A Comprehensive Study of the Beam Sync Mode

E.J. 11/12/24

- 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 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.
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- 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.
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- **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.

Figure 1

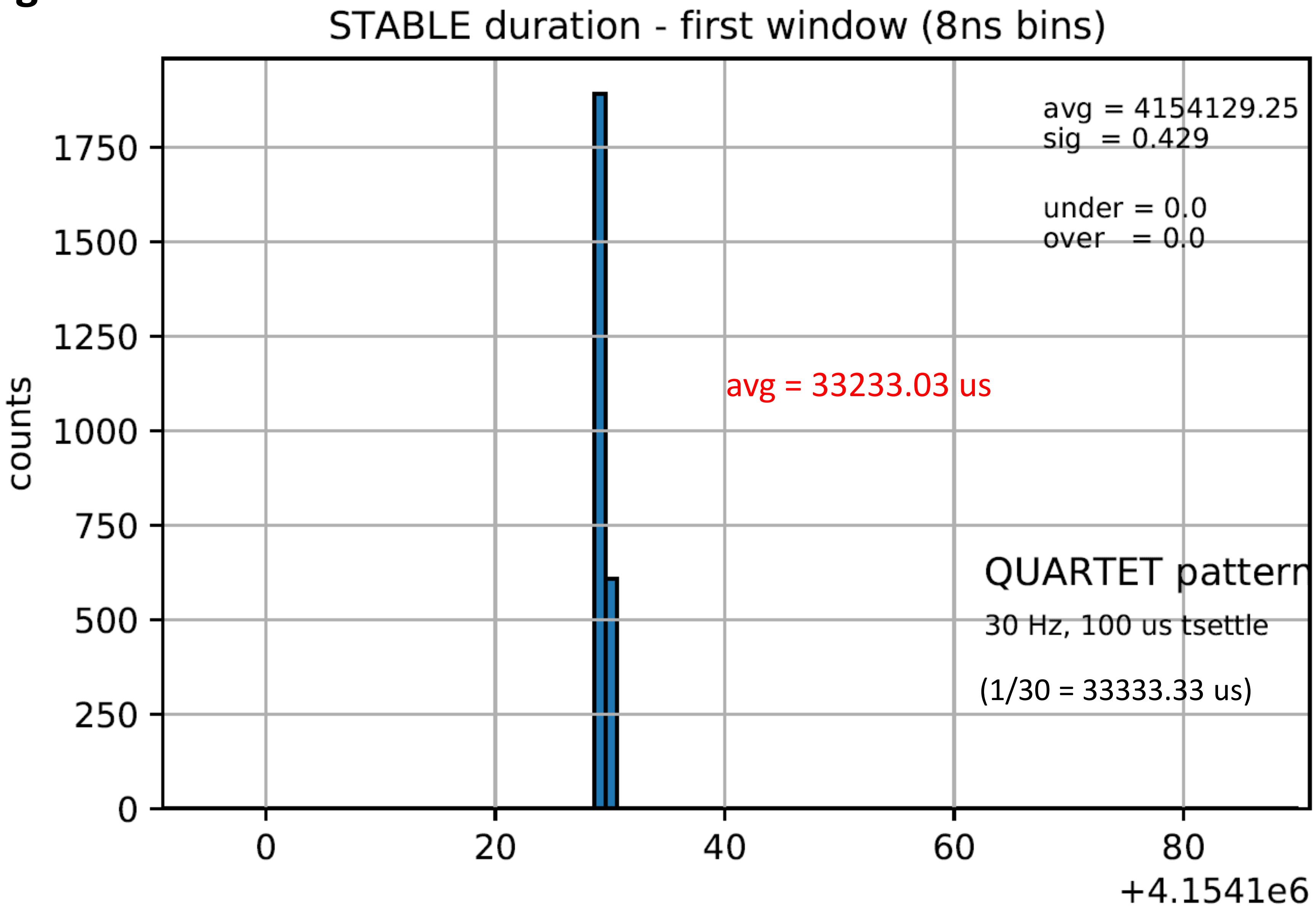
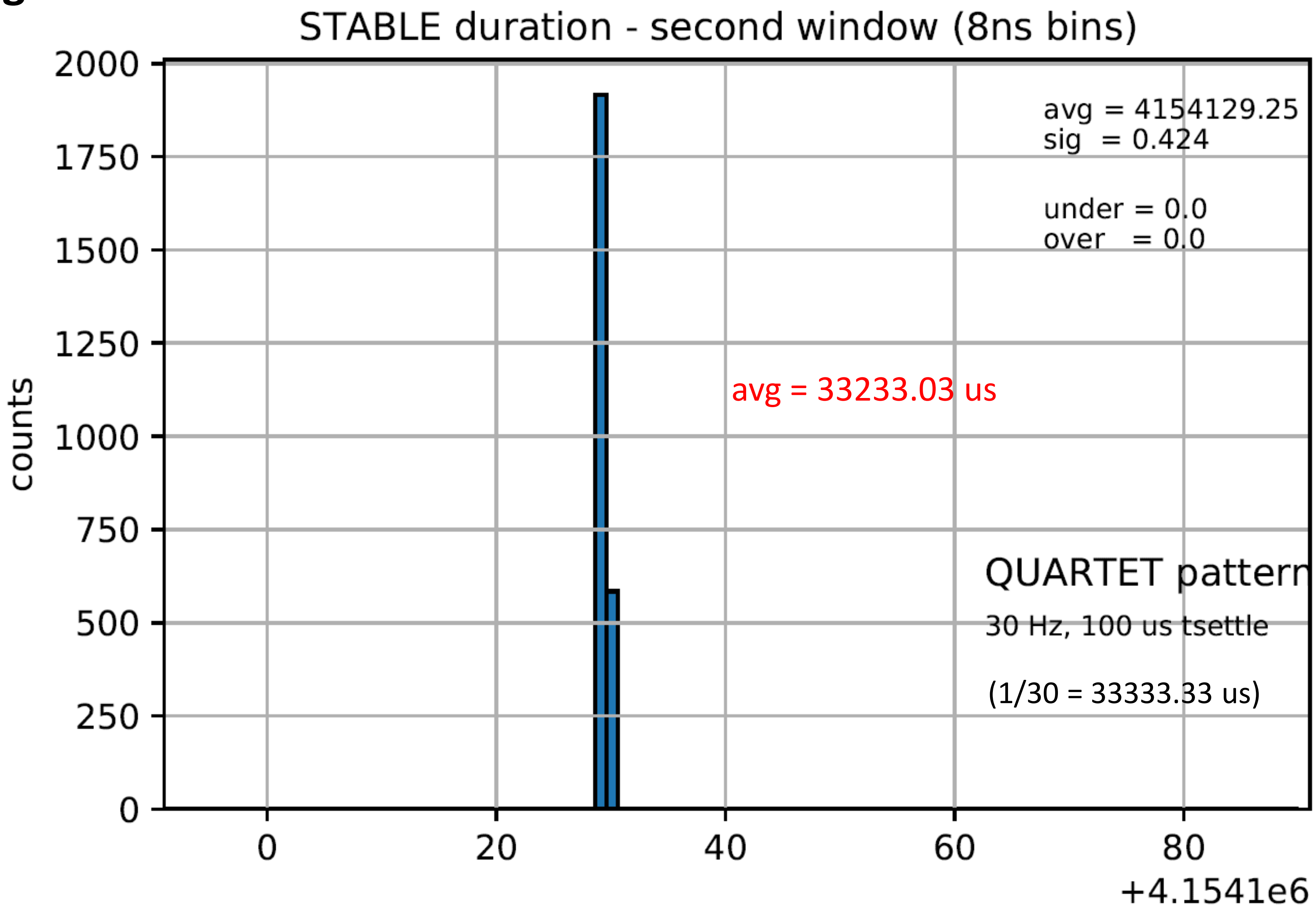

STABLE duration - first window (8ns bins)
avg = 4154129.25
sig = 0.429
under = 0.0
over = 0.0
avg = 33233.03 us
QUARTET pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)
counts
1750
1500
1250
1000
750
500
250
0
0
20
40
60
80
+4.1541e6

Figure 2



STABLE duration - second window (8ns bins)
2000
1750
1500
1250
1000
750
500
250
0
counts
0
20
40
60
80
+4.1541e6
avg = 4154129.25
sig = 0.424
under = 0.0
over = 0.0
avg = 33233.03 us
QUARTET pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 3

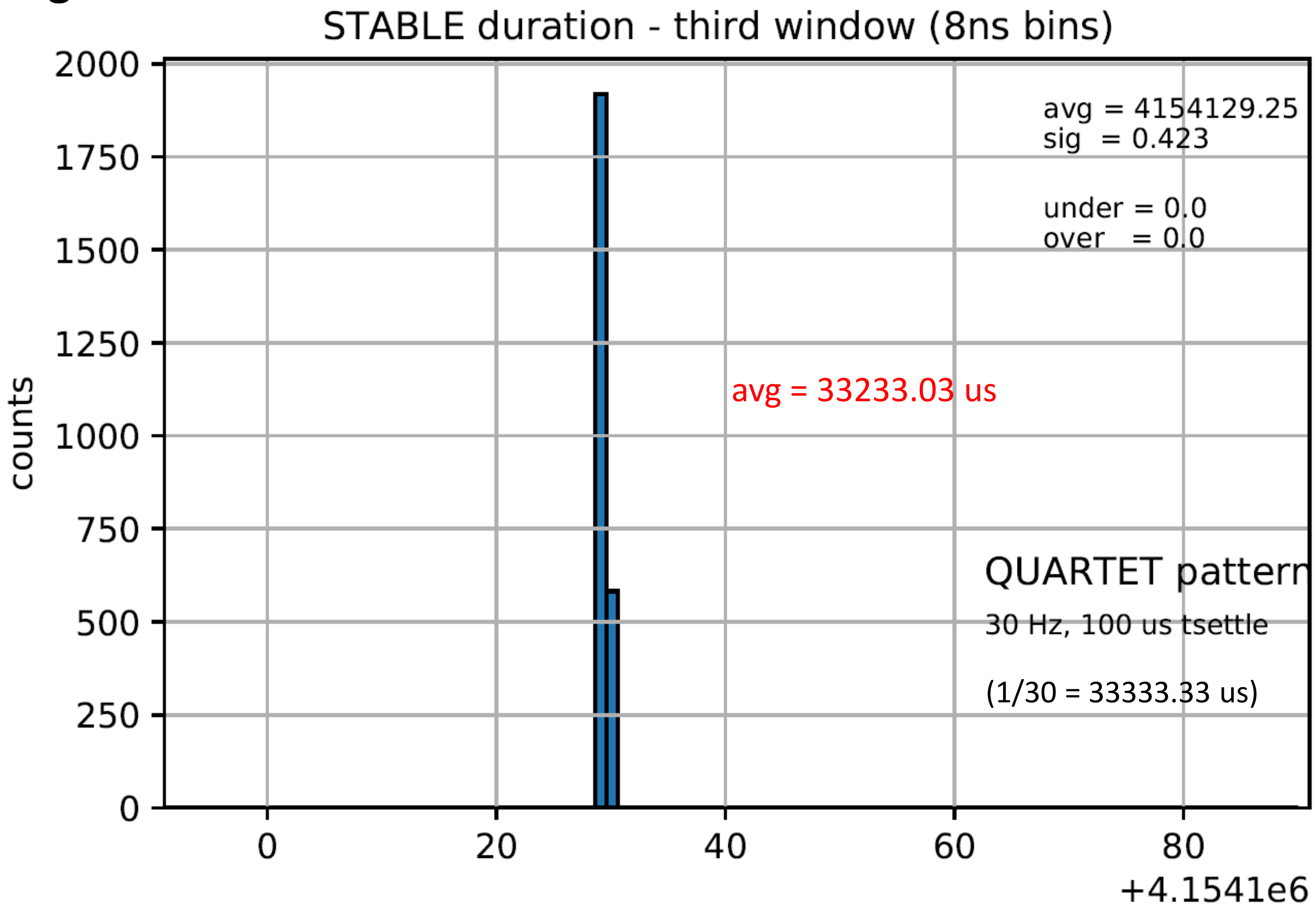

STABLE duration - third window (8ns bins)
counts
2000
1750
1500
1250
1000
750
500
250
0
0
20
40
60
80
+4.1541e6
avg = 4154129.25
sig = 0.423
under = 0.0
over = 0.0
avg = 33233.03 us
QUARTET pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 4

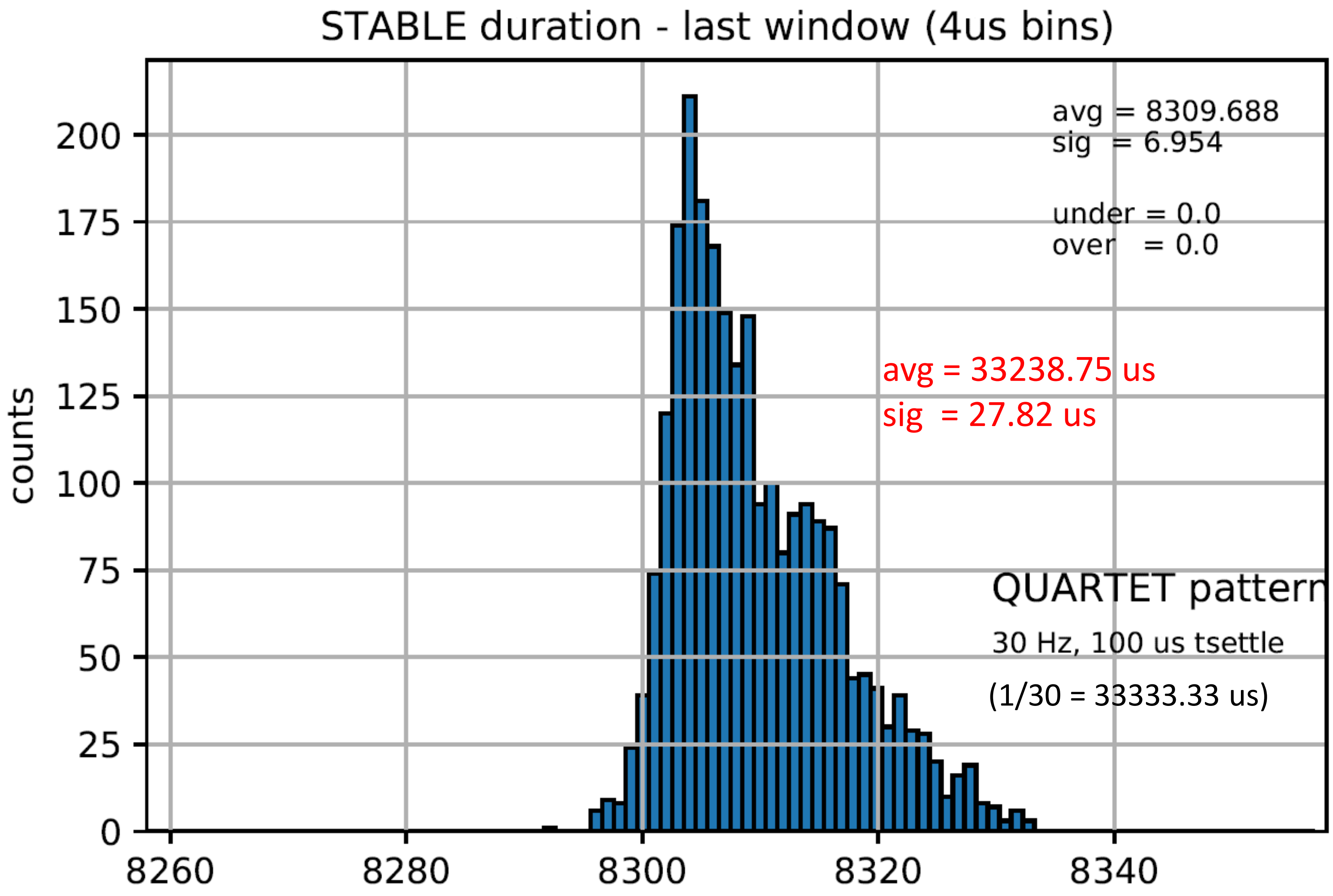

STABLE duration - last window (4us bins)
counts
200
175
150
125
100
75
50
25
0
8260
8280
8300
8320
8340
avg = 8309.688
sig = 6.954
under = 0.0
over = 0.0
avg = 33238.75 us
sig = 27.82 us
QUARTET pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 5

