Correlated noise in Lfoundry tile 21 with laser liquid nitrogen data

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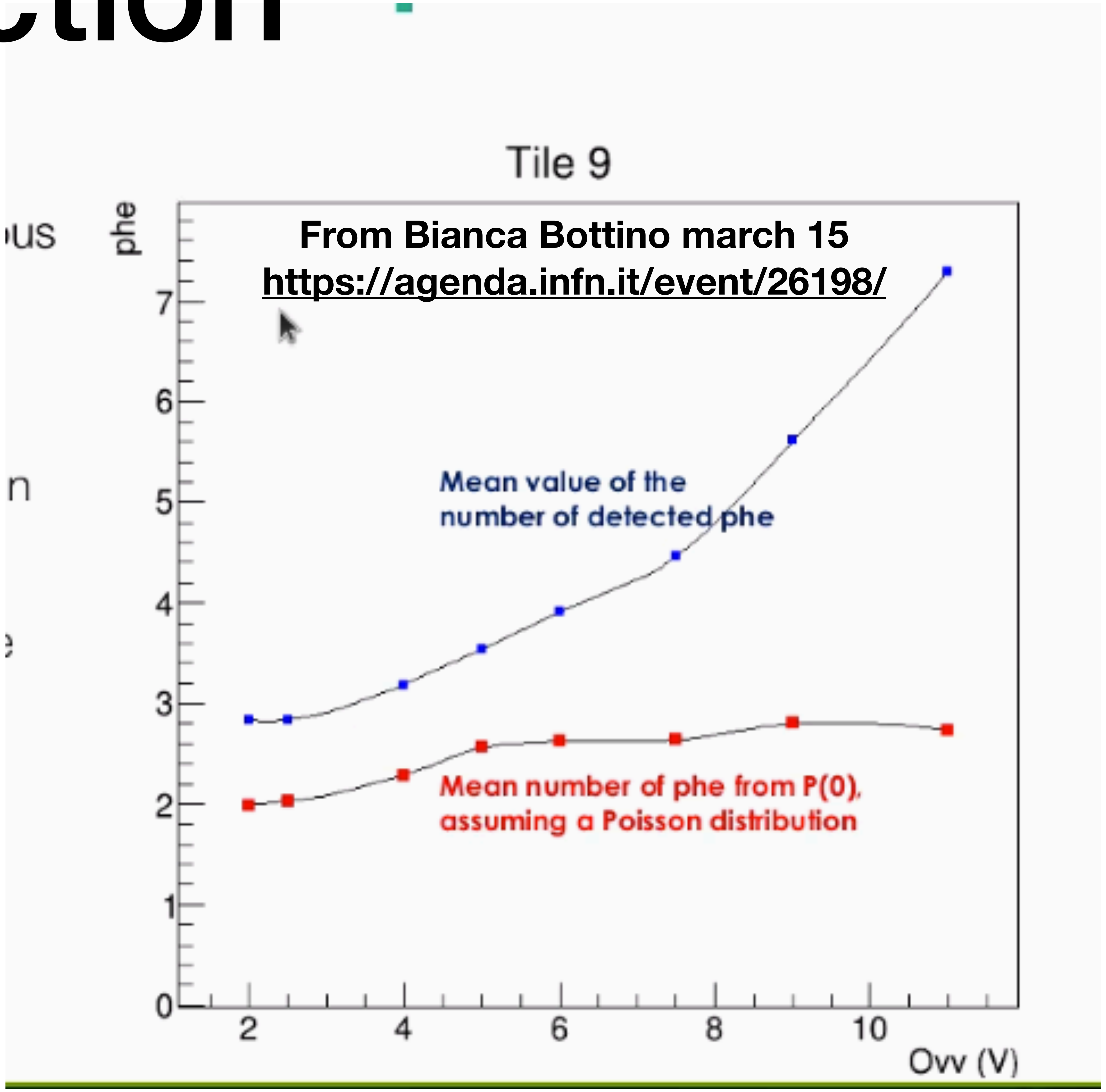
Introduction

- We want to model the pe distribution for simulation and VETO studies.
- On an LFoundry tile, with a TPC FEB.
- To disentangle the primary photon distribution from cross talk and afterpulsing.



Data

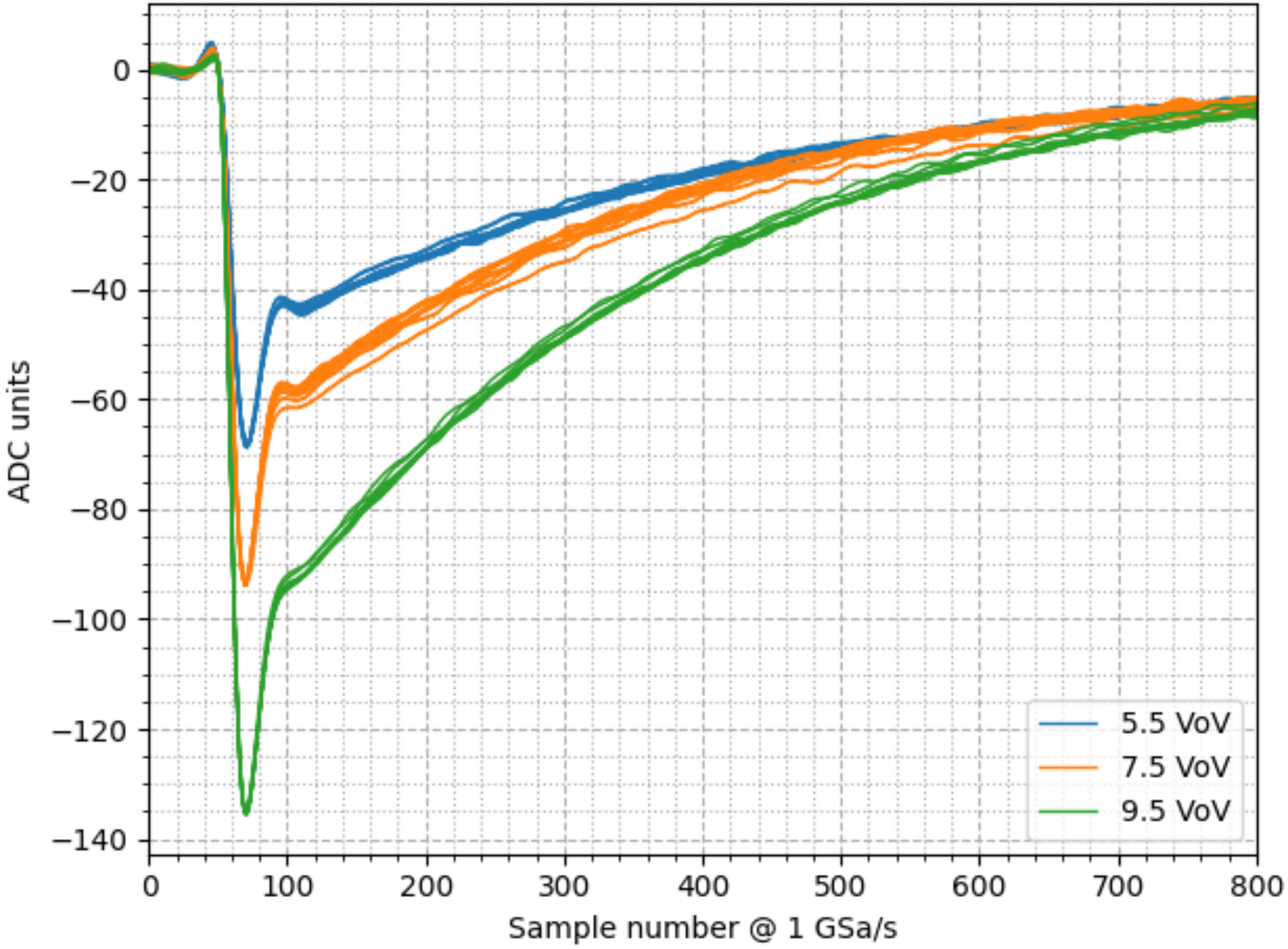
- http://ds50tb.lngs.infn.it:2180/SiPM/Tiles/LFOUNDRY/pre-production-test/TILE_21/
- Sampling frequency 1 GSa/s.
- Each event lasts 15 μs with 9 μs before the laser.
- Three overvoltages: 5.5 V, 7.5 V, 9.5 V.
- 200k events (3 seconds) in 10 files, per overvoltage.
- Data collected at the end of 2020.

Filter (1/2)

We use a cross correlation filter.
We do the template this way:

1. Compute the baseline with the pretrigger 8 μs.
2. Select 1 pe signals with a 1.5 μs integration.
3. Average over these waveforms the 3.5 μs segment starting from the laser pulse, to get a first template.
4. Use the first template to filter the 1 pe signals and align them, then average again.

We do the template separately for each of the 10 files.

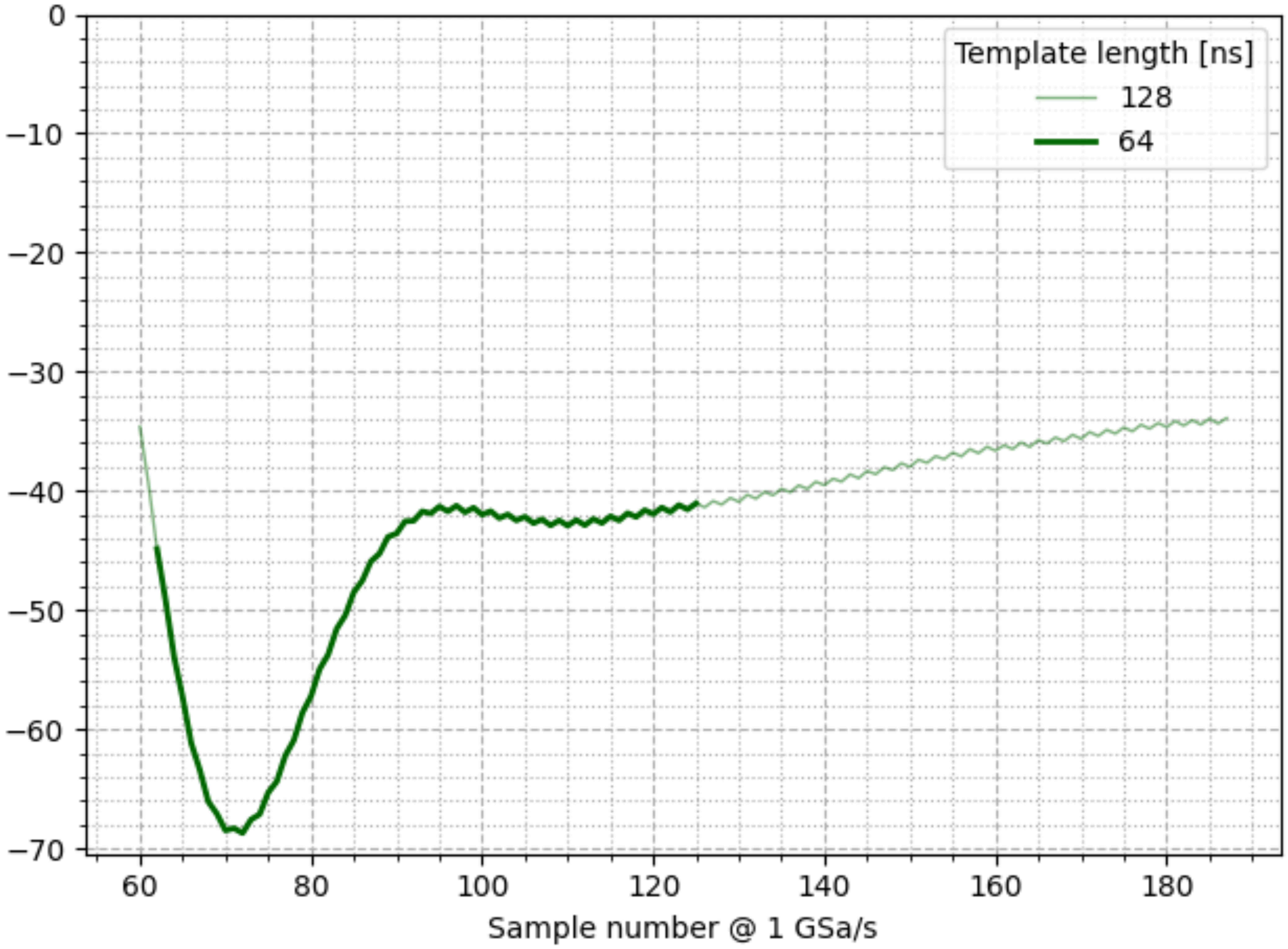


Filter (2/2)

We will use filters with different lengths.

We truncate the template by keeping the fixed length subtemplate that maximizes the sum of squares of the samples.

We will use the shortest possible filters to separate well close peaks (128 ns @ 5.5 VoV, 64 ns others).



