NCAL tests at ÚJV Řež

Lecroy Oscilloscope Analysis

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🧪 Prague Cyclotron Experiment – Setup Summary

- **Objective:**
Measure neutron detection efficiency and signal response of a plastic scintillator-based detector (NCAL) using a quasi-monoenergetic neutron beam.

Detector: NCAL (7-module plastic scintillator array with PMTs)

Neutron Source:

Reaction: ^{7}Li(p,n)

Target: Solid lithium (Li) foil

Proton Beam Energy: 32.5 MeV

Beam Structure: Gaussian bunches (FWHM 2–3 ns),
25 MHz → ~40 ns period

Intensity Range: 0.1–5.0 μA (adjustable in seconds)

Detector Positioning:

Detector Face Distance from Target: 3.376 ± 0.02 m

Detector Aperture: 8 × 8 cm²

Shielding Wall Location: Starts at 2.179 m, ends at 3.26 m

Expected Neutron Flux (QM Peak):
At 3.38 m and 5 μA beam current: interpolated between tabulated values
(~10^{3}–10^{4} n/cm²/s)

Measurement System:

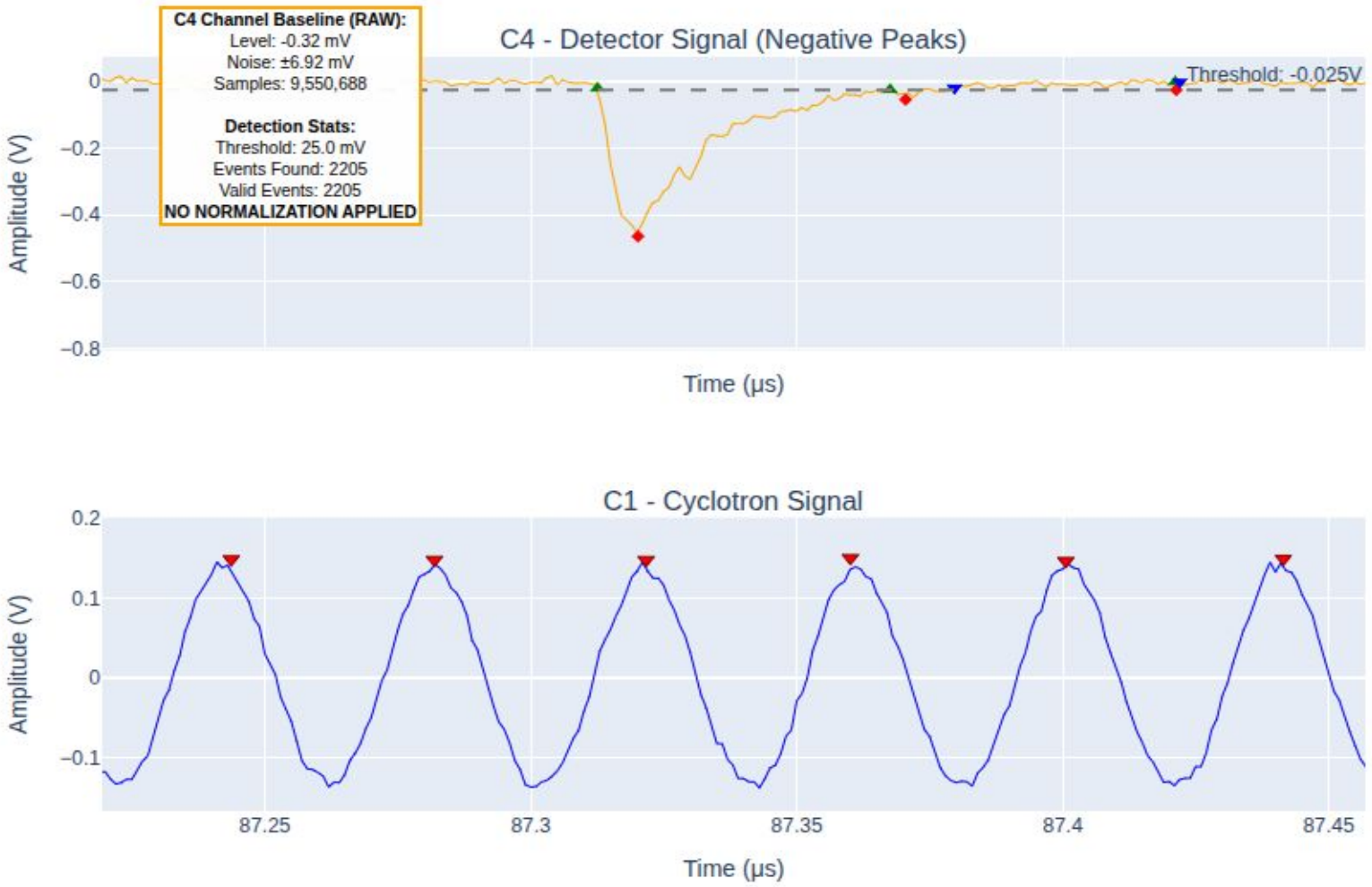
- Oscilloscope
- DiRich
- Digitizer: CAEN 8-channel waveform digitizer (1 kHz sampling)

Triggering: Reference RF signal from cyclotron (25 MHz, ~300 mV)

Polyethylene and lithium-loaded shielding available on site

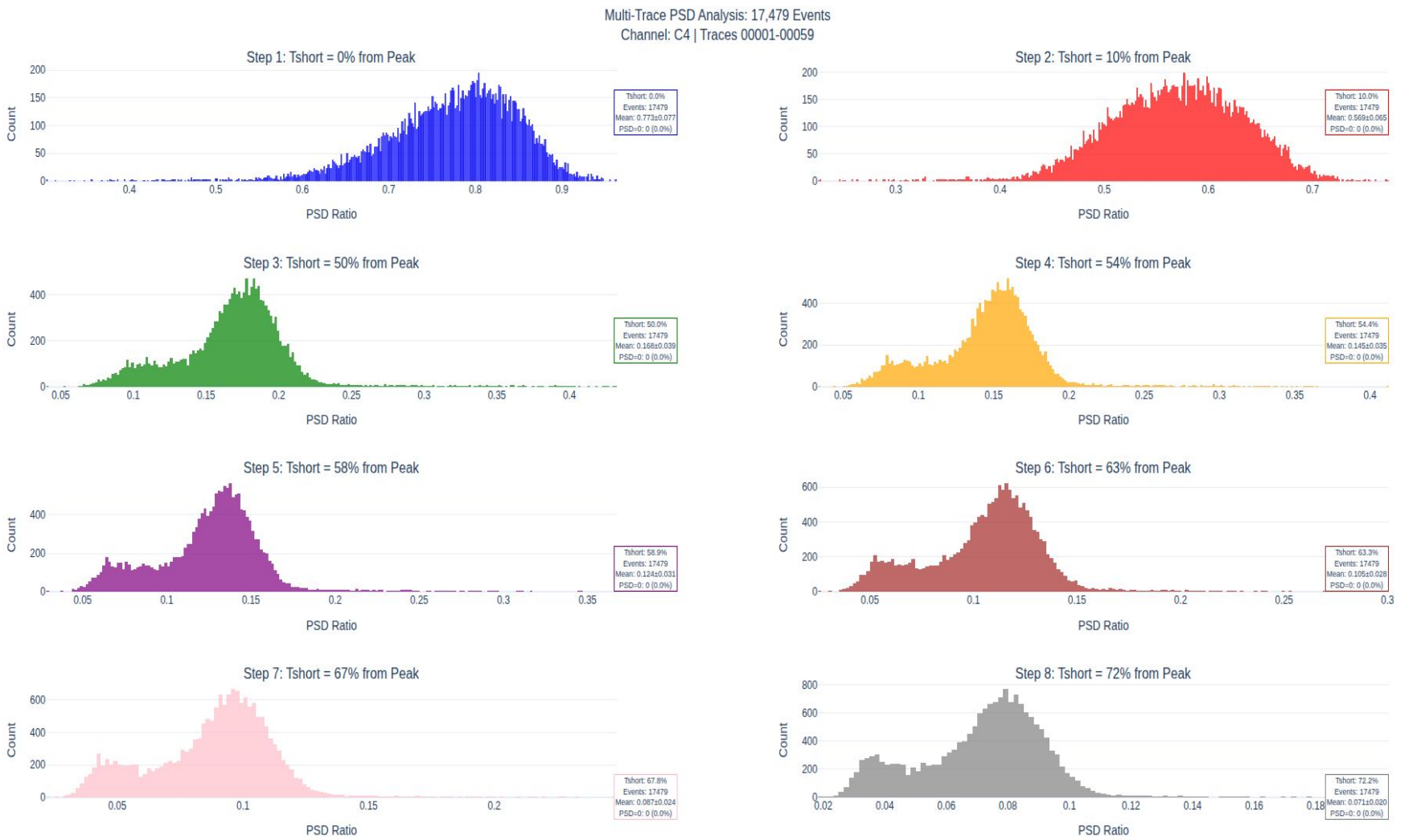
Gamma background present but manageable via pulse shape discrimination

