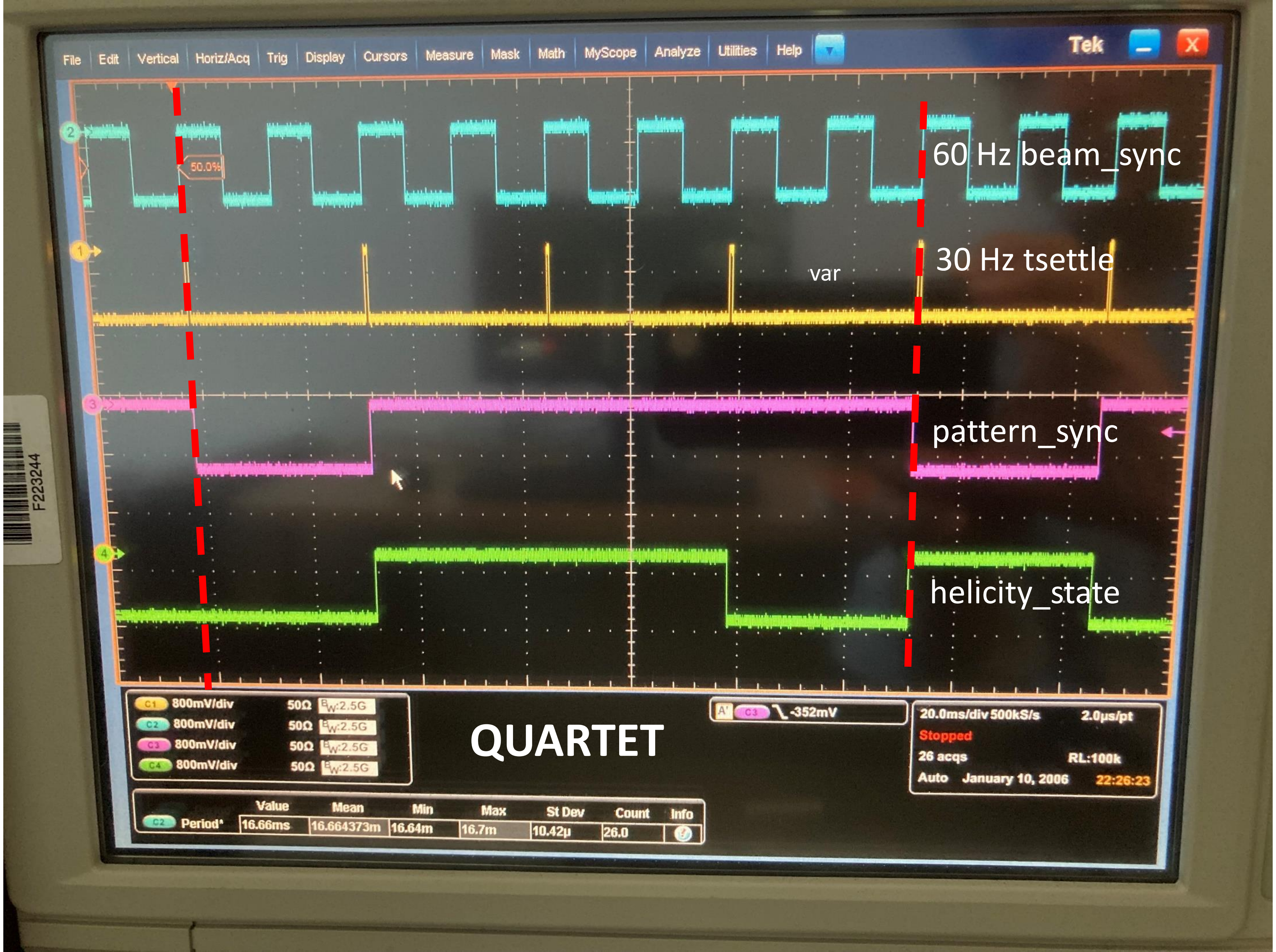
Helicity Generator - Beam Sync Mode

E.J. 12/4/24

- **Helicity Generator module** – 2010 (Roger Flood)

- **Free clock mode** - timing parameters derived from on-board clock (20 MHz)
- Values selected from tables (t_settle: 5 – 1000 µs, t_stable: 240 – 33330 µs)
- Helicity Patterns: toggle, pair, quartet, octet, hex, ocq, m64, 16q, 32p (some added recently)
- Mode successfully used since board deployment

- **Beam Sync mode** - Start of Helicity patterns are synchronized to the 60 Hz AC (zero crossing)
- t_settle frequency selected as **30**, **120**, or **240 Hz**
- t_settle value can be chosen as for free clock mode
- t_stable value determined by t_settle frequency and value
- Toggle, Pair, Quartet patterns only
- Duration of *last* window of pattern adjusted to ensure phase alignment with 60 Hz signal
- Mode did not function as planned – now fixed



60 Hz beam_sync

30 Hz tsettle

var

pattern_sync

helicity_state

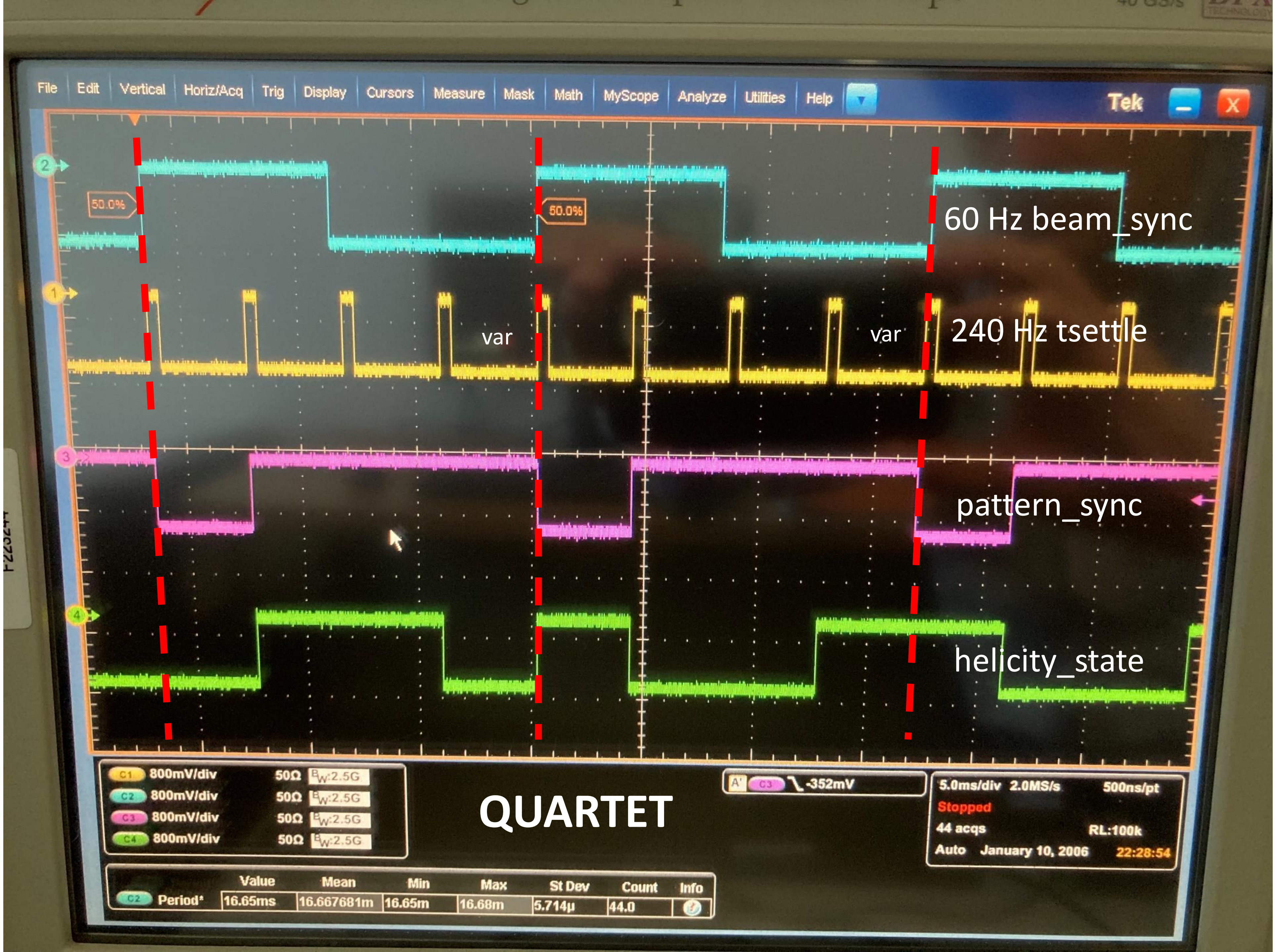
QUARTET

C1 800mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

A' C3 ╲ -352mV

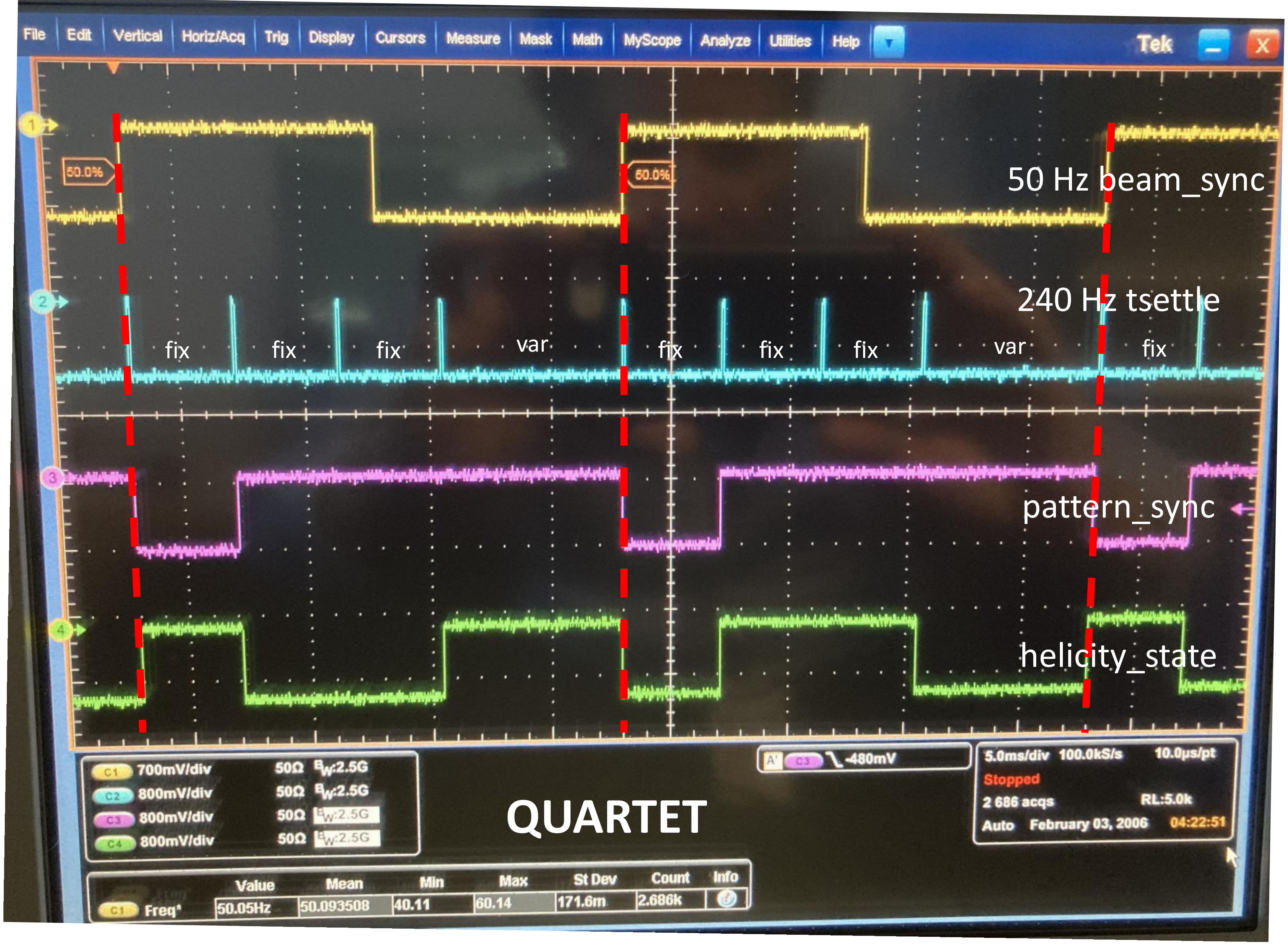
20.0ms/div 500kS/s 2.0µs/pt
Stopped
26 acqs RL:100k
Auto January 10, 2006 22:26:23

	Value	Mean	Min	Max	St Dev	Count	Info
C2 Period*	16.66ms	16.664373m	16.64m	16.7m	10.42µ	26.0	



QUARTET

	Value	Mean	Min	Max	St Dev	Count	Info
C2 Period*	16.65ms	16.667681m	16.65m	16.68m	5.714µ	44.0	



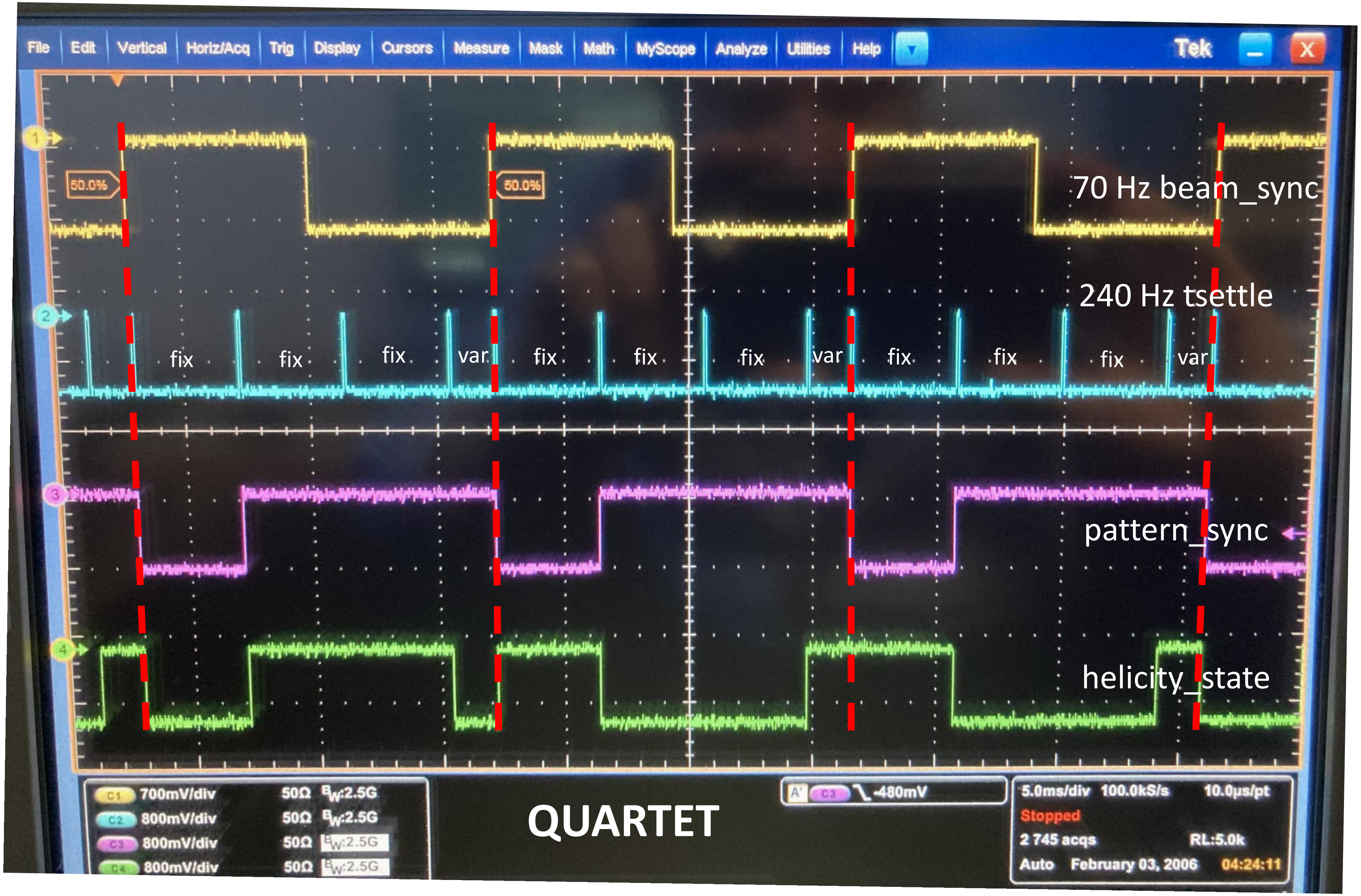
C1 700mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

QUARTET

A' C3 ╲ -480mV

5.0ms/div 100.0kS/s 10.0μs/pt
Stopped
2 686 acqs RL:5.0k
Auto February 03, 2006 04:22:51

	Value	Mean	Min	Max	St Dev	Count	Info
C1 Freq*	50.05Hz	50.093508	40.11	60.14	171.6m	2.686k	



70 Hz beam_sync

240 Hz tsettle

pattern_sync

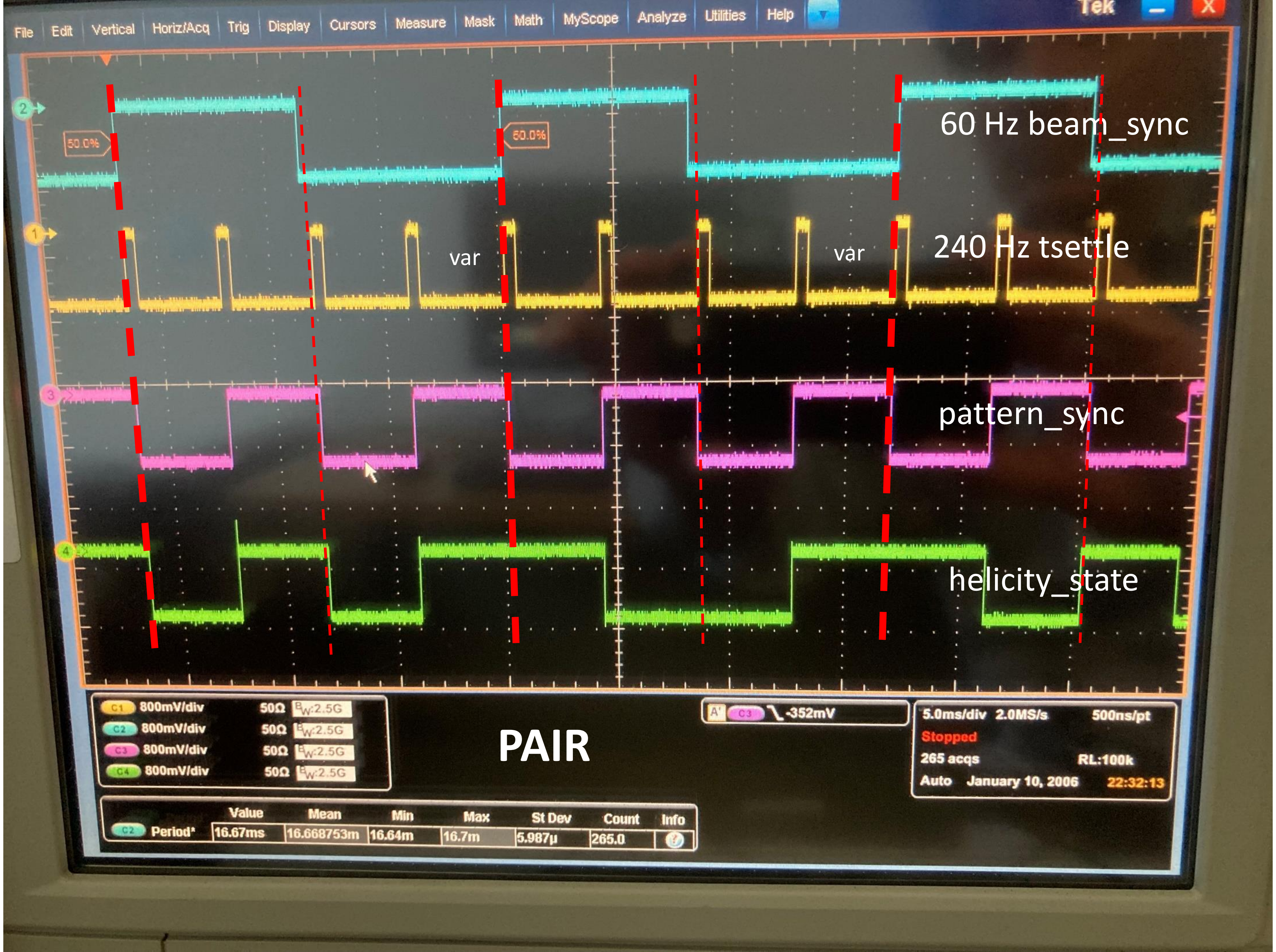
helicity_state

QUARTET

C1 700mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

A' C3 ╲ -480mV

5.0ms/div 100.0kS/s 10.0µs/pt
Stopped
2 745 acqs RL:5.0k
Auto February 03, 2006 04:24:11