Peak finding (1/3)

After filtering, to find the laser pulse:

1. Take a window of ±30 samples around the expected signal position (obtained from the trigger).

2. Take the minimum in the window, excluding minima occurring at the edges.

Peak finding (2/3)

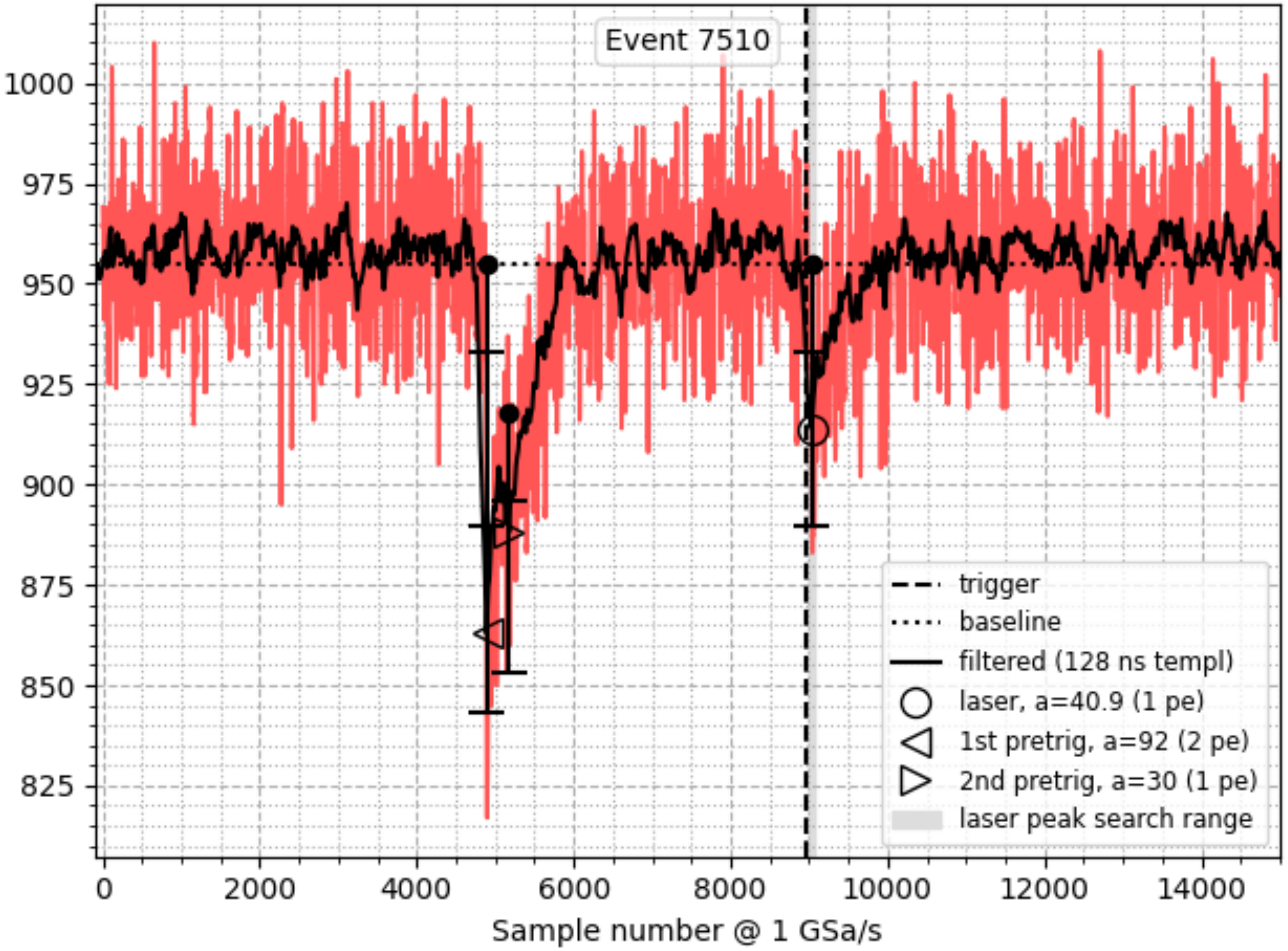
For peaks other than the laser one we use a prominence-based peak finder.

- We use the filtered waveform.
- We divide the event in pre- and post-laser regions and search separately.
- We keep the two highest-prominence peaks in each region.
- It is not necessary to require a minimum distance between peaks because the filtered waveform is smooth (on the scale of the filter length).

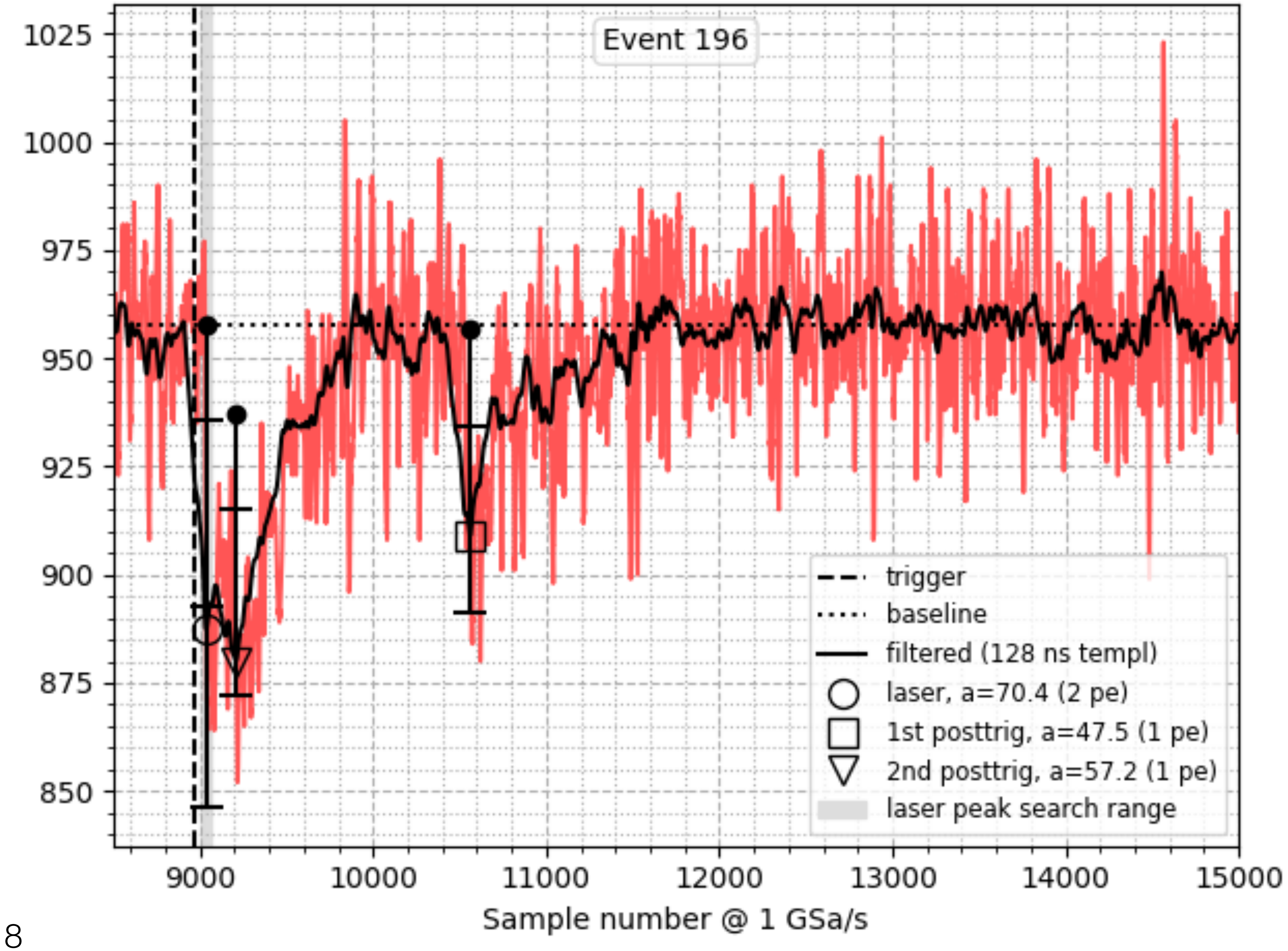
Peak finding (3/3)

Examples.

Pre-trigger



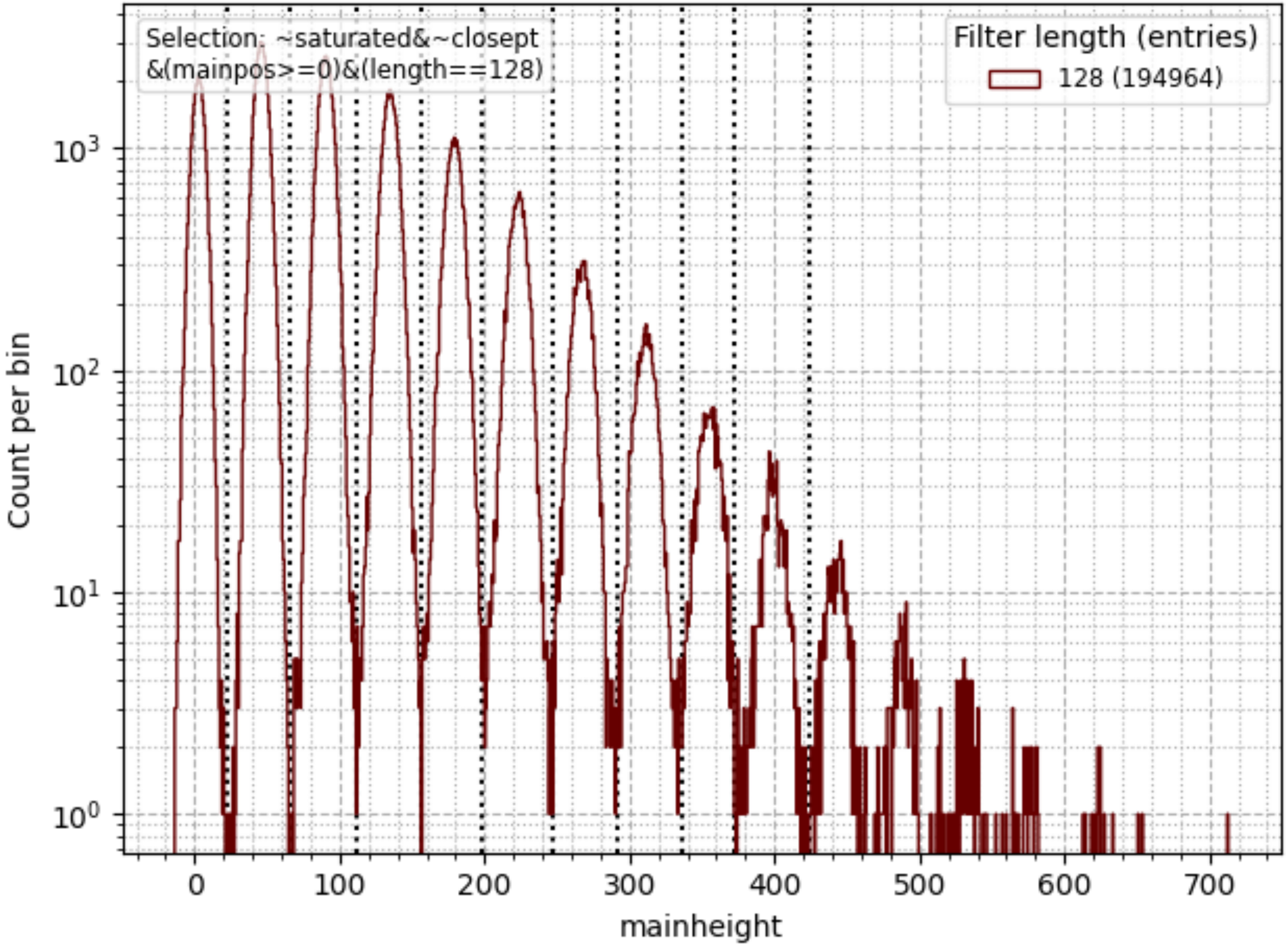
Post-trigger



Converting height to pe

We select events where the laser peak height should be reliable (isolated, not saturated).

We histogram the laser peak height, detect peaks in the histogram, and place boundaries at the midpoint between the most distant consecutive samples between each peak.



Amplitude for close peaks

Peaks close to each other influence each other's peak height in the filtered waveform.

We make this approximations: the position of the peak is not changed by the presence of other peaks (because the signal has a sharp peak).

To make it fast, instead of fitting the waveform, we use only the filtered peak heights. (For an untruncated noise-corrected matched filter this would be already optimal, it isn't for our truncated cross correlation filter).