Waveforms

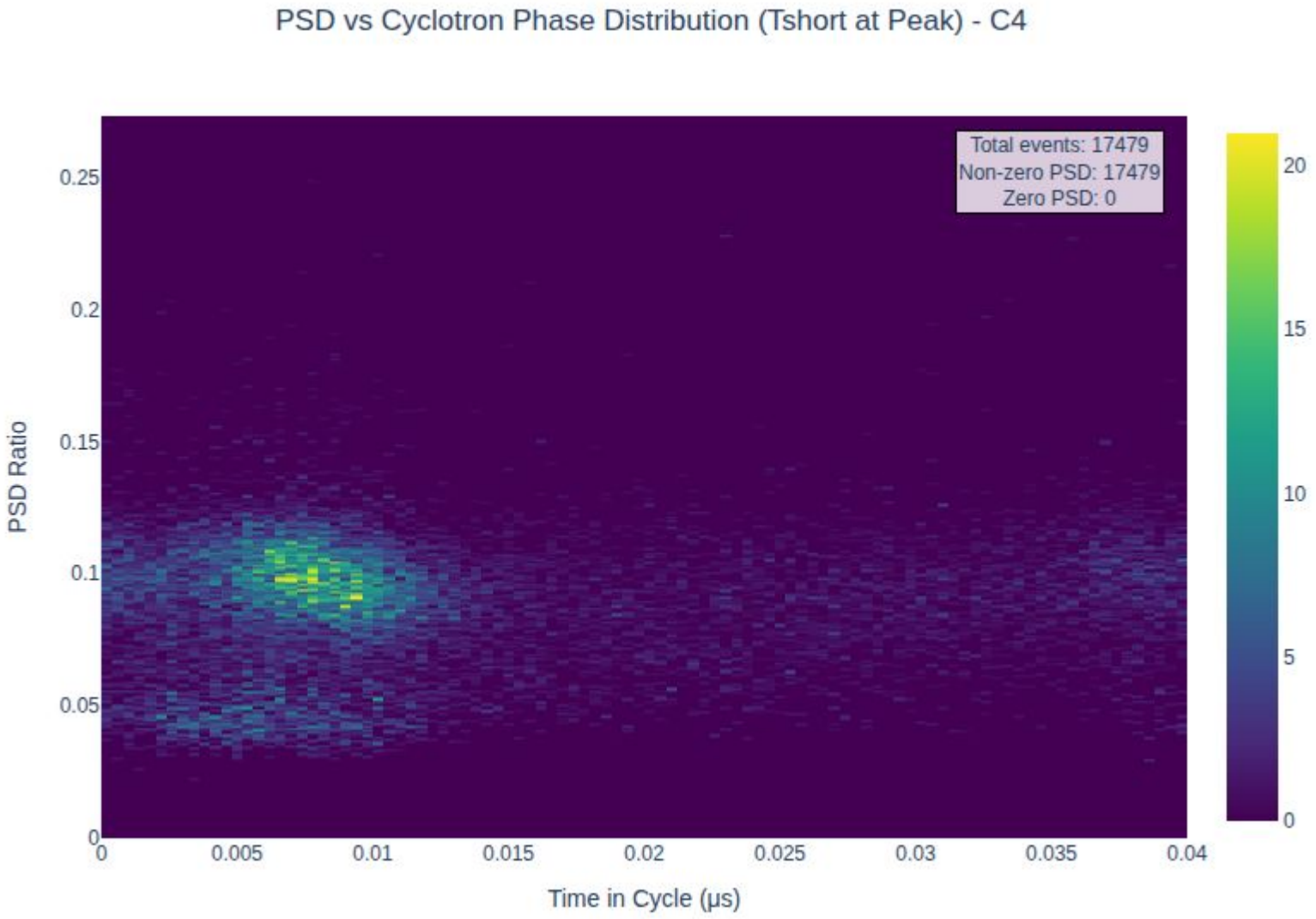

C4 Channel Baseline (RAW):
Level: -0.32 mV
Noise: ±6.92 mV
Samples: 9,550,688
Detection Stats:
Threshold: 25.0 mV
Events Found: 2205
Valid Events: 2205
NO NORMALIZATION APPLIED
C4 - Detector Signal (Negative Peaks)
Threshold: -0.025V
Amplitude (V)
0
−0.2
−0.4
−0.6
−0.8
Time (µs)
C1 - Cyclotron Signal
Amplitude (V)
0.2
0.1
0
−0.1
87.25
87.3
87.35
87.4
87.45
Time (µs)

Rough Pulse Shape Discrimination

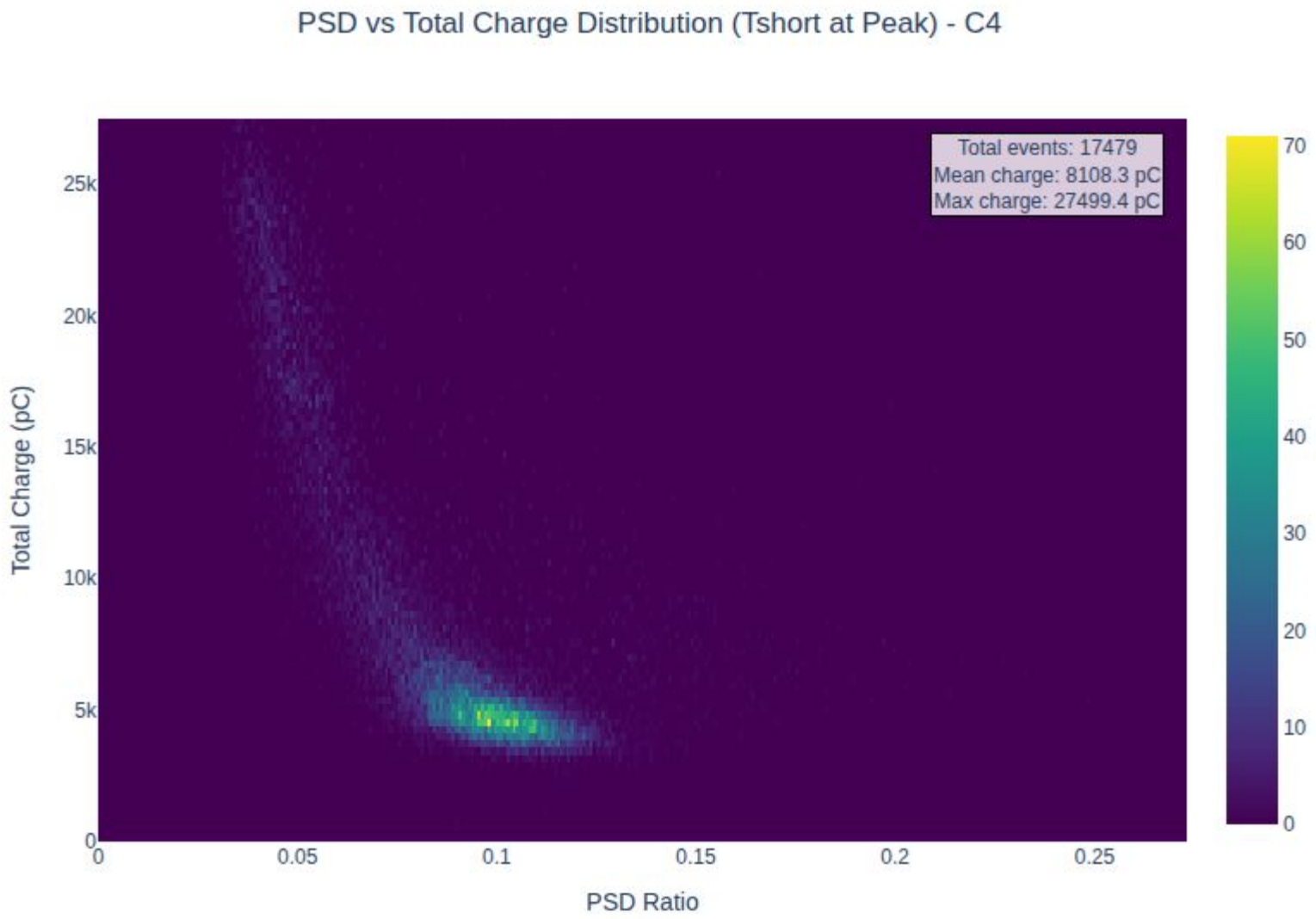
Pulse Shape Discrimination – Tshort by Width



Pulse Shape Discrimination vs Cycle Time



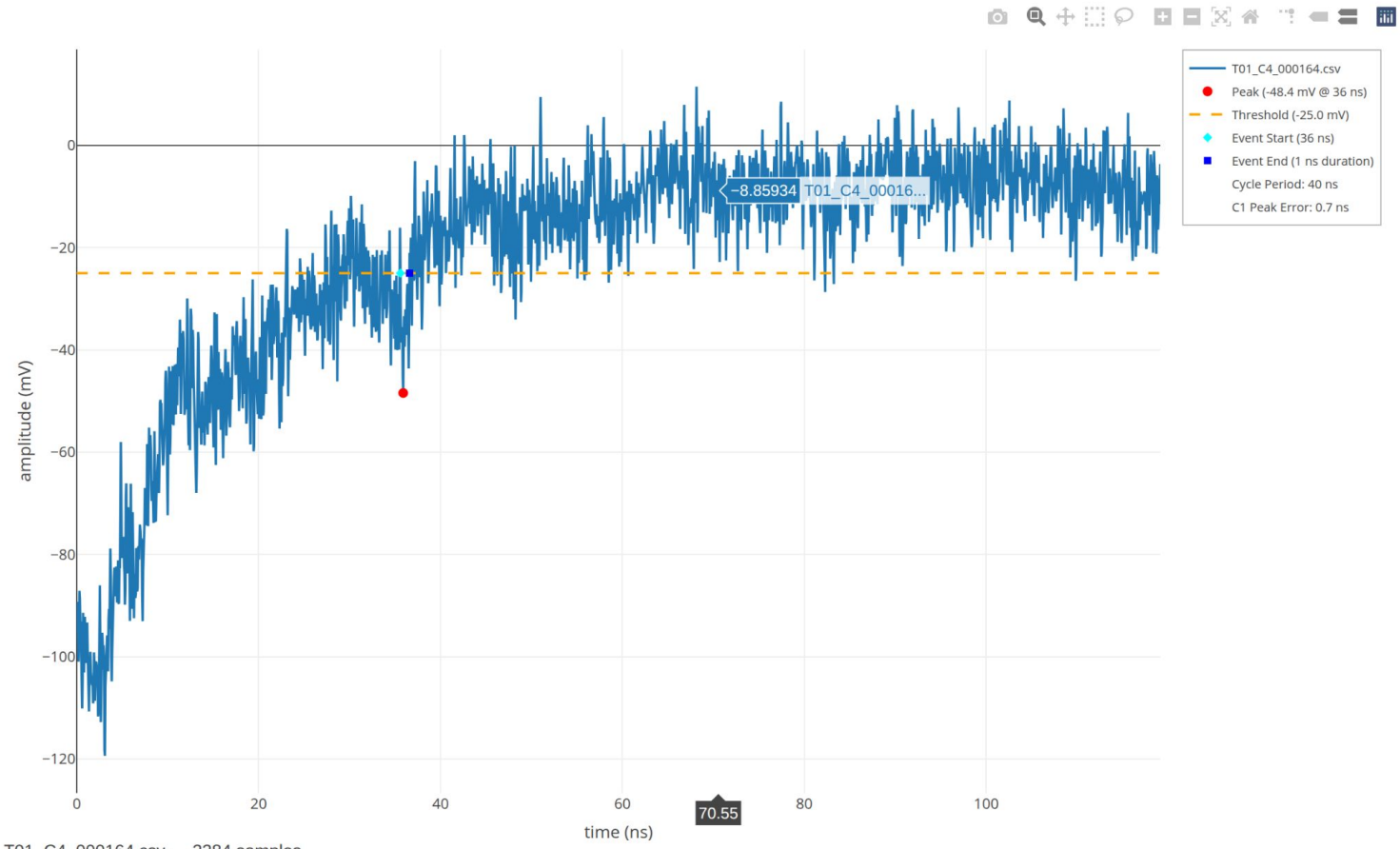
Pulse Shape Discrimination vs Cycle Time