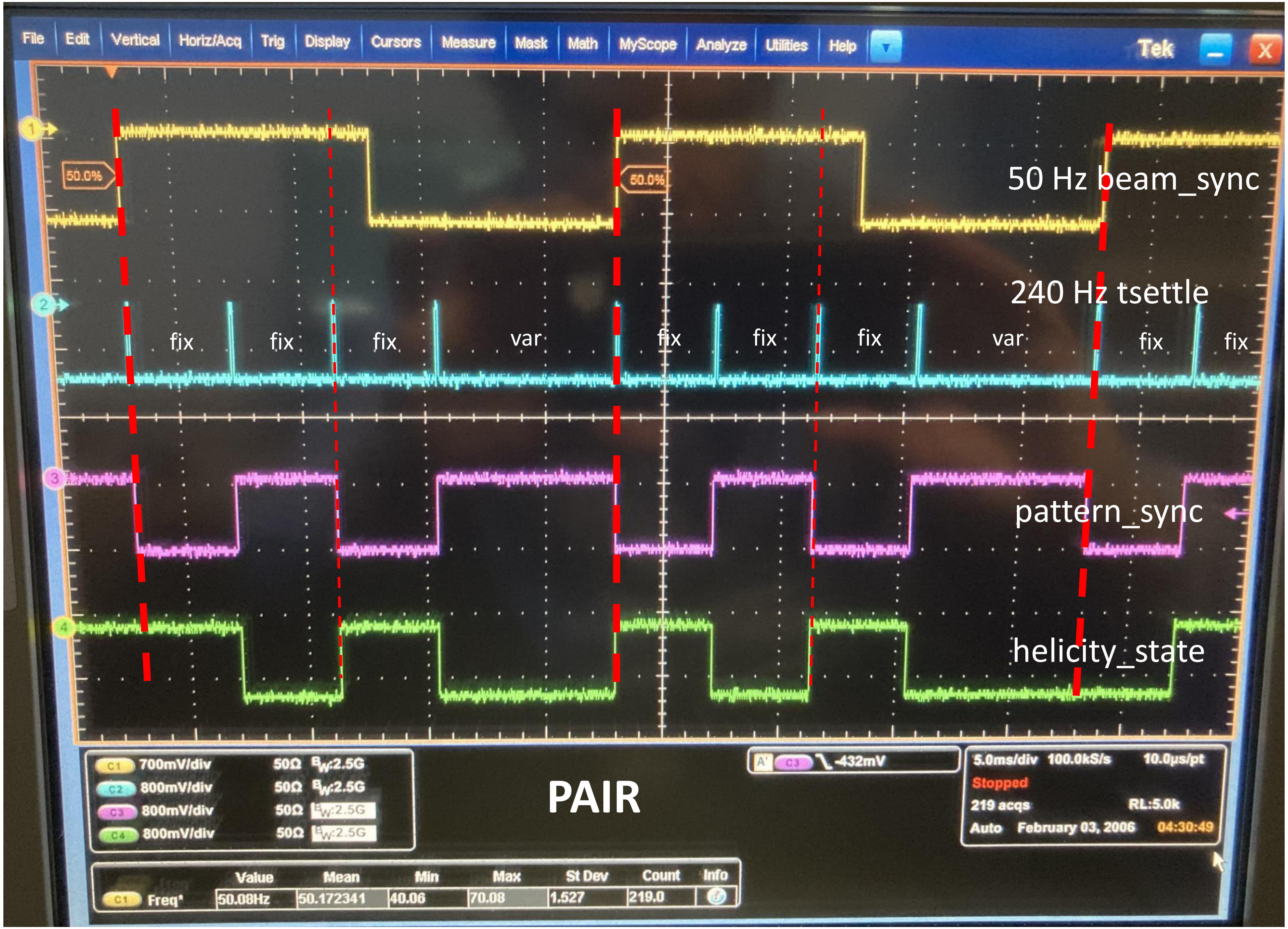


C1 800mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

A' C3 ╲ -352mV

5.0ms/div 2.0MS/s 500ns/pt
Stopped
265 acqs RL:100k
Auto January 10, 2006 22:32:13

	Value	Mean	Min	Max	St Dev	Count	Info
C2 Period*	16.67ms	16.668753m	16.64m	16.7m	5.987µ	265.0	

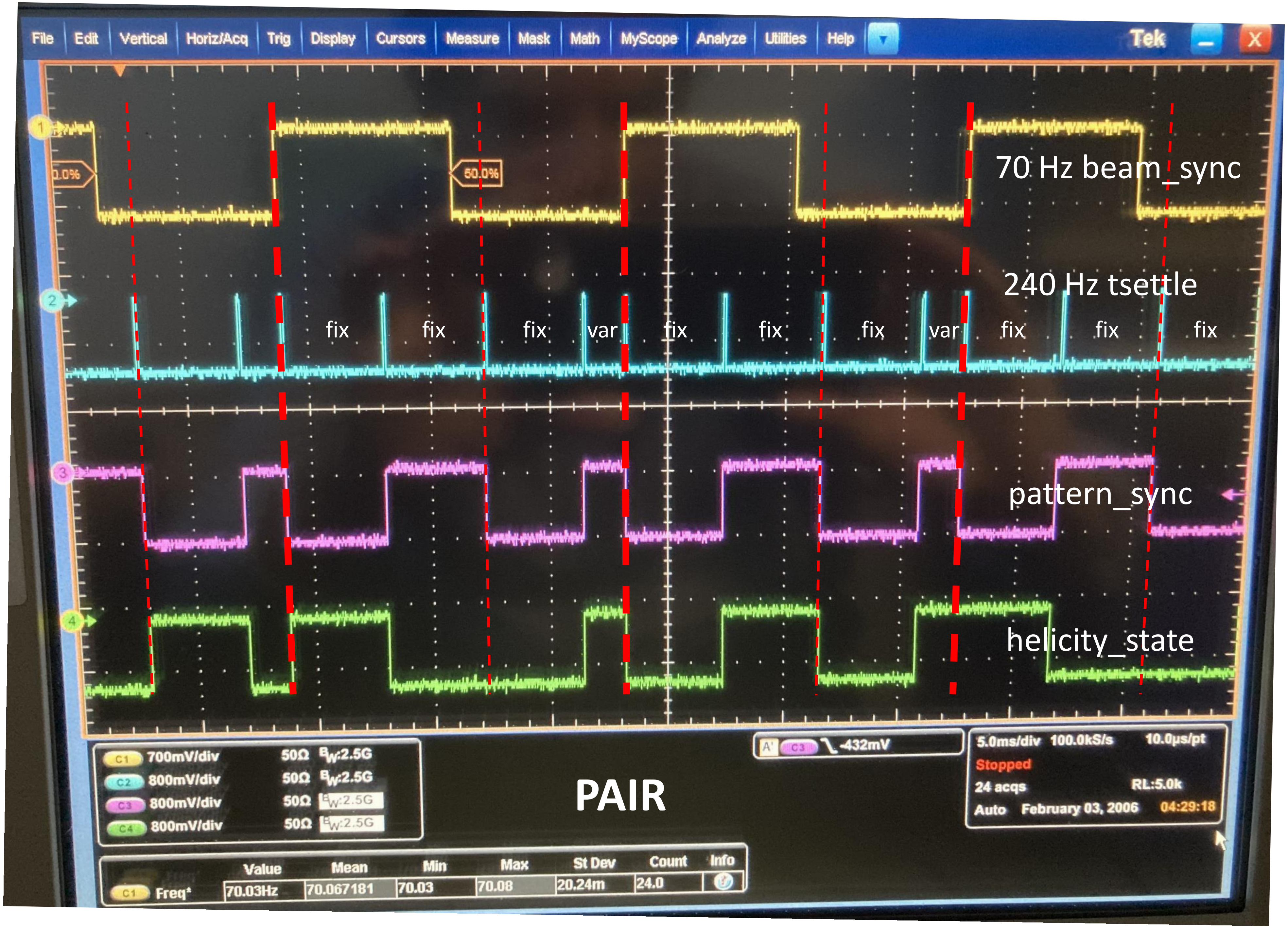


C1 700mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

A' C3 ⌊ -432mV

5.0ms/div 100.0kS/s 10.0μs/pt
Stopped
219 acqs RL:5.0k
Auto February 03, 2006 04:30:49

	Value	Mean	Min	Max	St Dev	Count	Info
C1 Freq*	50.08Hz	50.172341	40.06	70.08	1.527	219.0	



PAIR

C1 700mV/div 50Ω BW:2.5G
C2 800mV/div 50Ω BW:2.5G
C3 800mV/div 50Ω BW:2.5G
C4 800mV/div 50Ω BW:2.5G

A' C3 ⌈ -432mV

5.0ms/div 100.0kS/s 10.0µs/pt
Stopped
24 acqs RL:5.0k
Auto February 03, 2006 04:29:18

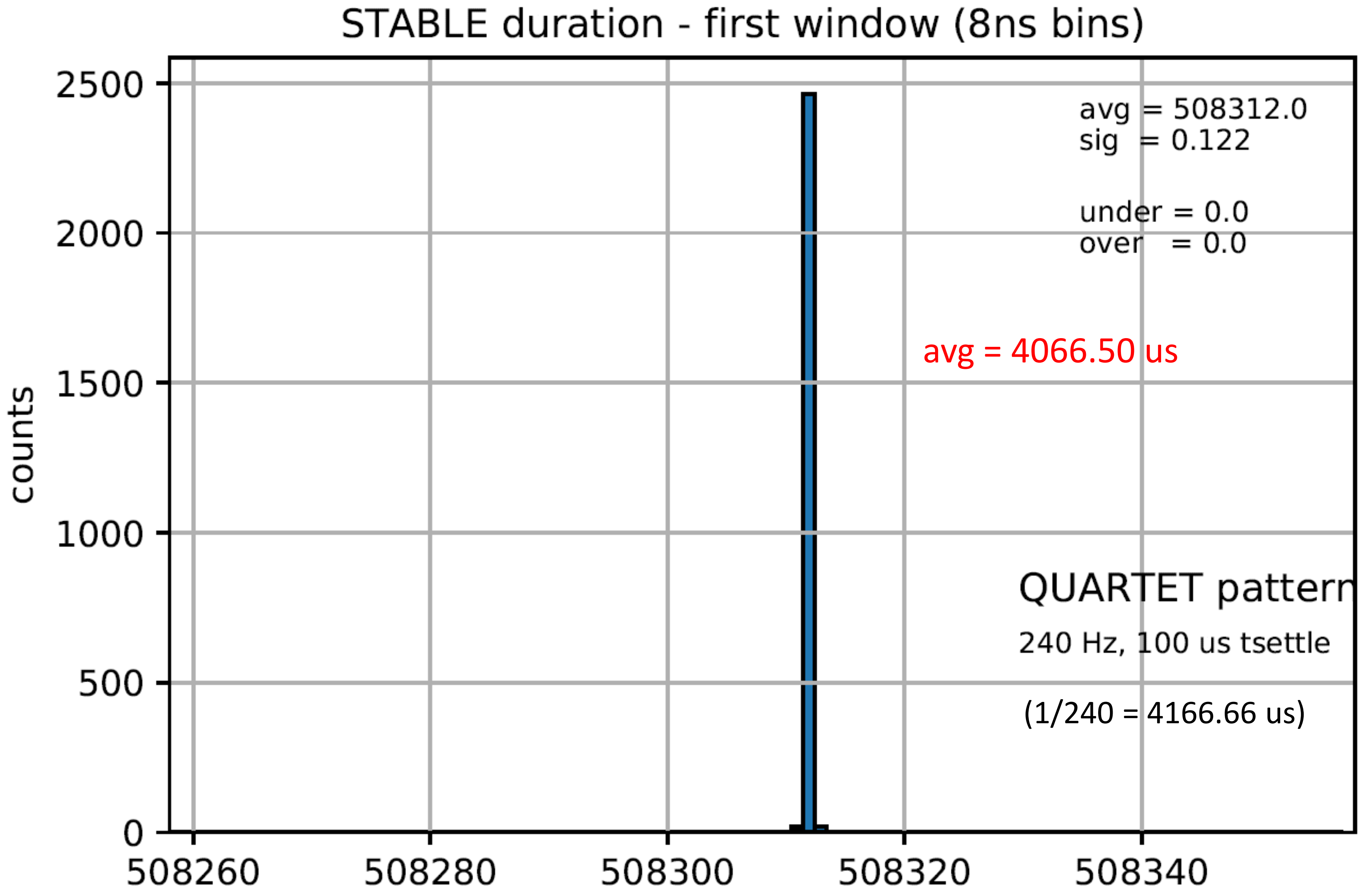
	Value	Mean	Min	Max	St Dev	Count	Info
C1 Freq	70.03Hz	70.067181	70.03	70.08	20.24m	24.0	

Helicity Decoder – 2024 (EJ, JW; data specifications by Paul King)

- High-performance VXS data acquisition board to record Helicity signals (t_stable, pattern_sync, pair_sync, helicity_ state) at trigger time
- Uses experiment system clock (250 MHz) or internal clock (for stand-alone use)
- Supports event blocking and high-speed readout (200 MB/s)
- Programmable trigger latency
- Programmable delay of Helicity signals to account for transport delays from source
- Records at time of trigger (adjusted for latency) :
  - states of 4 Helicity signals
  - time of trigger from start of t_stable period
  - time of trigger from end of t_stable period
  - **time of duration of last complete t_stable period** ********
  - time of duration of last complete t_settle period
  - counts of rising and falling edges of t_stable, pattern_sync, pair_sync
  - last 32 windows of pattern_sync
  - last 32 windows of pair_sync
  - last 32 windows of helicity state
  - last 32 windows of helicity_state at pattern_sync
  - recovered helicity seed from last 30 helicity_state values at pattern_sync

- To study the Beam Sync mode in greater detail Helicity Generator data was recorded using the Helicity Decoder in *test mode.*
- In *test mode* the Decoder records helicity data after the start of each Stable period.
- Data is recorded once per helicity window; the entire helicity sequence can be reconstructed.
- The Decoder measures the duration of each Stable period so we can check if the *last* window of the helicity pattern has variable duration consistent with expected variation in the 60 Hz Beam Sync signal.
- Similarly we can check that helicity windows that are *not* the last of the pattern have fixed duration.

Figure A



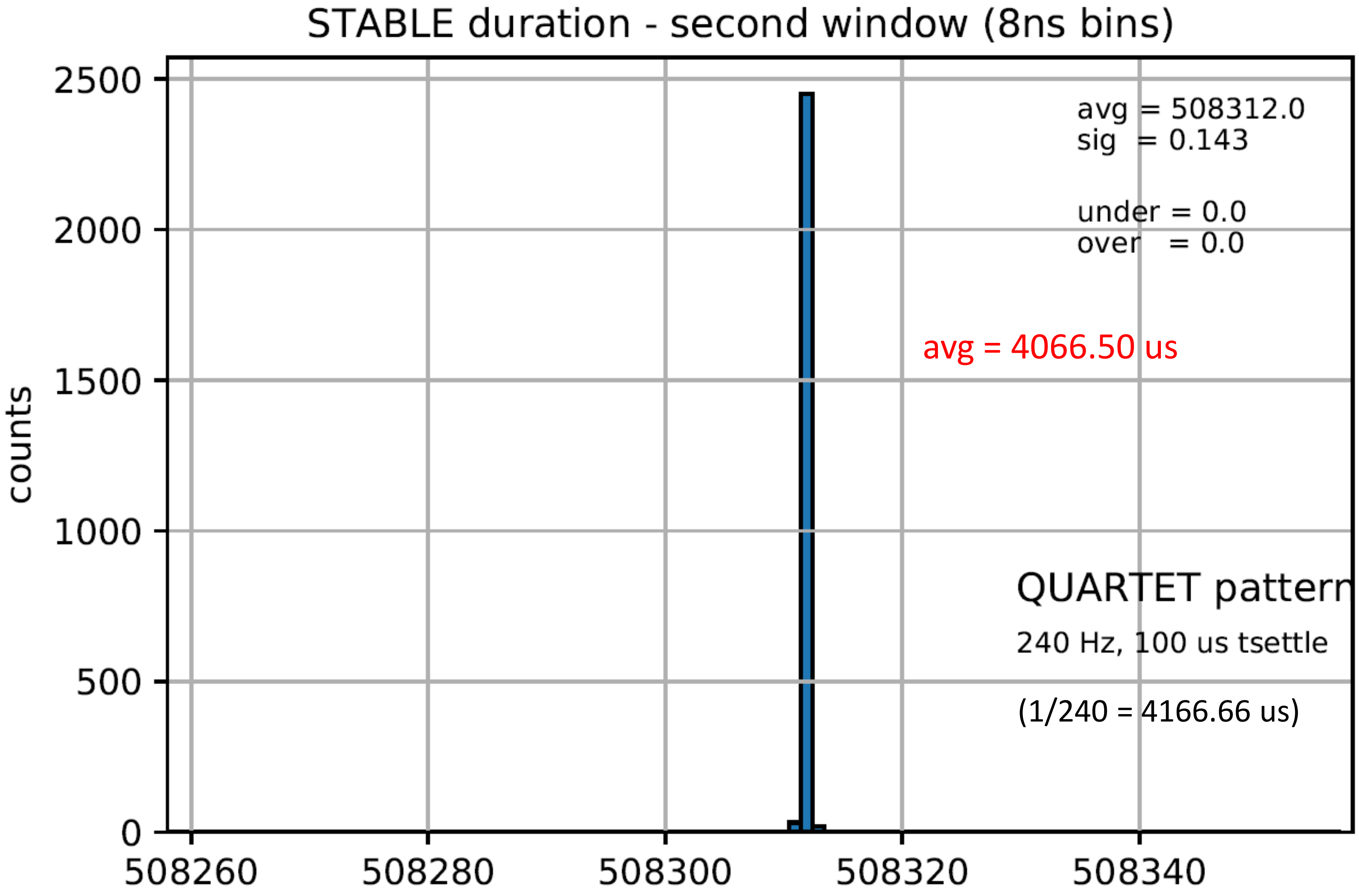
avg = 4066.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure B



STABLE duration - second window (8ns bins)

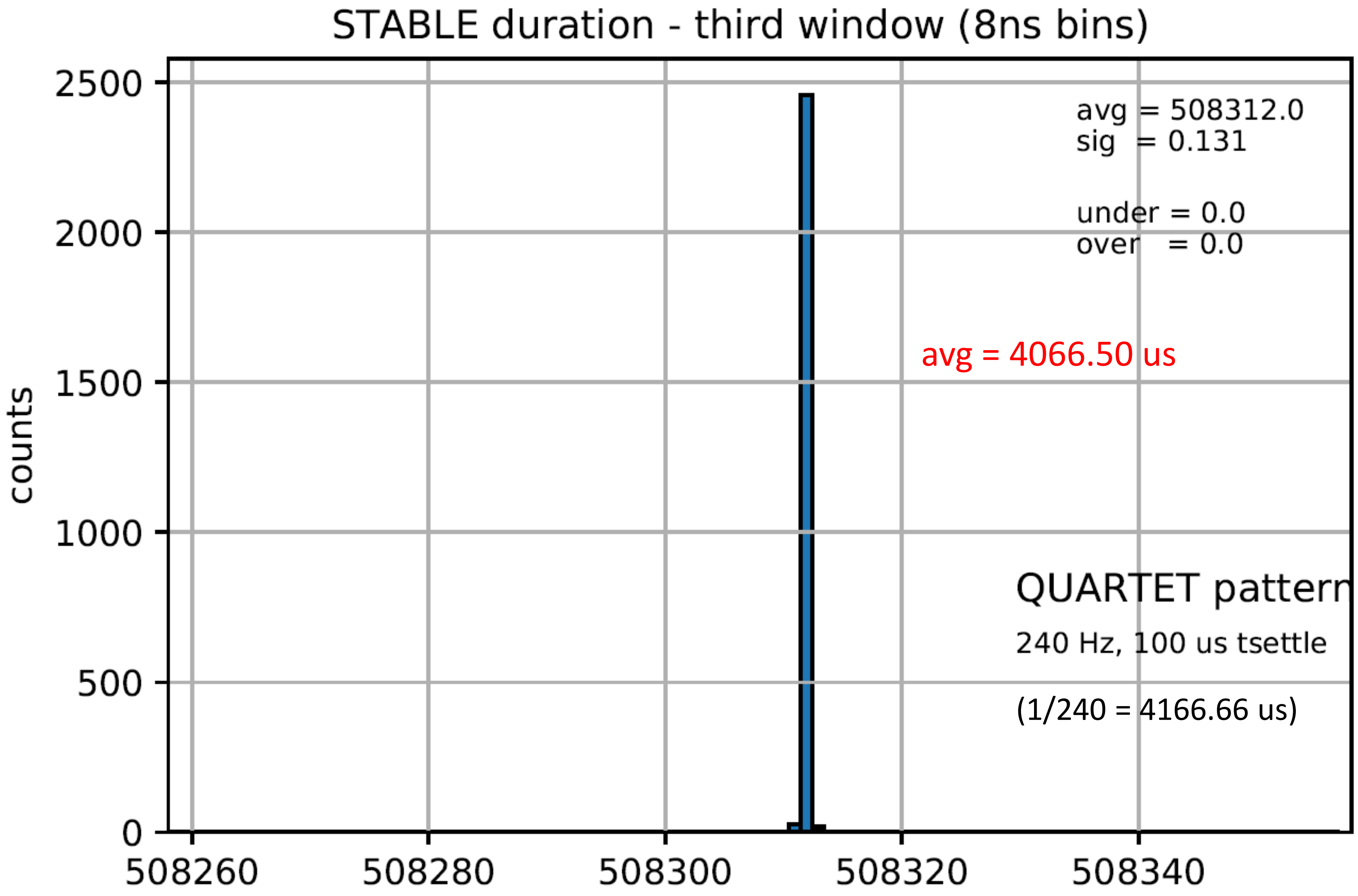
avg = 4066.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure C