If y_i is the filtered signal waveform, t_j and h_j the position and height of peak j, a_j the unknown amplitude of the signal j, we have the linear system

$$h_k = \sum_j y_{t_k - t_j} a_j$$

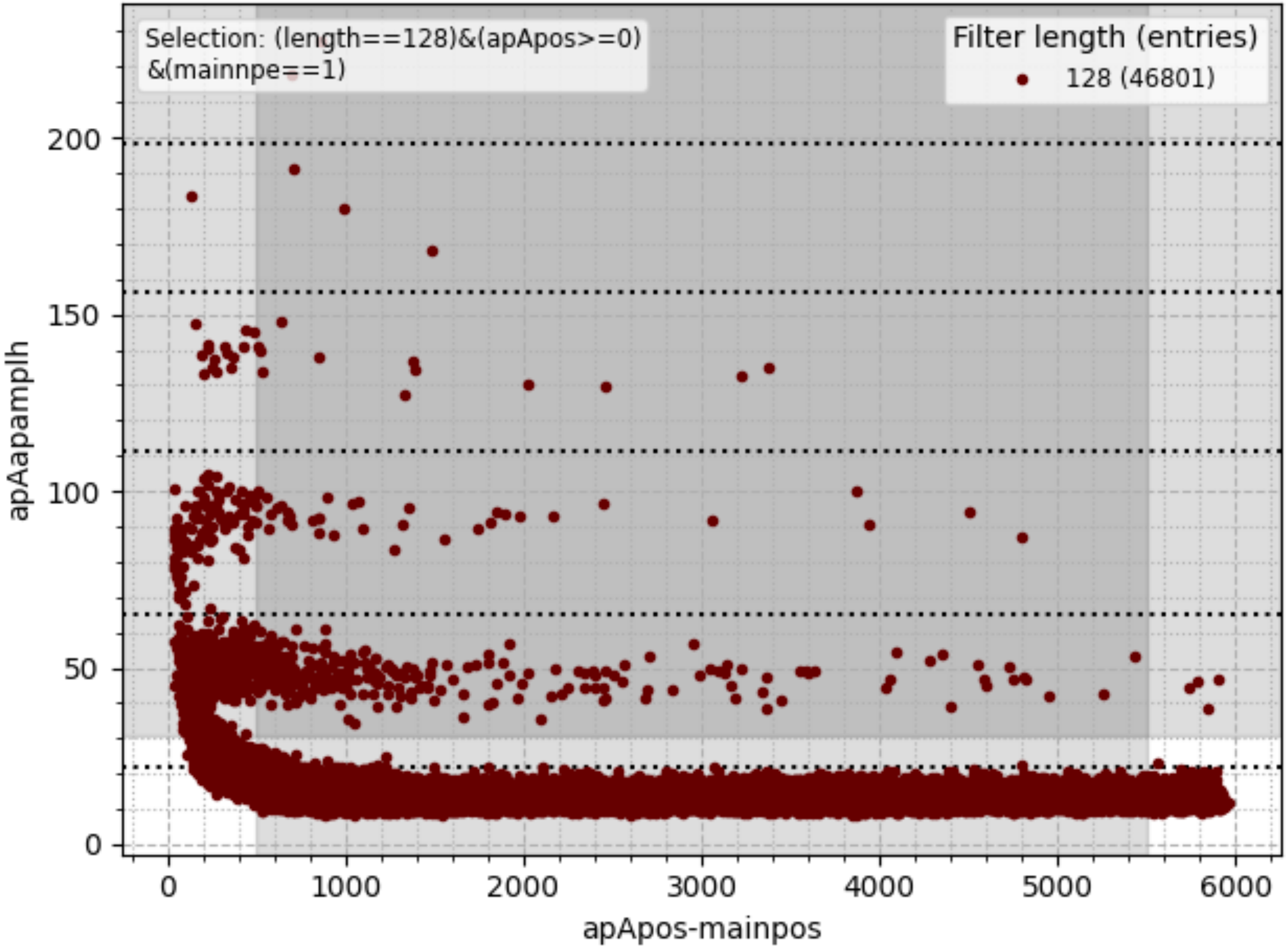
which we solve to find the amplitudes. The y is normalized to have peak height 1 such that a has the same units of h.

Afterpulses (1/3)

Scatter plot amplitude vs. delay from laser peak of post-trigger pulses for 1 pe laser peaks.

Afterpulses close to the laser are too small to be detected. Also, there could be peak finding artifacts.

So we take a window from 500 ns to 5500 ns after the laser peak, then choose the cut on the amplitude.

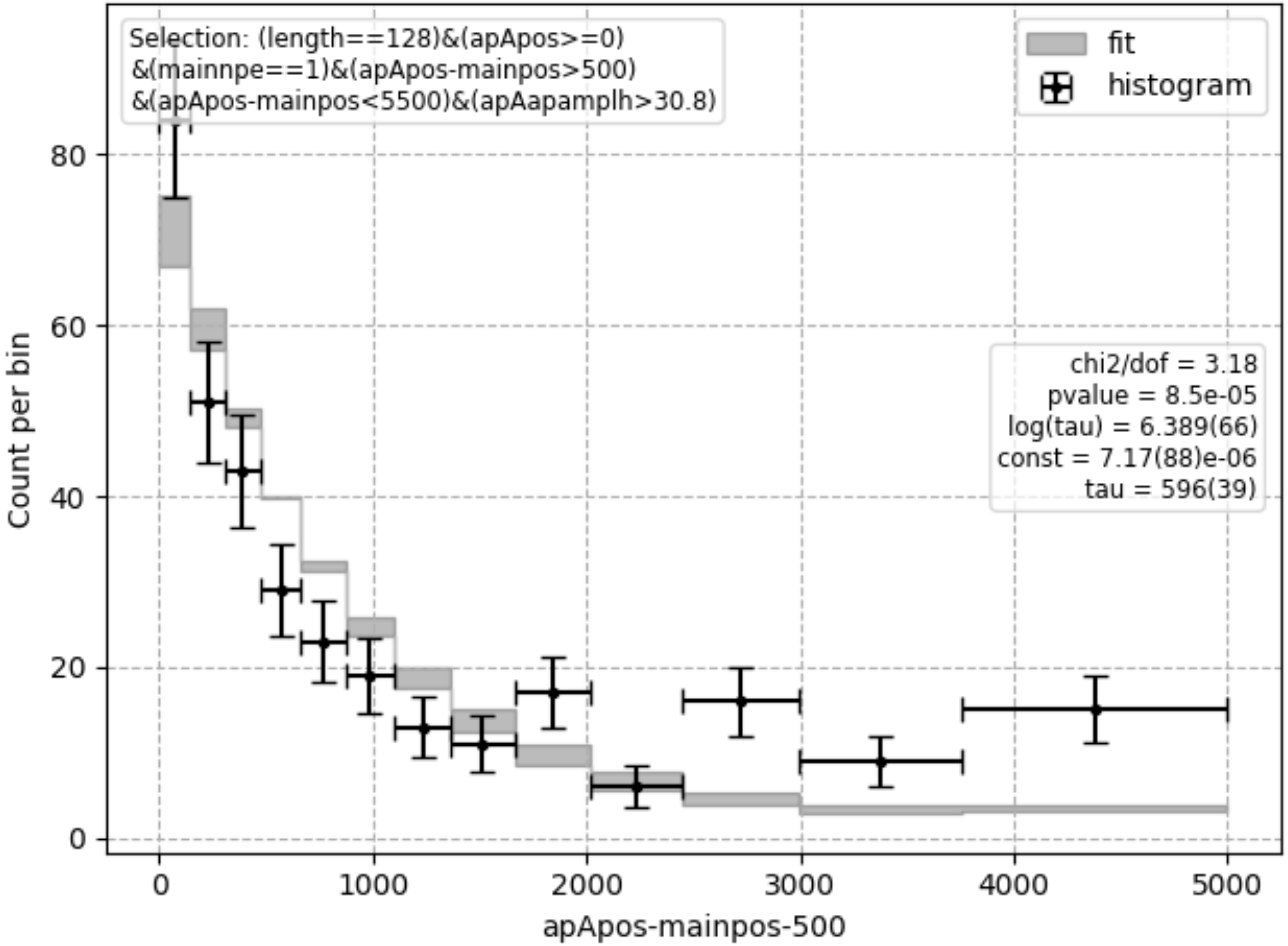


Afterpulses (2/3)

We fit with exponential + uniform where the uniform has a datapoint from the random pulses rate (measured separately, not shown).

The fit is not very good. For other overvoltages the shape of the residuals (data – fit) is similar.

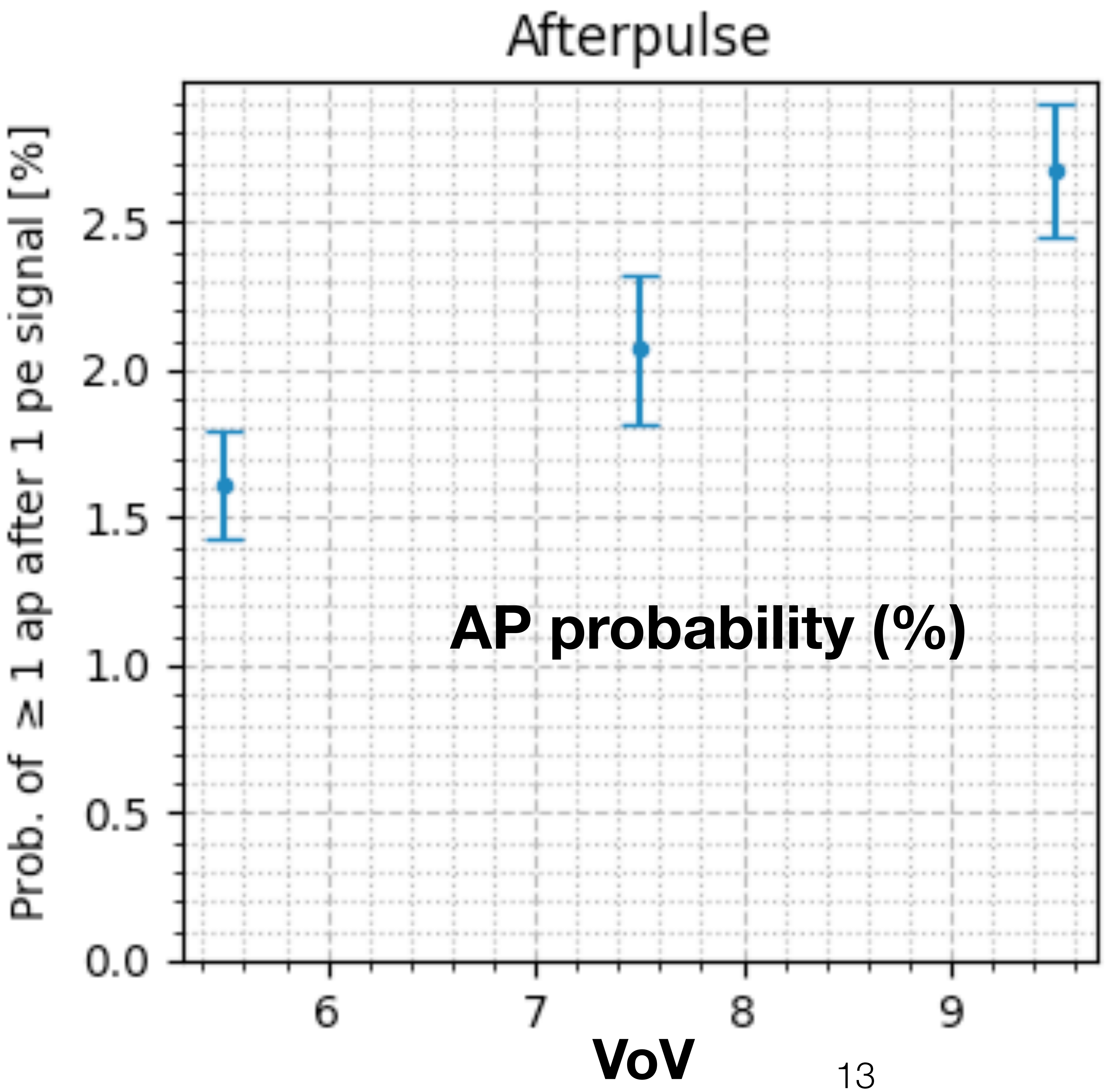
We rescale the tau error with sqrt(chi2/dof) to add a systematic.

