LuftBlick Report 2025003

Activity 1 Report

on L1 Retrieval and Instrument Improvement Tasks

Version 3 - 28 Feb 2026

Prepared by

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1 Document Change Record

Version	Date	Section	Observations
1	16 July 2025	All	First version
1.1	6 Aug 2025	All 3.1 Spectrometer Synchronization (WP1.3)	Added figure numbers. Clarified meaning of the “Potentially Comparable Routines” and “Comparable Repetitions”, in text and figure titles.
3	28 Feb 2026	3.1.3 3.1.4	Completed section. Added a new section.

2 Introduction

This Report, Version 1, is part of Deliverable (D) Group 4 under Work Package (WP) 1 - Instrument Stability and Spectral AOD. WP1 is the initial activity within the EUMETSAT "Service to Support the Pandonia Global Network for Copernicus Mission Cal/Val - Algorithm, Monitoring and Analysis" (PanAMA) framework.

Specifically, this report discusses relevant WP1 tasks derived from the comprehensive pool of identified PanAMA "L1 retrieval and instrument improvement tasks".

The document is split into two main chapters: Instrument improvement studies and (once applicable) L1 retrieval studies. Each chapter reports on completed and in-progress studies, as outlined in the corresponding living-planning document (in the form of a Trello board).

2.1 Acronyms and Abbreviations

BSS Blick Software Suite
CDT Cycle Delay Time
IT Integration time
ncy Number of cycles
s1 Spectrometer 1
s2 Spectrometer 2
PanSels Selected Pandoras for PanAMA project analysis.

3 Instrument Improvement Studies

3.1 Spectrometer Synchronization (WP1.3)

In Pandora 2S systems, the operational software “BlickO” orchestrates measurement routines where spectrometers usually acquire a sequence of bright measurements ("repetitions") followed by a single dark measurement. Each repetition averages multiple spectra ("cycles"). BlickO ensures that all spectrometers initiate their measurement sets simultaneously, with the resulting data recorded into separate L0 files for each spectrometer.

Given the distinct sensitivity of each spectrometer and the fact that they measure through different filters mounted on a shared filterwheel, the optimal integration time (IT) varies per spectrometer. Consequently, the number of cycles (ncy) of each spectrometer has to be adapted by the software to achieve synchronized total measurement durations for both bright and dark acquisitions.

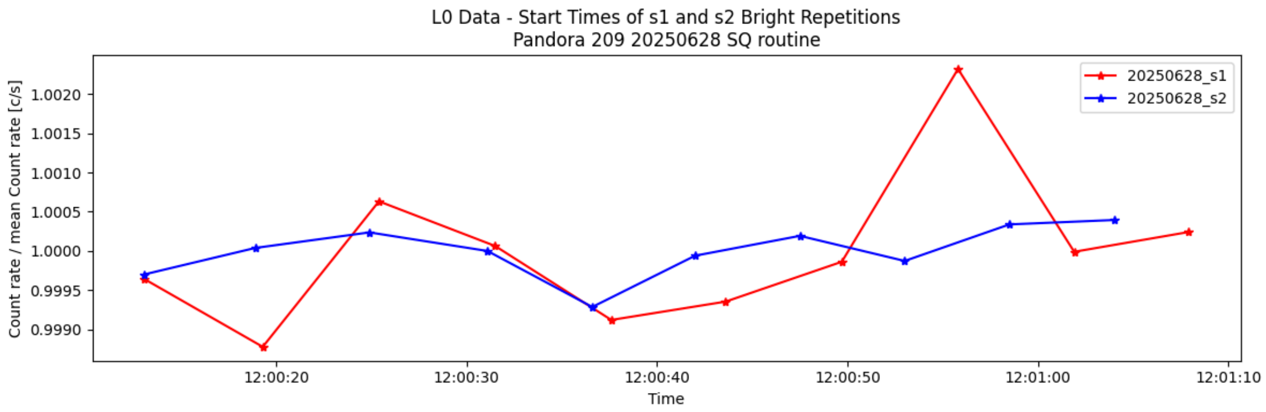

Figure 3.1-1: Start times of s1 and s2 bright repetitions

Figure 3.1-1 shows the L0 corrected count rates for a SQ routine, (Pandora 209 Izaña, 20250628). The spectrometer 1 (s1, uv) measurements are shown red while spectrometer 2 (s2, vis) in blue. It can be seen how one of the spectrometers (s2) finishes the bright repetitions before the other (s1). By definition, this routine is designed to last a total of 60 seconds, during which the system should acquire up to 10 repetitions, each with an expected duration of 6 seconds. However we can appreciate in both spectrometers that some repetitions are longer than expected, hence losing the s1/s2 repetitions synchronization.

A preliminary spectrometer synchronization analysis was performed on three consecutive clear-sky daily L0 files (P209, Izaña, SQ routine, 2025-06-27 to 2025-06-29). It was found that 226 out of 242 SQ routines (93.39%) were “potentially comparable”, meaning both spectrometers recorded the same number of bright repetitions. The remaining 6.61% correspond to SQ routines that produced a different number of repetitions for each spectrometer, which happens because at low light levels (twilight), the higher integration time required by the less sensitive spectrometer can occasionally prevent it from completing the maximum allowed number of repetitions within the available time. These results are shown in Figure 3.1-2.

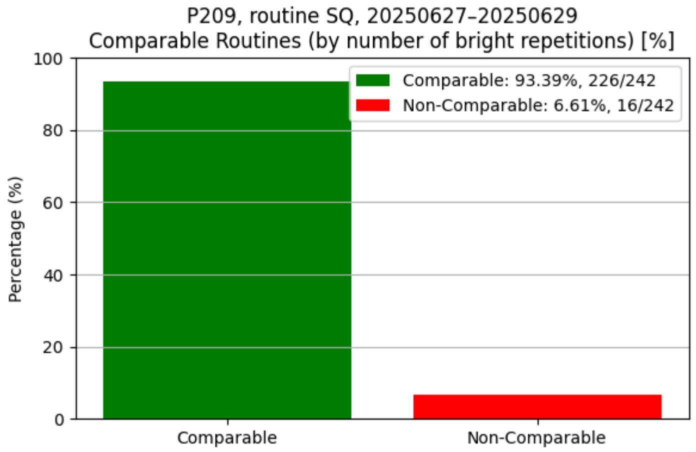

Figure 3.1-2: "Potentially comparable" SQ Routines in the preliminary analysis.

By analyzing the content of these "Potentially Comparable" SQ routines, it was found that although these routines contain the same number of bright repetitions for each spectrometer, some repetitions from one spectrometer do not have a time-synchronized counterpart in the other, to compare with. In the analyzed sample, the "potentially comparable" SQ routines generated a total of 2234 bright repetitions for each spectrometer. Among these, 1526 repetitions (68.4%) were considered synchronized, meaning the central time of the s1 repetition fell within the start and end times of any s2 repetition. The remaining 31.6% of the repetitions did not meet this time overlap condition, so they are out of synchronization. These results are shown in Figure 3.1-3.