Chapter 2 - Per event Analysis

New approach: Identify events, record them as separate files and then do the rest of the analysis.

QA: Observed issues with the previous code
Event validation is not strict enough



T01_C4_000164.csv — 2384 samples
Cycle Period: 40 ns
Event Duration: 1 ns
Peak: -48.4 mV @ 36 ns
C1 Peak Error: 0.7 ns

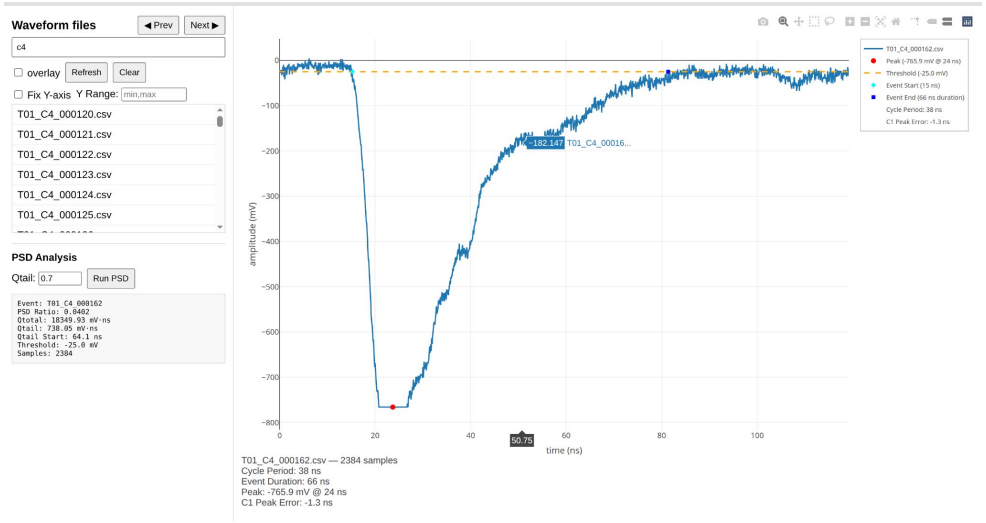
QA: Observed issues with the previous code
Event validation is not strict enough

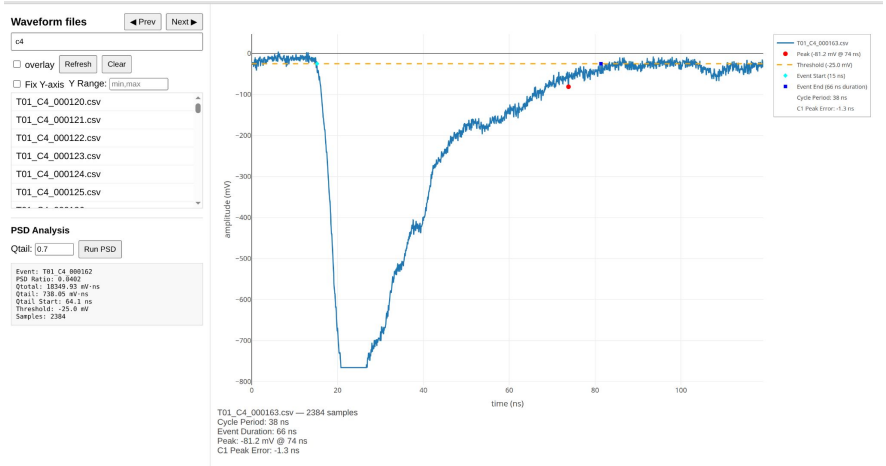
Added pulse width requirement for the event ID

```
PER-TRACE ANALYSIS RESULTS
----------------------------------------
Trace 01:
  Events detected: 1081
  Channels active: ['C3', 'C4']
  Valid cycle range: -0.000484524 to 0.000499761 seconds
  Analysis window: 984285.2 ns

Trace 02:
  Events detected: 1130
  Channels active: ['C3', 'C4']
  Valid cycle range: -0.000092296 to 0.000499783 seconds
  Analysis window: 592079.6 ns

PER-CHANNEL STATISTICS
----------------------------------------
C3:
  Events detected: 309
  Active in traces: [1, 2]

C4:
  Events detected: 1902
  Active in traces: [1, 2]
```

```
PER-TRACE ANALYSIS RESULTS
----------------------------------------
Trace 01:
  Events detected: 737
  Channels active: ['C3', 'C4']
  Valid cycle range: -0.000484524 to 0.000499761 seconds
  Analysis window: 984285.2 ns

Trace 02:
  Events detected: 828
  Channels active: ['C3', 'C4']
  Valid cycle range: -0.000092296 to 0.000499783 seconds
  Analysis window: 592079.6 ns

PER-CHANNEL STATISTICS
----------------------------------------
C3:
  Events detected: 263
  Active in traces: [1, 2]

C4:
  Events detected: 1302
  Active in traces: [1, 2]
```

QA: Observed issues with the previous code
Pile-up rejection needs to be introduced in Event selection





Problem: Same waveform, two events?

Explanation:

infinite reverse search for the start time, Event ID algorithm starts with peak finding and then boundary finding which produced this problem for some events.

fix:

- fixed reverse search at maximum distance 40ns
- required that no entries before the start point are greater than the reference peak
- switched from peak based eventID to start-end based

Data validation: Event detection pipeline

Event finding

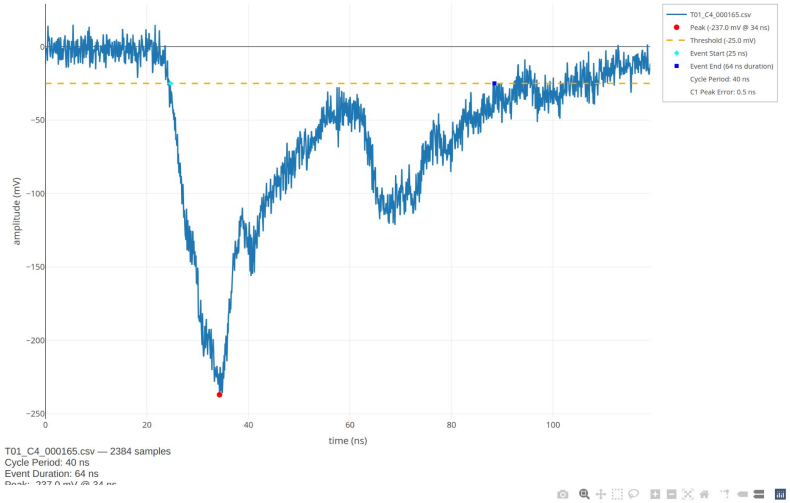
- **Set per-channel threshold** - Use known polarity (C2–C4 negative; C1 positive reference).
- **Threshold crossing (start)** - Detect the first negative-going crossing of the threshold to mark the event start.
- **Return crossing (end)** - Find the next crossing back across the threshold to mark the event end.
- **Peak inside region** - Within start→end, take the representative peak (min for negative signals).

Filters

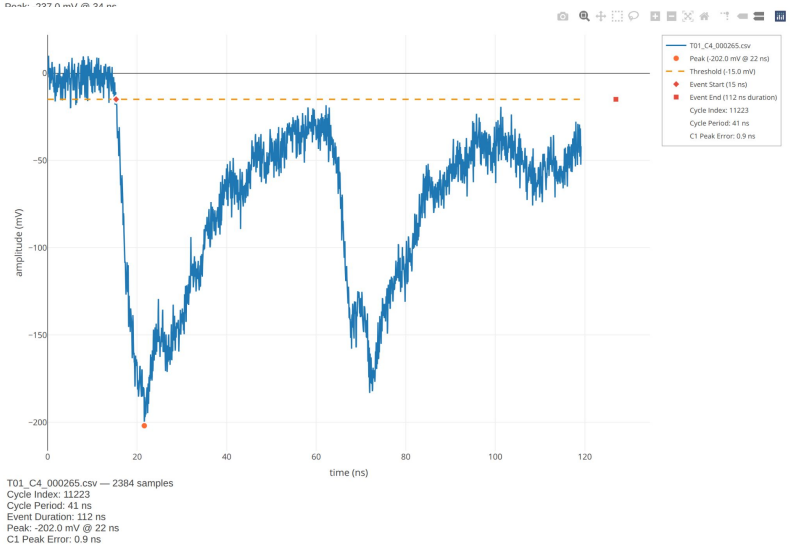
- **Amplitude (peak) -** Require peak magnitude to pass a per-channel limit (negative channels: peak ≤ −min_abs).
- **Width -** Duration = end − start must lie within per-channel [min_ns, max_ns].
- **Bounds -** Start must be inside the chosen C1 cycle; the cycle must lie within the global C1 span. Peak may extend beyond.
- **Duplicates -** Keep only the first event per (channel, cycle_index); drop later ones as dups.

