Bureau International des Poids et Mesures

Calibration bridging for the June and July 2021 satellite transponder frequency changes for European and transatlantic TWSTFT links

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reference: TM289-1-1
issue: 1
revision: 1
date: March 28, 2022
status: Issued

Abstract

This document sums up the bridging operations performed to maintain TWSTFT link continuity during the transition from 2016 contract to 2021 contract on the Telstar 11N satellite, which supports the Europe-Europe and USA-Europe links.

Document History

Issue	Revision	Date	Author	Comment
1	1	2022-03-28	FM	Fixed missing CI 546 in table 3
1	0	2022-03-09	FM	Fixed typo for PTB05-USNO01 ESIG in table 3 and on page 15
D	0	2022-03-04	FM	First release

Contents

Reference documents

[1] ITU-R. *The operational use of two-way satellite time and frequency transfer employing pseudorandom noise codes*. Recommendation ITU-R TF.1153-4. Tech. rep. Aug. 2015. URL: https://www.itu.int/dms_pubrec/itu-r/rec/tf/R-REC-TF.1153-4-201508-I!!PDF-E.pdf.

[2] Z. Jiang, W. Lewandowski, and D. Piester. "Calibration of TWSTFT links through the triangle closure condition". In: *40th Annual Precise Time and Time Interval (PTTI) Meeting*. Dec. 2008. URL: https://apps.dtic.mil/sti/pdfs/ADA503896.pdf.

[3] Z. Jiang, D. Piester, and K. Liang. "Restoring a TWSTFT calibration with a GPS bridge - A standard procedure for UTC time transfer". In: *EFTF-2010 24th European Frequency and Time Forum*. 2010, pp. 1–6. DOI: 10.1109/EFTF.2010.6533693.

[4] Z. Jiang et al. *Restoration the TWSTFT link calibration using GPSPPP bridging after the satellite change on Mjd 55769/27 July 2011 (TM 198)*. Tech. rep. BIPM, Aug. 28, 2011.

1 Introduction

After expiration of the 2016 contract, the European and American TWSTFT stations contributing to UTC were negotiating a new long term contract with the same provider and continue operation on the same satellite (T-11N). Due to the bandwidth upgrade the partners were however requested to modify their settings to move to a new transponder on the same satellite. This operation leads to changes in the internal delays that are normally measured during a calibration campaign. In order to maintain continuity during the period between the change of transponder and the next calibration trip, offsets to the old calibration values are calculated through the procedure of "bridging", i.e. comparison to another link which continuity is maintained during the whole procedure. A similar procedure has been used for previous changes, e.g. Jiang et al. [4] and Jiang, Piester, and Liang [3] from which we took inspiration. A notable difference is the availability of high stability GNSS IPPP links, which makes them ideal candidates for this operation.

In accordance with satellite operator request, the switch took place on MJD 59361 (27th May, 2021). However, shortly after, the operator requested another modification in the settings of the Eur-Eur links, to optimize their transponders usage. The request was unfortunately not negotiable and a new switch occured for these links on MJD 59397 (2nd July 2021), leading to second consecutive bridging operation for these links.

2 Bridging principle

Practical aspects of TWSTFT measurement data are summarized in ITU-R TF.1153-4 [1]. Prior to bridging, the data are calibrated and made available in two separated files, which corresponds to case $S = 1$ in the above reference. Using the same conventions, the difference between the two timescales is

$$\begin{aligned} \mathrm{UTC}(1) - \mathrm{UTC}(2) &= +0.5\,(\mathrm{TW}(1) + \mathrm{ESDVAR}(1)) + \mathrm{REFDELAY}(1) \\ &\quad -0.5\,(\mathrm{TW}(2) + \mathrm{ESDVAR}(2)) - \mathrm{REFDELAY}(2) \\ &\quad +0.5\,(\mathrm{CALR}(1,2) - \mathrm{CALR}(2,1)) \end{aligned} \tag{1}$$

For $S = 0$ we would possibly have $\mathrm{CALR}(1,2) \neq \mathrm{CALR}(2,1)$. If equation 1 is used, which is the case for $S = 1$, then $\mathrm{CALR}(1,2) = -\mathrm{CALR}(2,1)$ so it can be rewritten as:

$$\begin{aligned} \mathrm{UTC}(1) - \mathrm{UTC}(2) &= +0.5\,(\mathrm{TW}(1) + \mathrm{ESDVAR}(1)) + \mathrm{REFDELAY}(1) \\ &\quad -0.5\,(\mathrm{TW}(2) + \mathrm{ESDVAR}(2)) - \mathrm{REFDELAY}(2) \\ &\quad +\mathrm{CALR} \end{aligned} \tag{2}$$

where CALR appears with an opposite sign in data coming from each station. CALR is constant before and after the switch, so we can simplify equation 2 as

$$\Delta\mathrm{UTC}(t) = \Delta\mathrm{TW}_{\mathrm{uncal}}(t) + \mathrm{CALR} \tag{3}$$

where $\Delta\mathrm{UTC}(t) = \mathrm{UTC}(1) - \mathrm{UTC}(2)$ and $\Delta\mathrm{TW}_{uncal}(t) = 0.5\,(\mathrm{TW}(1) + \mathrm{ESDVAR}(1)) + \mathrm{REFDELAY}(1) - 0.5\,(\mathrm{TW}(2) + \mathrm{ESDVAR}(2)) - \mathrm{REFDELAY}(2)$ regroups all the terms that track the changes in UTC(k) differences over time.

The bridging link provides $\Delta\mathrm{UTC}(t)$ in an independent way. Therefore the difference between the two links should be constant before the switch (occurring at $t = t_0$):

$$[\Delta\mathrm{UTC}_{bridge}(t) - \Delta\mathrm{UTC}_{TW}(t)]_{t<t_0} = k \tag{4}$$

The link used as bridging reference is not presumed to be calibrated (it just has to be continuous and stable across the bridging period), so k can take any value.

After the switch ($t > t_0$), $\mathrm{CALR}_{\mathrm{new}}$ is unknown. If we force its value to 0 in the TW data files, the result of the link calculation is just the $\mathrm{TW}_{\mathrm{uncal}}(t)$ term in eq.3. If we calculate the difference with respect to the bridging link after the switch, we determine a new value k' such that

$$[\Delta\mathrm{UTC}_{bridge}(t) - \Delta\mathrm{TW}_{\mathrm{uncal}}(t)]_{t>t_0} = k' \tag{5}$$

Introducing the unknown CALR_{new}, we have

$$[\Delta\text{UTC}_{bridge}(t) - \Delta\text{UTC}_{TW}(t)]_{t>t_0} = k' - \text{CALR}_{\text{new}} \tag{6}$$

"Bridging the link" is equivalent to stating that

$$[\Delta\text{UTC}_{bridge}(t) - \Delta\text{UTC}_{TW}(t)]_{t<t_0} = [\Delta\text{UTC}_{bridge}(t) - \Delta\text{UTC}_{TW}(t)]_{t>t_0} \tag{7}$$

so

$$k = k' - \text{CALR}_{\text{new}} \tag{8}$$

Therefore the new CALR is simply determined by the difference between the offset of the TW link before and after the switch, with respect to the bridging link (see fig. 1 for a visualisation). The old CALR value is included in k (in fact, if both the TW and the bridging link were perfectly calibrated, $k = 0$), so

$$\text{CALR}_{\text{new}} = k' - k \tag{9}$$

3 Calculation method for k and k'

Two-way links and various kinds of methods for GPS links have different sampling and averaging periods. See table 2.

Table 2: Sampling and averaging period for links considered in this bridging procedure

Technique	method	sampling (s)	averaging period (s)
TWSTFT	SATRE	7200	120
TWSTFT	SDR	300	300
GPS	IPPP	30	30
GPS	P3	960	960
GPS	PPP	300	300

In order to compare two links together and obtain the k and k' values :

- For each point of the sparser link (i.e. the TW link), a sample of the denser link (i.e. the GPS link) centered on the TW data point and with a duration matching the TW sampling length is determined.

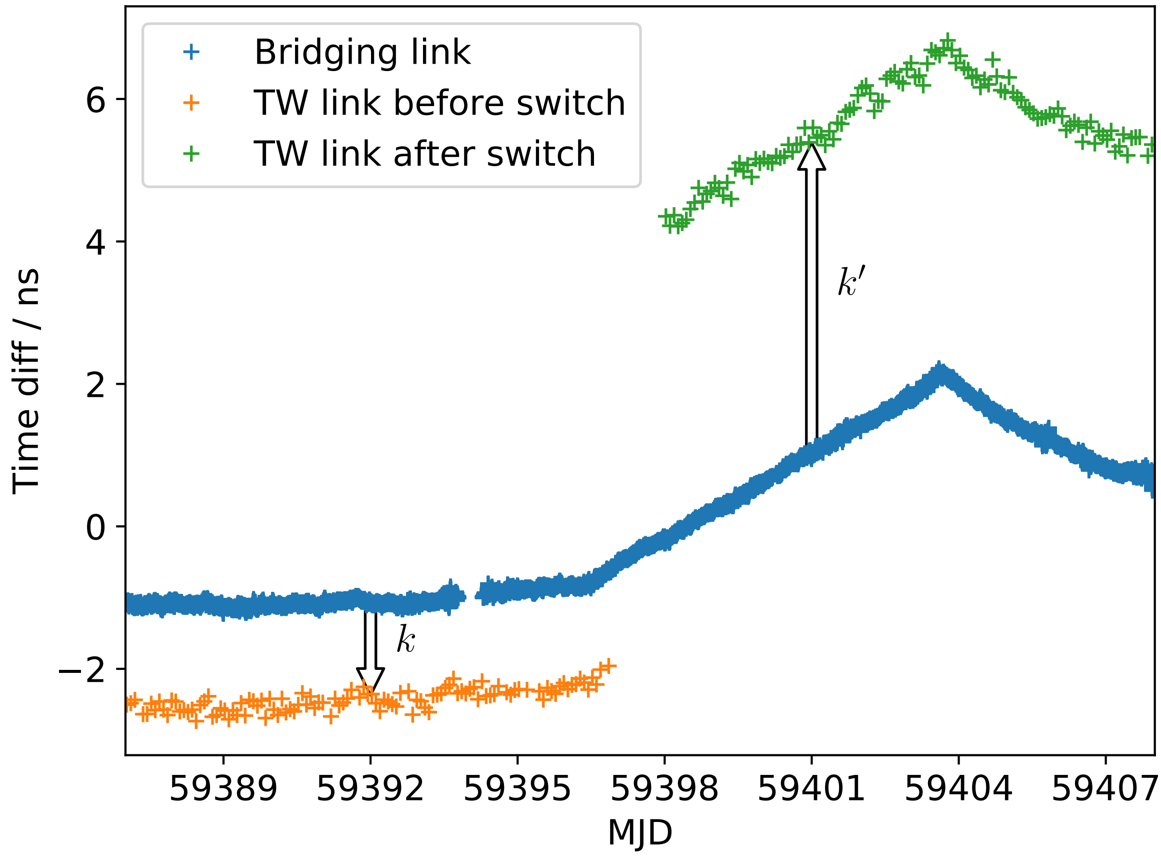


Figure 1: Illustration of the bridging principle. In this example, the bridging link is an IPPP link.

- A 1st-degree polynomial is fitted on the values of this sample, as away to take as many data points as available to reduce the noise, while taking into account a possible frequency offset between the two scales.
- The difference between the two links is assumed to be the difference between the TW data point value and the value interpolated thanks to the the above-mentionned polynomial, at the same date.

This provides as many link difference values as TW data points. Average value and standard deviation σ_{d} of the link difference values around the average value provide estimators of the link difference and its variability over the chose time interval.

4 Uncertainties

As seen on fig. 1, both the bridging link and the two-way link are affected by noise and, possibly, gaps. Additionally, two-way links are known to exhibit daily variations (so called "diurnals") of various intensity. Both k and k' values determination are therefore affected by uncertainties.

In order to mitigate the diurnal effect, values have been evaluated on 1-day periods. That is, the method described in sec. 3 has been applied on each day separately. Most of the variability appearing in the σ_{d} value thus comes from the diurnal pattern, which usually dominates the 1-day period. Ten contiguous days have been chosen before and after the switch, therefore providing ten values and their associated daily σ_{d}. Variations observed between these daily values are not always white noise, some trends have been detected. Hence, when combining these values it has been decided not to divide the standard deviation of daily values by $\sqrt{n}$, to take this non-normality into account.

It should be noted that averaging the diurnals over 1 day reduces the variability from 1 day to the other, but introduces an unknown systematic which can be as large as the diurnal's amplitude. This is usually not an issue when comparing two part of the link that share the same diurnal signature (any systematic introduced here is equal on both parts of the link, hence cancelling out when performing the substraction). In the present case, transitioning from 1 Mcps to 2.5 Mcps leads to a significant reduction of the diurnal pattern : if we introduce a systematic on the 1 Mcps part calculation, its counterpart on the 2.5 Mcps is much smaller. This is only partly accounted for by including the daily σ_{d} in the calculation and should probably affect more links that see important changes in their diurnal patterns, than links that stays at the same level.

In the end, both σ_{d} and the standard deviation σ of the daily averages around the mean of the respective full period of consecutive days contribute to the bridging uncertainty and should be taken into account. In order to get a representative value of σ_{d}, the median of their values for each 10-day period has been retained.

Bridging uncertainty has been considered to be the quadratic sum of daily and period uncertainties for each period, i.e. :

$$u_{\mathrm{bridge}} = \sqrt{med(\sigma_{\mathrm{d1}})^2 + \sigma_1^2 + med(\sigma_{\mathrm{d2}})^2 + \sigma_2^2} \tag{10}$$

In most well-behaved cases it is similar to a period-wide standard deviation calculation, but keeping this 1d characteristic period separation allows to monitor the relative importance of diurnals with respect to inter-methods drifts.

In the end, the uncertainty on the CALR value is the quadratic sum of the former CALR uncertainty and this bridging uncertainty :

$$u_{\text{new}} = \sqrt{u_{\text{old}}^2 + u_{\text{bridge}}^2} \quad (11)$$

Values are then rounded to the upper 100 ps.

5 Non-UTC links

Non-UTC links (i.e. links not connected to the pivot station, namely PTB) have been processed, as usual, by using Triangle Closure Calibration (TCC) as described in [2].

As a reminder, the method is to consider two stations A and B, and a pivot station P. If links $A - P$ and $B - P$ are calibrated, then a calibrated value for link between A and B can be obtained by substracting the two : $(A - B)_{\text{cal}} = (A - P) - (B - P)$. Thus the CALR value can be determined by the difference between the uncalibrated link and this indirect link, i.e.

$$\text{CALR} = (A - B)_{\text{uncal}} - [(A - P) - (B - P)] \quad (12)$$

In this case the link that are being substracted share the same sampling, but were evaluated on different time slot. For each data point in the first link, a linear interpolation between the two closest data points from the second link has been used to determine the difference and avoid to introduce systematics due to diurnal patterns.

Corresponding uncertainty is the quadratic sum of the UTC links uncertainty, and the standard deviation of each link difference.

6 ESDVAR values

ESDVAR is a parameter described in [1], allowing to encompass delay modifications in one station, for example due to physical setup changes. Its value is attached to one station (contrary to CALR, which absolute value is identical for both sides of the link). The choice to reset ESDVAR when a new calibration is performed is made by the network manager, as some special cases may require continuity.

In the present case:

For UTC links, the calibration values are simply transfered, so it has been decided to keep the ESDVAR value. As ESDVAR does not appear in the bridging equation, it is not necessary to propagate its uncertainty.

For non-UTC links, we effectively provide a new calibration by means of indirect links, without using previous ESDVAR values : we can therefore reset them without introducing any additional uncertainty.

7 Results

CALR values and associated uncertainties determined for each station pair through bridging or TCC is identified by a Calibration ID (CI).

The following sections present a summary of the results obtained for each CI : the upper frame contains all necessary parameters to be included in the ITU file, while the bottom part of the page contains additional plots and data related to the CALR determination.

7.1 UTC links

For links to PTB05, used as main links for UTC calculation, the top plot represents the bridging link (in black) and the TW data before (in blue) and after (in orange) the switch. The determined offset (indicated in the legend, with its corresponding uncertainty) is compensated so the plot presents comparable results. New CALR, old CALR and delta CALR, rounded to the nearest 10 ps, are presented in the table below the legend.

The nature of the bridging link and the GNSS receivers used to generate it are indicate in the top plot's title. In most cases the bridging link is GPS IPPP as it is the most stable available one. For VSL, PPP has been chosen because the receiver is linked to a Cesium clock and not a H maser, so the link's short term stability is worse, and our current algorithm for integer ambiguities determination has not been fully validated yet for this configuration.

The second plot represents the residuals between the two links after removal of the constant offset. It contains as many points as the TW data, and should be centered on 0. A 1st-order polynomial has been fitted to the residuals in order to highlight the residual drift and is displayed for information only (not taken into account in the calculation). Uncertainty on the slope is the corresponding coefficient in the correlation matrix resulting from the χ^2 fitting.

The third plot represents the difference between the daily average of TW points and the daily average of bridging link (again with the offset being compensated for plotting). Standard deviation is translated into error bars, legend indicates the mean value (where the offset is *not* compensated, so the value matches the offset indicated in the legend for the top plot), a standard deviation value of the daily values around the mean, and an amplitude value (i.e. max-min).

The two bottom plots are bar plots representing the number of data points per day for each link. It is used as an indicator that a peculiar daily value could be deteriorated due to large number of missed sessions.

Bottom text indicates which are the bridging periods before and after the switch (last MJD is included).

If data has been removed (e.g. outliers that have not been detected in the process, known spurious values, etc.) the discarded periods are listed for each link.

Because of the two-step switch (transponder change in June then frequency adjustement in July for Europe-Europe links), CALR values have been calculated twice, so some CIs have only been valid for one month.

7.2 Non-UTC links

Links not directed to PTB05 have been calibrated through TCC procedure. If link A-B has been calculated first in the process, then the reverse link B-A is not computed and its CALR value is considered to be the opposite of the A-B link.

The top plot represents the closure value, i.e. the difference between the calibrated indirect link (via PTB05) and the uncalibrated link (with CALR value forced to 0). The red line is horizontal and traces the median value. The retained value for CALR is this median, rounded to the nearest 10 ps.

The bottom plot is a histogram representation of the above, with the median represented as a red vertical line, mean as an orange dashed line (standard deviation is indicated in the legend) and the frequency of values in the sample in ordinate (no normalization, binning = 10 ps).

Median is chosen for CALR determination in order to provide robustness against outliers (see case of NPL02-VSL01 or NPL02-SP01, for example).

7.3 Summary of calibration values

Table 3: Summary of calibration values

CI	loc	rem	calr ns	est. unc. ns	esdvar ns	esig ns	MJD
533	NIST01	PTB05	-447.980	1.600	28.120	0.500	59403
533	PTB05	NIST01	447.980	1.600	-1406.260	0.640	59403
534	USNO01	PTB05	207.280	0.800	-7.200	0.200	59361
534	PTB05	USNO01	-207.280	0.800	6.400	0.640	59361
535	CH01	PTB05	-5.750	1.100	0.000	0.000	59361
535	PTB05	CH01	5.750	1.100	12.320	0.200	59361
536	IT02	PTB05	-120.800	1.100	0.000	0.000	59361
536	PTB05	IT02	120.800	1.100	12.320	0.200	59361
537	NPL02	PTB05	724.390	1.100	0.000	0.000	59361
537	PTB05	NPL02	-724.390	1.100	12.320	0.200	59361
538	OP01	PTB05	-7137.010	1.000	0.000	0.000	59361

CI	loc	rem	calr ns	est. unc. ns	esdvar ns	esig ns	MJD
538	PTB05	OP01	7137.010	1.000	12.320	0.200	59361
539	OP51	PTB55	-2027.220	0.600	0.000	0.000	59361
539	PTB55	OP51	2027.220	0.600	12.320	0.200	59361
540	ROA01	PTB05	23.030	1.000	0.000	0.000	59361
540	PTB05	ROA01	-23.030	1.000	12.320	0.200	59361
541	SP01	PTB05	-1.990	1.200	0.000	0.000	59361
541	PTB05	SP01	1.990	1.200	12.320	0.200	59361
542	VSL01	PTB05	-1.390	1.000	0.000	0.000	59361
542	PTB05	VSL01	1.390	1.000	12.320	0.200	59361
543	CH01	PTB05	-5.940	1.200	0.000	0.000	59397
543	PTB05	CH01	5.940	1.200	12.320	0.200	59397
544	IT02	PTB05	-121.420	1.300	0.000	0.000	59397
544	PTB05	IT02	121.420	1.300	12.320	0.200	59397
545	OP01	PTB05	-7137.460	1.100	0.000	0.000	59397
545	PTB05	OP01	7137.460	1.100	12.320	0.200	59397
546	OP51	PTB55	-2027.320	0.700	18.166	0.156	59397
546	PTB55	OP51	2027.320	0.700	12.320	0.200	59397
547	ROA01	PTB05	22.530	1.100	0.000	0.000	59397
547	PTB05	ROA01	-22.530	1.100	12.320	0.200	59397
548	SP01	PTB05	-1.950	1.300	0.000	0.000	59397
548	PTB05	SP01	1.950	1.300	12.320	0.200	59397
549	VSL01	PTB05	-1.570	1.100	0.000	0.000	59397
549	PTB05	VSL01	1.570	1.100	12.320	0.200	59397
550	NPL02	PTB05	724.690	1.200	0.000	0.000	59397
550	PTB05	NPL02	-724.690	1.200	12.320	0.200	59397
551	CH01	IT02	115.130	1.800	0.000	0.000	59397
551	IT02	CH01	-115.130	1.800	0.000	0.000	59397
552	CH01	NPL02	-730.830	1.800	0.000	0.000	59397
552	NPL02	CH01	730.830	1.800	0.000	0.000	59397
553	CH01	NIST01	-281.500	2.100	0.000	0.000	59397
553	NIST01	CH01	281.500	2.100	0.000	0.000	59397
554	CH01	OP01	7131.620	1.700	0.000	0.000	59397
554	OP01	CH01	-7131.620	1.700	0.000	0.000	59397
555	CH01	ROA01	-28.510	1.700	0.000	0.000	59397
555	ROA01	CH01	28.510	1.700	0.000	0.000	59397
556	CH01	SP01	-4.090	1.800	0.000	0.000	59397
556	SP01	CH01	4.090	1.800	0.000	0.000	59397
557	CH01	USNO01	-212.720	1.500	0.000	0.000	59397
557	USNO01	CH01	212.720	1.500	0.000	0.000	59397
558	CH01	VSL01	-4.500	1.700	0.000	0.000	59397
558	VSL01	CH01	4.500	1.700	0.000	0.000	59397
559	IT02	NPL02	-845.820	1.800	0.000	0.000	59397
559	NPL02	IT02	845.820	1.800	0.000	0.000	59397

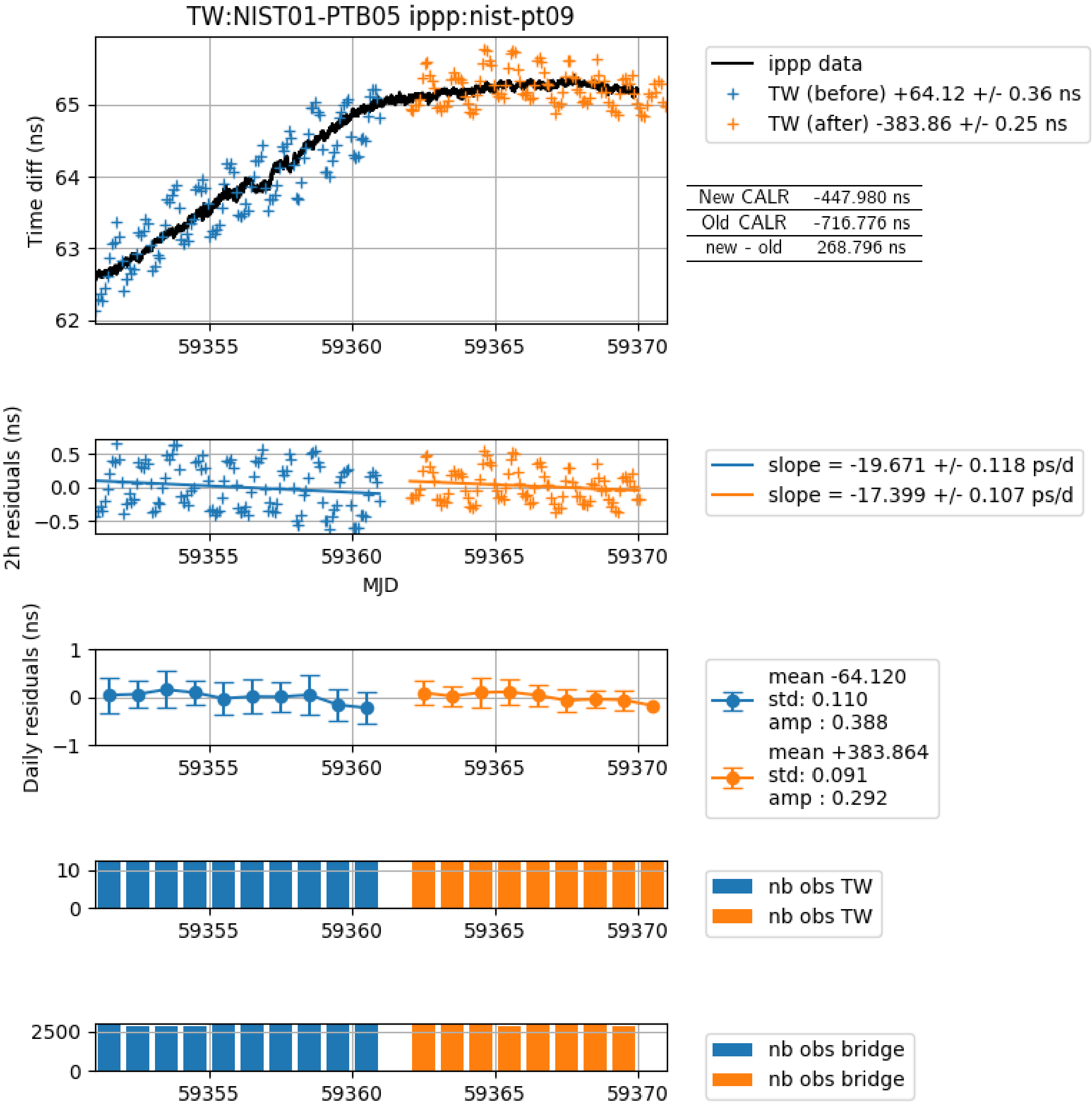
CI	loc	rem	calr ns	est. unc. ns	esdvar ns	esig ns	MJD
560	IT02	NIST01	-396.730	2.100	0.000	0.000	59397
560	NIST01	IT02	396.730	2.100	0.000	0.000	59397
561	IT02	OP01	7016.400	1.800	0.000	0.000	59397
561	OP01	IT02	-7016.400	1.800	0.000	0.000	59397
562	IT02	ROA01	-143.560	1.800	0.000	0.000	59397
562	ROA01	IT02	143.560	1.800	0.000	0.000	59397
563	IT02	SP01	-118.950	1.900	0.000	0.000	59397
563	SP01	IT02	118.950	1.900	0.000	0.000	59397
564	IT02	USNO01	-327.980	1.600	0.000	0.000	59397
564	USNO01	IT02	327.980	1.600	0.000	0.000	59397
565	IT02	VSL01	-119.930	1.800	0.000	0.000	59397
565	VSL01	IT02	119.930	1.800	0.000	0.000	59397
566	NPL02	OP01	7862.420	1.700	0.000	0.000	59397
566	OP01	NPL02	-7862.420	1.700	0.000	0.000	59397
567	NPL02	ROA01	702.340	1.700	0.000	0.000	59397
567	ROA01	NPL02	-702.340	1.700	0.000	0.000	59397
568	NPL02	SP01	726.880	4.300	0.000	0.000	59397
568	SP01	NPL02	-726.880	4.300	0.000	0.000	59397
569	NPL02	VSL01	726.170	6.800	0.000	0.000	59397
569	VSL01	NPL02	-726.170	6.800	0.000	0.000	59397
570	NIST01	OP01	7412.460	2.000	0.000	0.000	59397
570	OP01	NIST01	-7412.460	2.000	0.000	0.000	59397
571	NIST01	ROA01	252.840	2.000	0.000	0.000	59397
571	ROA01	NIST01	-252.840	2.000	0.000	0.000	59397
572	NIST01	SP01	277.790	2.100	0.000	0.000	59397
572	SP01	NIST01	-277.790	2.100	0.000	0.000	59397
573	NIST01	VSL01	276.710	2.000	0.000	0.000	59397
573	VSL01	NIST01	-276.710	2.000	0.000	0.000	59397
574	OP01	ROA01	-7160.190	1.600	0.000	0.000	59397
574	ROA01	OP01	7160.190	1.600	0.000	0.000	59397
575	OP01	SP01	-7135.760	1.800	0.000	0.000	59397
575	SP01	OP01	7135.760	1.800	0.000	0.000	59397
576	OP01	USNO01	-7343.800	1.400	0.000	0.000	59397
576	USNO01	OP01	7343.800	1.400	0.000	0.000	59397
577	OP01	VSL01	-7136.010	1.600	0.000	0.000	59397
577	VSL01	OP01	7136.010	1.600	0.000	0.000	59397
578	ROA01	SP01	24.440	1.800	0.000	0.000	59397
578	SP01	ROA01	-24.440	1.800	0.000	0.000	59397
579	ROA01	USNO01	-183.950	1.400	0.000	0.000	59397
579	USNO01	ROA01	183.950	1.400	0.000	0.000	59397
580	ROA01	VSL01	23.880	1.600	0.000	0.000	59397
580	VSL01	ROA01	-23.880	1.600	0.000	0.000	59397
581	SP01	USNO01	-208.900	1.600	0.000	0.000	59397

