

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY -LIGO-

LIGO Laboratory /LIGO Scientific Collaboration

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aLIGO Timing System's Accuracy during O2		
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Abstract

Advanced LIGO (aLIGO) data is recorded by a data acquisition system (DAQ) that is driven entirely by the GPS-backed aLIGO Timing Distribution System. Several independent clock's 1PPS signals are compared to each other to provide timing performance witness signals. At each site, a [Microsemi 4310b Cs-III](#) Cesium-standard atomic clock checks for transient or short-term timing problems (see [LIGO-T1700298](#) for details), and two [CNS Clock II GPS clocks](#) and a GPS-backed NTP server check for long-term/absolute timing problems.

We measured the time delay between aLIGO Timing Distribution System 1PPS and the aforementioned Timing Diagnostic System's CNS Clock II GPS clock's and a GPS-backed NTP server's 1PPS signals for aLIGO's second observation run (O2). The Timing Distribution System performance was proper.

1. Introduction

The aLIGO Timing Distribution System is a custom timing solution that provides end-to-end timing signal integrity at the hardware level, ensuring absolute synchronization across all aLIGO sites to the GPS time standard (and UTC) below the required tolerance.

Auxiliary to the timing distribution system, there are **diagnostic** features which rely on a heterogeneous set of independent clocks to continuously measure the Timing Distribution System's accuracy and performance on different time scales. These diagnostic features and independent clocks are functionally distinct from the Timing Distribution System, and collectively are called the aLIGO **Timing Diagnostic System**. The Timing Diagnostic System checks, among other things, guarantees that the Timing Distribution System is synchronized to GPS time. One of the main functions of the Timing Distribution System is to mark the start of each second with a voltage pulse ("One Pulse Per Second" or "1PPS"), which can be compared to independent Timing Diagnostic System reference clock 1PPS signals to verify that the Timing Distribution System's 1PPS is consistent within specifications.

One of the reference signal types used at each site are CNS Clock II GPS clocks that provide long-term consistency measurements. These measurements can pinpoint local problems related to the GPS receiver or distribution system, however the GPS space segment is not tested by them.

2. Timing System Performance during O2

During LIGO's second observation run (O2), the Timing Distribution System performance – regarding CNS Clock II GPS clock and a GPS-backed NTP server Time Difference - was well within specification during all observing time segments.

The GPS-backed NTP server in the Mass Storage Room (MSR) at the Corner Station at Hanford showed variations from mean of less than $\pm 150\text{ns}$ vs. the Timing Distribution System 1PPS signal at all times (*Figure 1: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LHO during O2.* (EPICS channel name: H1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)), with most values within $\pm 80\text{ns}$. The CNS II clocks, located at end stations X and Y, showed variations of $\pm 90\text{ns}$ from the mean time difference at all times (*Figure 2: Timing*



Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O2. (EPICS channel name: H1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1) and *Figure 3: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O2. (EPICS channel name: H1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)*, respectively).

Note 1: The X and Y End CNS II clocks were both disconnected for <20 minutes each on February 22, 2017 at 20:32 and 18:22 UTC, respectively. These [planned](#) outages had no effect on [Timing Distribution System](#) performance, and no more than one clock was taken offline at a time. There were no other losses of [Timing Diagnostic System](#) signal at LHO during O2.

The NTP server at the Corner Station at Livingston showed variations from mean of less than ± 100 ns vs. the [Timing Distribution System](#) 1PPS signal at all times (*Figure 4: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)*). The CNS II clocks in the X and Y stations showed variations of less than ± 90 ns from the mean time difference at all times (*Figure 5: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)* and *Figure 6: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)*, respectively).

Note 2: There was a single 4 minute outage at the end of an L1:DMT-ANALYSIS_READY data quality segment in the LLO time difference signals during O2, starting at around 14:05 UTC on June 5, 2017. The unrecorded time difference values were coincident with the Beckhoff issues at the X End Station that presumably caused lock loss at 14:09 UTC, as recorded in [FRS 8268](#). LHO was not in observing mode at this time.