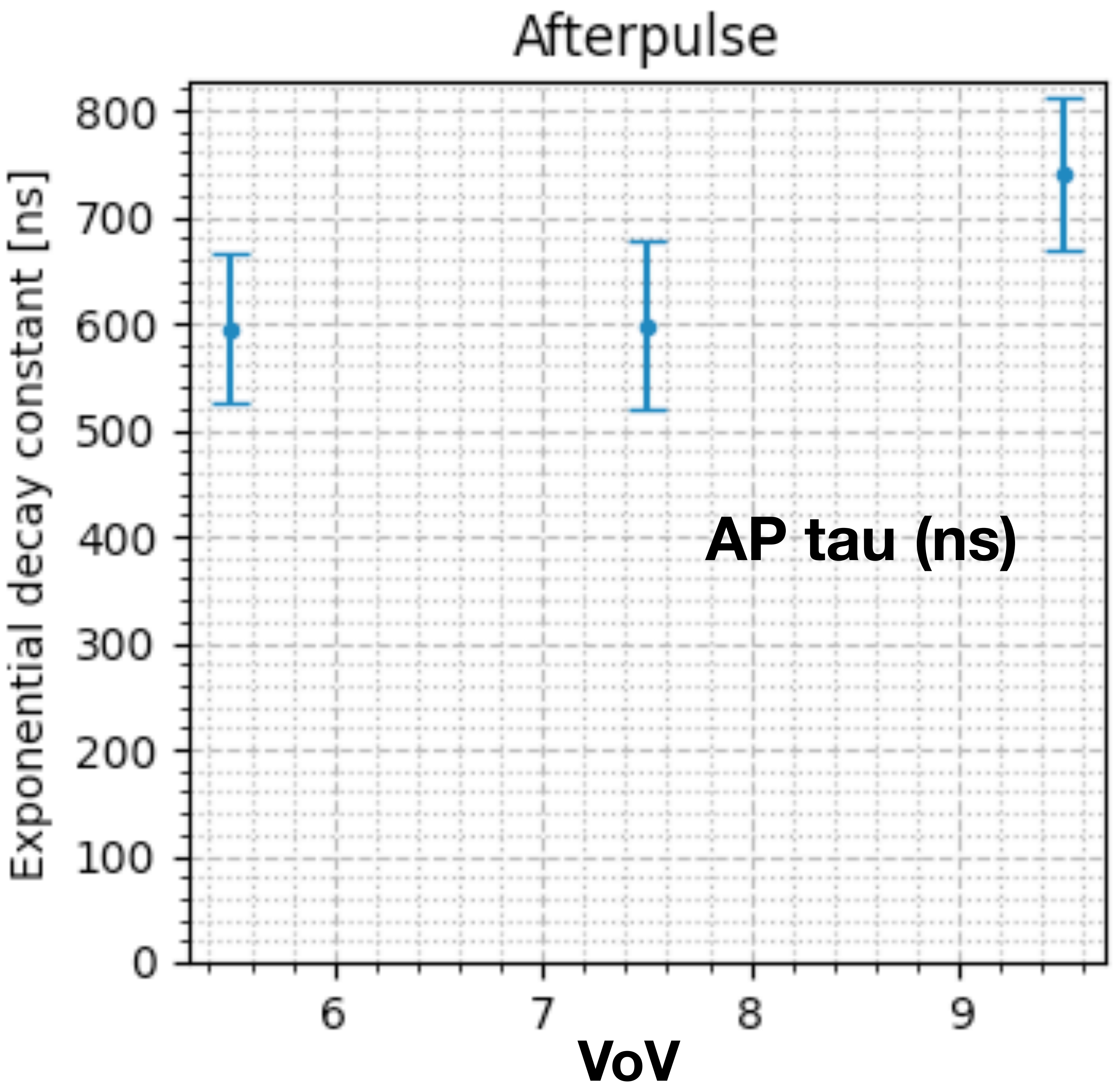


Afterpulses (3/3)

Correcting the afterpulse count for the temporal cut with the fitted model (exponential+background), we obtain this.

Although the model is not very good, if a simulation was run with these parameters, it would reproduce the correct afterpulse count with delay above 500 ns.





Direct cross talk model

Poisson branching process: each pulse generates a poisson count of child pulses with mean μ_B. The total number of pulses (root + descendants) is Borel distributed:

$$P(n; \mu_B) = \exp(-\mu_B n)\frac{(\mu_B n)^{n-1}}{n!}$$

DCT for afterpulses and random pulses

If the initial number of pulses is poisson-distributed with mean μ_P, the total with cross talk is:

$$P(n; \mu_P, \mu_B) = \exp\big(-(\mu_P + n\mu_B)\big)\frac{\mu_P(\mu_P + n\mu_B)^{n-1}}{n!}$$

DCT for laser

References: arXiv 1109.2014, 1609.01181.

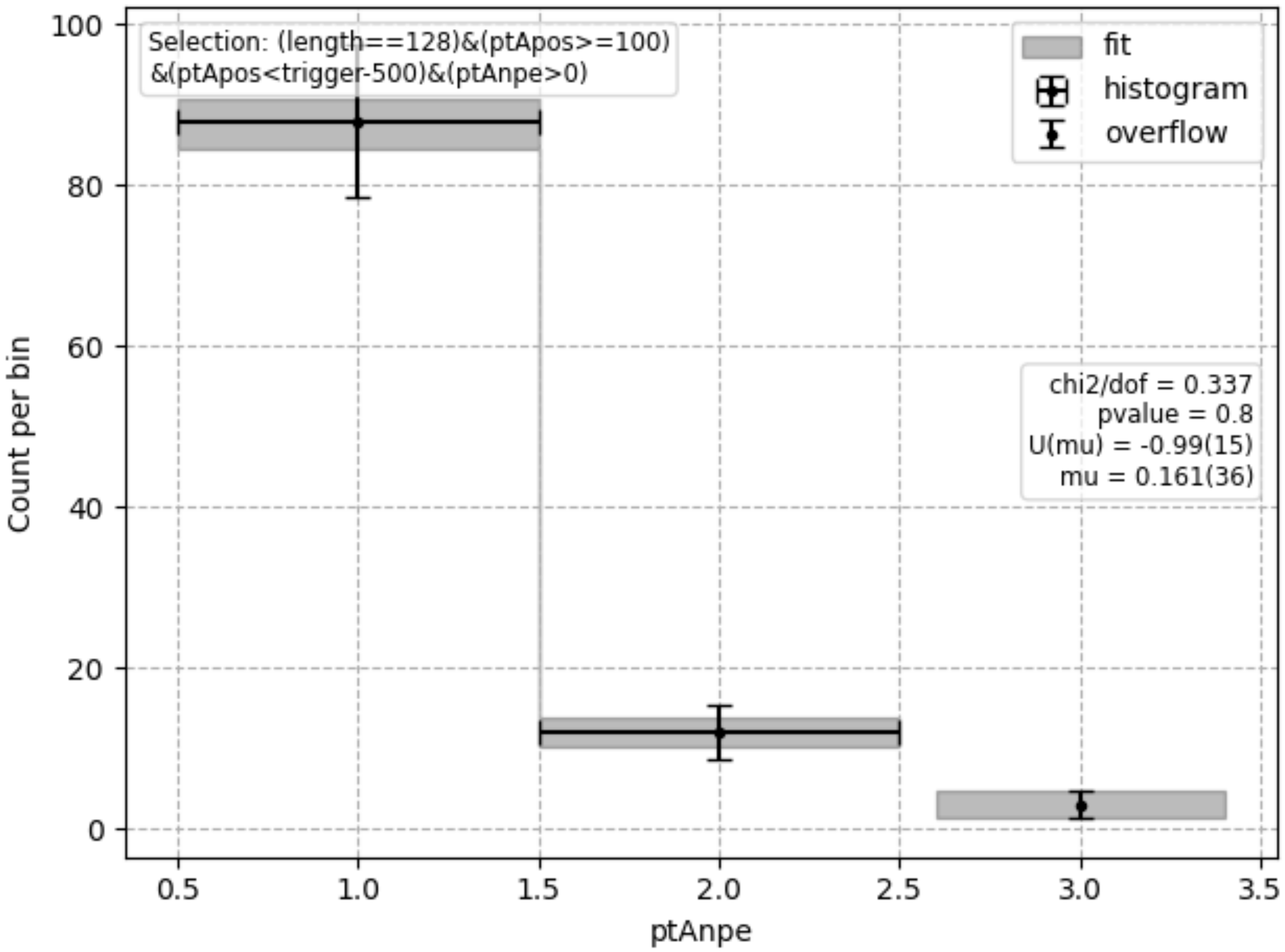
Cross talk in pre-trigger pulses

We count the pe of appropriately selected pre-trigger pulses, using the pe boundaries.

We fit with the Borel distribution.

The last bin is an overflow bin, fitted with the integral to infinity.

These fits work well at all overvoltages.



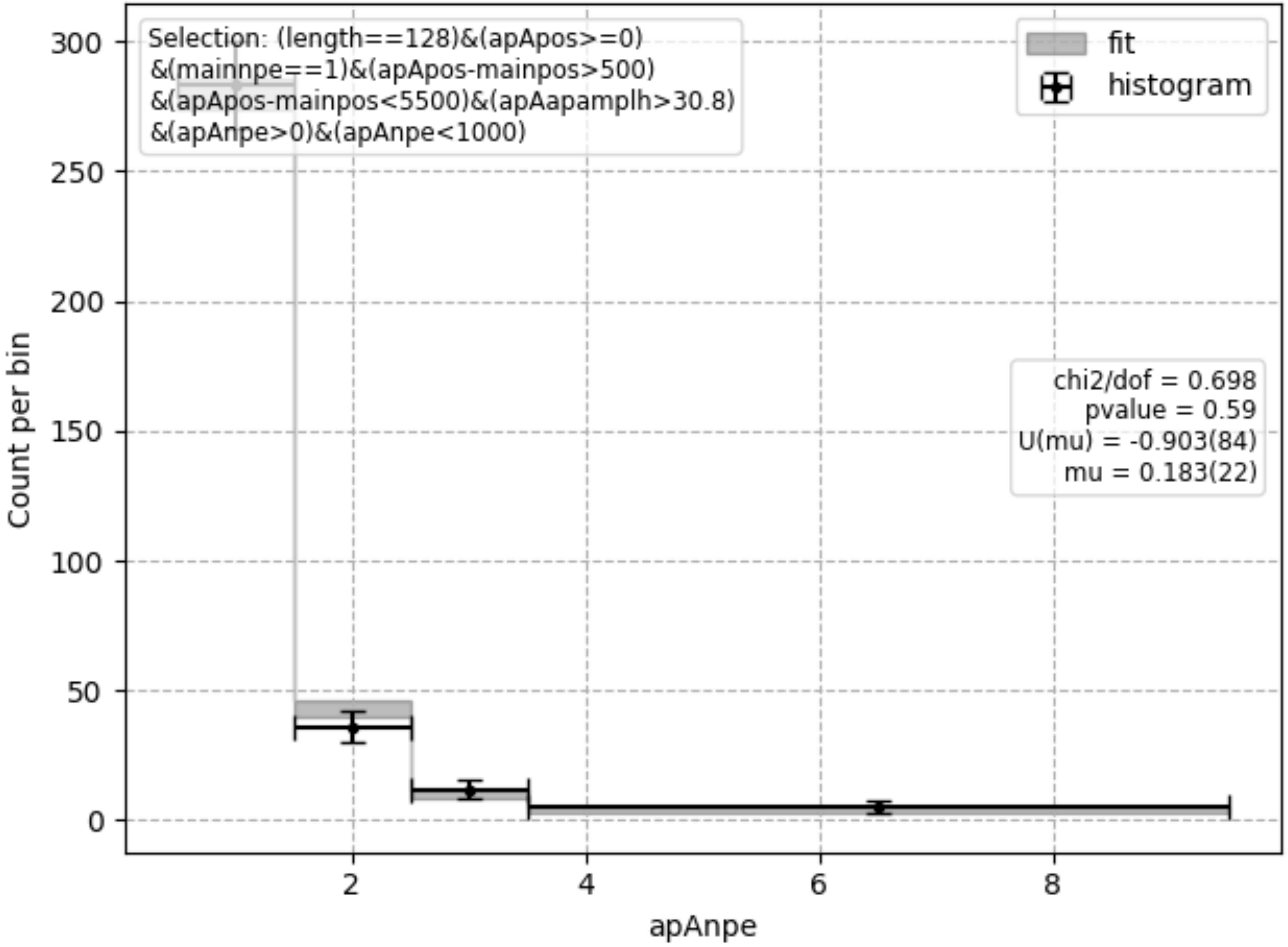
Cross talk in afterpulses

We redo it similarly for laser afterpulses.

This time we don't fit the overflow because it gives problems at higher overvoltages.

Still need to investigate if this is due to wrong model or problems in the analysis.

Without overflow, all fine.