CI	loc	rem	calr ns	est. unc. ns	esdvar ns	esig ns	MJD
581	USNO01	SP01	208.900	1.600	0.000	0.000	59397
582	SP01	VSL01	-0.750	1.800	0.000	0.000	59397
582	VSL01	SP01	0.750	1.800	0.000	0.000	59397
583	USNO01	VSL01	207.910	1.400	0.000	0.000	59397
583	VSL01	USNO01	-207.910	1.400	0.000	0.000	59397

CI 533, NIST01-PTB05

```
* CAL    533 TYPE: CAL 393 BRIDGED    MJD: 59361 EST. UNCERT.:    1.600 ns

LOC     REM     CI  S       CALR      ESDVAR  ESIG
NIST01 PTB05   533 1  -447.980      28.120 0.500
PTB05  NIST01  533 1   447.980  -1406.260 0.640
```

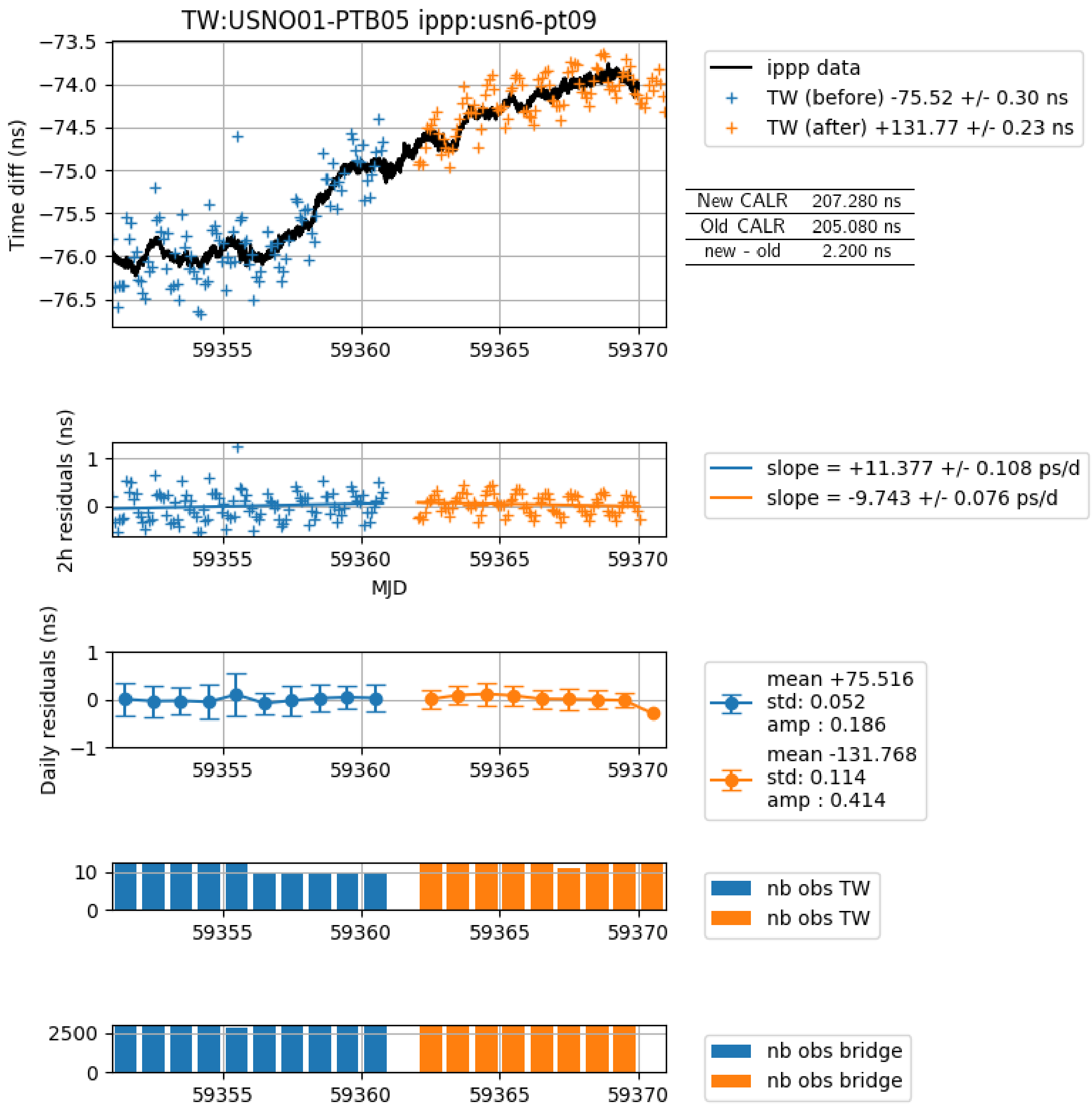


1st period: 59351-59360   2nd period: 59362-59370

CI 534, USNO01-PTB05

```
* CAL    534 TYPE: CAL 395 BRIDGED    MJD: 59361 EST. UNCERT.:    0.800 ns

LOC     REM     CI  S      CALR     ESDVAR  ESIG
USNO01  PTB05   534 1   207.280     -7.200 0.200
PTB05   USNO01  534 1  -207.280      6.400 0.640
```

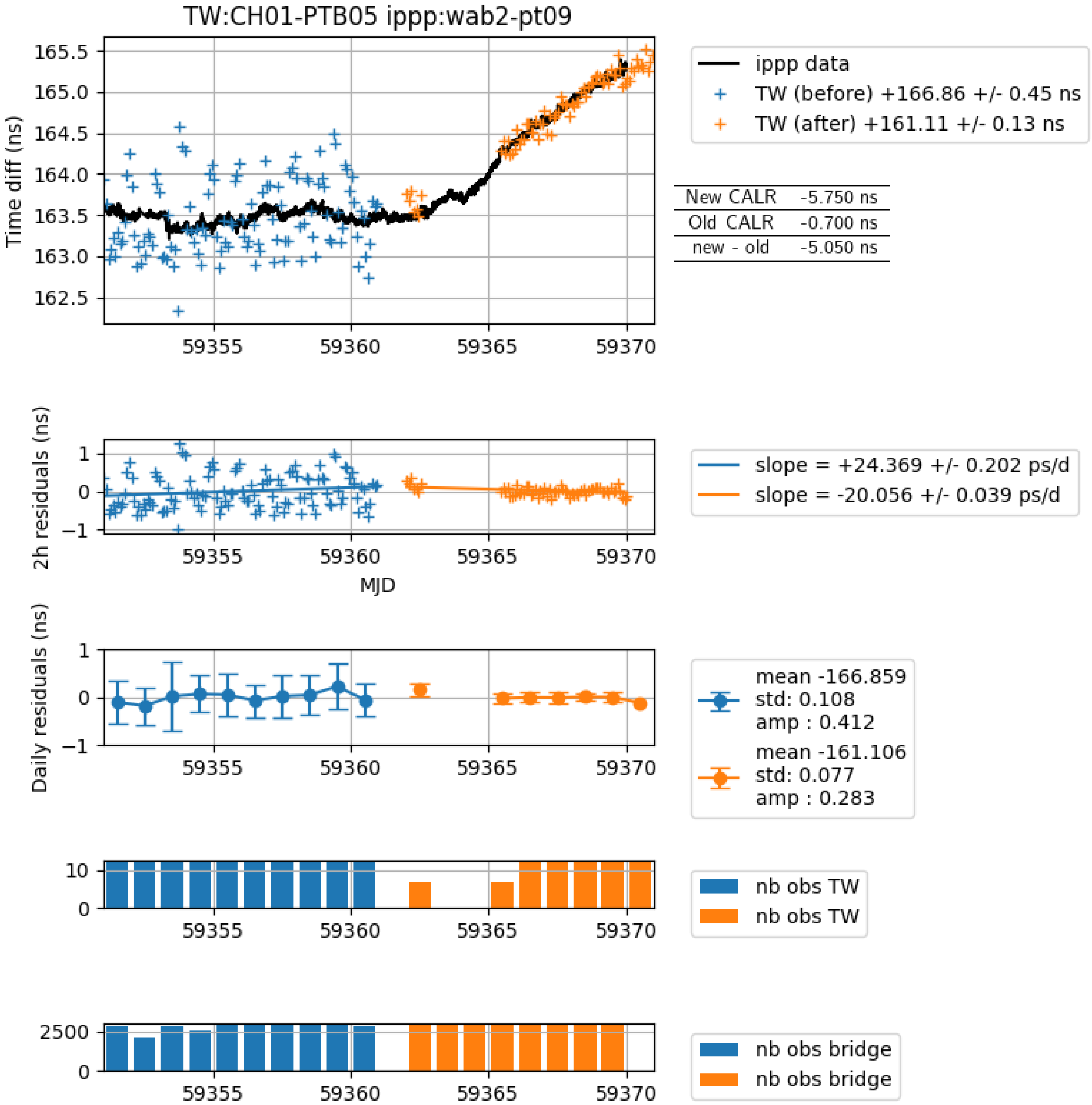


1st period: 59351-59360   2nd period: 59362-59370

CI 535, CH01-PTB05

```
* CAL    535 TYPE: CAL 523 BRIDGED    MJD: 59361 EST. UNCERT.:     1.100 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
CH01    PTB05   535 1     -5.750      0.000 0.000
PTB05   CH01    535 1      5.750     12.320 0.200
```

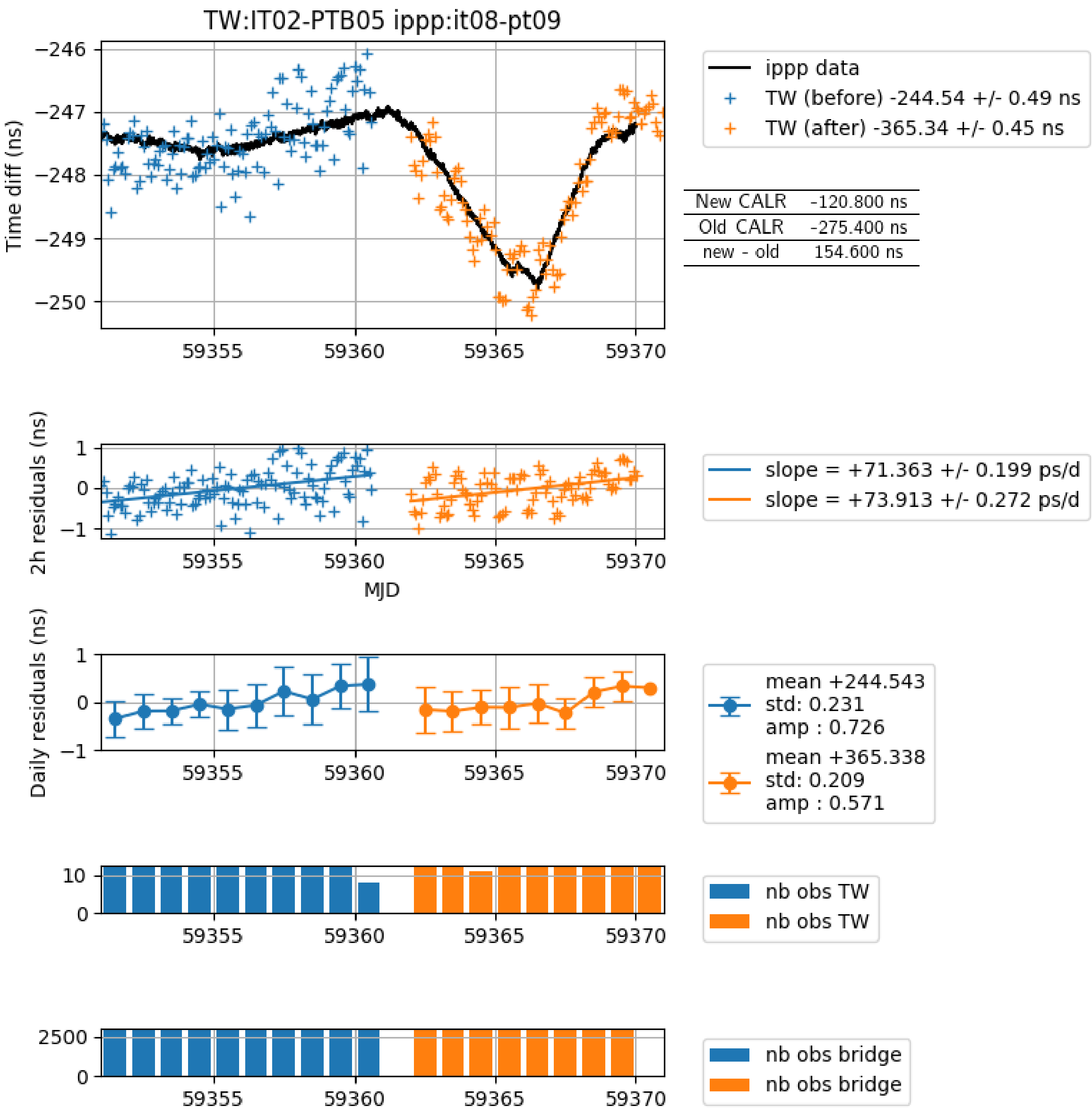


1st period: 59351-59360   2nd period: 59362-59370

CI 536, IT02-PTB05

```
* CAL    536 TYPE: CAL 502 BRIDGED    MJD: 59361 EST. UNCERT.:    1.100 ns

LOC     REM     CI  S     CALR     ESDVAR  ESIG
IT02    PTB05   536 1  -120.800     0.000 0.000
PTB05   IT02    536 1   120.800    12.320 0.200
```



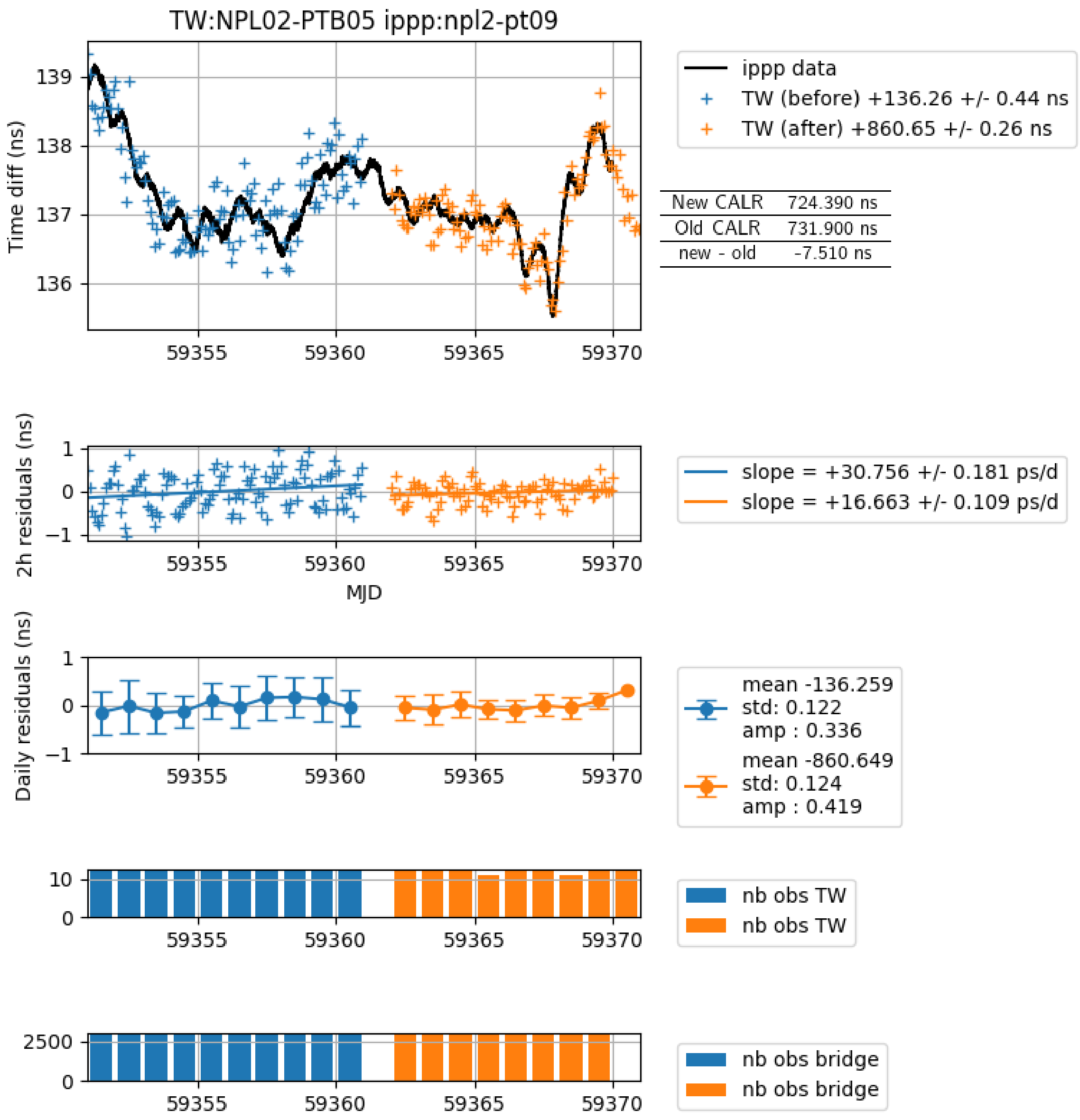
1st period: 59351-59360   2nd period: 59362-59370

Discarded ippp data: 59352.518 - 59352.5194

CI 537, NPL02-PTB05

```
* CAL    537 TYPE: CAL 525 BRIDGED    MJD: 59361 EST. UNCERT.:    1.100 ns

LOC     REM     CI  S      CALR     ESDVAR  ESIG
NPL02   PTB05   537 1    724.390     0.000 0.000
PTB05   NPL02   537 1   -724.390    12.320 0.200
```

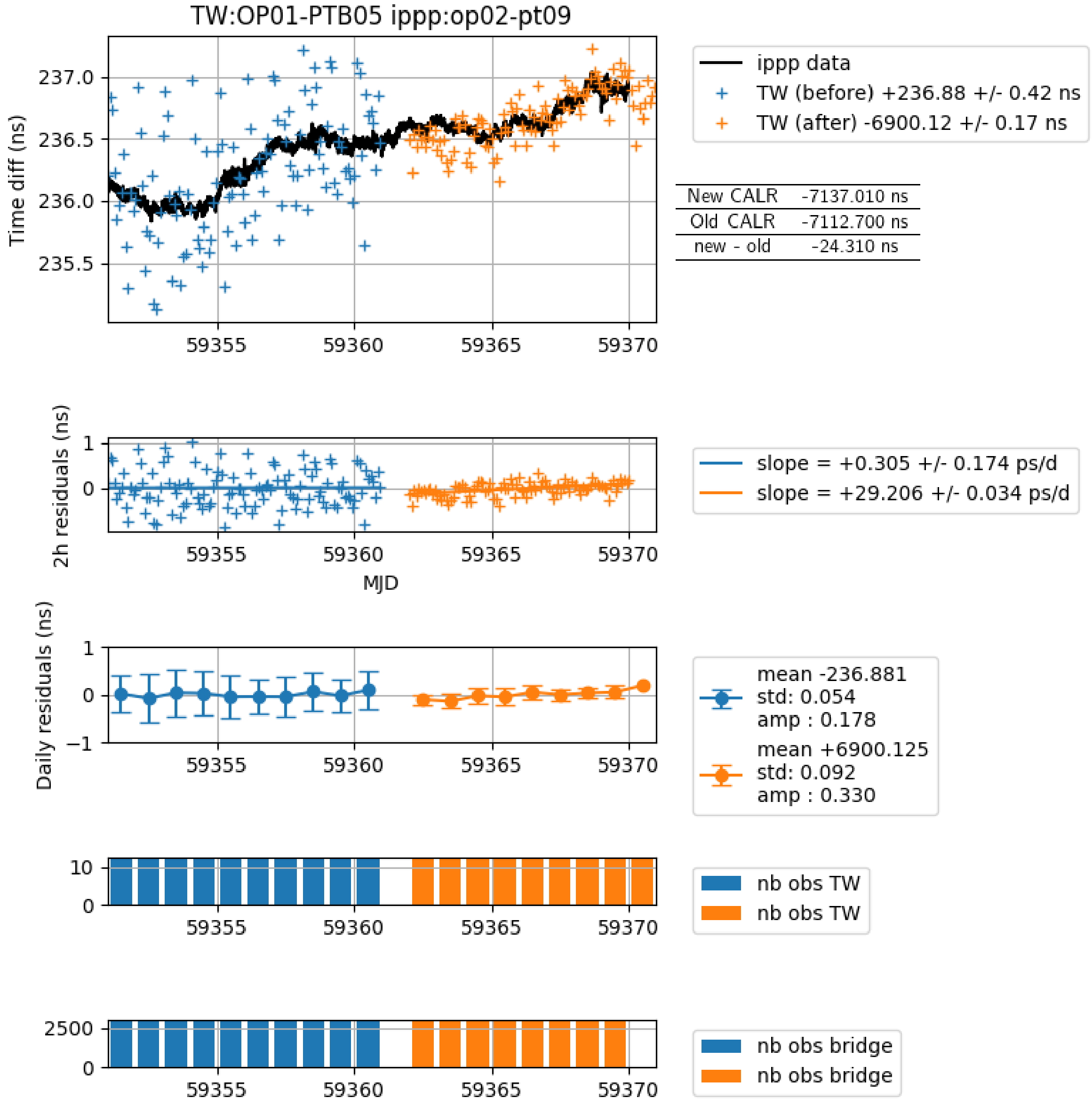


1st period: 59351-59360   2nd period: 59362-59370

CI 538, OP01-PTB05

```
* CAL   538 TYPE: CAL 503 BRIDGED    MJD: 59361 EST. UNCERT.:    1.000 ns

LOC    REM     CI  S      CALR     ESDVAR  ESIG
OP01   PTB05   538 1 -7137.010     0.000 0.000
PTB05  OP01    538 1  7137.010    12.320 0.200
```

