“Does Anybody Really Know What Time it is?”*

D. Dehmeshki, E. Frahm, R, Rusack, R. Saradhy, Y. Tousi
The University of Minnesota

*Chicago Transit Authority — 1969.

Precision Timing Needs a Better Clocks

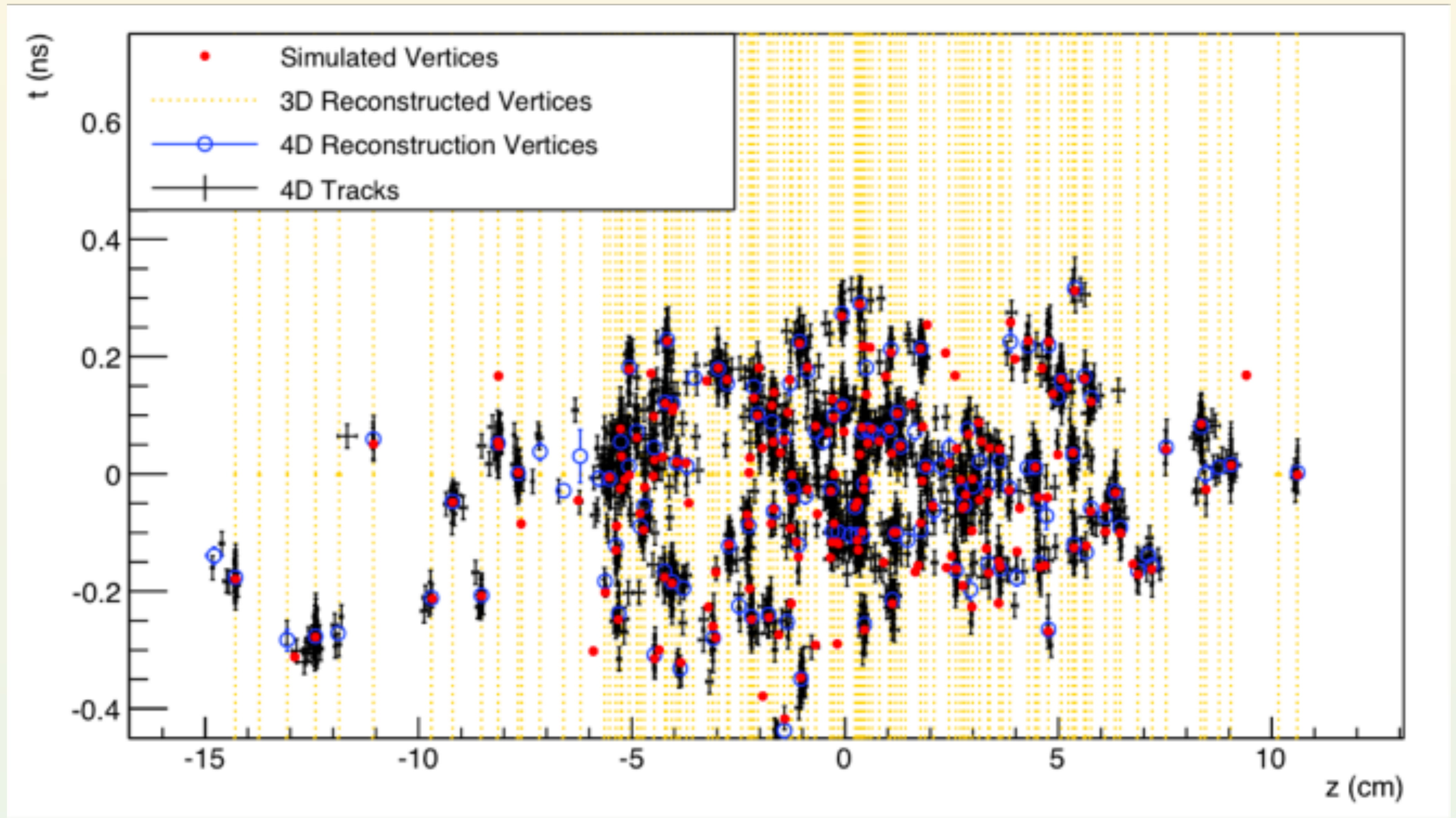
This may seem obvious but if you want to measure the time of an interaction in your detector you need to have a reference clock with a jitter that adds marginally to the precision measurement you are making with your detector.

And if you are using the time difference between two sensors then both clocks need to be synchronized to better than the precision of the two sensors.

You cannot measure a 1 ps time difference if your clock has 5 ps of jitter.

As we push the limits of time measurements to ~1 ps, we need to have reference clocks that are stable at < 1ps.

Why Do We Need to Know the Time?