*Note 3: The LLO Y End CNS II Clock was not properly connected during the first 15 days of O2. The first 15 days of the LLO Y End CNS II time difference have therefore been excluded from the plot (*Figure 6: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)*). [The connection was fixed on the 15th day](#) as part of [work permit 3748](#). The other [Timing Diagnostic System](#) time difference channels indicate that the [Timing Distribution System](#) was performing normally at LLO during this time.*

*Note 4: Starting on May 2, 2017, the LLO X End comparator (which is used to measure the CNS II time difference) began malfunctioning, leading to erratic measurements of the CNS II time difference. The comparator was [replaced with a spare](#) during the May commissioning break, after which the CNS II time difference values returned to their previous behavior. Values recorded during segments when the comparator was clearly malfunctioning were removed from the plot for the X End CNS II time difference (*Figure 5: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)*). The other time difference channels showed normal performance from the [Timing Distribution System](#) during these 6 days. There were no other losses of [Timing Diagnostic System](#) signal at LLO during O2.*



In conclusion, the time differences measured by the **Timing Diagnostic System**'s CNS II GPS clocks indicate that the **Timing Distribution System** performance did not suffer from problems.



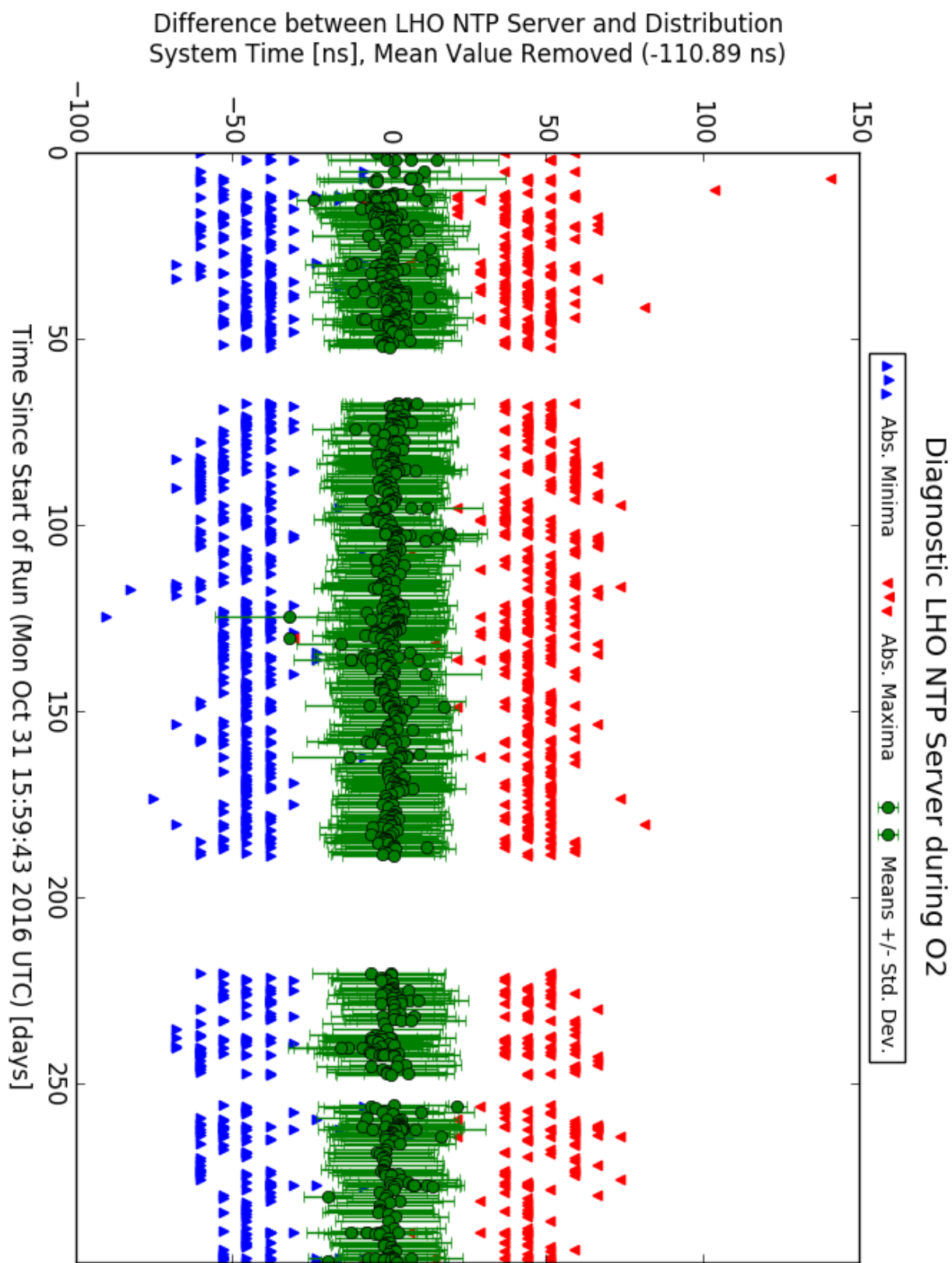


Figure 1: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LHO during O2. (EPICS channel name: H1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)