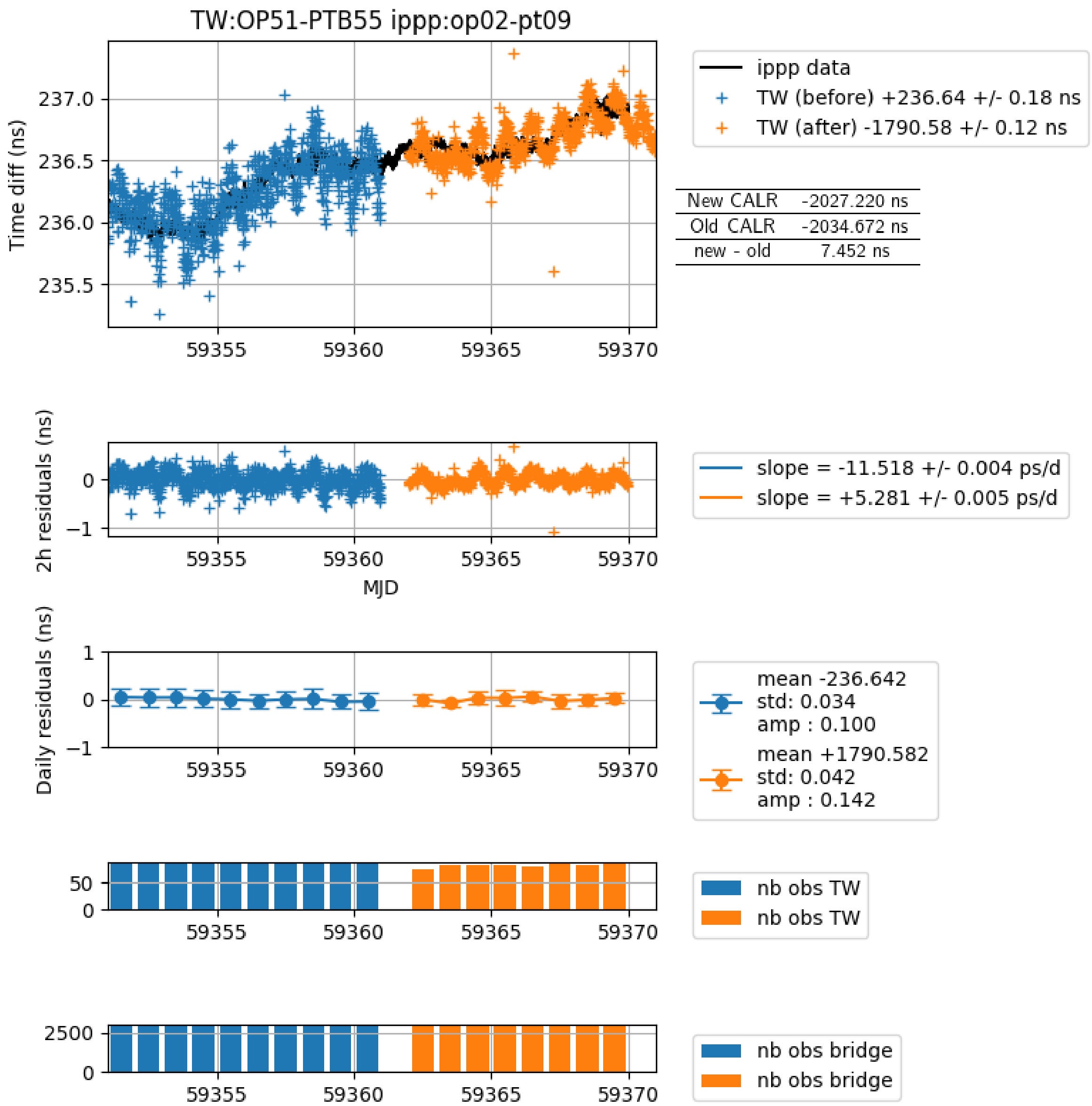


1st period: 59351-59360   2nd period: 59362-59370

CI 539, OP51-PTB55

```
* CAL    539 TYPE: CAL 517 BRIDGED    MJD: 59361 EST. UNCERT.:    0.600 ns

LOC     REM     CI  S       CALR     ESDVAR  ESIG
OP51    PTB55   539 1 -2027.220     18.166 0.156
PTB55   OP51    539 1  2027.220     12.320 0.200
```

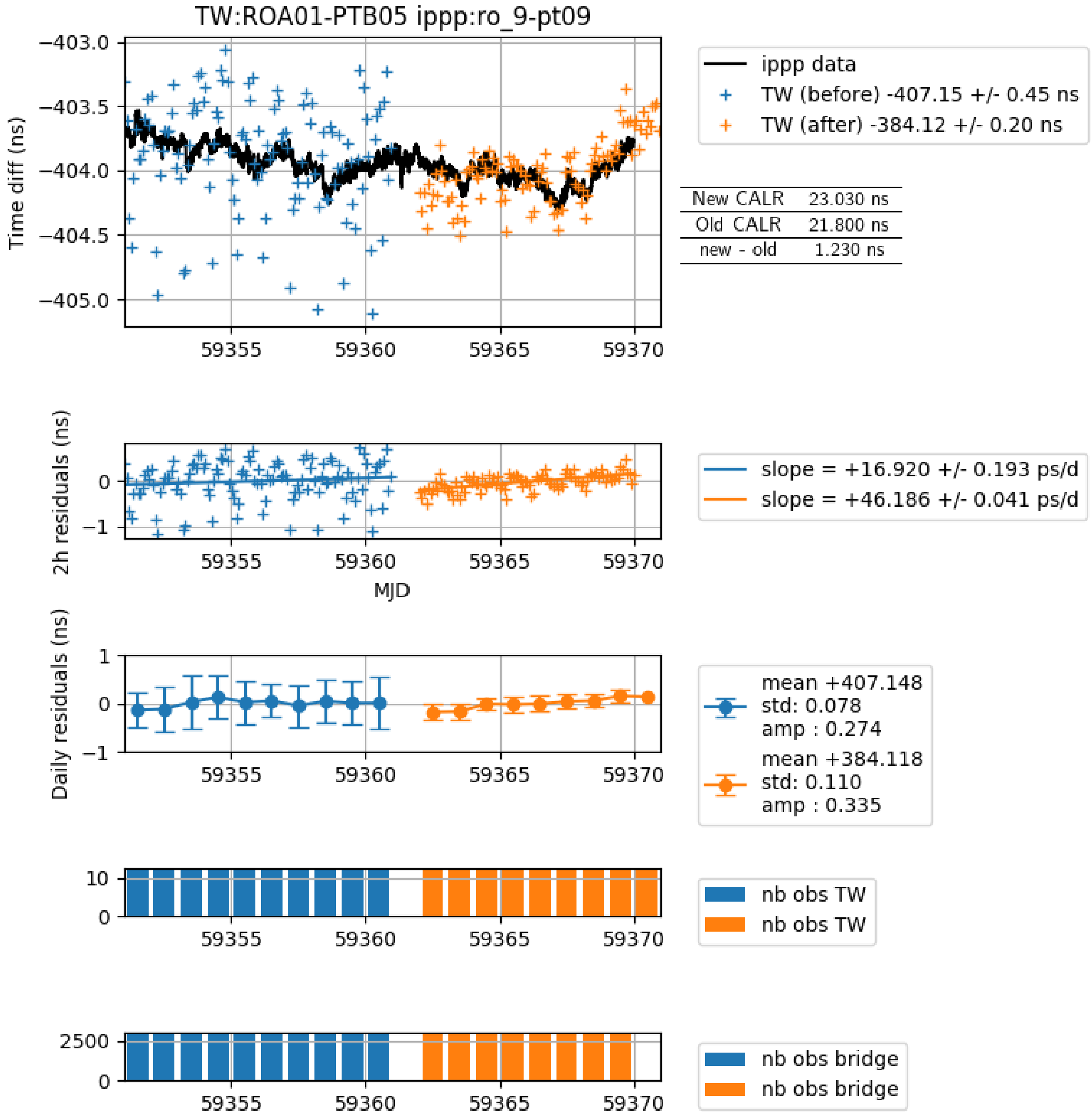


1st period: 59351-59360   2nd period: 59362-59370

CI 540, ROA01-PTB05

```
* CAL    540 TYPE: CAL 504 BRIDGED    MJD: 59361 EST. UNCERT.:    1.000 ns

LOC      REM      CI   S        CALR      ESDVAR   ESIG
ROA01    PTB05    540  1      23.030       0.000  0.000
PTB05    ROA01    540  1     -23.030      12.320  0.200
```

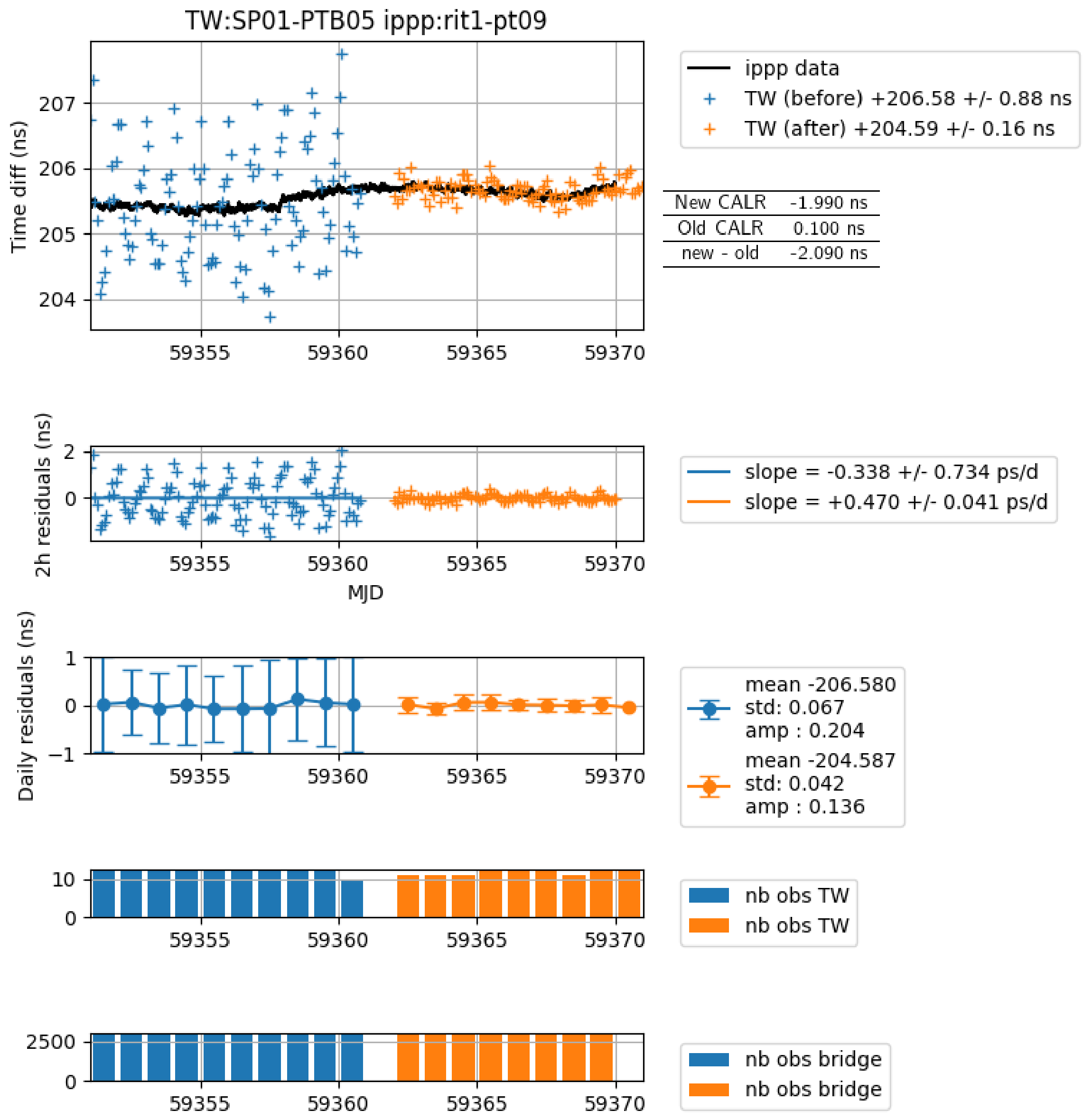


1st period: 59351-59360   2nd period: 59362-59370

CI 541, SP01-PTB05

```
* CAL    541 TYPE: CAL 496 BRIDGED    MJD: 59361 EST. UNCERT.:    1.200 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
SP01    PTB05   541  1     -1.990      0.000 0.000
PTB05   SP01    541  1      1.990     12.320 0.200
```

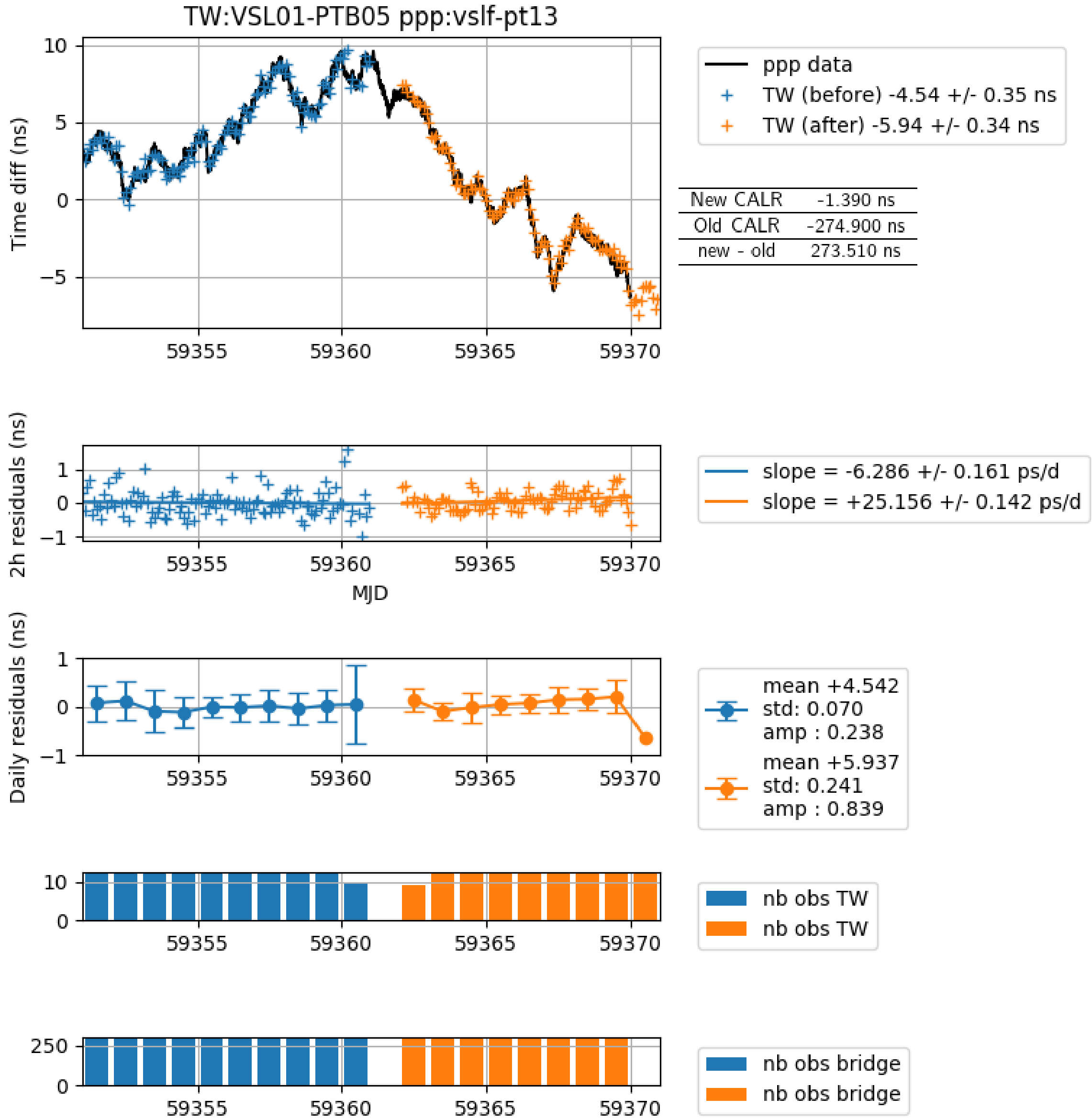


1st period: 59351-59360   2nd period: 59362-59370

CI 542, VSL01-PTB05

```
* CAL    542 TYPE: CAL 527 BRIDGED    MJD: 59361 EST. UNCERT.:    1.000 ns

LOC     REM     CI  S       CALR     ESDVAR  ESIG
VSL01   PTB05   542 1     -1.390      0.000 0.000
PTB05   VSL01   542 1      1.390     12.320 0.200
```

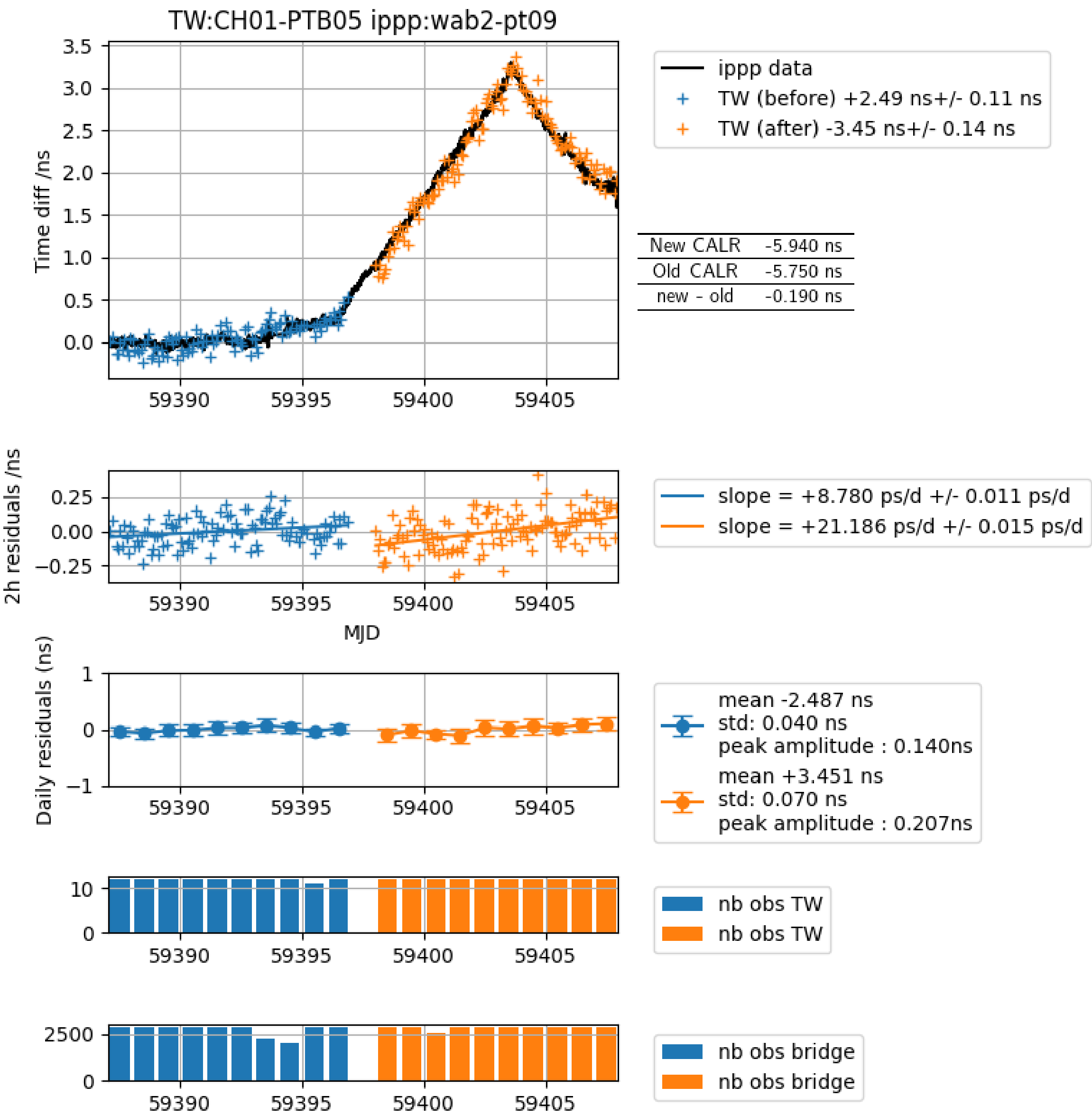


1st period: 59351-59360   2nd period: 59362-59370

CI 543, CH01-PTB05

* CAL 543 TYPE: CAL 535 BRIDGED MJD: 59397 EST. UNCERT.: 1.200 ns

LOC	REM	CI	S	CALR	ESDVAR	ESIG
CH01	PTB05	543	1	-5.940	0.000	0.000
PTB05	CH01	543	1	5.940	12.320	0.200

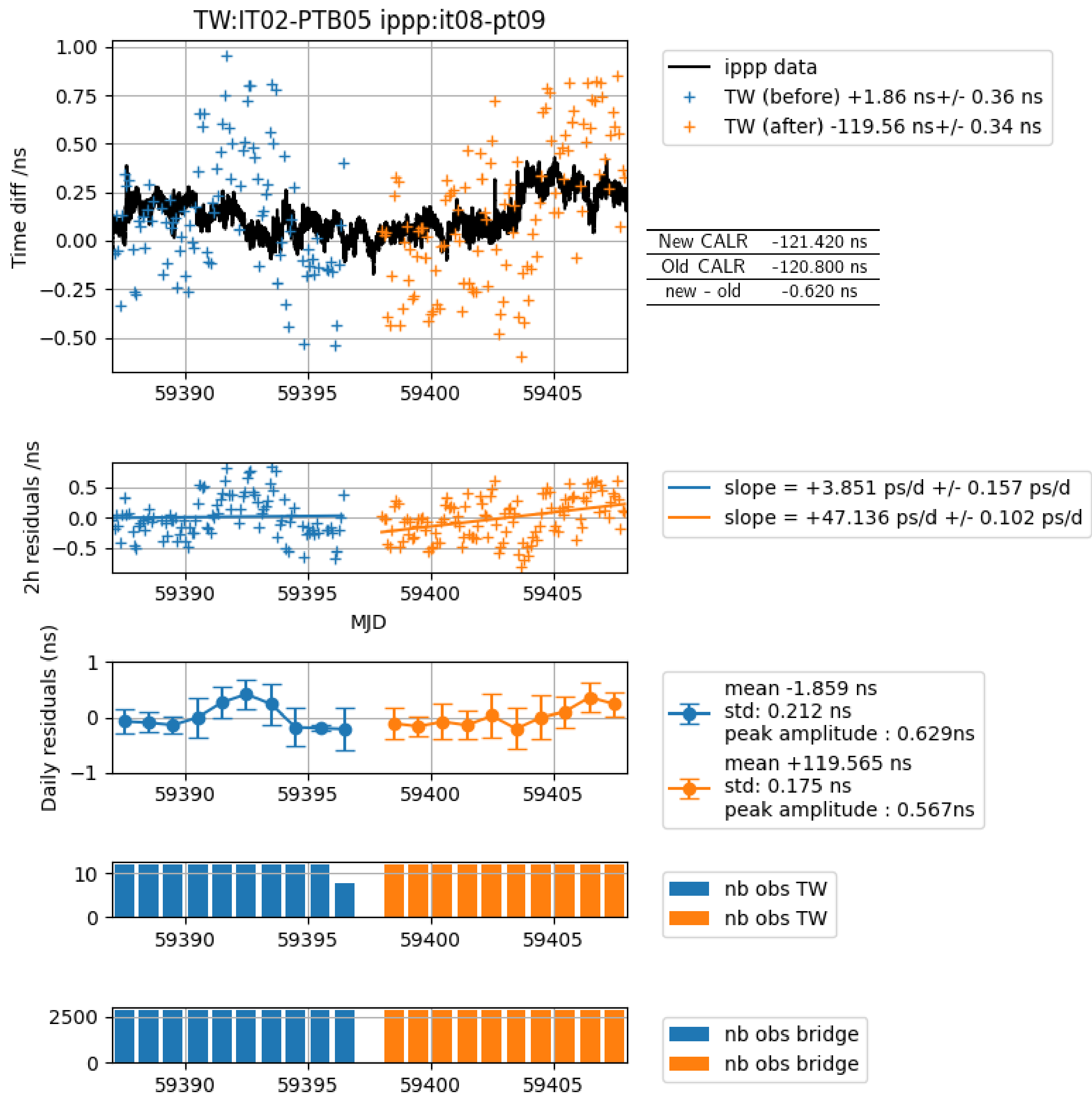


1st period: 59387-59396 2nd period: 59398-59407

CI 544, IT02-PTB05

```
* CAL    544 TYPE: CAL 536 BRIDGED    MJD: 59397 EST. UNCERT.:    1.300 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
IT02    PTB05   544  1   -121.420      0.000  0.000
PTB05   IT02    544  1    121.420     12.320  0.200
```



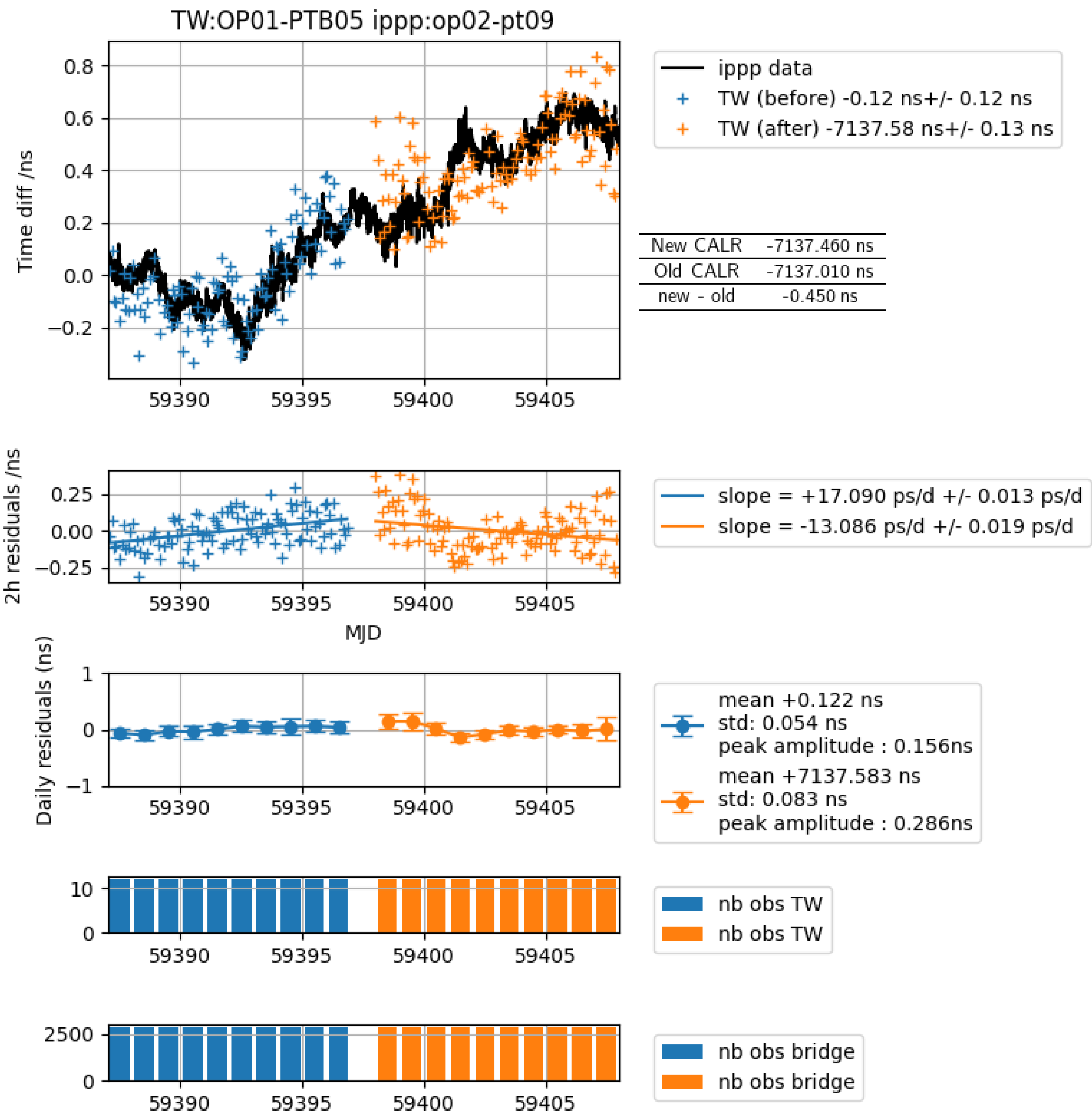
1st period: 59387-59396   2nd period: 59398-59407