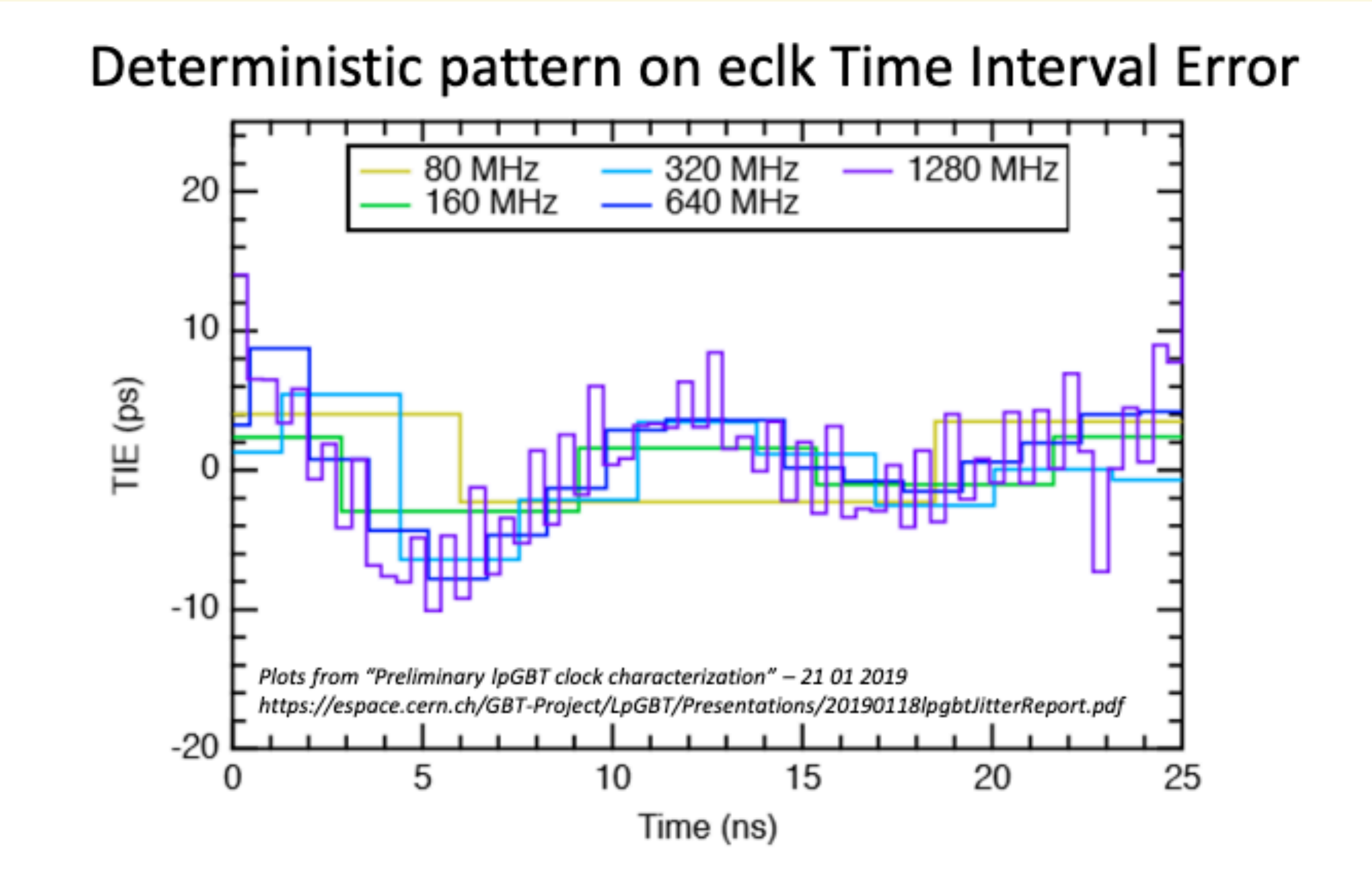
HL-LHC position v. time of 140 pile up bunch crossing.

Many new applications are pushing the boundaries of precision timing measurements to improve background suppression and precision measurements.

Further developments will need even finer precision.

State-of-the-Art Today

LpGBT used to distrubute a high precision clock derived by clock-recovery from the 2.56 Gbs downlink control signal.



From Talk by T. Kugathasan December 2020.