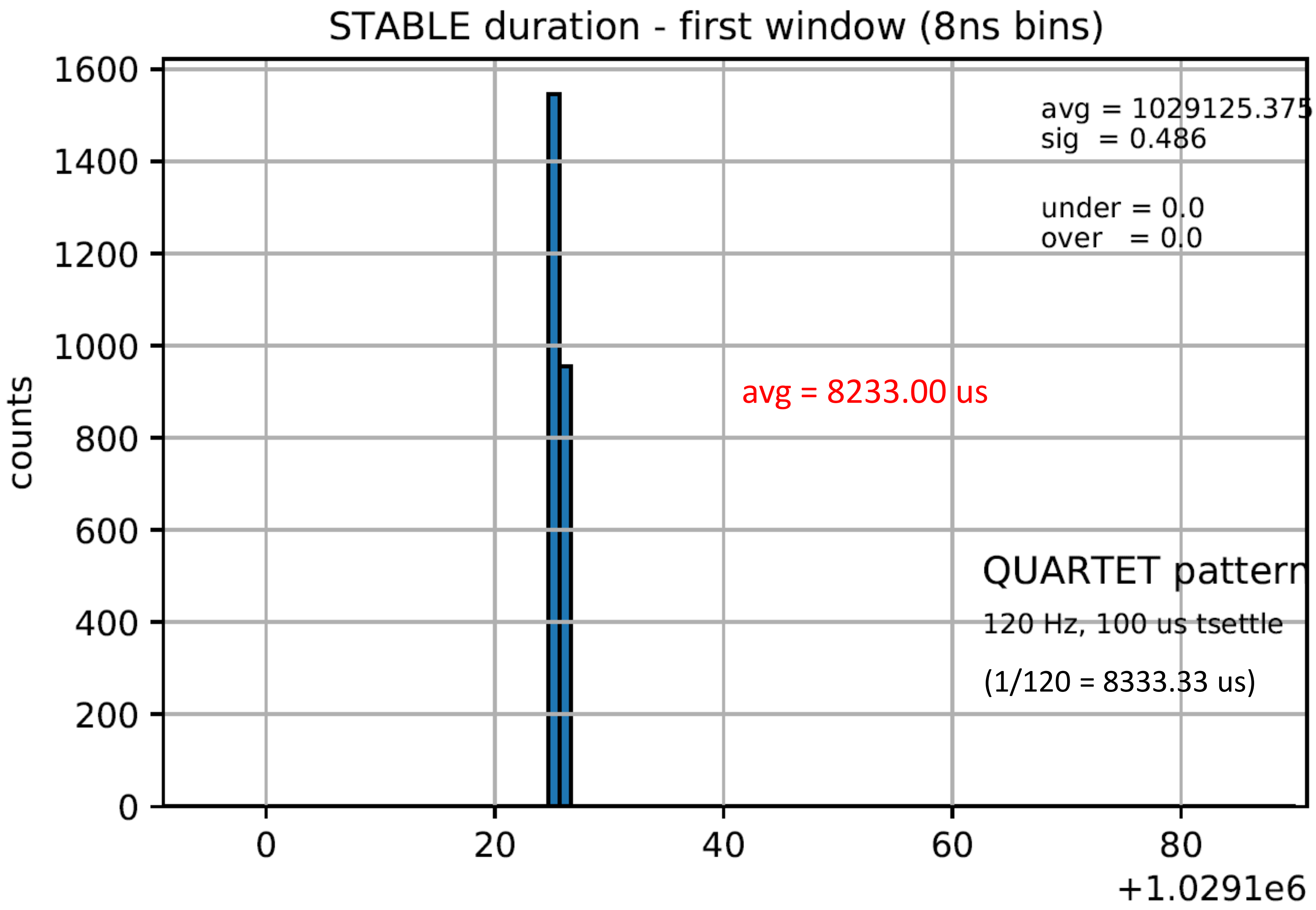

STABLE duration - first window (8ns bins)
1600
1400
1200
1000
800
600
400
200
0
counts
0
20
40
60
80
+1.0291e6
avg = 1029125.375
sig = 0.486
under = 0.0
over = 0.0
avg = 8233.00 us
QUARTET pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 6

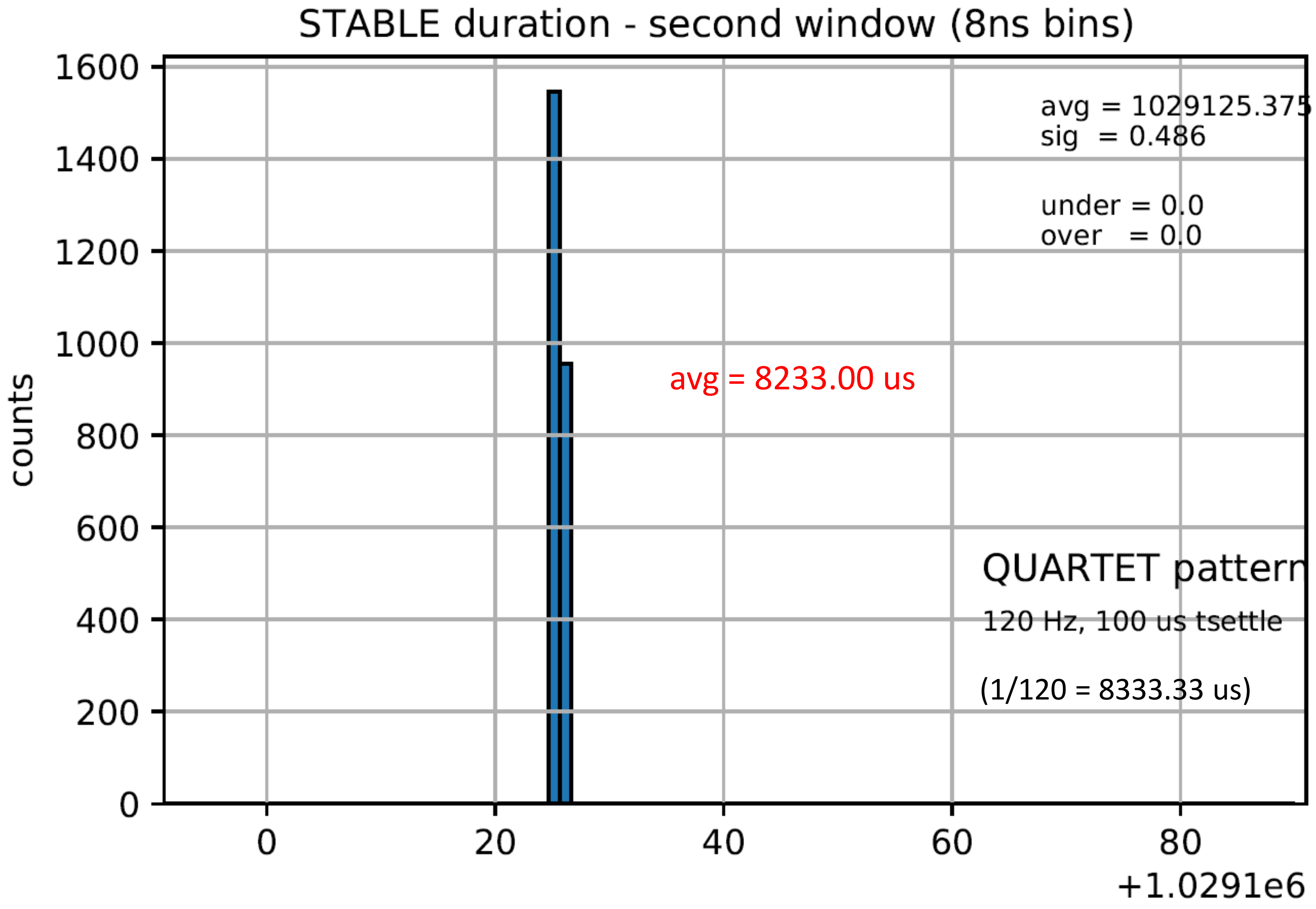
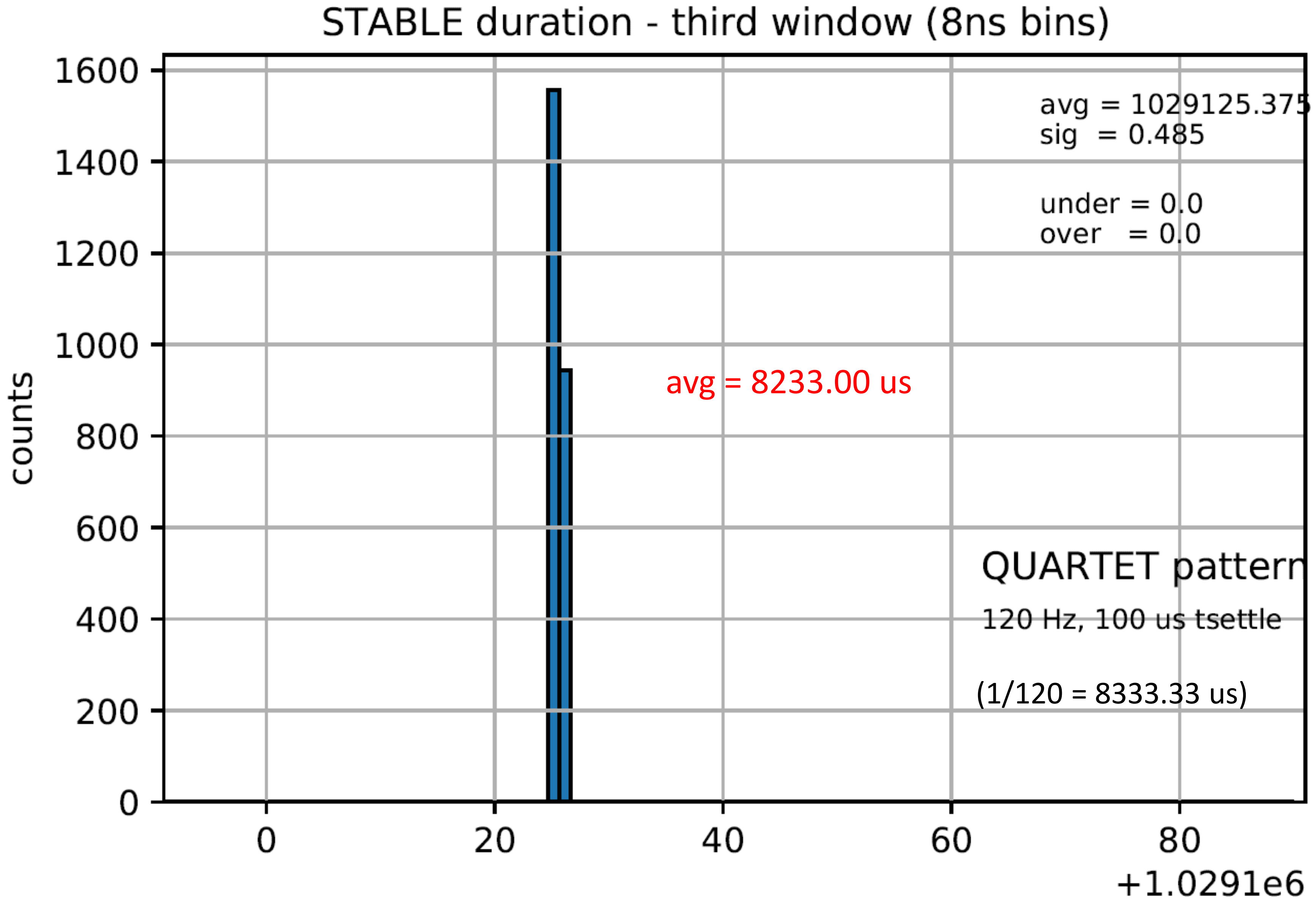

STABLE duration - second window (8ns bins)
avg = 1029125.375
sig = 0.486
under = 0.0
over = 0.0
avg = 8233.00 us
QUARTET pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)
counts
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
+1.0291e6