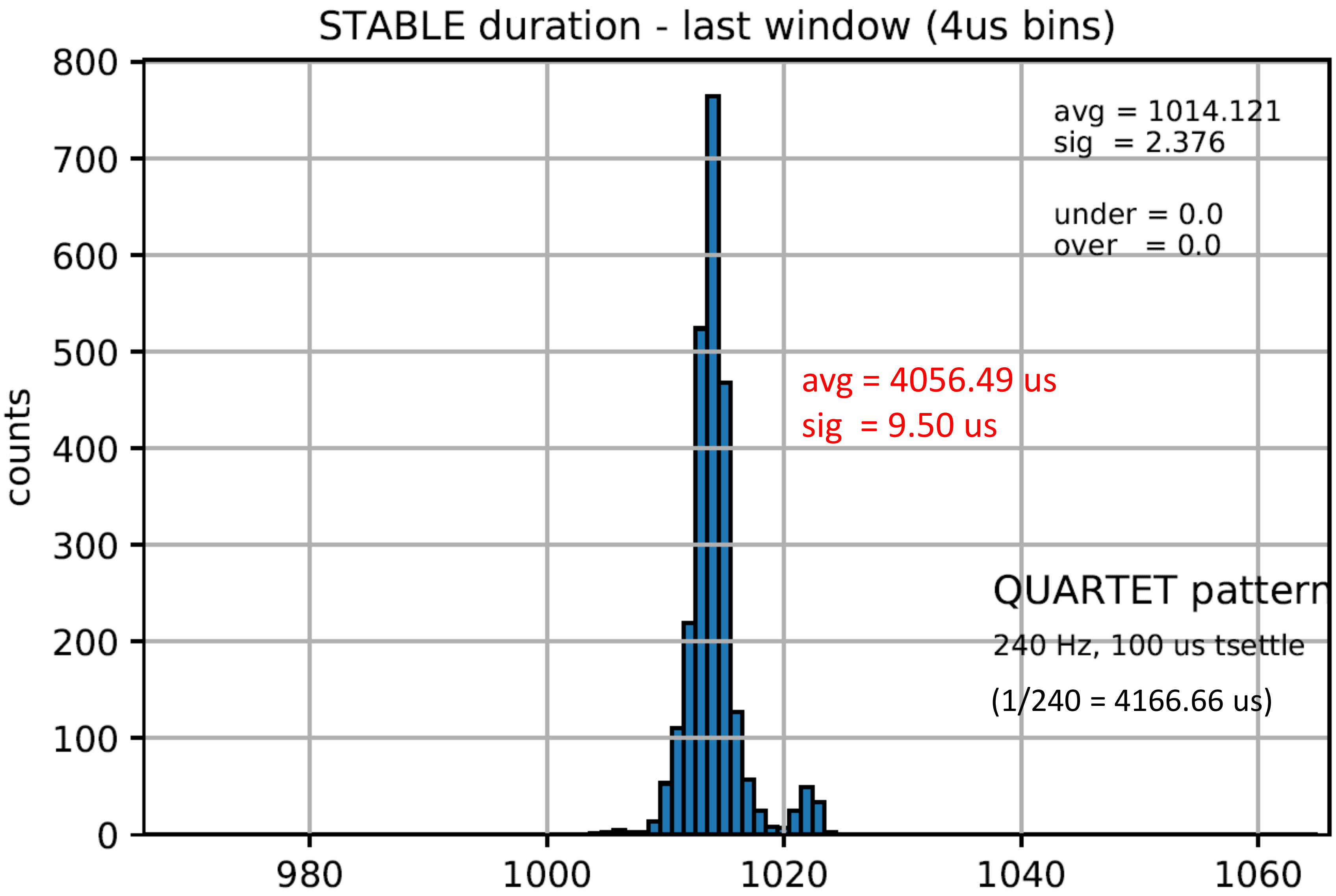
avg = 4066.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure D



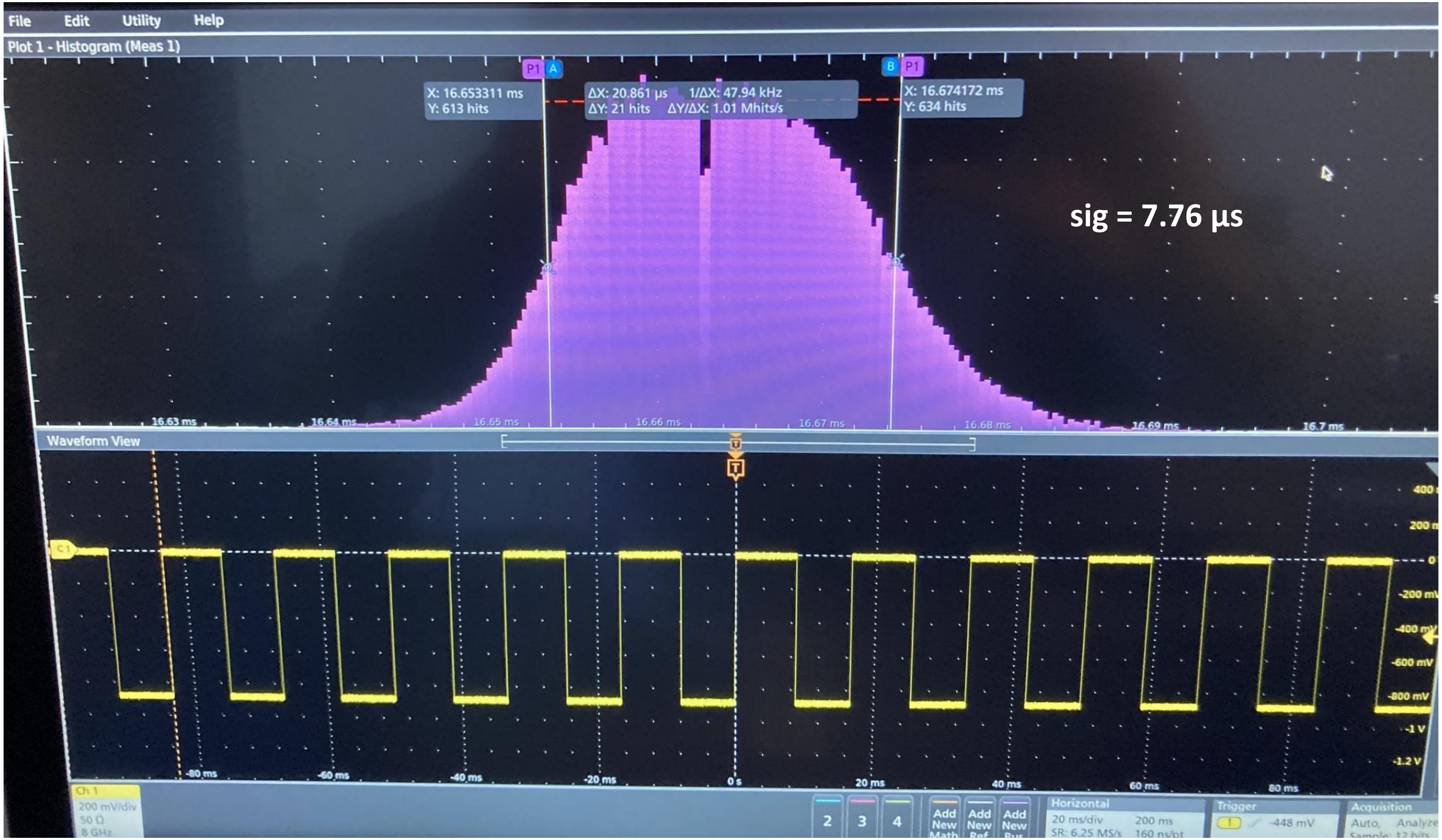
avg = 4056.49 us
sig = 9.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Measurement of jitter from 60 Hz Line Synchronization Box



X: 16.653311 ms
Y: 613 hits

ΔX: 20.861 µs 1/ΔX: 47.94 kHz
ΔY: 21 hits ΔY/ΔX: 1.01 Mhits/s

X: 16.674172 ms
Y: 634 hits

Ch 1
200 mV/div
50 Ω
8 GHz

Horizontal
20 ms/div 200 ms
SR: 6.25 MS/s 160 ns/pt

Trigger
1 -448 mV

Acquisition
Auto, Analyze
Sample: 12 bits

sig = 7.76 µs

(with help
from W. Gu)

A Comprehensive Study of the Beam Sync Mode

E.J. (updated 12/4/24)

- Helicity Generator data in all Beam Sync modes was recorded using the Helicity Decoder in *test mode.*
- Generator: **30**, **120**, **240 Hz** tsettle frequency; **Quartet**, **Pair**, **Toggle** patterns; 100 us tsettle duration.
- In *test mode* the Decoder records helicity data after the start of each Stable period.
- Data is recorded once per helicity window; the entire helicity sequence can be reconstructed.
- The Decoder also measures the duration of each Stable period so we can check if the *last* window of the helicity pattern has variable duration consistent with expected variation in the 60 Hz Beam Sync signal.
- Similarly we can check that helicity windows that are *not* the last of the pattern have fixed duration.
- **Figures 1 – 12** show the measured distributions of Stable duration for the **Quartet** pattern for tsettle frequencies of **30, 120,** and **240 Hz**. The first three of four windows have a fixed Stable duration as expected. The last window has a variable Stable duration due to phase locking to the 60 Hz signal. It is interesting to note that the amount of variation in Stable duration depends on tsettle frequency.
- **Figures 13 – 16** show the measured distributions of Stable duration for the **Pair** pattern for tsettle frequencies of **30** and **120 Hz**. The first window has a fixed Stable duration as expected. The last window has a variable Stable duration. The amount of variation in Stable duration depends on tsettle frequency.
- **Figures 20 – 23** show the measured distributions of Stable duration for the **Toggle** pattern for tsettle frequencies of **30** and **120 Hz**. The first window has a fixed Stable duration as expected. The last window has a variable Stable duration. The amount of variation in Stable duration depends on tsettle frequency.

- At the higher tsettle frequency of **240 Hz** the **Pair** and **Toggle** patterns behave differently. Four helicity windows fit into a single 60 Hz period. Because these patterns have only two windows each, *phase locking to the 60 Hz signal will occur every two patterns.* One pattern will have a fixed Stable duration for both windows (fixed pattern). The *next* pattern will have a last window with variable Stable duration due to phase locking to the 60 Hz signal (variable pattern)
- To study this situation each Helicity *pattern* is assigned a count and the data is divided into *even* and *odd* sets. If a fixed pattern is tagged as *even*, all fixed patterns should be *even* and all *odd* patterns should be variable. Conversely, if a fixed pattern is tagged as *odd*, all fixed patterns should be *odd* and all *even* patterns should be variable. The actual *even* or *odd* assignment is only used as an analysis tool.
- **Figures 17 – 19** show the measured distributions of Stable duration for the **Pair** pattern with a tsettle frequency of **240 Hz**. The first window of all **Pair** patterns has fixed duration. All *odd* numbered **Pair** patterns have both windows of fixed duration. All *even* numbered **Pair** patterns have a last window of variable duration.
- **Figures 24 – 26** show the measured distributions of Stable duration for the **Toggle** pattern with a tsettle frequency of **240 Hz**. The first window of all **Toggle** patterns have fixed duration. All *odd* numbered **Toggle** patterns have both windows of fixed duration. All *even* numbered **Toggle** patterns have a last window of variable duration.

- The following Table summarizes the variation in Stable duration (column 3) as a function of pattern and tsettle frequency. All runs have 10K Helicity windows which explains the differences in Run Time and Number of Measurements.

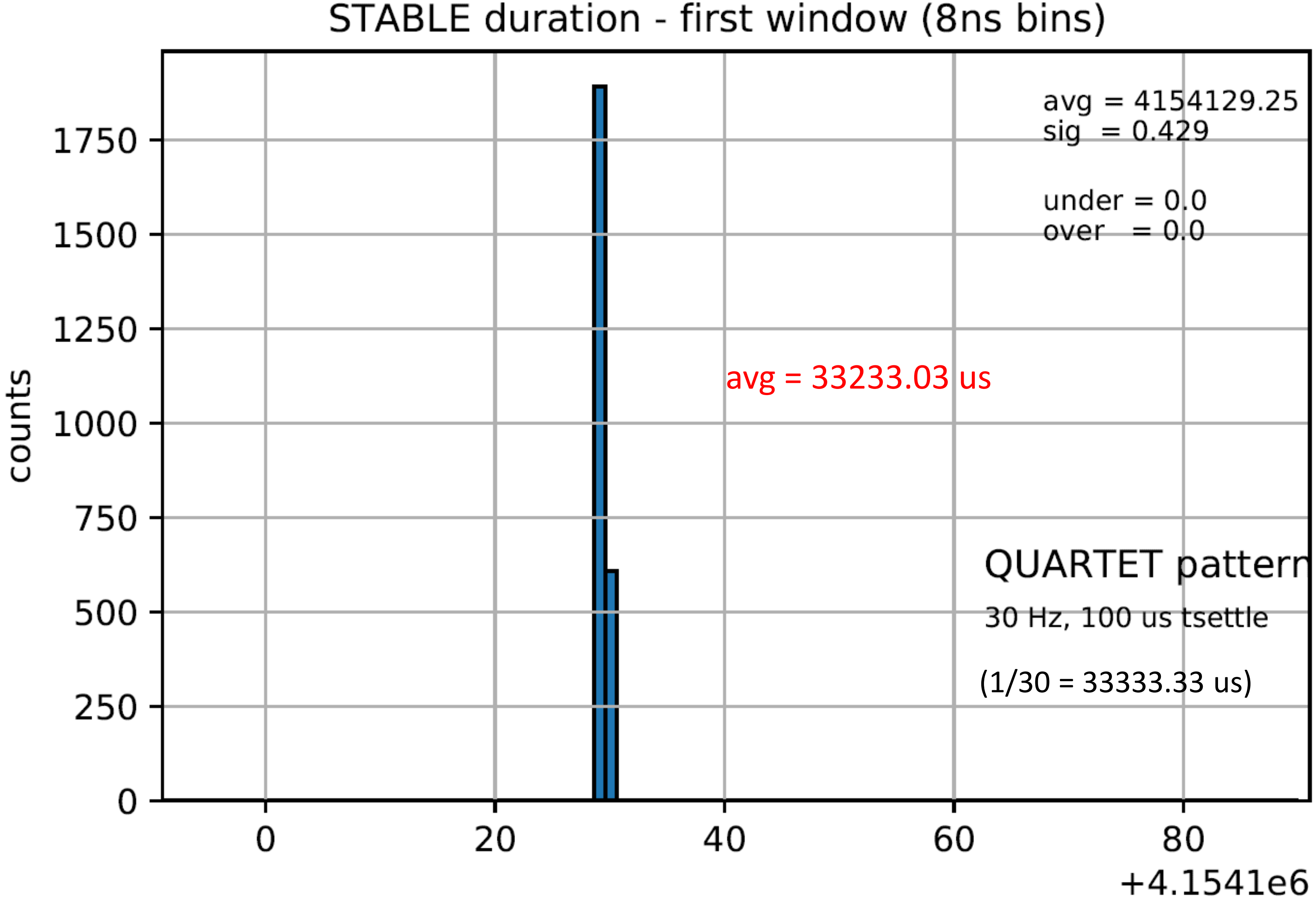
pattern	tsettle frequency (Hz)	sigma (last window) (µs)	Number of 60 Hz periods in pattern	Run time (seconds)	Number of Measurements
QUARTET	30	27.82	8	333.333	2500
	120	9.79	2	83.333	2500
	240	9.50	1	41.666	2500
PAIR	30	20.33	4	333.333	5000
	120	8.52	1	83.333	5000
	240	9.29	0.5	41.666	5000
TOGGLE	30	14.54	4	333.333	5000
	120	8.41	1	83.333	5000
	240	8.49	0.5	41.666	5000

- Column 4 in the Table shows the number of 60 Hz periods within the pattern. For the **240 Hz Quartet**, **120 Hz Pair**, and **120 Hz Toggle** patterns we are measuring the cycle to cycle jitter in the 60 Hz signal. This is not true for the other cycles. For example, the **30 Hz Quartet** is measuring the variation in the 60 Hz signal **eight** periods apart.

- If the jitter in the 60 Hz Beam Sync signal from the Line Synchronization box was truly random and the average 60 Hz frequency was stable over the run, the results in column 3 should be the same. The measurements suggest non-random components in the 60 Hz signal.
- --
- The structure of the 60 Hz signal can be investigated by plotting consecutive measurements of Stable duration from the **120 Hz Pair**, **240 Hz Quartet**, or **120 Hz Toggle** data. Each of these contain exactly **one** 60 Hz period in the pattern, so the variation measurements of 60 Hz are cycle to cycle.
- **Figure 27** shows the first 160 measurements from the **120 Hz Pair** mode run. A periodic structure is clearly visible in the 60 Hz signal.
- **Figure 28** shows measurements from the **120 Hz Pair** mode for several 8.3 second intervals across the run. A slow shift in the average is visible which increases the measured variation (sigma) in Stable duration. Note that the entire run is **83 seconds** long.
- --
- **Figure 29** shows measurements from the entire **30 Hz Quartet** mode run. Large variations in the average are apparent (~100µs => 0.6% of 60 Hz period). This results in the large **27.8 µs** sigma detected in the Stable duration. Note that this run is **333 seconds** long (**4x** the **120 Hz Pair** mode). A longer run is more likely to detect such an excursion in the average value of the 60 Hz period.

- The 60 Hz Beam Sync signal from the Line Synchronization box was replaced by a HP pulse generator signal of 60 Hz frequency.
- **Figure 30** and **Figure 31** show the Stable duration of the last window of the Quartet pattern for 30 Hz and 240 Hz tsettle frequencies. As expected, the variation is significantly less than that of the Line Synchronization box signal.

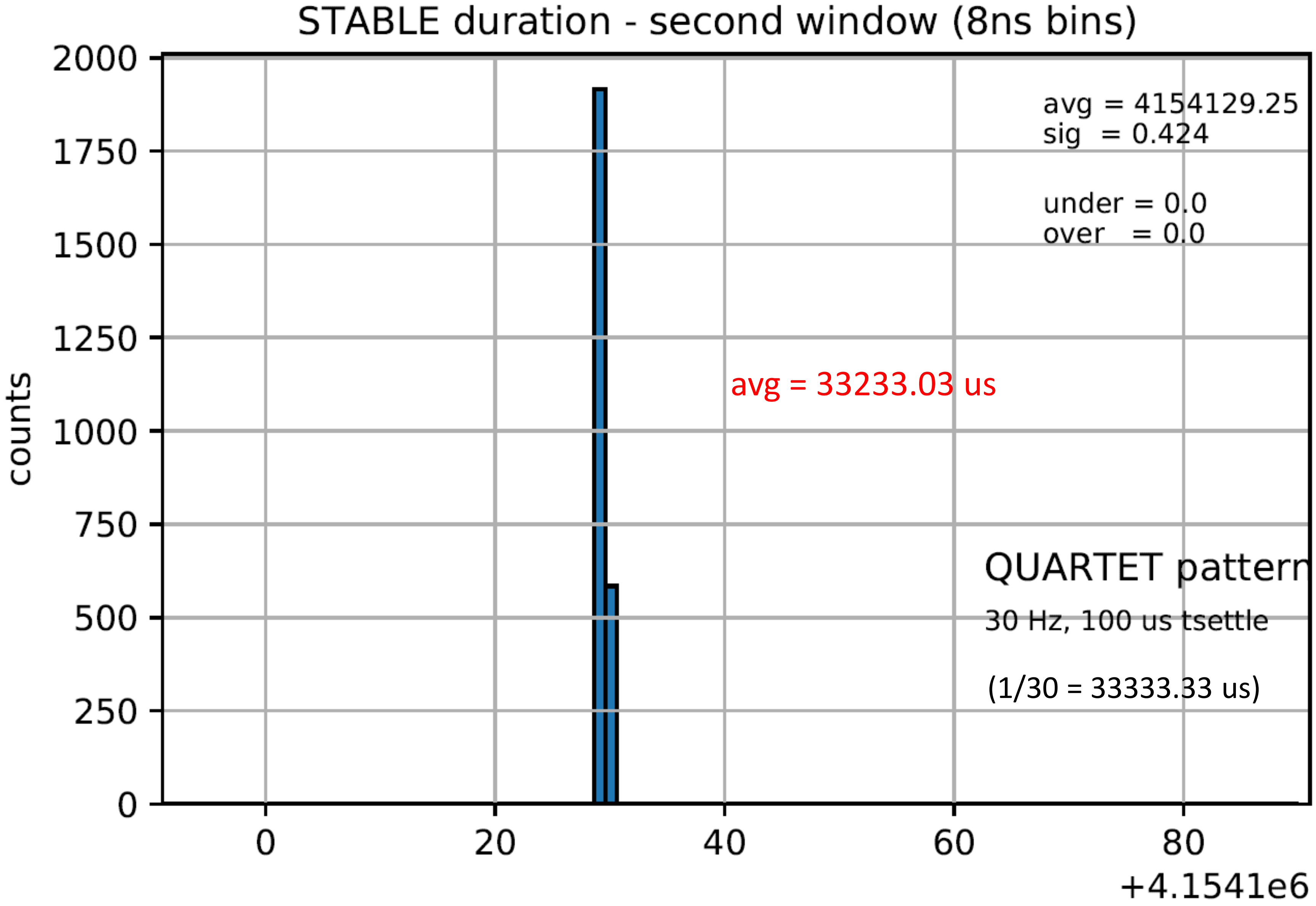
Figure 1



avg = 33233.03 us

(1/30 = 33333.33 us)

Figure 2

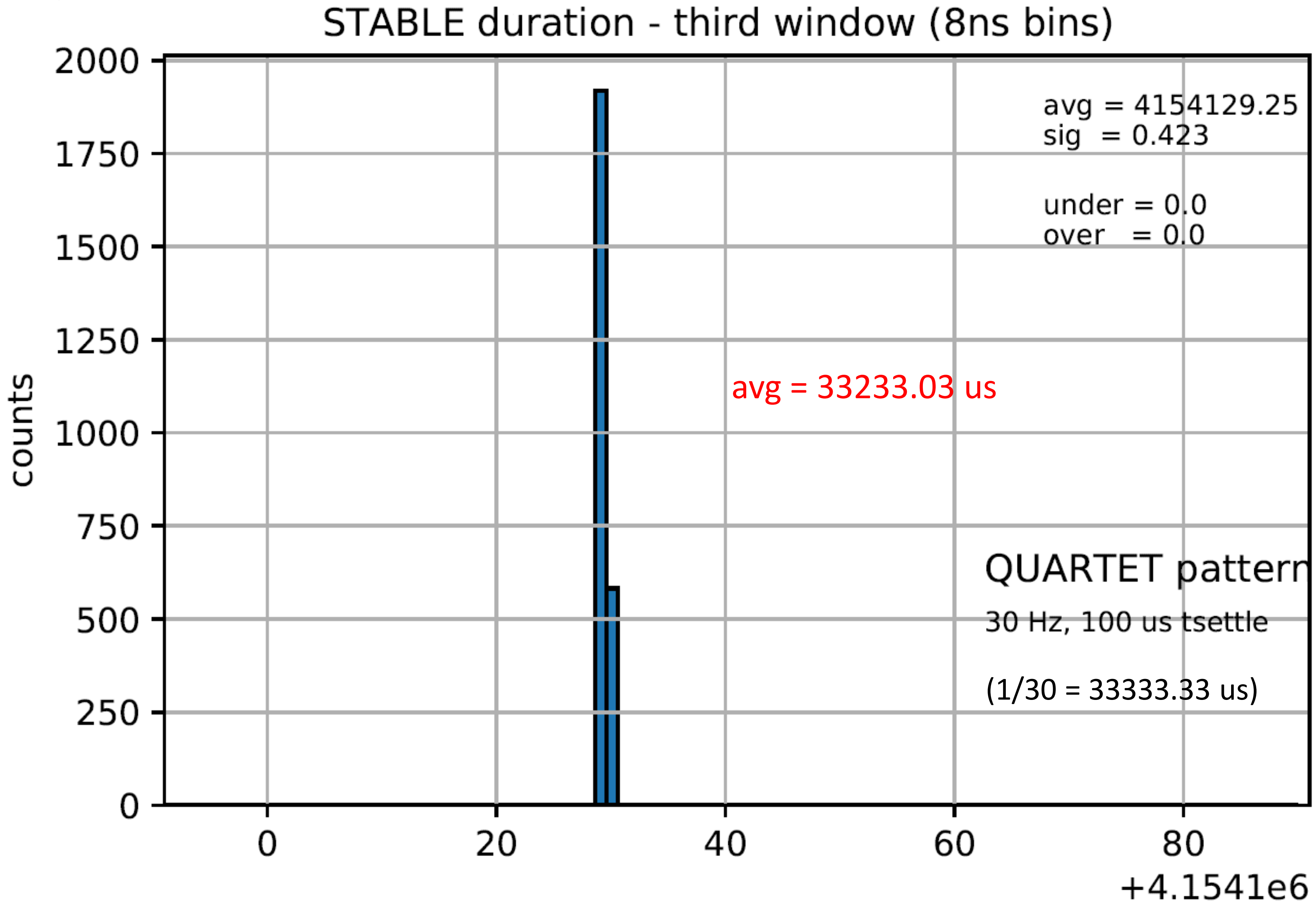


avg = 33233.03 us

30 Hz, 100 us tsettle

(1/30 = 33333.33 us)