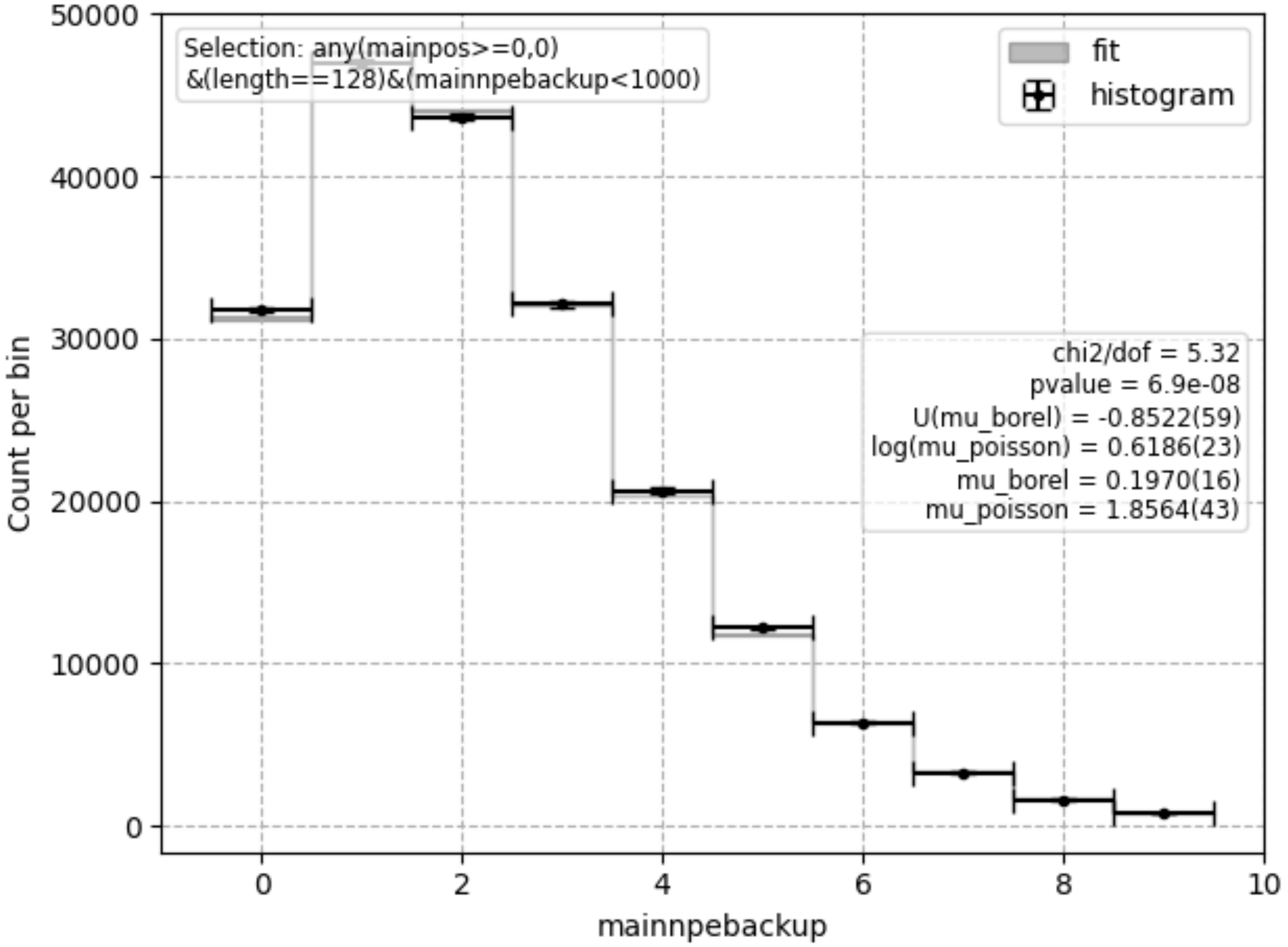
Cross talk in laser pulses

We fit using the Poisson+Borel distribution.

We don't fit the overflow as for afterpulses.

The chisquares are always bad but here the sample size is very high, the agreement is satisfactory.

We add systematics multiplying the error by sqrt(chi2/dof).

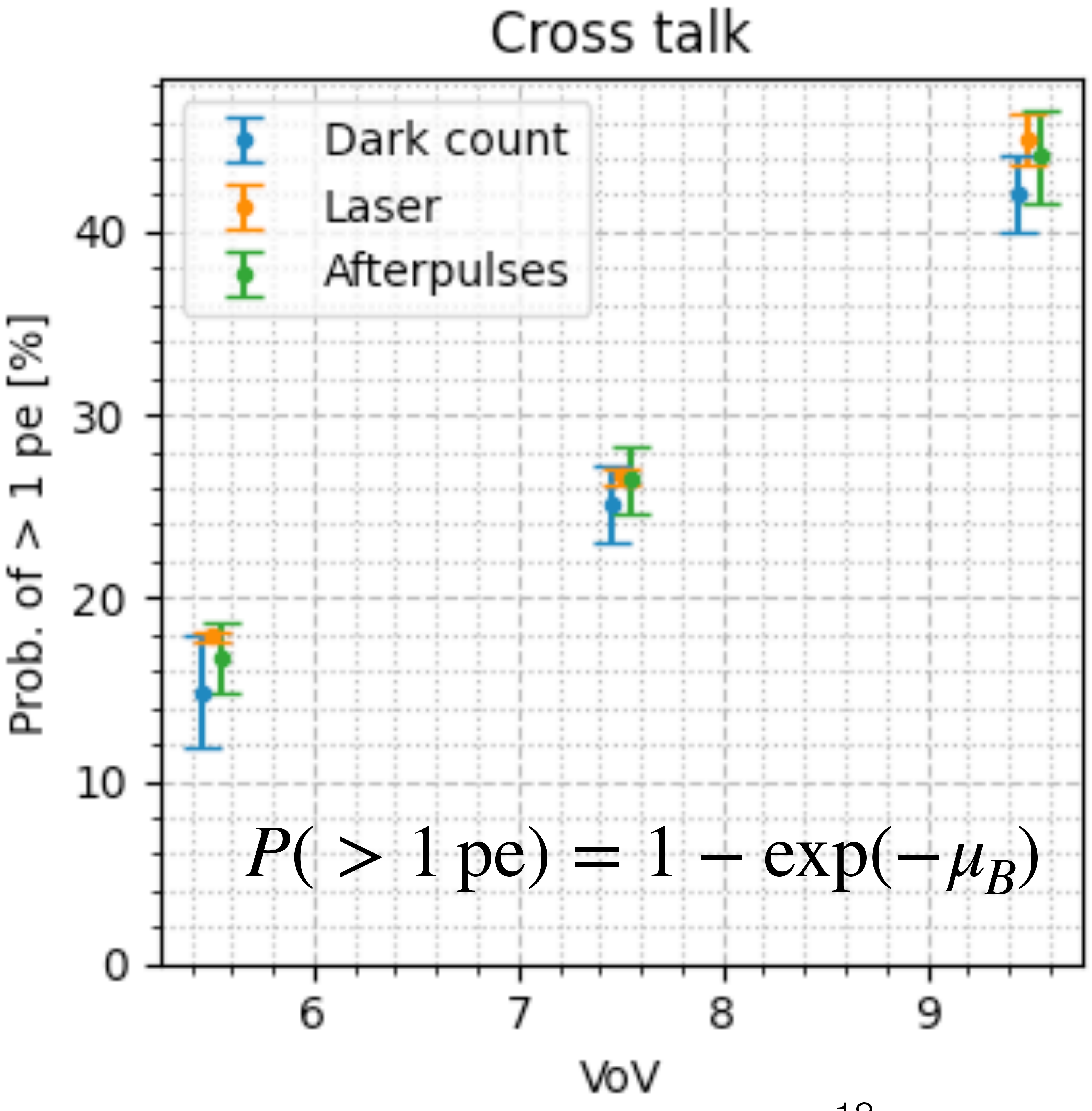


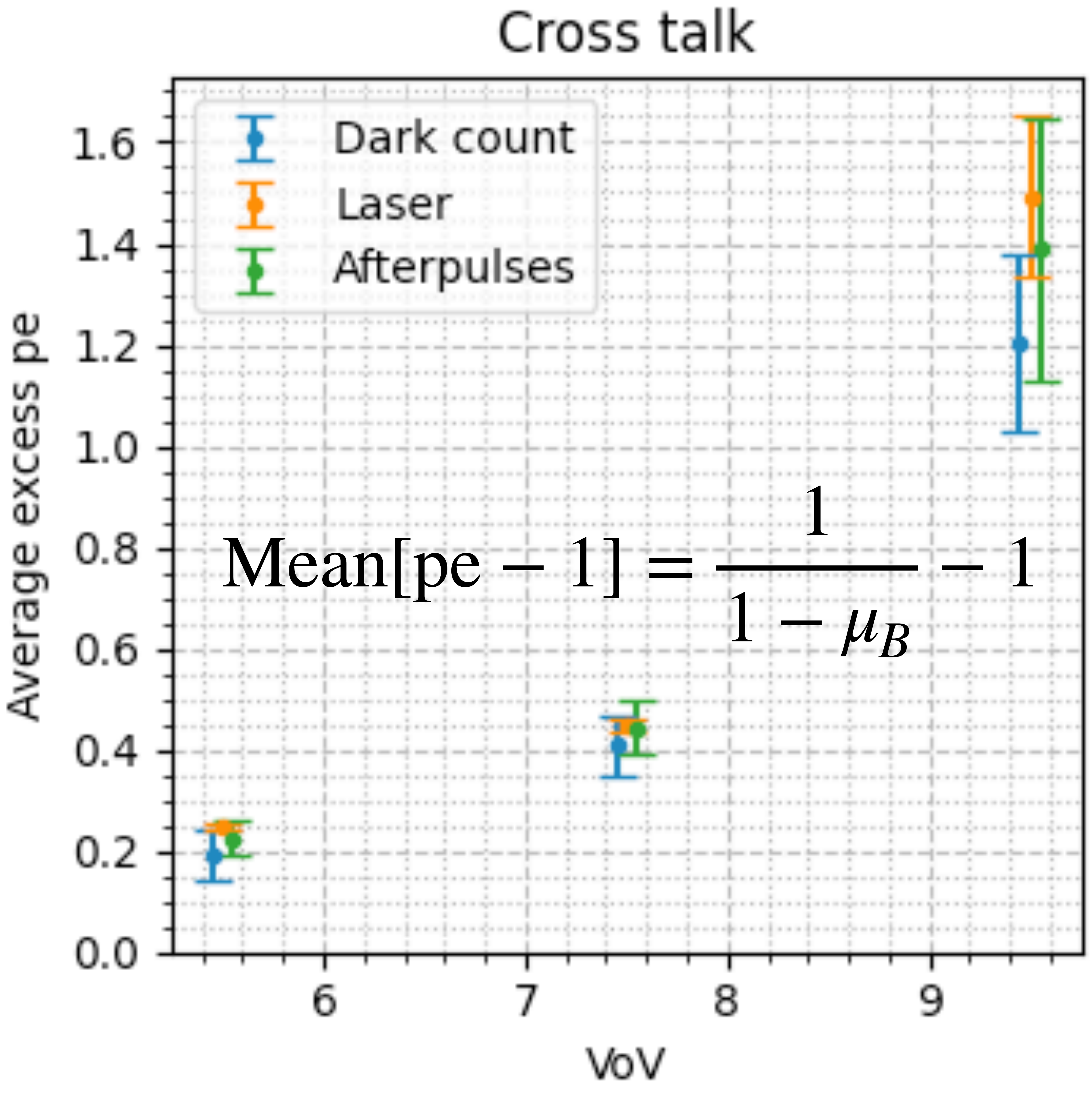
Cross talk results (1/2)

We express the amount of cross talk in two different ways: A. the probability of having cross talk, and B. the average number of excess pe.

Both computed from the fitted model.

The different measurements agree.