Discarded ippp data: 59352.518 - 59352.5194

CI 545, OP01-PTB05

```
* CAL    545 TYPE: CAL 538 BRIDGED    MJD: 59397 EST. UNCERT.:    1.100 ns

LOC     REM     CI  S       CALR     ESDVAR  ESIG
OP01    PTB05   545 1 -7137.460      0.000 0.000
PTB05   OP01    545 1  7137.460     12.320 0.200
```

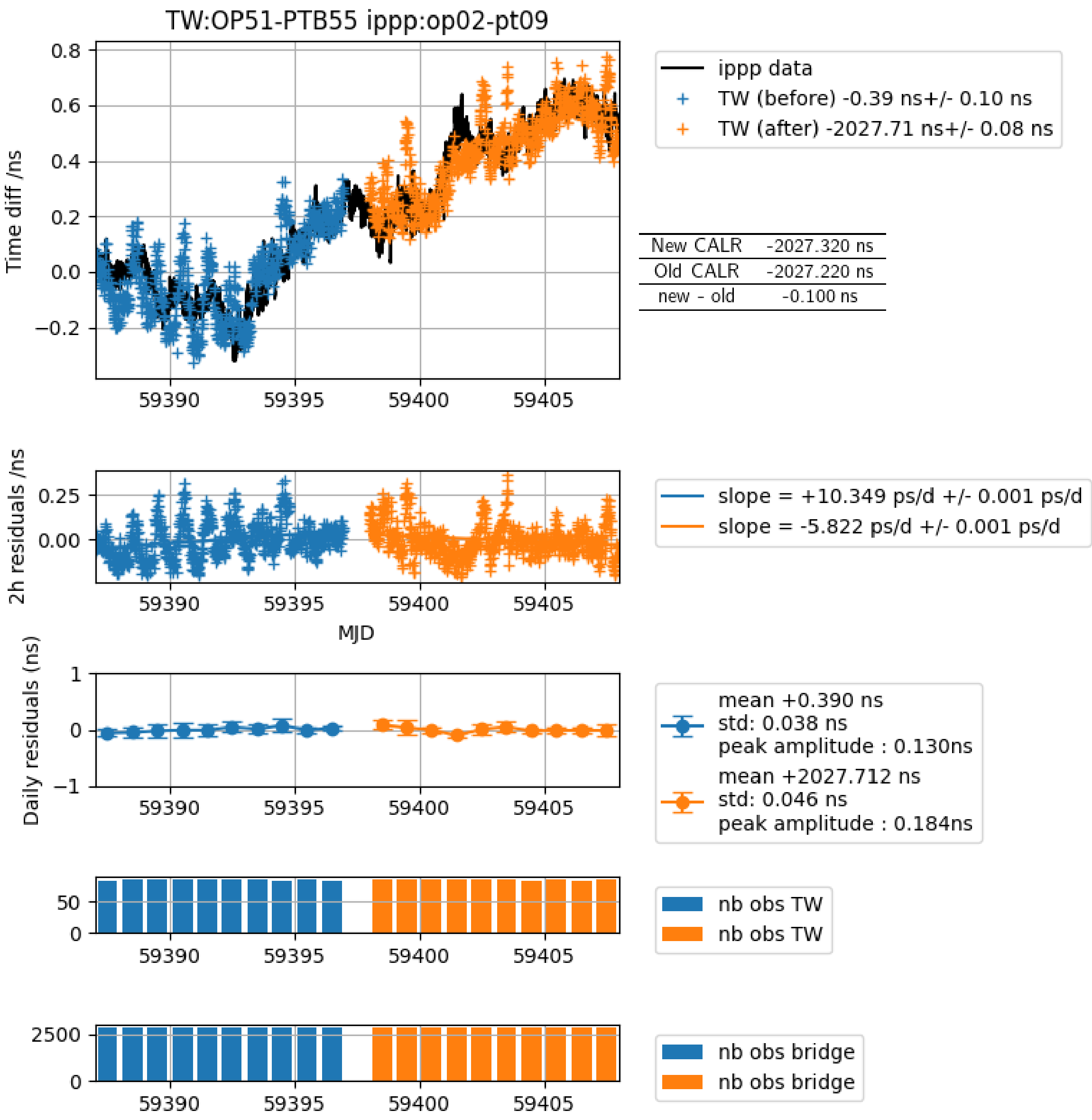


1st period: 59387-59396   2nd period: 59398-59407

CI 546, OP51-PTB55

* CAL 546 TYPE: CAL 539 BRIDGED MJD: 59397 EST. UNCERT.: 0.700 ns

LOC	REM	CI	S	CALR	ESDVAR	ESIG
OP51	PTB55	546	1	-2027.320	18.166	0.156
PTB55	OP51	546	1	2027.320	12.320	0.200

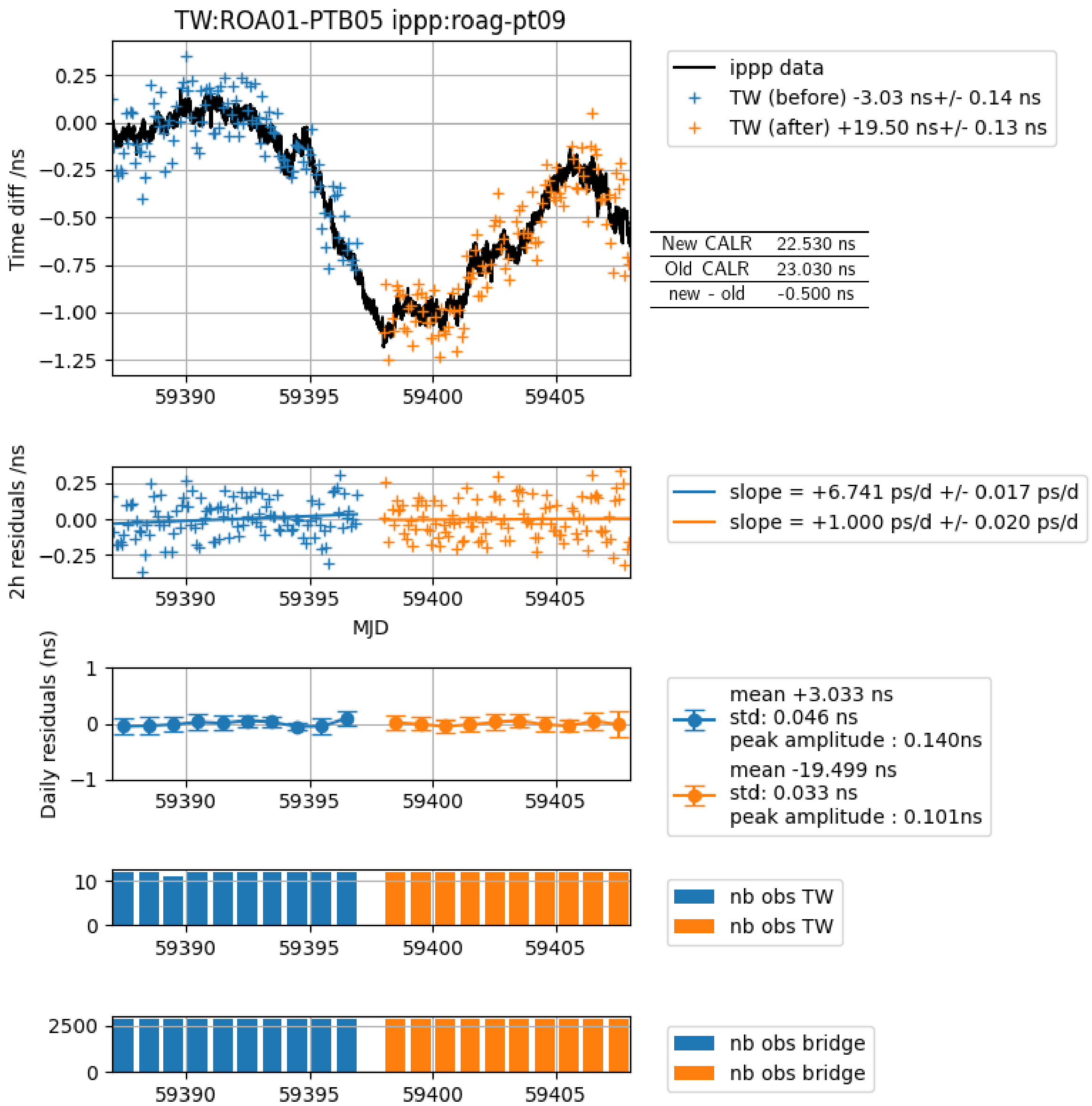


1st period: 59387-59396 2nd period: 59398-59407

CI 547, ROA01-PTB05

```
* CAL    547 TYPE: CAL 540 BRIDGED    MJD: 59397 EST. UNCERT.:    1.100 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
ROA01   PTB05   547 1     22.530      0.000 0.000
PTB05   ROA01   547 1    -22.530     12.320 0.200
```



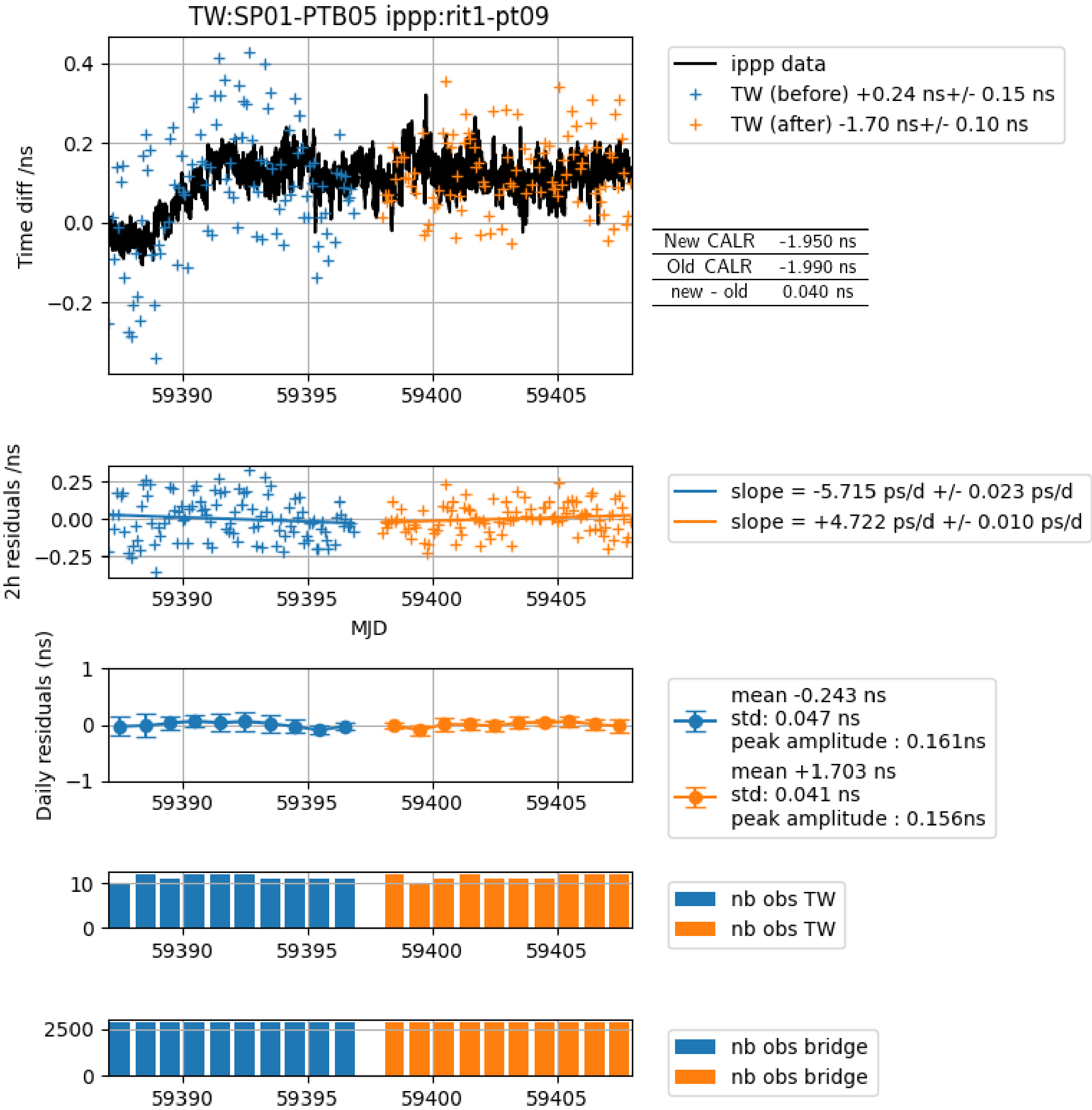
1st period: 59387-59396   2nd period: 59398-59407

Discarded ippp data: 59402.6253 - 59402.6254
59409.3416 - 59402.3417

CI 548, SP01-PTB05

```
* CAL    548 TYPE: CAL 541 BRIDGED    MJD: 59397 EST. UNCERT.:    1.300 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
SP01    PTB05   548 1      -1.950      0.000 0.000
PTB05   SP01    548 1       1.950     12.320 0.200
```

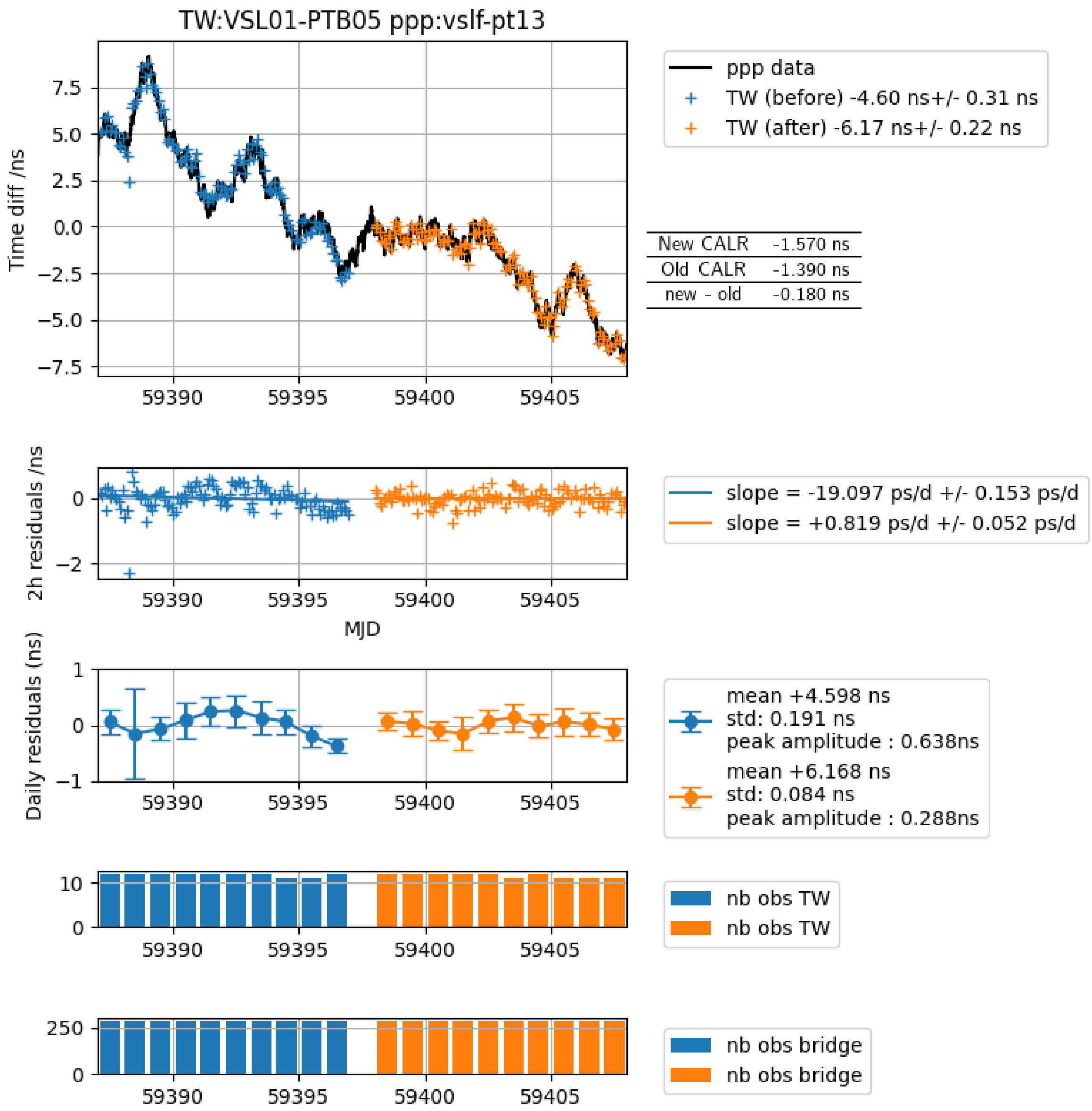


1st period: 59387-59396   2nd period: 59398-59407

CI 549, VSL01-PTB05

```
* CAL    549 TYPE: CAL 542 BRIDGED    MJD: 59397 EST. UNCERT.:    1.100 ns

LOC     REM     CI   S       CALR     ESDVAR  ESIG
VSL01   PTB05   549 1     -1.570      0.000 0.000
PTB05   VSL01   549 1      1.570      0.000 0.200
```

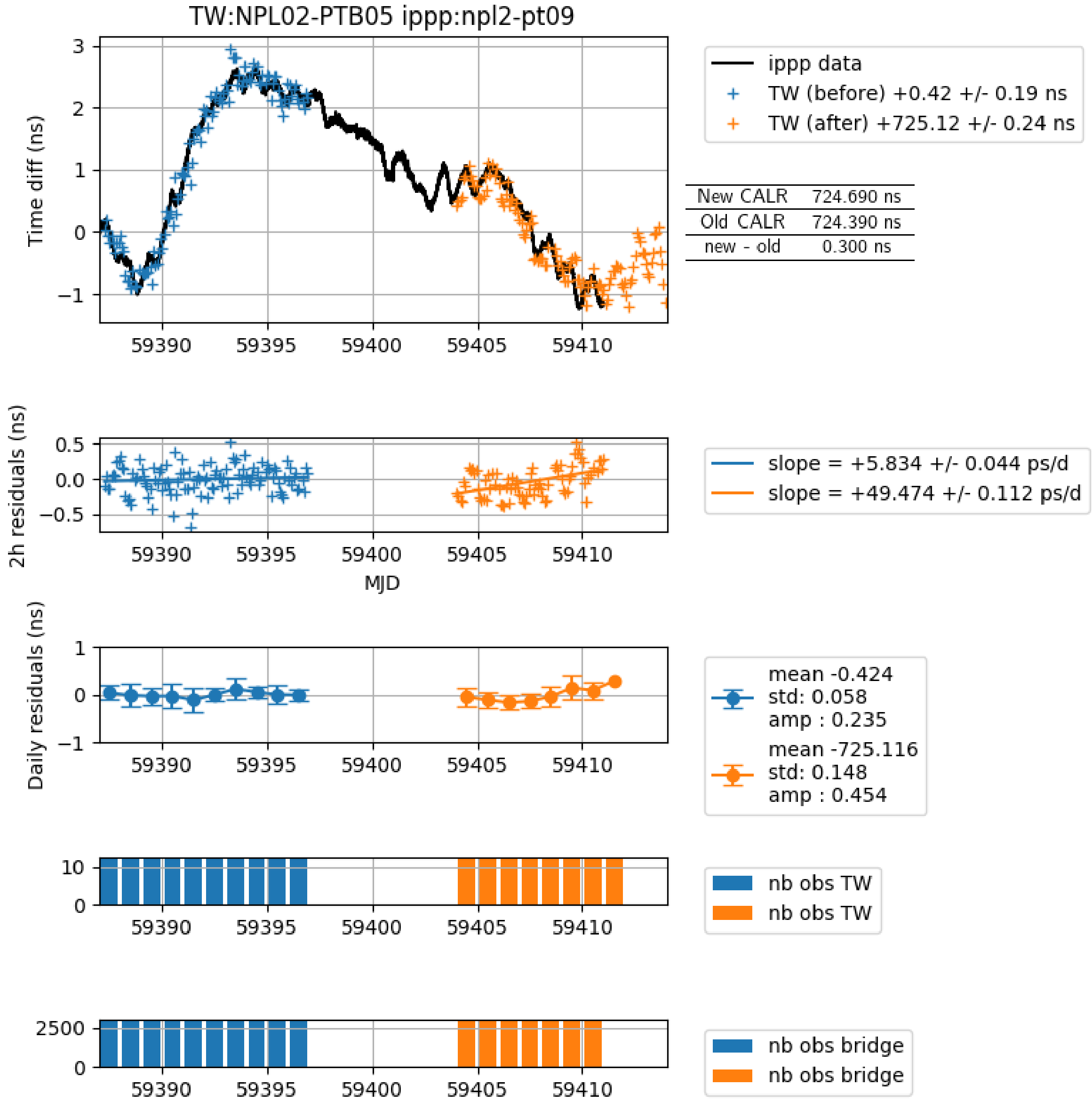


1st period: 59387-59396   2nd period: 59398-59407

CI 550, NPL02-PTB05

```
* CAL    550 TYPE: CAL 537 BRIDGED    MJD: 59361 EST. UNCERT.:    1.200 ns

LOC     REM     CI  S       CALR     ESDVAR  ESIG
NPL02   PTB05   550 1    724.690     0.000 0.000
PTB05   NPL02   550 1   -724.690    12.320 0.200
```

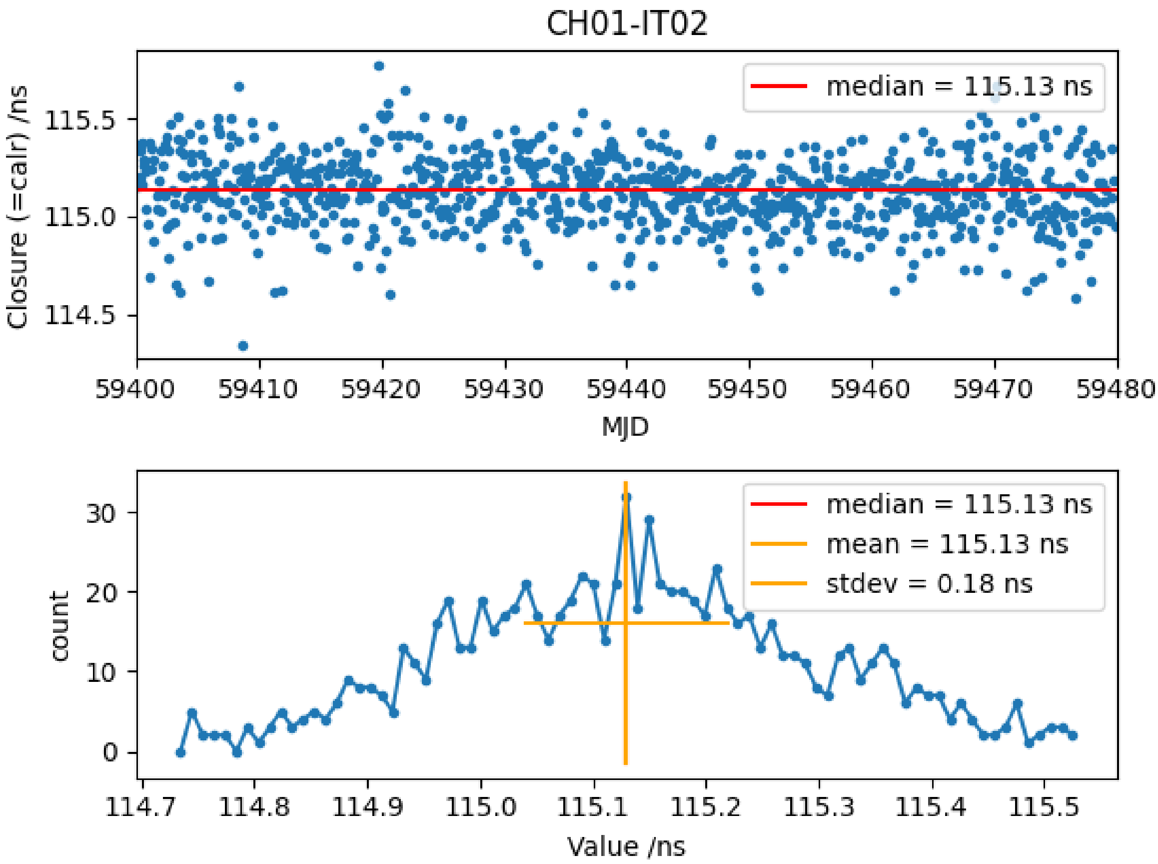


1st period: 59387-59396   2nd period: 59404-59413

Discarded TW data: 59405.7 - 59405.8

CI 551, CH01-IT02

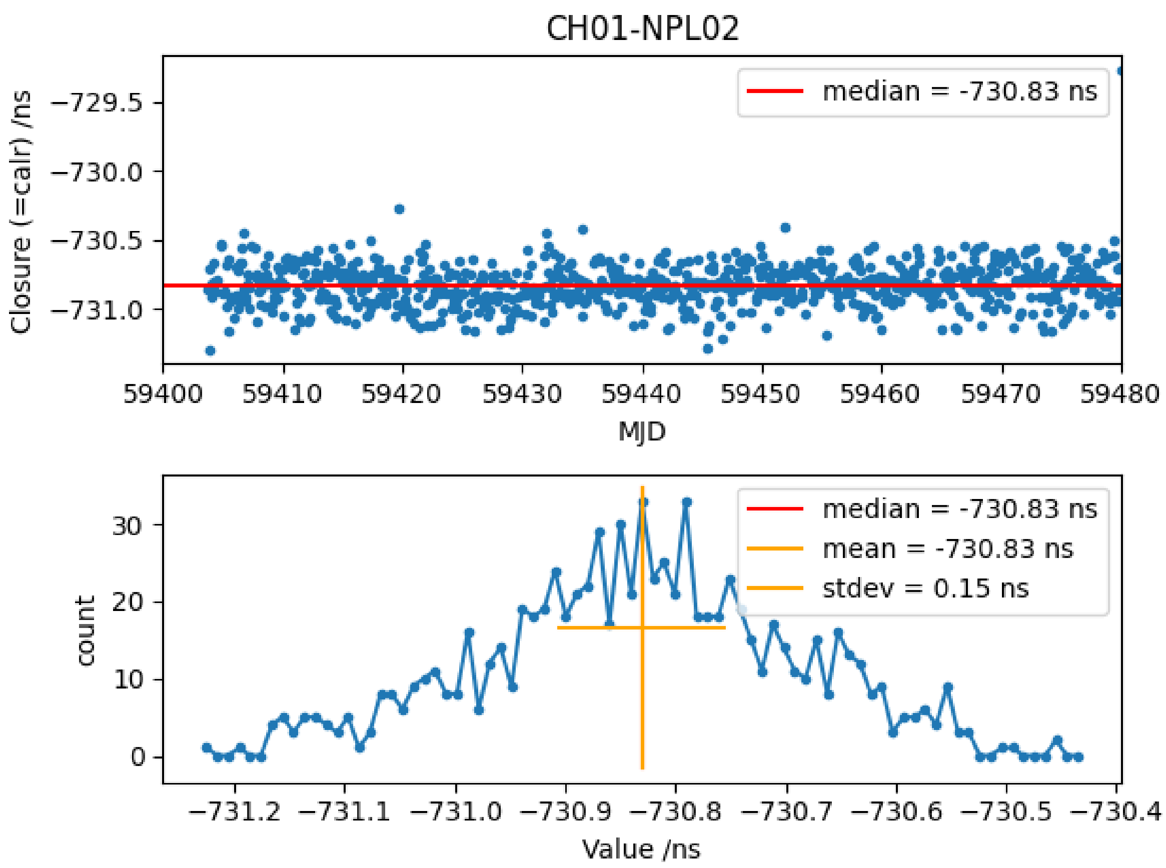
```
* CAL    551 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
CH01    IT02    551  1    115.130      0.000 0.000
IT02    CH01    551  1   -115.130      0.000 0.000
```