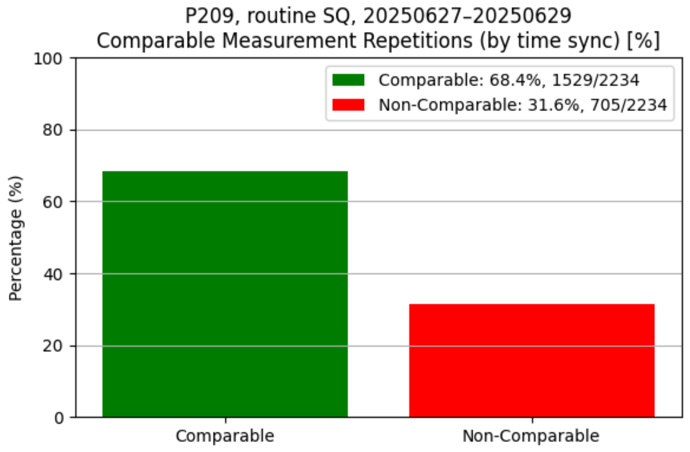

Figure 3.1-3: Comparable bright repetitions of the "potentially comparable" SQ routines.

To quantify the degree of desynchronization between the two spectrometers, the time differences between the corresponding bright repetitions have been analyzed, meaning the central time of the n-th repetition from one spectrometer is compared with the n-th repetition from the other, for each routine of the "potentially comparable" ones. These differences are summarized in the histogram shown in Figure 3.1-4.

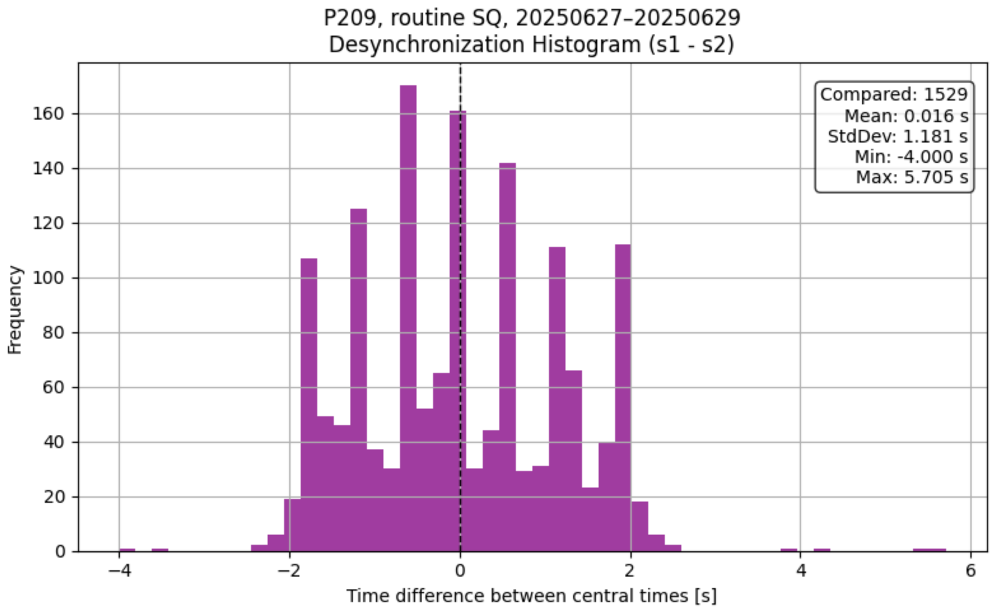

Figure 3.1-4: L0 measurements desynchronization histogram (20250627-29)

This histogram illustrates how frequently different magnitudes of desynchronization occur between spectrometers, for the preliminary study case.

By analyzing the desynchronization histogram, the first key observation is that the average synchronization between spectrometers is quite good, as indicated by the very small mean shift of approximately 16 milliseconds. This suggests that, on the whole, the system is achieving its goal of temporal alignment between the two spectrometers during measurements. However, the second observation reveals a contrasting issue: the variability in synchronization is significant, with a standard deviation of over 1 second and individual shifts ranging from -4 to +5.7 seconds. This means that while the spectrometers are on average synchronized, individual repetitions often diverge significantly from perfect alignment. This broad spread implies the presence of non-deterministic delays or fluctuations in the timing.

In the further sections of this report it is analyzed why this synchronization is not working as expected, and thereby compromising the ability to perform complementary data evaluations across both spectrometers.

3.1.1 Analyze the reason for the poor synchronization

To understand the cause of the observed synchronization issues, it is essential to examine how measurement duration is theoretically determined and how **BlickO** attempts to estimate it in practice.

Each spectrometer measurement repetition consists of the average of a defined number of cycles (ncy), where each cycle corresponds to one individual spectrum acquisition at a specific integration time (IT). The integration time is the duration during which the detector is exposed to light collecting photons before readout. Theoretically (ideally), the total duration of a measurement repetition would be:

$$Theoretical\ Duration = ncy \cdot IT$$

However, in practice, the actual duration of a measurement is longer than the theoretical value due to overhead introduced by hardware and software processes, such as triggering, data transfer, and communication latency. To account for this, BlickO estimates a parameter named **cycle delay time** (CDT), which represents the additionally required time per cycle beyond the integration time for measuring, data transmission and data handling.

This parameter is calculated by BlickO at software startup, using statistical analysis over the first N measurement repetitions after the spectrometer is connected. This value is then reused to estimate the duration of all subsequent measurements as:

$$Estimated\ Duration \approx ncy \cdot (IT + CDT)$$

In earlier versions, BlickO calculated the CDT using an arithmetic mean:

$$CDT_{mean\ i} = \frac{Actual\ Duration_i - Theoretical\ Duration_i}{ncy_i}$$

$$CDT_{mean} = median(CDT_{mean\ 1}, CDT_{mean\ 2}, \ldots, CDT_{mean\ N})$$

Despite this correction mechanism, tests showed that real measurement durations frequently deviate from the estimated ones. This usually leads to one spectrometer completing a repetition significantly earlier than the other. Since repetitions are executed independently per spectrometer, the faster device continues to the next repetition without waiting, thereby causing cumulative desynchronization.

Notably, the problem was found to be particularly prominent in Avantes spectrometers, where, due to API limitations (cannot measure “by packs” due the necessity of querying the blind pixels data right after each cycle), BlickO performs a single trigger call to start a multi-cycle measurement, but then must individually handle each data arrival event raised by the Avantes DLL for every measured cycle. This architecture introduces additional variability, as the software must respond separately to each event, and the actual delay between successive cycles fluctuates significantly.

Independent test scripts (bypassing BlickO’s full hardware control logic) confirmed that this timing irregularity originates outside the Pandora software, validating that the root cause lies either within the spectrometer hardware/driver stack or host communication processes.