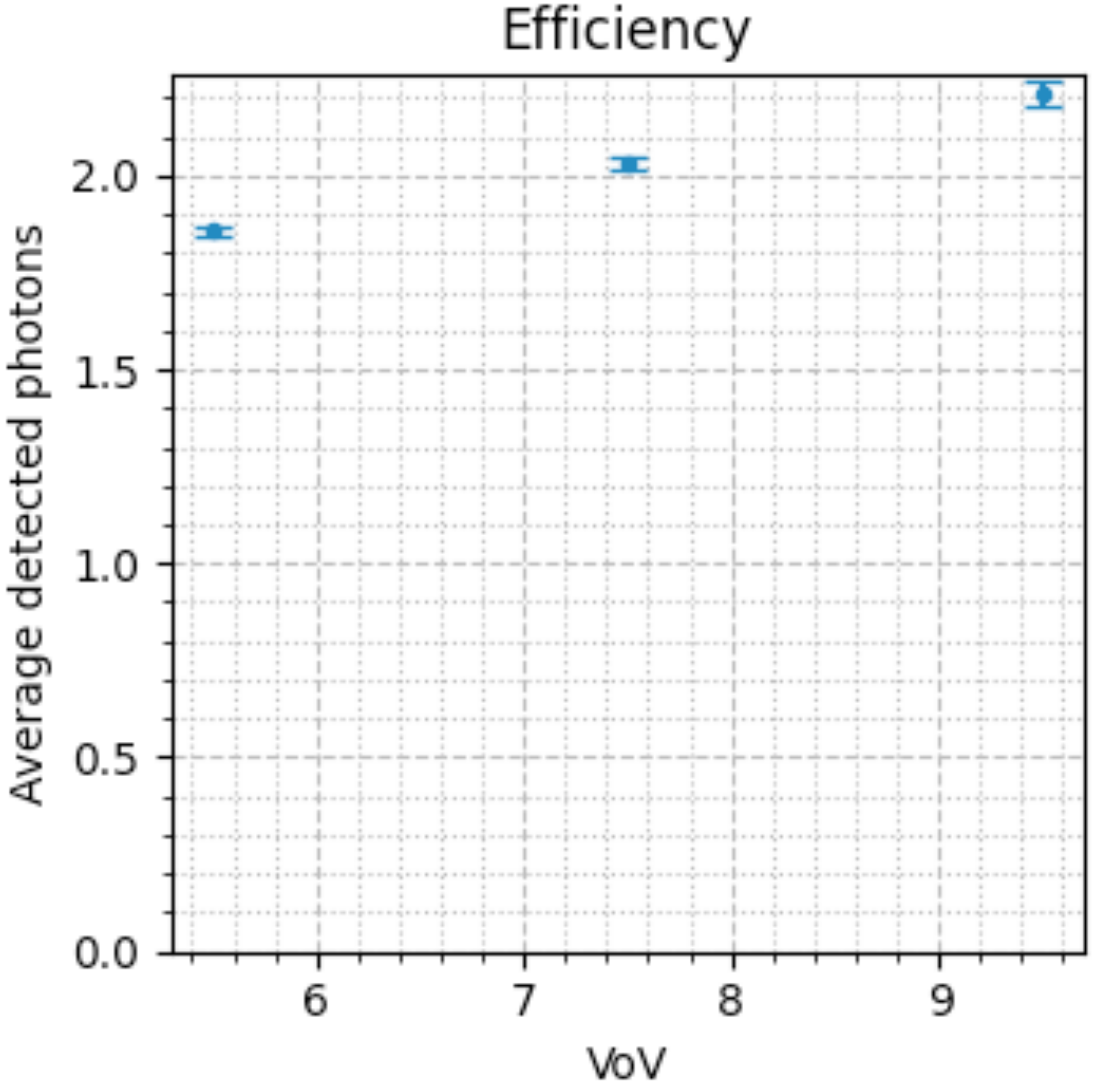


Cross talk results (2/2)

We check the other parameter in the model: the mean laser pe before cross talk μ_P.

Expected to be proportional to PDE, if laser is stable and illumination conditions constant.

Increasing, as expected.



Conclusions

We have analyzed correlated noises using cross correlation filter and peak finding (instead of charge integration methods).

The Poisson branching process model for the direct cross-talk seems good, as reported in the literature.

The laser pe distribution seems to be Poissonian in LNGS.

This model can be used to interpret VETO data.

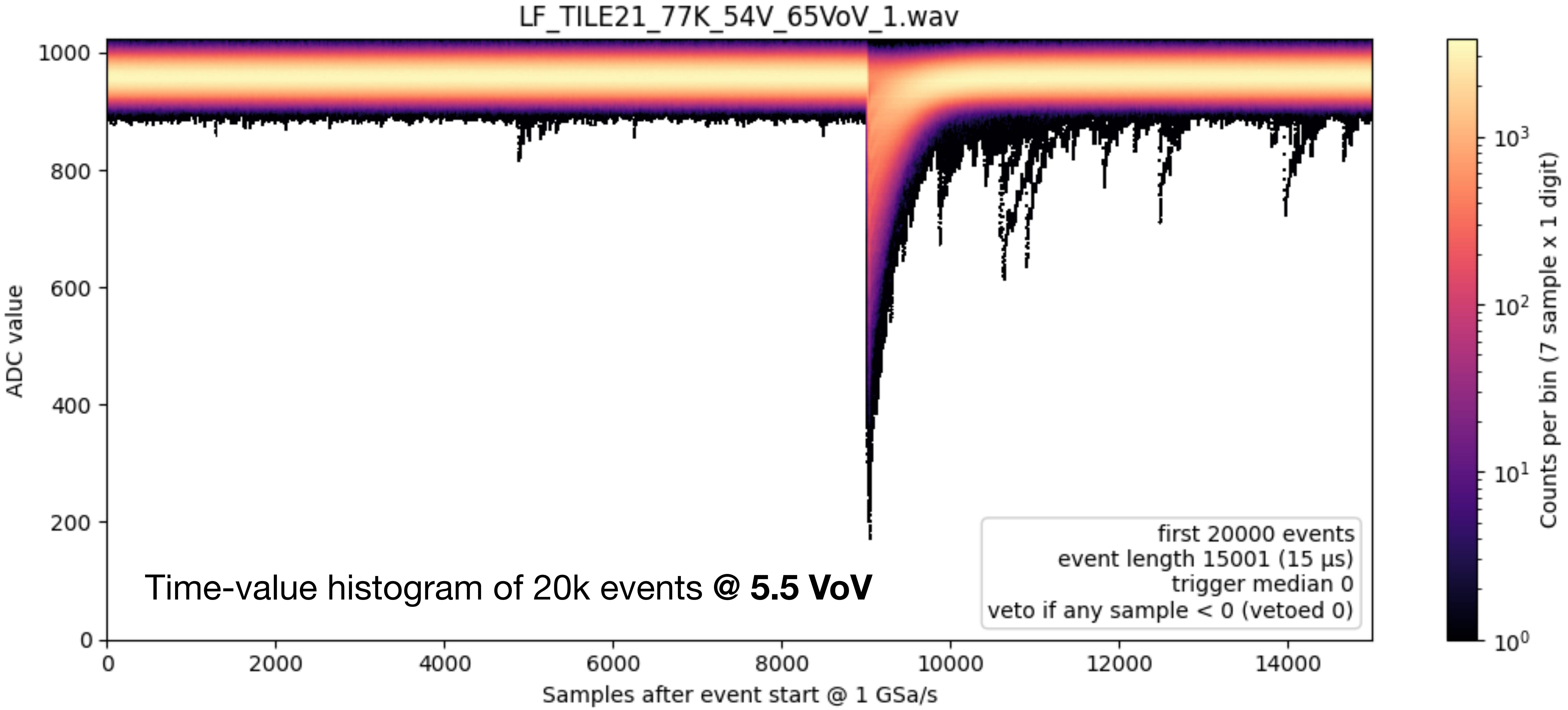
The afterpulse decay distribution appears different from the expected exponential. Fitting the exponential, tau = (650 ± 100) ns.

If it is not a bug in the analysis, maybe there are two populations of afterpulses with two taus, due to different energy levels?

Or different afterpulse tau for each SiPM in the PDM?

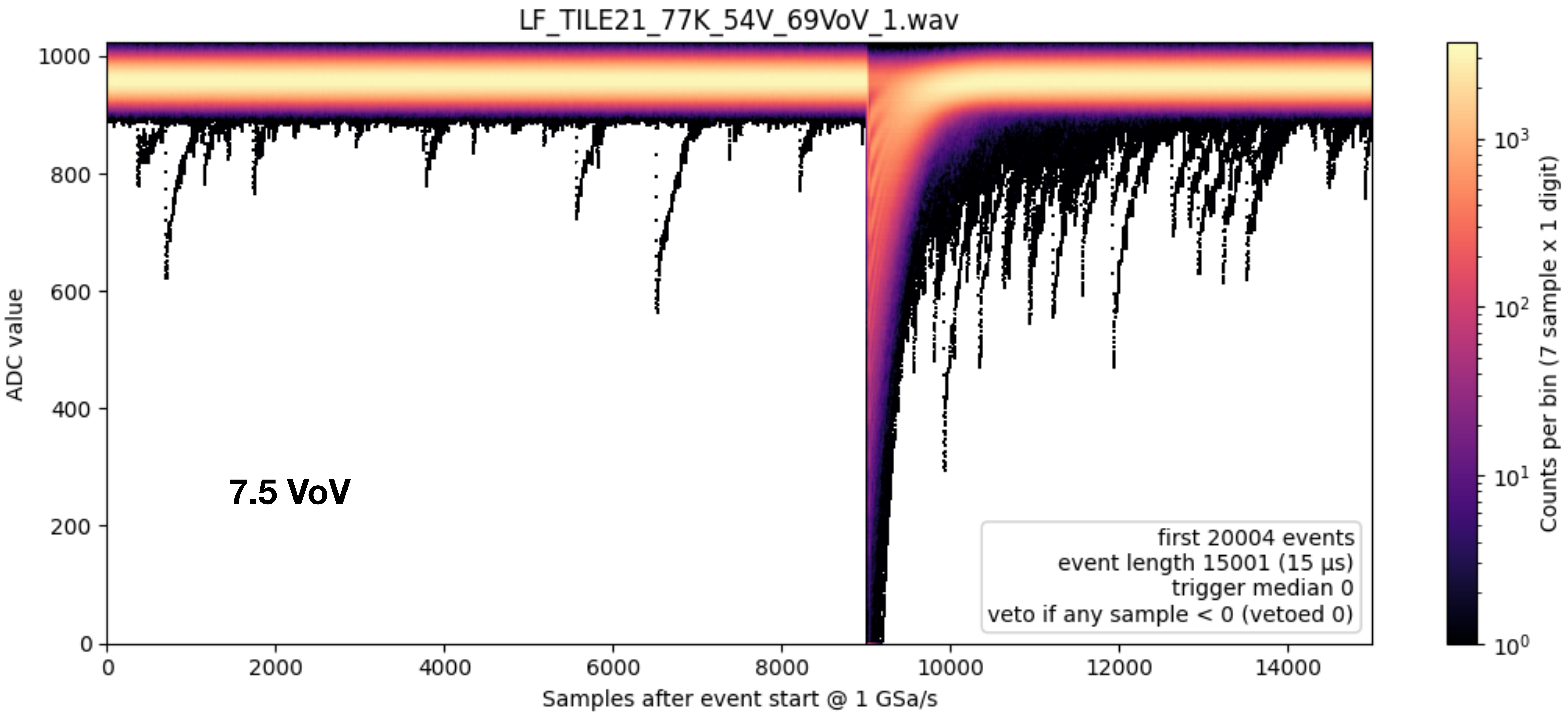
Backup slides

Data (1/3)



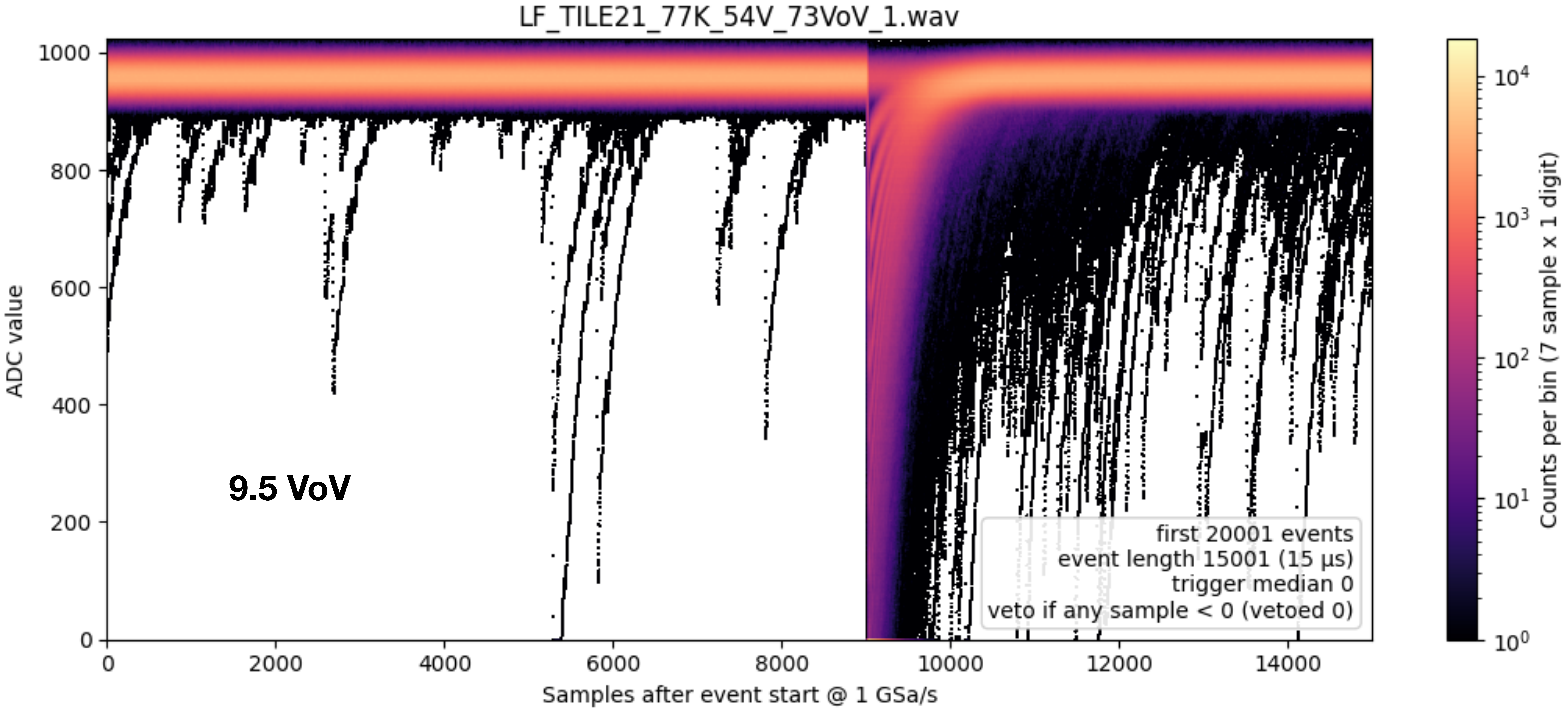
LF_TILE21_77K_54V_65VoV_1.wav
ADC value
Samples after event start @ 1 GSa/s
Counts per bin (7 sample x 1 digit)
first 20000 events
event length 15001 (15 µs)
trigger median 0
veto if any sample < 0 (vetoed 0)
Time-value histogram of 20k events @ **5.5 VoV**