- **C2: 447985 regions → amp:447975 → width:8 → bounds:0 → dups:0 → FINAL:2**
- **C3: 89244 regions → amp:85198 → width:3739 → bounds:4 → dups:28 → FINAL:275**
- **C4: 272334 regions → amp:270010 → width:1484 → bounds:12 → dups:36 → FINAL:792**

Validitation and QA: Pile-up rejection needs to be introduced in Event selection



T01_C4_000165.csv — 2384 samples
Cycle Period: 40 ns
Event Duration: 64 ns



T01_C4_000265.csv — 2384 samples
Cycle Index: 11223
Cycle Period: 41 ns
Event Duration: 112 ns
Peak: -202.0 mV @ 22 ns
C1 Peak Error: 0.9 ns

Pile-Up Detection – Summary

- Detects overlapping signals (pile-up) in PMT waveforms
- Works on negative polarity signals

Key idea:

Dynamic threshold between baseline and peak:

`Lpile = thr + alpha × (peak - thr)`

Triggers pile-up if any of the following is true:

- **Re-entry rule**:
  Signal drops below `Lpile` again after peak
  → must be delayed, persistent, and deep enough
- **Extra wide dip**:
  Another below-threshold segment is too wide
- **Two dips with high middle**:
  Two minima with an above-threshold "mountain" in between

Filters out weak signals:

- Ignores events where main peak depth < `min_peak_depth_factor × |thr|`

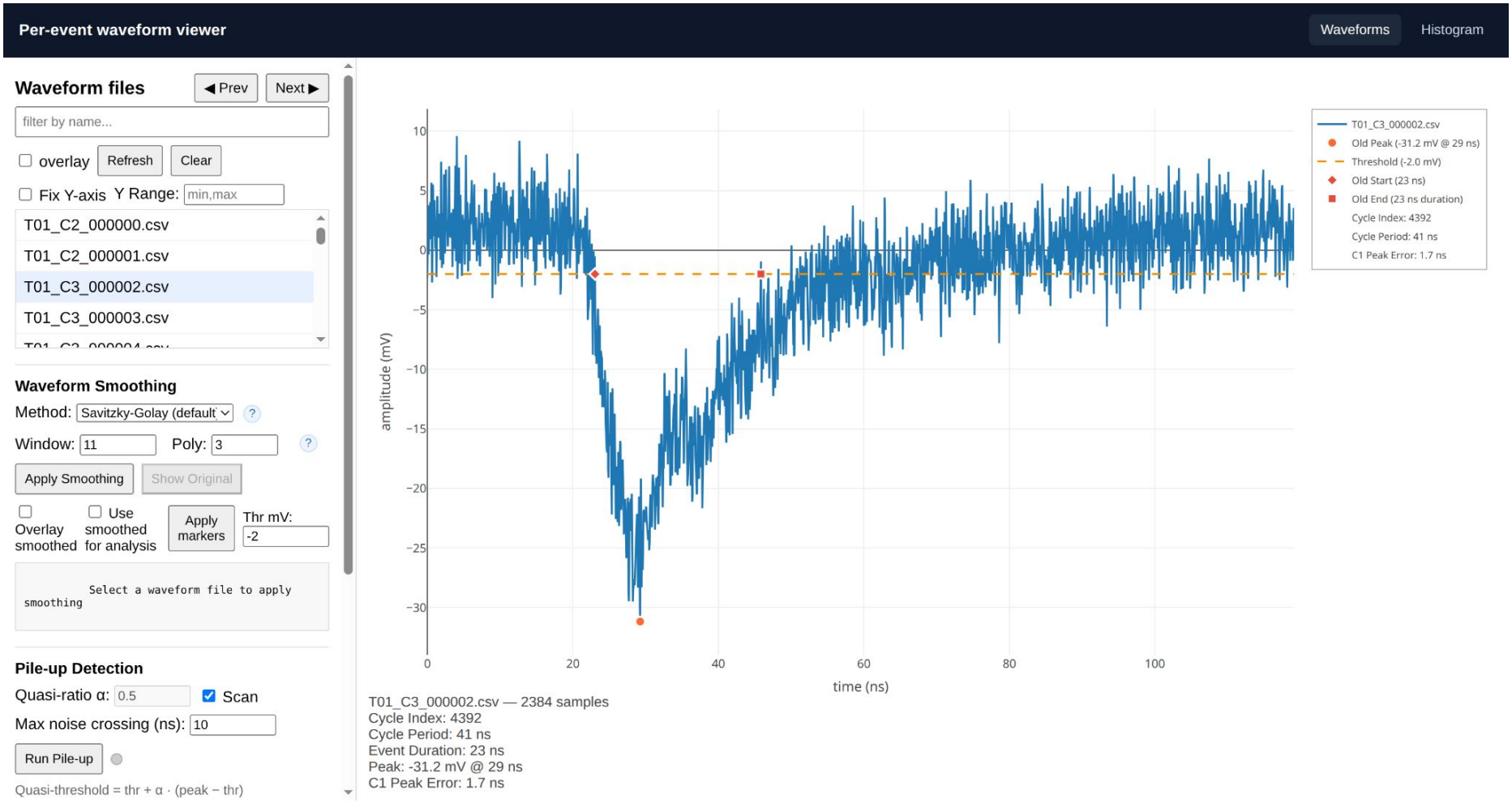
Tunable parameters:

- `alpha`, `min_sep_ns`, `min_dur_ns`, `prom_frac`, `max_noise_cross_ns`

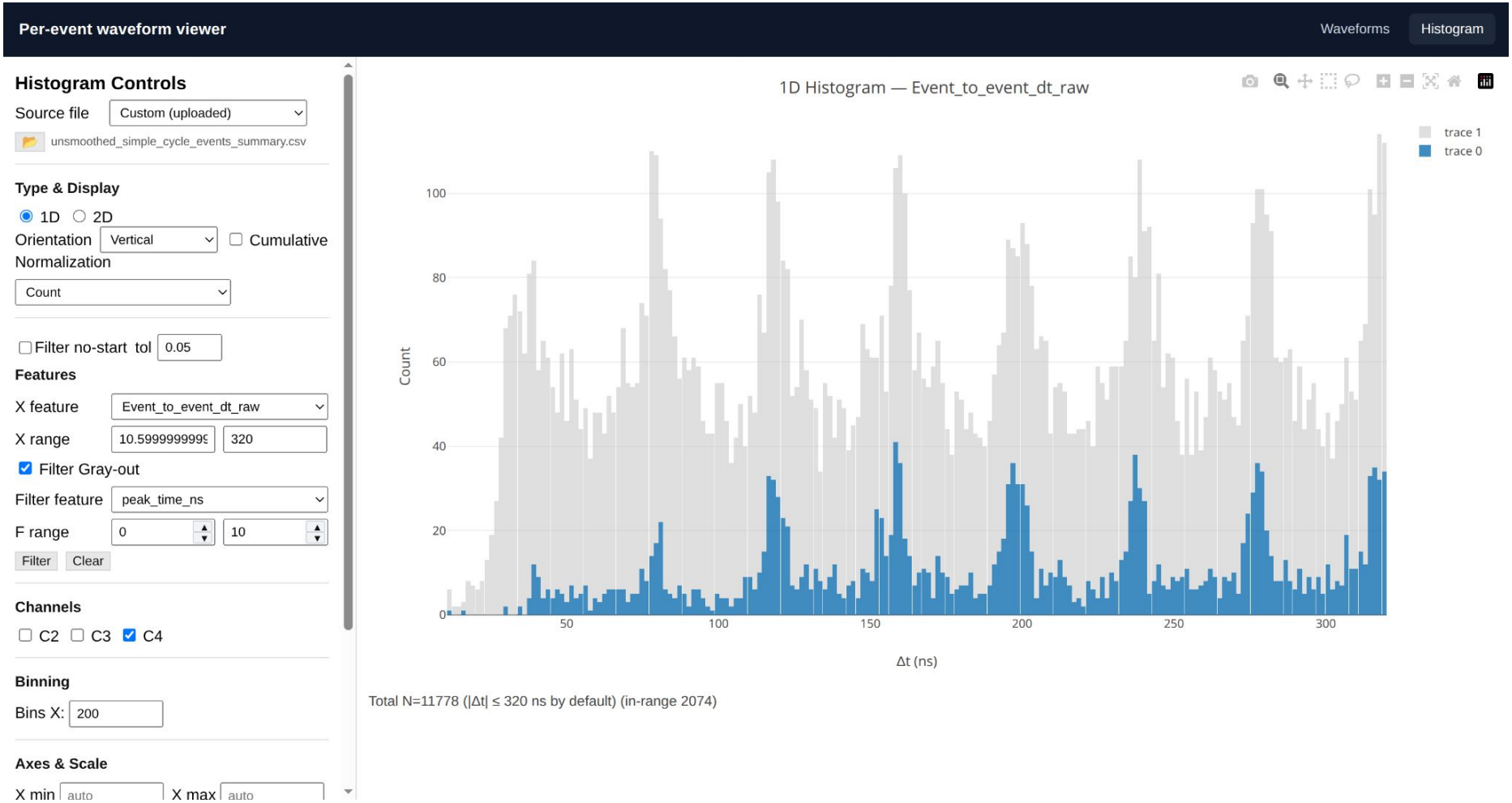
Optional feature:

- Scan over multiple alpha values to improve detection robustness

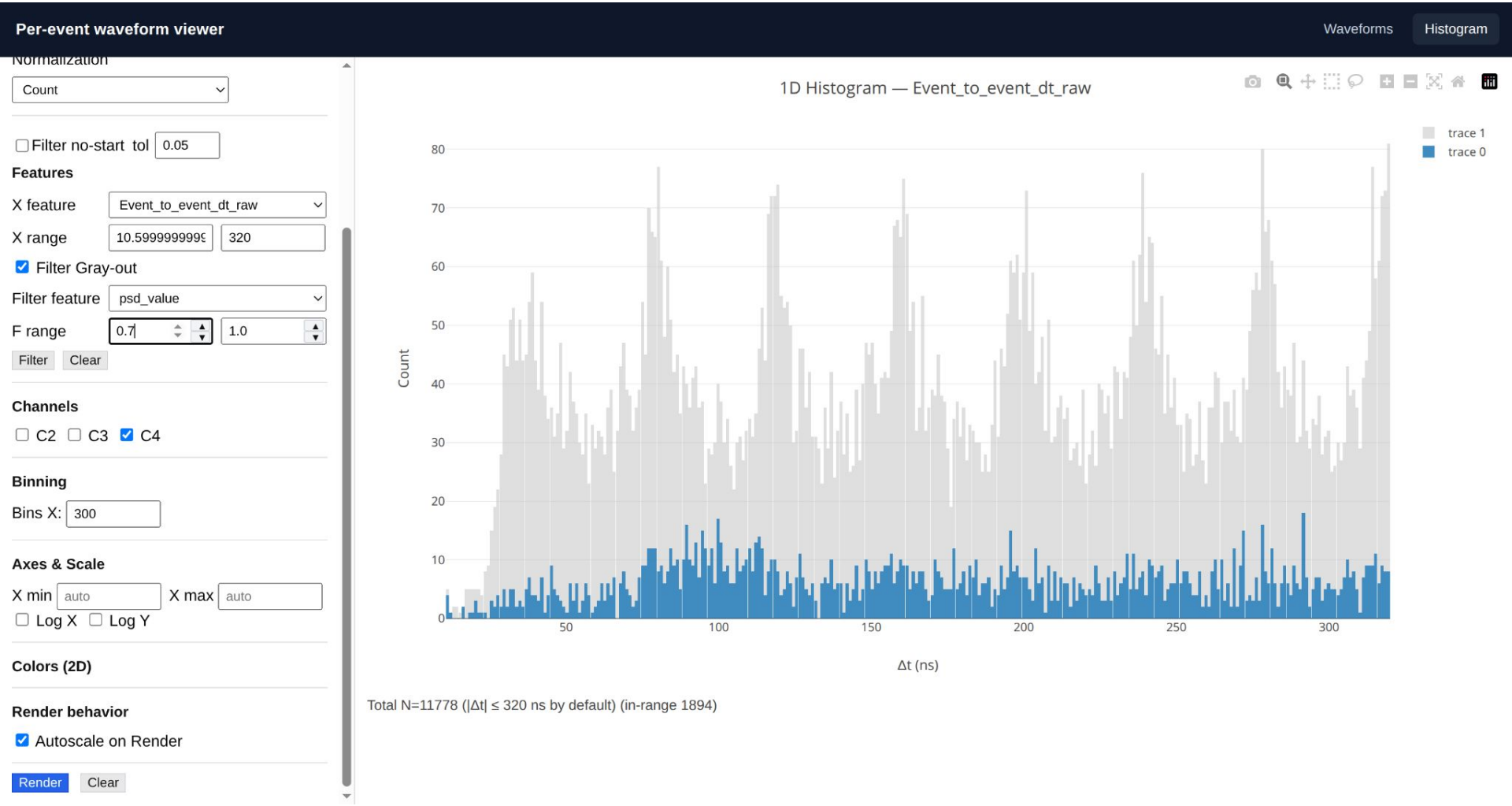
Single Waveform Plotting Suite



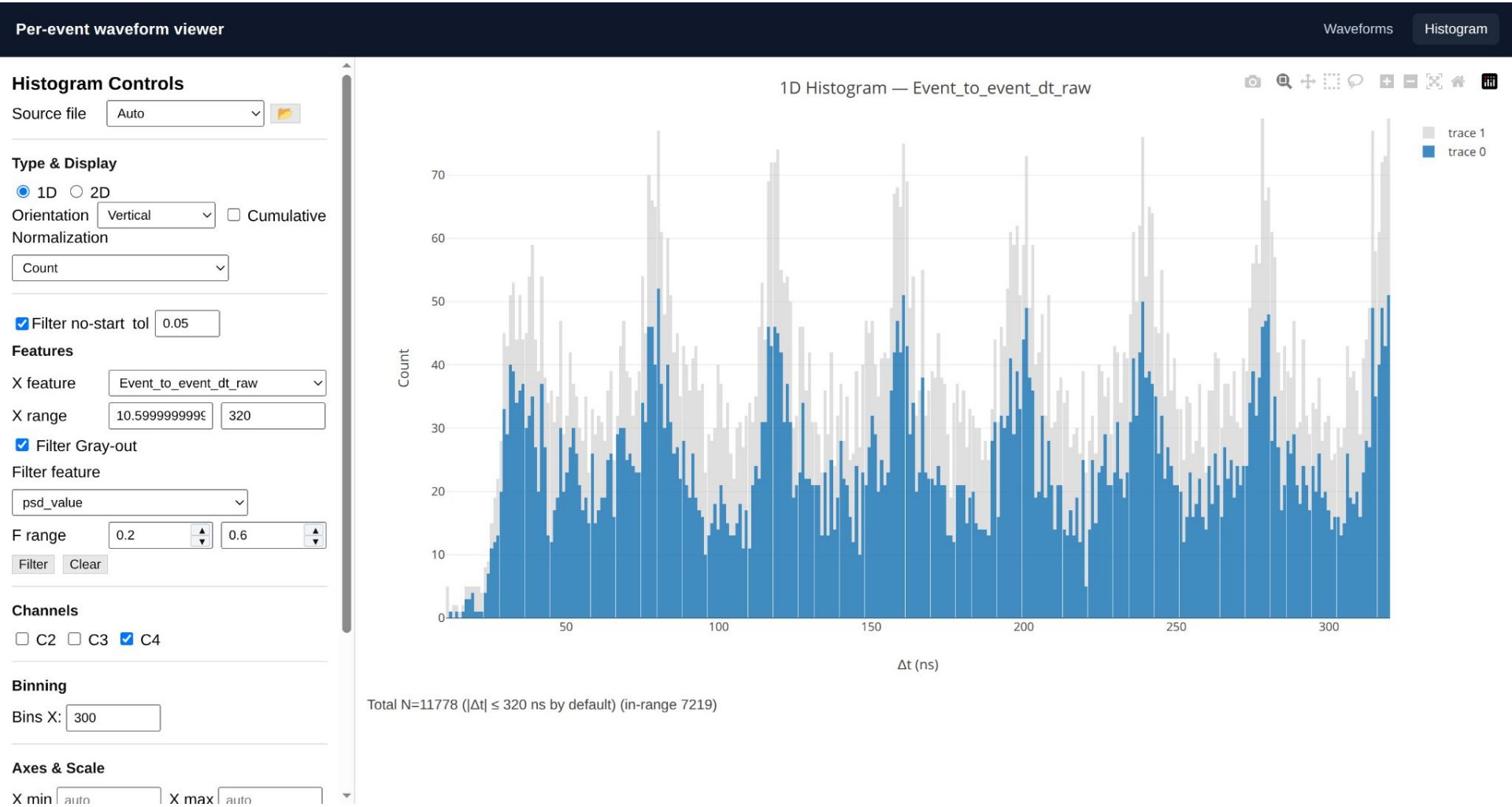
Peak to Peak distances



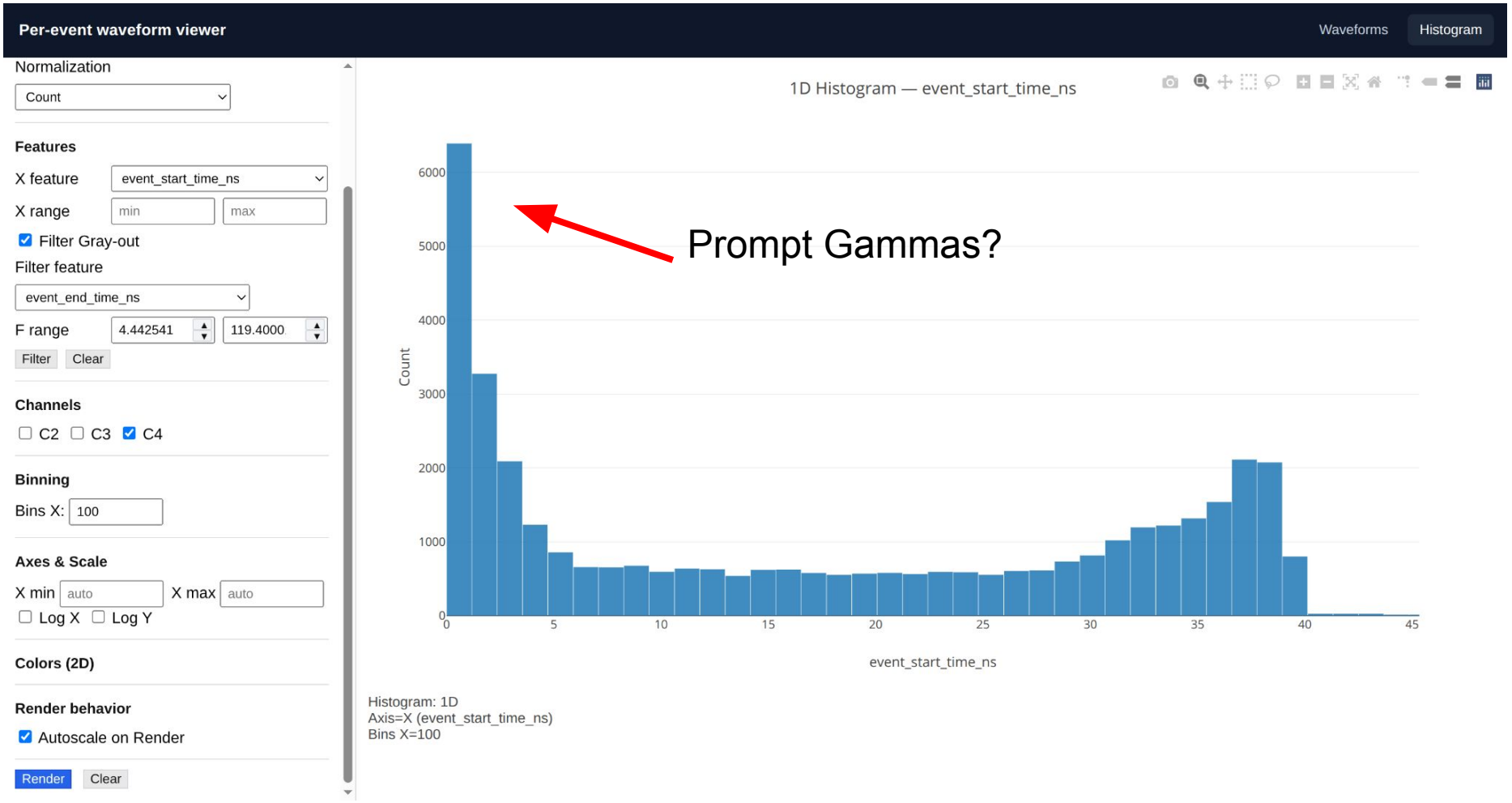
Peak to Peak distances



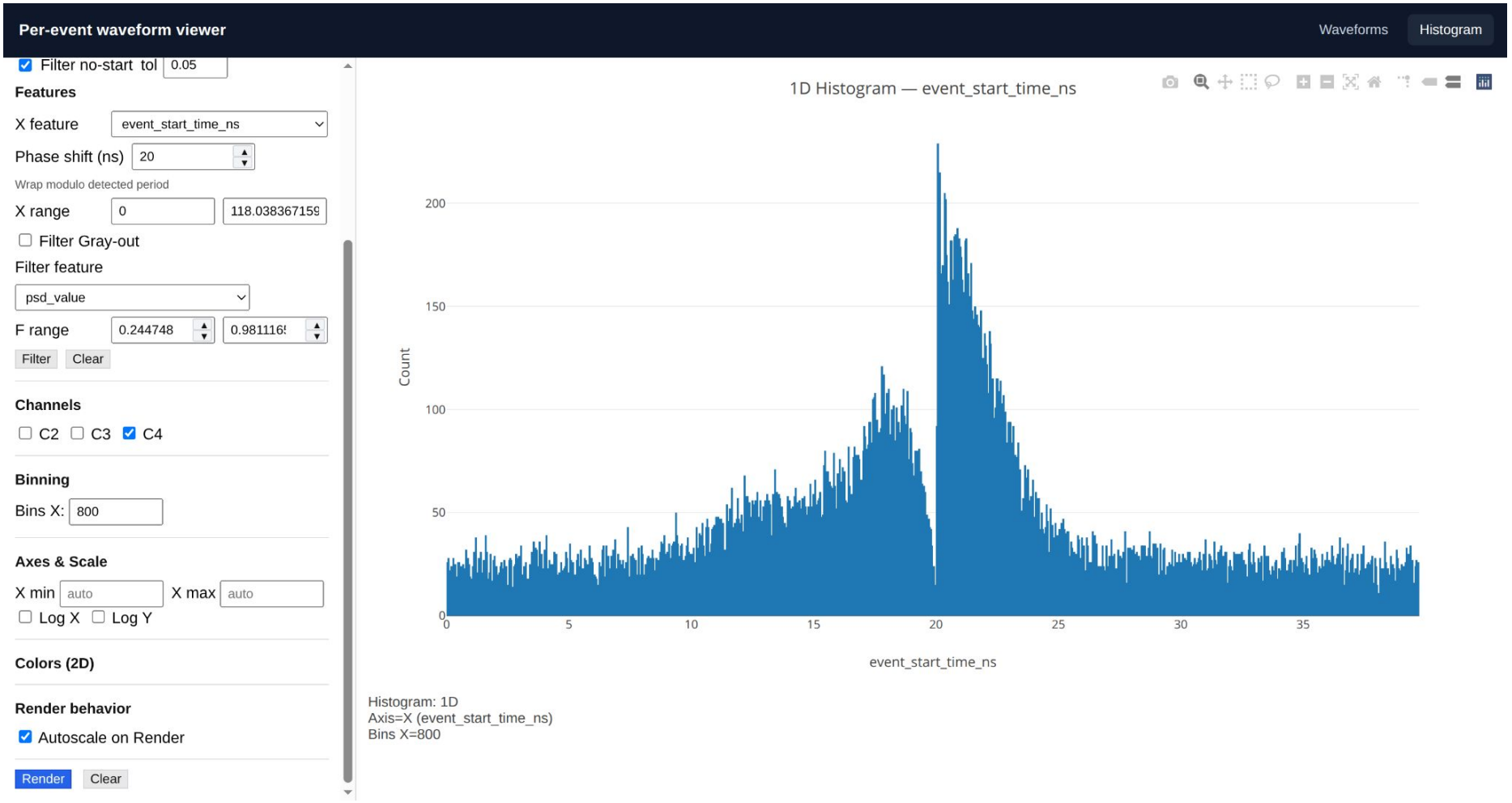
Peak to Peak distances



Histogram Plotting Suite



Histogram Plotting Suite



Per-event waveform viewer Waveforms Histogram

Histogram Controls