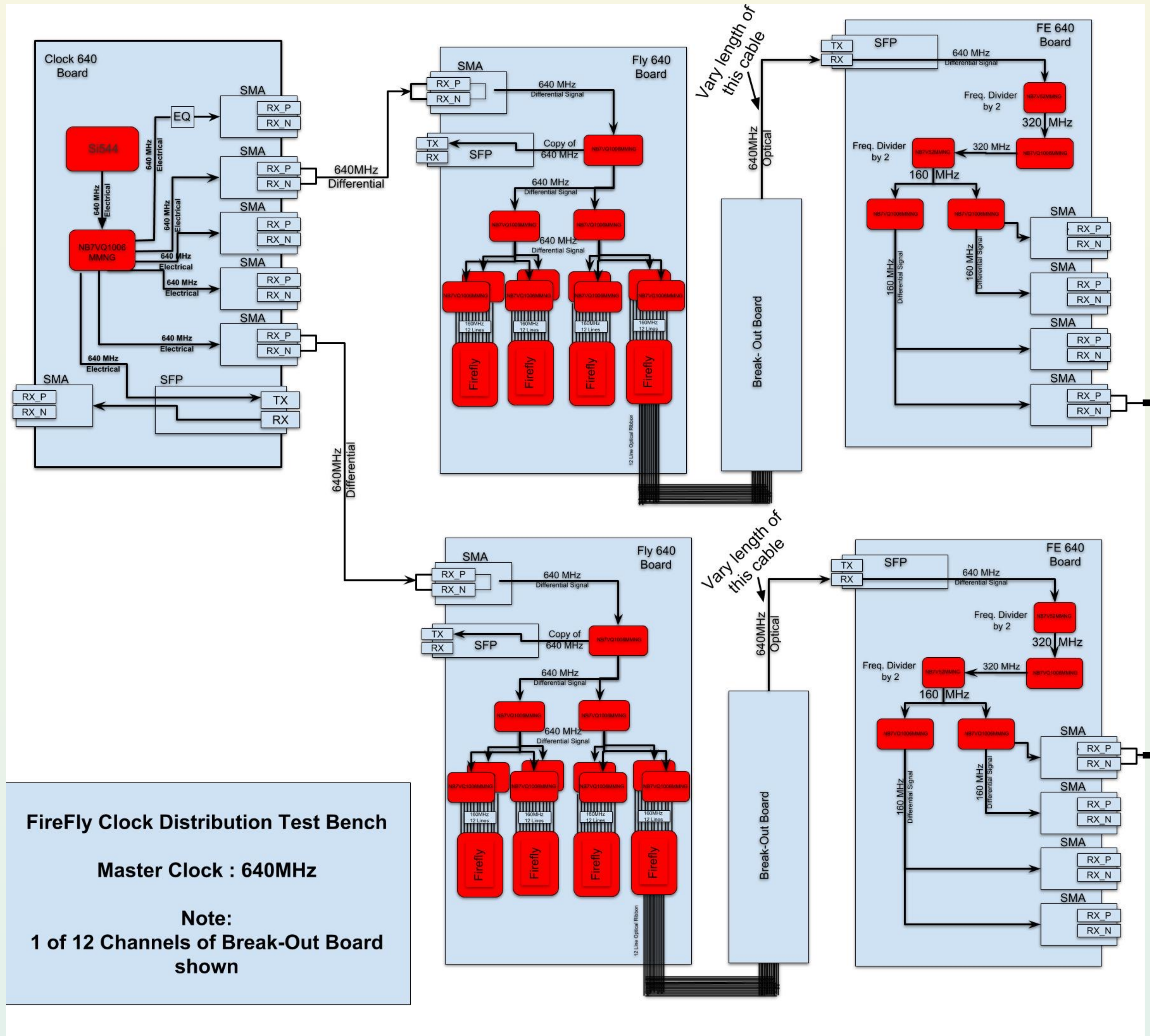
LpGBT-v0

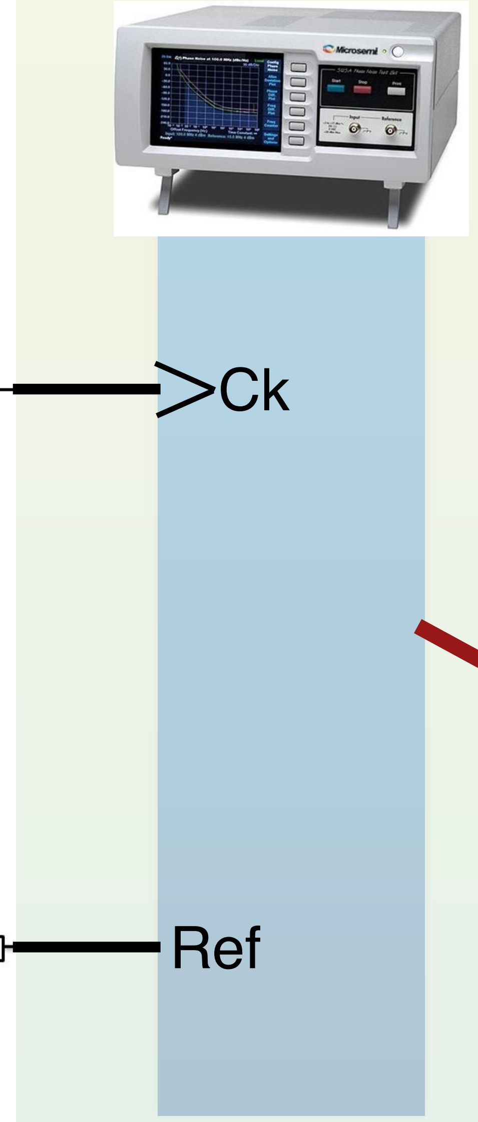
- Random jitter 2.2 ps
- Deterministic jitter peak-to-peak 25 ps.

Source identified and LpGBT-v1 expected to reduce deterministic jitter.

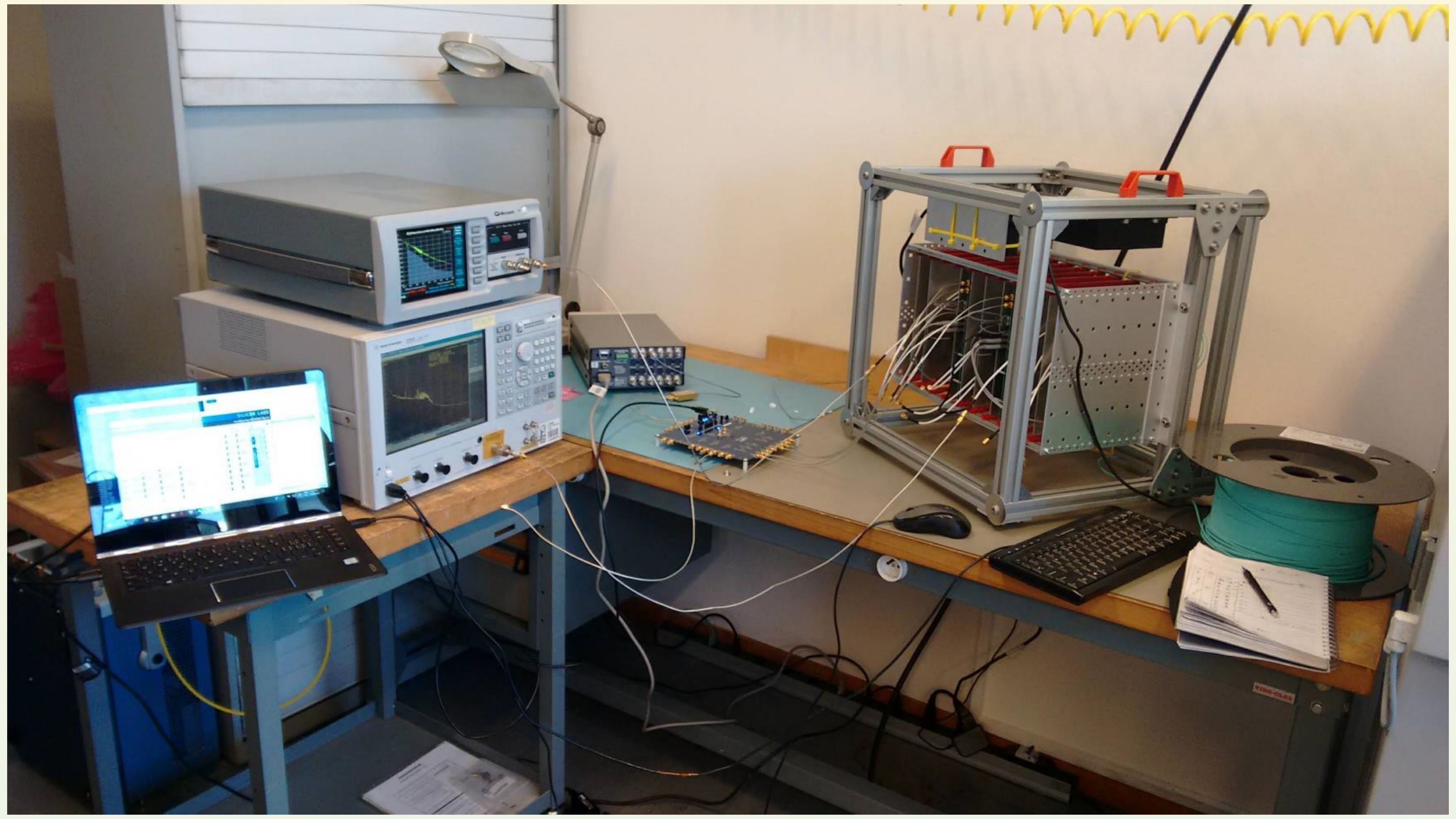
How to go to less than 1 picosecond?