Data (2/3)



LF_TILE21_77K_54V_69VoV_1.wav
ADC value
1000
800
600
400
200
0
2000
4000
6000
8000
10000
12000
14000
Samples after event start @ 1 GSa/s
7.5 VoV
first 20004 events
event length 15001 (15 µs)
trigger median 0
veto if any sample < 0 (vetoed 0)
Counts per bin (7 sample x 1 digit)
10^3
10^2
10^1
10^0

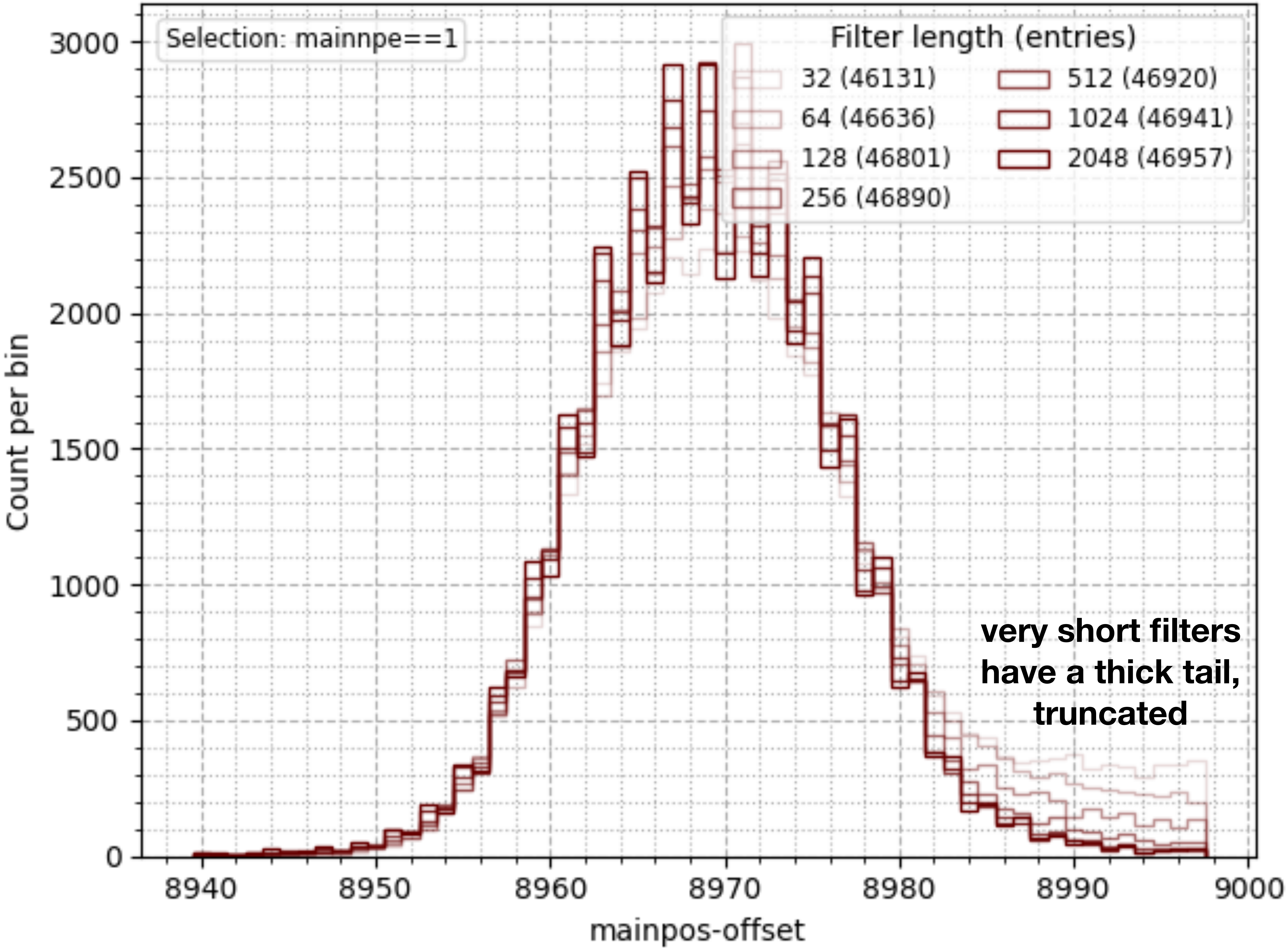
Data (3/3)


LF_TILE21_77K_54V_73VoV_1.wav
ADC value
1000
800
600
400
200
0
0
2000
4000
6000
8000
10000
12000
14000
Samples after event start @ 1 GSa/s
9.5 VoV
first 20001 events
event length 15001 (15 µs)
trigger median 0
veto if any sample < 0 (vetoed 0)
Counts per bin (7 sample x 1 digit)
10^4
10^3
10^2
10^1
10^0

Laser peak finding (1/4)

Distribution of the laser peak position for 1 pe pulses.

The distribution is skewed to the right and **truncated**. We have to **make sure this is not due to afterpulsing**, because it would bias the afterpulse count.



Laser peak finding (2/4)

I found the tail is due to random fluctuation, not afterpulses.

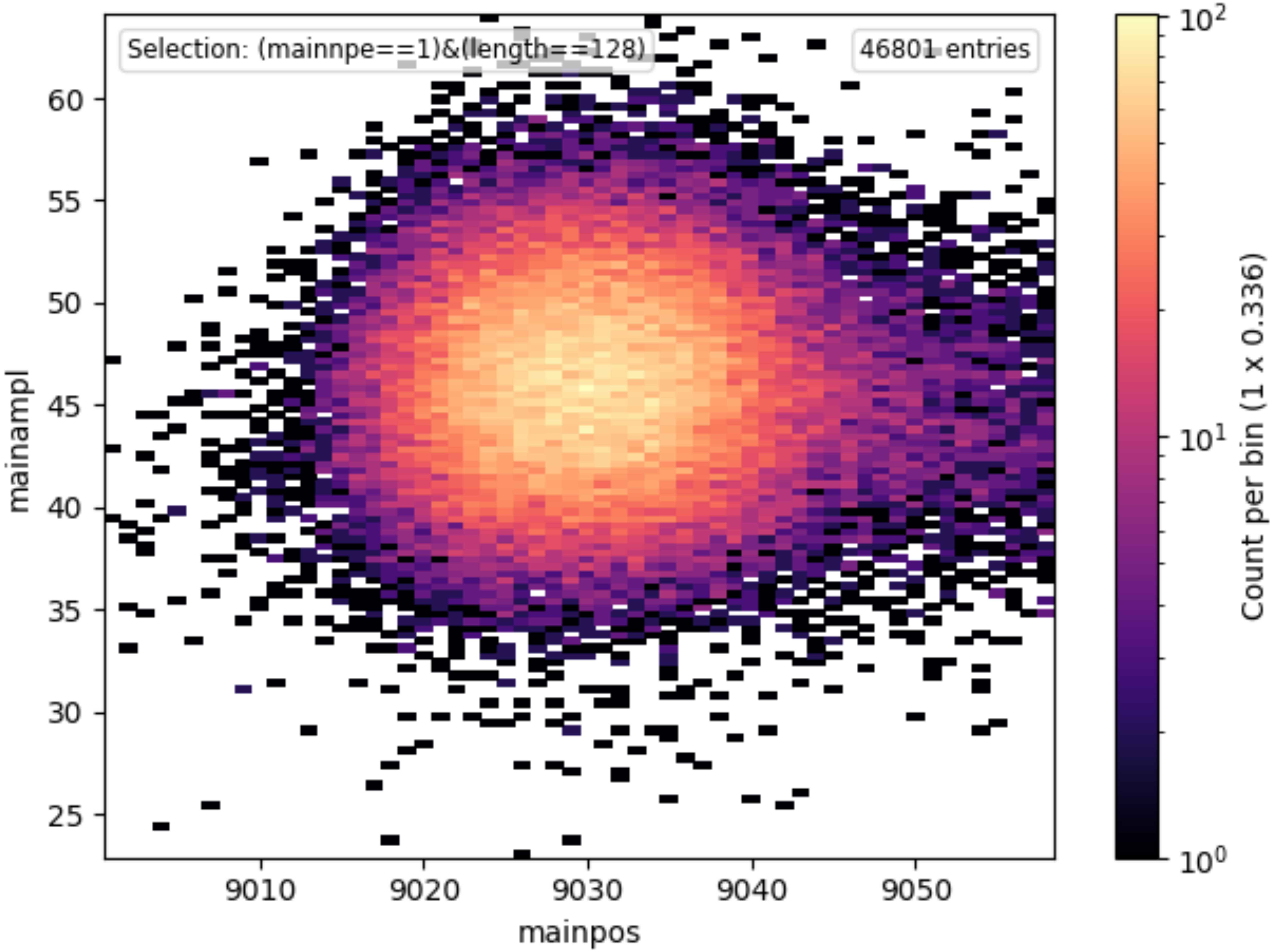
- It appears with short filters because they have lower SNR.
- It is to the right because of the asymmetric signal shape.

Evidence in the next slides.

Laser peak finding (3/4)

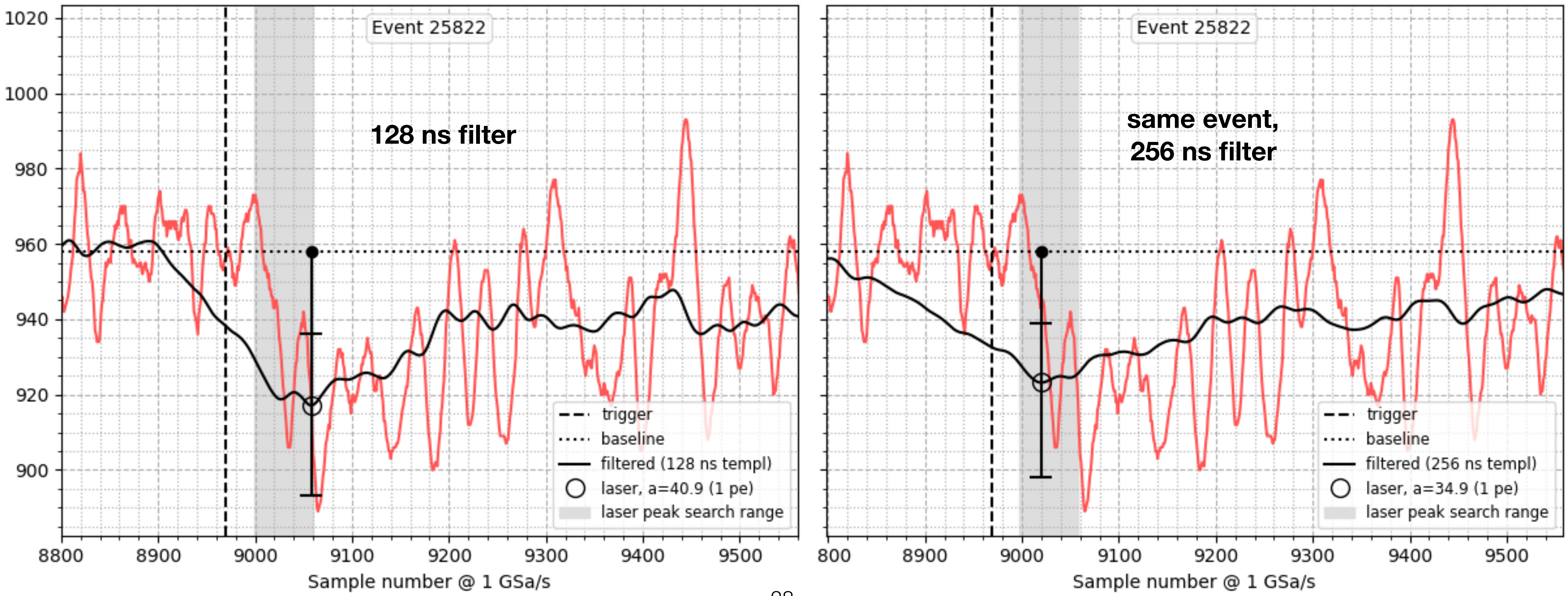
Position-amplitude histogram with short filter.