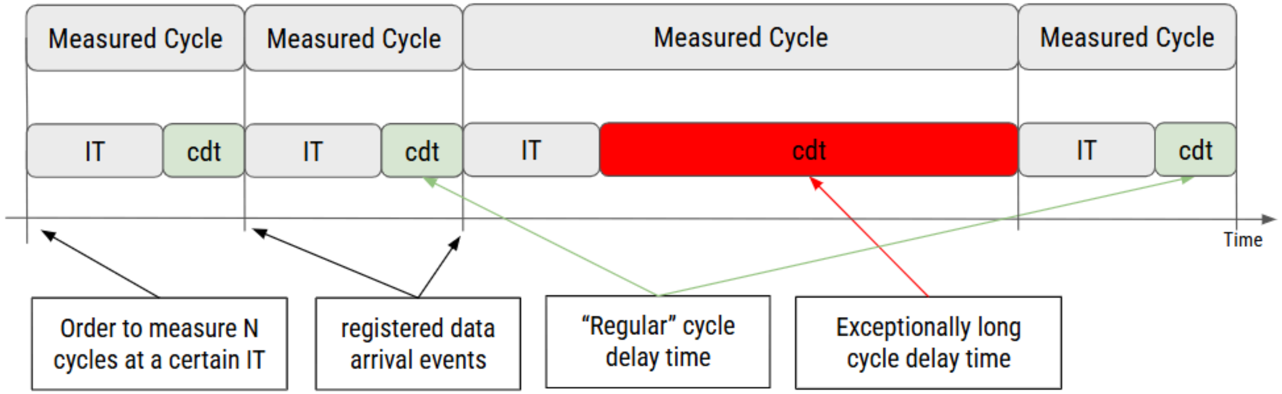

Figure 3.1-5: Spectrometer capture "Timing"

This image represents the data capture "timing", during a testing measurement. The software requests the spectrometer to measure a certain number of cycles at a certain integration time (IT), and then the time of the data arrival events is registered. By analyzing the timing of these events it was noticed that there is a highly variable cycle delay time among the measured cycles.

Since the selection of a correct CDT is crucial for the proper estimation of the duration of future measurements, some improvements have already been applied to the software (from 2023 PaNIR project), like using a different methodology to calculate the CDT, using the median of the data arrival events instead of an arithmetic mean:

$$CDT_{median\ i} = median(diff(data\ arrival\ events) - IT)$$

$$CDT_{median} = median(CDT_{median\ 1}, CDT_{median\ 2}, \dots, CDT_{median\ N})$$

This change helped mitigate the influence of sporadically long delay outliers that can distort the initial calculation of a fixed CDT, thereby slightly improving the accuracy of duration estimates. However, since these exceptionally long cycle delays continue to occur unpredictably, discrepancies between estimated and actual durations still persist.

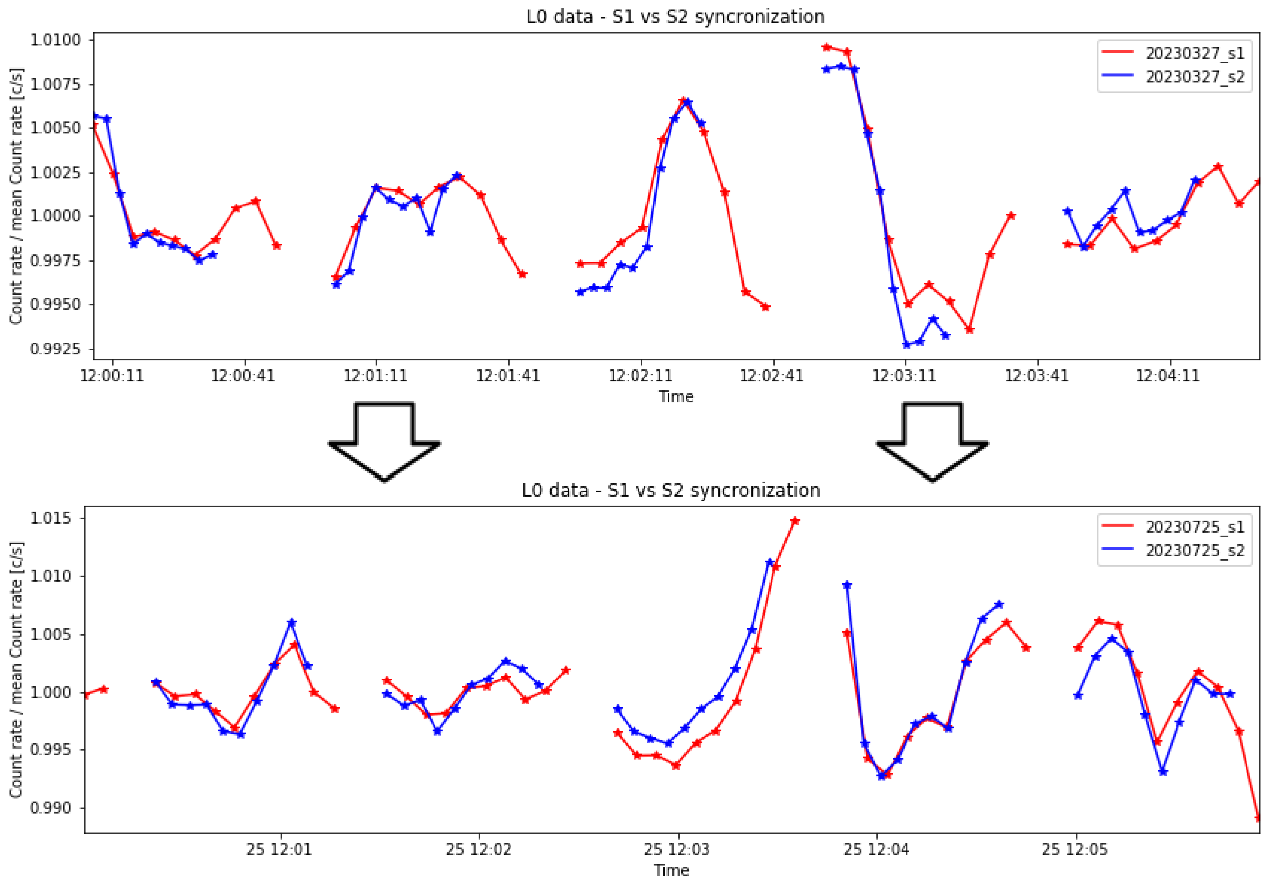

Figure 3.1-6: Before and after replacing the CDT determination methodology

This figure shows how the change in the CDT determination methodology slightly improved the s1/s2 synchronization for the Pandora 234 "PaNIR", SS routine. The upper panel shows several SS routines captured using a CDT determined by the mean method (CDT_{mean}*), while the lower panel shows a few routines acquired after a software update, where CDT was determined using the median method (*CDT_{median}*).*

Further analysis has been made, in order to analyze the dependency of the CDT determination with respect to the parameters of the samples used to calculate it, such as the integration time and number of cycles.

