Relative Internal Delay Measurement between Precise Time Systems at J-PARC and Super-K

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Motivation

- We have not yet accounted for possible **internal delay** differences in the two Precise Time System GPS receivers

- We want to measure the **internal delay** of our Precise Time GPS receivers at J-PARC (PT00) and Super-K (PT01)

- A direct measurement of the **internal delay** of a receiver requires expensive and complex calibration hardware.

- Instead, we will measure the **relative internal delay** of two receivers using a intermediary calibration receiver.

  – Measure relative internal delay between PT00 and PT04

  – Measure relative internal delay between PT01 and PT04

  – From these measurements, calculate relative internal delay between PT00 and PT01: INTDLY(PT00)-INTDLY(PT01)

Programme

- We take the following as the definition of observables G(X), where X is the location of the observations
  - $G(X) = TS(X) - GPSTime + INTDLY(X) - PPSDLY(X)$

    where INTDLY() is the **internal delay** of receiver at site X

    and PPSDLY() is the 1-pulse-per-second delay at site X
- If we take A & B to be two disparate sites, we can write:
  - $G(A) = TS(A) - GPSTime + INTDLY(A) - PPSDLY(A)$
  - $G(B) = TS(B) - GPSTime + INTDLY(B) - PPSDLY(B)$

  which yields
  - $G(A)-G(B) = TS(A)-TS(B) + INTDLY(A-B) - PPSDLY(A-B)$

    where INTDLY(A-B) is the **relative internal delay** between the two receivers at sites A & B

    and GPSTime is eliminated
- Thus, we can solve for INTDLY(A-B) provided we can measure PPSDLY(A-B) and...
- Combine it with recorded observables, G(), *in a way such that TS(A-B) can be eliminated*
- This is done using a transportable intermediate receiver that can be compared to local receivers at both sites A & B.
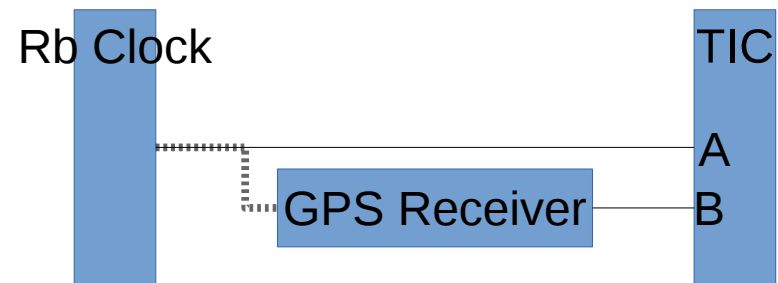
PPS Delay Measurement

- The PPS delay can be measured directly

- It is the difference between the signal that marks the timescale at each site and the signal that leaves the GPS receiver

- In order to measure the PPS delay of a GPS receiver, we need to configure the receiver to deliver the internal clock time, instead of GPS time