If the tail was due to afterpulses, I would expect a positive correlation. Instead it seems slightly negative.



Laser peak finding (4/4)

I also looked at many events in the tail. They are mostly like this: a bit longer filter is sufficient to cancel the noise and bring back the position to the center.

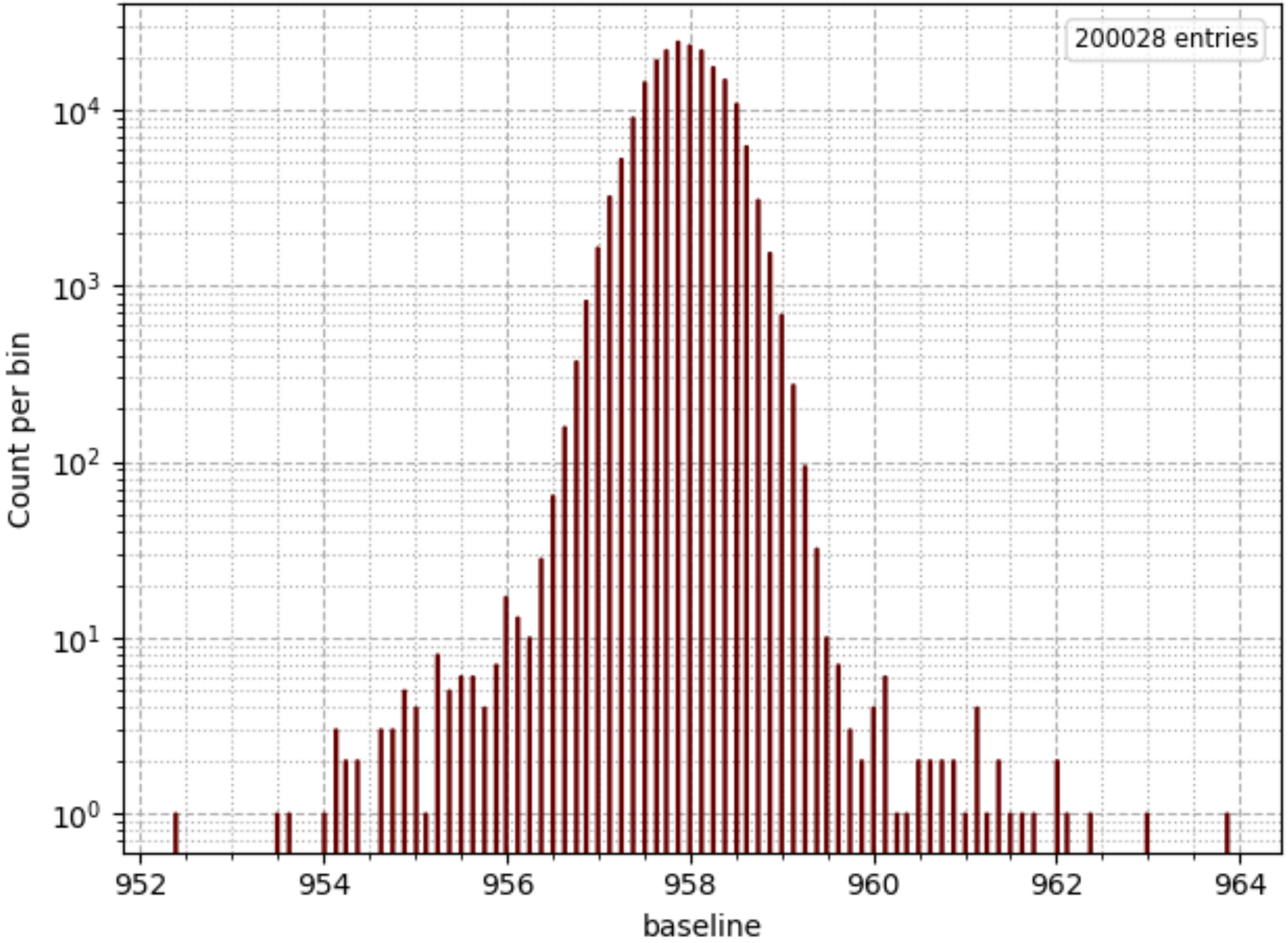


Baseline (1/4)

- I compute the baseline as the median of the pre-trigger region.
- To avoid discretizing too much (the median is discrete), I average the medians of 8 interleaved subarrays.
- If any pre-trigger sample is less than 700, I reuse the baseline from a previous event.

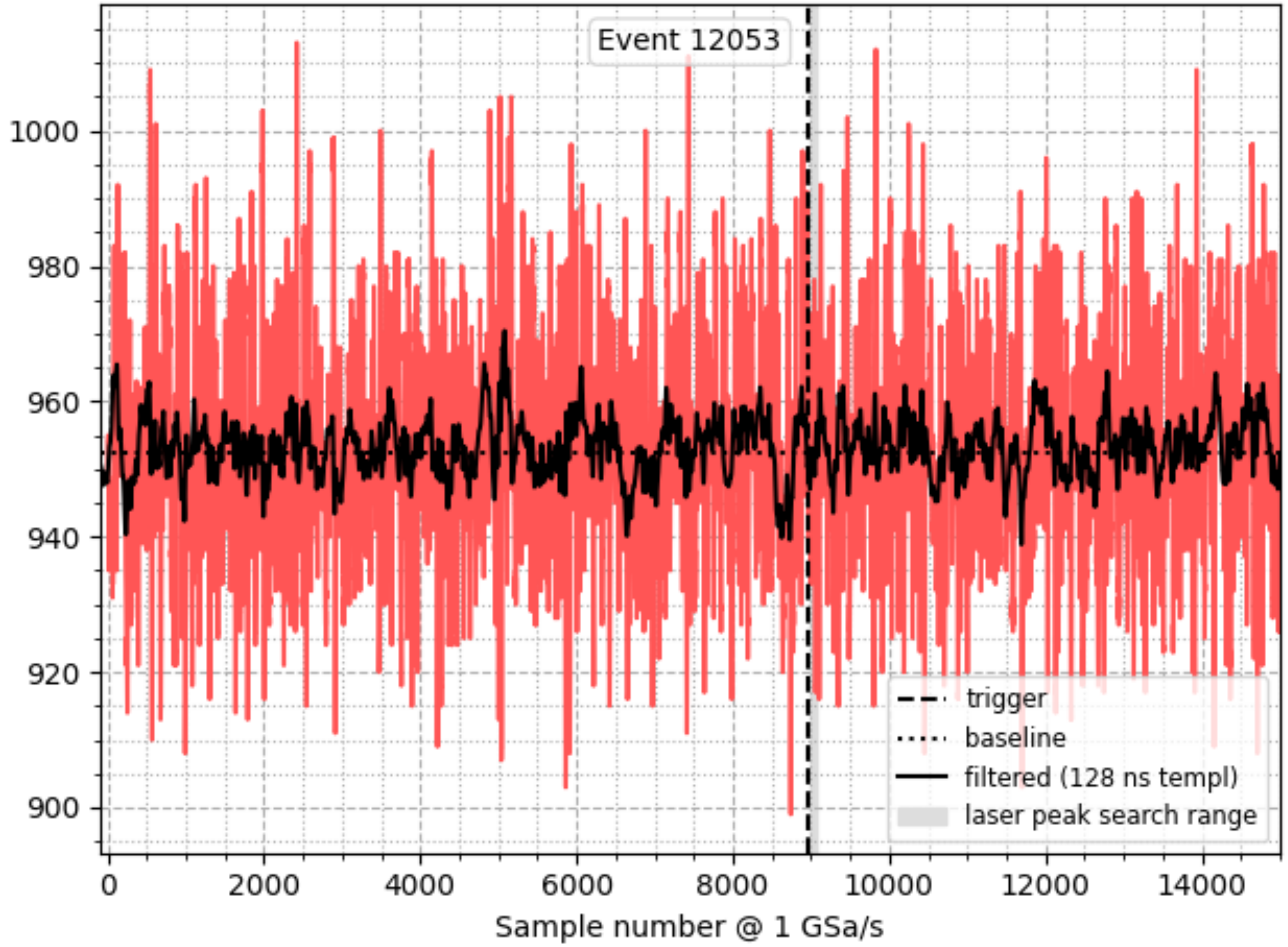
Baseline (2/4)

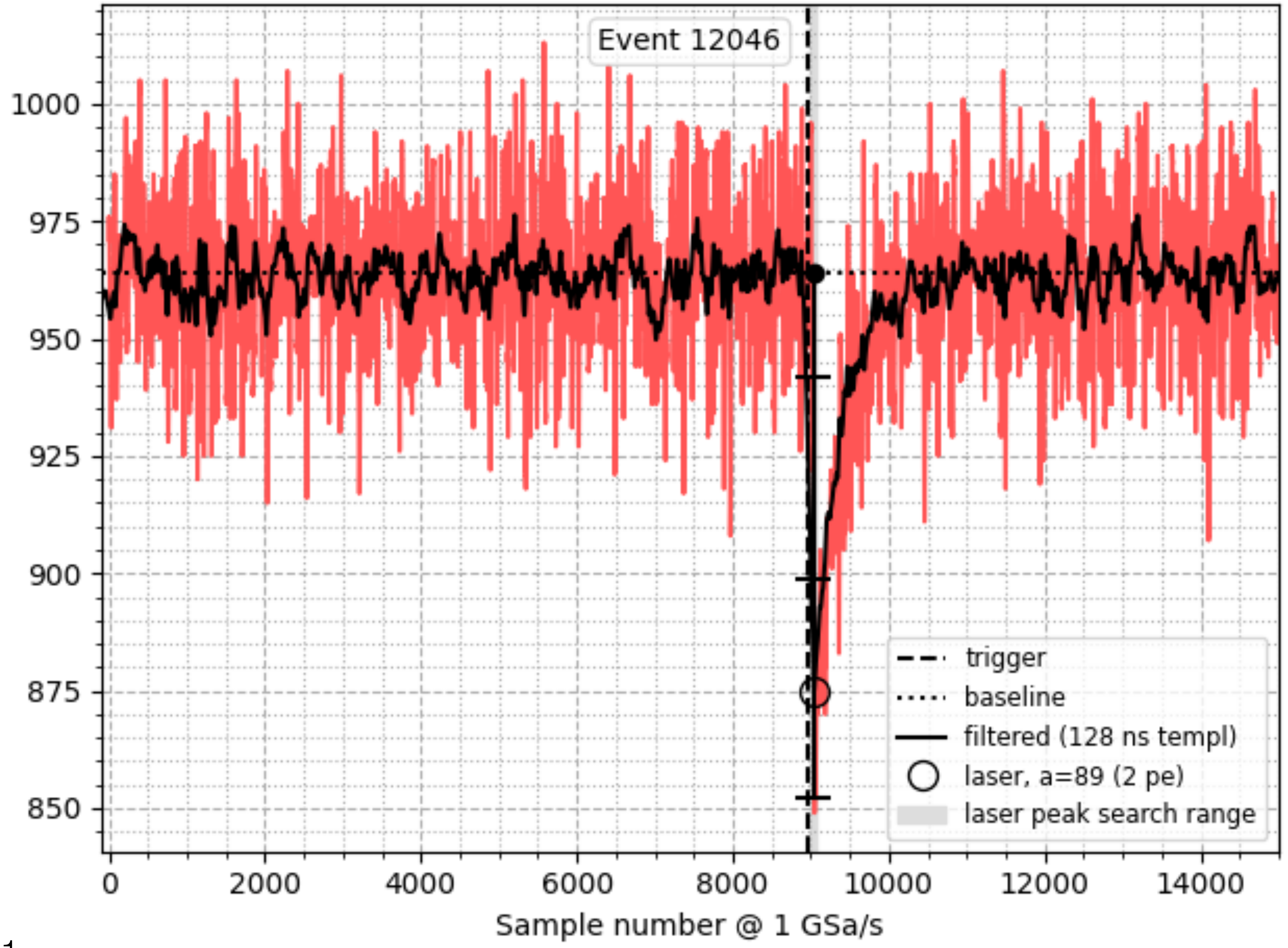
Distribution of the baseline (logscale). There's a small tail to the left.



Baseline (3/4)

The leftmost and rightmost events in the previous histogram. They are genuinely extreme baselines.





Baseline (4/4)

The events in the left tail instead are mostly events with dark pulses. This means that dark pulses will have their amplitude underestimated, by at most 4. This is not a problem so I did not fix it.