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

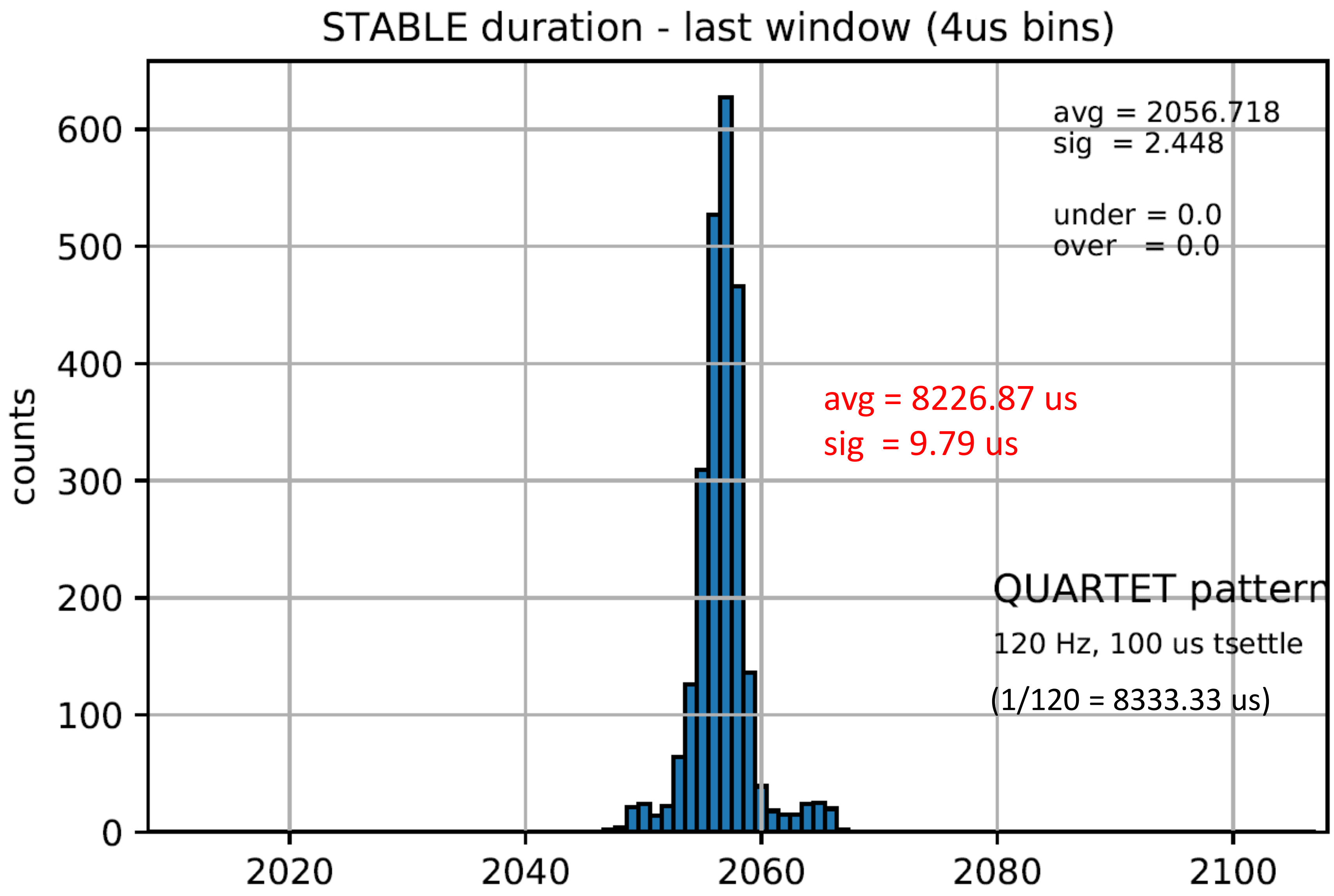

STABLE duration - last window (4us bins)
avg = 2056.718
sig = 2.448
under = 0.0
over = 0.0
avg = 8226.87 us
sig = 9.79 us
QUARTET pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)
counts
0
100
200
300
400
500
600
2020
2040
2060
2080
2100

Figure 9

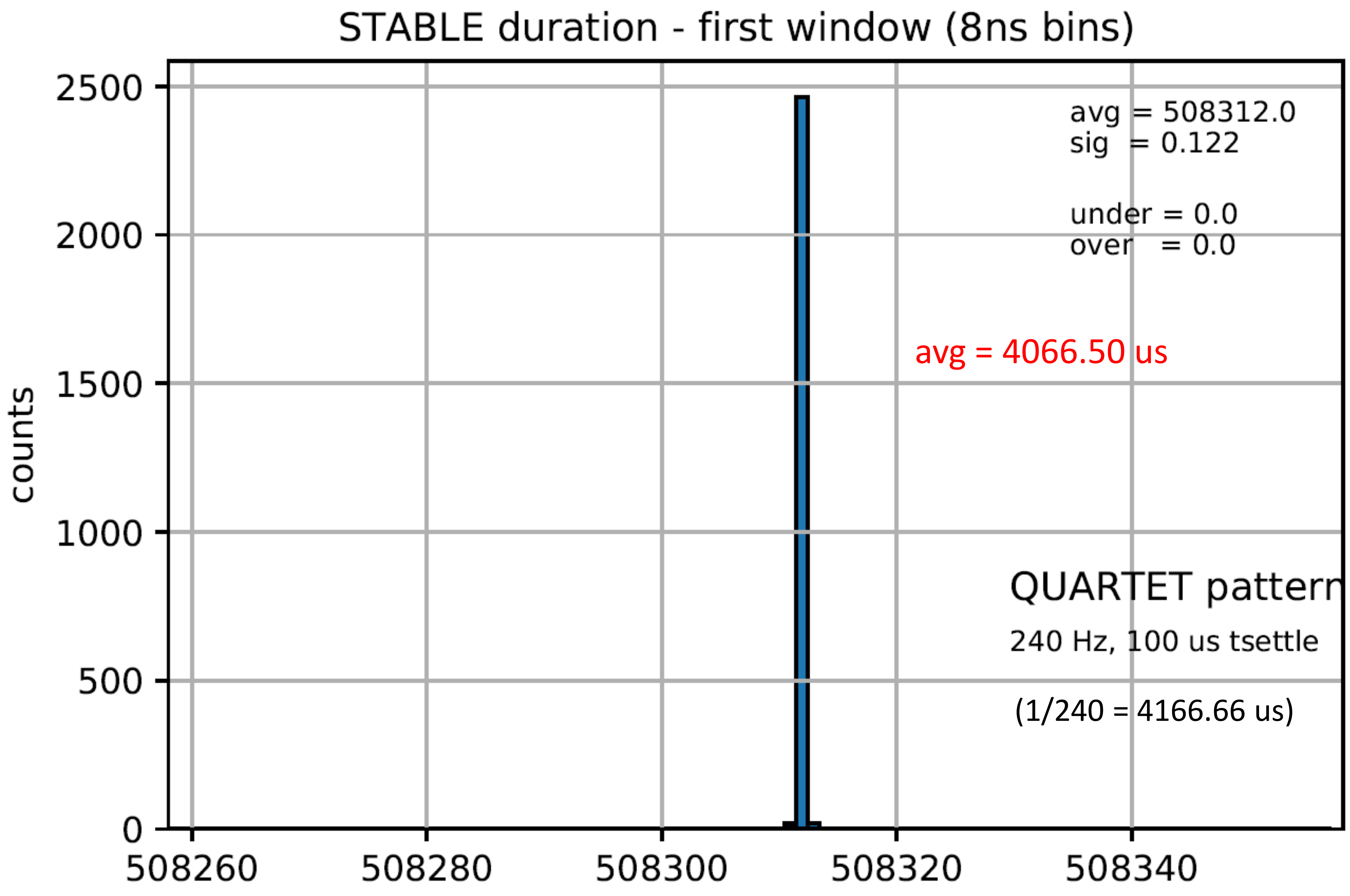

STABLE duration - first window (8ns bins)
avg = 508312.0
sig = 0.122
under = 0.0
over = 0.0
avg = 4066.50 us
QUARTET pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
2500
2000
1500
1000
500
0
508260
508280
508300
508320
508340

Figure 10

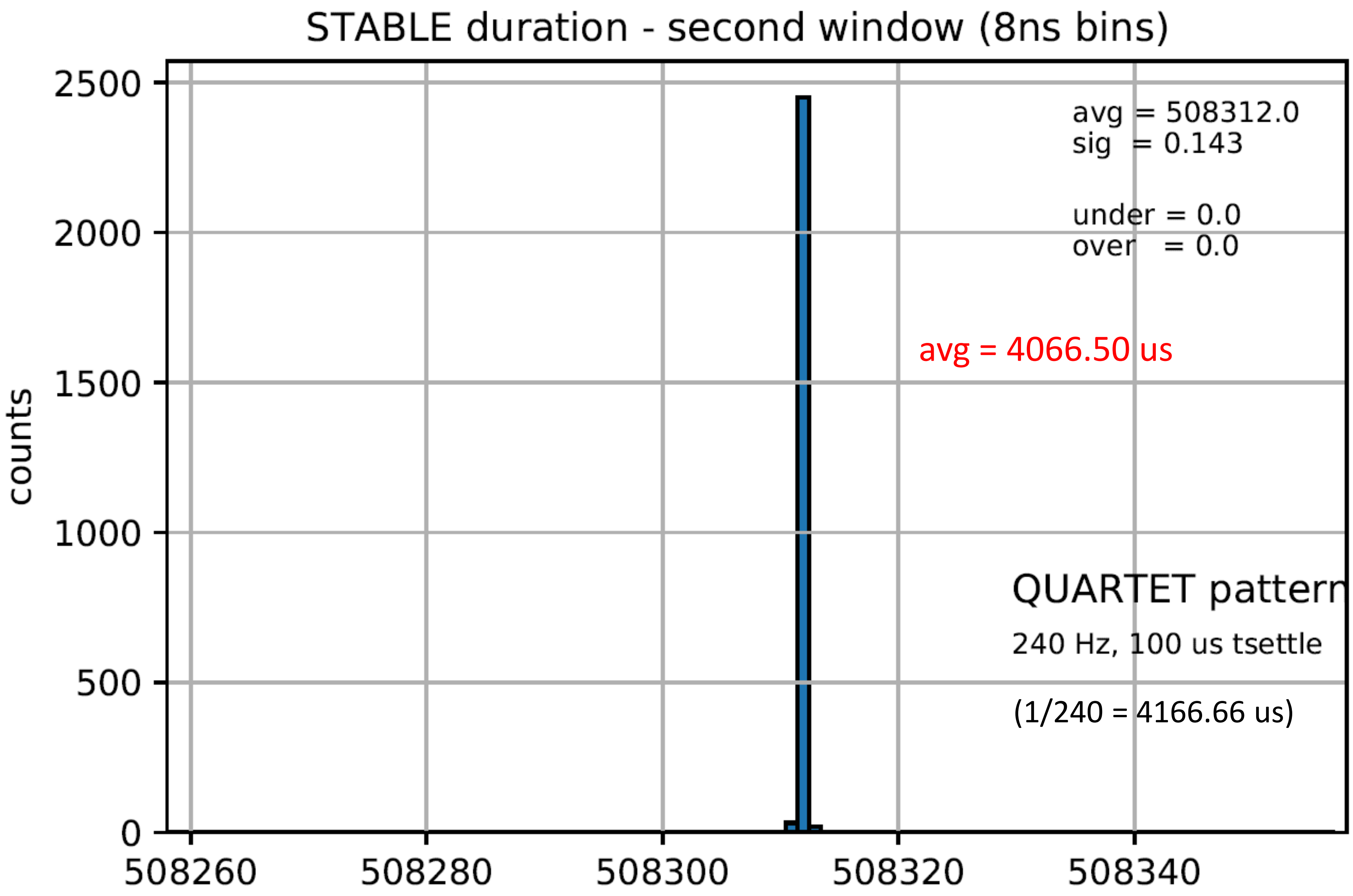

STABLE duration - second window (8ns bins)
counts
2500
2000
1500
1000
500
0
508260
508280
508300
508320
508340
avg = 508312.0
sig = 0.143
under = 0.0
over = 0.0
avg = 4066.50 us
QUARTET pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)

Figure 11

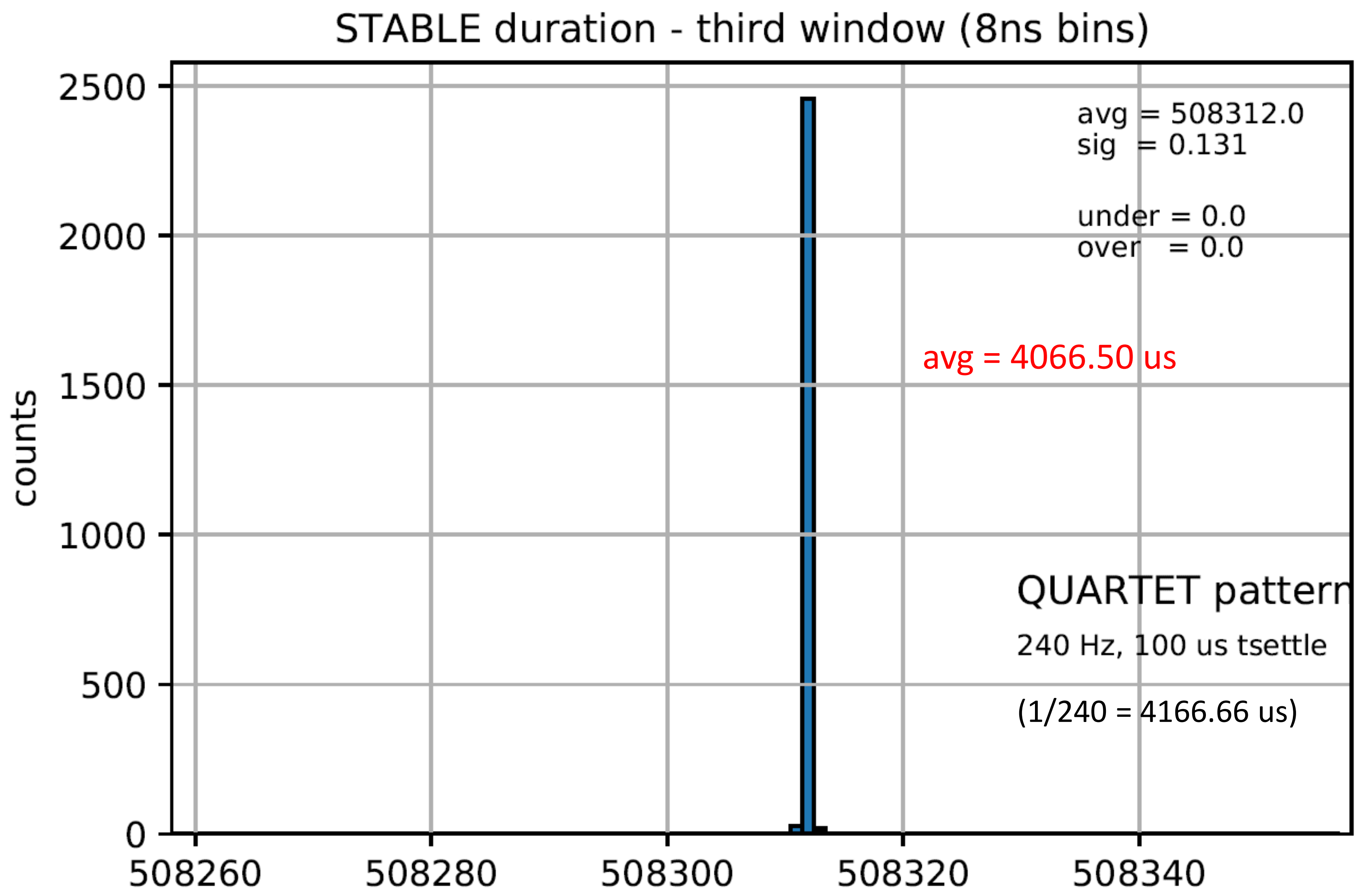

STABLE duration - third window (8ns bins)
counts
2500
2000
1500
1000
500
0
508260
508280
508300
508320
508340
avg = 508312.0
sig = 0.131
under = 0.0
over = 0.0
avg = 4066.50 us
QUARTET pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)