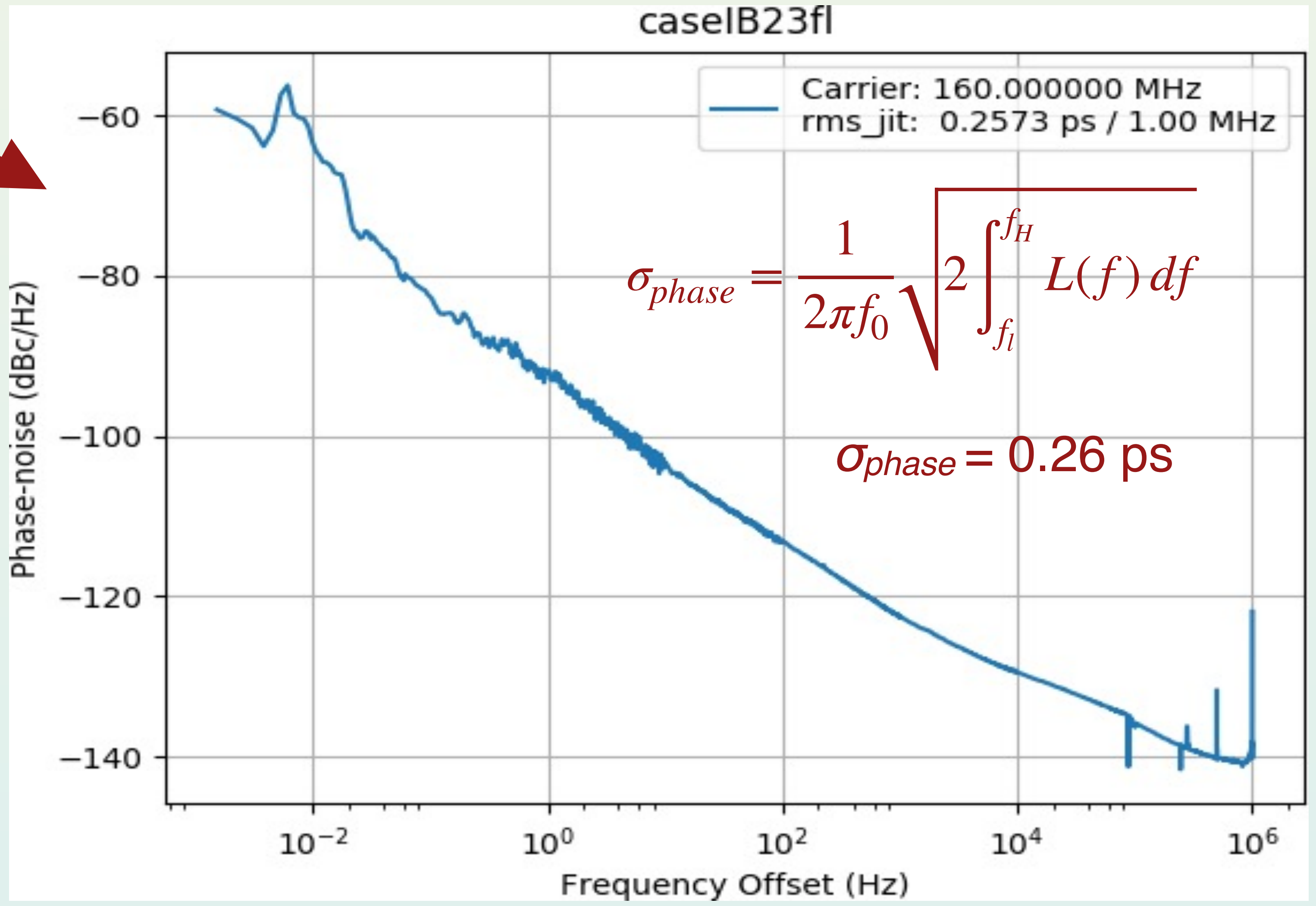
'Pure' Clock Distribution System





Microsemi
5275A





Phase Noise Plot 0.1 Hz - 1 MHz

RF Quality Fanout from ON Semiconductors.

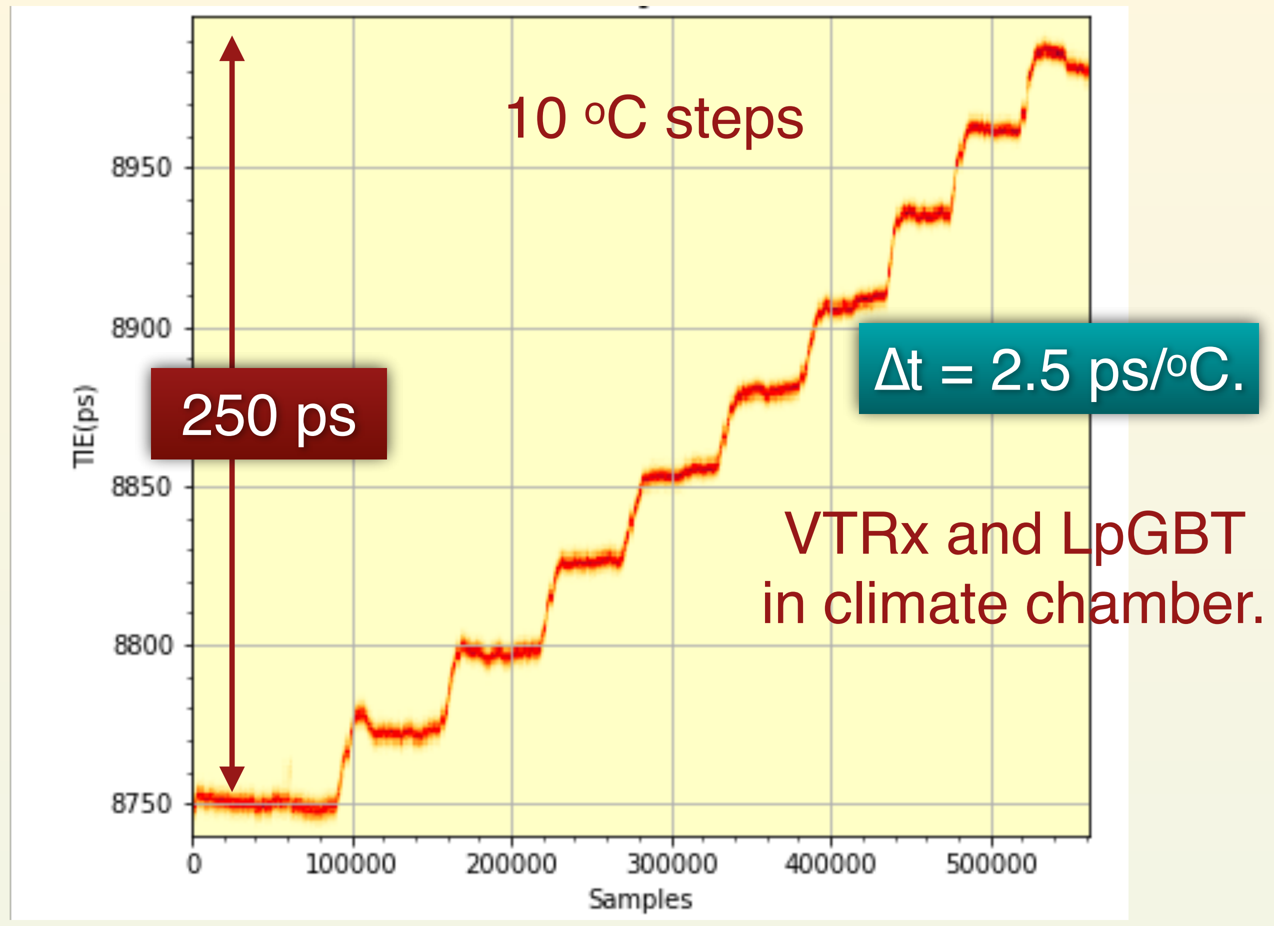
NB7VQ1005MMNG — max data rate 10 Gbps.