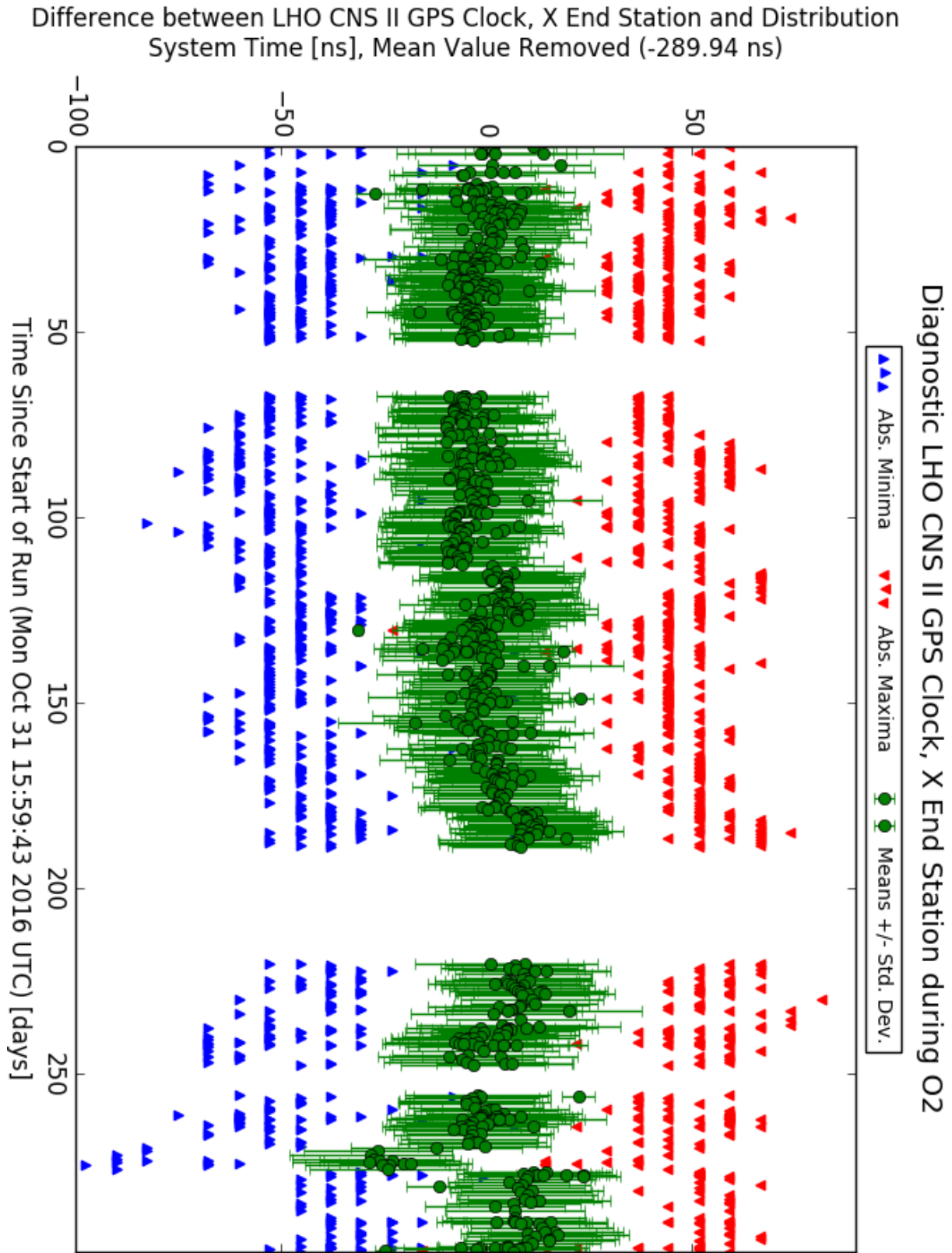


Figure 2: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O2. (EPICS channel name: H1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)