Figure 12

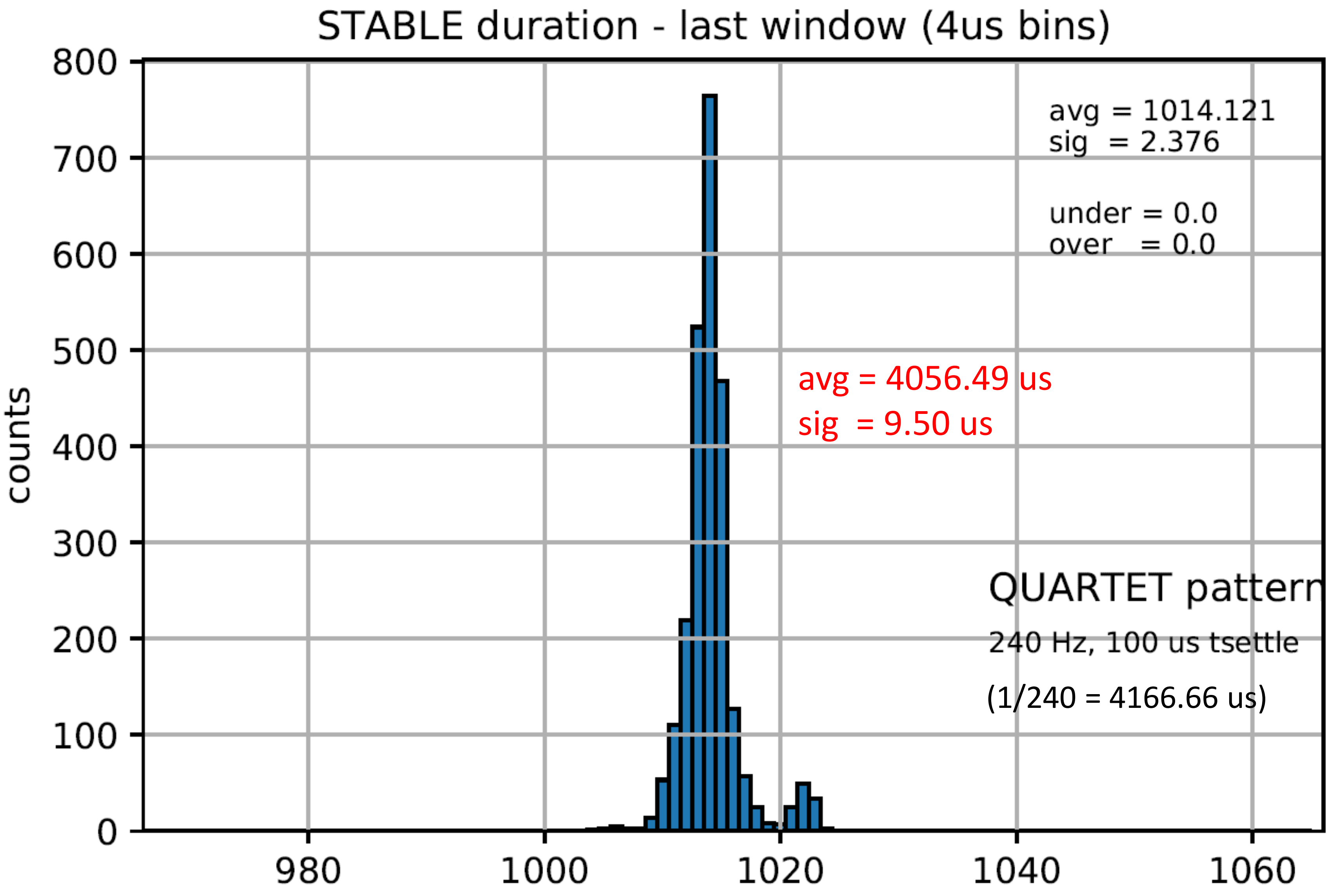

STABLE duration - last window (4us bins)
counts
avg = 1014.121
sig = 2.376
under = 0.0
over = 0.0
avg = 4056.49 us
sig = 9.50 us
QUARTET pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
800
700
600
500
400
300
200
100
0
980
1000
1020
1040
1060

Figure 13

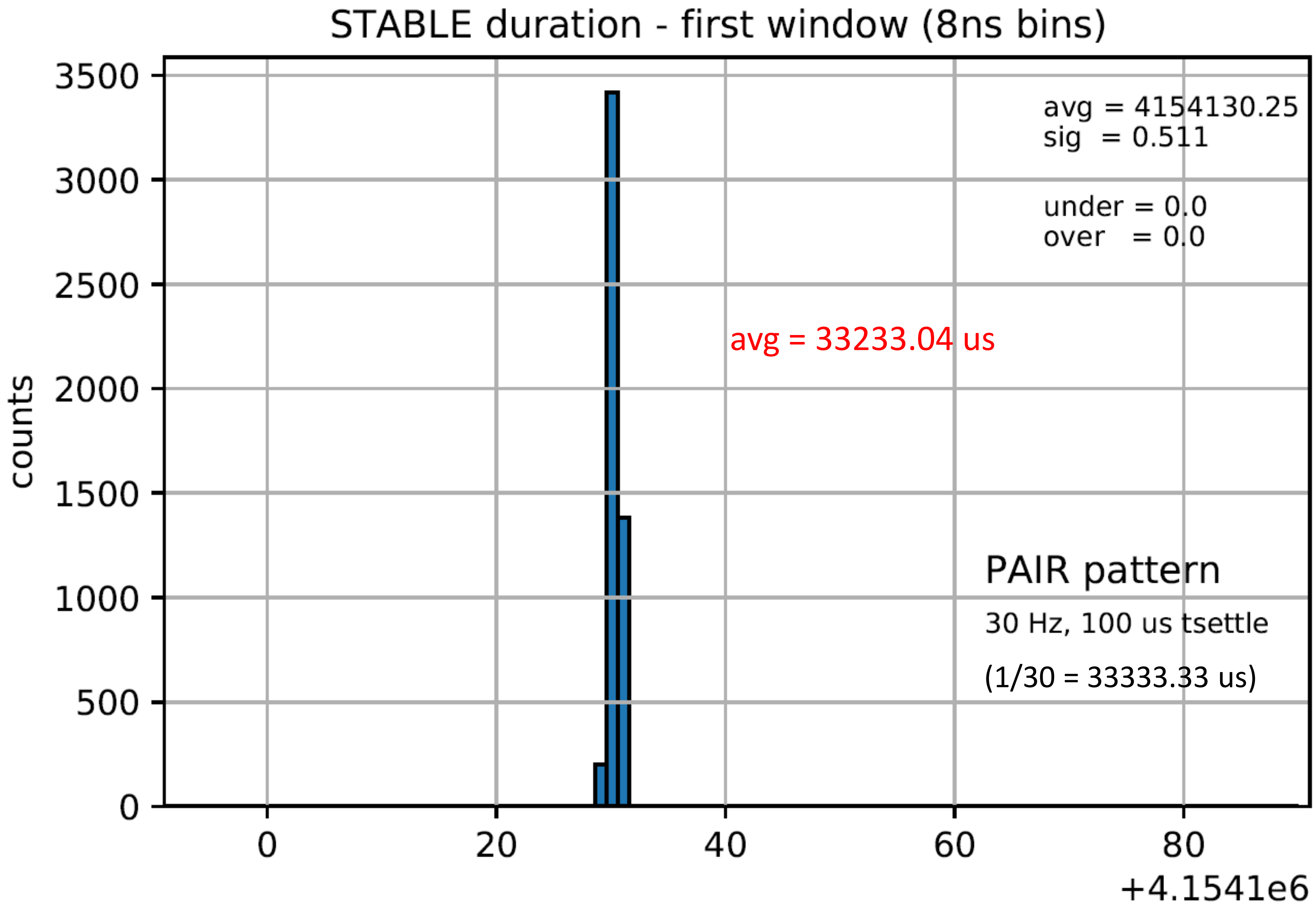

STABLE duration - first window (8ns bins)
avg = 4154130.25
sig = 0.511
under = 0.0
over = 0.0
avg = 33233.04 us
PAIR pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)
counts
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+4.1541e6

Figure 14

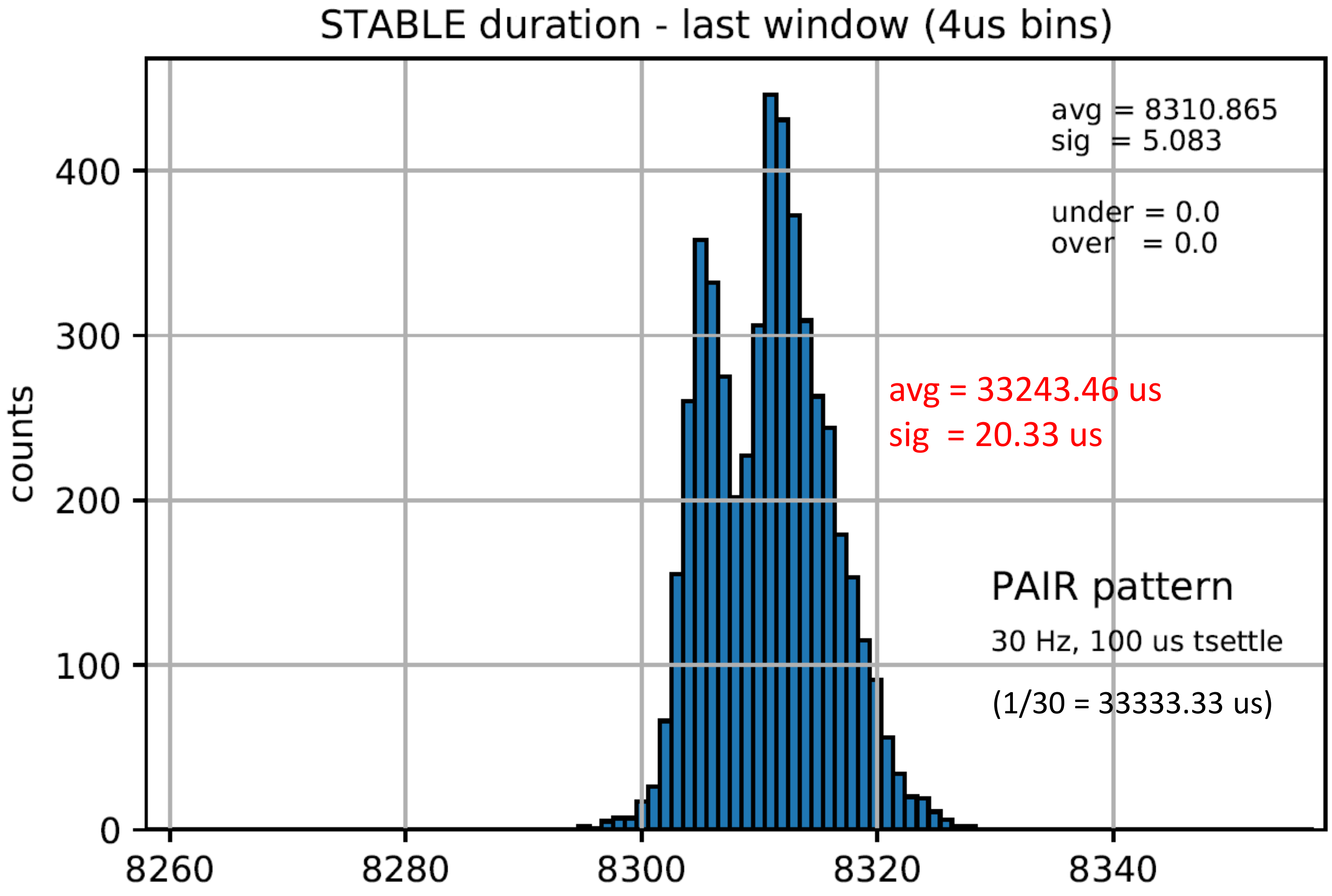

STABLE duration - last window (4us bins)
counts
400
300
200
100
0
8260
8280
8300
8320
8340
avg = 8310.865
sig = 5.083
under = 0.0
over = 0.0
avg = 33243.46 us
sig = 20.33 us
PAIR pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 15

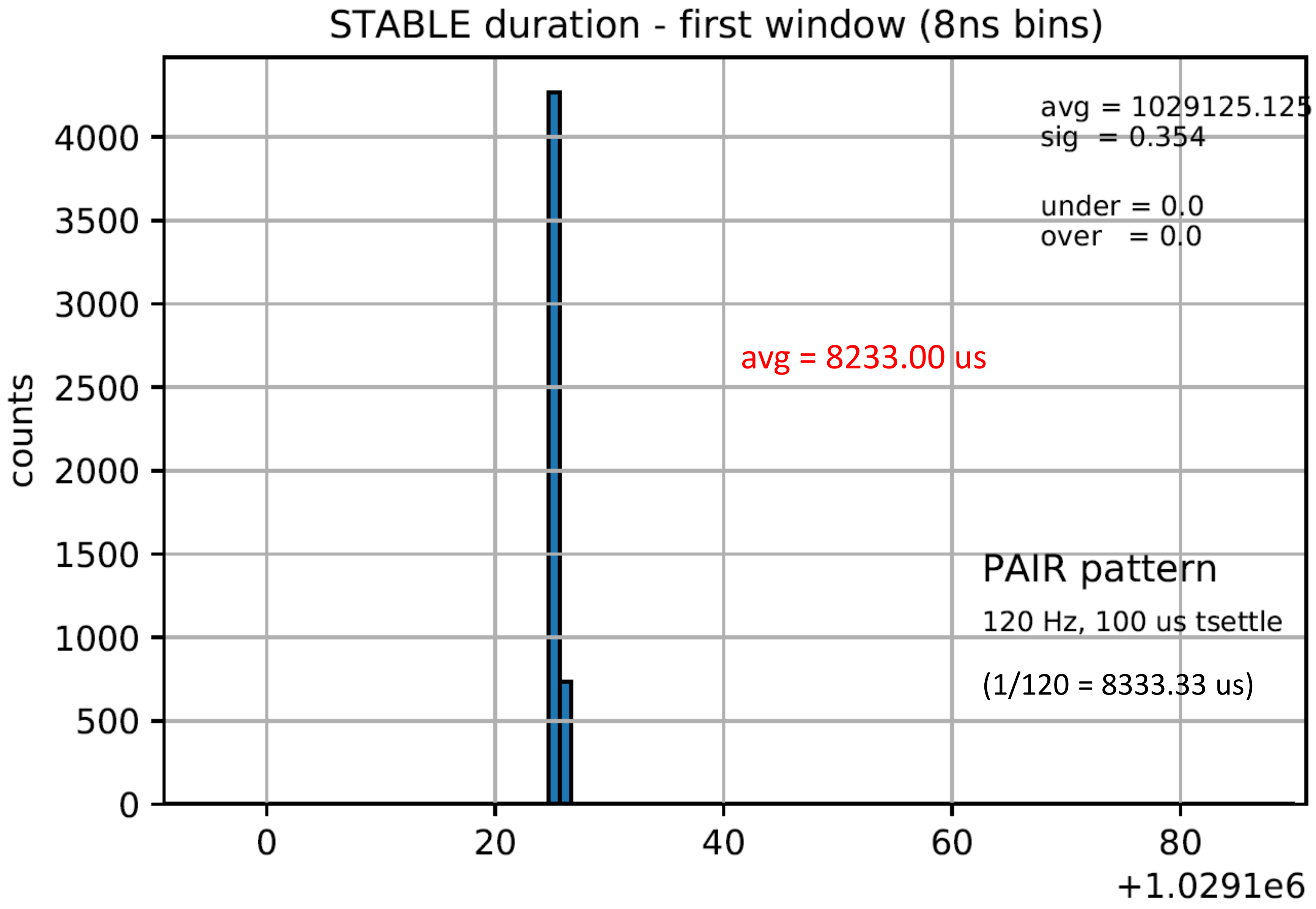

STABLE duration - first window (8ns bins)
avg = 1029125.125
sig = 0.354
under = 0.0
over = 0.0
avg = 8233.00 us
PAIR pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)
counts
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+1.0291e6