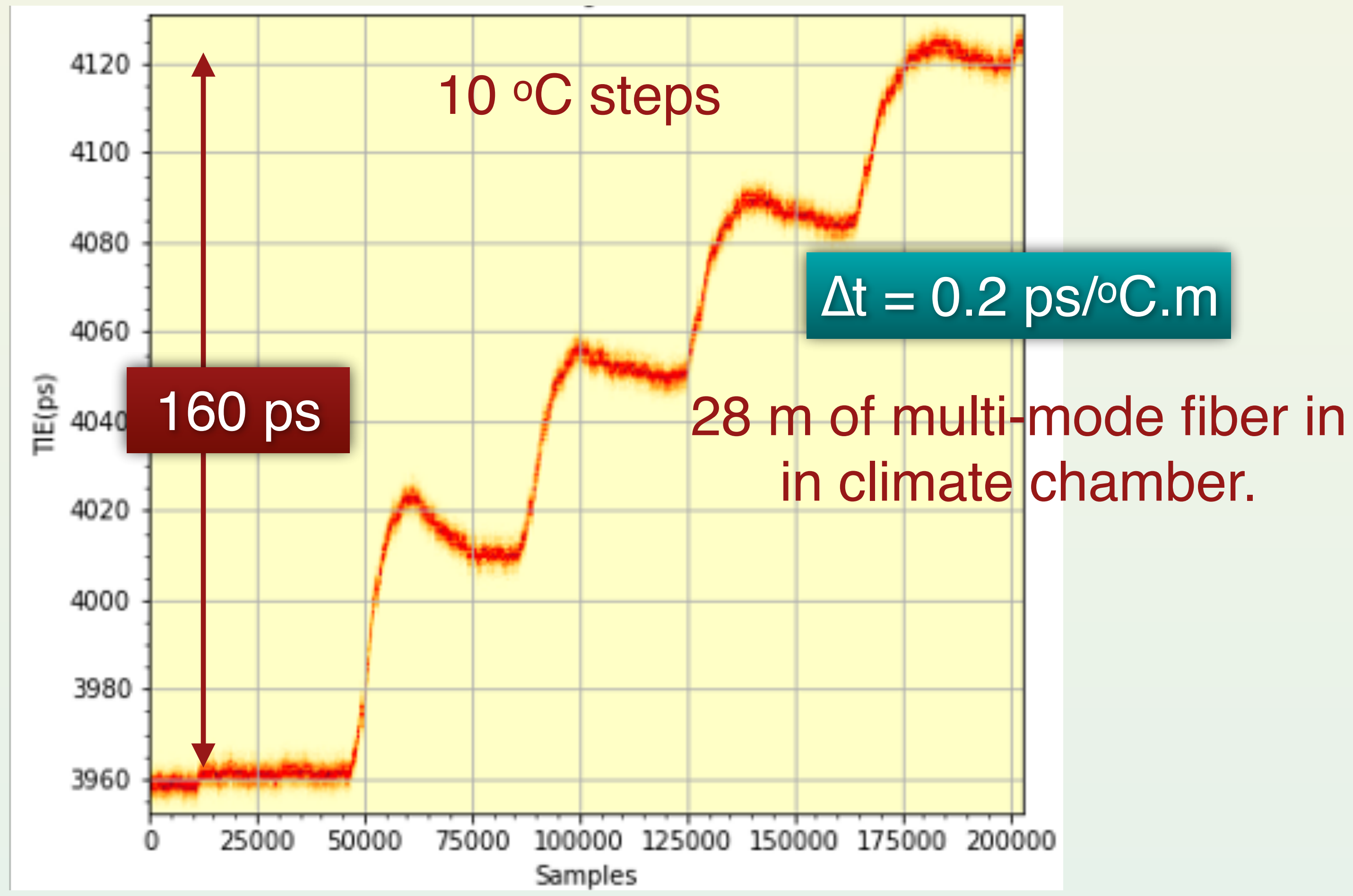
Reference Clocks Drift

Environmental effects can introduce wander* in the clock signal and the relative times between clocks can drift.

100 m long multi-mode fiber variation in propagation time is ~20 ps/°C.

So how do you monitor the time of any clock and correct for drifts?





Measurements made at the CERN HPTD Lab.