  - PolaRx4 Configuration
    - TimeScale = RxClock
    - 1PPS Delay = 0 ns

Rb Clock

TIC

A

GPS Receiver
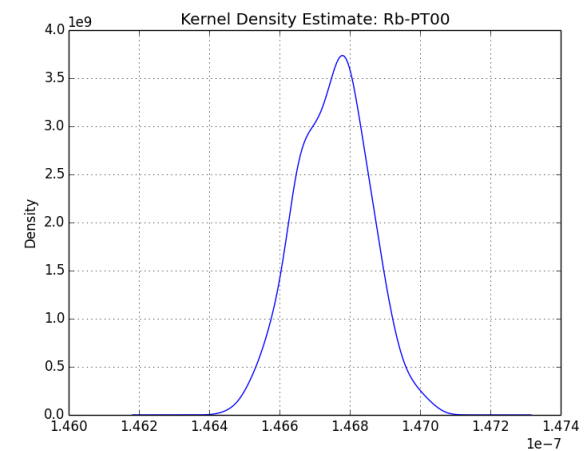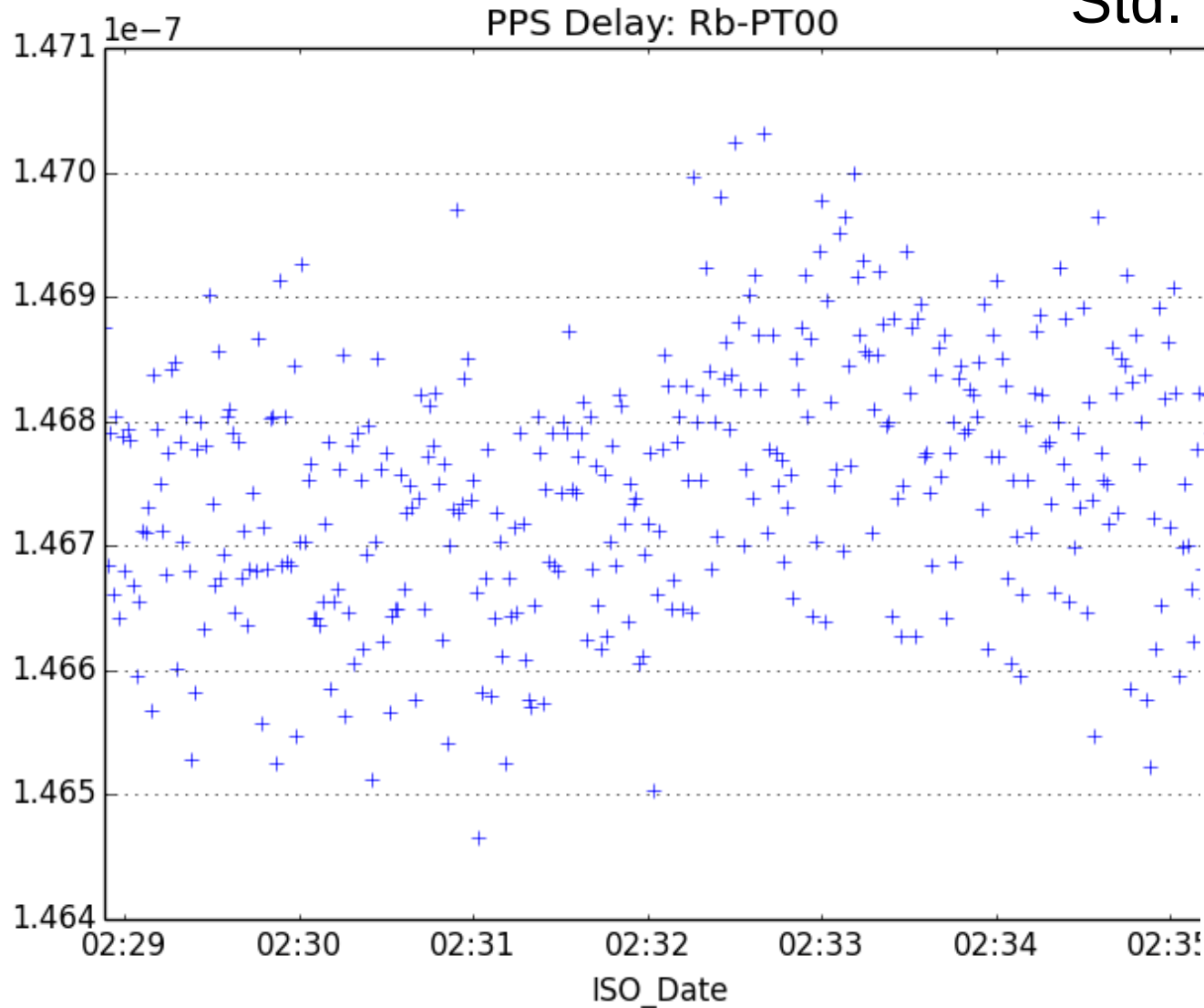
B
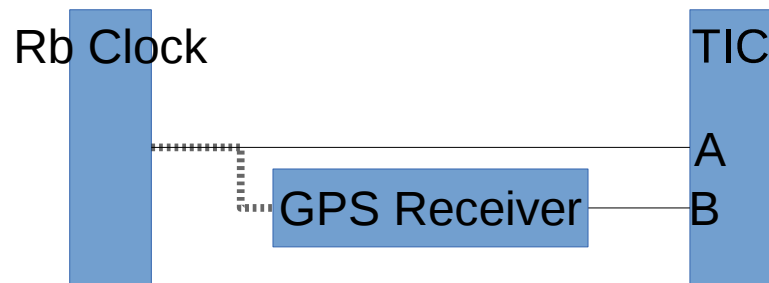
PPS Delay Measurement