Type & Display

○ 1D ◉ 2D

Features

X feature: event_duration_ns

Y feature: psd_value

Channels

☑ C2 ☑ C3 ☑ C4

Binning

Bins X: 800

Bins Y: 800

Axes & Scale

X min: auto X max: auto

Y min: auto Y max: auto

☐ Log X ☐ Log Y

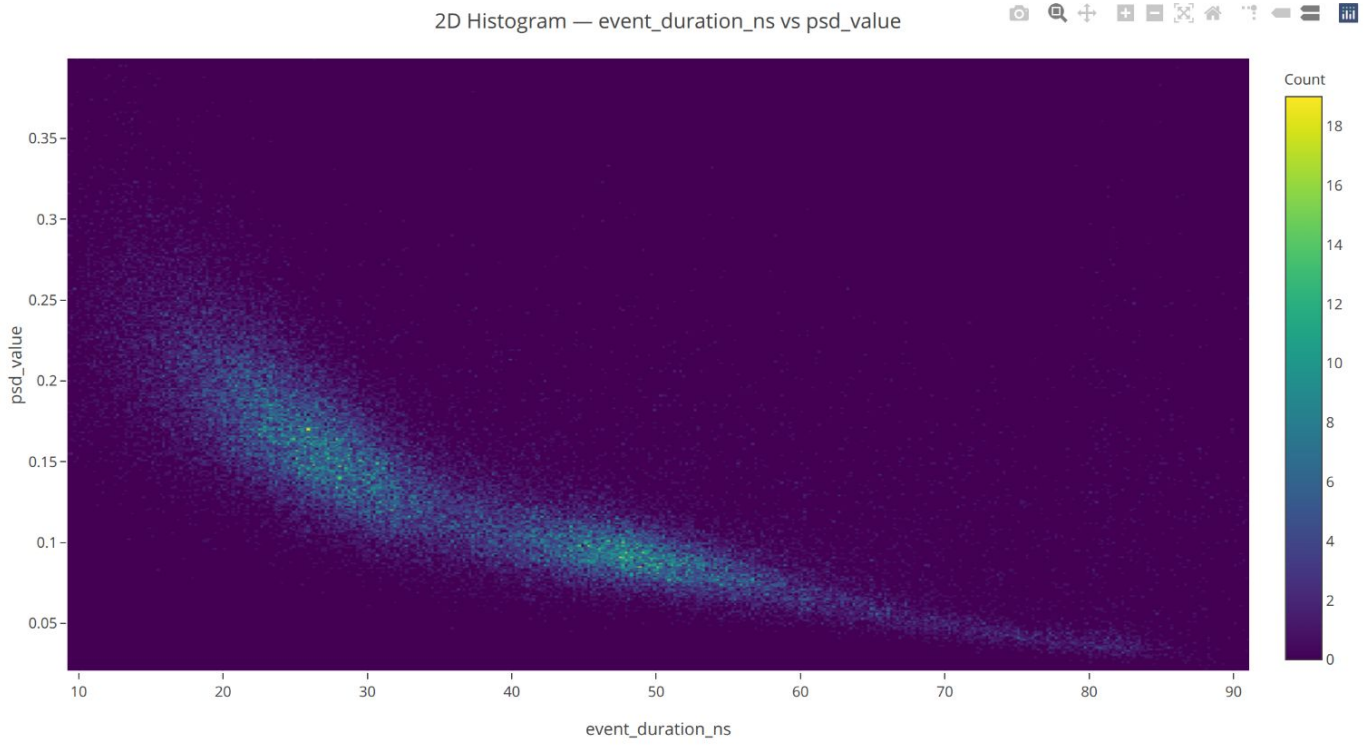
Colors (2D)

Colorscale: Viridis (sequential)

☐ Contours ☐ Reverse

Z min: auto Z max: auto

Render Clear



X N=59319 min=1.312 max=119.350 mean=36.278
Y N=59319 min=0.021 max=0.809 mean=0.139