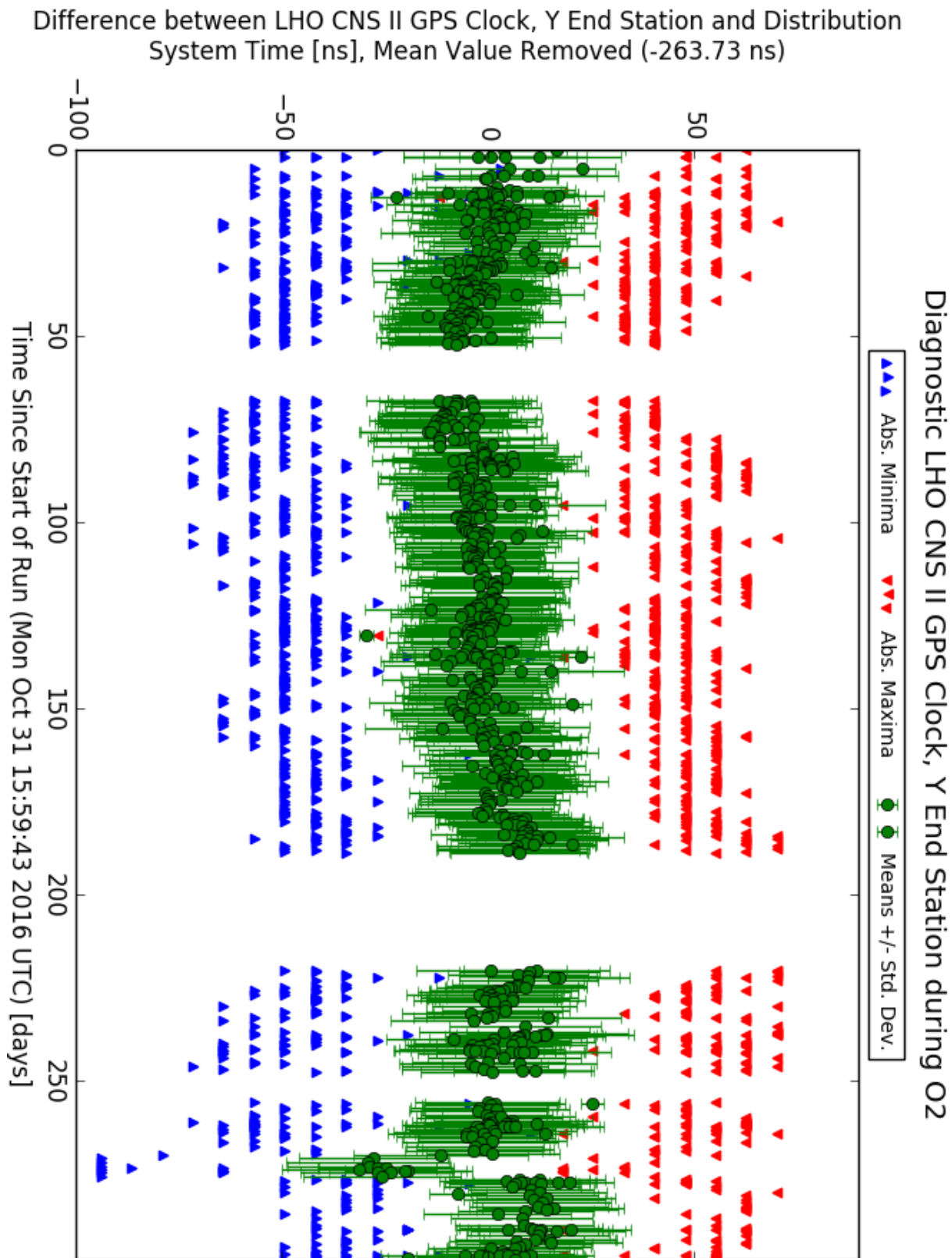


Figure 3: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O2. (EPICS channel name: H1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)