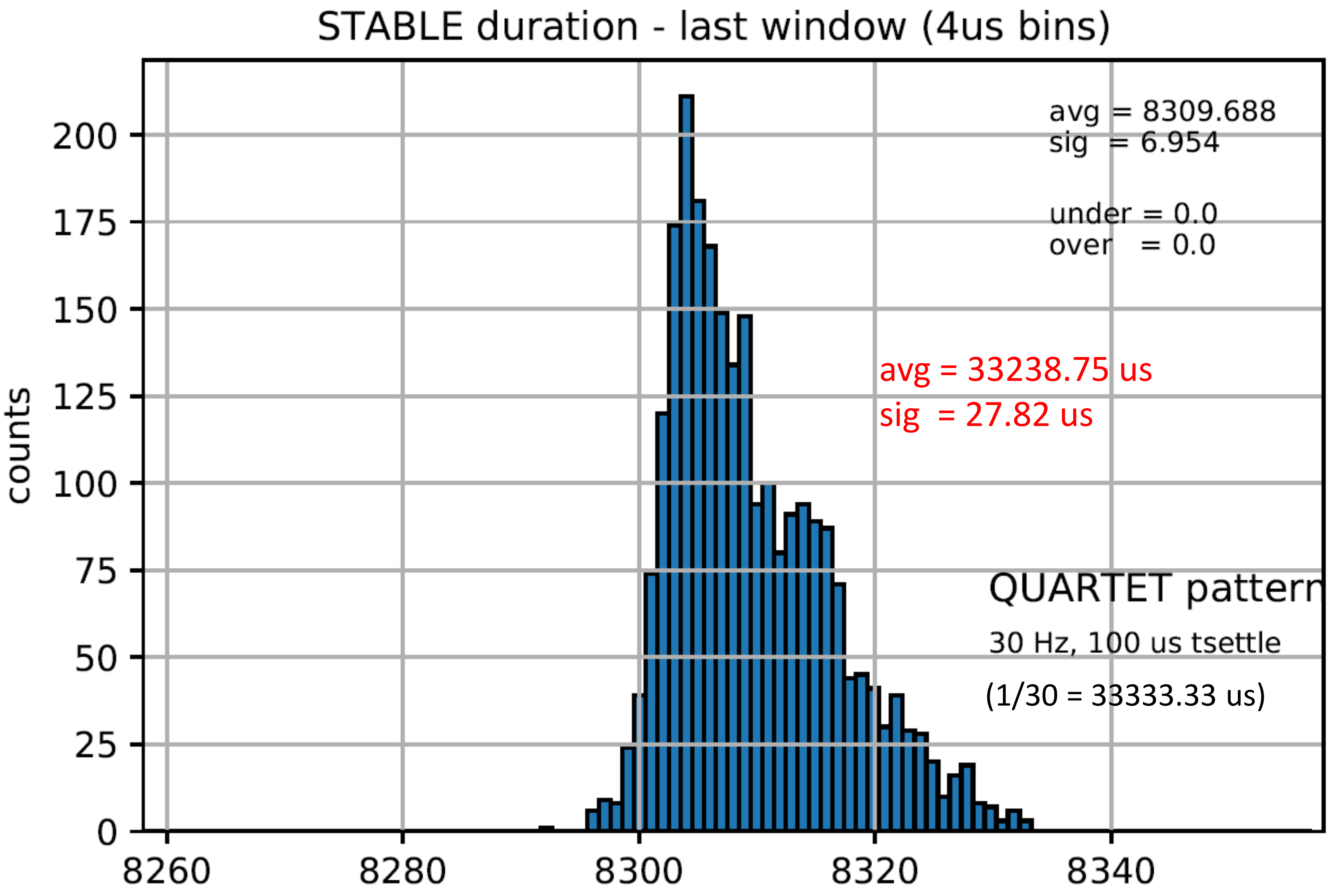
Figure 3



avg = 33233.03 us

(1/30 = 33333.33 us)

Figure 4



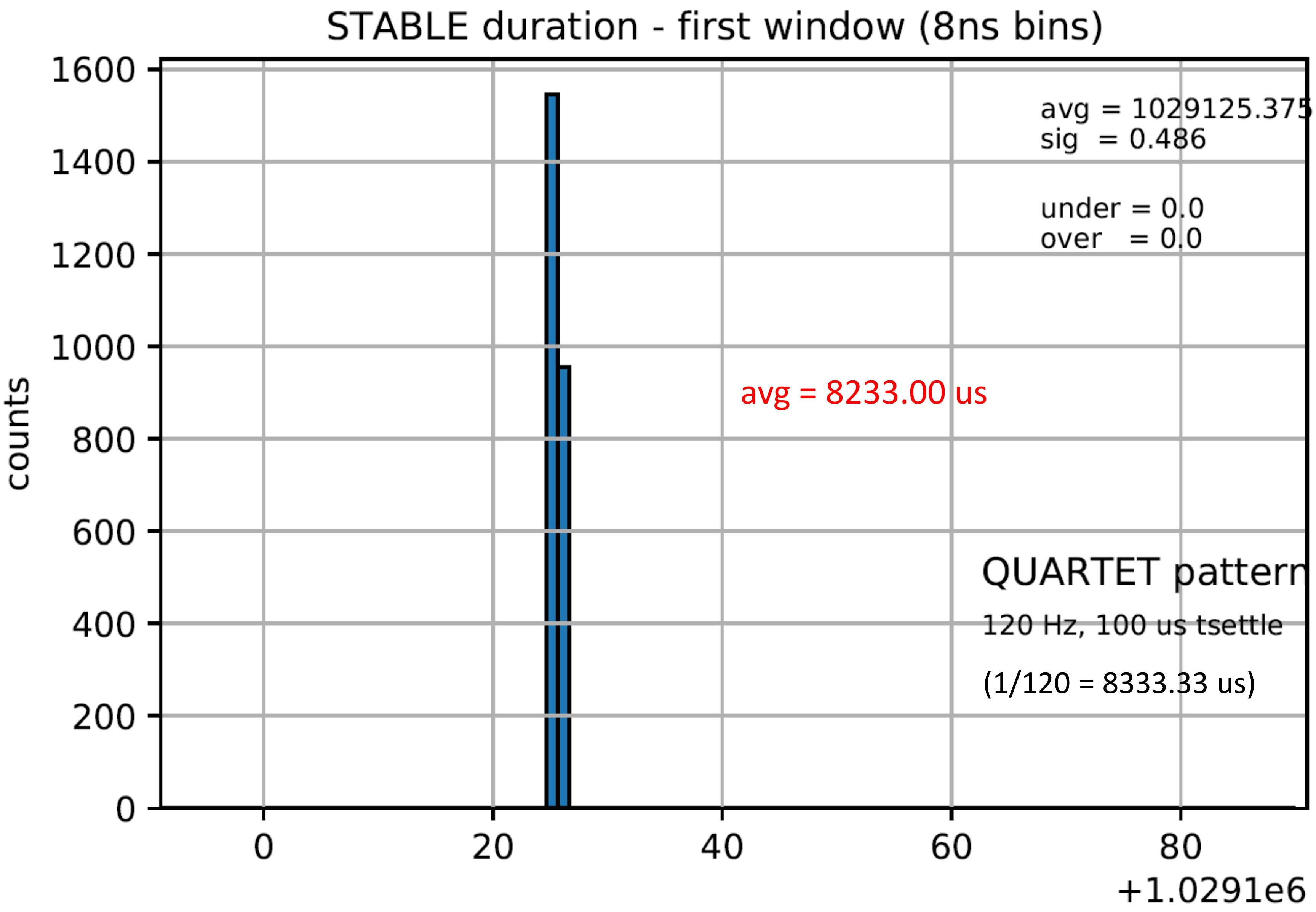
avg = 33238.75 us
sig = 27.82 us

QUARTET pattern

30 Hz, 100 us tsettle

(1/30 = 33333.33 us)

Figure 5



avg = 8233.00 us

120 Hz, 100 us tsettle

(1/120 = 8333.33 us)

Figure 6

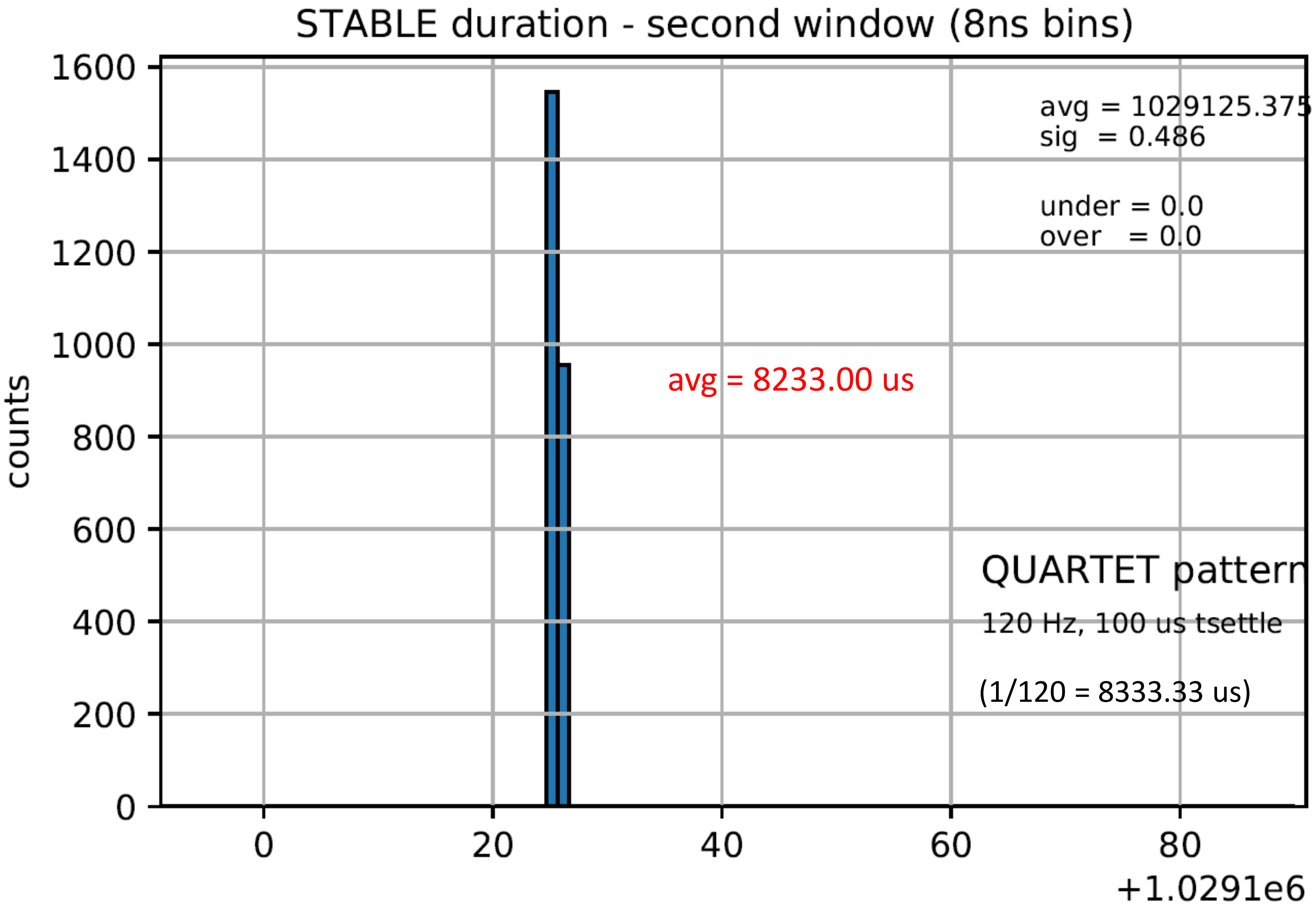

STABLE duration - second window (8ns bins)
counts
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
+1.0291e6
avg = 1029125.375
sig = 0.486
under = 0.0
over = 0.0
avg = 8233.00 us
QUARTET pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 7

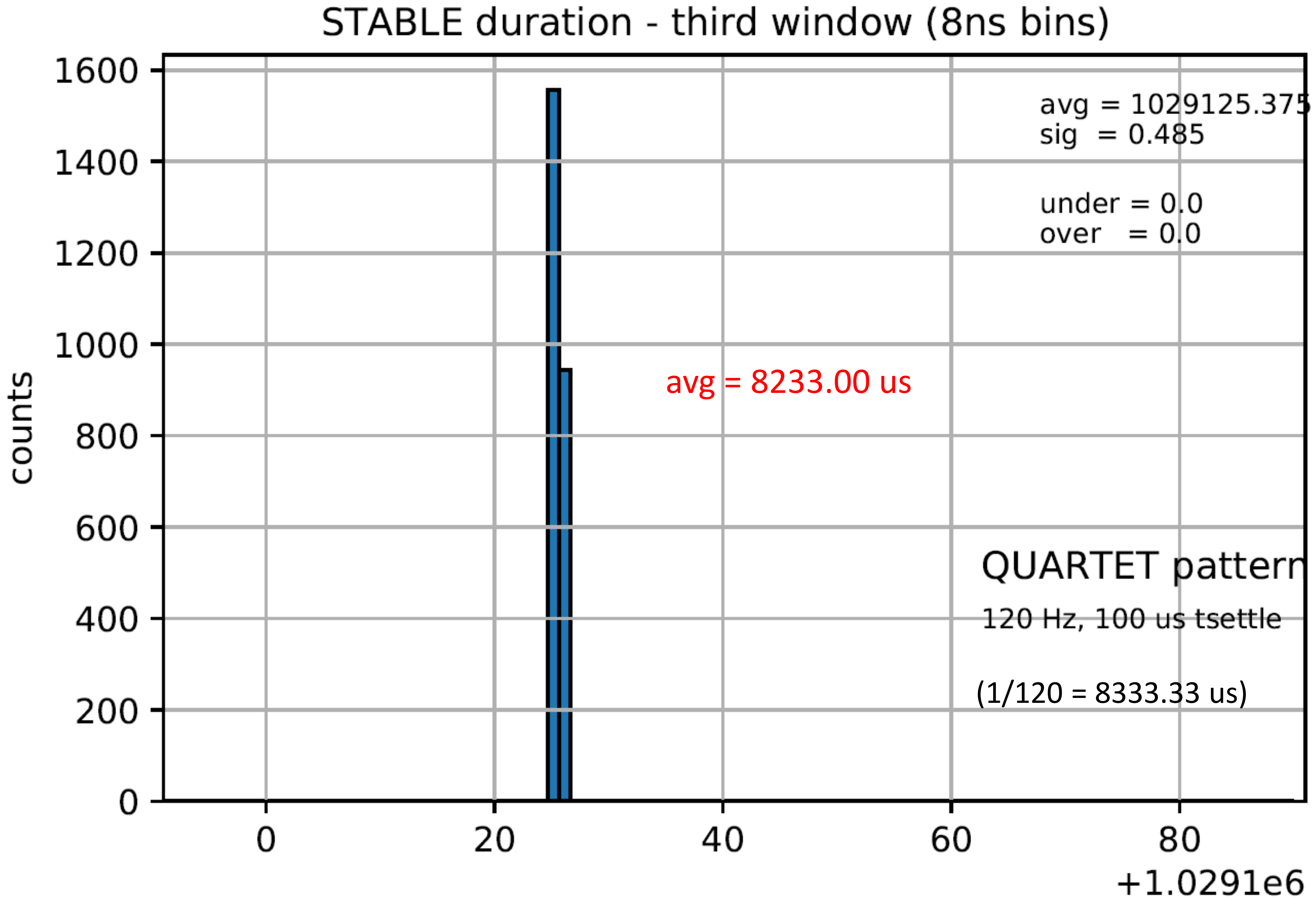
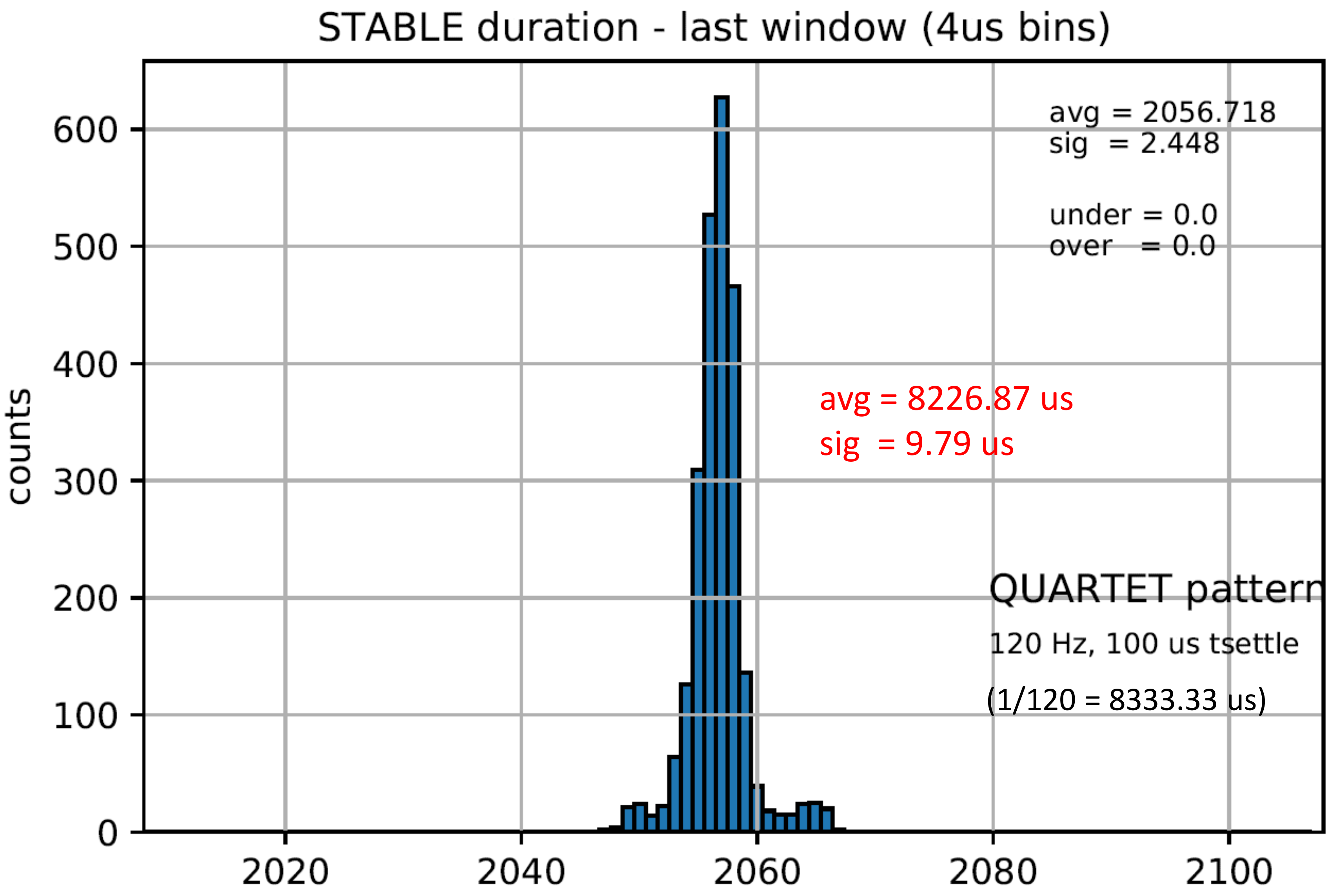

STABLE duration - third window (8ns bins)
counts
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
+1.0291e6
avg = 1029125.375
sig = 0.485
under = 0.0
over = 0.0
avg = 8233.00 us
QUARTET pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