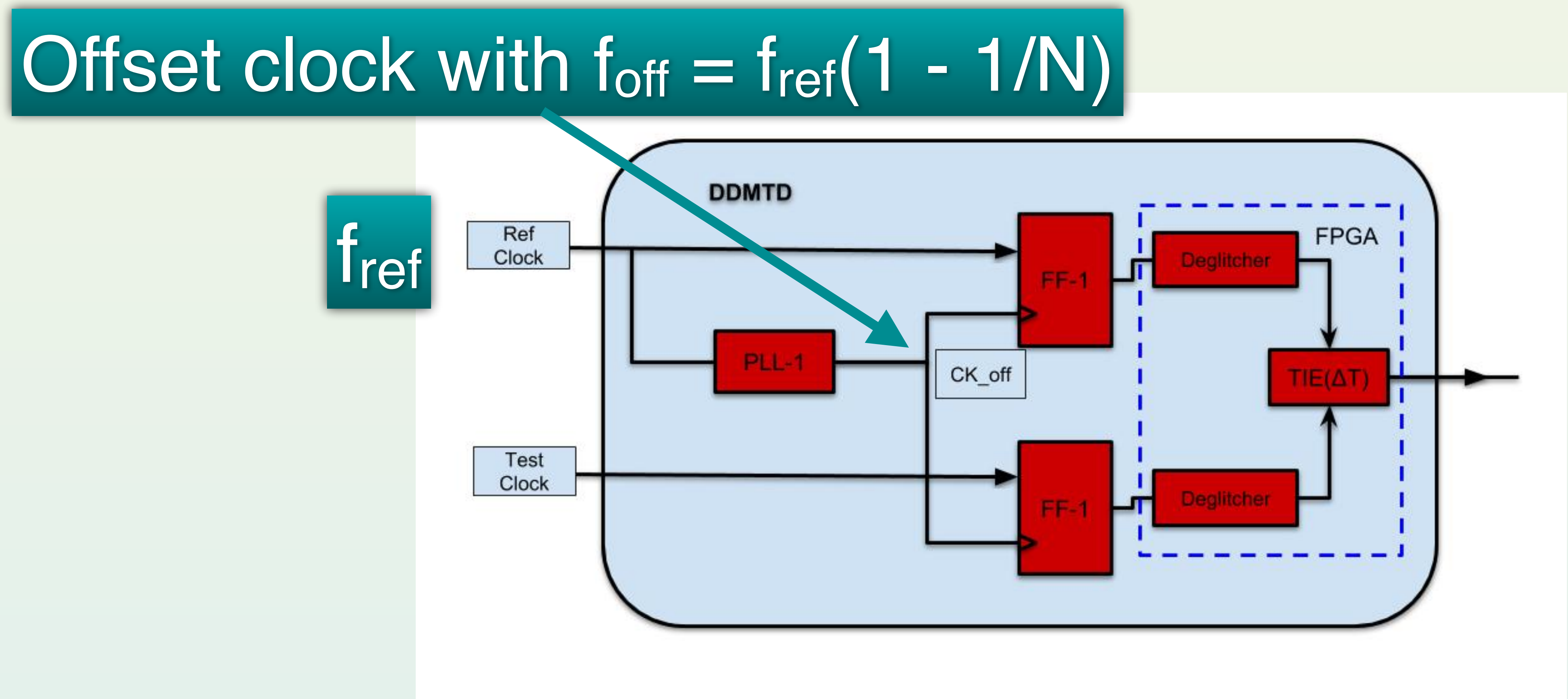
*Wander is usually defined as clock phase variations at the 1 Hz level - distinct from jitter.

How Do You Know What Time It Is?

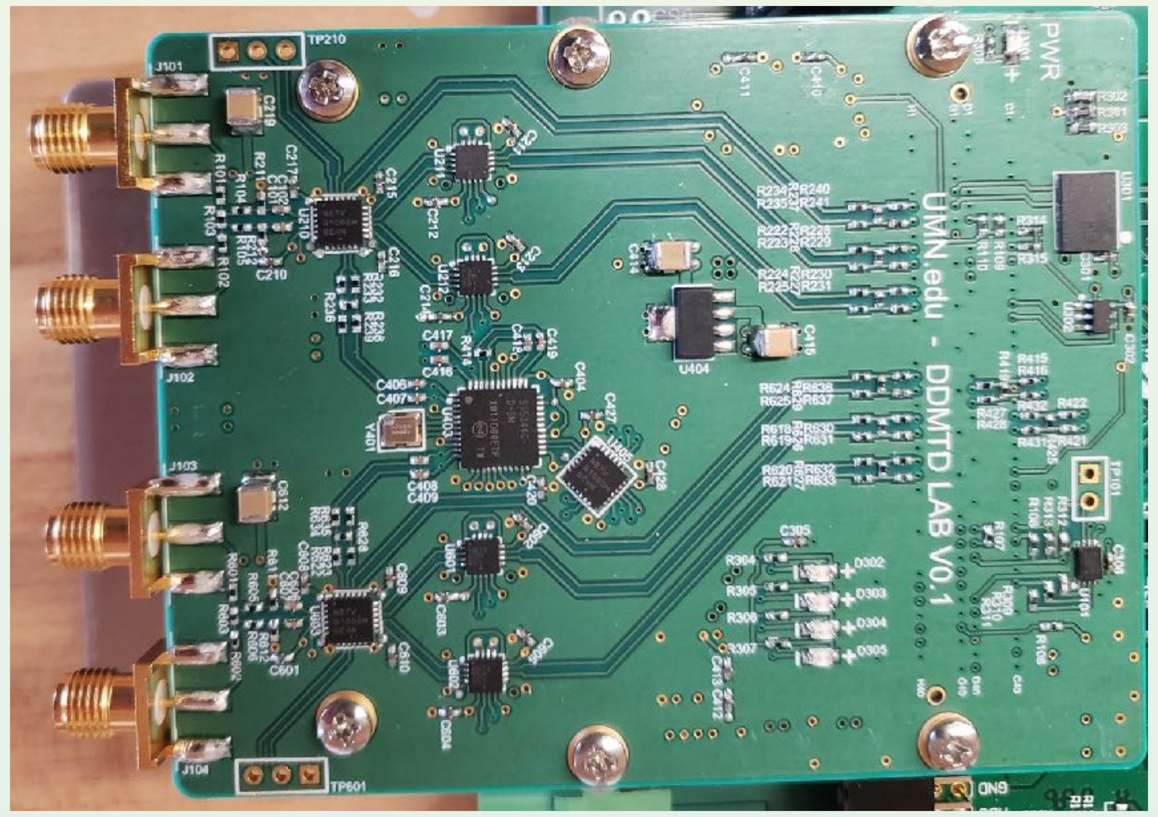
Measuring drifts

Basic method that goes back to FM is radio is to heterodyne the signal.