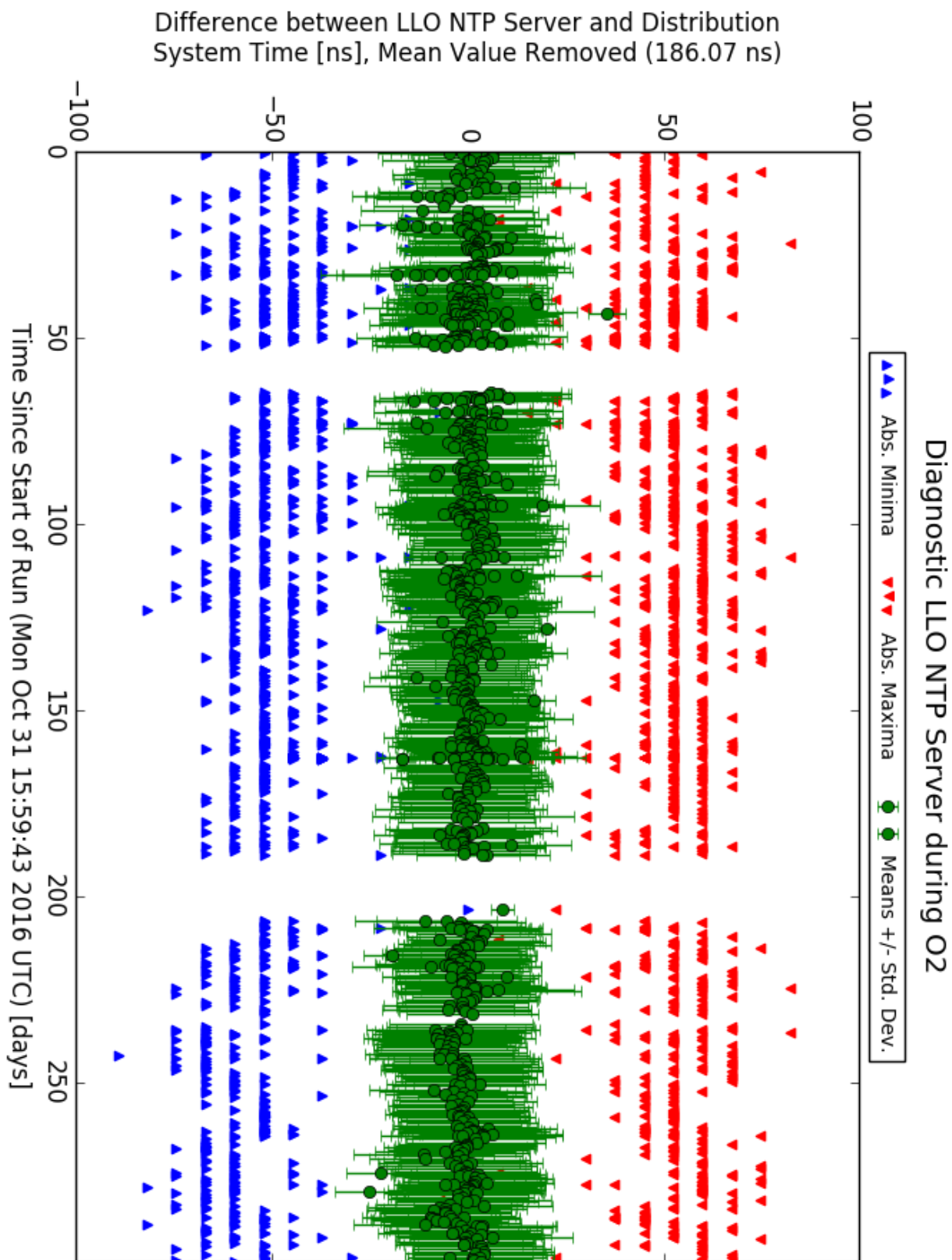


Figure 4: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)