Comparison period: 59400-59480

CI 552, CH01-NPL02

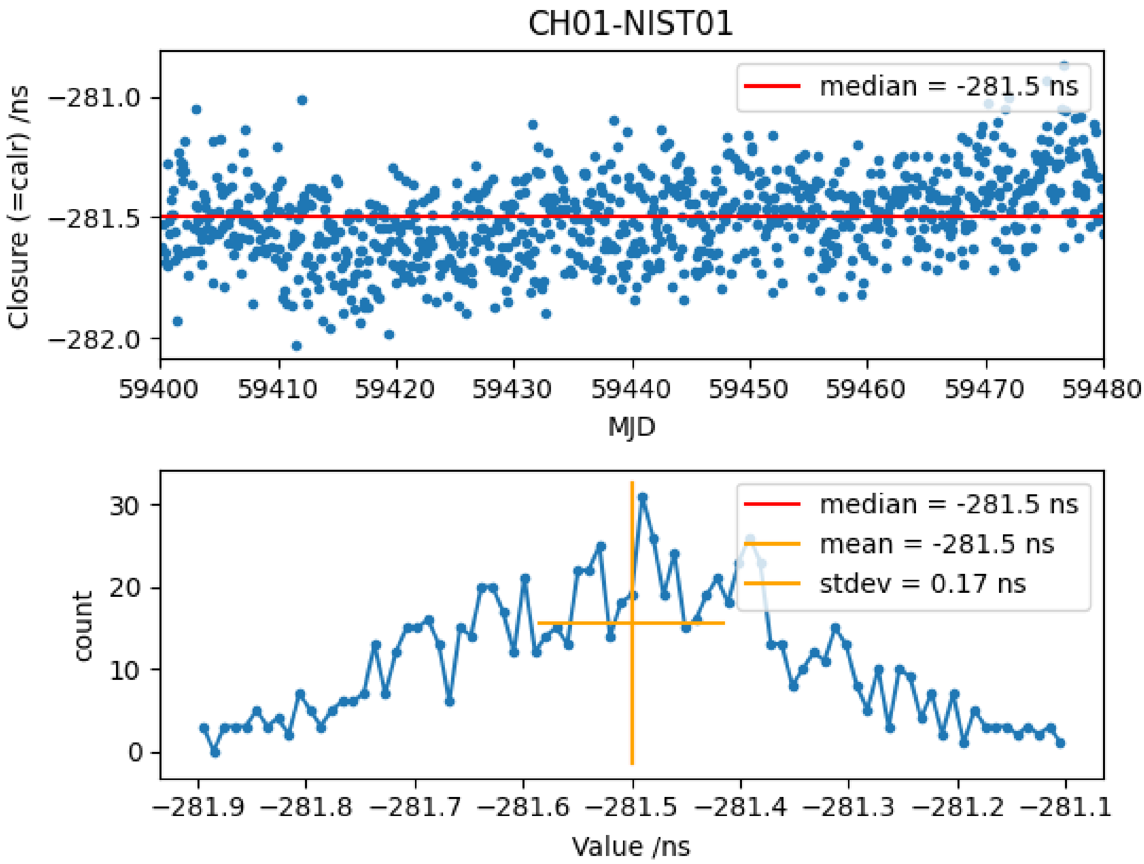
```
* CAL   552 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI  S       CALR     ESDVAR  ESIG
CH01    NPL02   552 1   -730.830      0.000 0.000
NPL02   CH01    552 1    730.830      0.000 0.000
```



Comparison period: 59400-59480

CI 553, CH01-NIST01

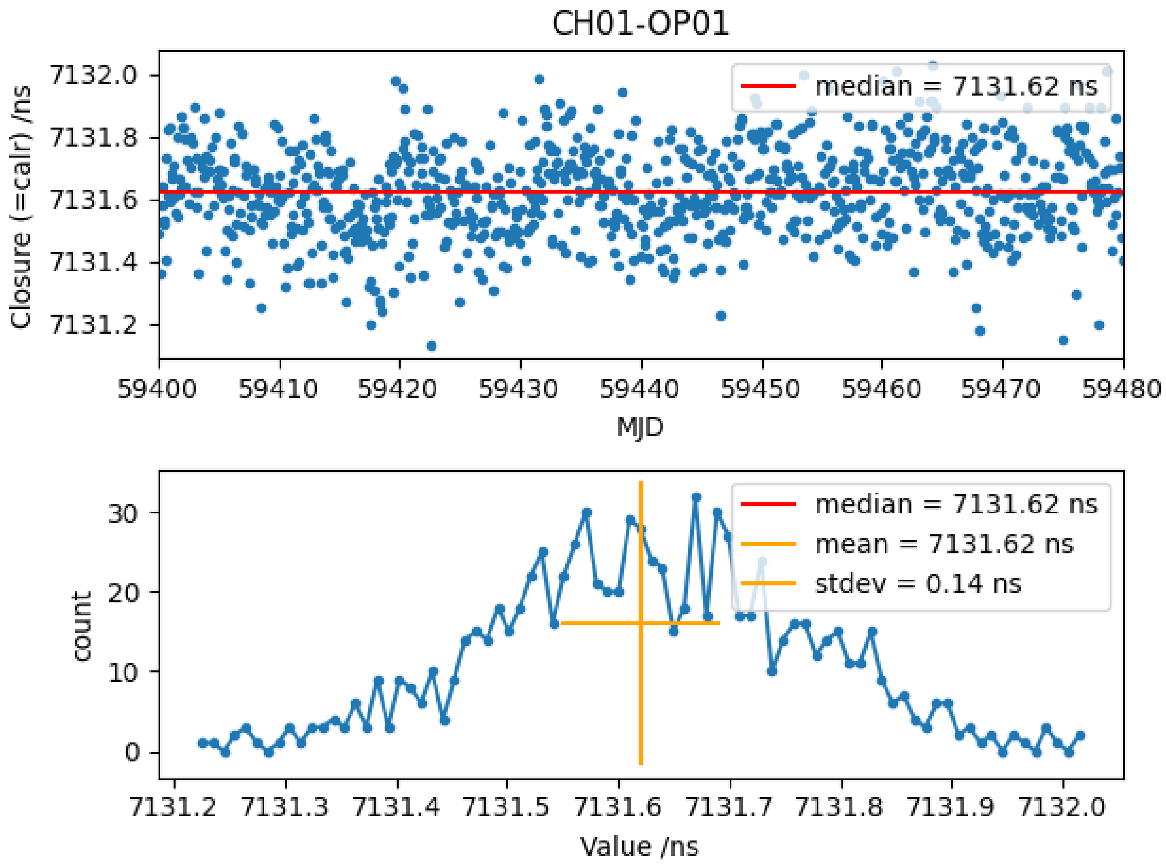
* CAL	553 TYPE: TRIANGLE CLOSURE		MJD: 59397 EST. UNCERT.:			2.100 ns
LOC	REM	CI	S	CALR	ESDVAR	ESIG
CH01	NIST01	553	1	-281.500	0.000	0.000
NIST01	CH01	553	1	281.500	0.000	0.000



Comparison period: 59400-59480

CI 554, CH01-OP01

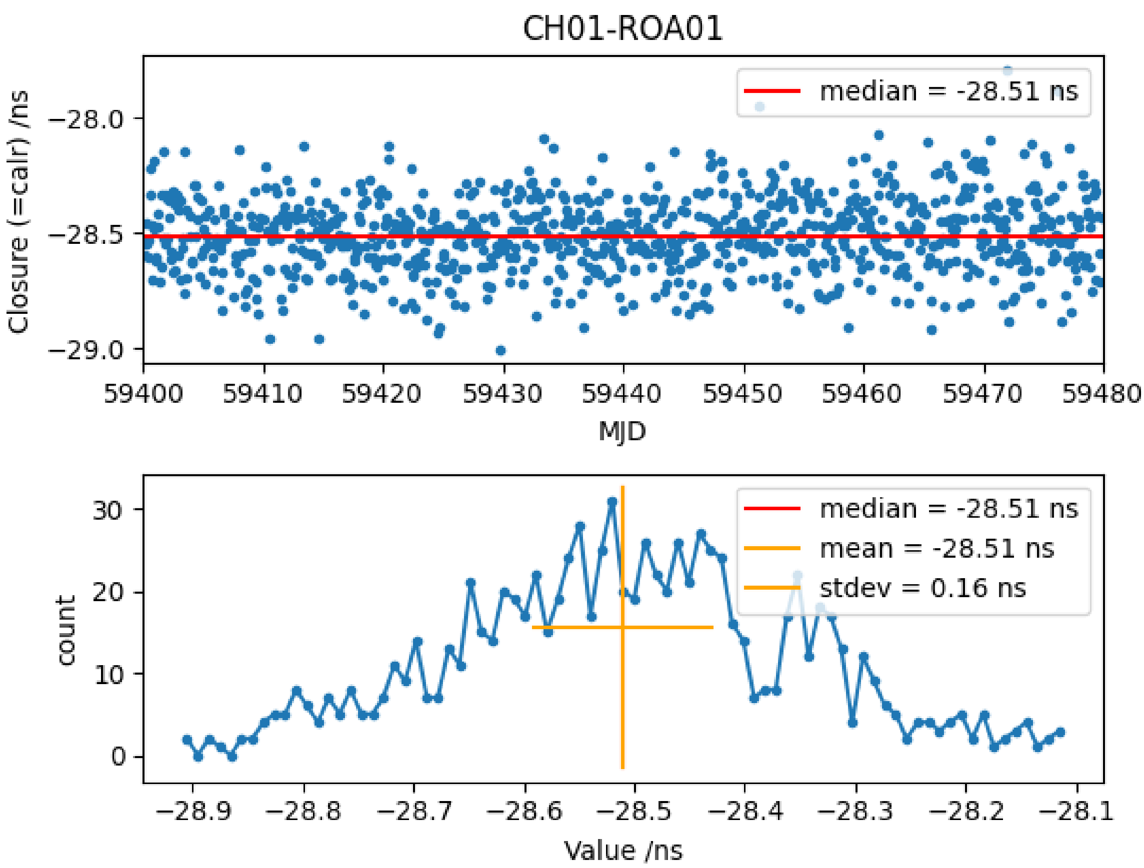
```
* CAL    554 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.700 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
CH01    OP01    554  1   7131.620      0.000 0.000
OP01    CH01    554  1  -7131.620      0.000 0.000
```



Comparison period: 59400-59480

CI 555, CH01-ROA01

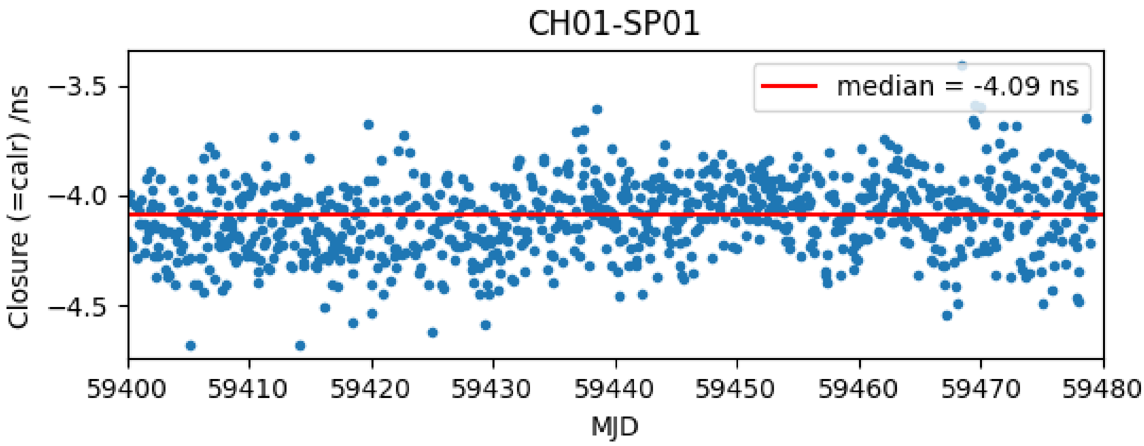
```
* CAL   555 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.700 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
CH01    ROA01   555  1    -28.510      0.000 0.000
ROA01   CH01    555  1     28.510      0.000 0.000
```

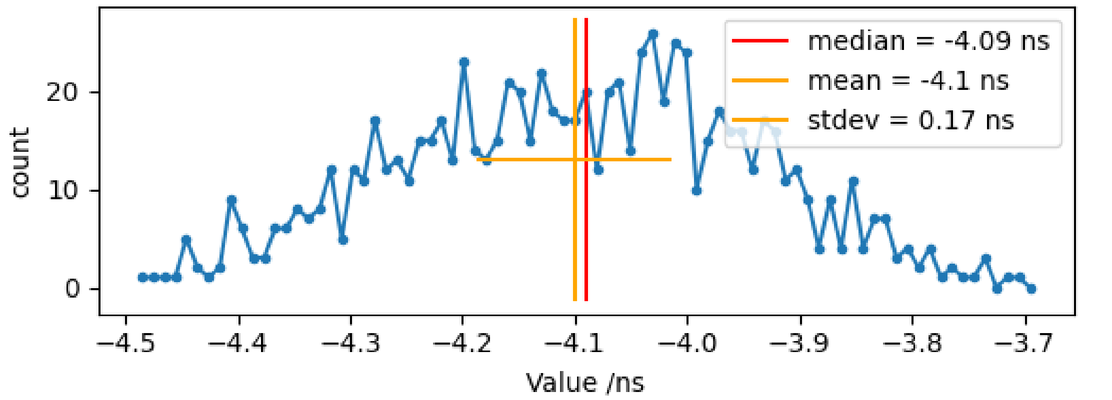


Comparison period: 59400-59480

CI 556, CH01-SP01

```
* CAL    556 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
CH01    SP01    556 1     -4.090      0.000 0.000
SP01    CH01    556 1      4.090      0.000 0.000
```

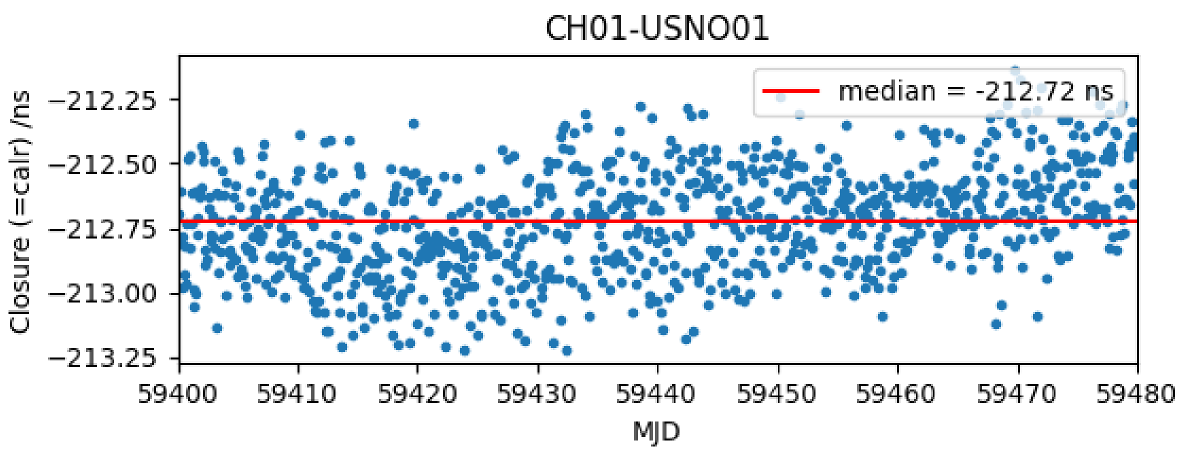


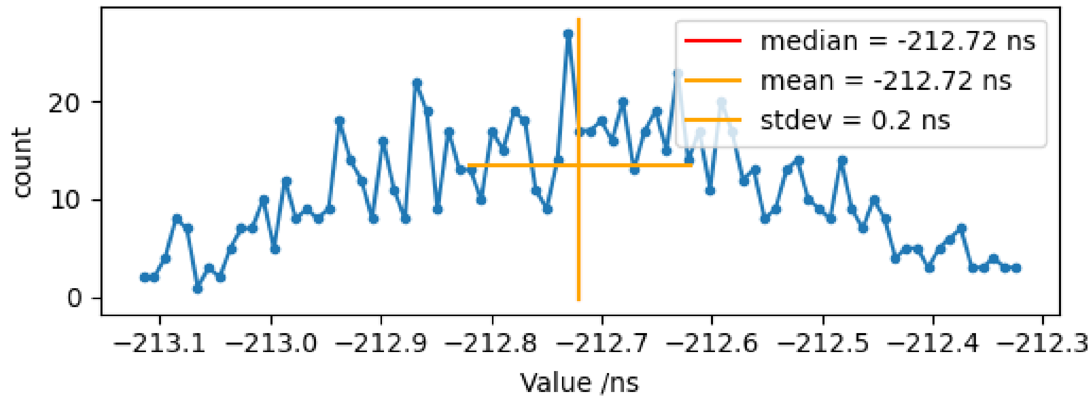


Comparison period: 59400-59480

CI 557, CH01-USNO01

```
* CAL    557 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.500 ns
LOC      REM      CI   S       CALR      ESDVAR  ESIG
CH01     USNO01  557  1   -212.720      0.000 0.000
USNO01  CH01     557  1    212.720      0.000 0.000
```

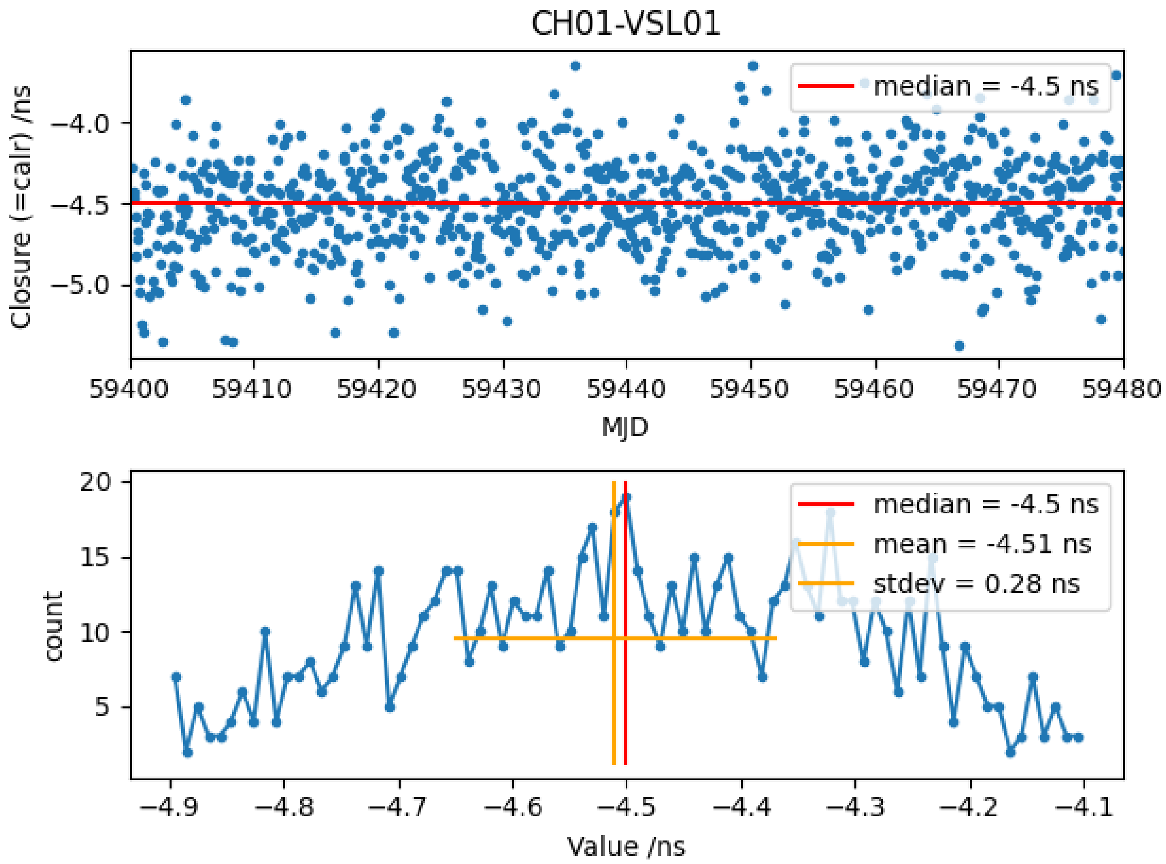




Comparison period: 59400-59480

CI 558, CH01-VSL01

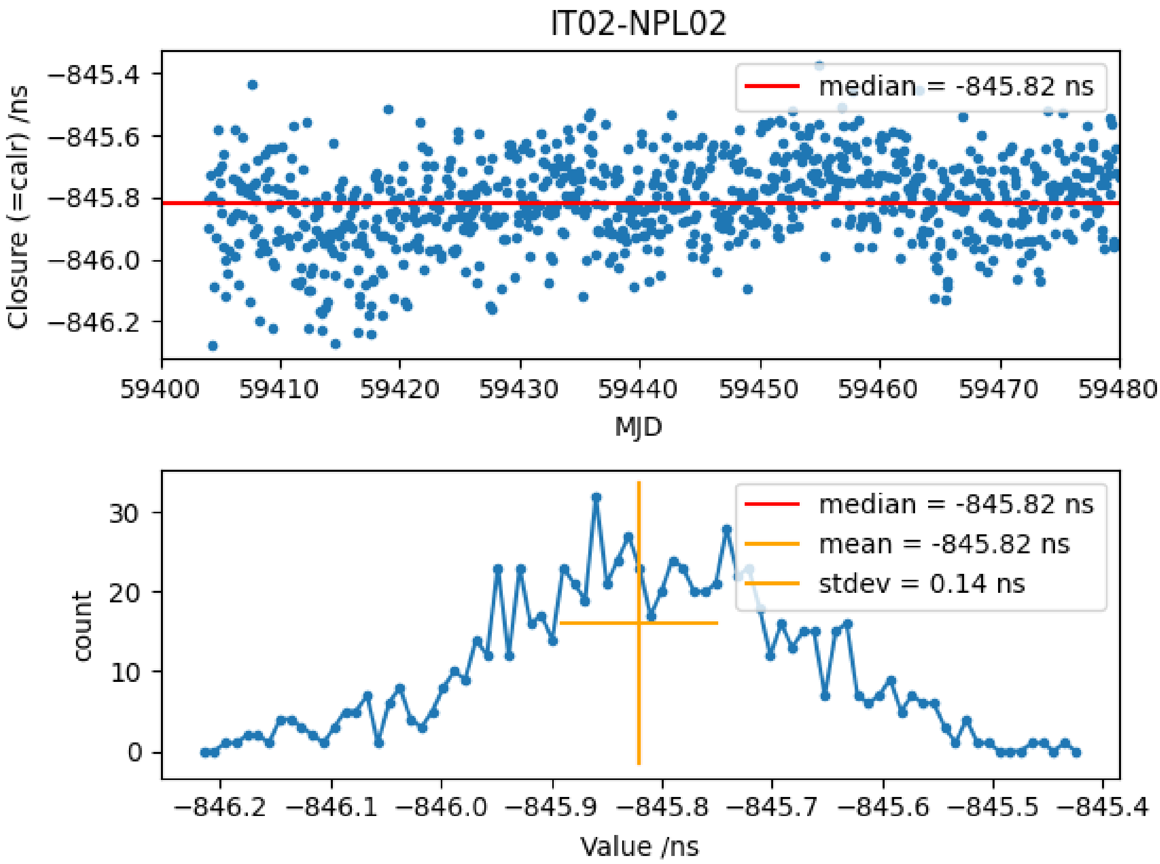
```
* CAL    558 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.700 ns
LOC      REM      CI   S        CALR      ESDVAR  ESIG
CH01     VSL01    558  1      -4.500       0.000  0.000
VSL01    CH01     558  1       4.500       0.000  0.000
```