- Procedure

  - Synchronize the receiver with 1PPS input from Rb clock

  - Disconnect Rb clock from receiver & reconnect to TIC channel A

  - Connect 1PPS output from receiver to TIC channel B
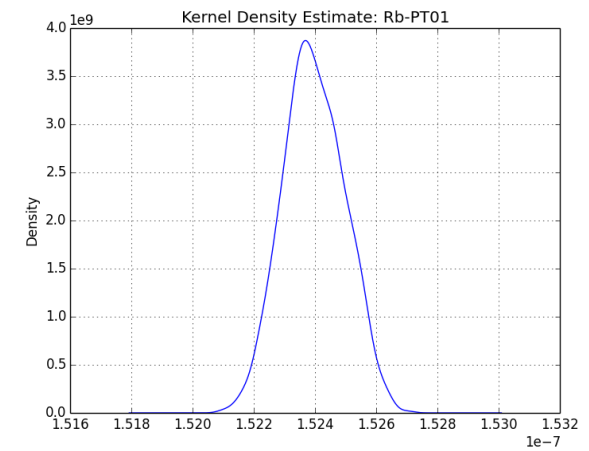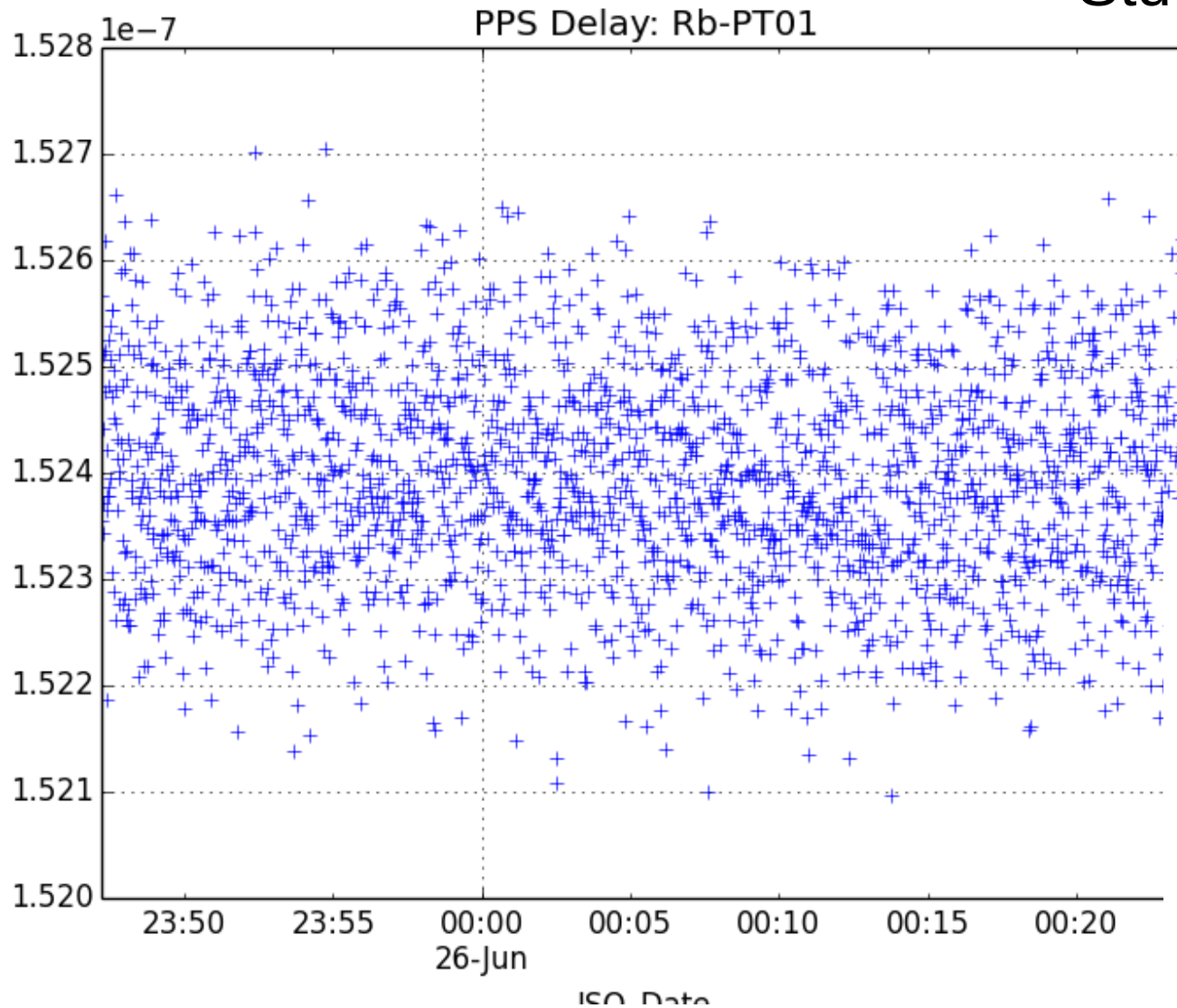
  - Measure with TIC

Rb Clock   TIC

A

GPS Receiver   B

PPSDLY Measurement: PT00-Rb

Mean value: 146.75 ns
Std. Dev.: 0.10 ns

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PPSDLY Measurement: PT01-Rb

Mean value: 152.40 ns
Std. Dev.: 0.10 ns

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PPSDLY Measurement: PT04-Rb_{NU1}