Per-event waveform viewer Waveforms Histogram

Histogram Controls

Type & Display

○ 1D ◉ 2D

Features

X feature: event_duration_ns

Y feature: psd_value

Channels

☐ C2 ☐ C3 ☑ C4

Binning

Bins X: 800

Bins Y: 800

Axes & Scale

X min: auto X max: auto

Y min: auto Y max: auto

☐ Log X ☐ Log Y

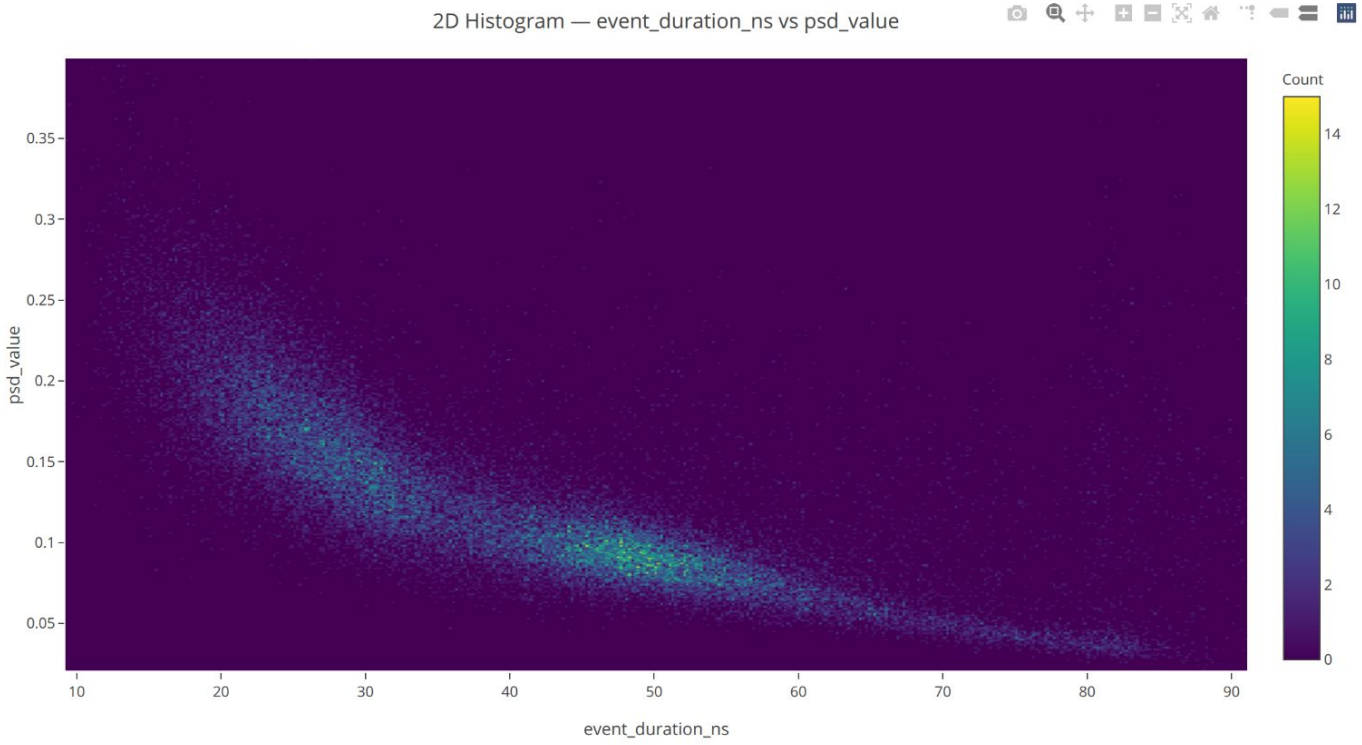
Colors (2D)

Colorscale: Viridis (sequential)

☐ Contours ☐ Reverse

Z min: auto Z max: auto

Render Clear



X N=39657 min=1.312 max=119.350 mean=40.357
Y N=39657 min=0.021 max=0.809 mean=0.128

Per-event waveform viewer Waveforms Histogram

Histogram Controls

Type & Display

1D 2D

Features

X feature: event_duration_ns

Y feature: psd_value

Channels

C2 C3 C4

Binning

Bins X: 800

Bins Y: 800

Axes & Scale

X min: auto X max: auto

Y min: auto Y max: auto

Log X Log Y

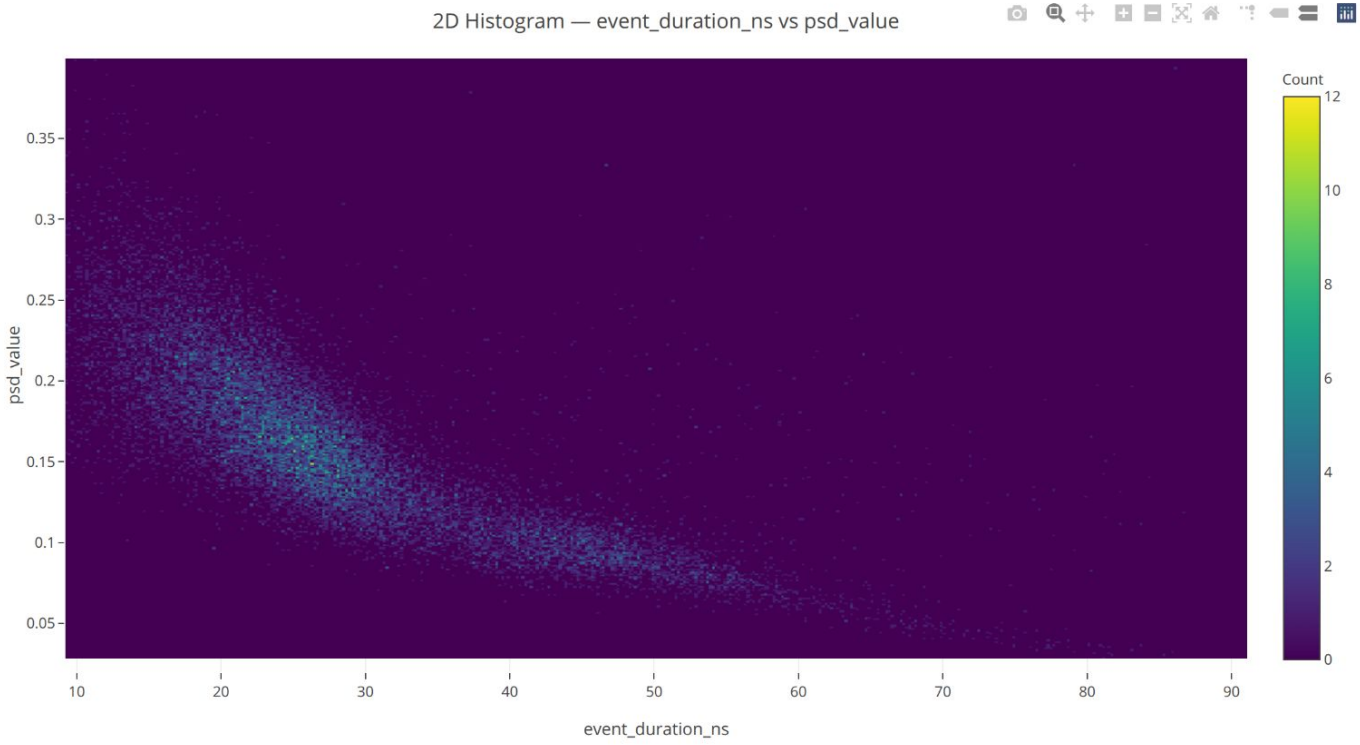
Colors (2D)

Colorscale: Viridis (sequential)

Contours Reverse

Z min: auto Z max: auto

Render Clear



X N=19494 min=1.679 max=98.193 mean=28.113
Y N=19494 min=0.029 max=0.655 mean=0.162

Per-event waveform viewer Waveforms Histogram

Histogram Controls

Type & Display

1D 2D

Features

X feature: qtail_start_time_ns

Y feature: qtotal_mV_ns

Channels

C2 C3 C4

Binning

Bins X: 800

Bins Y: 800

Axes & Scale

X min: auto X max: auto

Y min: auto Y max: auto

Log X Log Y

Autoscale on Render

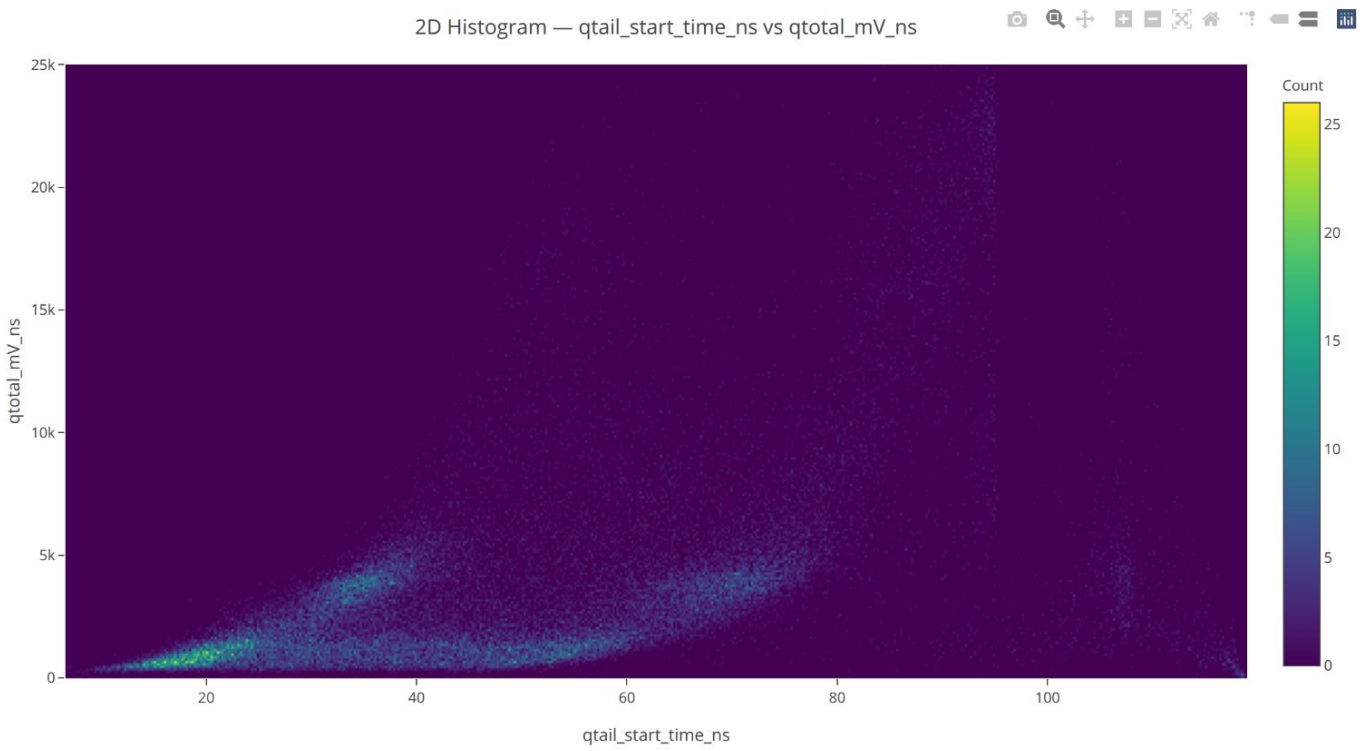
Colors (2D)