Comparison period: 59400-59480

CI 559, IT02-NPL02

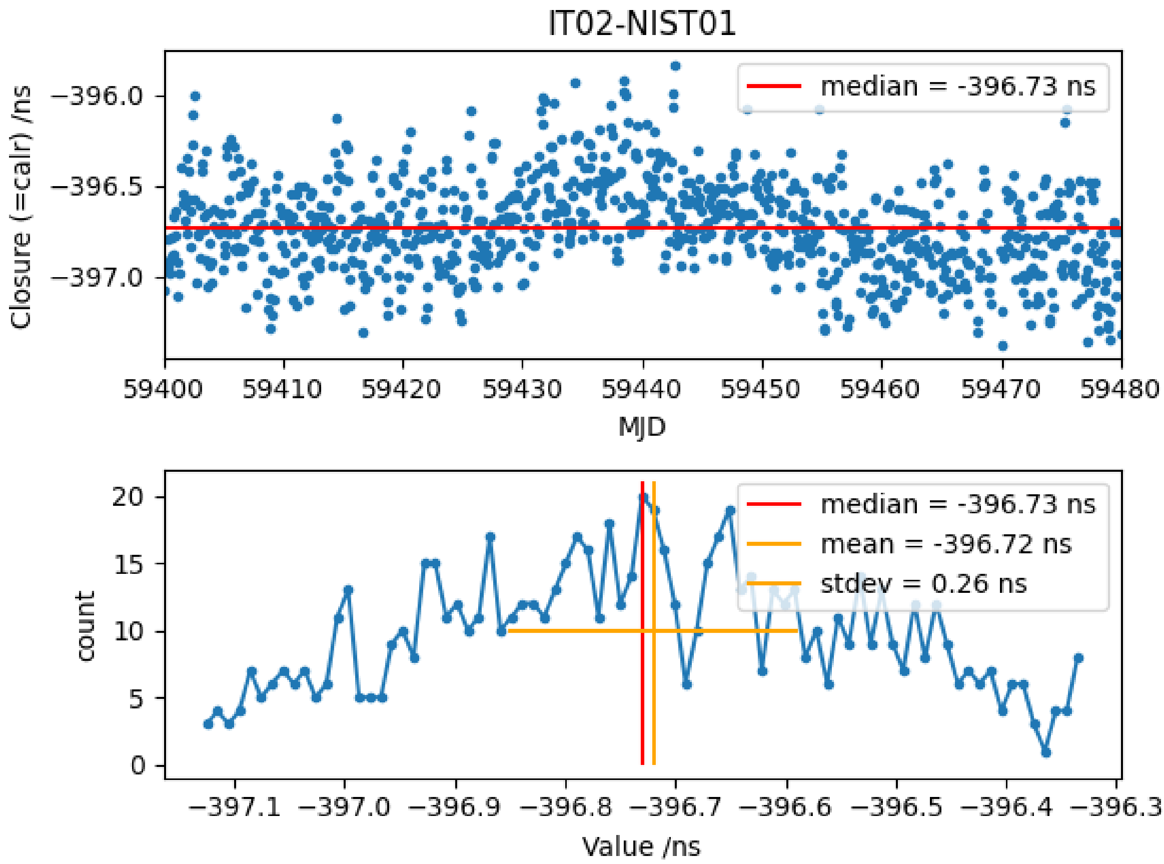
```
* CAL    559 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
IT02    NPL02   559 1   -845.820      0.000 0.000
NPL02   IT02    559 1    845.820      0.000 0.000
```



Comparison period: 59400-59480

CI 560, IT02-NIST01

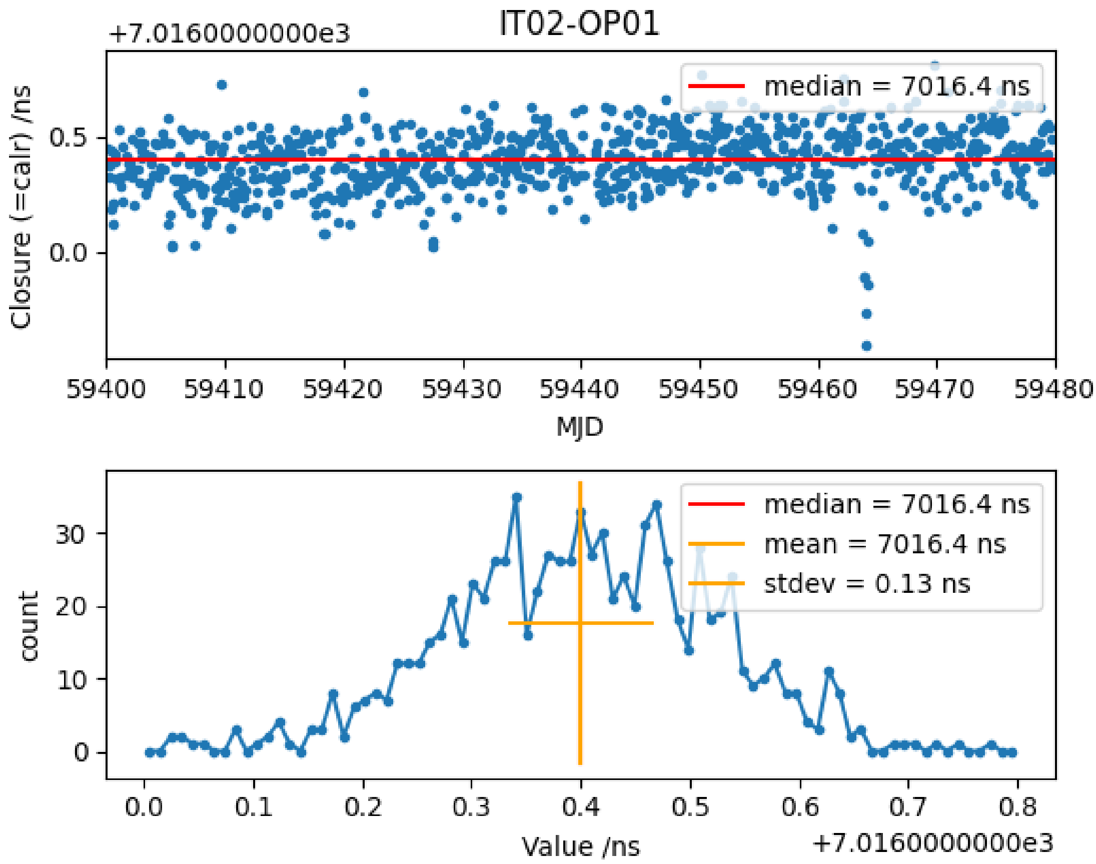
```
* CAL    560 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    2.100 ns
LOC     REM     CI  S       CALR     ESDVAR  ESIG
IT02    NIST01 560 1  -396.730      0.000 0.000
NIST01 IT02    560 1   396.730      0.000 0.000
```



Comparison period: 59400-59480

CI 561, IT02-OP01

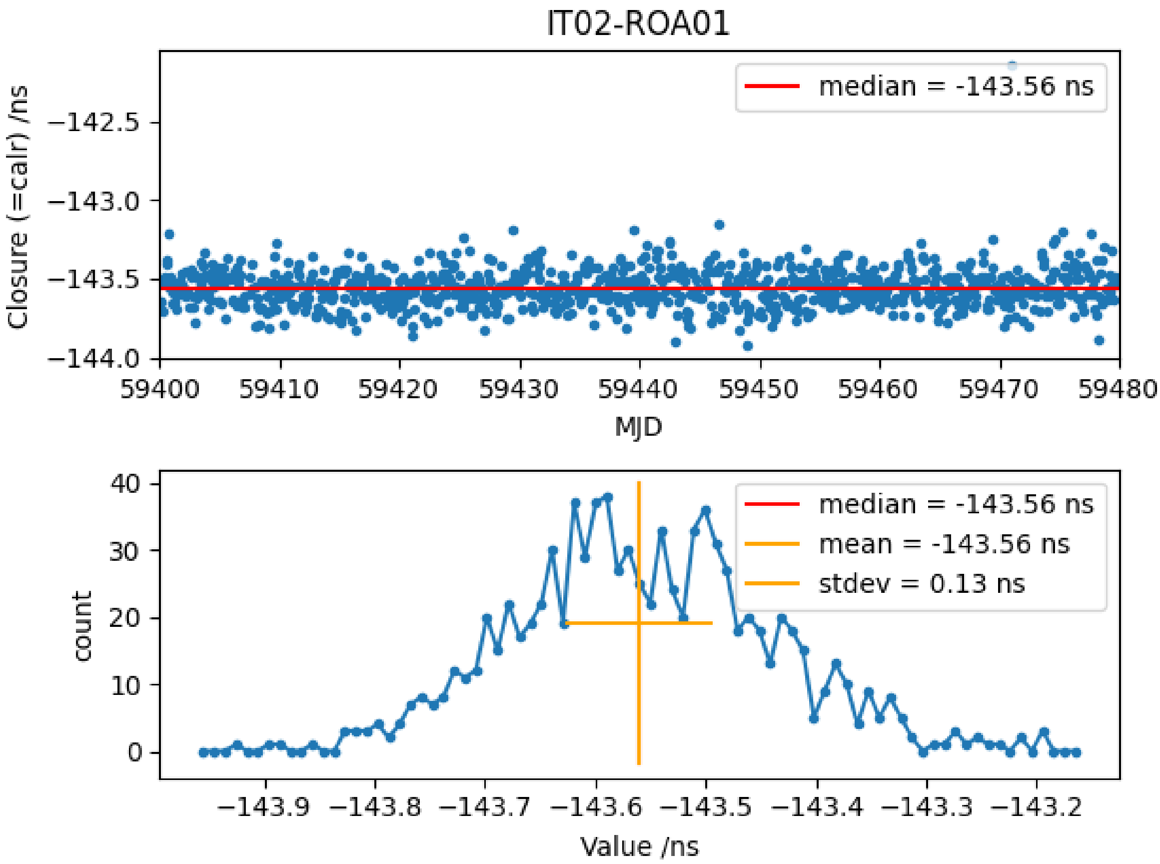
```
* CAL    561 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
IT02    OP01    561  1   7016.400      0.000  0.000
OP01    IT02    561  1  -7016.400      0.000  0.000
```



Comparison period: 59400-59480

CI 562, IT02-ROA01

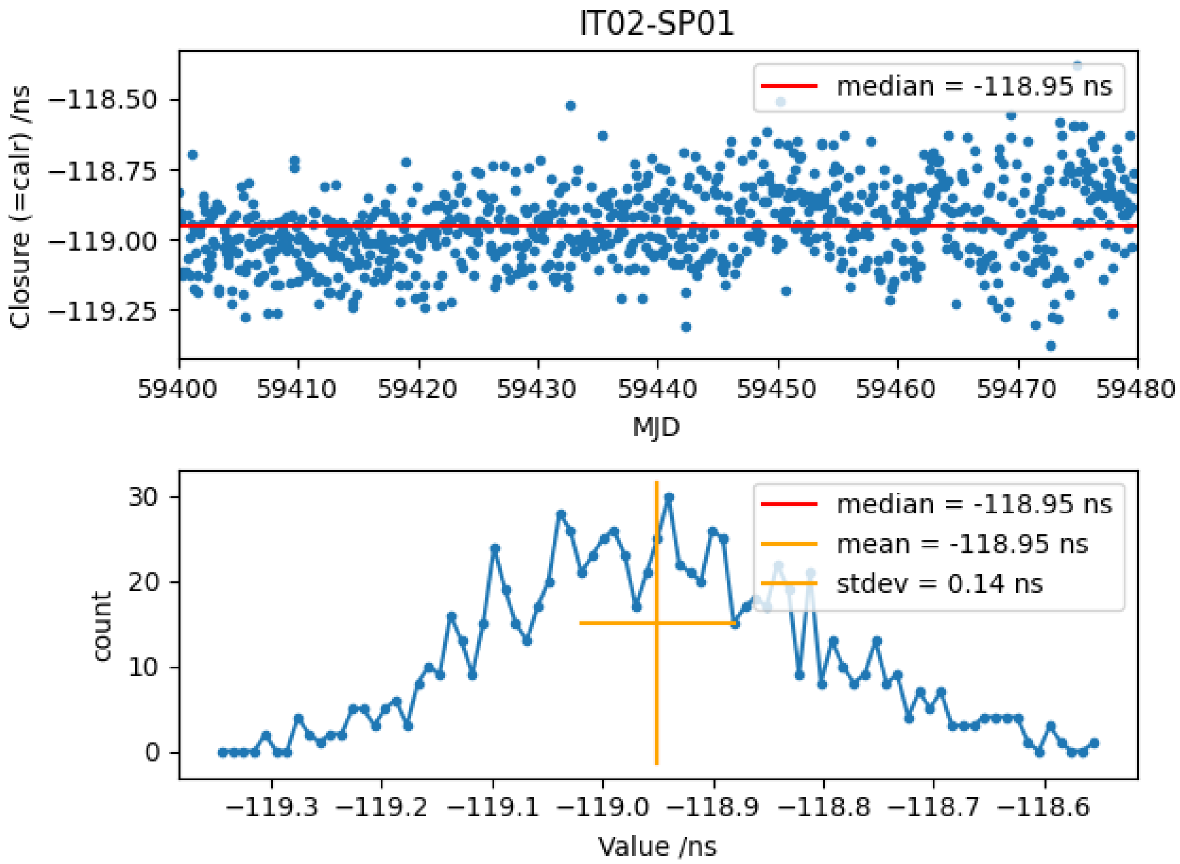
```
* CAL    562 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC      REM     CI   S       CALR     ESDVAR  ESIG
IT02     ROA01   562  1    -143.560     0.000 0.000
ROA01    IT02    562  1     143.560     0.000 0.000
```



Comparison period: 59400-59480

CI 563, IT02-SP01

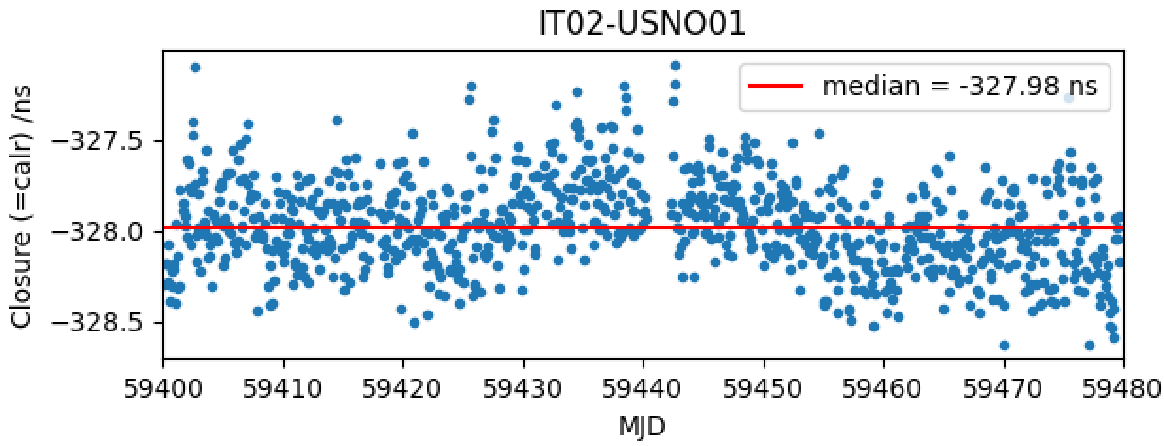
```
* CAL   563 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.900 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
IT02    SP01    563 1   -118.950      0.000 0.000
SP01    IT02    563 1    118.950      0.000 0.000
```

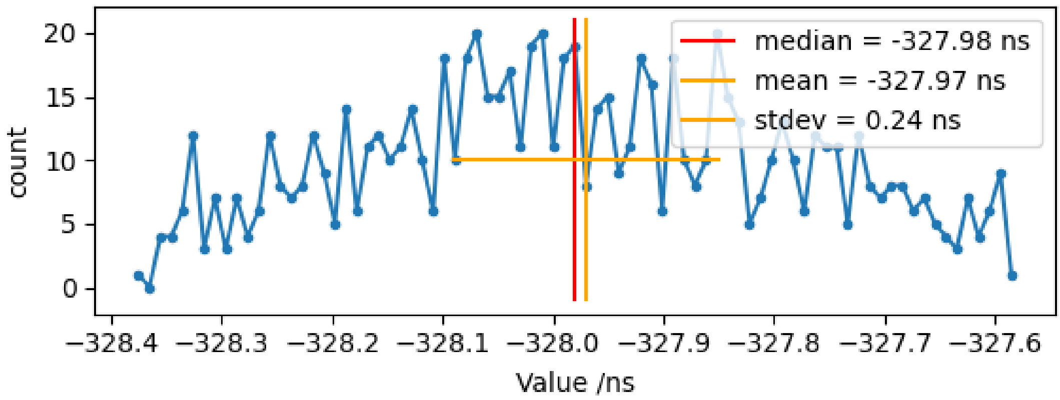


Comparison period: 59400-59480

CI 564, IT02-USNO01

```
* CAL    564 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.600 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
IT02    USNO01 564  1   -327.980      0.000 0.000
USNO01  IT02    564  1    327.980      0.000 0.000
```

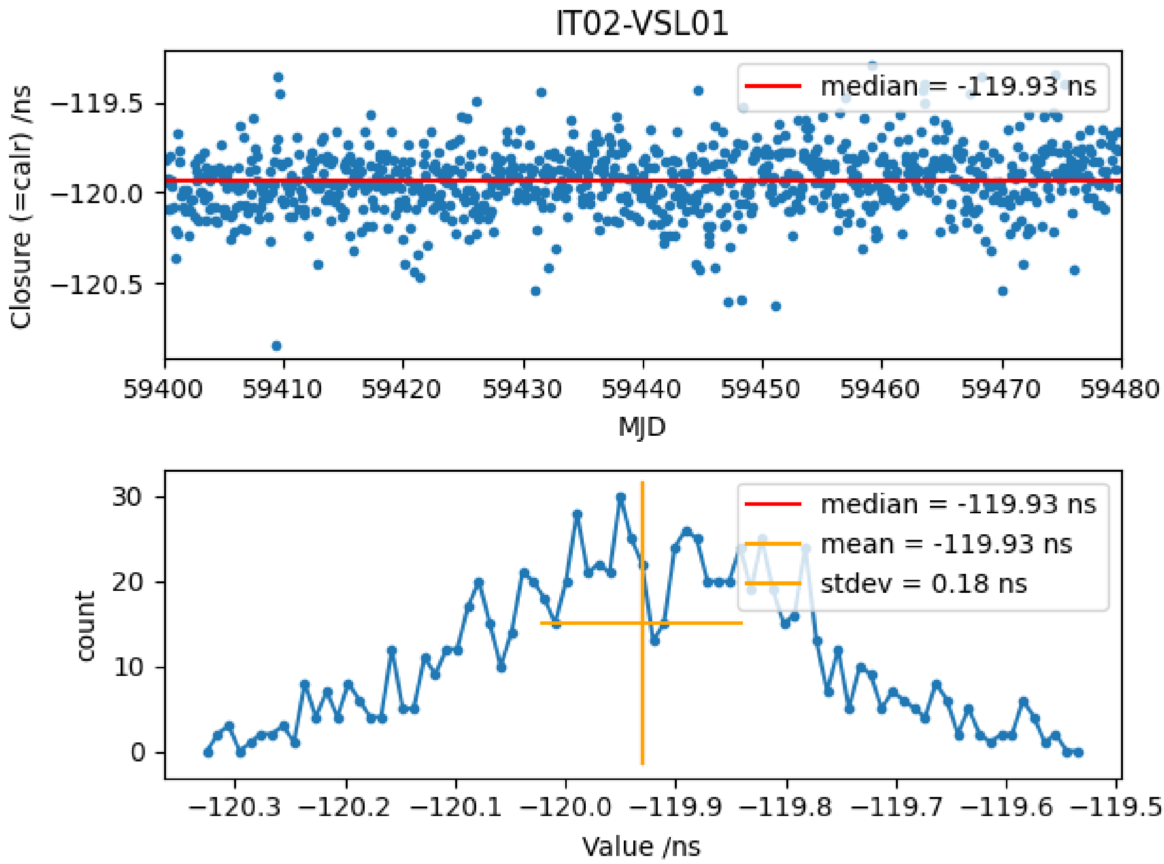




Comparison period: 59400-59480

CI 565, IT02-VSL01

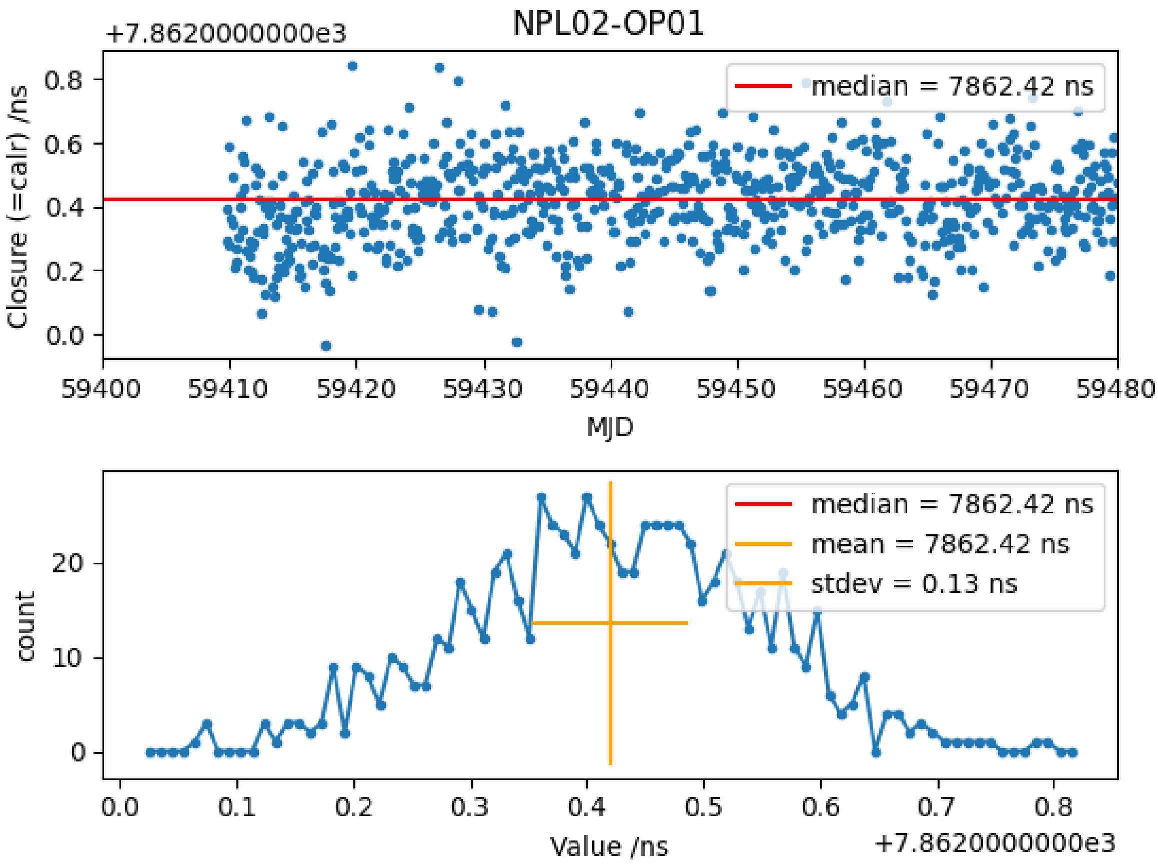
```
* CAL    565 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC      REM     CI   S        CALR     ESDVAR  ESIG
IT02     VSL01   565  1   -119.930       0.000 0.000
VSL01    IT02    565  1    119.930       0.000 0.000
```



Comparison period: 59400-59480

CI 566, NPL02-OP01

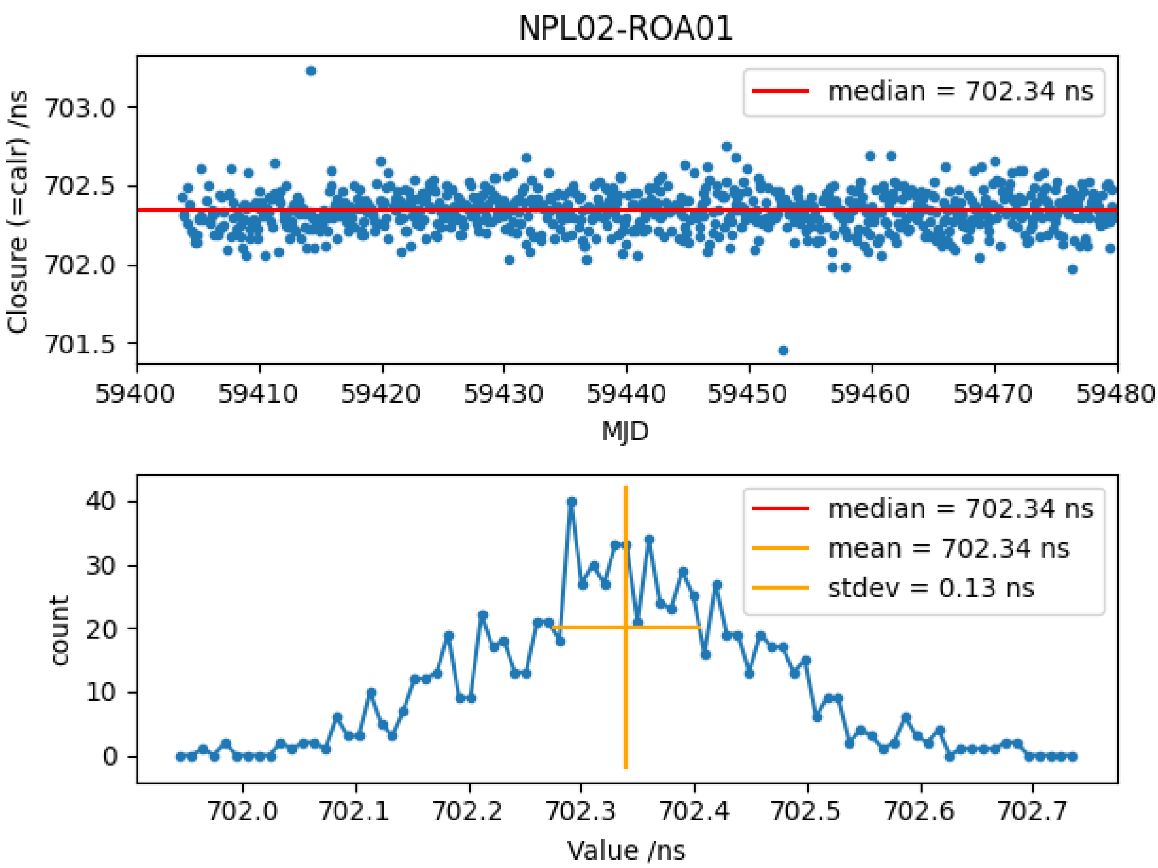
```
* CAL    566 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.700 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
NPL02   OP01    566  1   7862.420       0.000  0.000
OP01    NPL02   566  1  -7862.420       0.000  0.000
```



