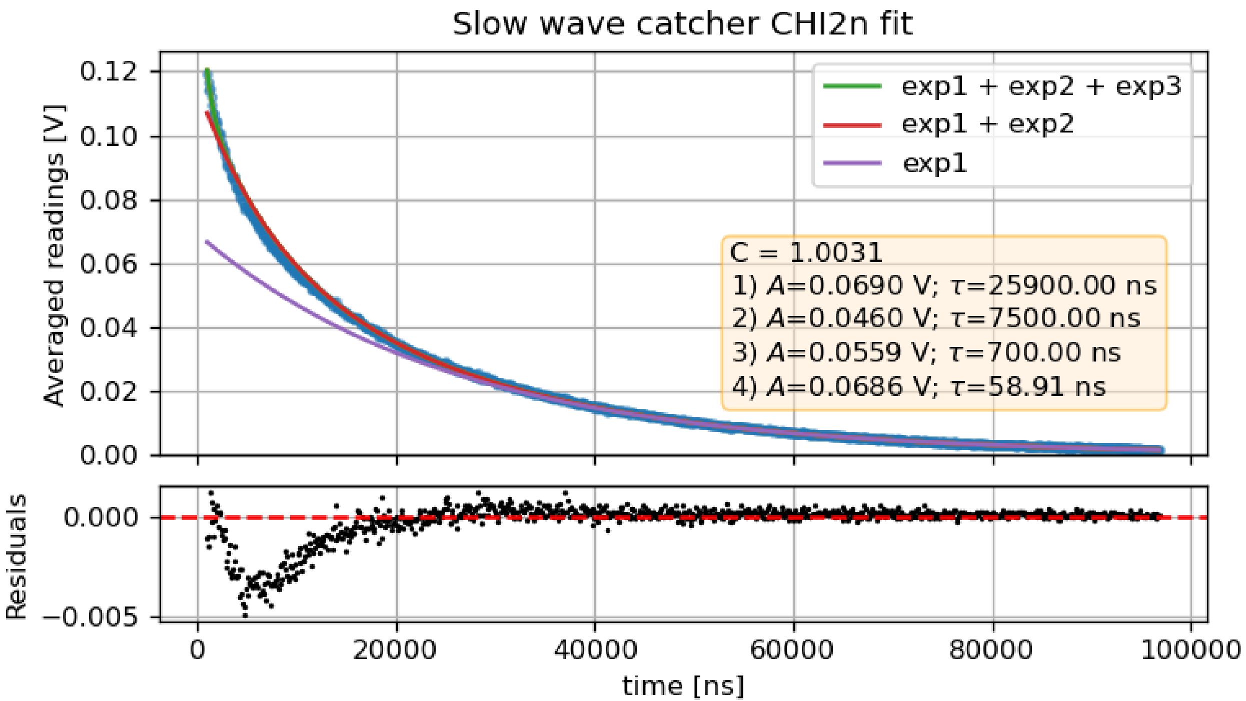
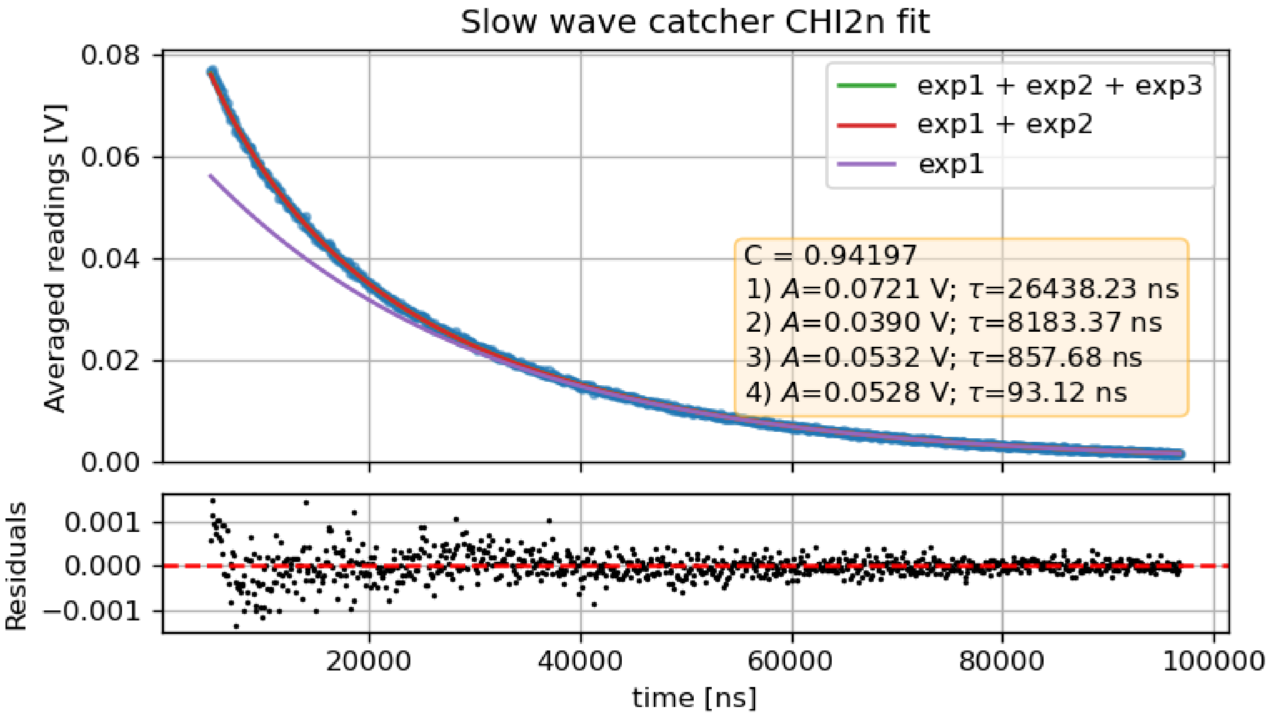
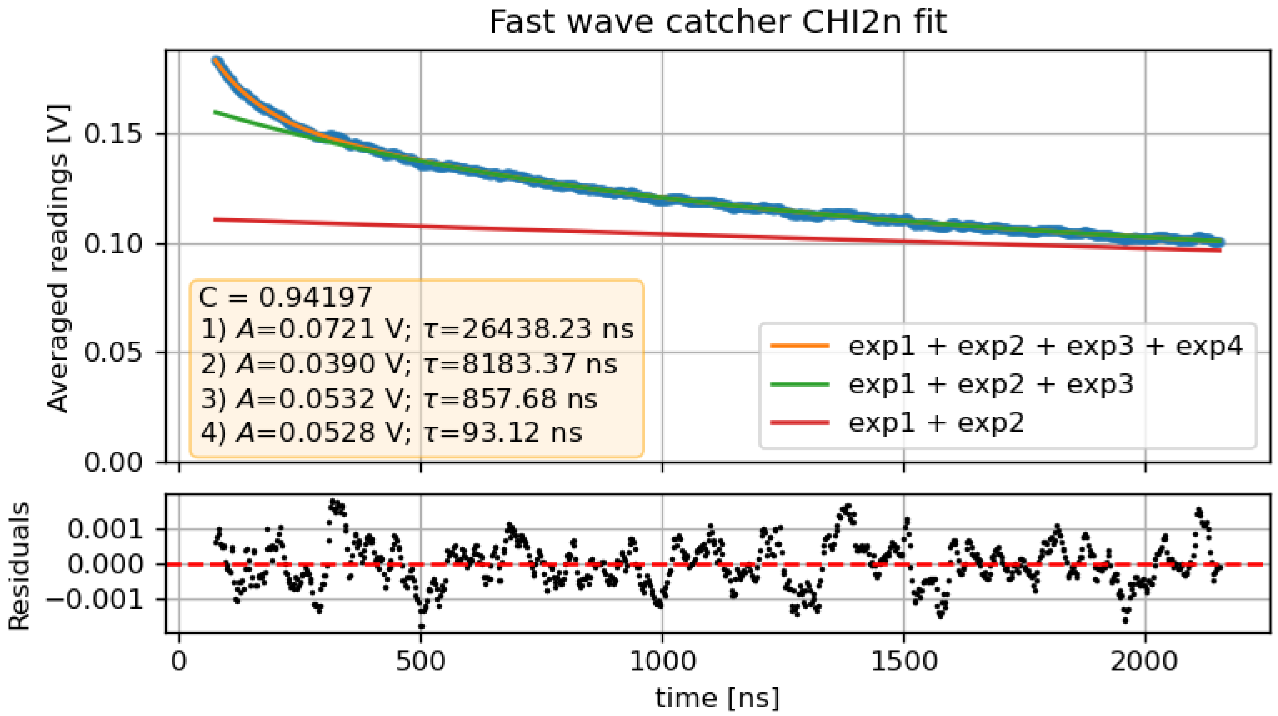
# Fix the tau parameters to published values



# Fit if slow data starts from 5 µs





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# Summary

| Parameter | MSE fit | CHI2 fit | Published tau fit | 5 µs slow start fit |
|---|---|---|---|---|
| C | 0.9916 | 0.9883 | 1.0031 | 0.9420 |
| A1 | 0.0765 | 0.0719 | 0.0690 | 0.0721 |
| A2 | 0.0420 | 0.0419 | 0.0460 | 0.0390 |
| A3 | 0.0462 | 0.0489 | 0.0559 | 0.0532 |
| A4 | 0.0557 | 0.0537 | 0.0686 | 0.0528 |
| tau1 | 25091.66 | 25978.51 | 25900.0 | 26438.23 |
| tau2 | 5112.91 | 6500.17 | 7500.0 | 8183.37 |
| tau3 | 762.98 | 870.01 | 700.0 | 857.68 |
| tau4 | 88.65 | 97.98 | 58.915 | 93.12 |