Colorscale: Viridis (sequential)

Contours Reverse

Z min: auto Z max: auto

Render Clear



X N=39657 min=6.752 max=118.957 mean=47.617
Y N=39657 min=30.088 max=42873.027 mean=3395.202

Per-event waveform viewer

Waveforms | Histogram

Histogram Controls

Source file: Custom (uploaded)

unsmoothed_simple_cycle_events_summary.csv

Type & Display

1D 2D

Filter no-start tol 0.05

Features

X feature: event_start_time_ns

Phase shift (ns): 20

Wrap modulo detected period

X range: 0 — 118.522375963

Y feature: peak_amplitude_mV

Y range: -1243.5100097 — -49.750801086

Filter feature: trace_number

F range: 1 — 59

Filter | Clear

Channels

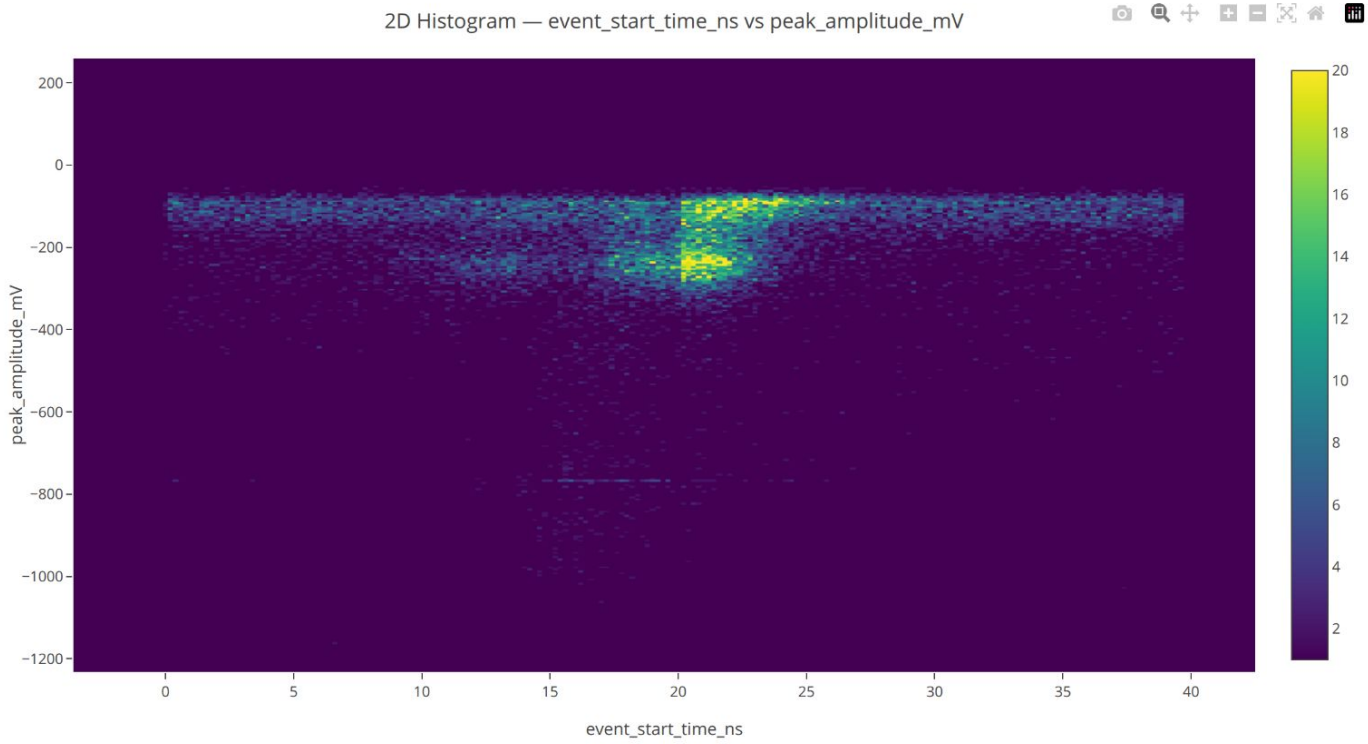
C2 C3 C4

Binning

Bins X: 300

Bins Y: 300

Axes & Scale



X N=38773 min=0.000 max=39.745 mean=19.806
Y N=38773 min=-1243.510 max=-49.751 mean=-208.422

Per-event waveform viewer

Waveforms | Histogram

Y feature: qtail_mV_ns

Y range: 3.47838020443 — 26874.2506607

Filter feature: trace_number

F range: 1 — 59

Filter | Clear

Channels

☐ C2 ☐ C3 ☑ C4

Binning

Bins X: 700

Bins Y: 700

Axes & Scale

X min: auto X max: auto

Y min: auto Y max: auto

☐ Log X ☐ Log Y

Colors (2D)

Colorscale: Viridis (sequential)

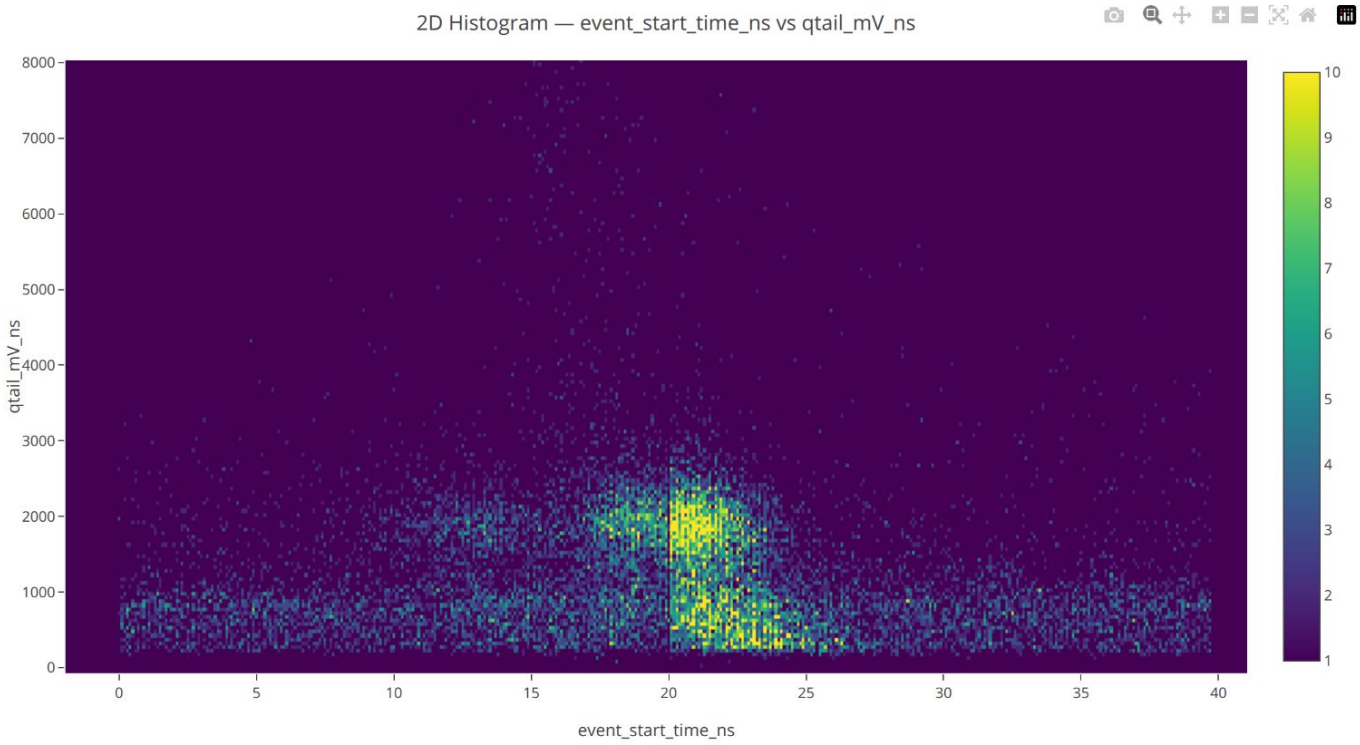
☐ Contours ☐ Reverse

Z min: 1 Z max: 10

Render behavior

☑ Autoscale on Render

Render | Clear



X N=38773 min=0.000 max=39.745 mean=19.806

Y N=38773 min=3.478 max=24377.545 mean=1637.757

Thank you for your attention!

Questions and discussions