Mean value: 147.28 ns
Std. Dev.: 0.12 ns

Paul DeStefano: T2K TOF
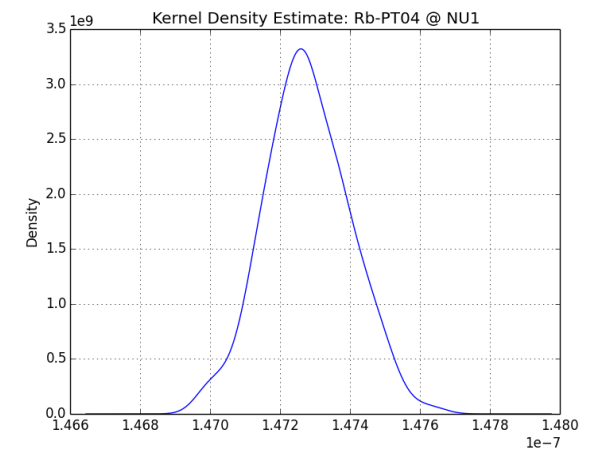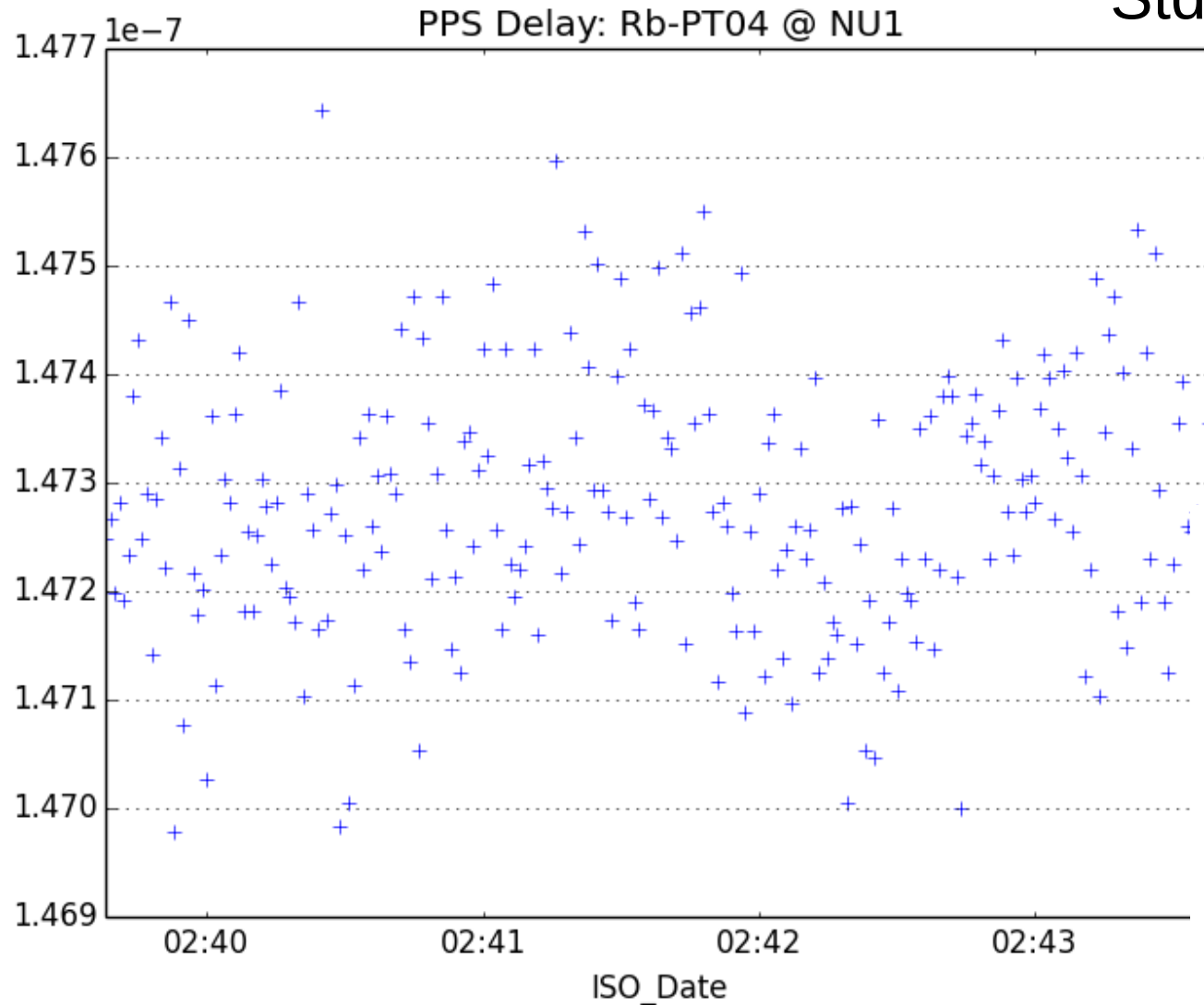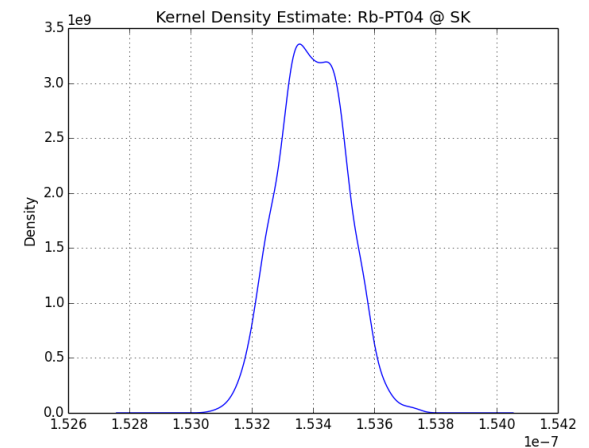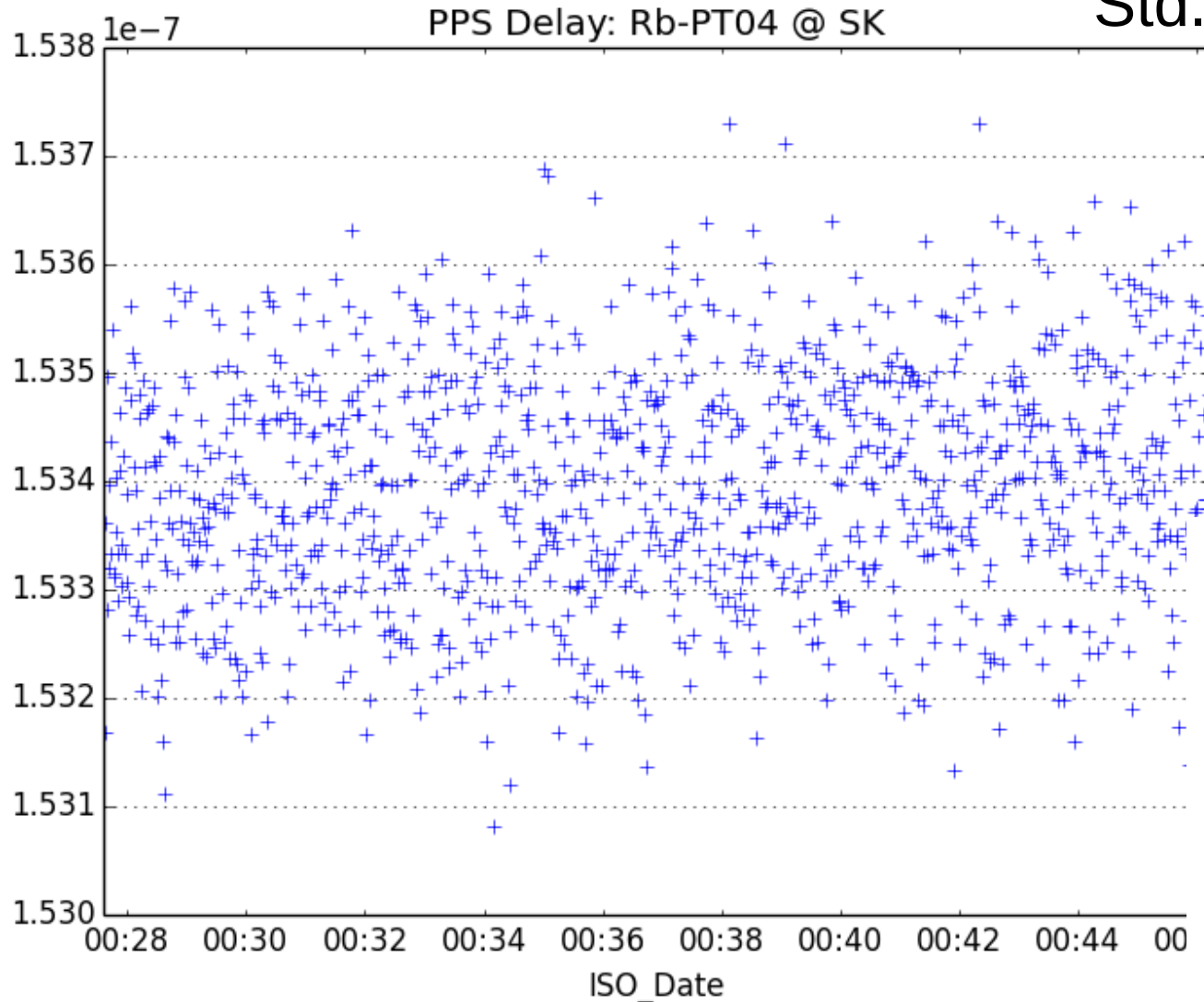
PPSDLY Measurement: PT04-Rb_{SK}