Comparison period: 59400-59480

CI 567, NPL02-ROA01

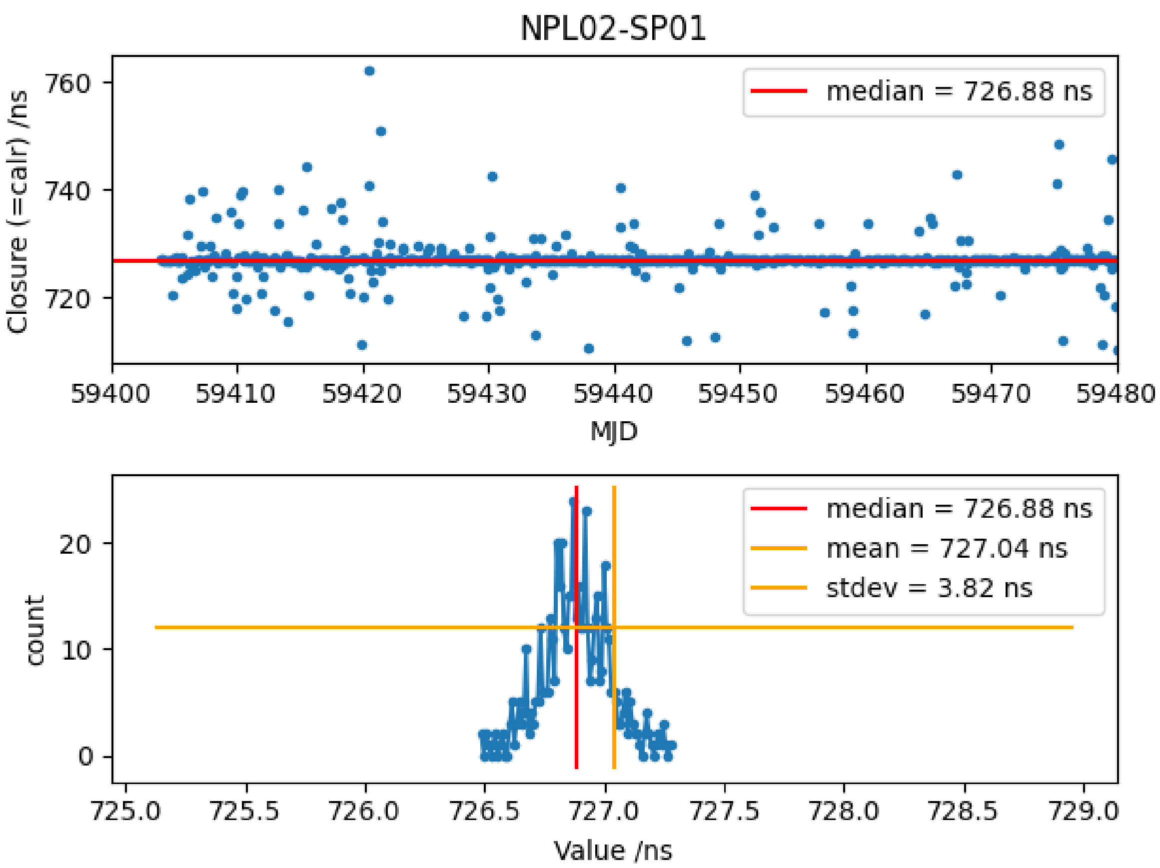
```
* CAL    567 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.700 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
NPL02   ROA01   567 1    702.340      0.000 0.000
ROA01   NPL02   567 1   -702.340      0.000 0.000
```



Comparison period: 59400-59480

CI 568, NPL02-SP01

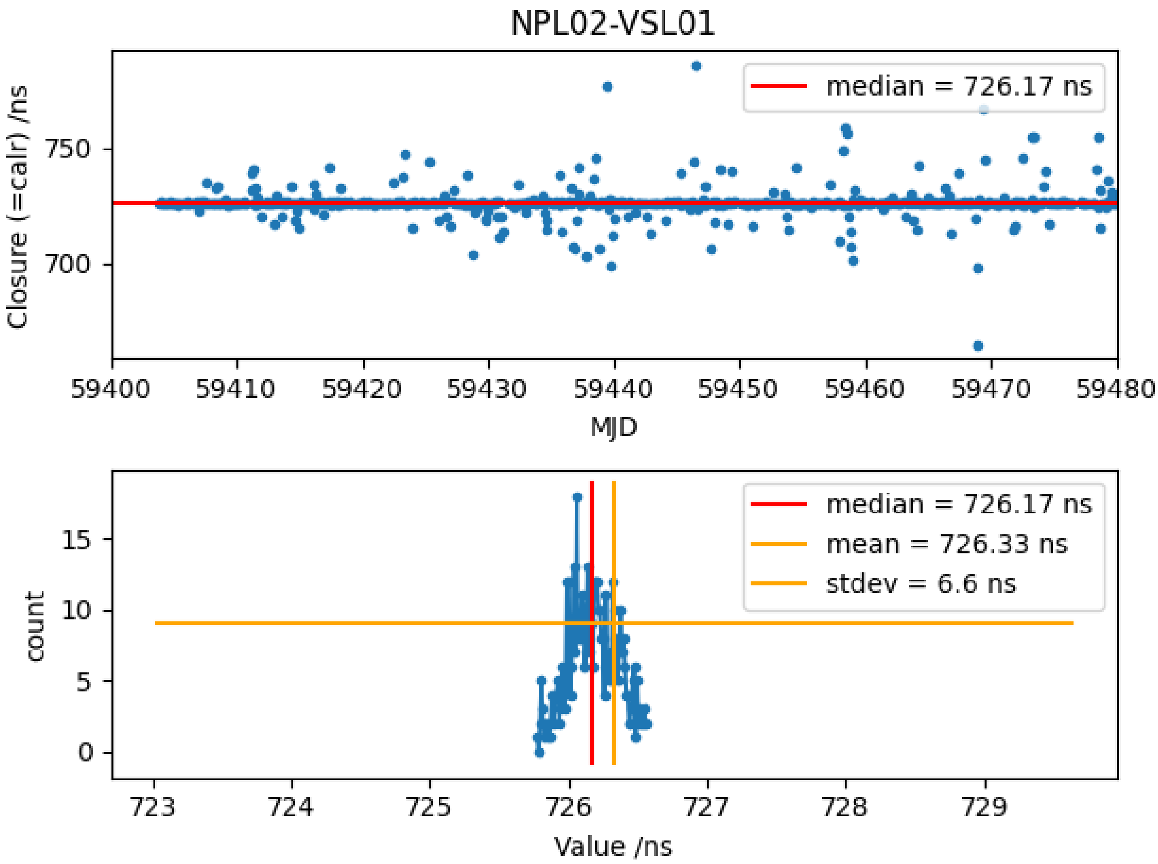
```
* CAL    568 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    4.300 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
NPL02   SP01    568  1    726.880      0.000 0.000
SP01    NPL02   568  1   -726.880      0.000 0.000
```



Comparison period: 59400-59480

CI 569, NPL02-VSL01

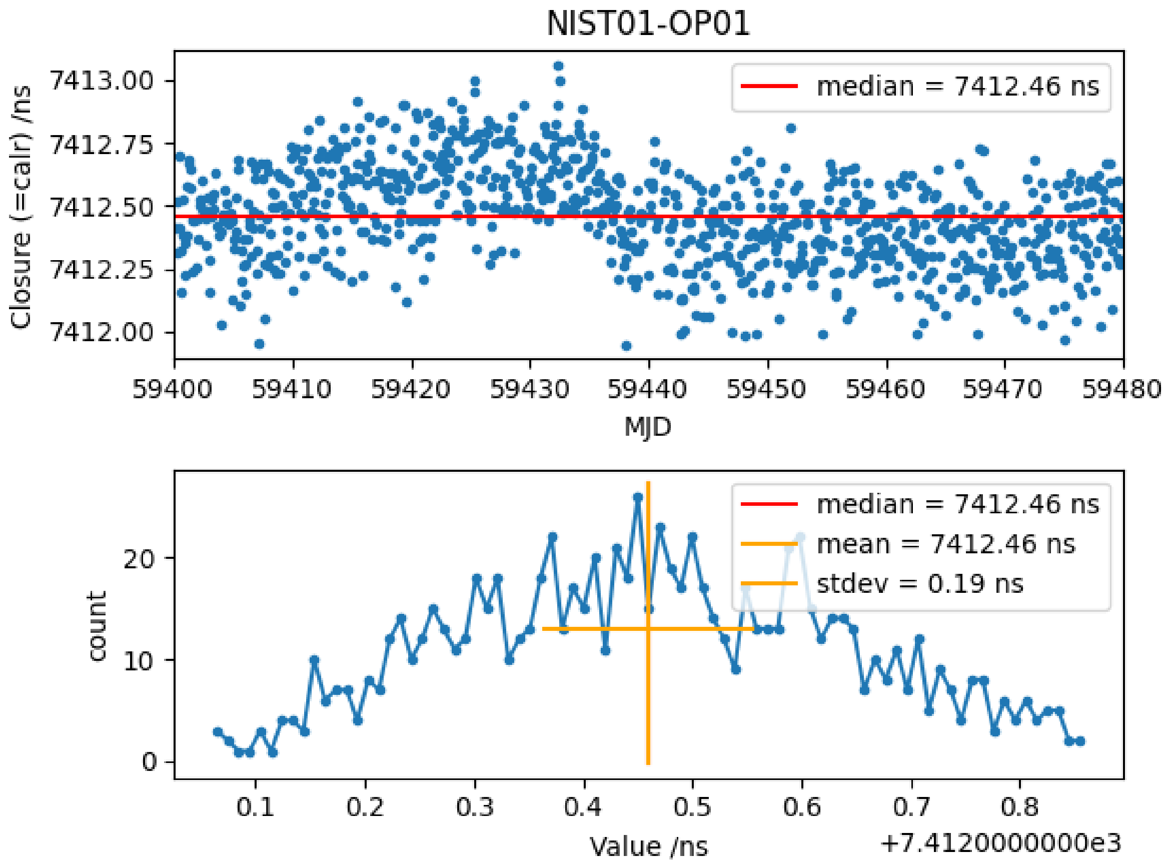
```
* CAL    569 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:     6.800 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
NPL02   VSL01   569  1    726.170      0.000 0.000
VSL01   NPL02   569  1   -726.170      0.000 0.000
```



Comparison period: 59400-59480

CI 570, NIST01-OP01

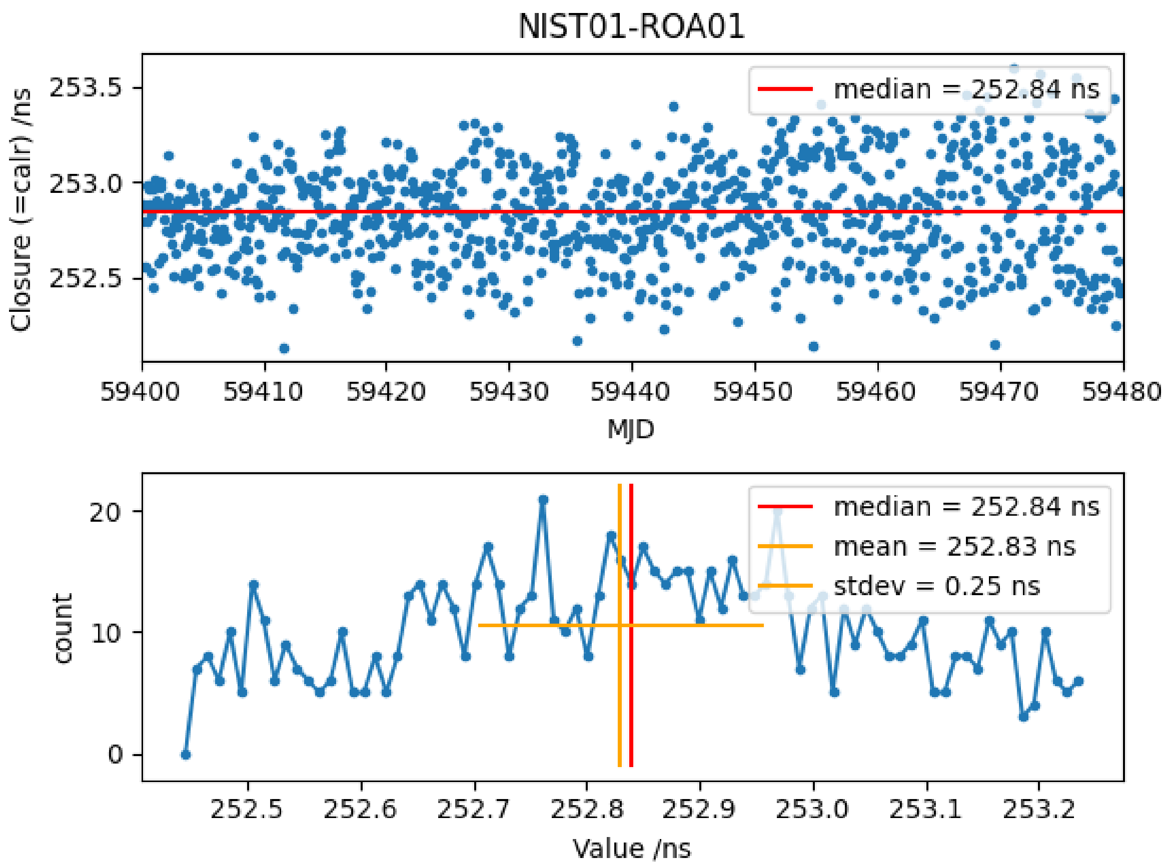
```
* CAL    570 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    2.000 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
NIST01  OP01    570  1   7412.460      0.000  0.000
OP01    NIST01  570  1  -7412.460      0.000  0.000
```



Comparison period: 59400-59480

CI 571, NIST01-ROA01

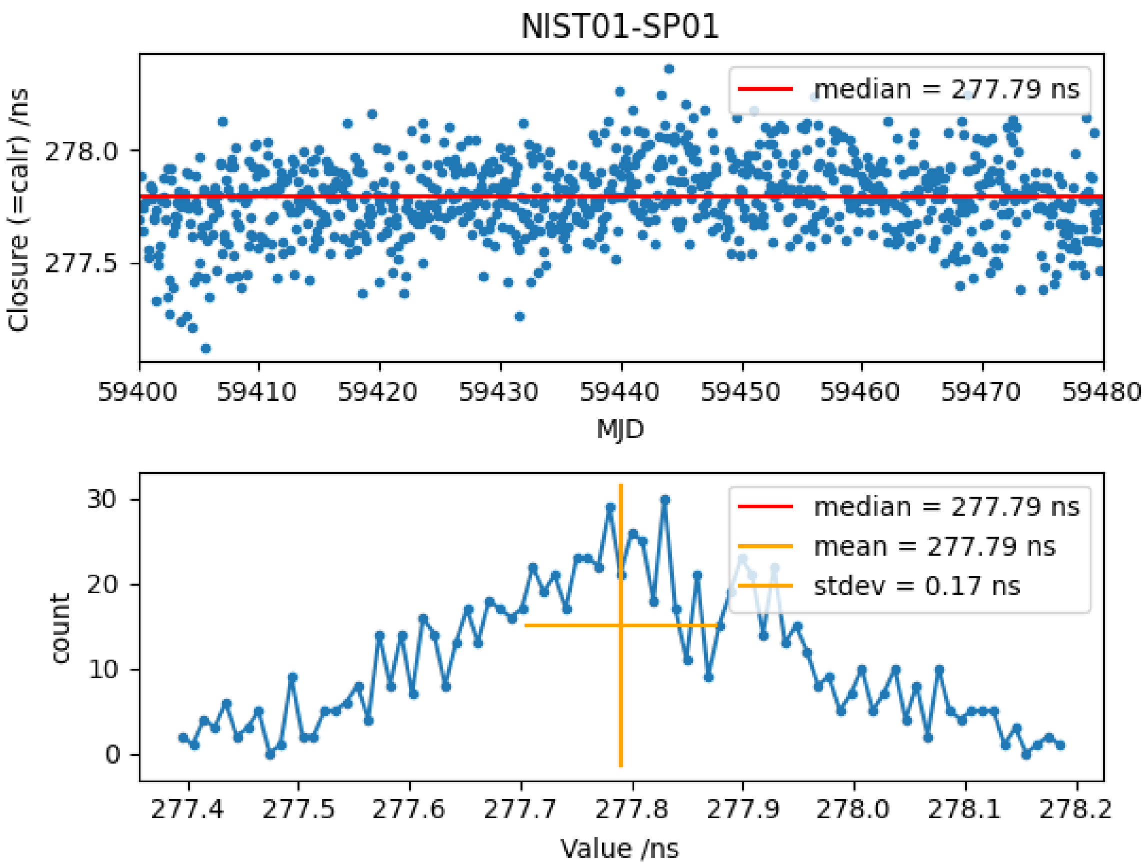
```
* CAL   571 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    2.000 ns
LOC     REM    CI  S      CALR     ESDVAR  ESIG
NIST01 ROA01  571 1    252.840      0.000 0.000
ROA01  NIST01 571 1   -252.840      0.000 0.000
```



Comparison period: 59400-59480

CI 572, NIST01-SP01

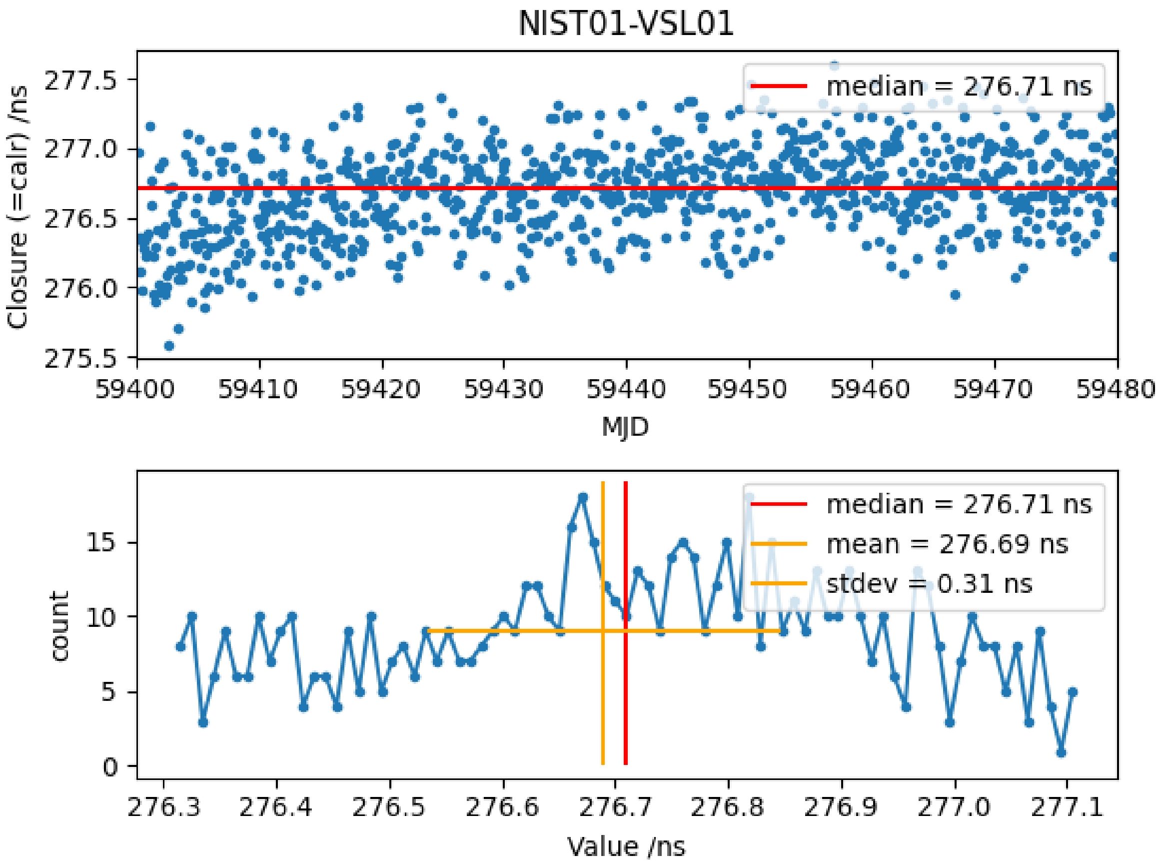
```
* CAL    572 TYPE: TRIANGLE CLOSURE      MJD: 59397 EST. UNCERT.:     2.100 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
NIST01 SP01    572 1    277.790      0.000 0.000
SP01   NIST01 572 1   -277.790      0.000 0.000
```



Comparison period: 59400-59480

CI 573, NIST01-VSL01

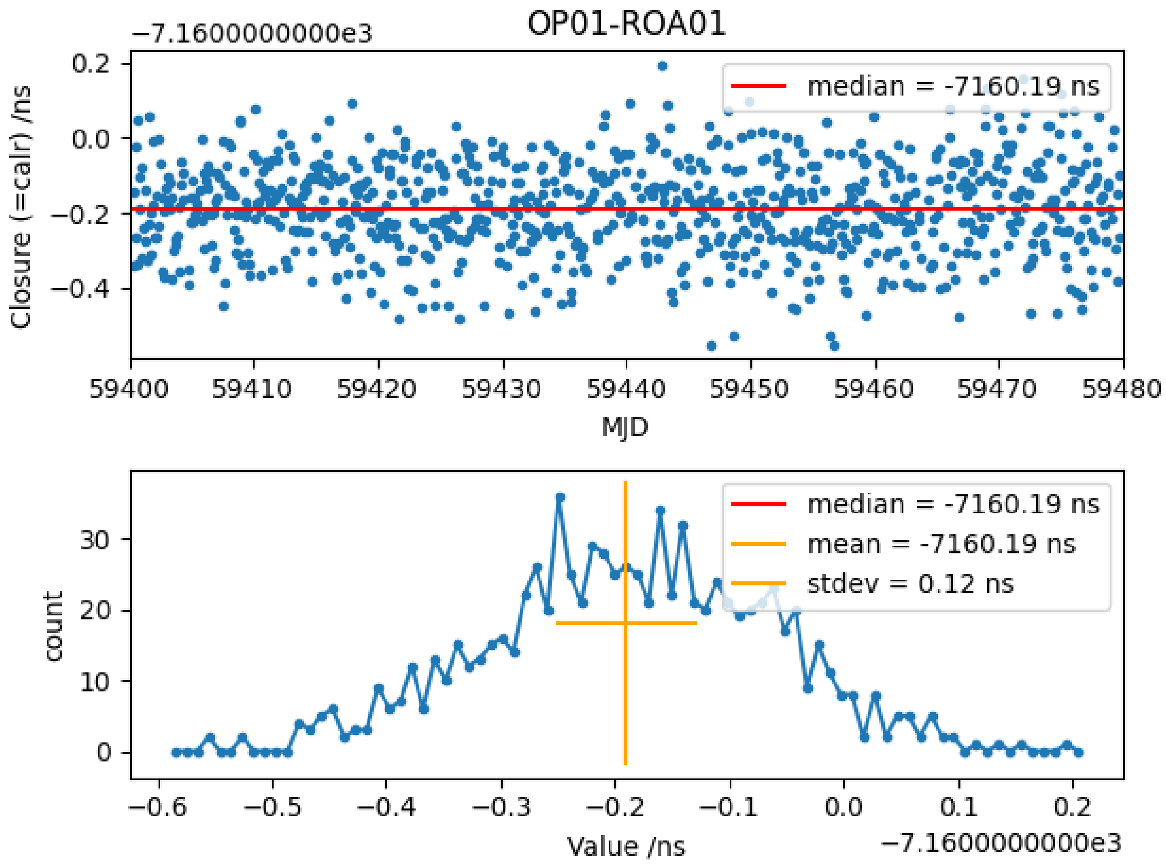
```
* CAL    573 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    2.000 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
NIST01 VSL01   573 1    276.710      0.000 0.000
VSL01   NIST01 573 1   -276.710      0.000 0.000
```



Comparison period: 59400-59480

CI 574, OP01-ROA01

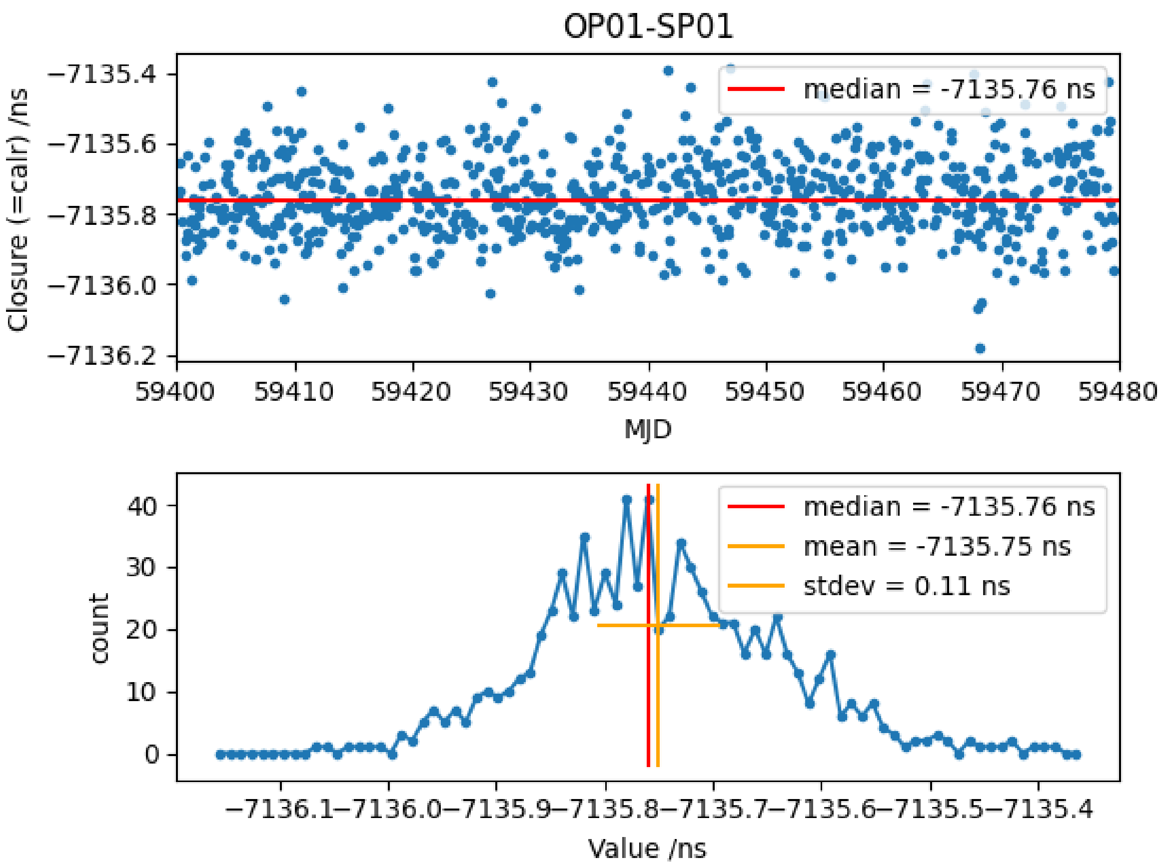
```
* CAL   574 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.600 ns
LOC     REM     CI  S        CALR     ESDVAR  ESIG
OP01    ROA01   574 1 -7160.190      0.000 0.000
ROA01   OP01    574 1  7160.190      0.000 0.000
```