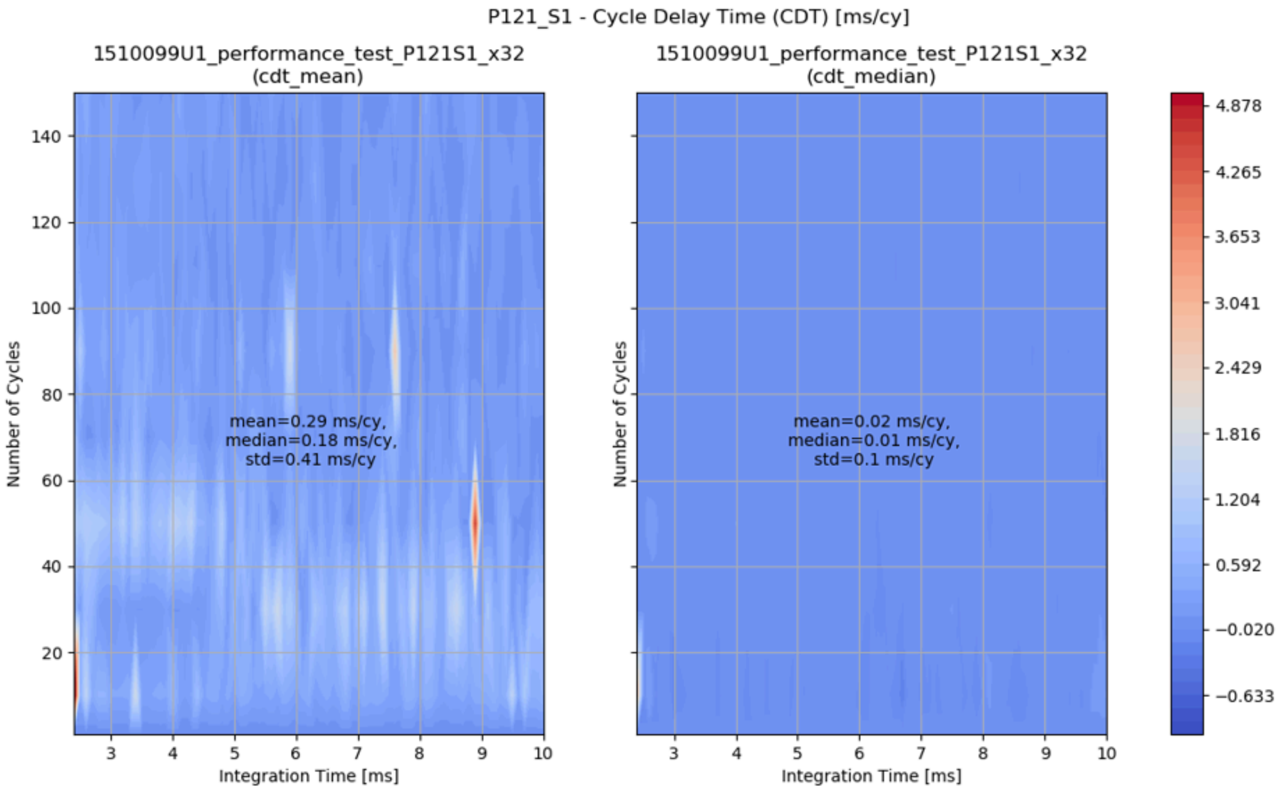

Figure 3.1-7: Mean and Median Cycle delay time, for different ncy and IT.

This figure shows that determining CDT using the median is less sensitive to the choice of ncy and IT during the sampling process, thereby reducing the likelihood of selecting an inaccurate CDT value at startup. However, the left plot already suggests that CDT may not be best represented as a fixed value, but rather as a variable one that depends on both ncy and IT.

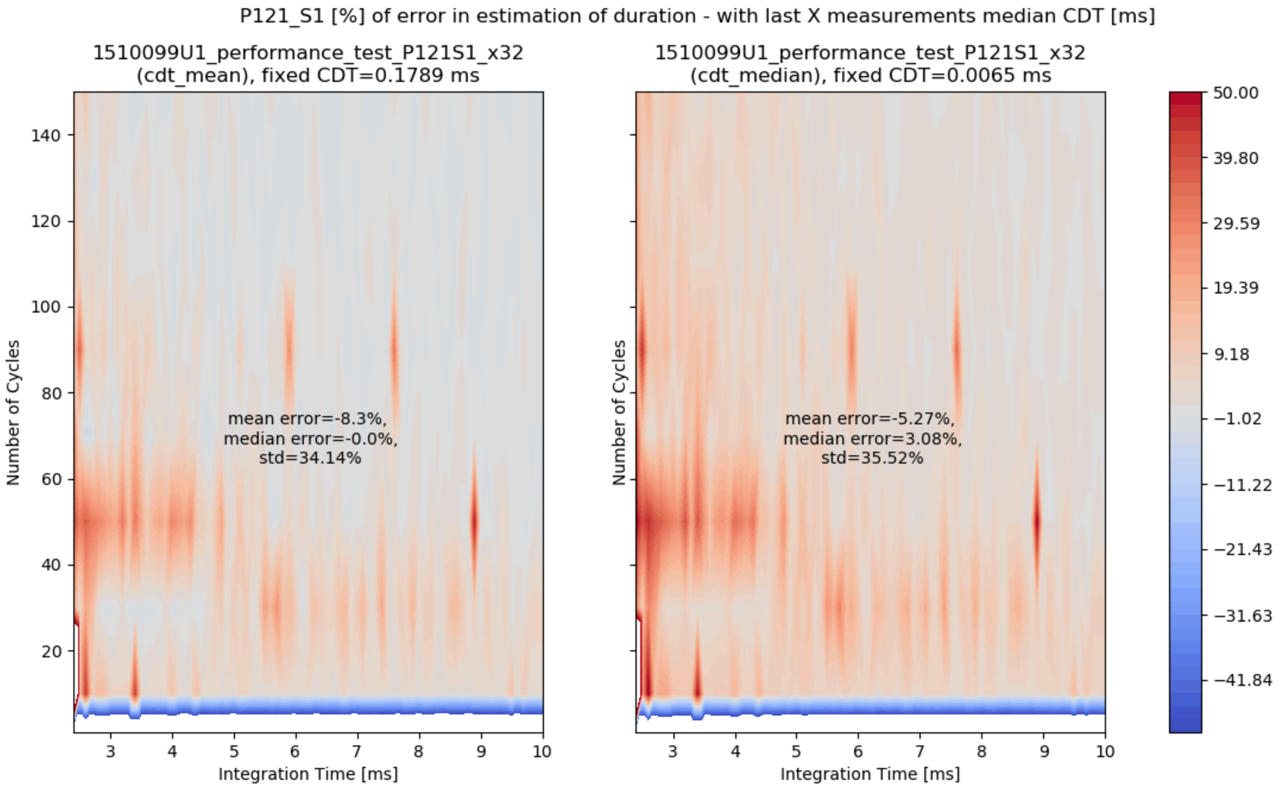

Figure 3.1-8: Error in the estimation of the durations, using the mean and median CDT.

This image shows how the average error in the duration estimation is lower, when using the CDT_{median}. However the similar moderated standard deviations shows that eventual errors in the estimation of the measurements will still happen, due the random nature of the problem.

3.1.1.1 Investigated Hipoteses

Trying to determine the reason of the randomly longer cycle delay times, the following Hypothesis have been analyzed:

Hipotesis	Evaluation
A) **Spectrometer clocking mismatch**: Spectrometer sending already measured data to the host machine at a certain clocking speed, which doesn't match the integration time.	Unlikely. The clock operates at MHz rates, too fast to explain observed delays. Also the problem seems to be random, not cyclic.
B) **Delays in the OS message queue (WndProc)**: After a measurement is requested, the avantes dll waits until each of the requested cycles is ready, and then it sends a message through the windows messaging system (WndProc) so that the open GUI-based windows apps react to this message. If the Operative System is busy, there could be random delays to send this message.	Even bypassing Windows messaging (via the alternative Avantes Library function AVS_Measure_Callback), variability persists.

Hipotesis	Evaluation
C) **Python GIL/thread switching:** The Python application being affected by the Python GIL (Global Interpreter Lock), which is switching the active threads of a threaded application at a certain rate, delaying the activation of the thread that is waiting for the data arrival event.	Random delays persist even using minimal threaded testing scripts.
D) **USB/data transmission clogs:** Random clogs in the spectrometer data transmission, caused by either the spectrometer readout electronics, USB connectivity, or host machine CPU status.	**Most probable cause**, although not addressable via software.