Figure 16

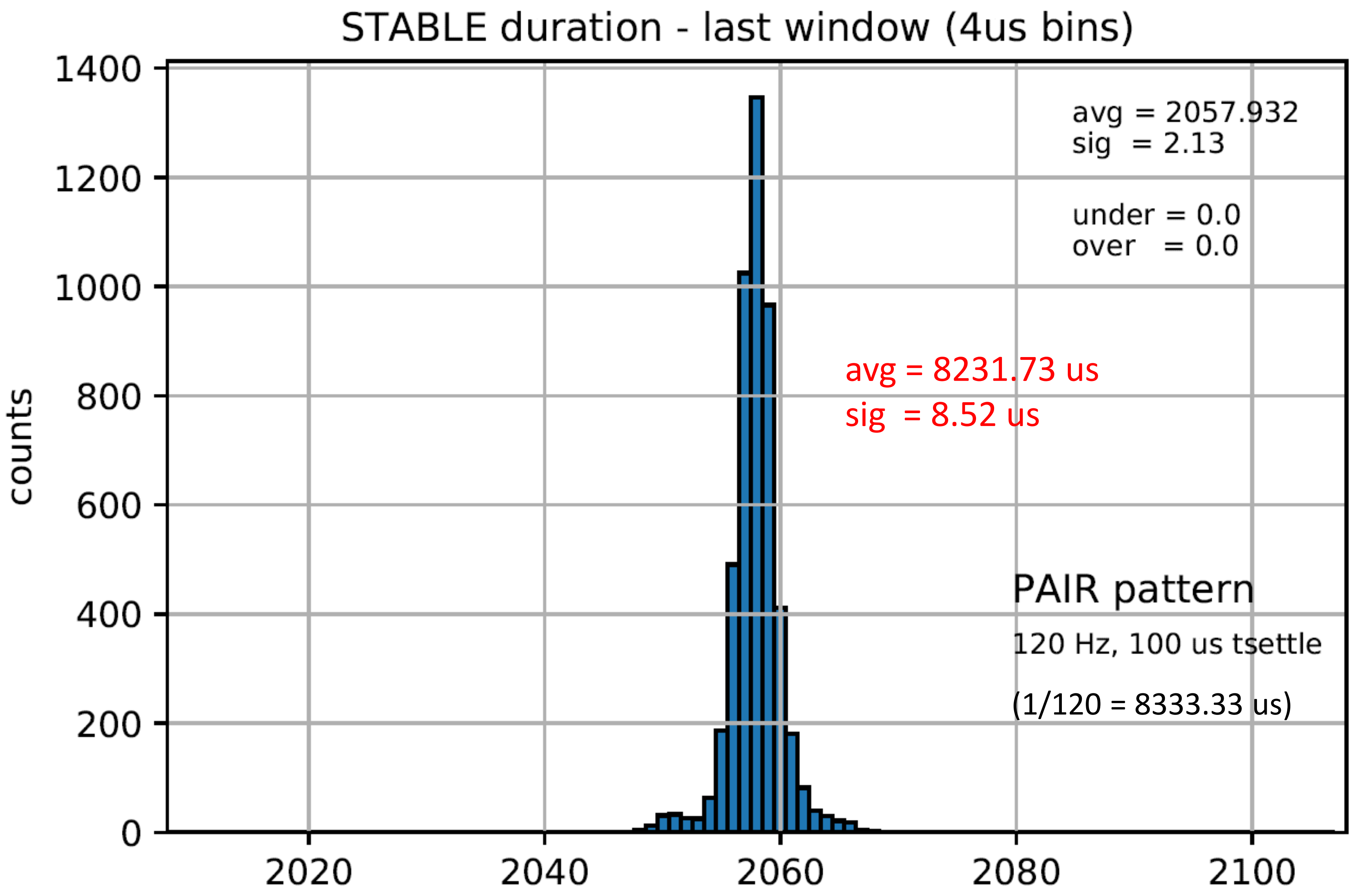
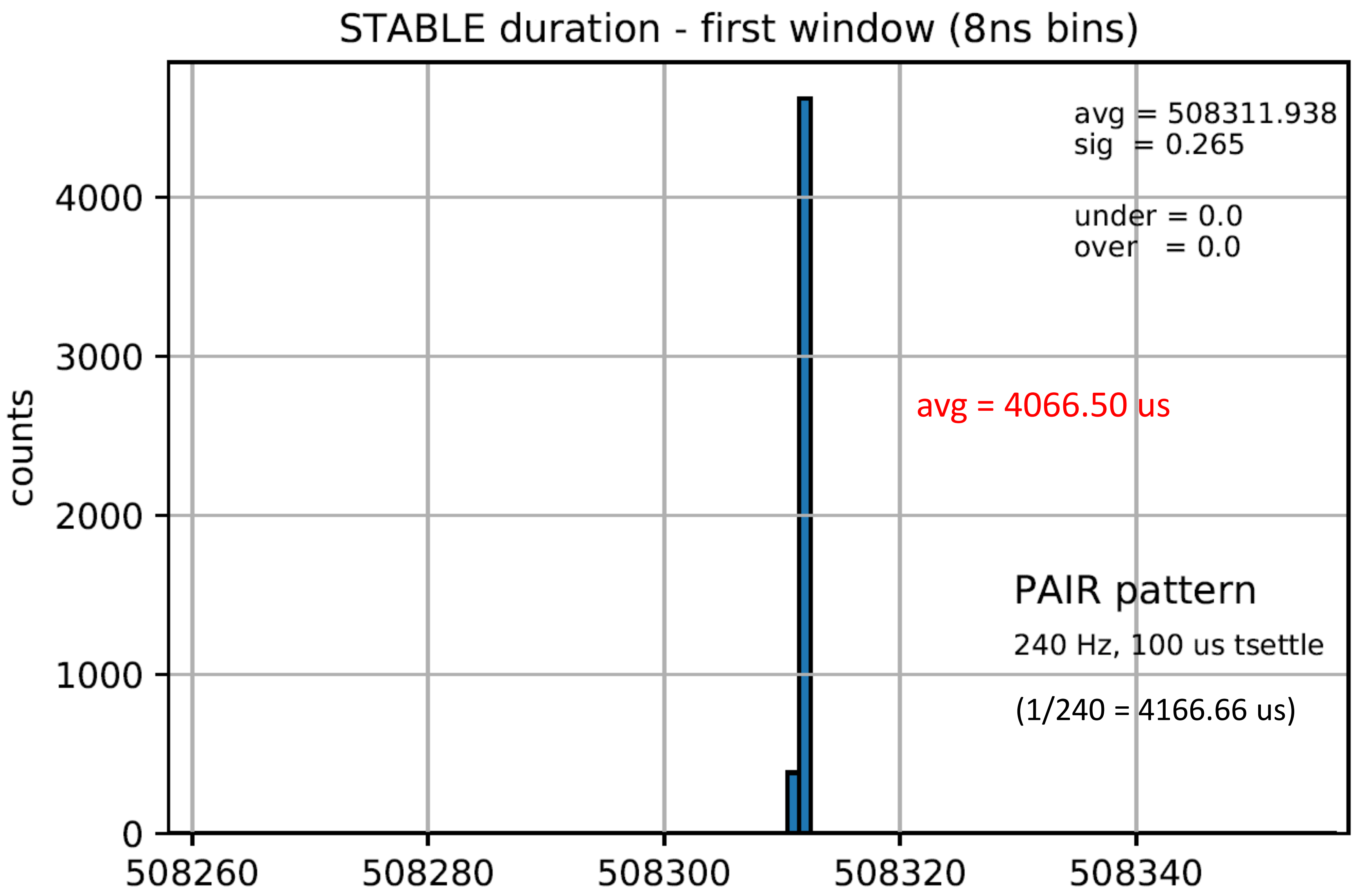

STABLE duration - last window (4us bins)
counts
1400
1200
1000
800
600
400
200
0
2020
2040
2060
2080
2100
avg = 2057.932
sig = 2.13
under = 0.0
over = 0.0
avg = 8231.73 us
sig = 8.52 us
PAIR pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 17



STABLE duration - first window (8ns bins)
avg = 508311.938
sig = 0.265
under = 0.0
over = 0.0
avg = 4066.50 us
PAIR pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
4000
3000
2000
1000
0
508260
508280
508300
508320
508340

Figure 18

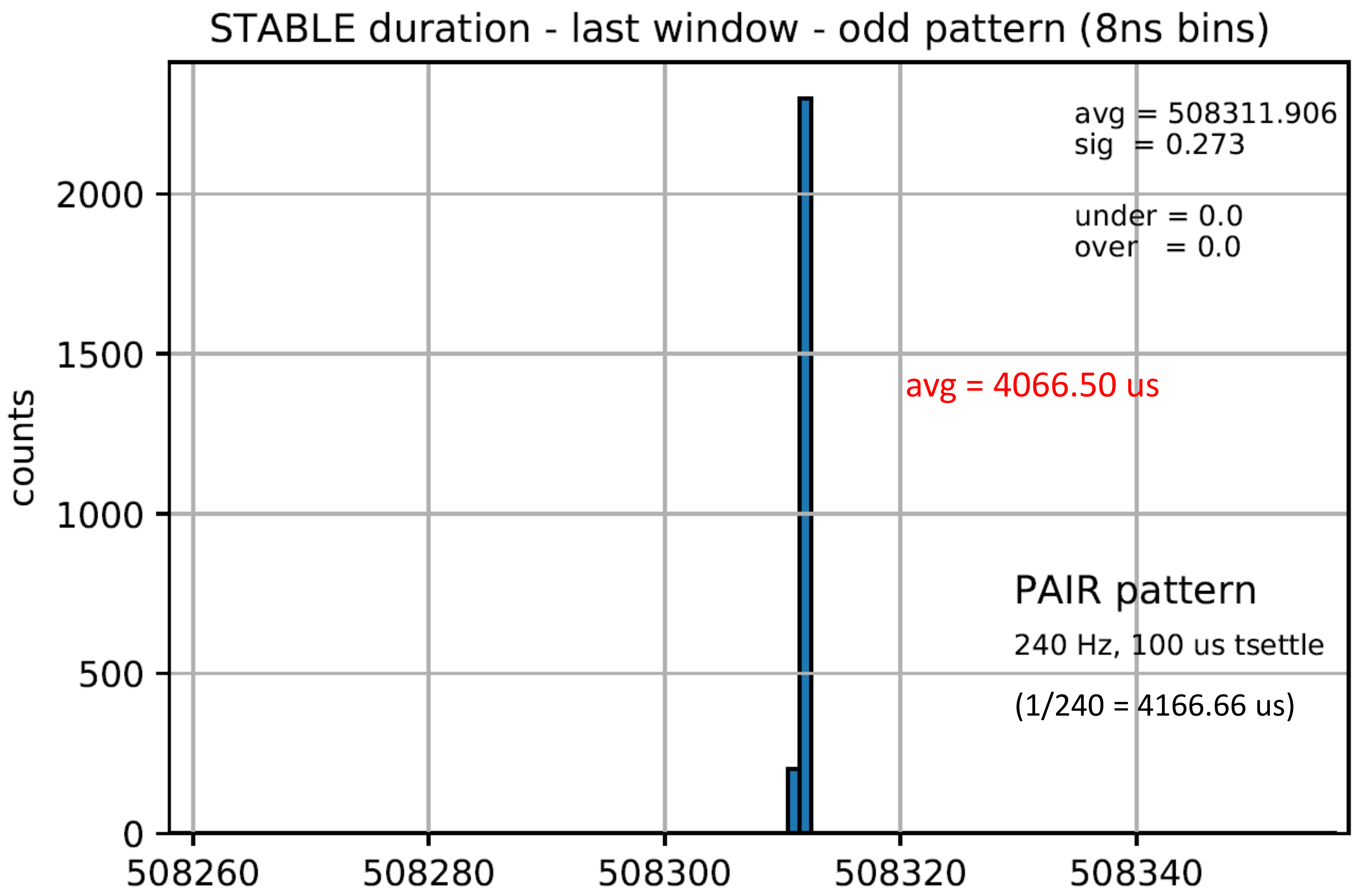

STABLE duration - last window - odd pattern (8ns bins)
avg = 508311.906
sig = 0.273
under = 0.0
over = 0.0
avg = 4066.50 us
PAIR pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
0
500
1000
1500
2000
508260
508280
508300
508320
508340