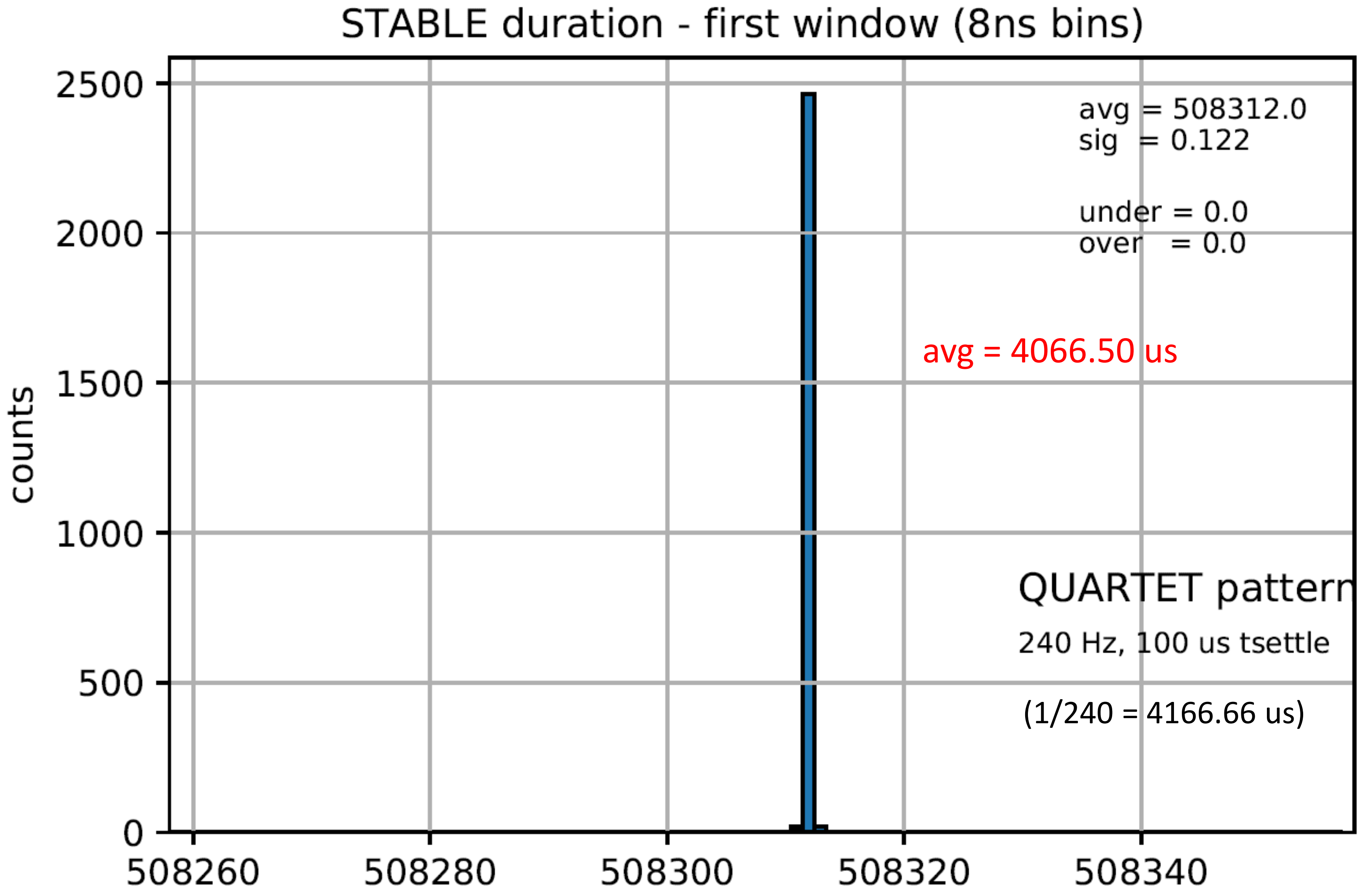
Figure 8



avg = 8226.87 us
sig = 9.79 us

(1/120 = 8333.33 us)

Figure 9



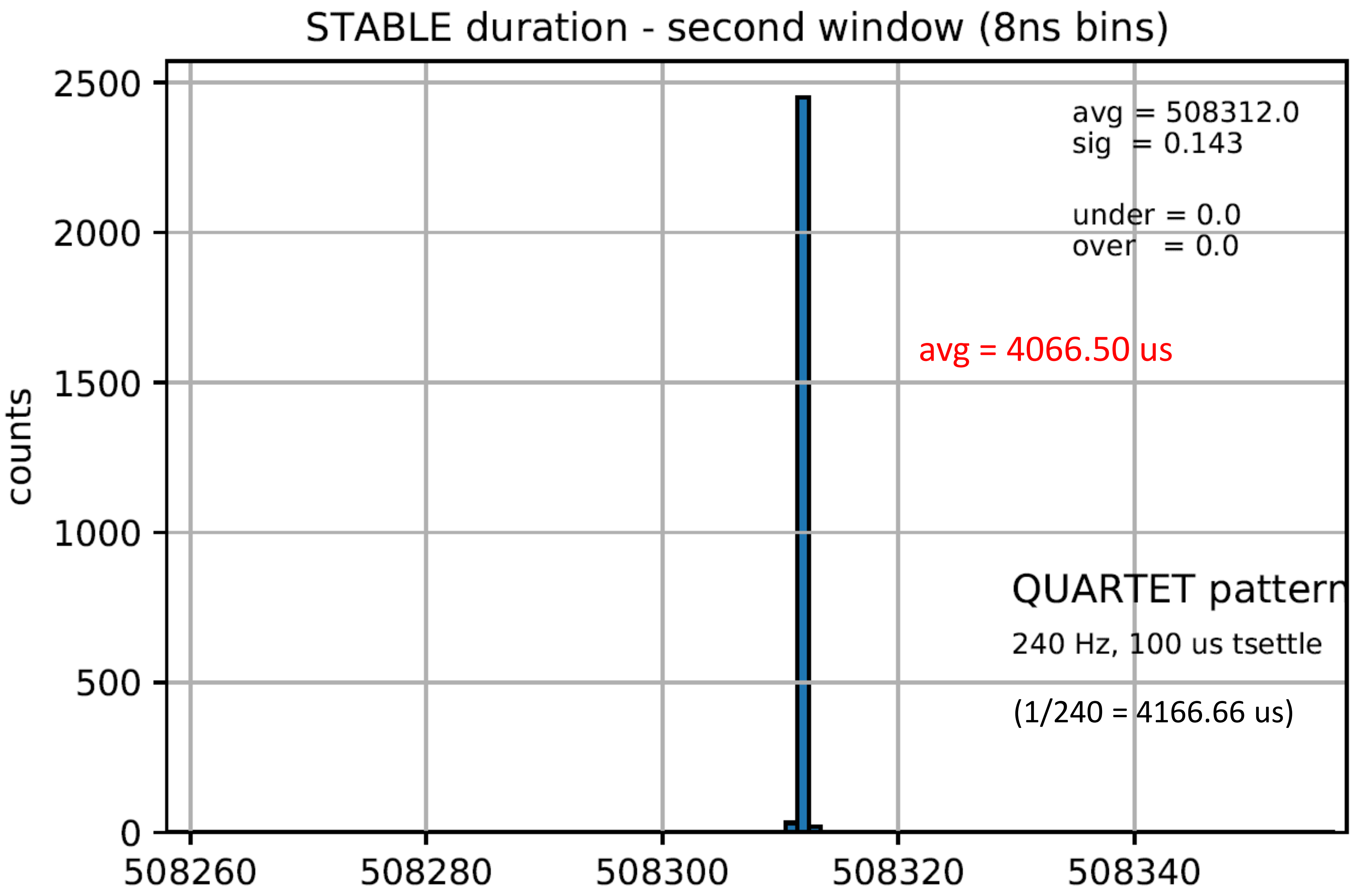
avg = 4066.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure 10



avg = 4066.50 us

(1/240 = 4166.66 us)

Figure 11

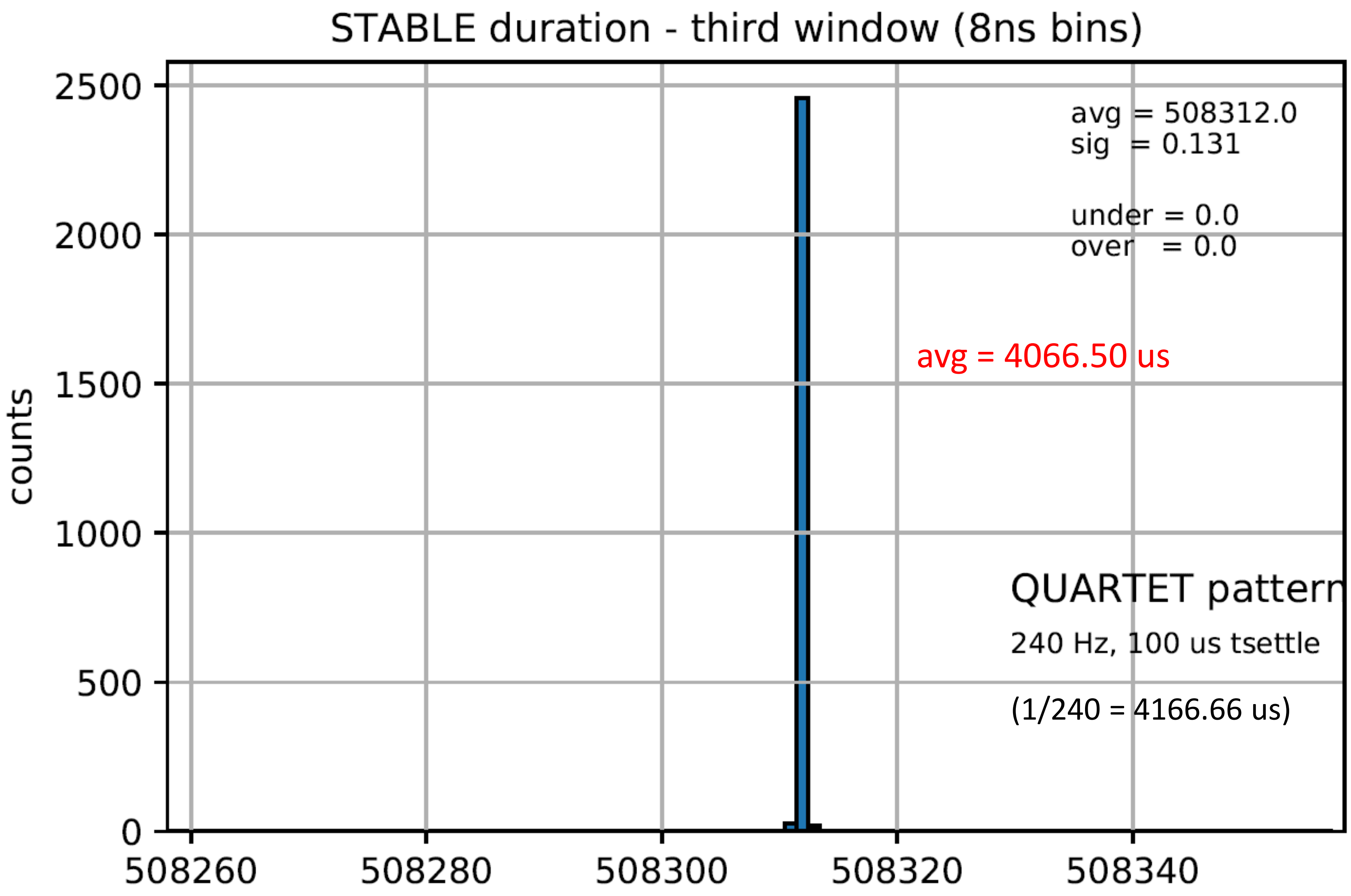
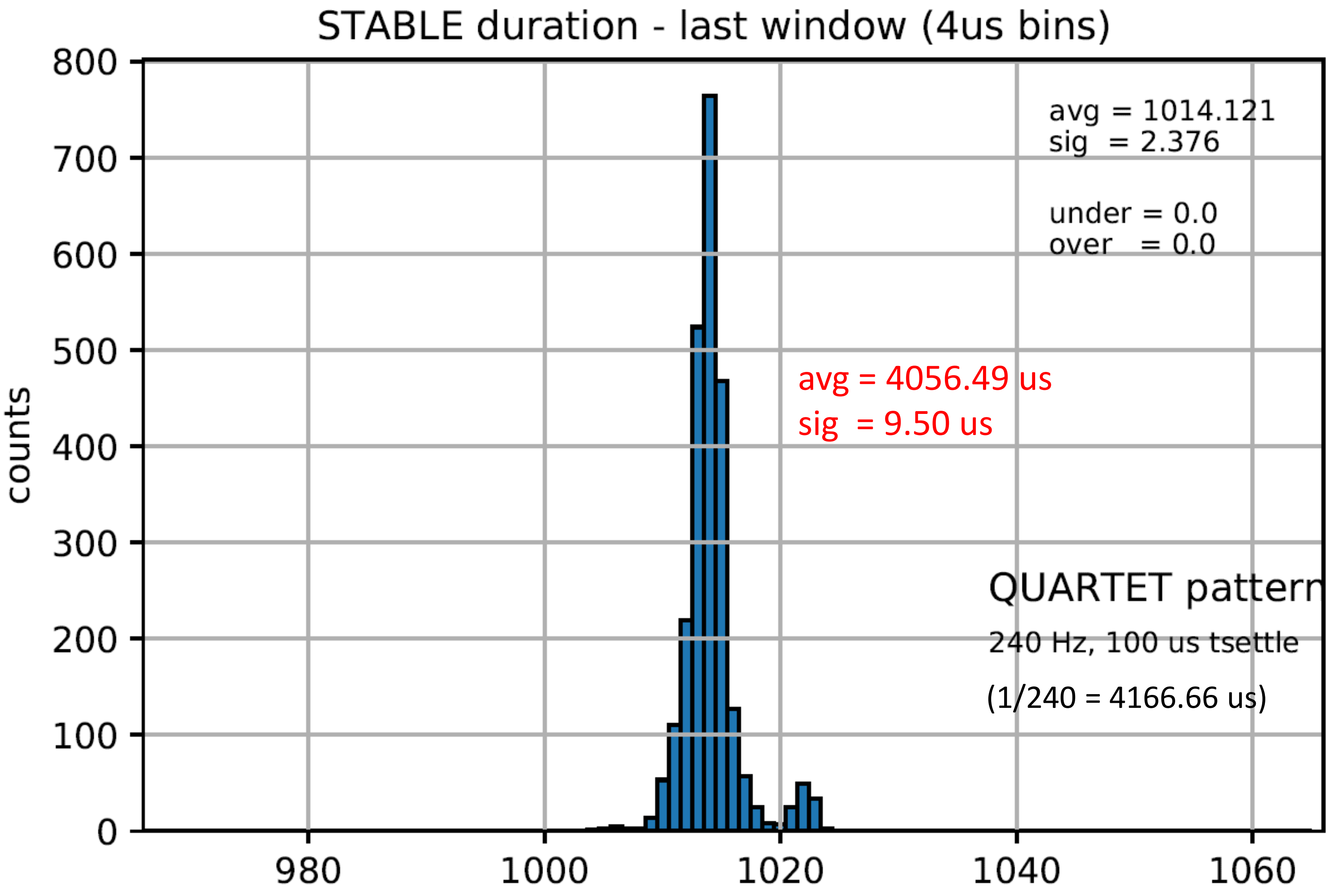

STABLE duration - third window (8ns bins)
counts
2500
2000
1500
1000
500
0
508260
508280
508300
508320
508340
avg = 508312.0
sig = 0.131
under = 0.0
over = 0.0
avg = 4066.50 us
QUARTET pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)

Figure 12



avg = 4056.49 us
sig = 9.50 us

QUARTET pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure 13

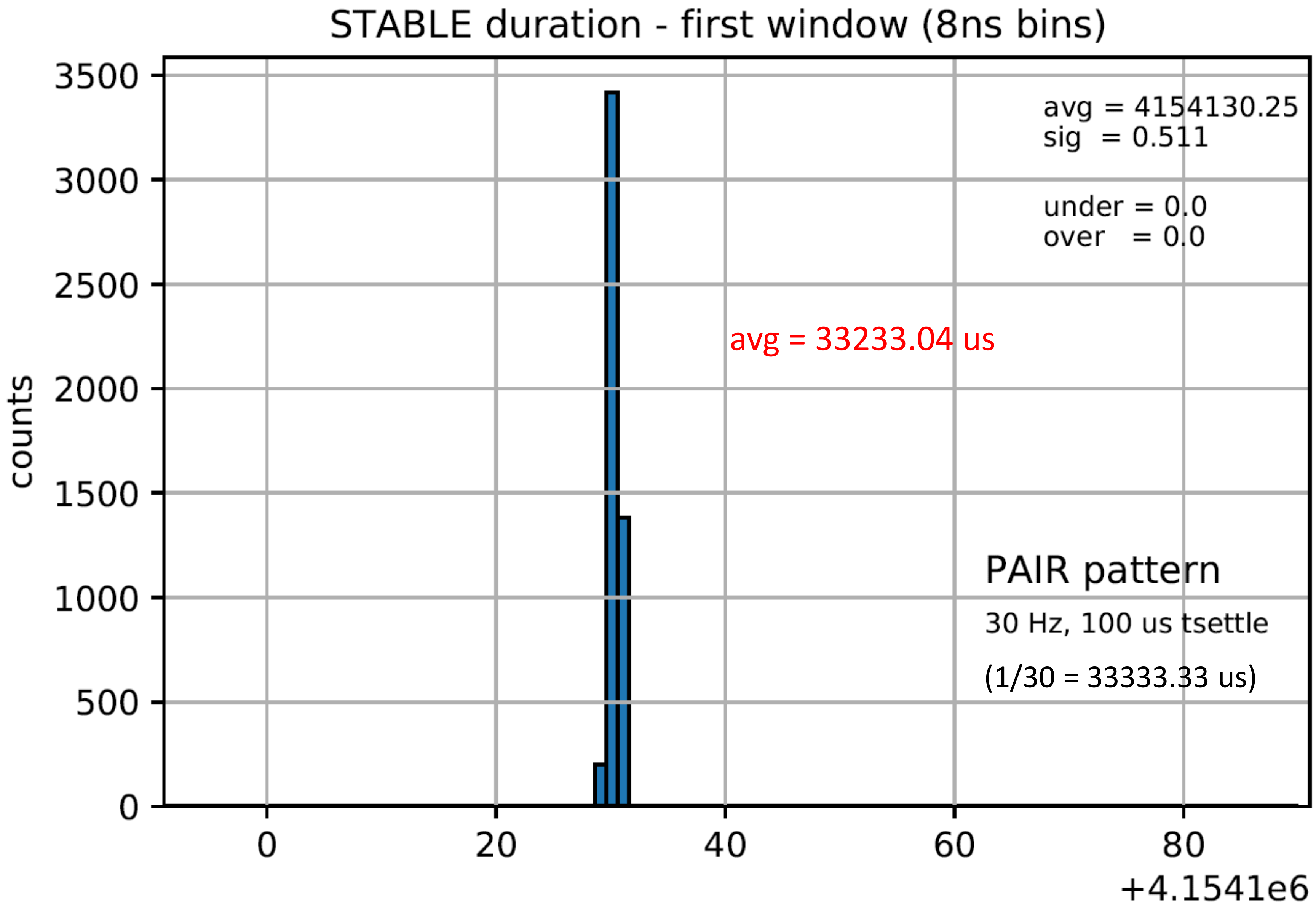
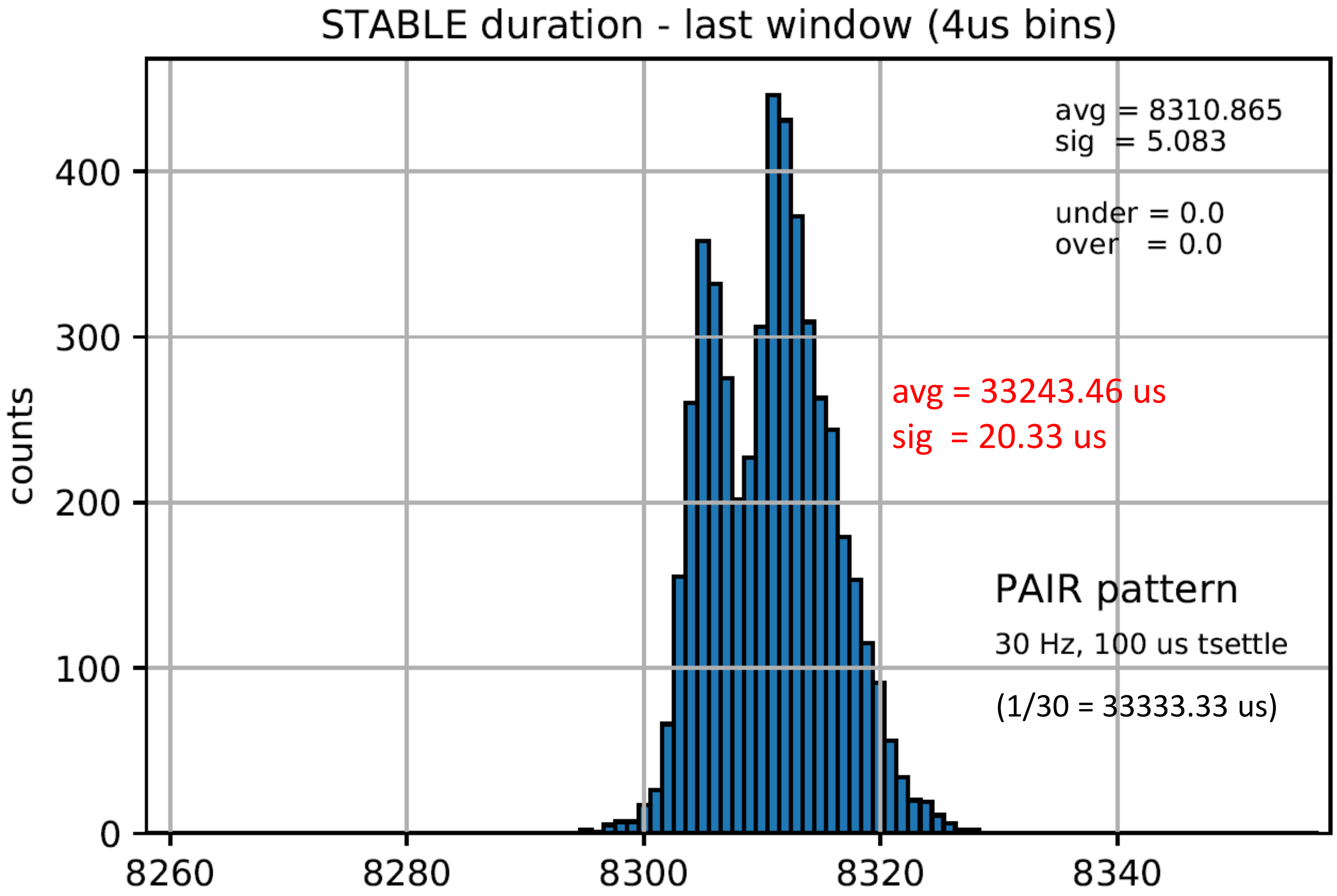
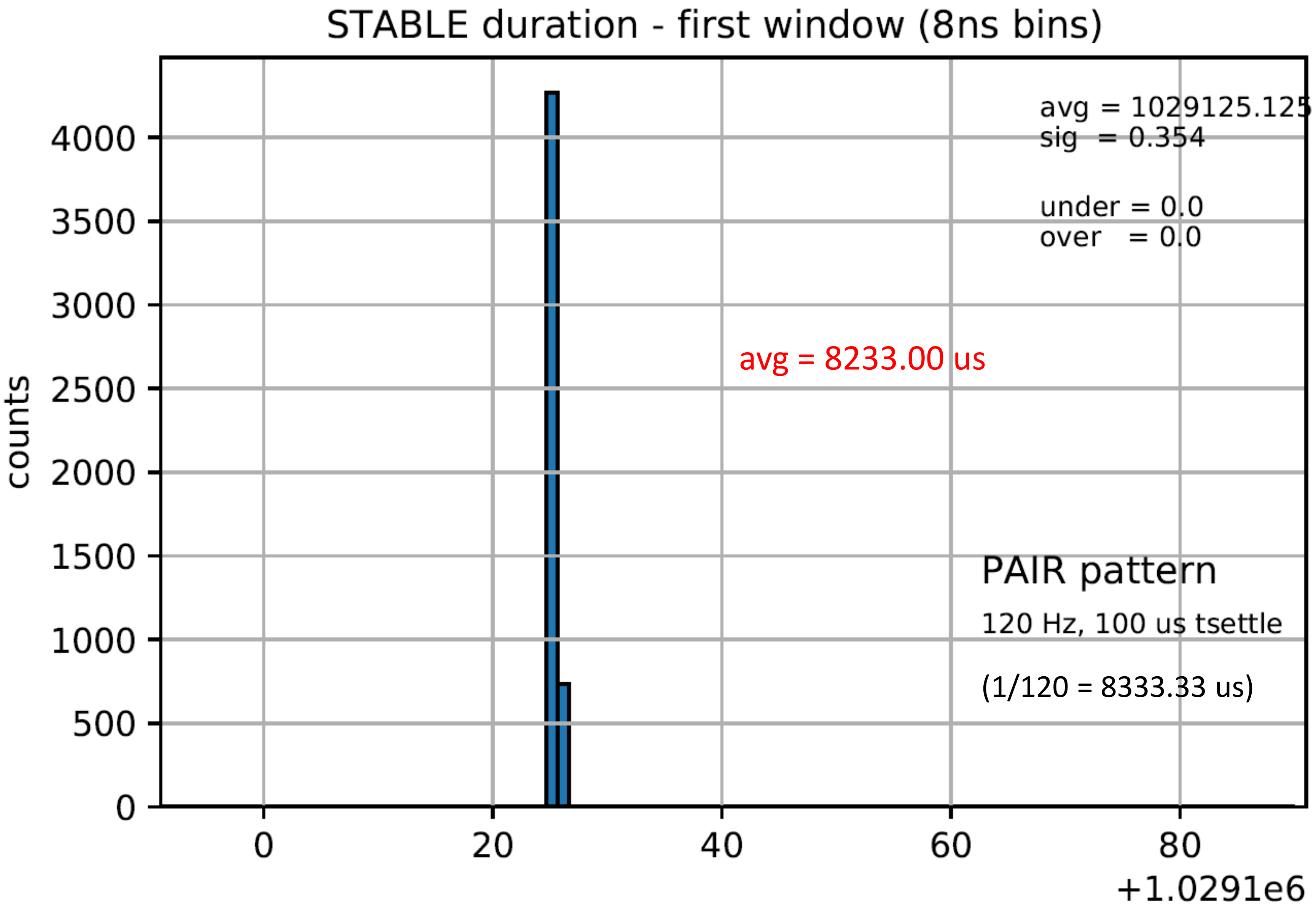