3.1.1.2 Proposed Improvements

Based on the analysis, the following actions were identified to enhance synchronization:

1. **Implement a "Sync Repetitions Mode":**

   Introduce SYNCREPETITIONS=YES flag in BlickO routines. When enabled and two spectrometers are connected with equal repetitions, the faster spectrometer waits for the slower one before proceeding to the next repetition. There will still be problems at low light conditions (morning, twilight), where each spectrometer is not measuring the same number of repetitions (due filters limitation), but it would improve the synchronization for the rest of the day.

2. **Get rid of the OS messaging system to flag the data arrival events:**

   Replace the AVS_Measure() by the new AVS_Measure_Callback() function, which is available in the latest version of the Avantes dll. This function would allow to decouple the Avantes data arrival events from the UI message processing. Although not a full fix, this reduces latency in software response to the Avantes dll signals.

3. **Replace the existing fixed CDT estimation with a lookup table:**

   Replace the current method used to estimate a fixed cycle delay time (based on statistics from the first 30 measurements after software startup), with a lookup table, where the CDT used for duration estimation depends on the IT and ncy of the upcoming measurement. This table would contain multiple CDT values, each associated with a specific range of IT and ncy. Such classification significantly reduces the likelihood of selecting an inappropriate CDT, thereby improving the accuracy of the estimated measurement duration.

The proposed improvements will be implemented incrementally, as it may not be necessary to apply all of them to achieve satisfactory results.

3.1.2 Modify BlickO to improve synchronization

- 20 May 2025:
  - The "Sync Repetitions" feature was implemented on Blick v1.8.76, and enabled by default for the SS and SQ measurement routines.
  - Awaiting the selection of the "PanSels" (Selected Pandoras for PanAMA project analysis) for further validation on selected Pandora systems.

3.1.3 Test the updated Software on selected Pandoras

- 1 Jun 2025:
  - Blick v1.8.76 testing version was installed on Pandora 209 (Izaña, Tenerife).
- 30 Jun 2025:
  - Preliminary results show significantly improved alignment of the bright repetitions across s1/s2, of the comparable SQ routines (Fig 3.1-9, and Fig 3.1-10).
  - Minor residual drift persists, which would cause a slight shift in center measurements time when processing up to L2 (Fig 3.1-11). Reasons still to be determined, but the effect is negligible. (s1 usually starts measurements 0.5s before S2).
  - It was concluded that no extra modifications are needed, with just the "Sync Repetitions" feature is enough to have properly synchronized & comparable repetitions.

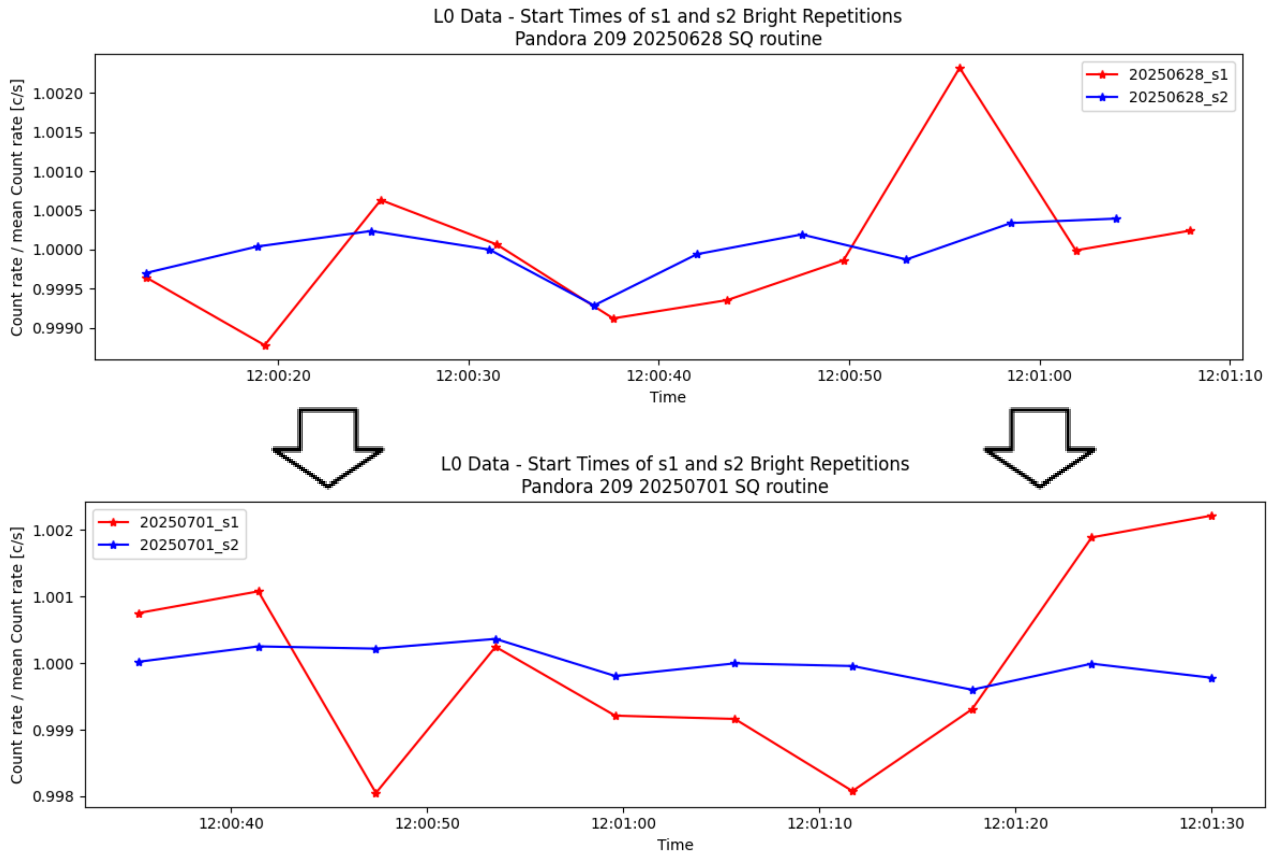

Figure 3.1-9: Start times of s1 and s2 bright repetitions before and after "Sync Repetitions" improvement