Comparison period: 59400-59480

CI 575, OP01-SP01

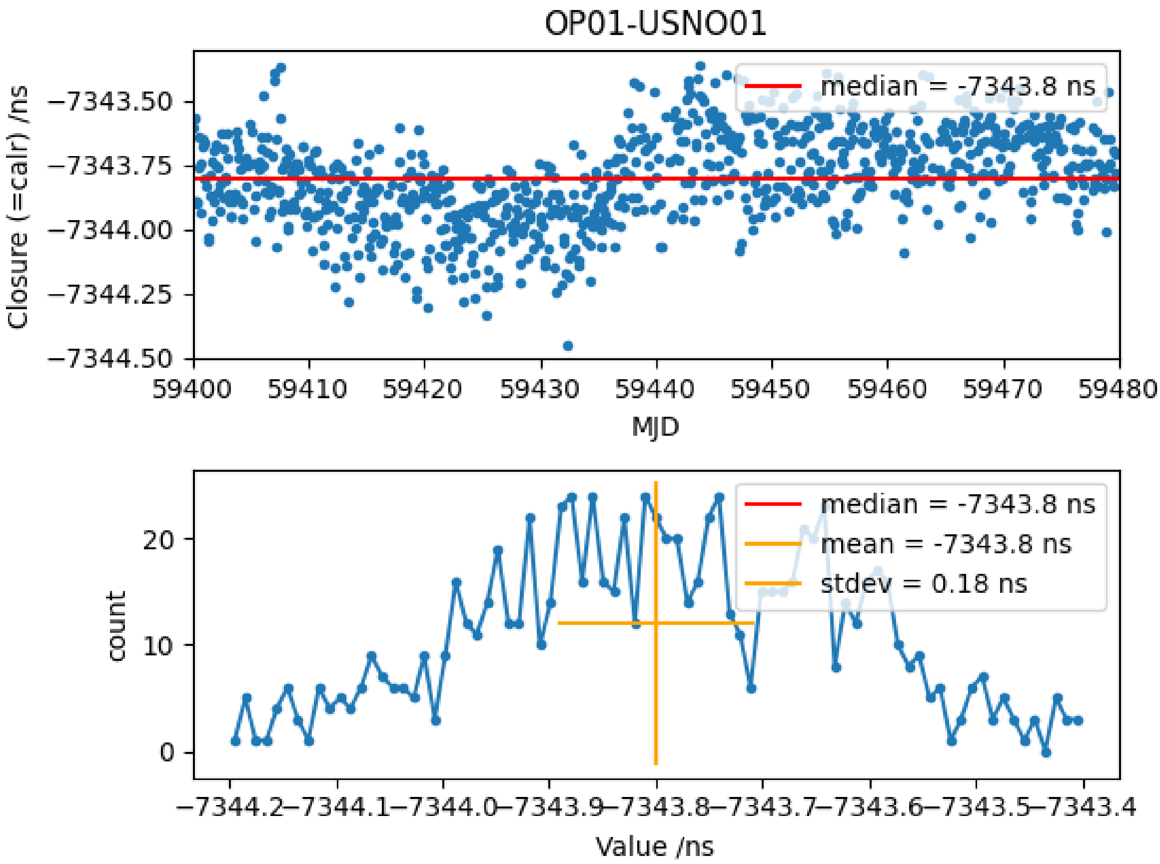
```
* CAL    575 TYPE: TRIANGLE CLOSURE      MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
OP01    SP01    575 1 -7135.760      0.000 0.000
SP01    OP01    575 1  7135.760      0.000 0.000
```



Comparison period: 59400-59480

CI 576, OP01-USNO01

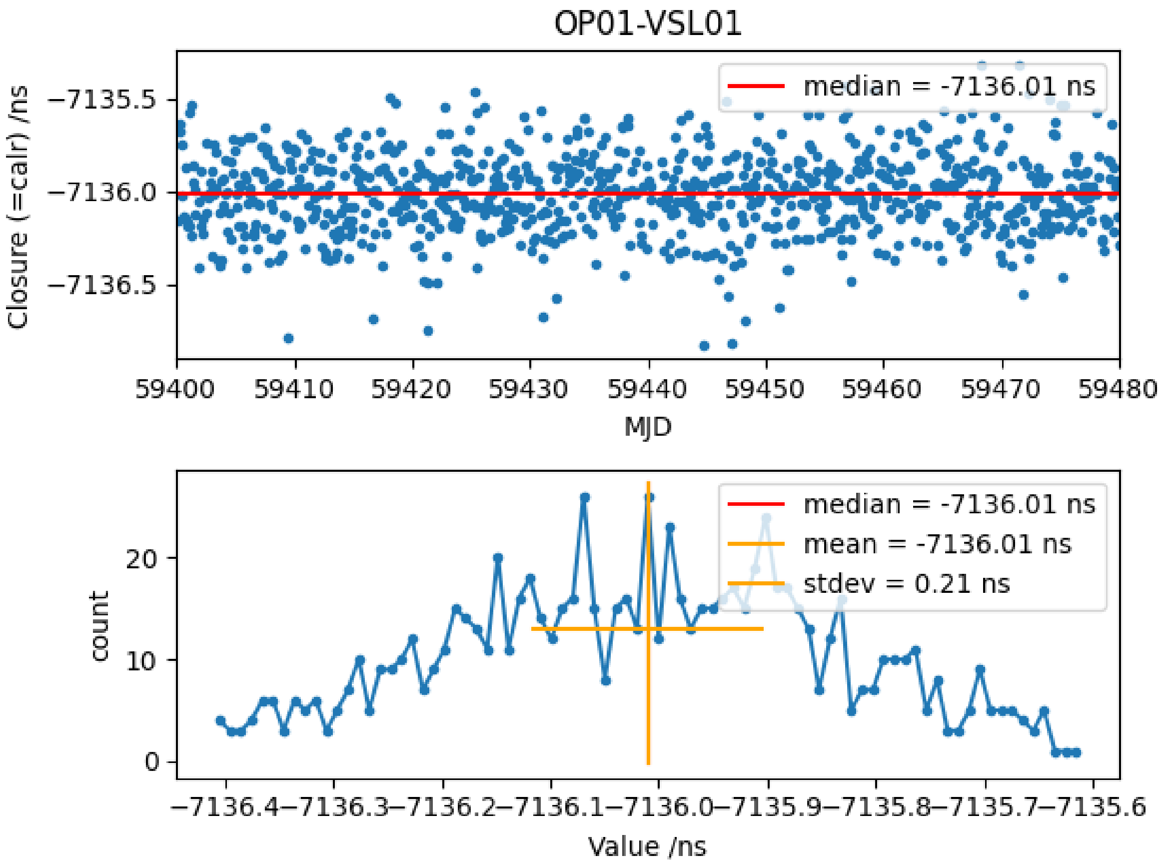
```
* CAL    576 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.400 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
OP01    USNO01 576 1 -7343.800      0.000 0.000
USNO01 OP01    576 1  7343.800      0.000 0.000
```



Comparison period: 59400-59480

CI 577, OP01-VSL01

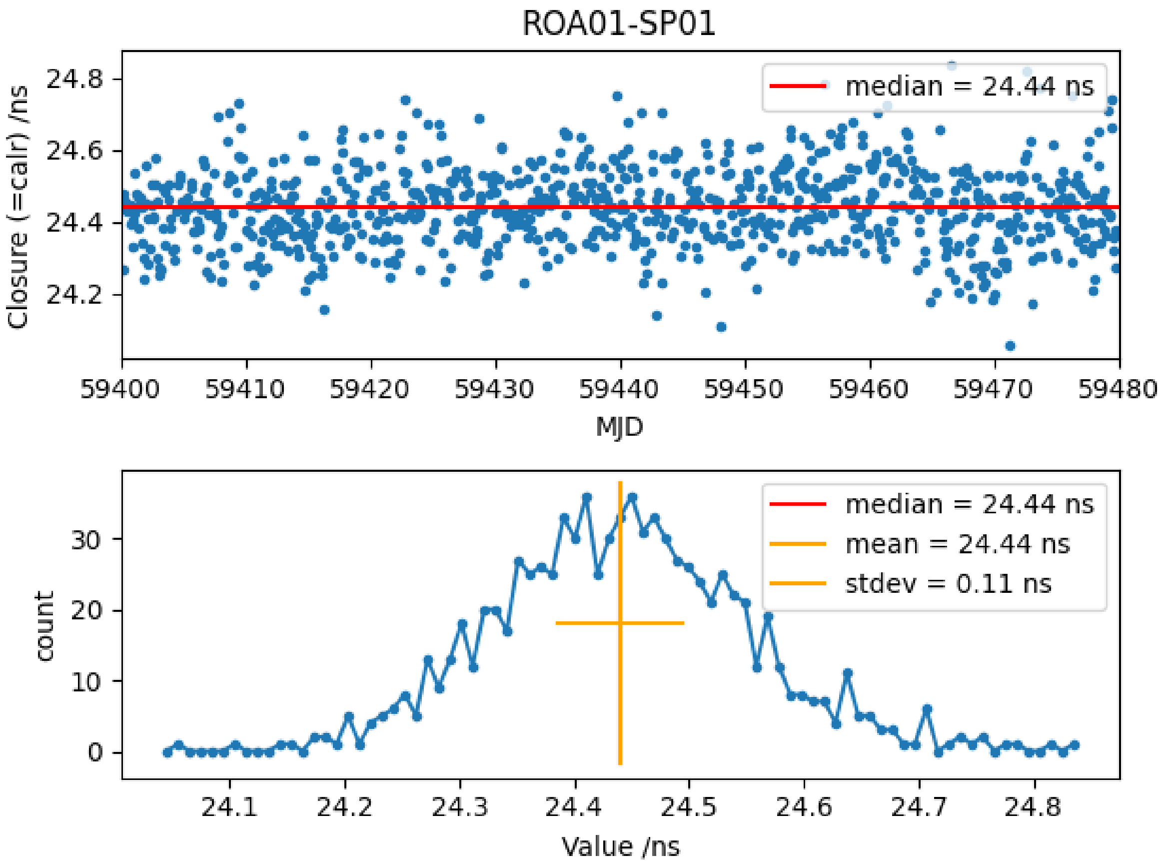
```
* CAL    577 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.600 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
OP01    VSL01   577  1 -7136.010       0.000  0.000
VSL01   OP01    577  1  7136.010       0.000  0.000
```



Comparison period: 59400-59480

CI 578, ROA01-SP01

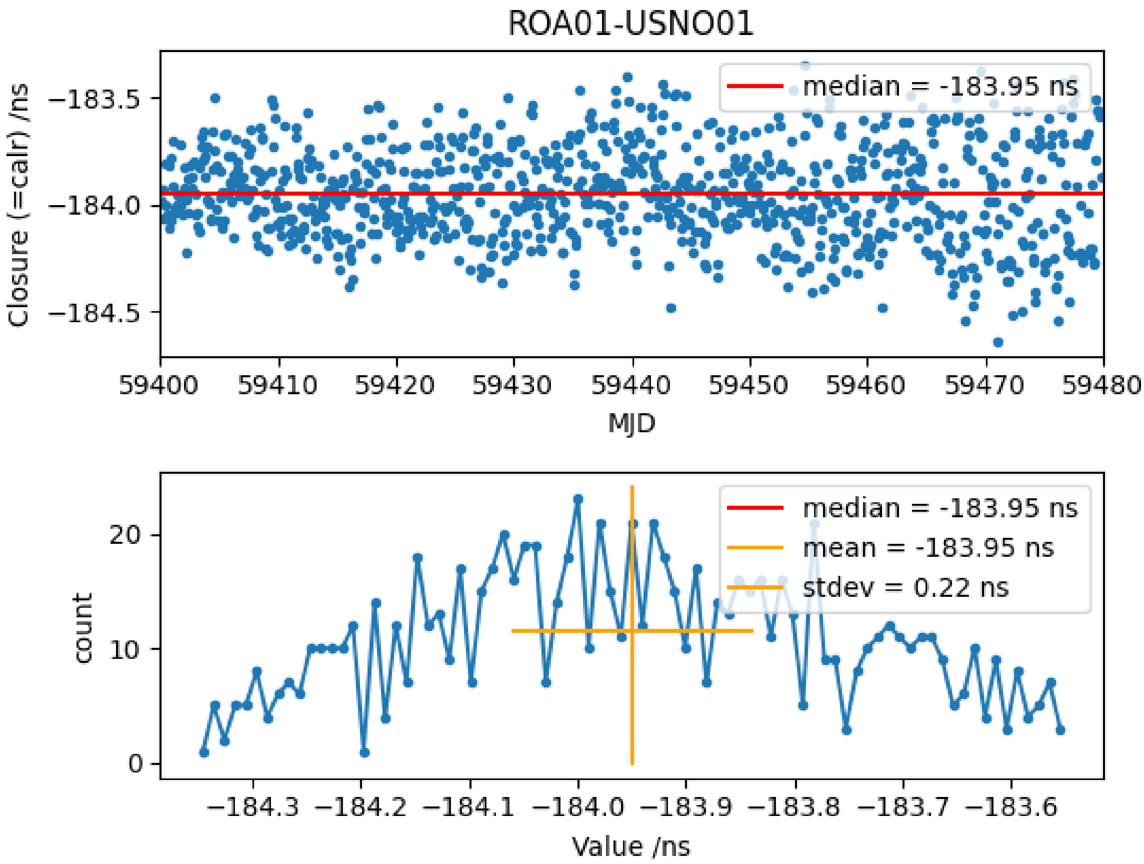
```
* CAL    578 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
ROA01   SP01    578  1     24.440      0.000 0.000
SP01    ROA01   578  1    -24.440      0.000 0.000
```



Comparison period: 59400-59480

CI 579, ROA01-USNO01

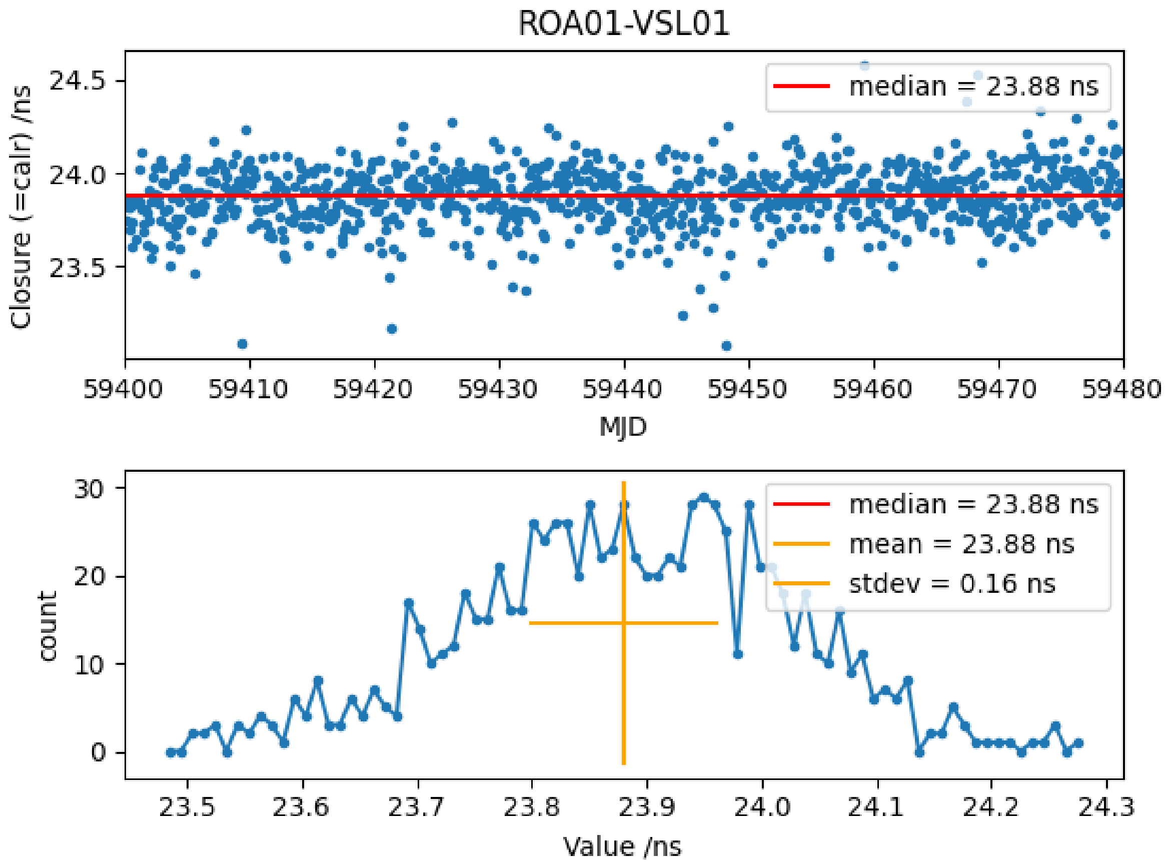
```
* CAL    579 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.400 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
ROA01   USNO01  579  1  -183.950      0.000 0.000
USNO01  ROA01   579  1   183.950      0.000 0.000
```



Comparison period: 59400-59480

CI 580, ROA01-VSL01

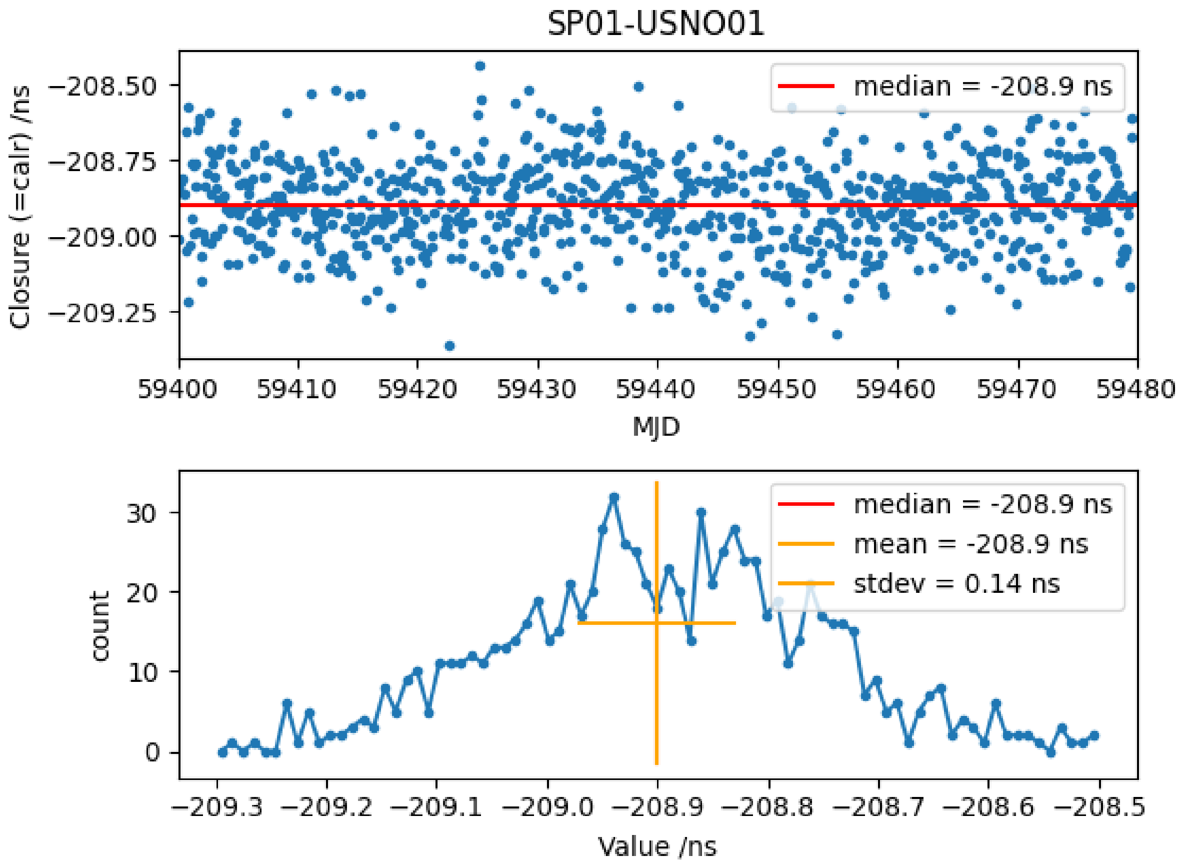
```
* CAL   580 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.600 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
ROA01   VSL01   580  1     23.880      0.000 0.000
VSL01   ROA01   580  1    -23.880      0.000 0.000
```



Comparison period: 59400-59480

CI 581, SP01-USNO01

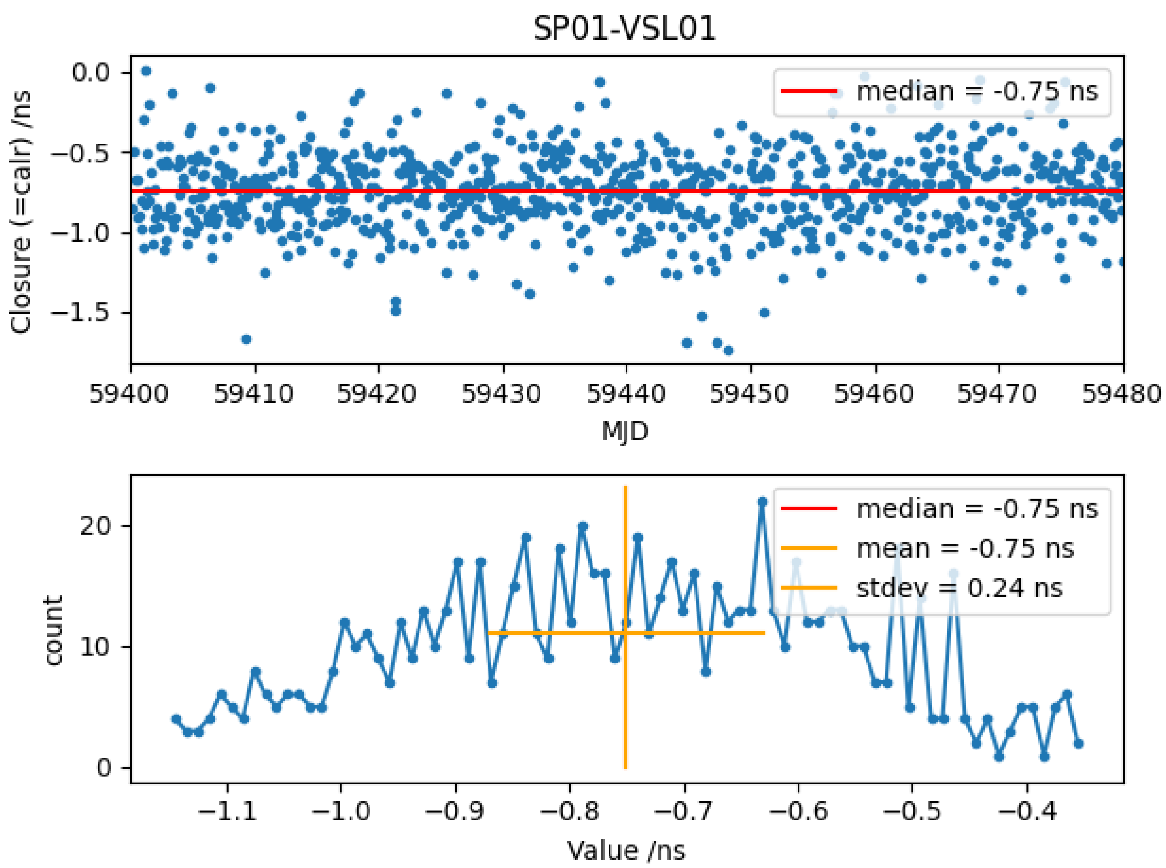
```
* CAL    581 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.600 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
SP01    USNO01 581 1   -208.900      0.000 0.000
USNO01 SP01    581 1    208.900      0.000 0.000
```



Comparison period: 59400-59480

CI 582, SP01-VSL01

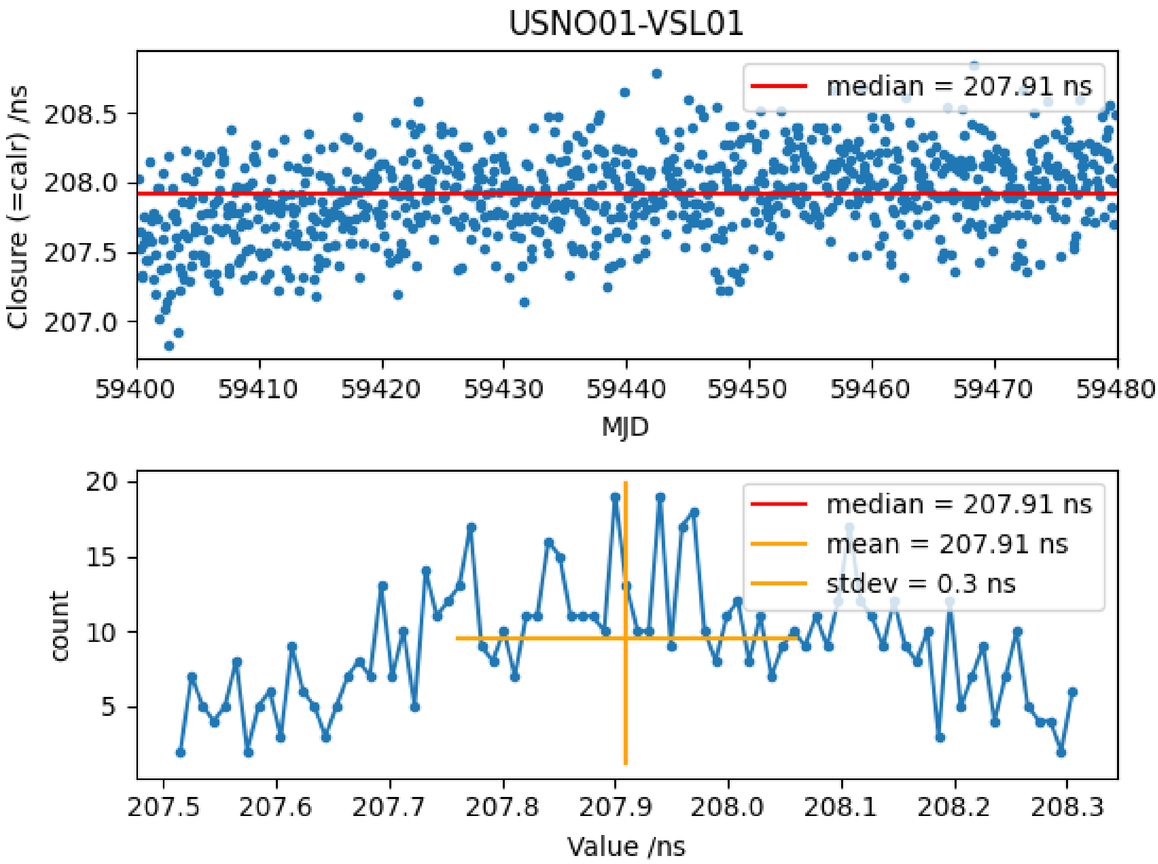
```
* CAL    582 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.800 ns
LOC     REM     CI   S        CALR     ESDVAR  ESIG
SP01    VSL01   582 1       -0.750      0.000 0.000
VSL01   SP01    582 1        0.750      0.000 0.000
```



Comparison period: 59400-59480

CI 583, USNO01-VSL01

```
* CAL    583 TYPE: TRIANGLE CLOSURE     MJD: 59397 EST. UNCERT.:    1.400 ns
LOC     REM     CI   S       CALR     ESDVAR  ESIG
USNO01 VSL01   583 1    207.910      0.000 0.000
VSL01   USNO01 583 1   -207.910      0.000 0.000
```



Comparison period: 59400-59480