Digital Dual Mean Time Difference (DDMTD) circuit*



DDMTD Schematic

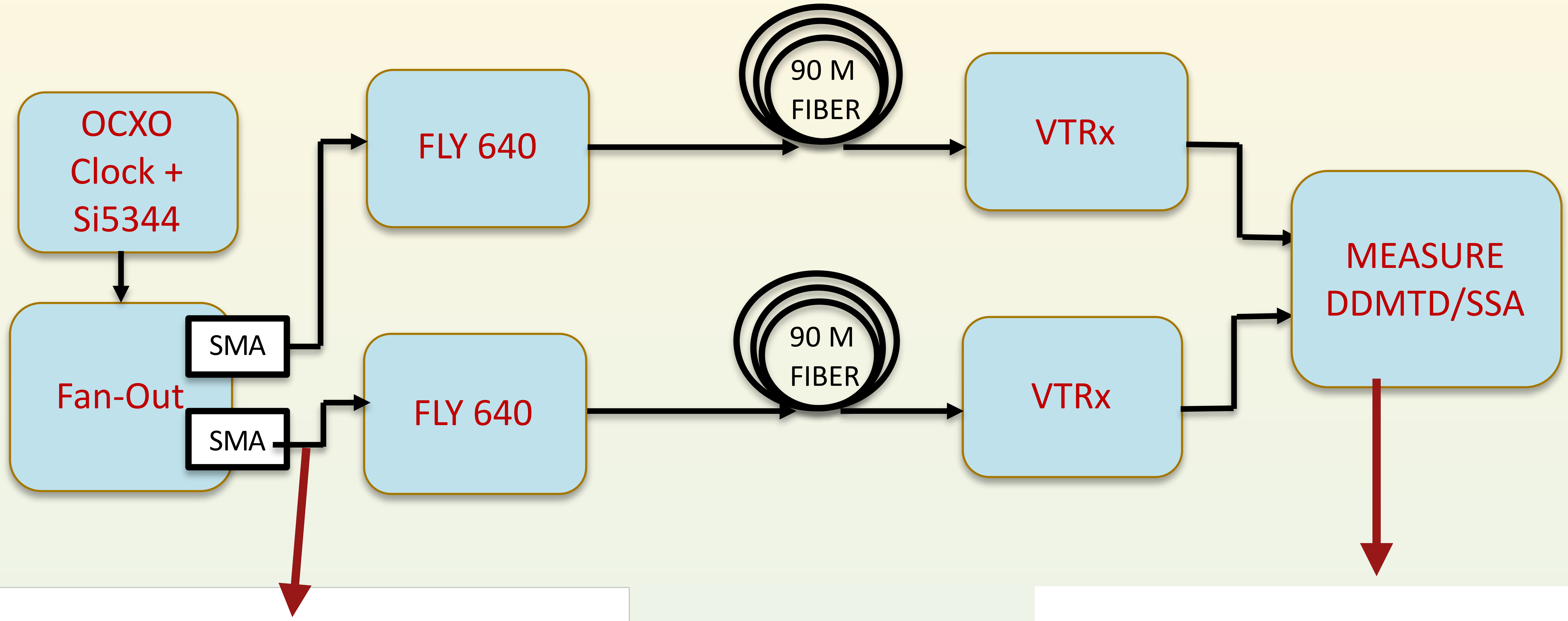


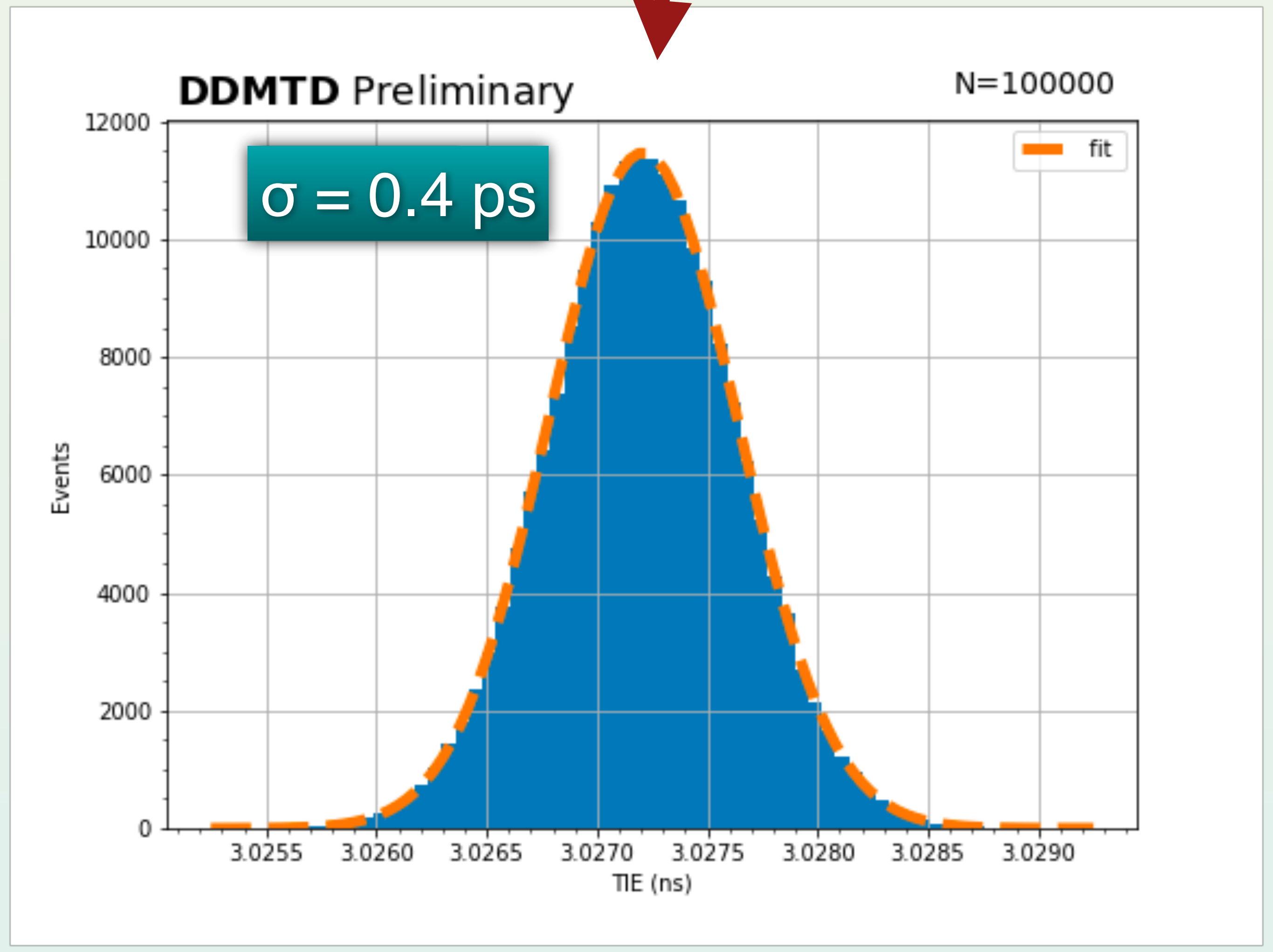
First version of DDMTD