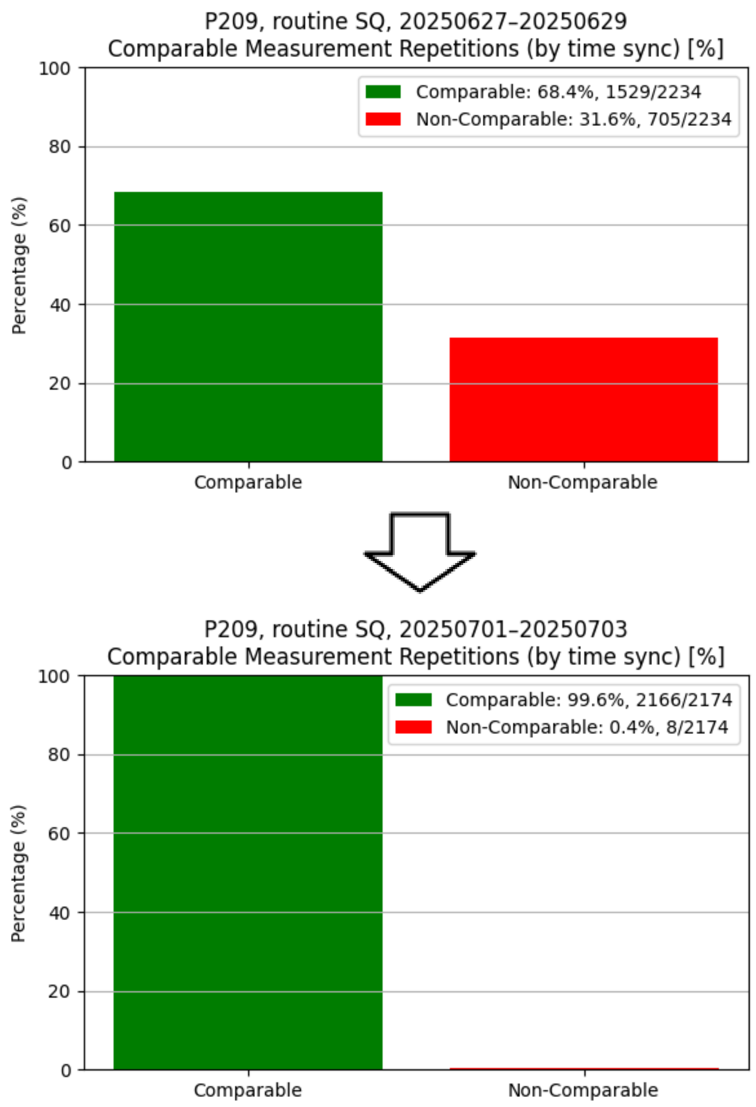

Figure 3.1-10: Comparable bright repetitions of the “potentially comparable” SQ routines, before and after “Sync Repetitions” improvement, for Pandora 209 (Izaña).

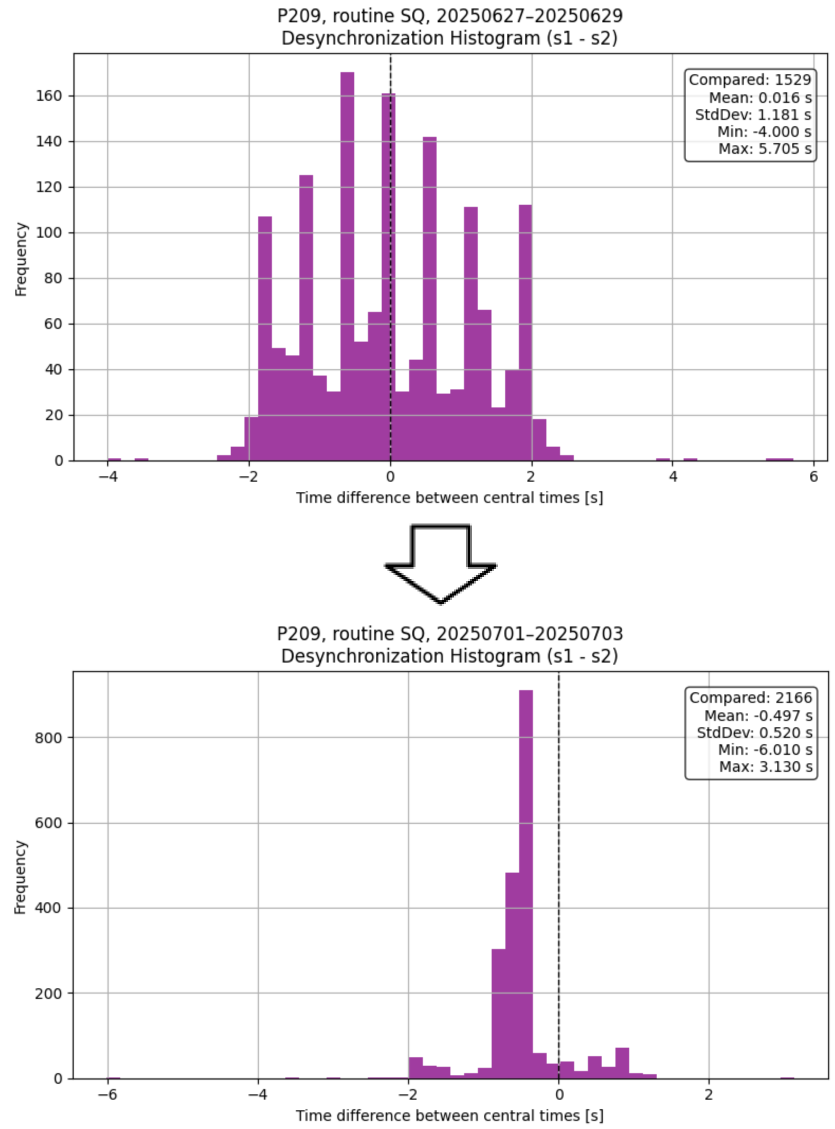

Figure 3.1-11: Desynchronization Histograms before and after “Sync Repetitions” improvement, for Pandora 209 (Izaña)

- 16 Jul 2025:
  - Updated software (now at version v1.8.77) was installed at Pandora 121.
- 5 Aug 2025:
  - Noticed instability issues in the spectrometers (a random "Error in communication occurred" Avantes DLL problem, creating several recovery events per day). A support request was sent to Avantes. Installation of the updated software on the PanSels is postponed until a solution is found.
- 12 Dec 2025:
  - Blick v1.8.87 was compiled, with the spectrometer issues resolved. (No support was provided by Avantes; instead, we reverted to an older DLL version, which proved to be more stable.)
- 29 Jan 2026:
  - Blick v1.8.87 was installed on 19 of the 31 PanSels.
- 4 Feb 2026:
  - A problem was observed where the UI freezes while running the L0 routine (Windows 11 related).
- 9 Feb 2026:
  - Blick v1.8.88 was compiled, with the UI freezing problems solved.
- 11 Feb 2026:
  - Blick v1.8.88 was installed on 27 of the 31 PanSels. The remaining 4 instruments (P54, P68, P76 and P251) cannot be updated because they are not accessible at the moment. The timeline of the updated software deployment is shown in Figure 3.1.12.