Mean value: 153.40 ns
Std. Dev.: 0.11 ns

PPS Delay Results

- Measurements Summary
  - PPSDLY(PT00-Rb) = 146.75 ns
  - PPSDLY(PT01-Rb) = 152.40 ns
  - PPSDLY(PT04-Rb@NU1) = 147.28 ns
  - PPSDLY(PT04-Rb@SK) = 153.40 ns
- PPS delay difference calculations
  - PPSDLY(PT04)-PPSDLY(PT00) = 0.53 ns
  - PPSDLY(PT04)-PPSDLY(PT01) = 1.00 ns

Internal Delay Measurement

- We now have measured PPS delays *relative to the intermediate receiver PT04*

- We use the same relative measurement strategy for the **internal delay**

  – G(A)-G(PT04) = TS(A)-TS(PT04) + INTDLY(A-PT04) – PPSDLY(A-PT04)

  – G(B)-G(PT04) = TS(B)-TS(PT04) + INTDLY(B-PT04) – PPSDLY(B-PT04)

    where TS(x)-TS(PT04) must be zero if we connect the local receiver at site A and the PT04 receiver to the same timescale source.

- This leaves only observables G(), which we noted previously could be PPP Post-Processing results.

Internal Delay Measurement

- Both receivers remain running from the PPSDly measurement and are, therefore, still synchronized to the local Rb Clock input.

- Delay cables have equal length, so the timescale, TS(), must be the same for both receivers.

Rb Clock

GPS Receiver B

GPS Receiver A

TIC

A

B

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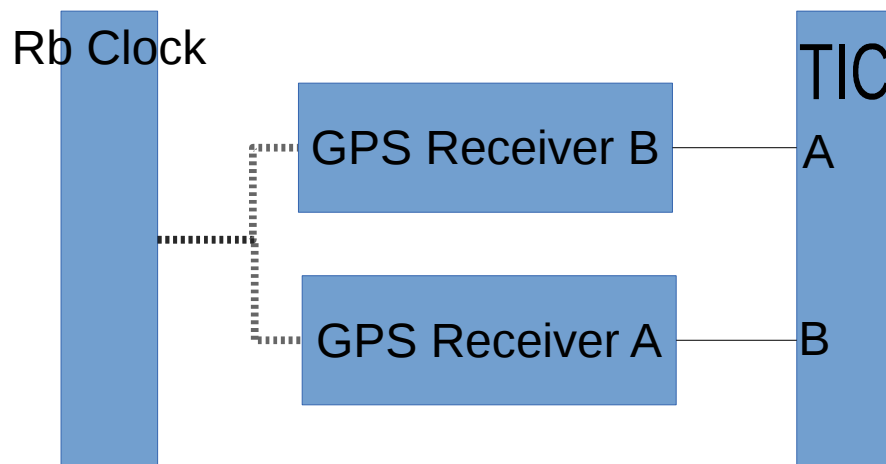
Relative Internal Delay: PT04-PT00

INTDLY(PT04-PT00)=[G(PT04)-G(PT00)]+PPSDLY(PT04-PT00)