Figure 19

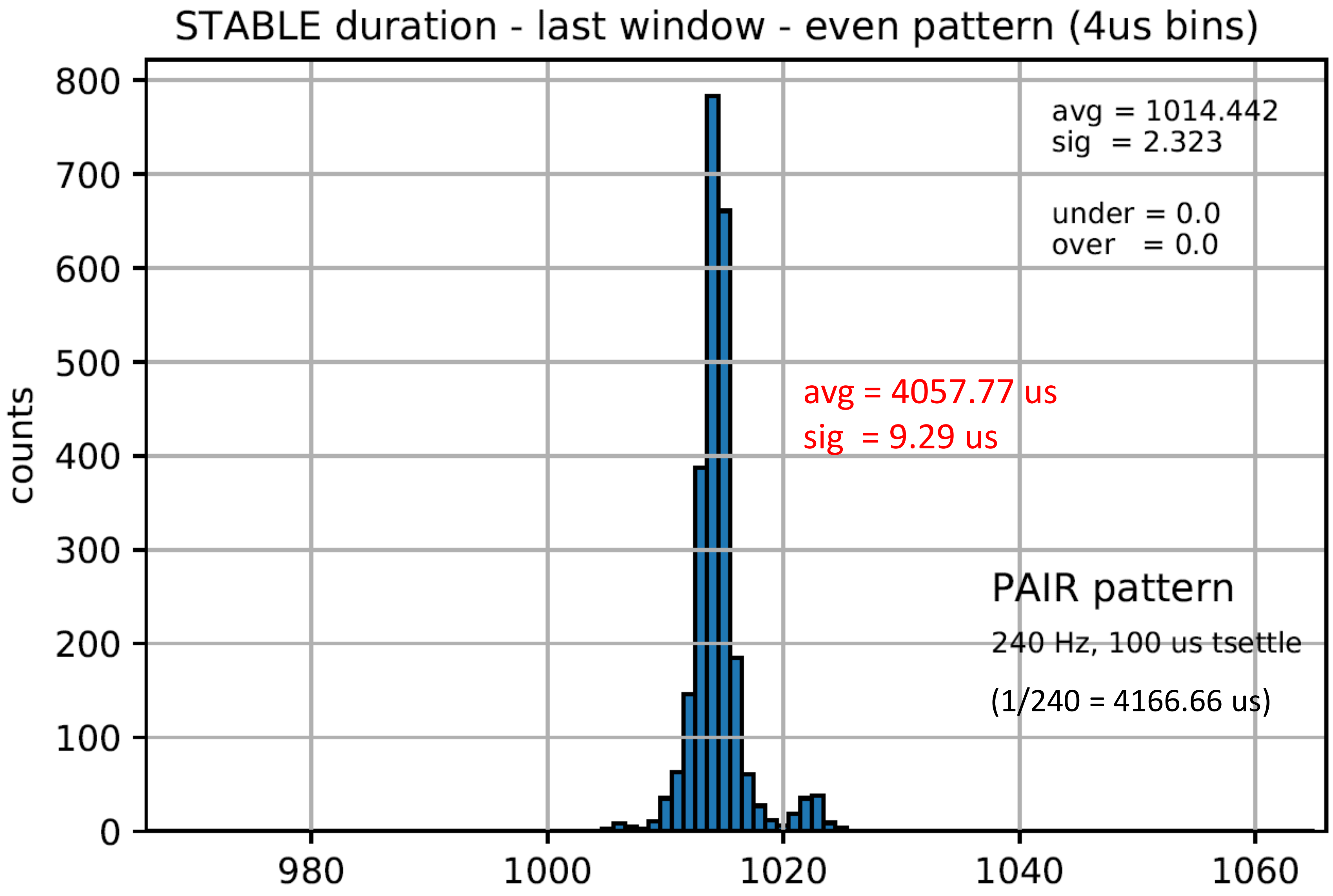

STABLE duration - last window - even pattern (4us bins)
avg = 1014.442
sig = 2.323
under = 0.0
over = 0.0
avg = 4057.77 us
sig = 9.29 us
PAIR pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
800
700
600
500
400
300
200
100
0
980
1000
1020
1040
1060

Figure 20

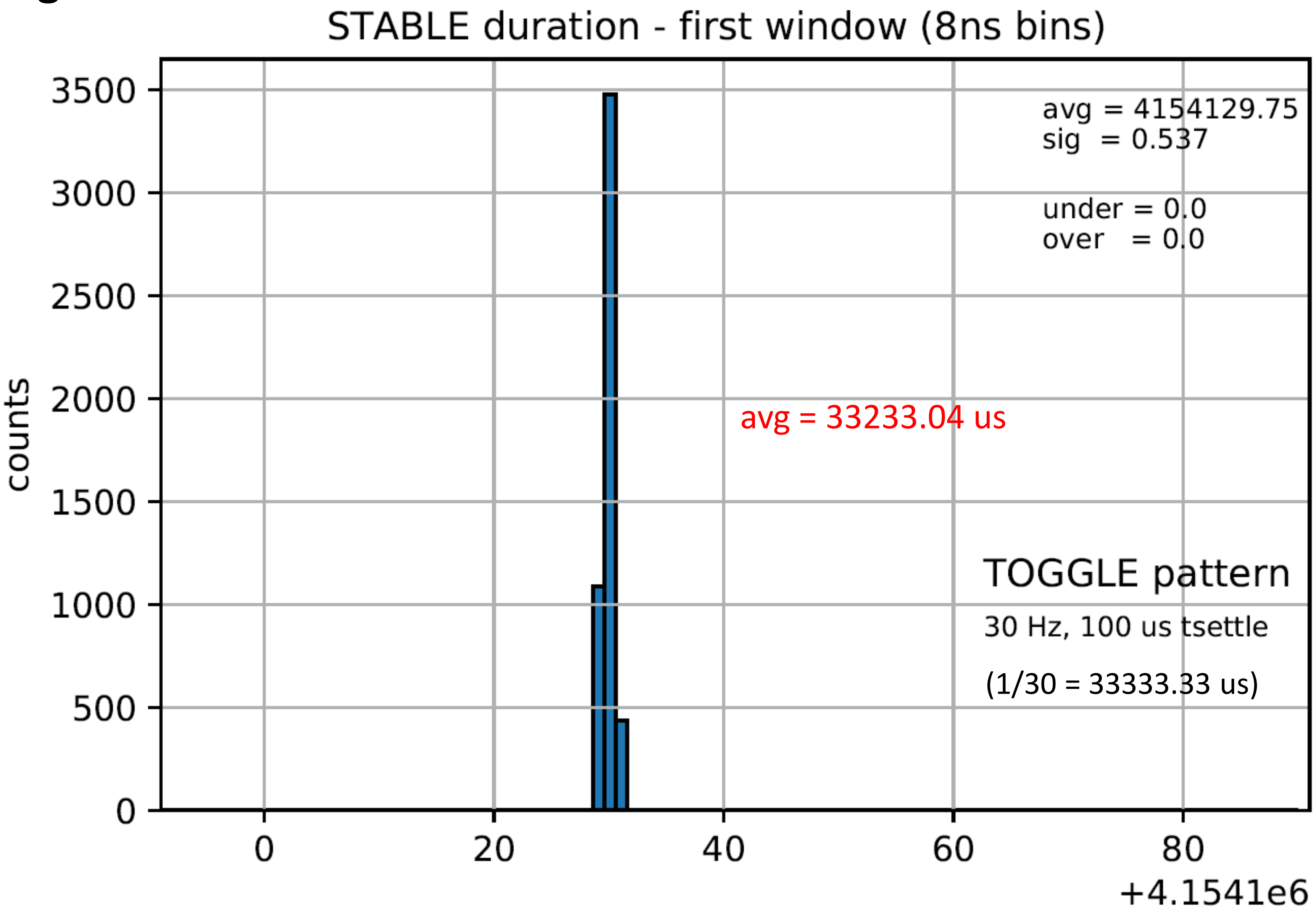

STABLE duration - first window (8ns bins)
counts
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+4.1541e6
avg = 4154129.75
sig = 0.537
under = 0.0
over = 0.0
avg = 33233.04 us
TOGGLE pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)

Figure 21

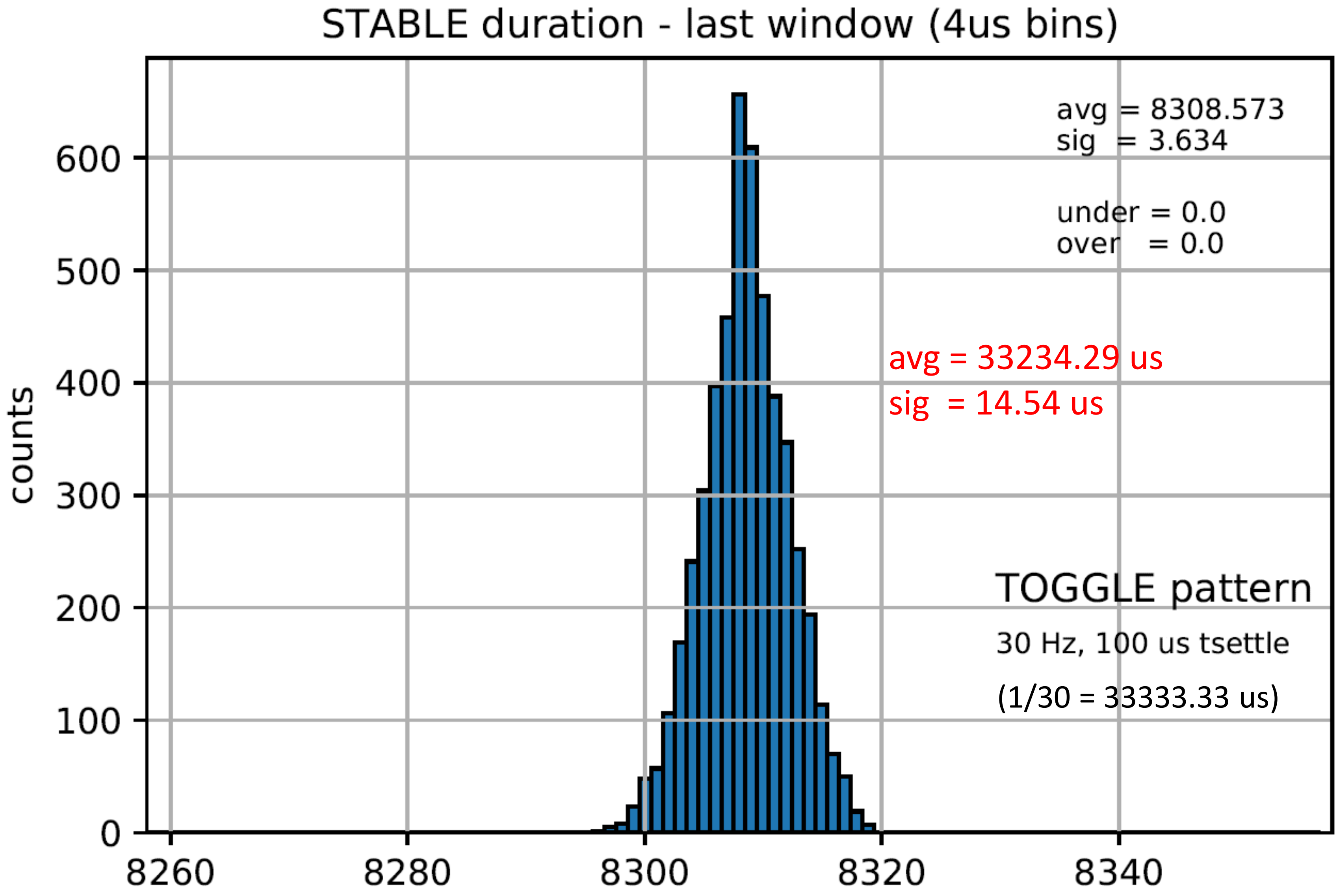

STABLE duration - last window (4us bins)
avg = 8308.573
sig = 3.634
under = 0.0
over = 0.0
avg = 33234.29 us
sig = 14.54 us
TOGGLE pattern
30 Hz, 100 us tsettle
(1/30 = 33333.33 us)
counts
0
100
200
300
400
500
600
8260
8280
8300
8320
8340