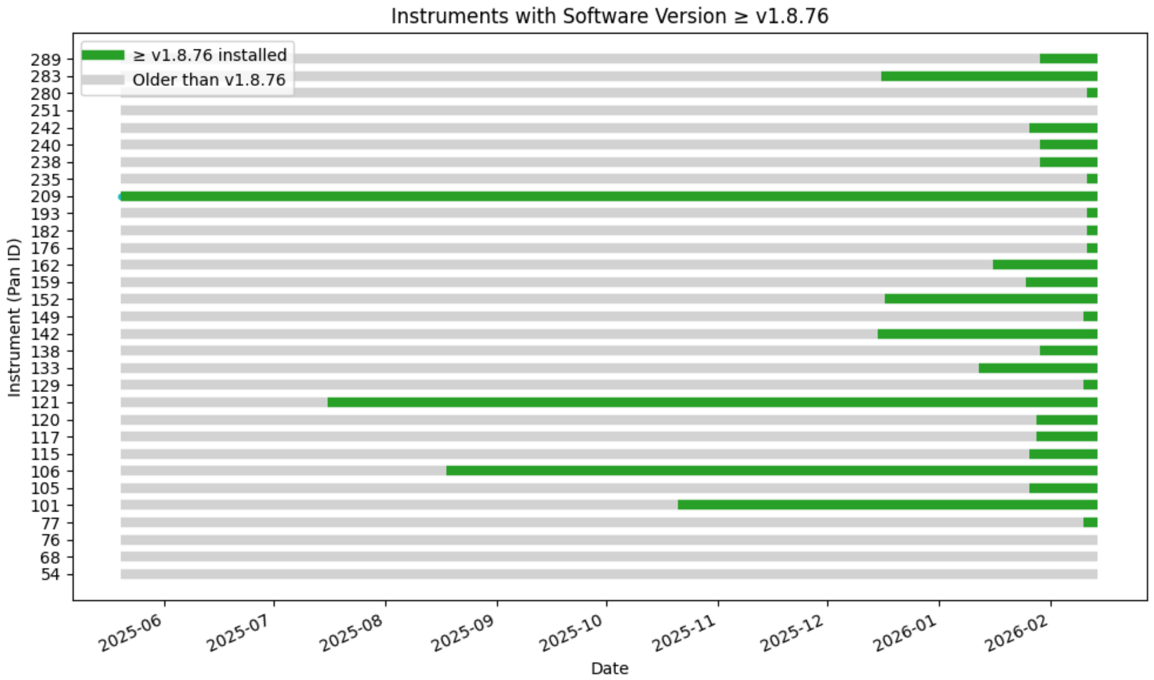

Figure 3.1-12: Software update status over time for the PanAMA related instruments.

- 18 Feb 2026:
  - As a validation step after software update in all available PanSels, the same s1/s2 synchronization analysis was intentionally extended to two additional instruments, Pandora 121 (Izaña) and Pandora 115 (Rome-ISAC). These units were selected specifically to verify that the synchronization improvements also apply to CCD-based instruments, in contrast to Pandora 209, which is CMOS-based. The results shown in figures (3.1.13, 3.1.14, 3.1.15, 3.1.16) demonstrate that synchronization has also improved in these CCD-based instruments.

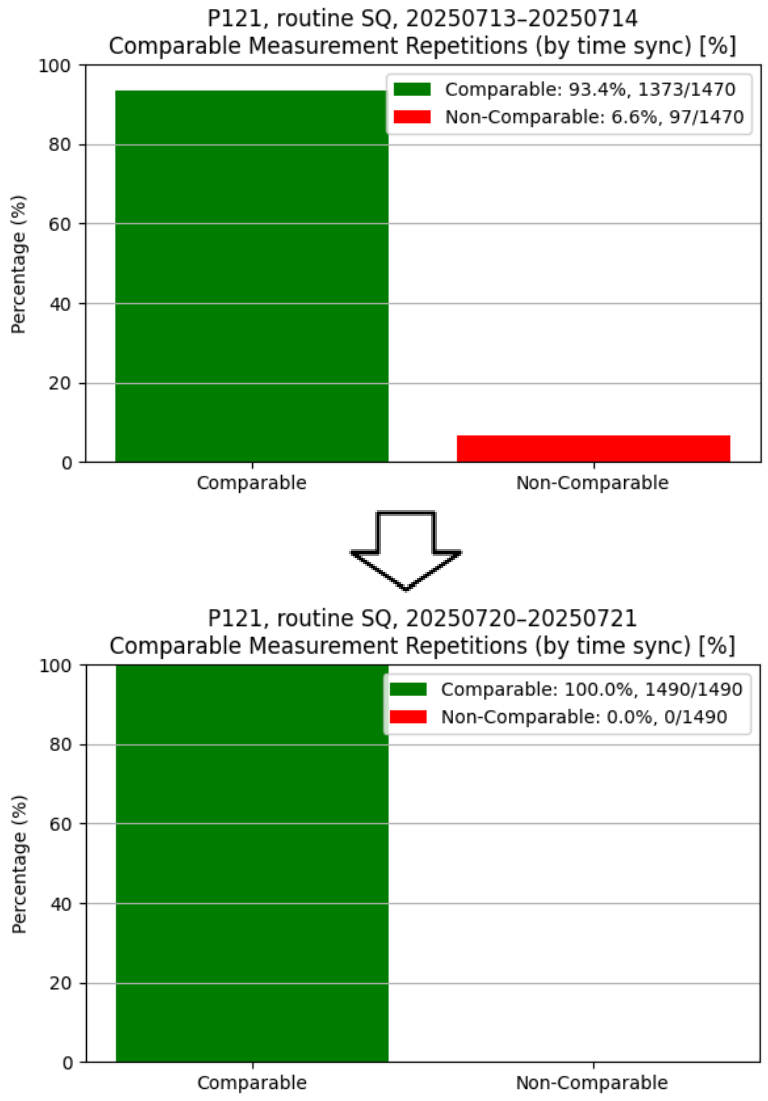

Figure 3.1-13: Comparable bright repetitions of the “potentially comparable” SQ routines, before and after “Sync Repetitions” improvement, for Pandora 121 (Izaña)

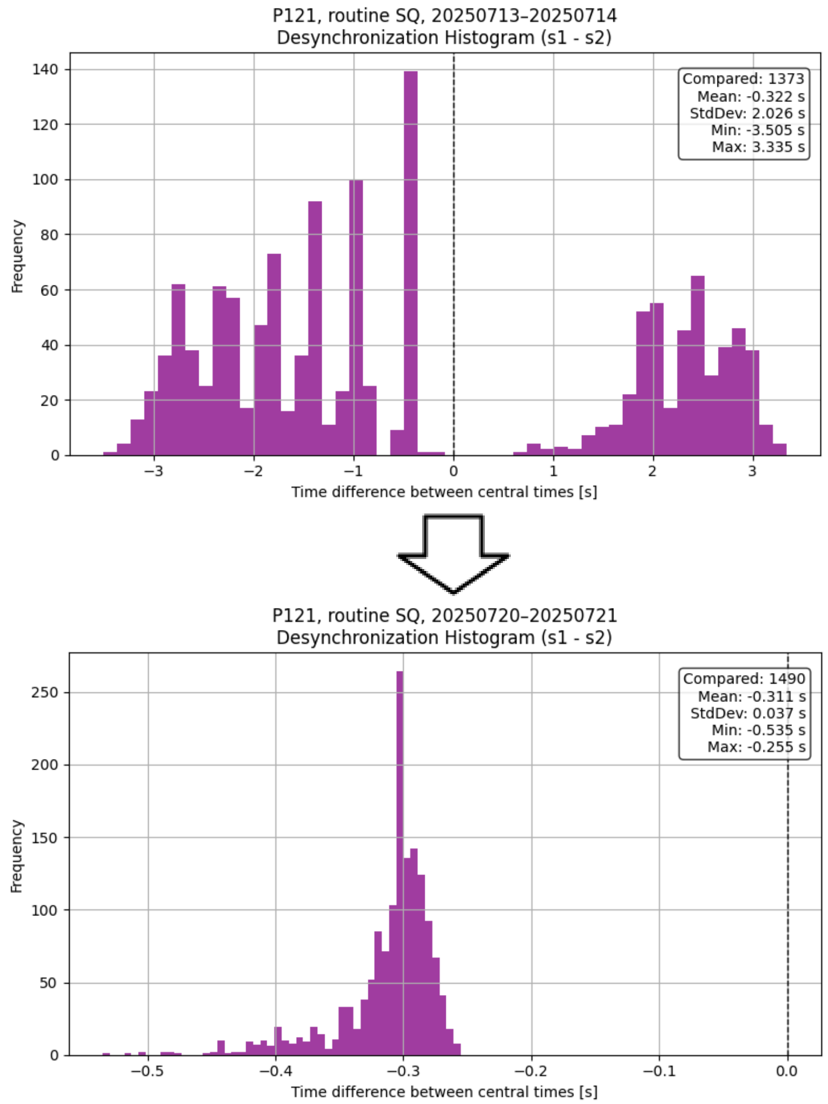

Figure 3.1-14: Desynchronization Histograms before and after “Sync Repetitions” improvement, for Pandora 121 (Izaña)