Relative Internal Delay: PT04-PT00 (PPP)
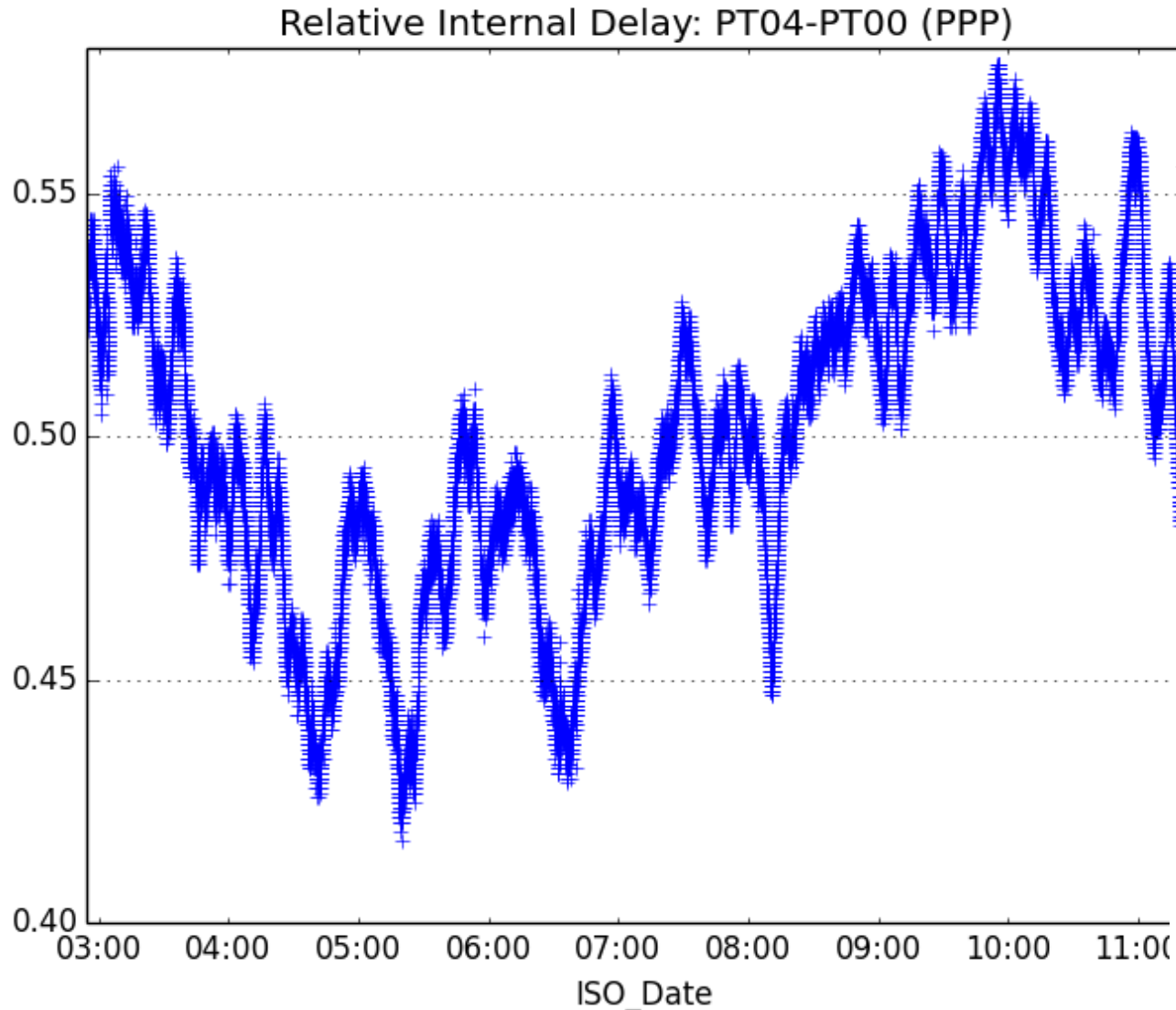
Mean value: 0.50 ns
Std. Dev.: 0.03 ns
Uncertainty: 0.22 ns

Kernel Density Estimate: Rel.Intl.Dly: PT04-PT00 (PPP)
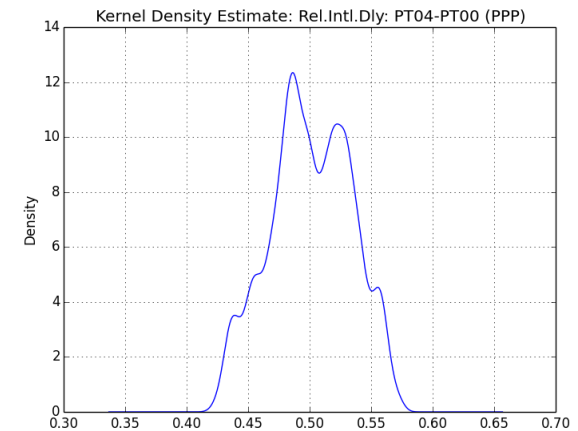
Relative Internal Delay: PT04-PT01