Figure 22

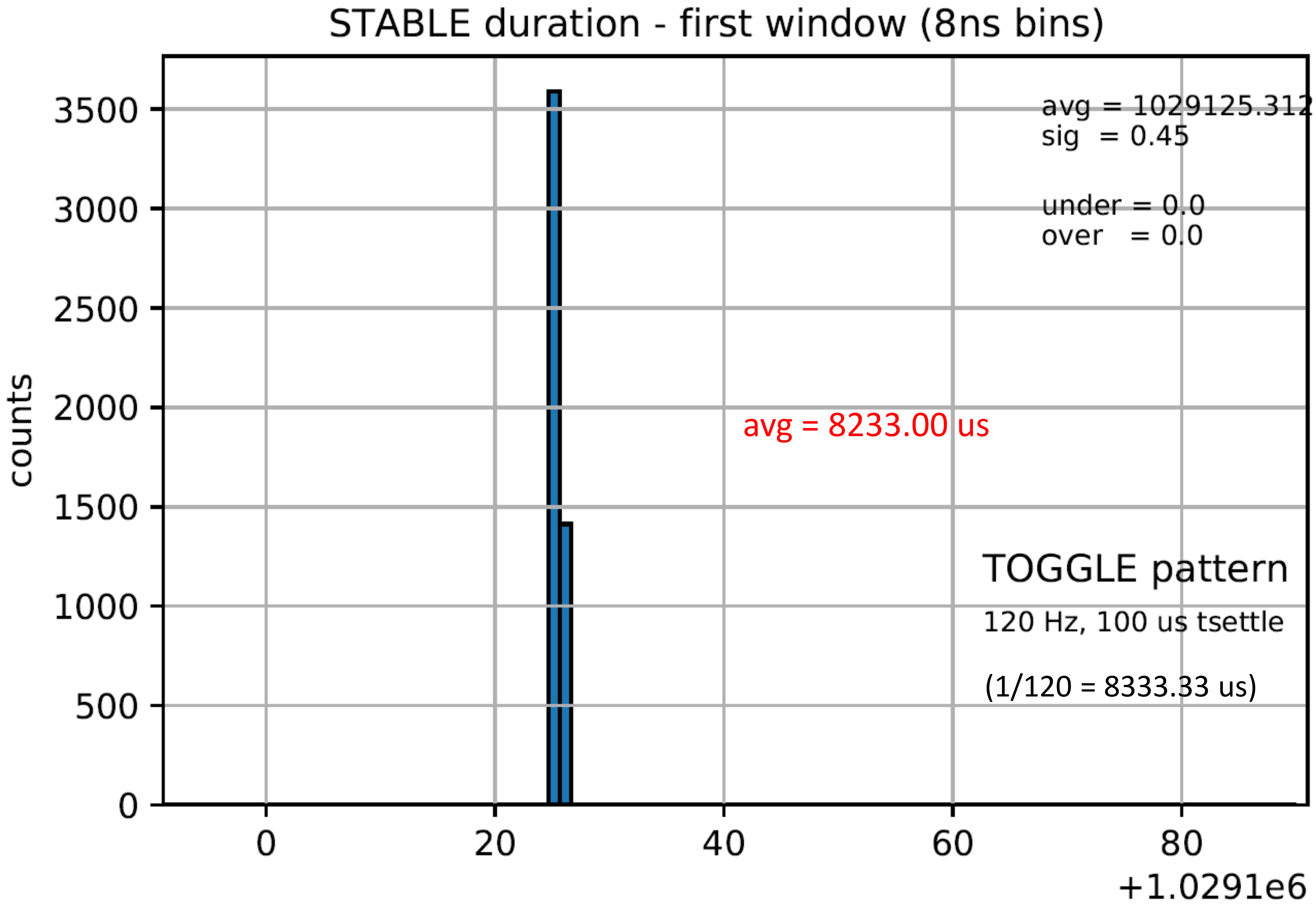
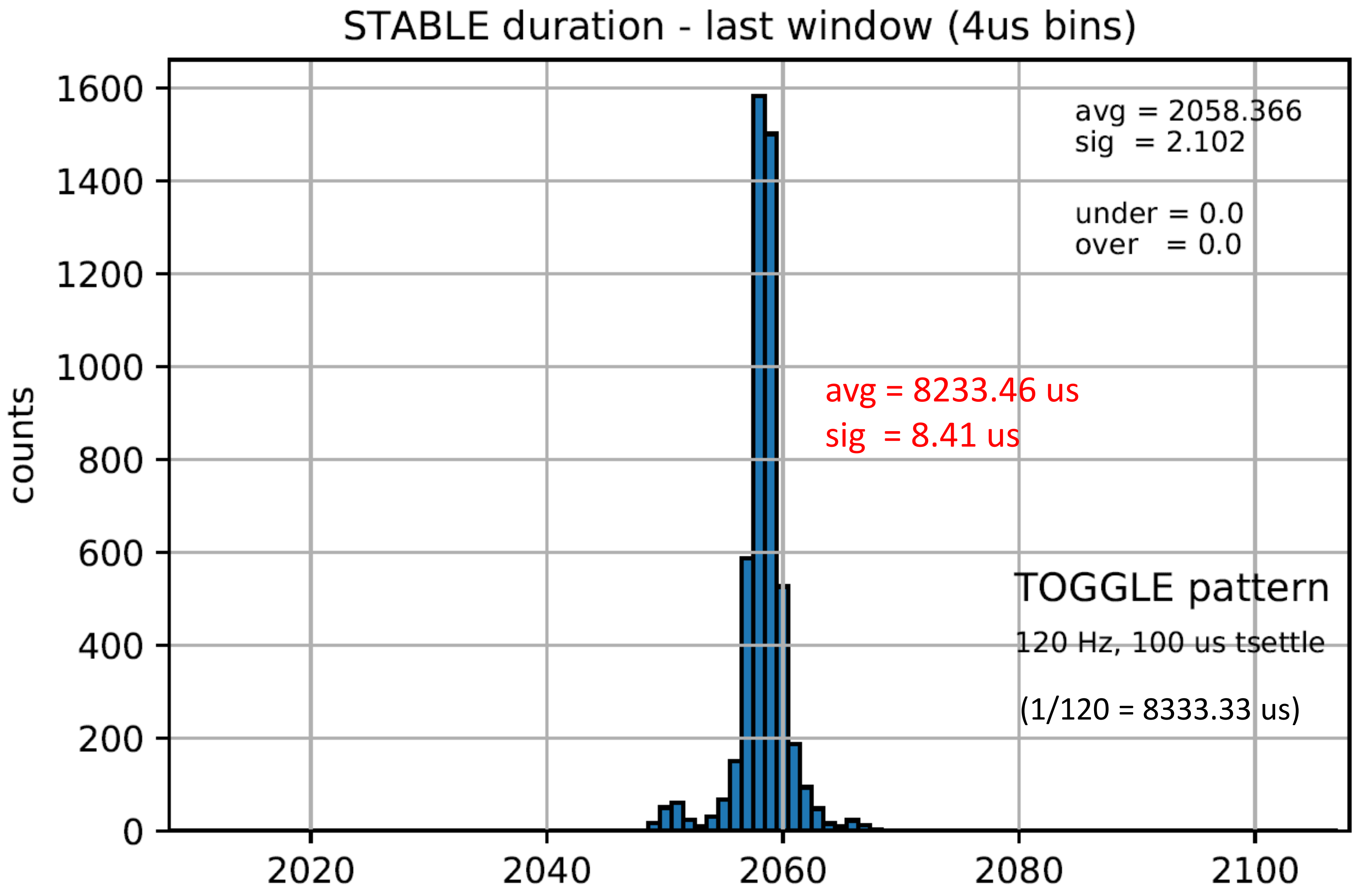

STABLE duration - first window (8ns bins)
counts
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
+1.0291e6
avg = 1029125.312
sig = 0.45
under = 0.0
over = 0.0
avg = 8233.00 us
TOGGLE pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 23



STABLE duration - last window (4us bins)
1600
1400
1200
1000
800
600
400
200
0
counts
2020
2040
2060
2080
2100
avg = 2058.366
sig = 2.102
under = 0.0
over = 0.0
avg = 8233.46 us
sig = 8.41 us
TOGGLE pattern
120 Hz, 100 us tsettle
(1/120 = 8333.33 us)

Figure 24

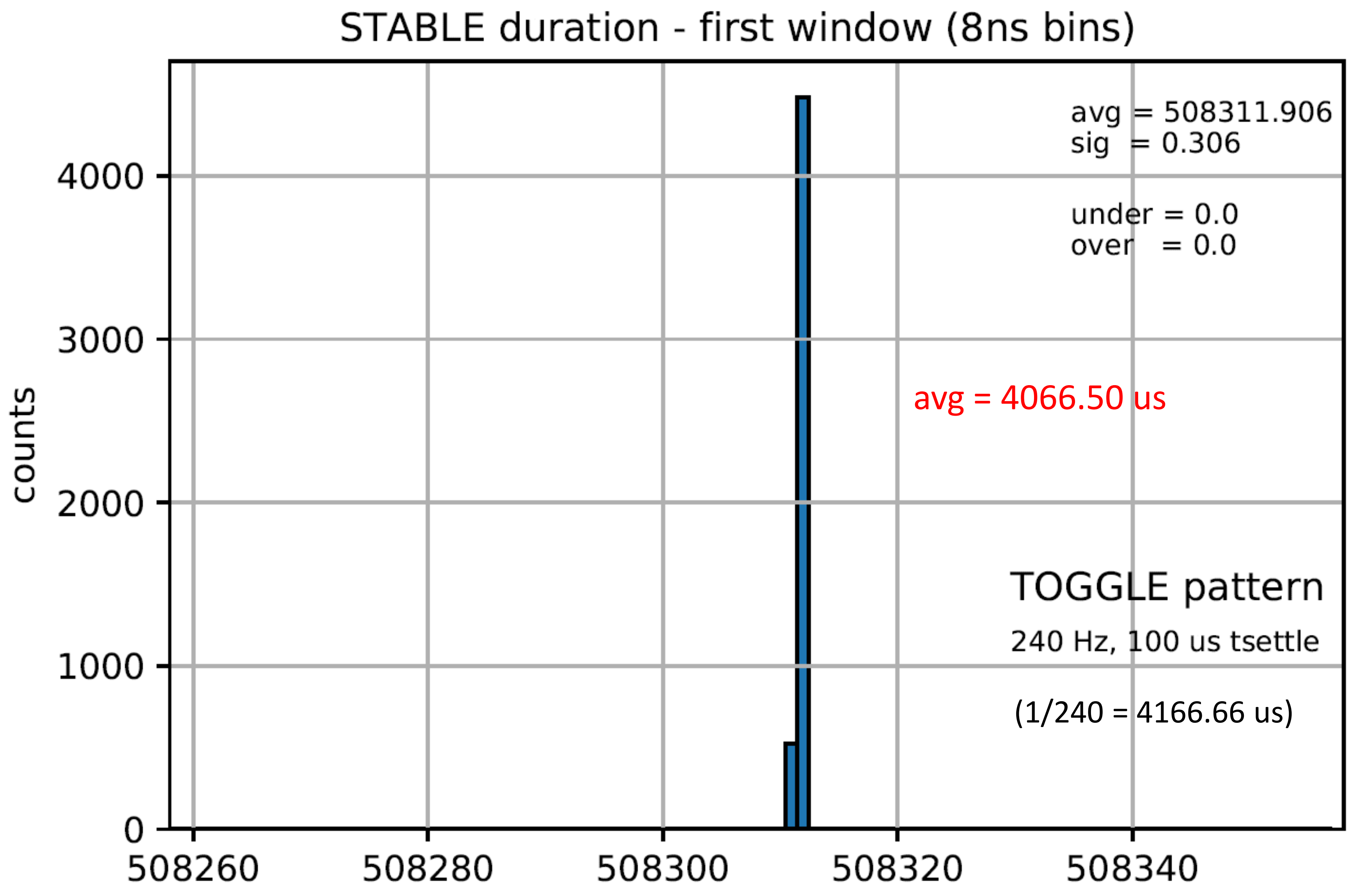

STABLE duration - first window (8ns bins)
avg = 508311.906
sig = 0.306
under = 0.0
over = 0.0
avg = 4066.50 us
TOGGLE pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
4000
3000
2000
1000
0
508260
508280
508300
508320
508340

Figure 25

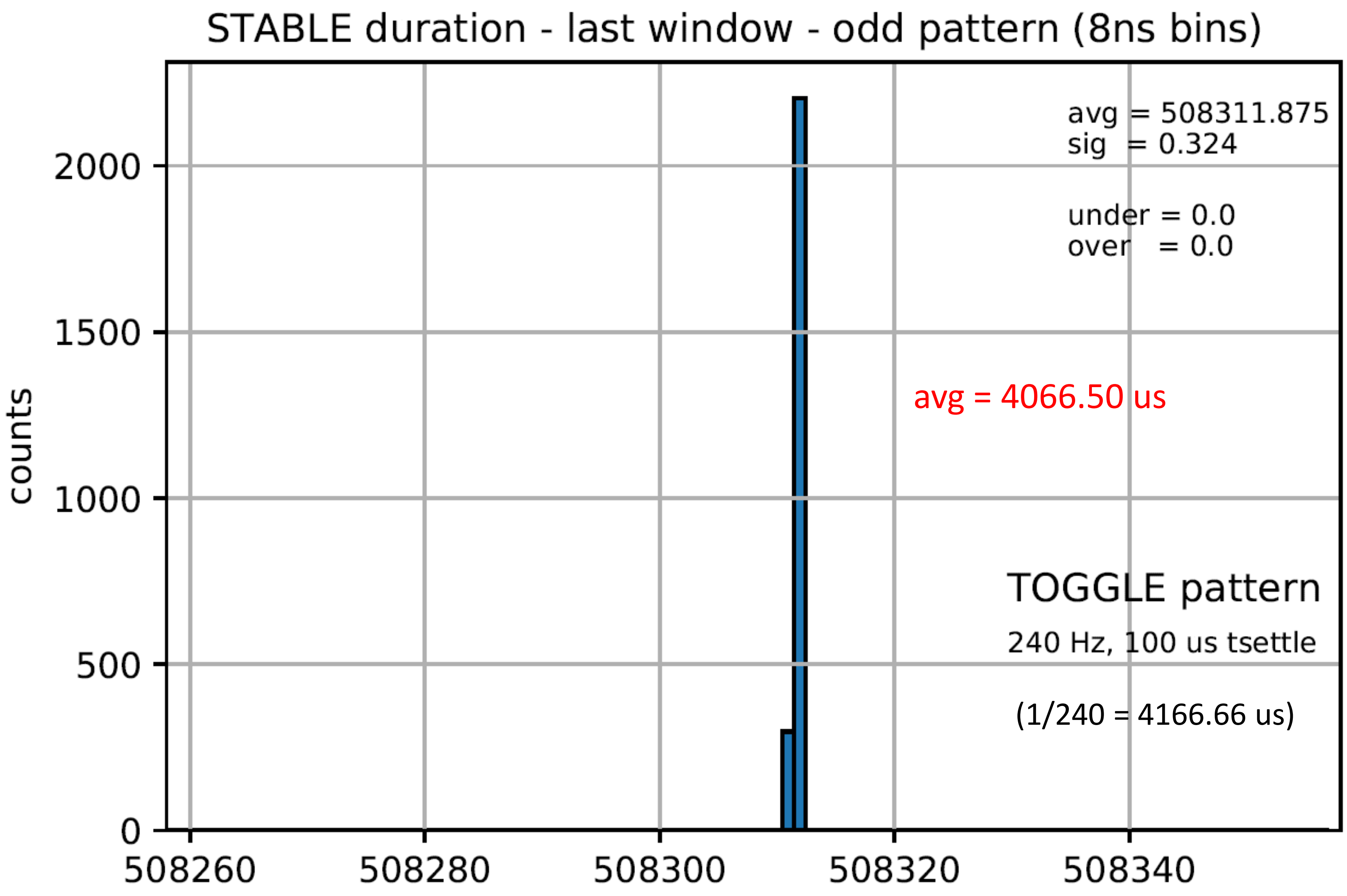
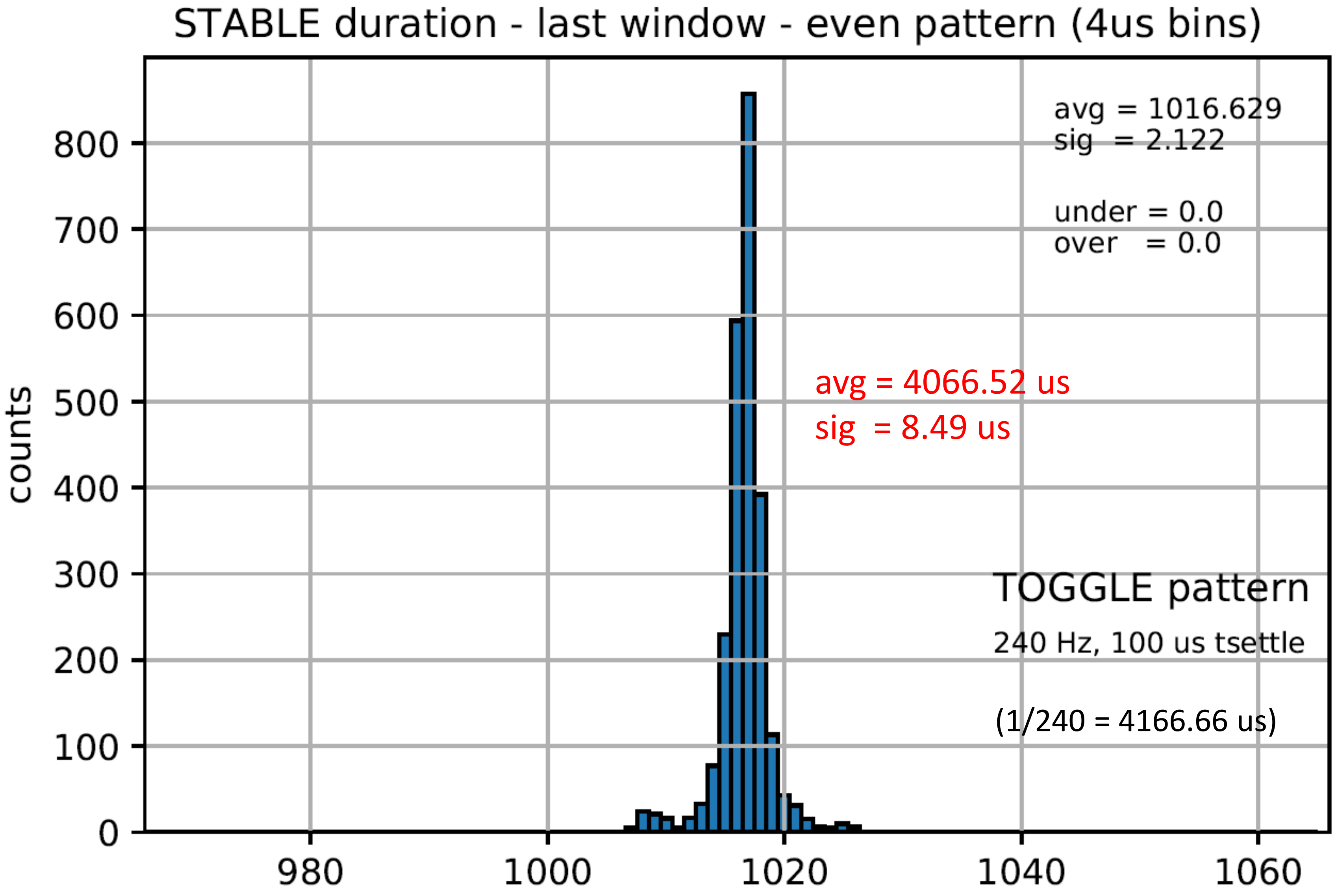