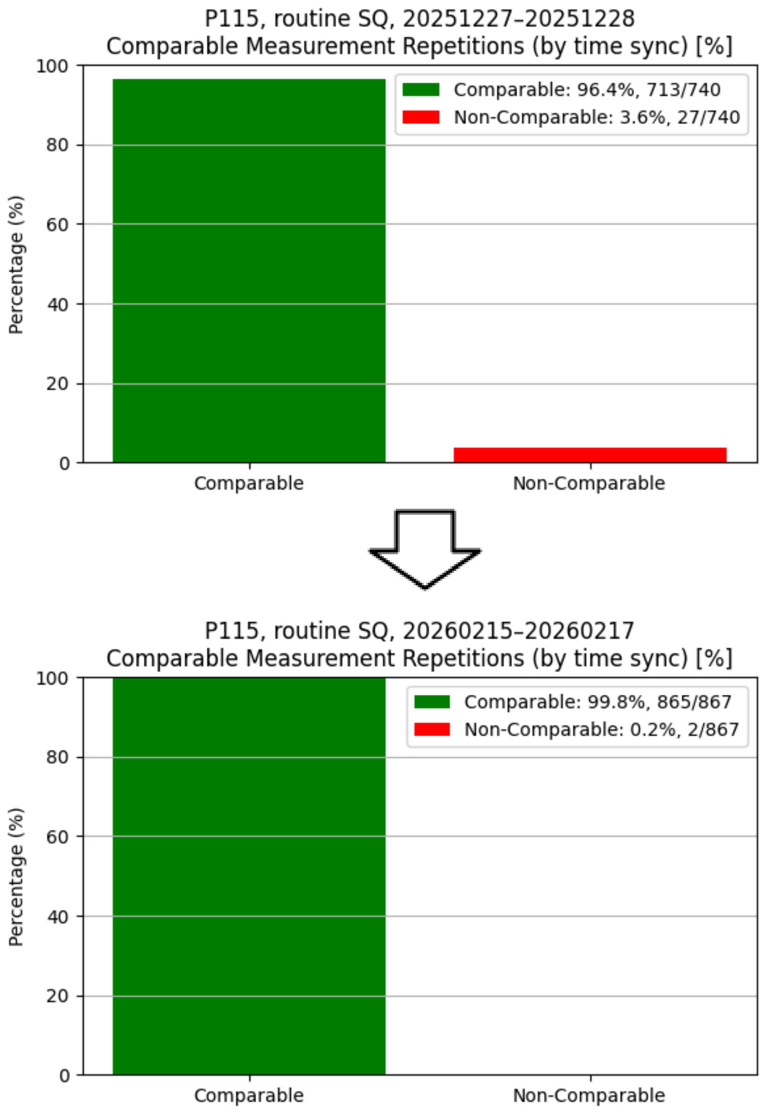

Figure 3.1-15: Comparable bright repetitions of the “potentially comparable” SQ routines, before and after “Sync Repetitions” improvement, for Pandora 115 (Rome-ISAC).

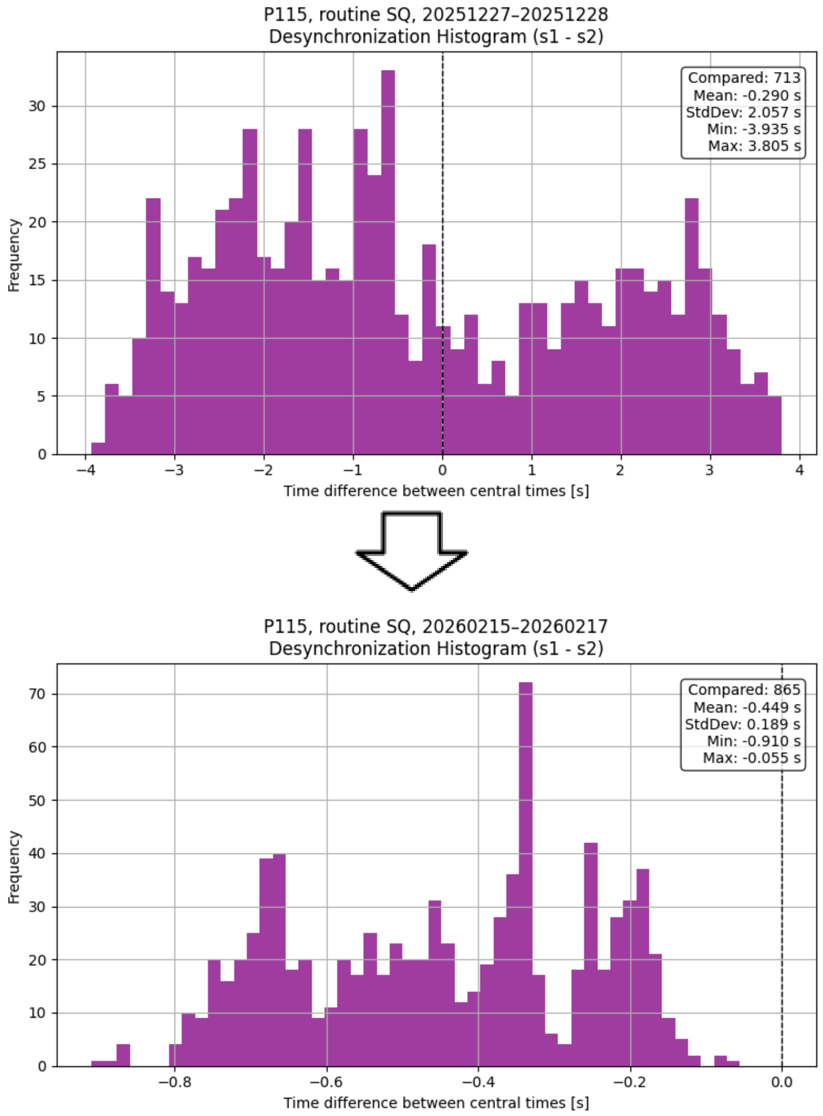

Figure 3.1-16: Desynchronization Histograms before and after “Sync Repetitions” improvement, for Pandora 115 (Rome-ISAC).

3.1.4 Apply the software modifications to the entire PGN Network.

The proposed software modifications will be rolled out across the entire PGN Network as part of the regular software upgrade cycle. The deployment will follow the established PGN upgrade procedures and will therefore be implemented according to the network's standard upgrade schedule and intrinsic timing.

Since software upgrades within PGN are subject to timing constraints and coordination requirements arising from other ongoing projects (e.g., POp), the integration of this new feature will be aligned with these existing procedures.

This approach ensures a smooth and controlled deployment, and no issues are expected regarding the implementation across the PGN Network.