INTDLY(PT04-PT01)=[G(PT04)-G(PT01)]+PPSDLY(PT04-PT01)
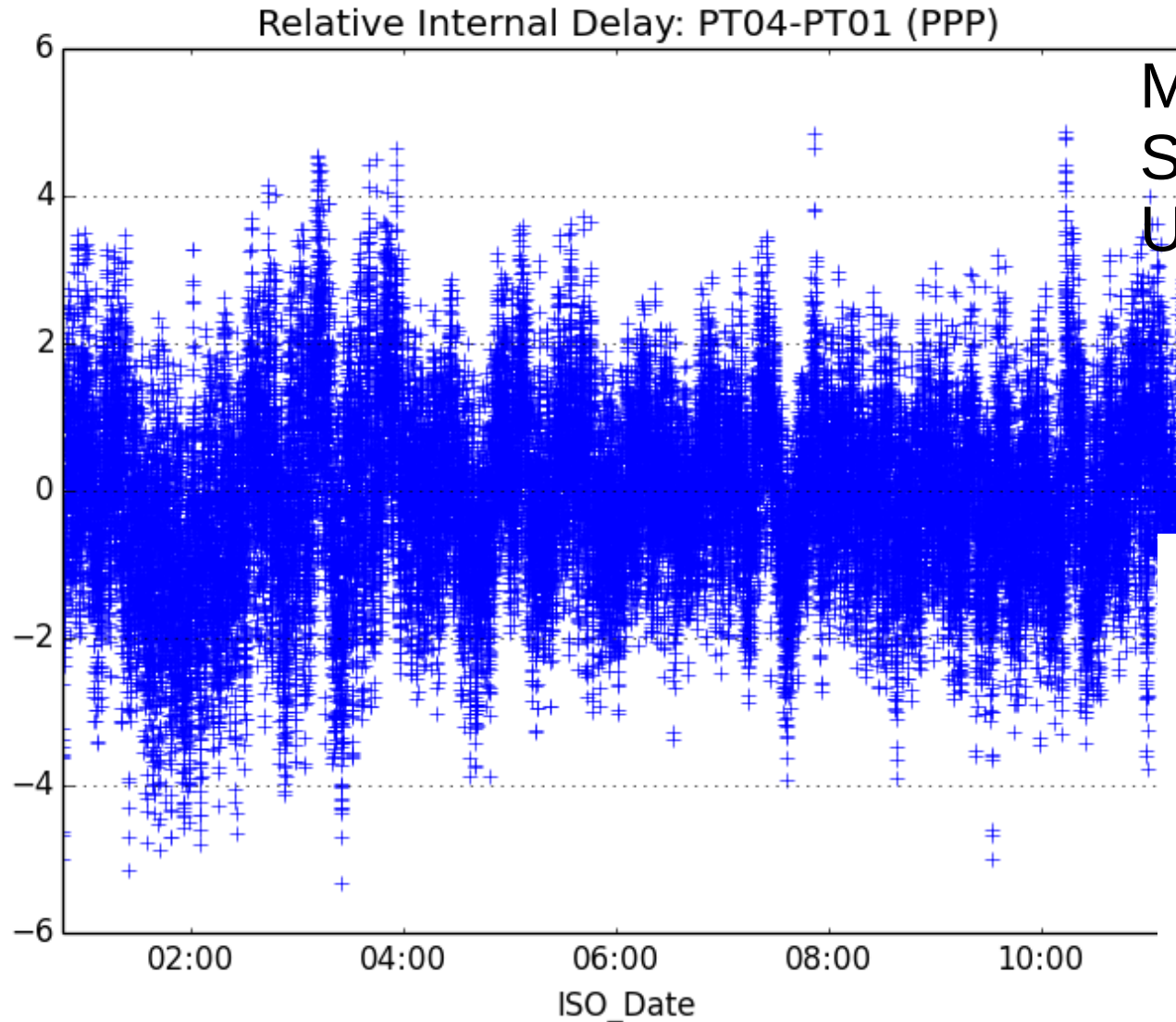
Mean value: -0.07 ns
Std. Dev.: 1.22 ns
Uncertainty: 1.25 ns

Relative Internal Delay: PT04-PT01 (PPP)

Kernel Density Estimate: Rel.Intl.Dly: PT04-PT01 (PPP)
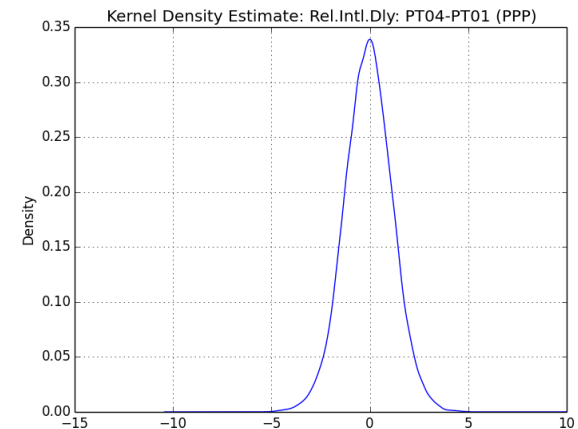
Relative Internal Delay NU1-SK

- Measurement Summary
  - PPSDLY(PT04)-PPSDLY(PT00) = 0.53 ns
  - PPSDLY(PT04)-PPSDLY(PT01) = 1.00 ns
- Intermediate Results
  - INTDLY(PT04)-INTDLY(PT00) = 0.50 ns
  - INTDLY(PT04)-INTDLY(PT01) = -0.07 ns
- Calculated Internal Delay
  - INTDLY(PT00)-INTDLY(PT01) = -0.07 – 0.50

$$= - 0.57 \text{ ns}$$

Uncertainty

- ## PPSDLY **difference** (type A)

  - Measured directly by TIC

  - TIC systematic errors cancel because the PPSDLY **difference** is a difference of measurements from the same TIC

  - Therefore, we estimate type A uncertainty as the sum in quadrature of unbiased standard deviation of the mean values of the two differenced PPSDLY measurements.

Uncertainty: PPSDLY(PT04-PT00)	
Component	Type A
PPSDLY(PT00)	0.10 ns
PPSDLY(PT04)	0.12 ns
Total	0.16 ns

Uncertainty: PPSDLY(PT04-PT01)	
Component	Type A
PPSDLY(PT01)	0.10 ns
PPSDLY(PT04)	0.11 ns
Total	0.15 ns

Uncertainty

- PPSDLY **difference** (B)

  – PPSDLY may change during internal delay measurement.