STABLE duration - first window (8ns bins)
counts
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+4.1541e6
avg = 4154130.25
sig = 0.511
under = 0.0
over = 0.0
avg = 33233.04 us
PAIR pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 14



STABLE duration - last window (4us bins)
counts
0
100
200
300
400
8260
8280
8300
8320
8340
avg = 8310.865
sig = 5.083
under = 0.0
over = 0.0
avg = 33243.46 us
sig = 20.33 us
PAIR pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 15



avg = 8233.00 us

PAIR pattern

120 Hz, 100 us tsettle

(1/120 = 8333.33 us)

Figure 16

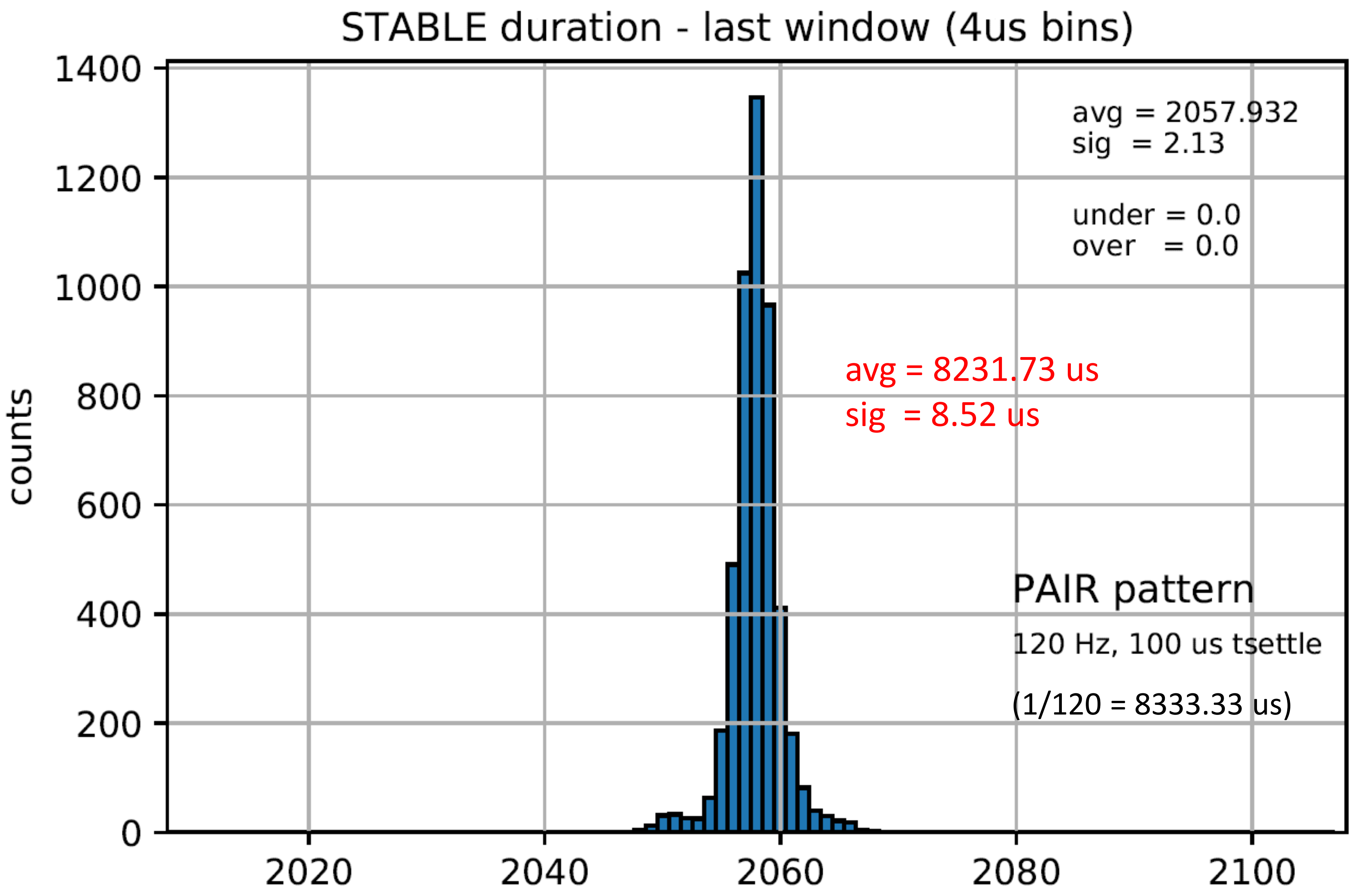
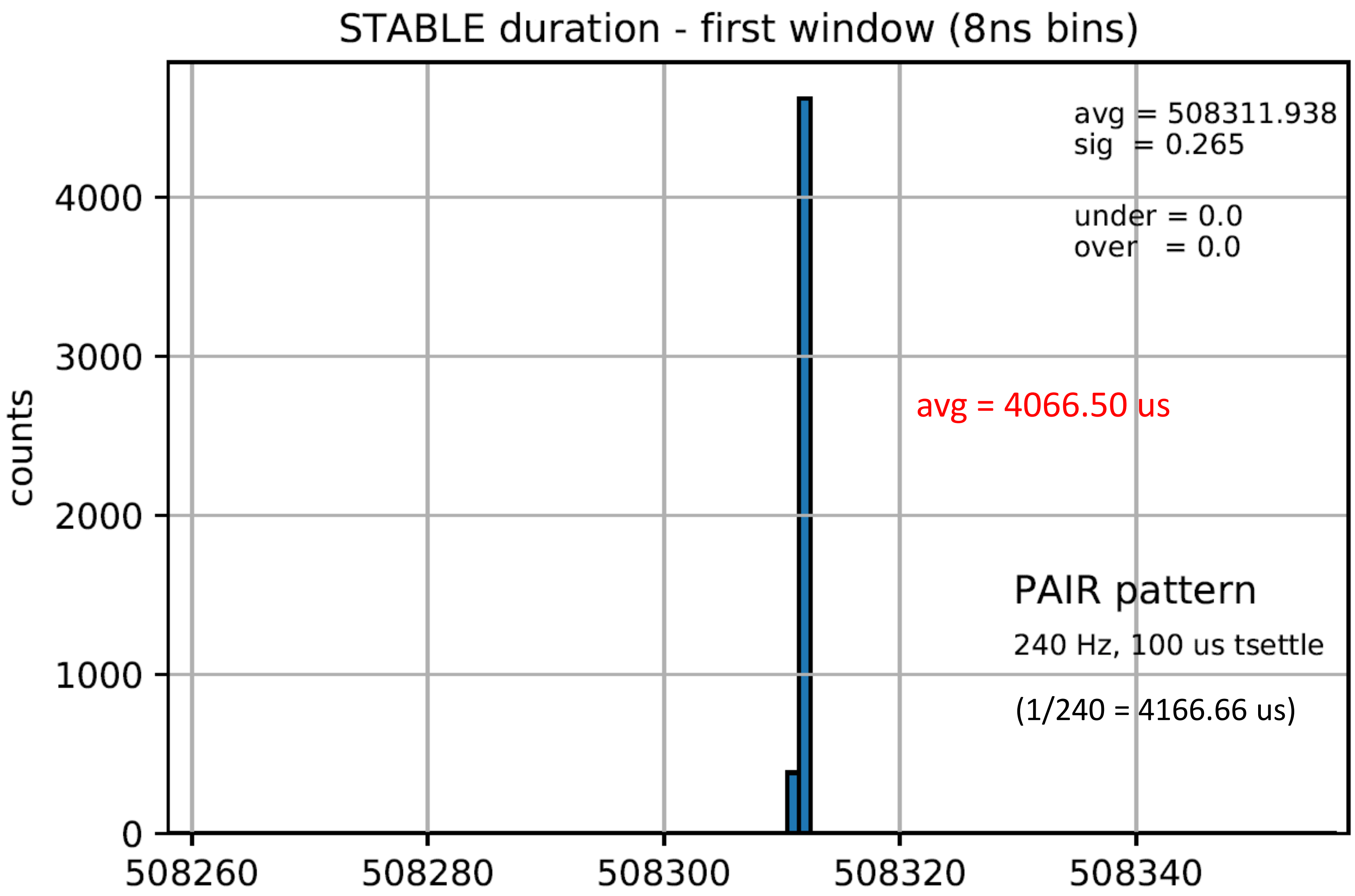

STABLE duration - last window (4us bins)
counts
0
200
400
600
800
1000
1200
1400
2020
2040
2060
2080
2100
avg = 2057.932
sig = 2.13
under = 0.0
over = 0.0
avg = 8231.73 us
sig = 8.52 us
PAIR pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 17



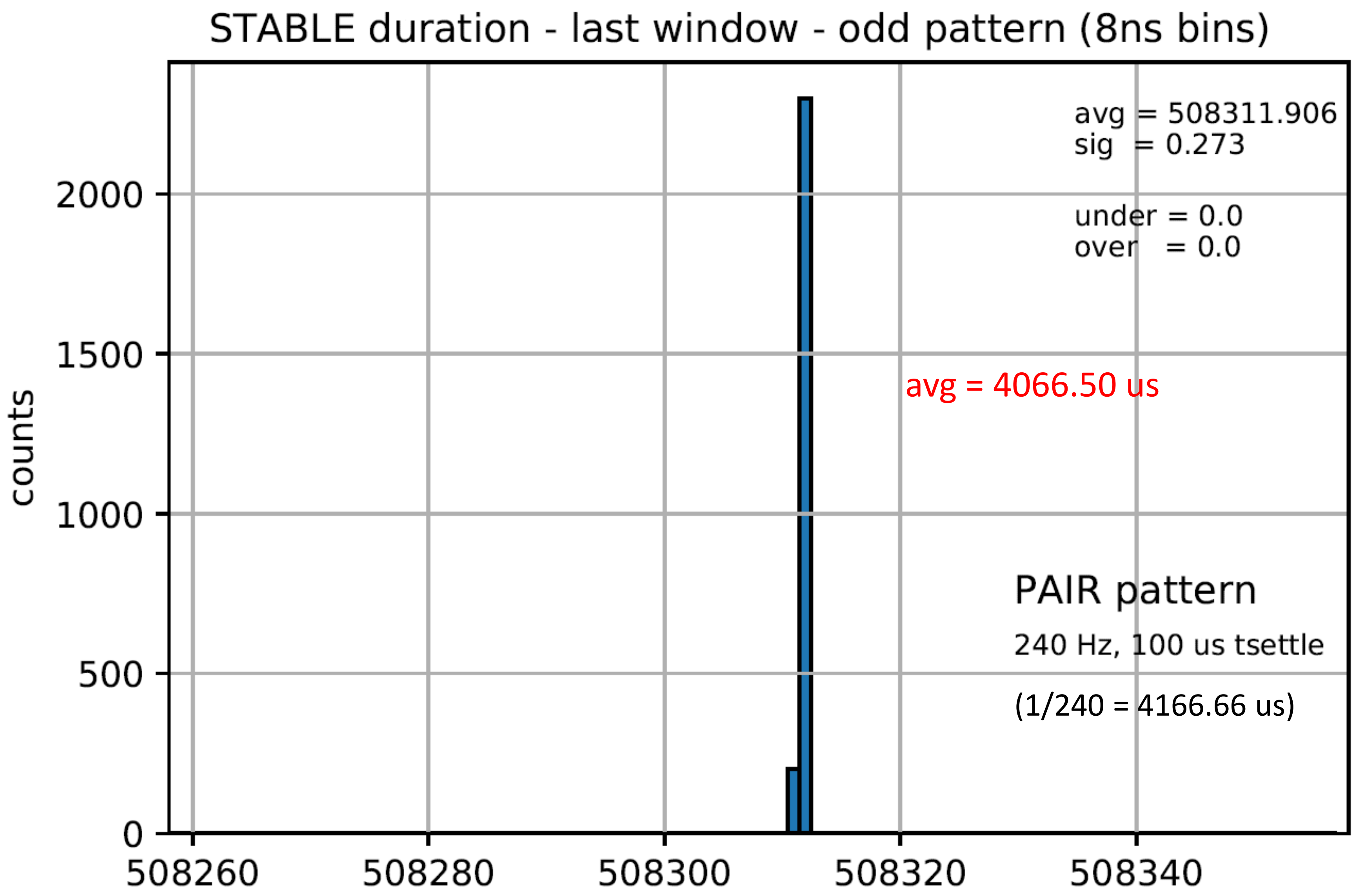
avg = 4066.50 us

PAIR pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure 18



avg = 4066.50 us

PAIR pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure 19

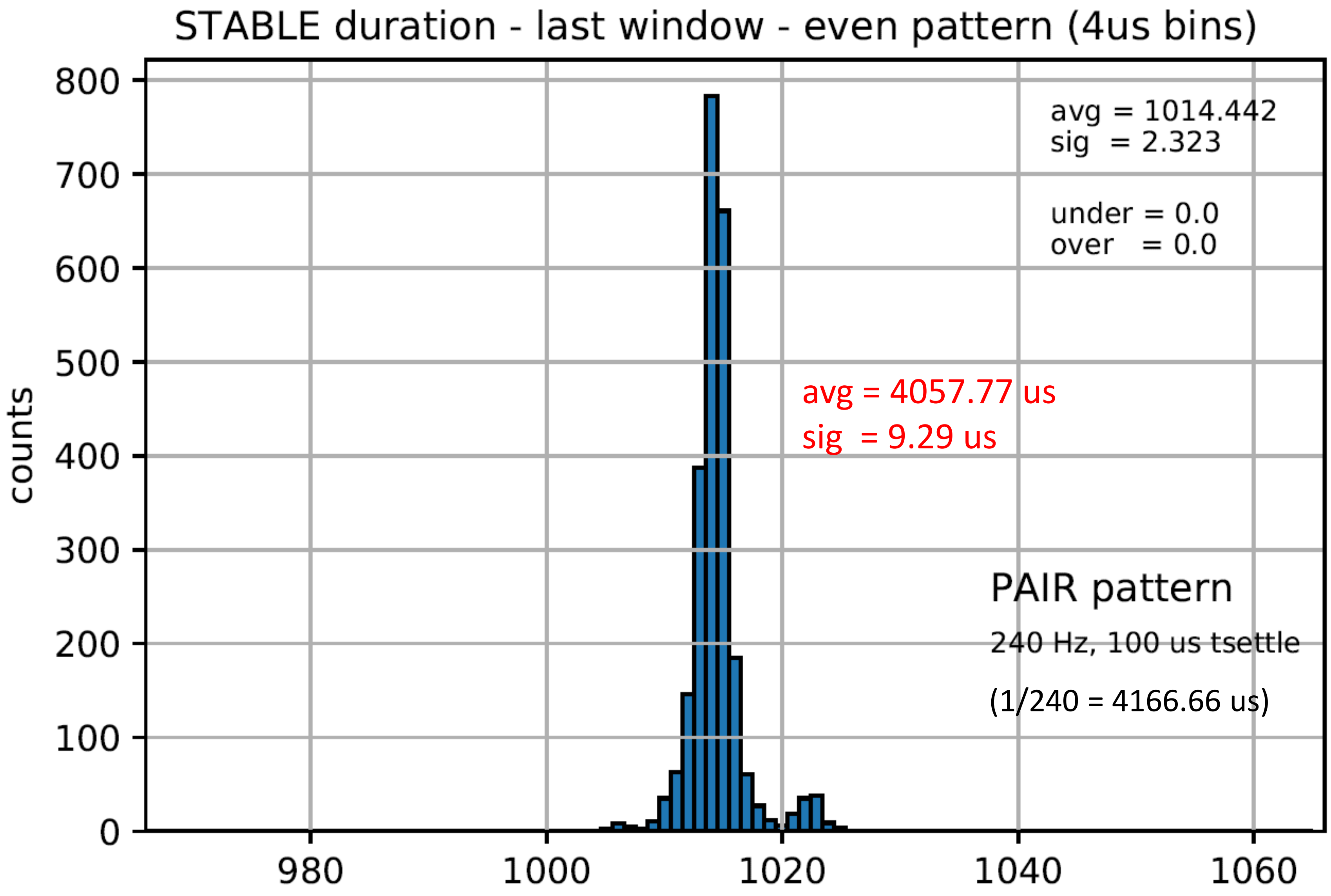
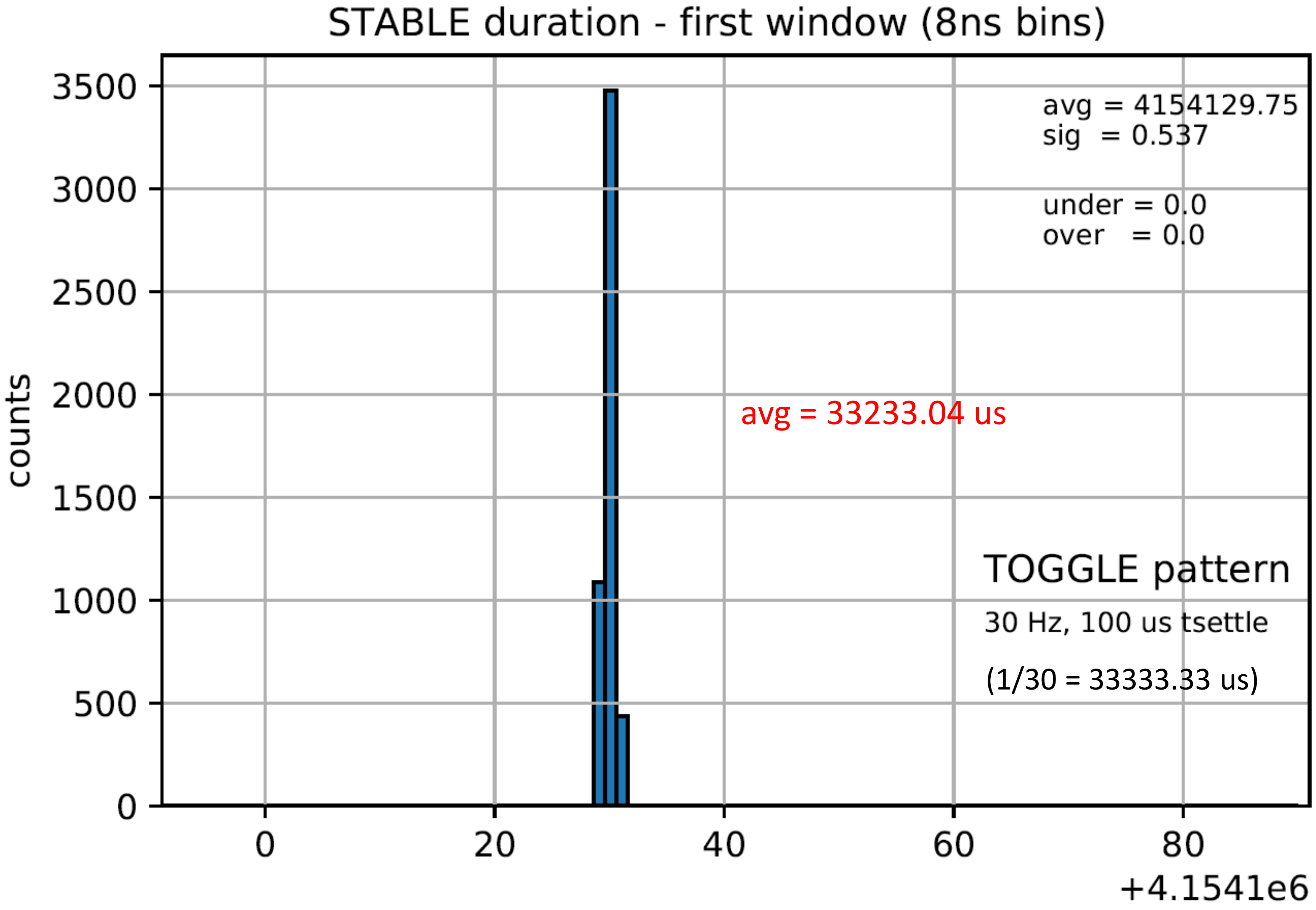