STABLE duration - last window - odd pattern (8ns bins)
avg = 508311.875
sig = 0.324
under = 0.0
over = 0.0
avg = 4066.50 us
TOGGLE pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
2000
1500
1000
500
0
508260
508280
508300
508320
508340

Figure 26



STABLE duration - last window - even pattern (4us bins)
avg = 1016.629
sig = 2.122
under = 0.0
over = 0.0
avg = 4066.52 us
sig = 8.49 us
TOGGLE pattern
240 Hz, 100 us tsettle
(1/240 = 4166.66 us)
counts
0
100
200
300
400
500
600
700
800
980
1000
1020
1040
1060

Figure 27

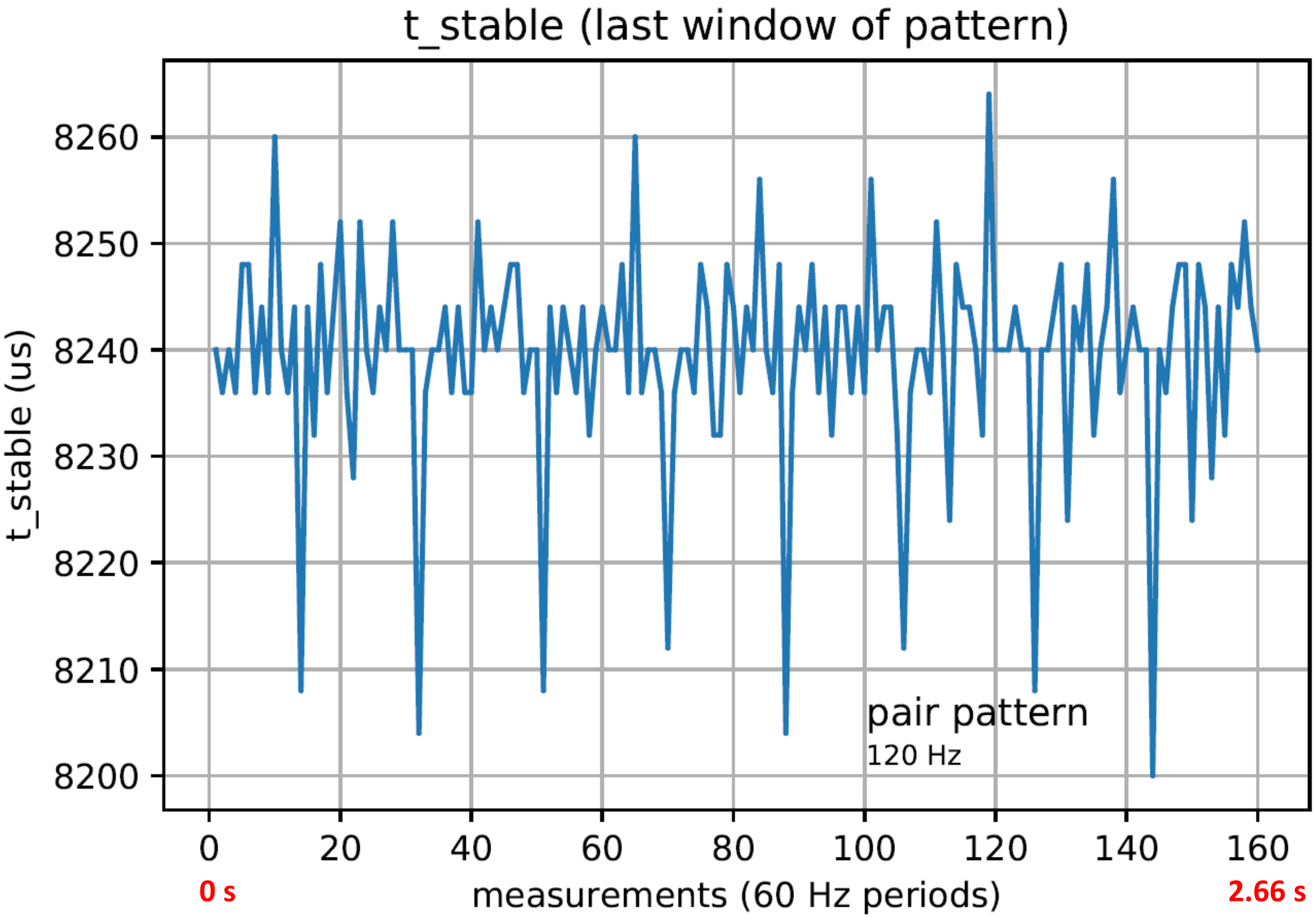
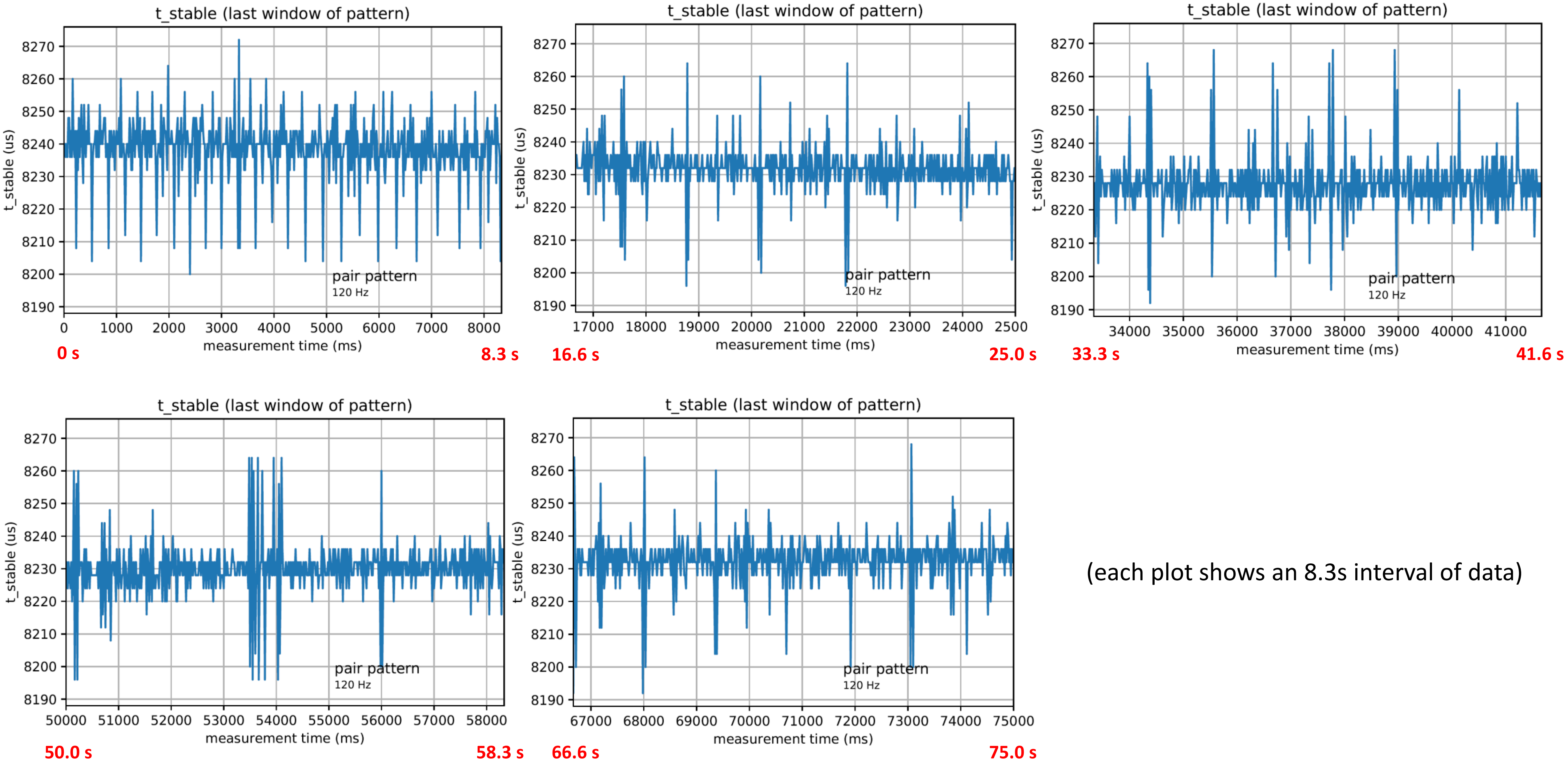
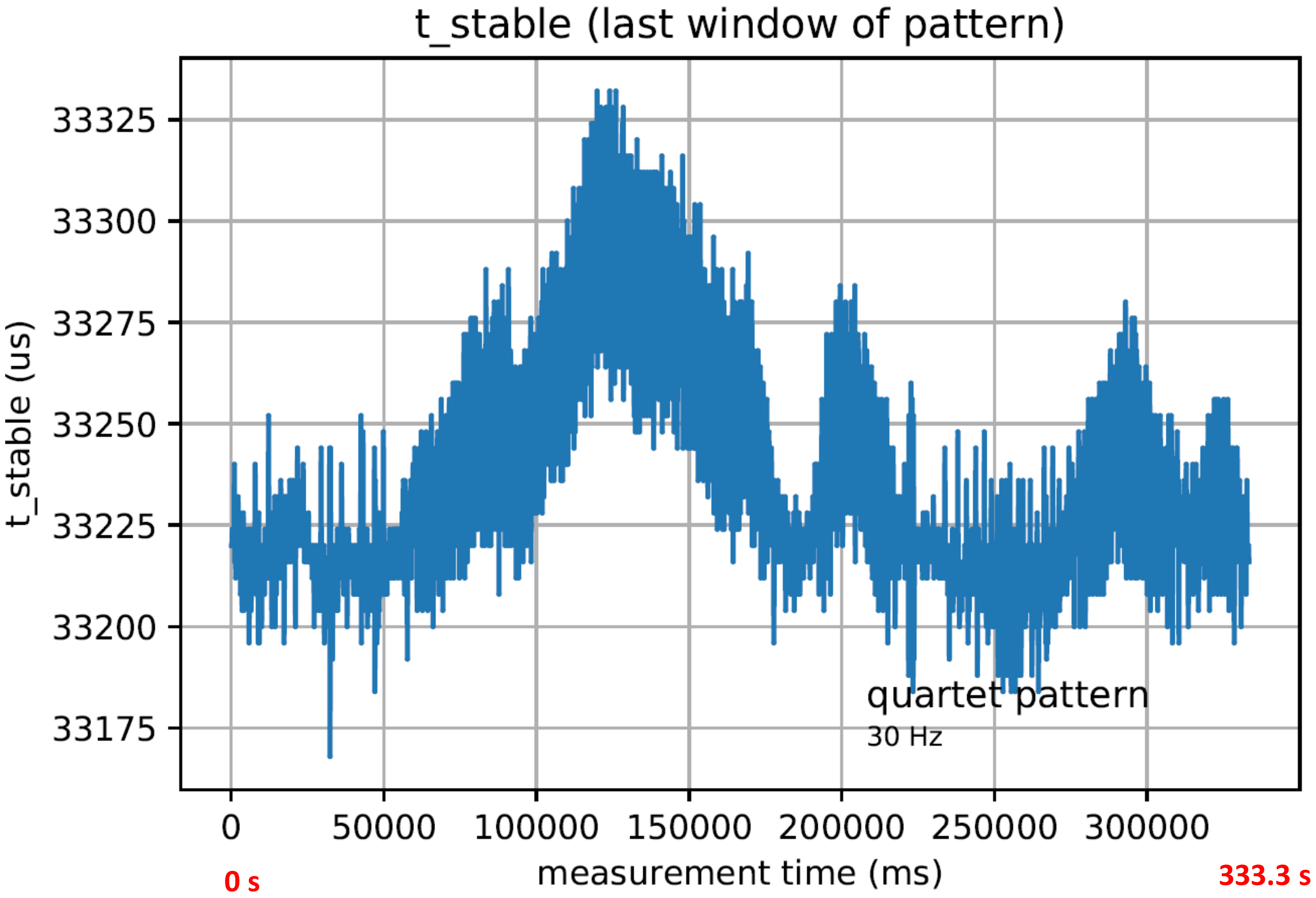

t_stable (last window of pattern)
8260
8250
8240
8230
8220
8210
8200
t_stable (us)
0
20
40
60
80
100
120
140
160
measurements (60 Hz periods)
0 s
2.66 s
pair pattern
120 Hz

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