  – Estimate as the range of 10 sample mean values

PT04@NU1 PPSDLY Systematic Uncertainty (10 sample mean)

Range: 0.18 ns
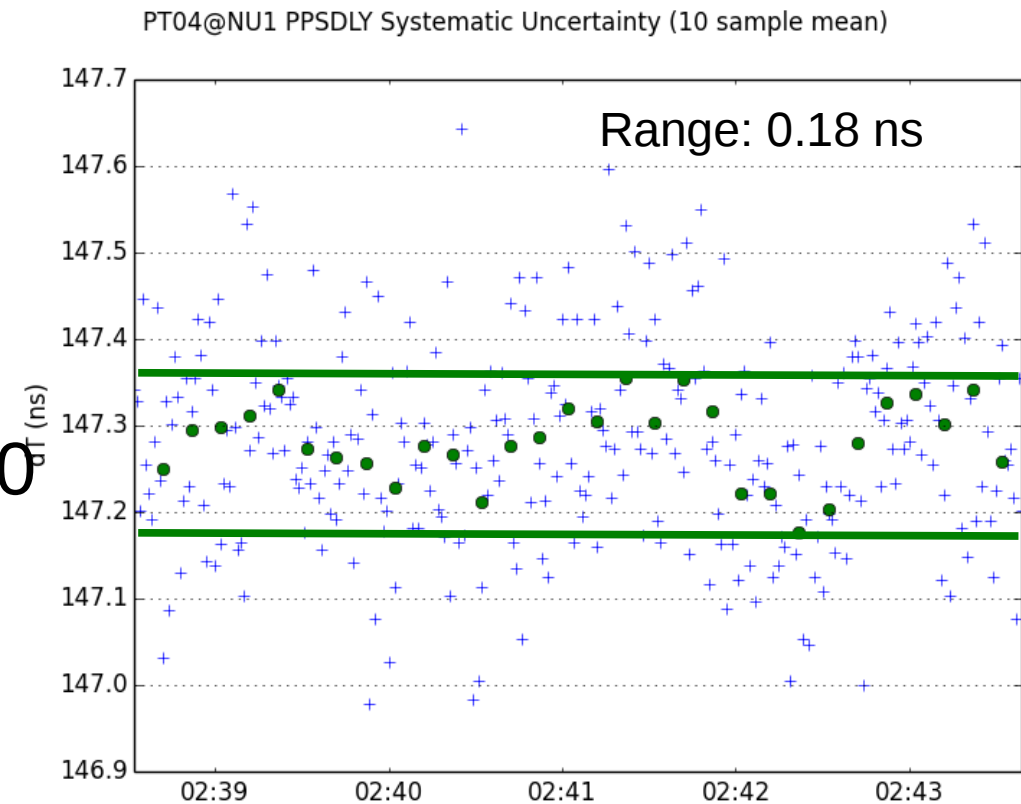
Uncertainty: PPSDLY(PT04-PT00)		
Component	Type A	Type B
PPSDLY(PT00)	0.10 ns	0.20 ns
PPSDLY(PT04)	0.12 ns	0.18 ns
Total	0.16 ns	0.27 ns

Uncertainty: PPSDLY(PT04-PT01)		
Component	Type A	Type B
PPSDLY(PT01)	0.10 ns	0.19 ns
PPSDLY(PT04)	0.11 ns	0.18 ns
Total	0.15 ns	0.26 ns

Uncertainty

- Relative Internal Delay (Type A)
  - Estimate as the sum in quadrature of the unbiased standard deviation of G(A)-G(B) and the total Type A uncertainty of the PPDLY difference measurement

Uncertainty: INTDLY(PT04-PT00)	
Component	Type A
PPSDLY(PT04-PT00)	0.16 ns
G(PT04-PT00)	0.03 ns
Total	0.16 ns

Uncertainty: INTDLY(PT04-PT01)	
Component	Type A
PPSDLY(PT04-PT01)	0.15 ns
G(PT04-PT01)	1.22 ns
Total	1.23 ns

Uncertainty

- ## G(X): Rx Clock vs GNSS Time observations (Type B)

  - Composite measurement, multiple sources of uncertainty

    - Receiver clock filter group delays
    - GNSS satellite internal delay
    - Receiver time solution uncertainty
    - Receiver fixed-position uncertainty
    - Post-Processing time solution uncertainty

  - Estimate as the range of 100 sample mean values

Uncertainty: INTDLY(PT04-PT00)			Uncertainty: INTDLY(PT04-PT01)		
Component	Type A	Type B	Component	Type A	Type B
PPSDLY(PT04-PT00)	0.16 ns	0.27 ns	PPSDLY(PT04-PT01)	0.15 ns	0.26 ns
G(PT04-PT00)	0.03ns	0.15 ns	G(PT04-PT01)	1.22 ns	4.37 ns
Total	0.16 ns	0.31 ns	Total	1.23 ns	4.38 ns

Final Result

Component	Value (ns)	Uncertainty Type A	Uncertainty Type B
PPSDLY(PT04-PT00)	0.53	0.16	0.27
PPSDLY(PT04-PT01)	1.00	0.15	0.27
INTLDLY(PT04-PT00)	0.50	0.03	0.15
INTLDLY(PT04-PT01)	-0.07	1.22	4.37
Final Measurement	-0.57	1.28	4.39