STABLE duration - last window - even pattern (4us bins)
counts
800
700
600
500
400
300
200
100
0
980
1000
1020
1040
1060
avg = 1014.442
sig = 2.323
under = 0.0
over = 0.0
avg = 4057.77 us
sig = 9.29 us
PAIR pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)

Figure 20



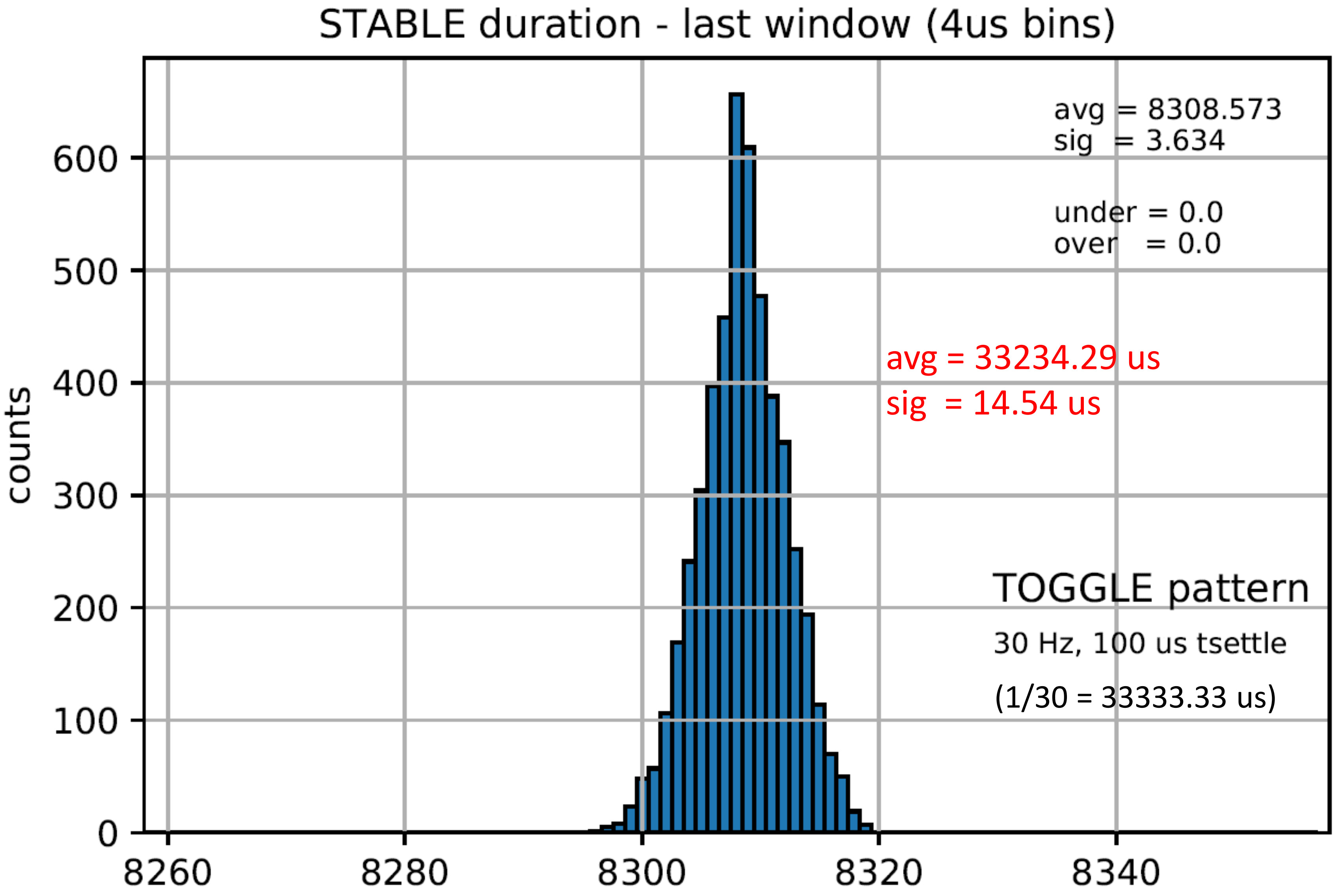
avg = 33233.04 us

TOGGLE pattern

30 Hz, 100 us tsettle

(1/30 = 33333.33 us)

Figure 21



avg = 33234.29 us
sig = 14.54 us

TOGGLE pattern

30 Hz, 100 us tsettle

(1/30 = 33333.33 us)

Figure 22

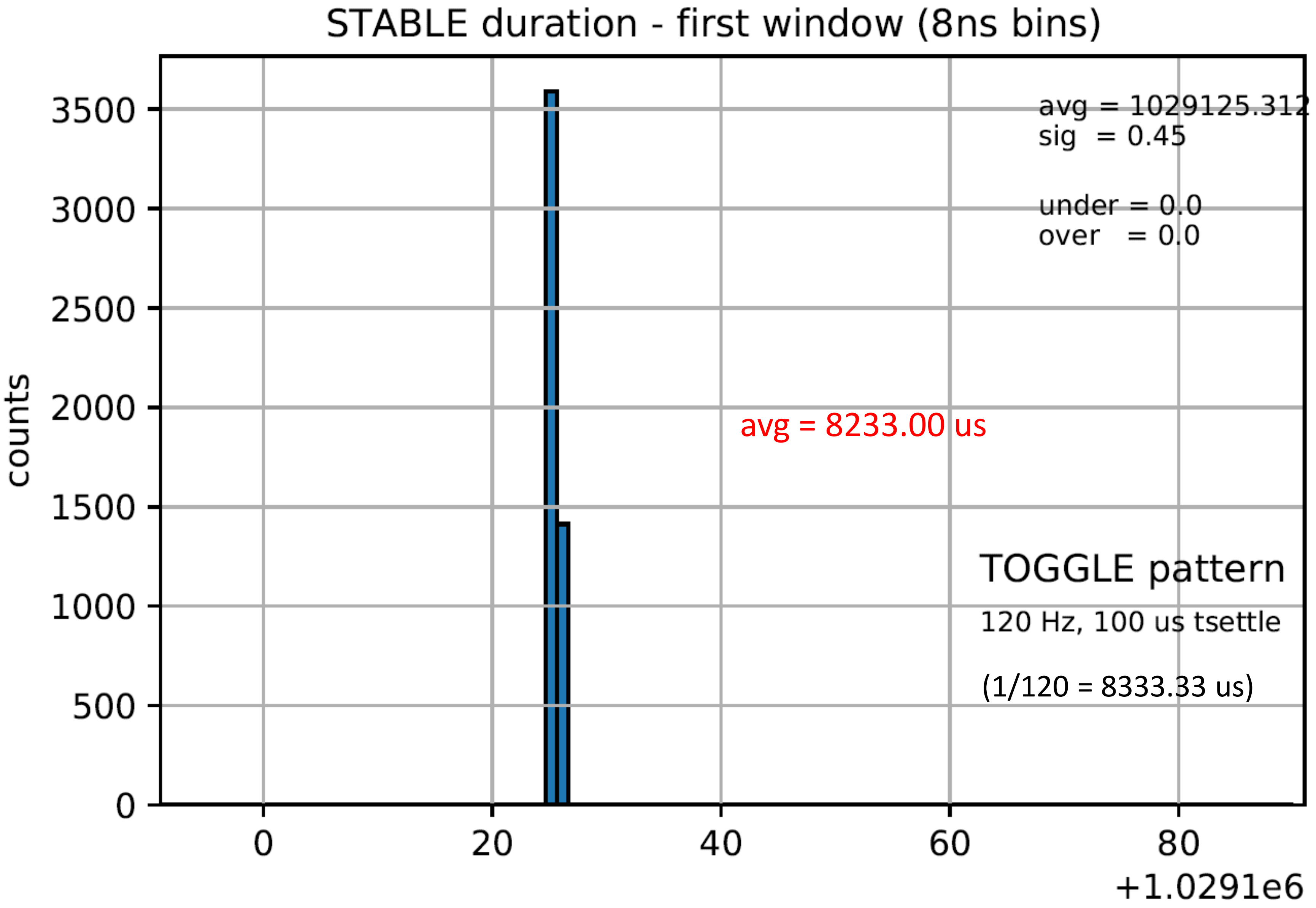
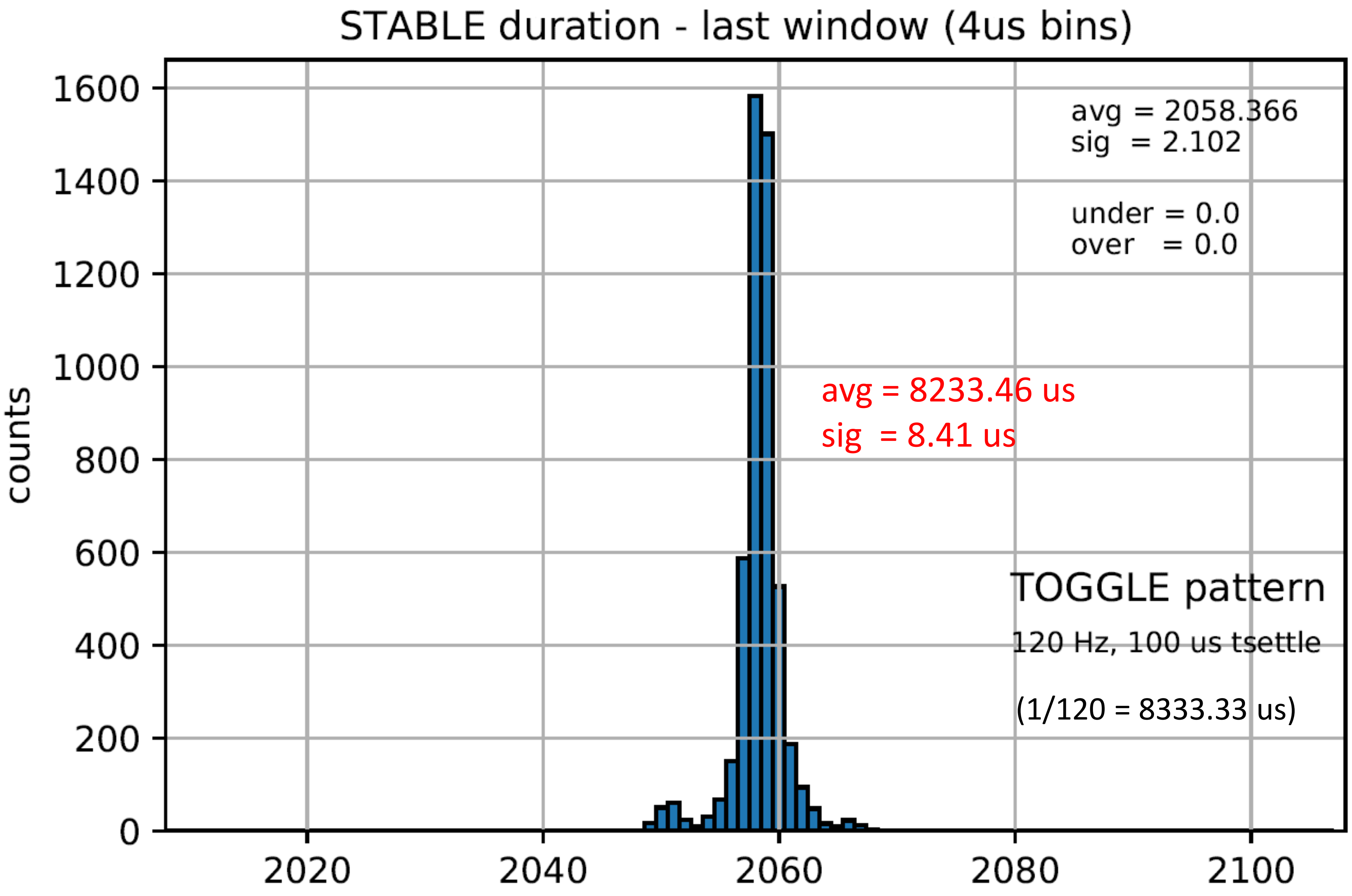

STABLE duration - first window (8ns bins)
counts
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+1.0291e6
avg = 1029125.312
sig = 0.45
under = 0.0
over = 0.0
avg = 8233.00 us
TOGGLE pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 23



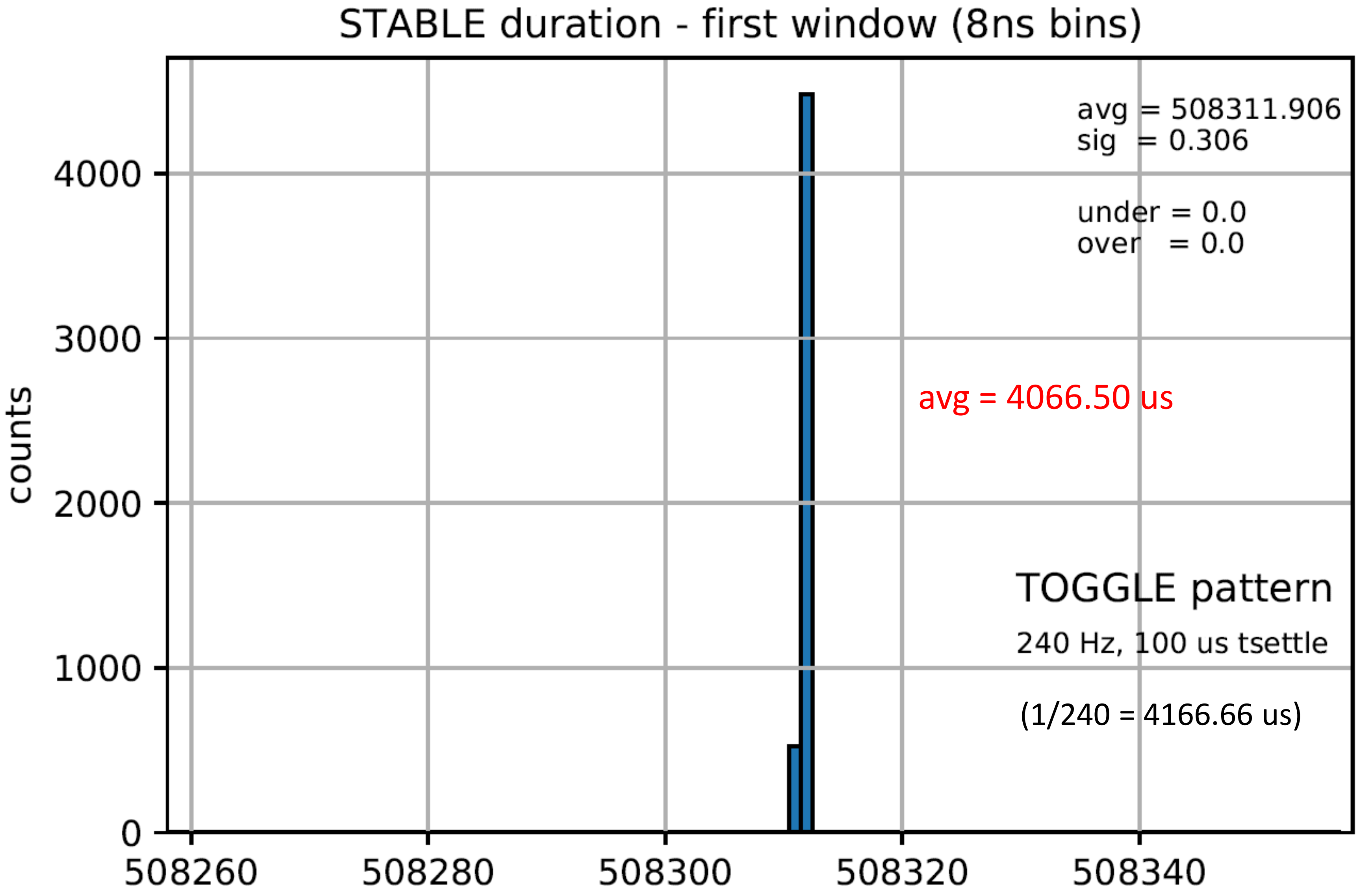
avg = 8233.46 us
sig = 8.41 us

TOGGLE pattern

120 Hz, 100 us tsettle

(1/120 = 8333.33 us)

Figure 24



avg = 4066.50 us

(1/240 = 4166.66 us)

Figure 25

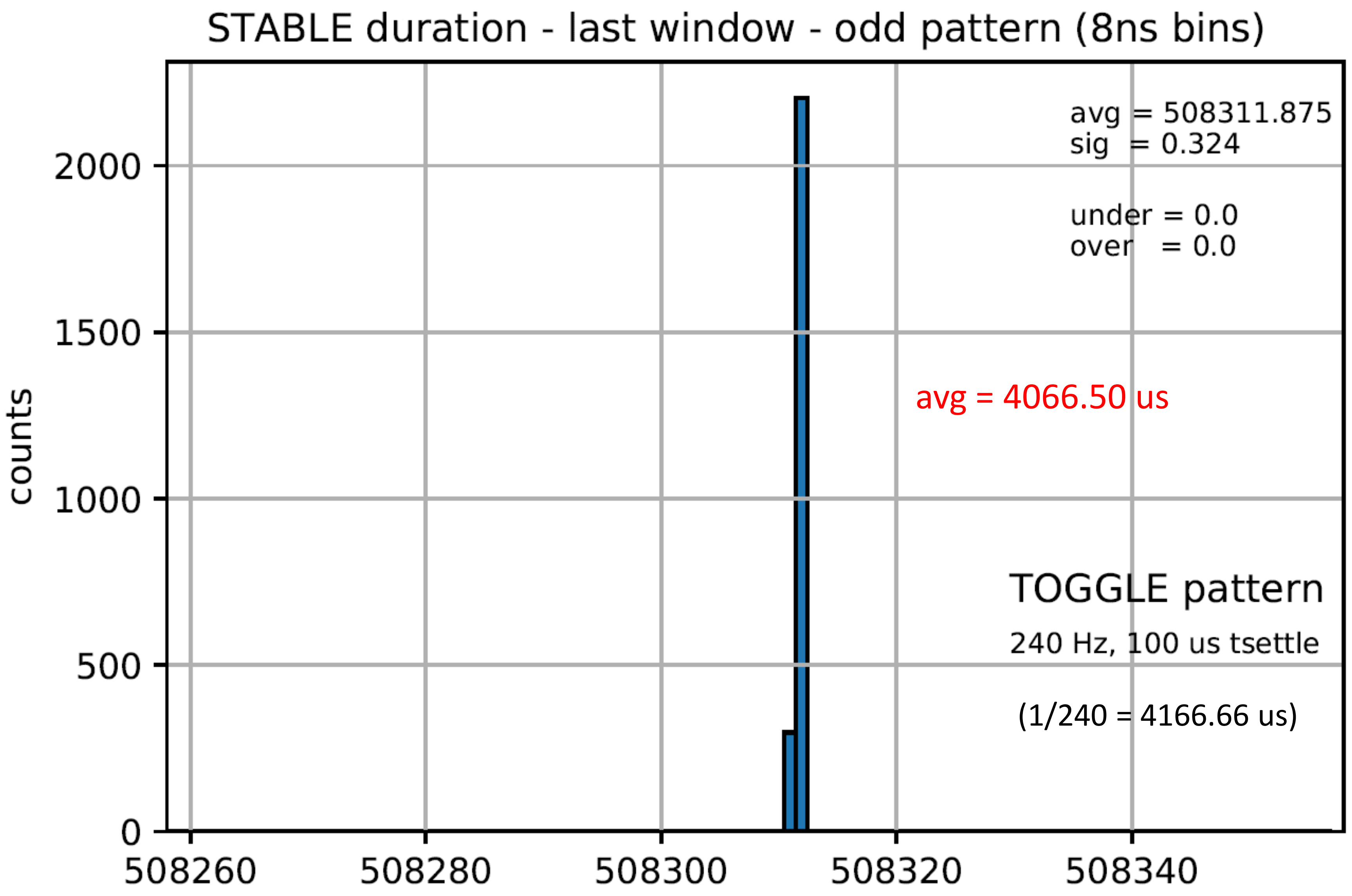
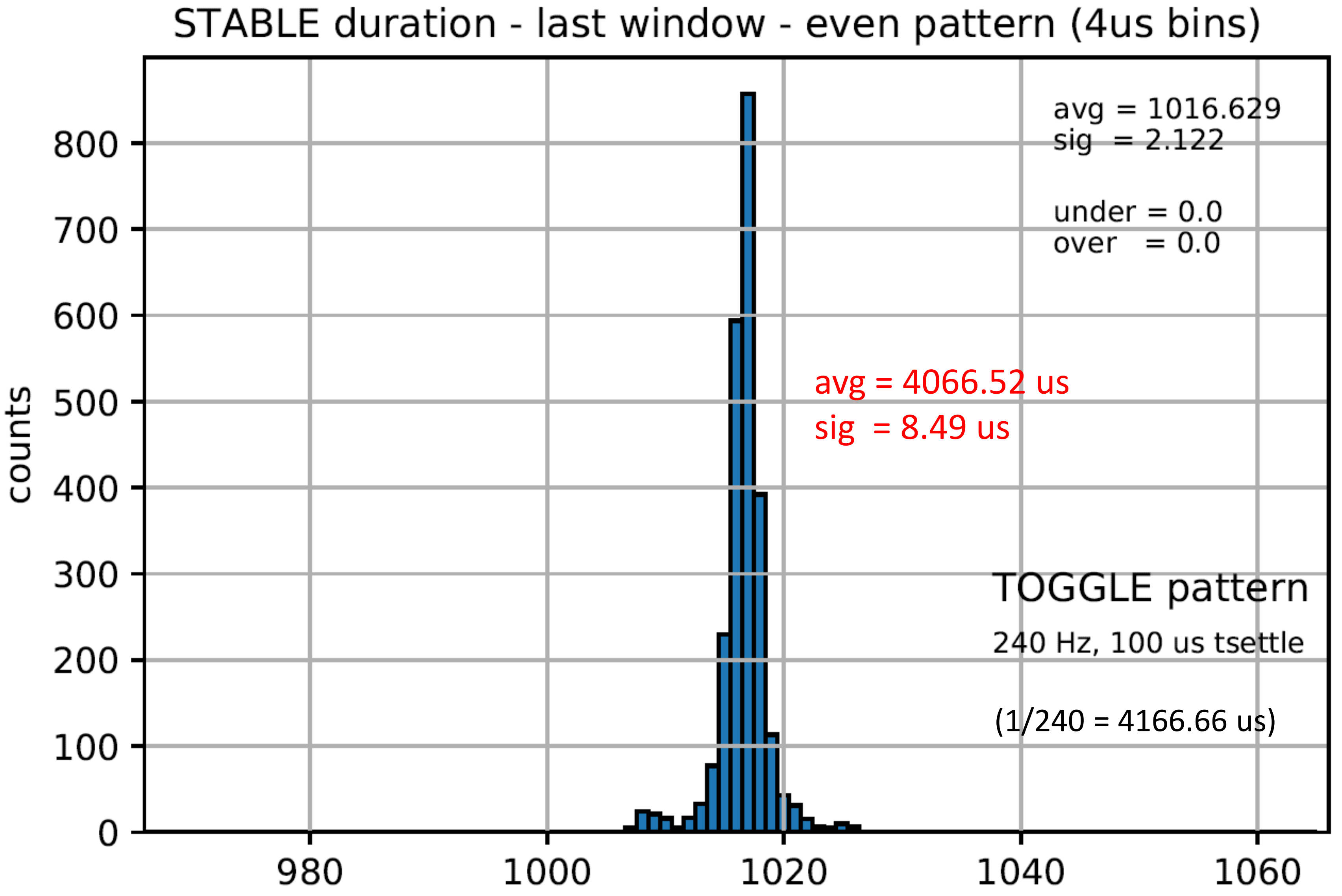