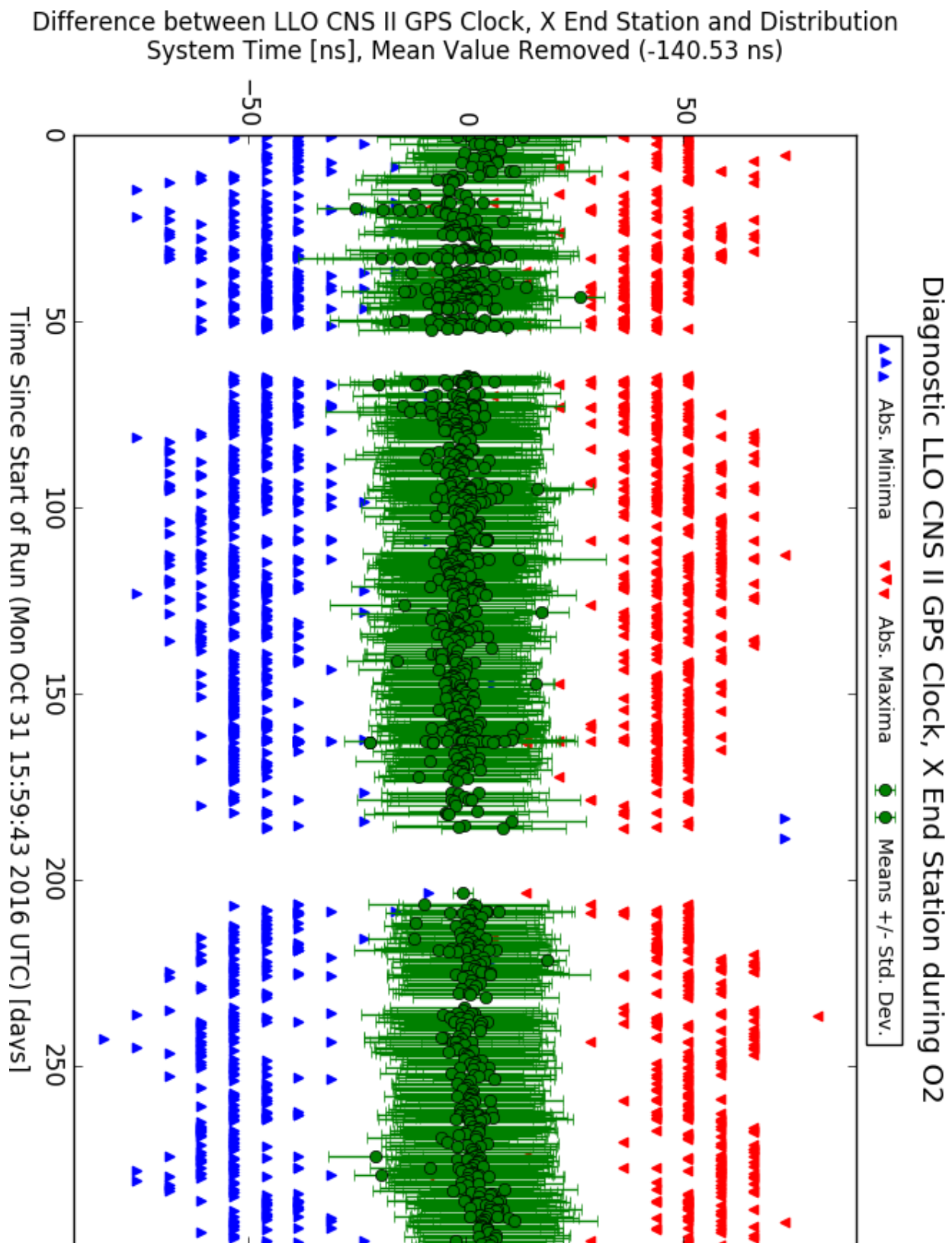


Figure 5: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2.
(EPICS channel name: L1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)



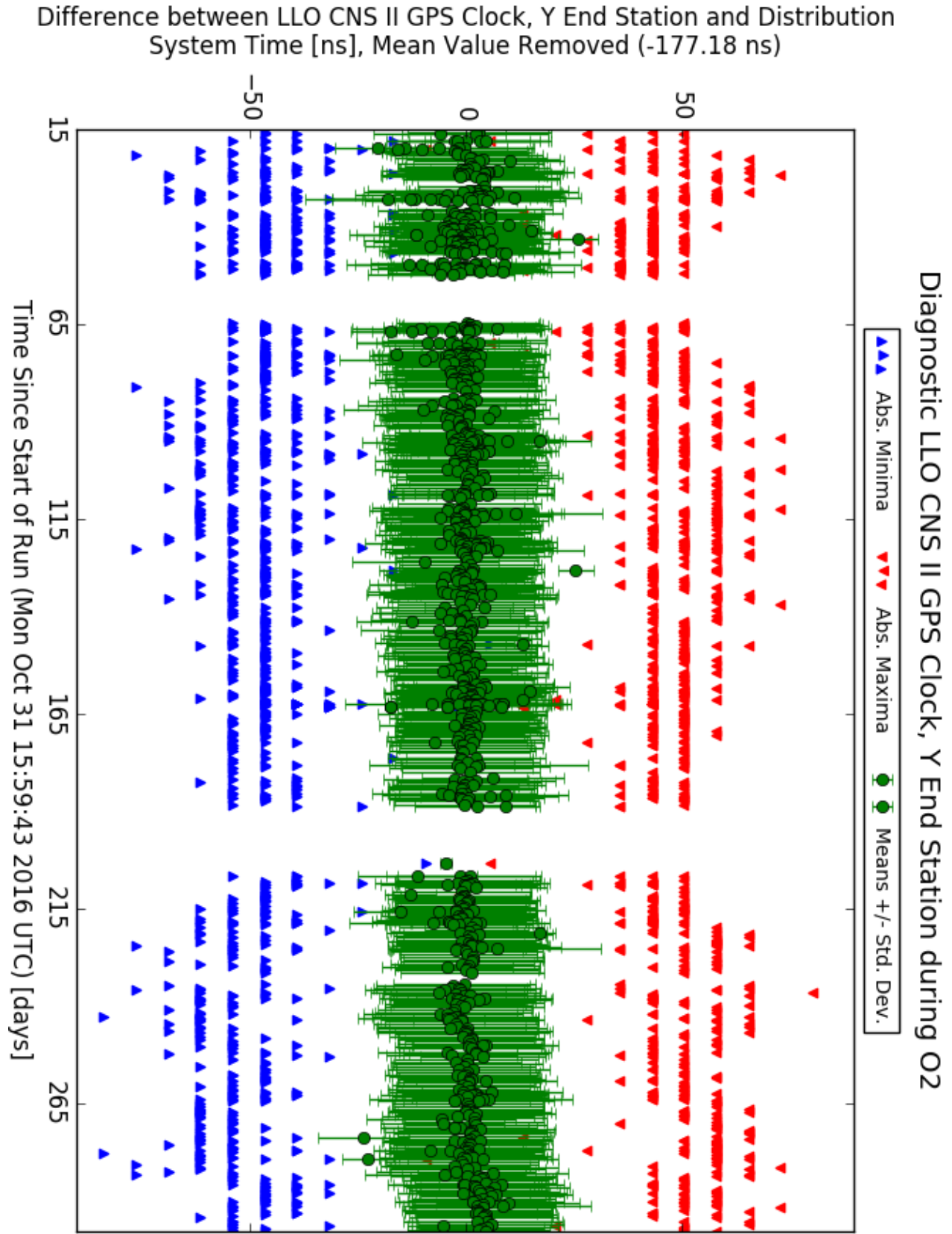


Figure 6: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O2. (EPICS channel name: L1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1)