STABLE duration - last window - odd pattern (8ns bins)
counts
0
500
1000
1500
2000
508260
508280
508300
508320
508340
avg = 508311.875
sig = 0.324
under = 0.0
over = 0.0
avg = 4066.50 us
TOGGLE pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)

Figure 26



avg = 4066.52 us
sig = 8.49 us

TOGGLE pattern

240 Hz, 100 us tsettle

(1/240 = 4166.66 us)

Figure 27

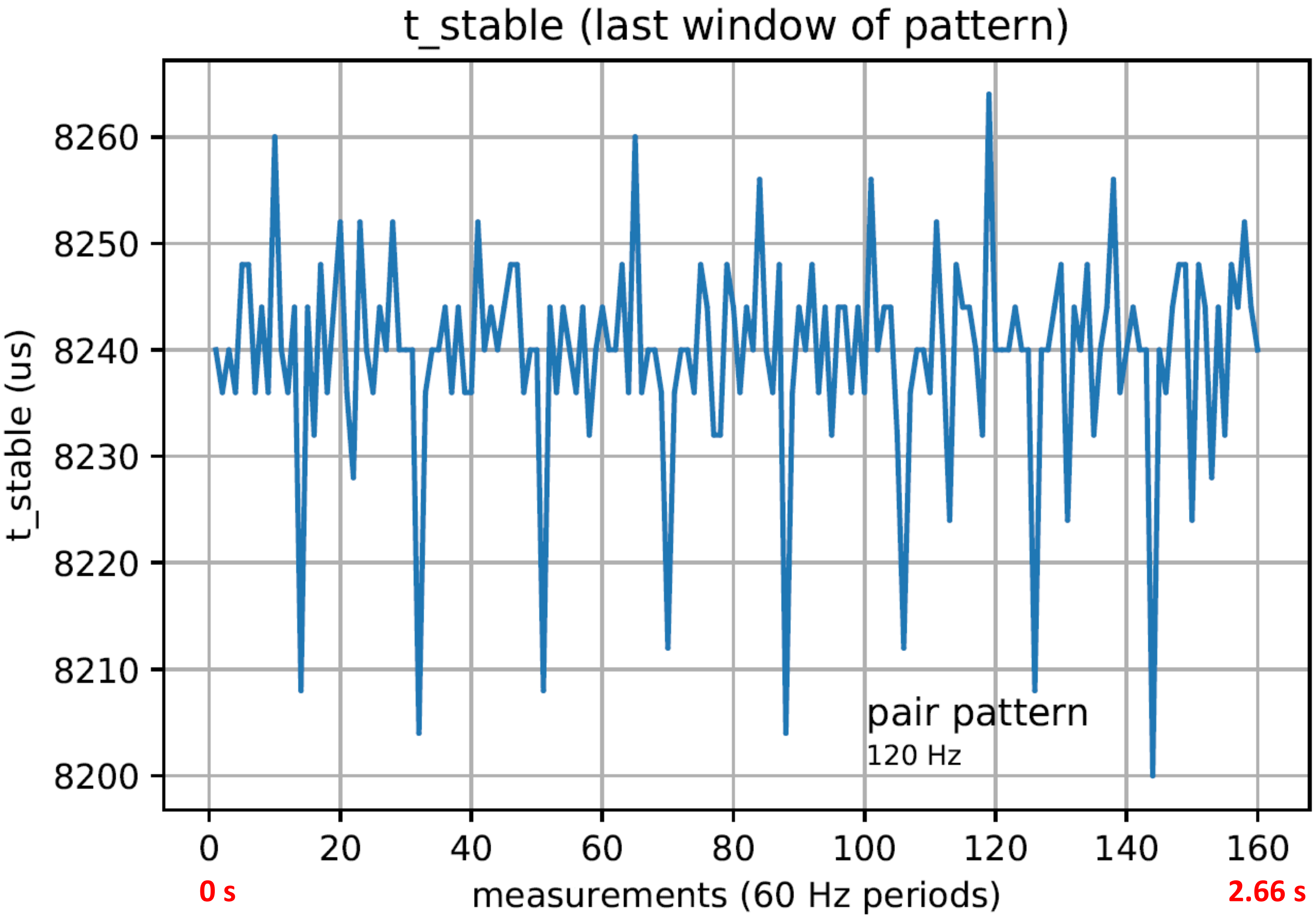
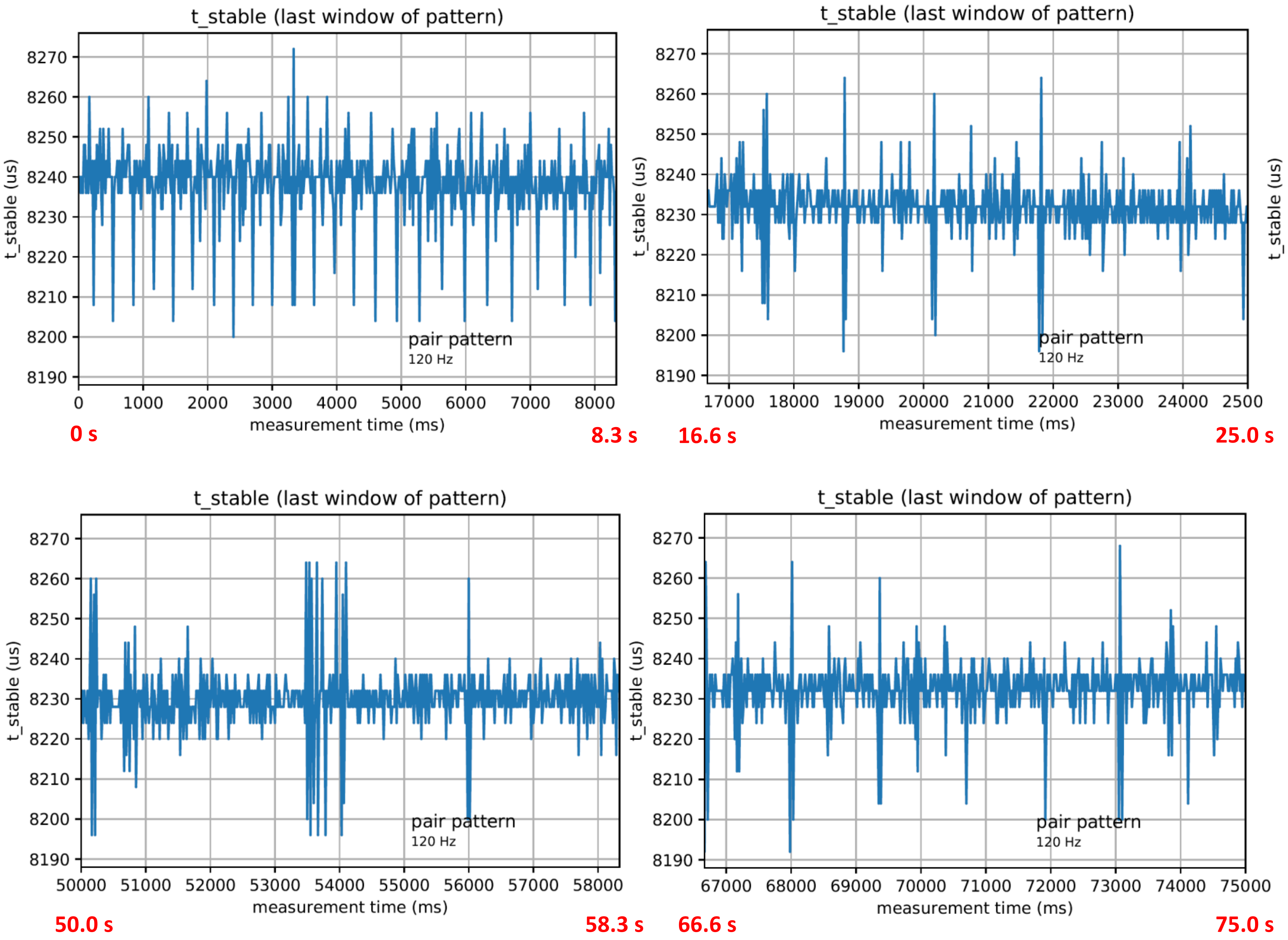

t_stable (last window of pattern)
t_stable (us)
8200
8210
8220
8230
8240
8250
8260
0
20
40
60
80
100
120
140
160
measurements (60 Hz periods)
0 s
2.66 s
pair pattern
120 Hz

Figure 28



(each plot shows an 8.3s interval of data)

Figure 29

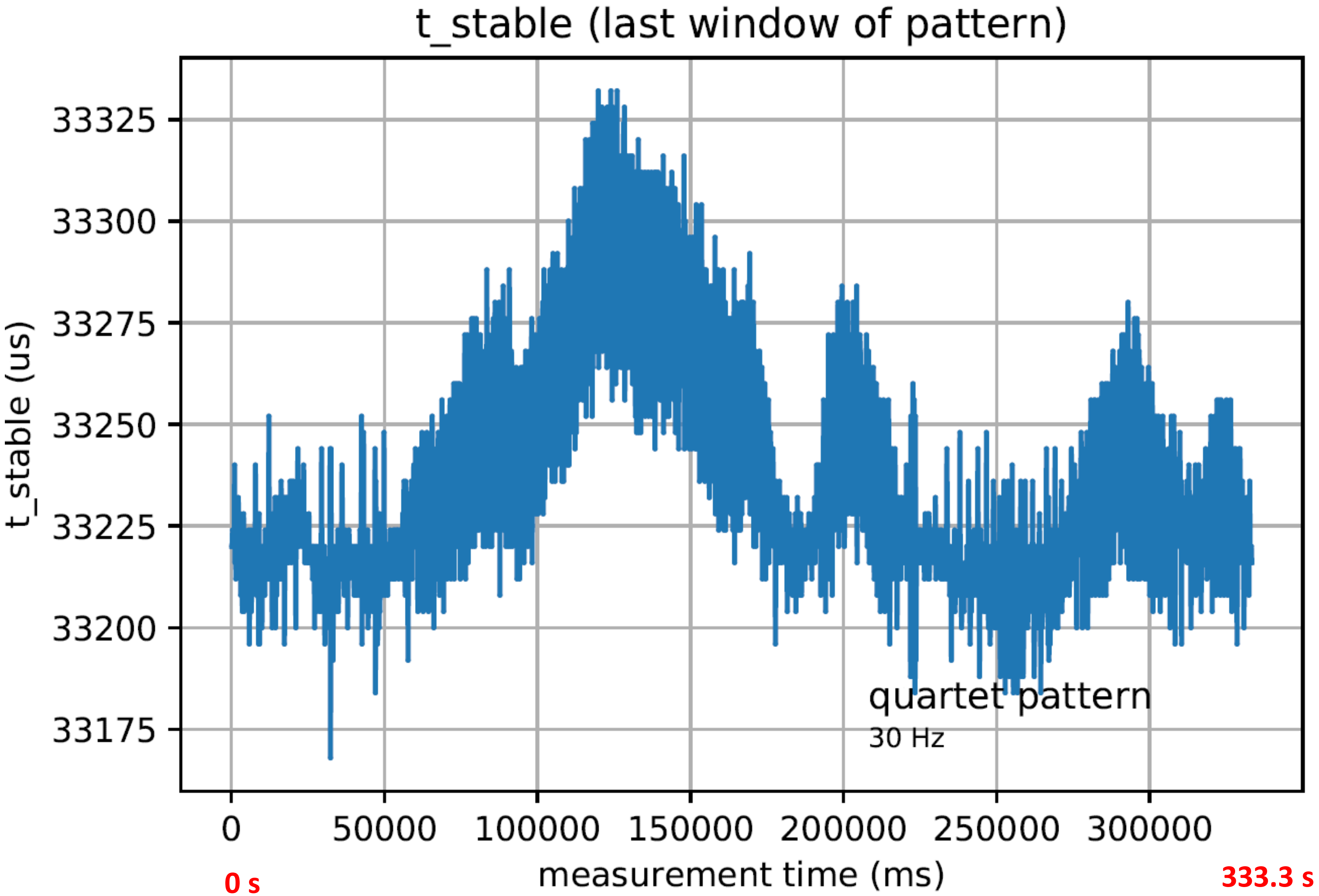
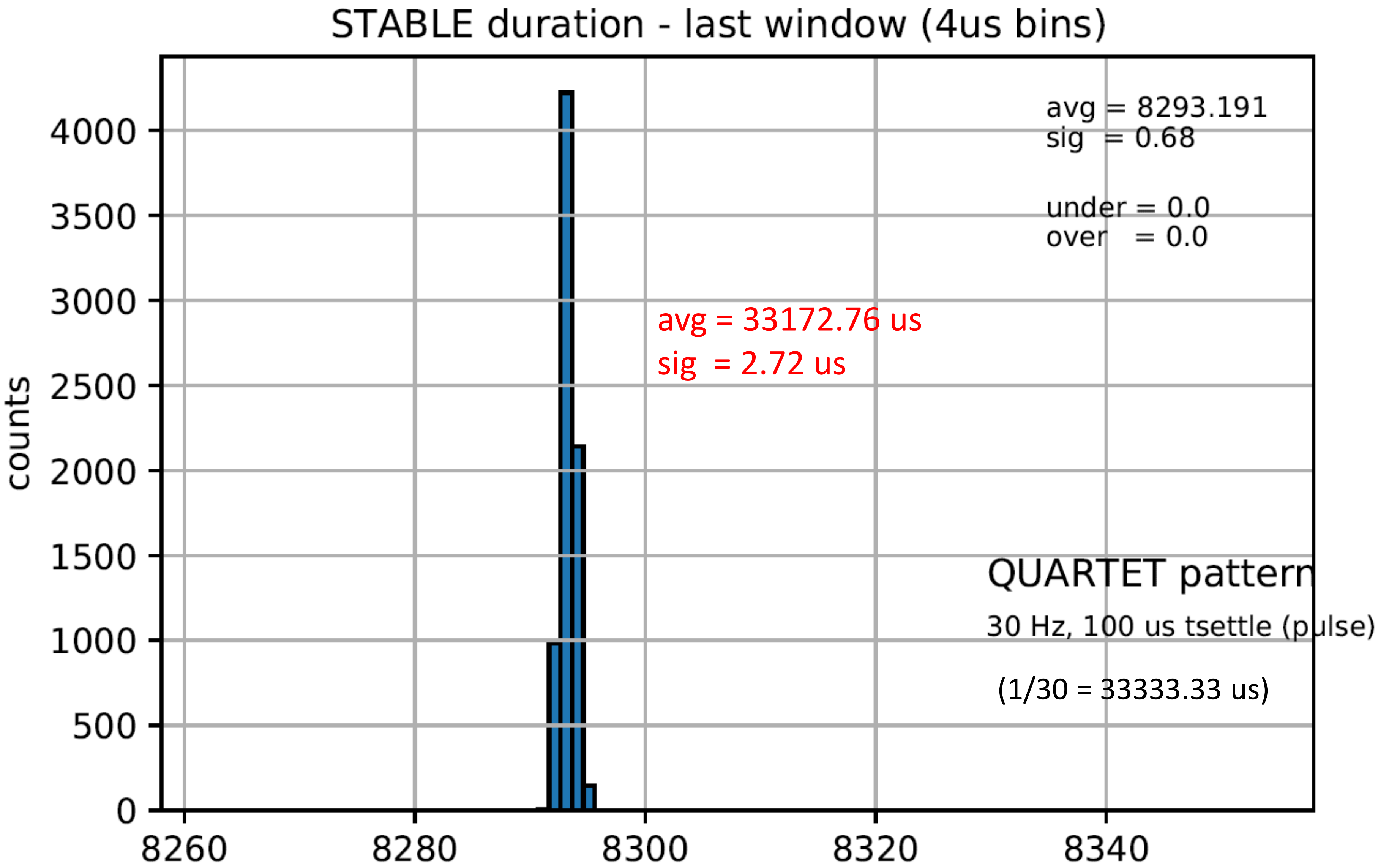

t_stable (last window of pattern)
t_stable (us)
33325
33300
33275
33250
33225
33200
33175
0
50000
100000
150000
200000
250000
300000
measurement time (ms)
quartet pattern
30 Hz
0 s
333.3 s

Figure 30

Signal source: HP Pulse Generator



avg = 33172.76 us
sig = 2.72 us

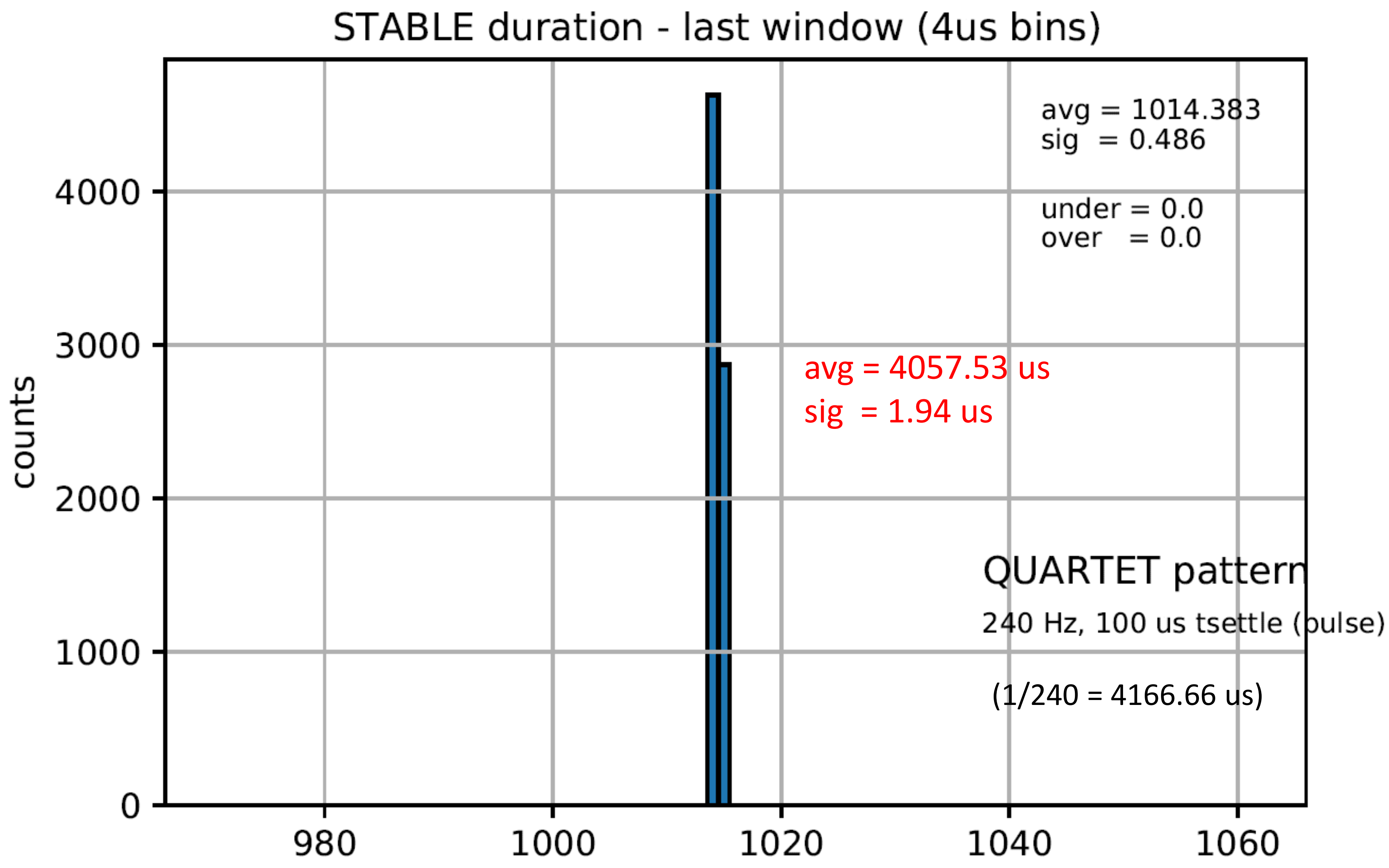
QUARTET pattern

30 Hz, 100 us tsettle (pulse)

(1/30 = 33333.33 us)

Figure 31

Signal source: HP Pulse Generator



avg = 4057.53 us
sig = 1.94 us

QUARTET pattern

240 Hz, 100 us tsettle (pulse)

(1/240 = 4166.66 us)