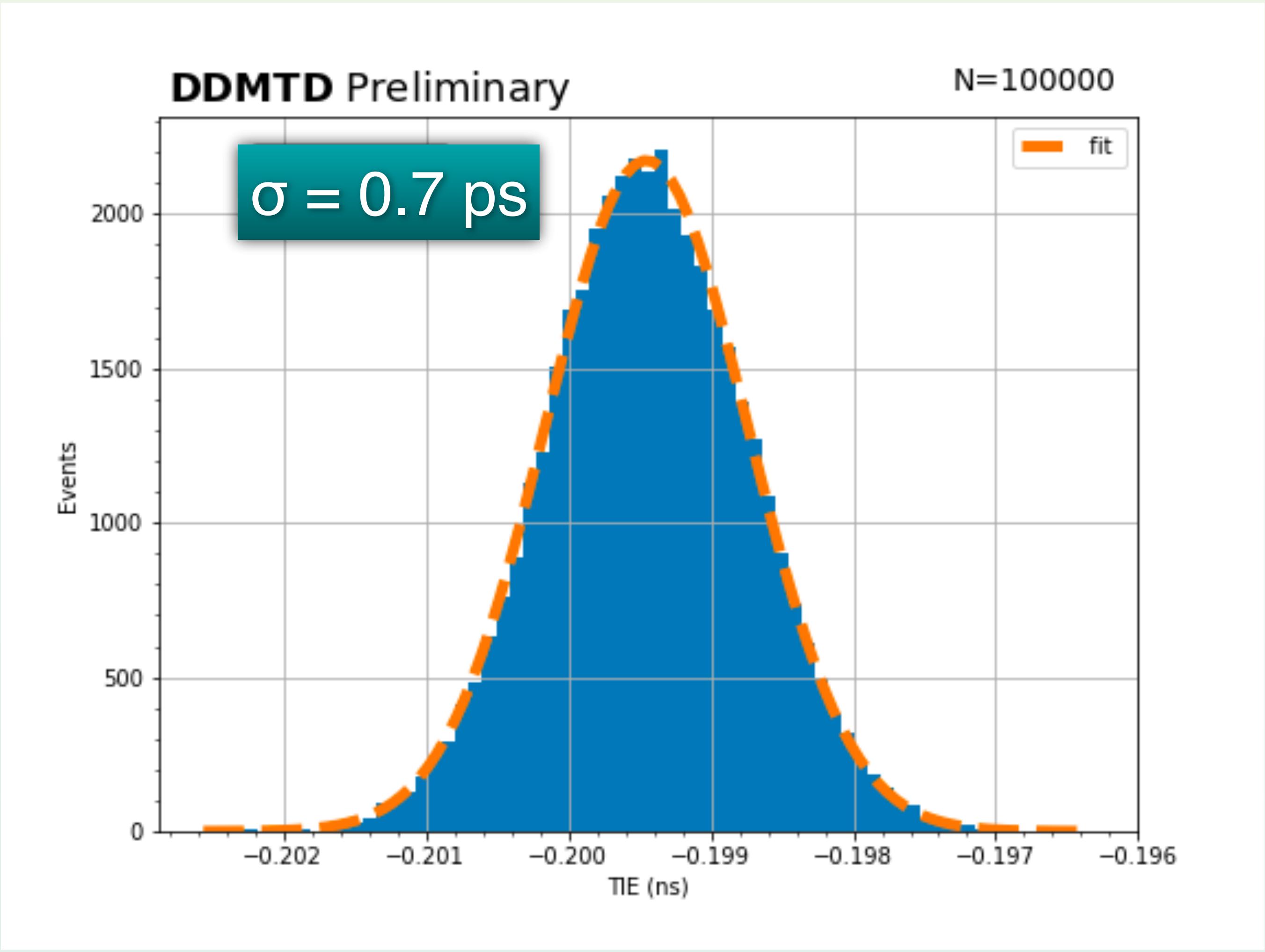
Use DDMTD to measure time drifts averaged over many cycles.

*First proposed by Pedro Moriera in 2010

Measuring it

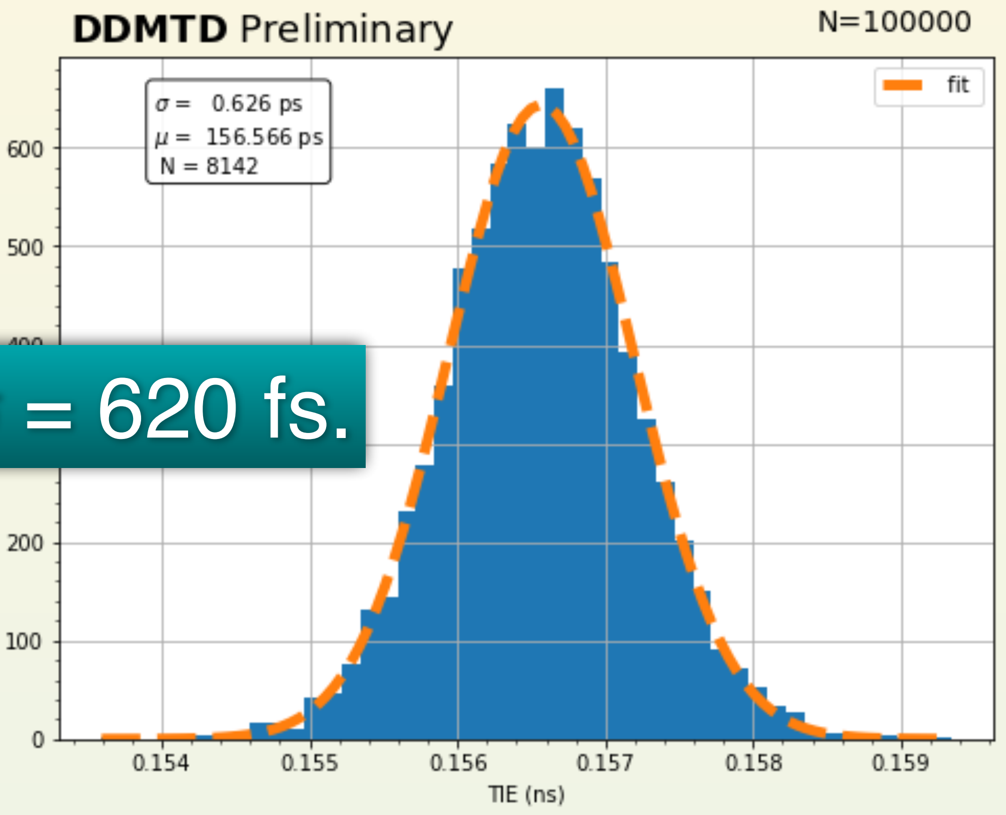




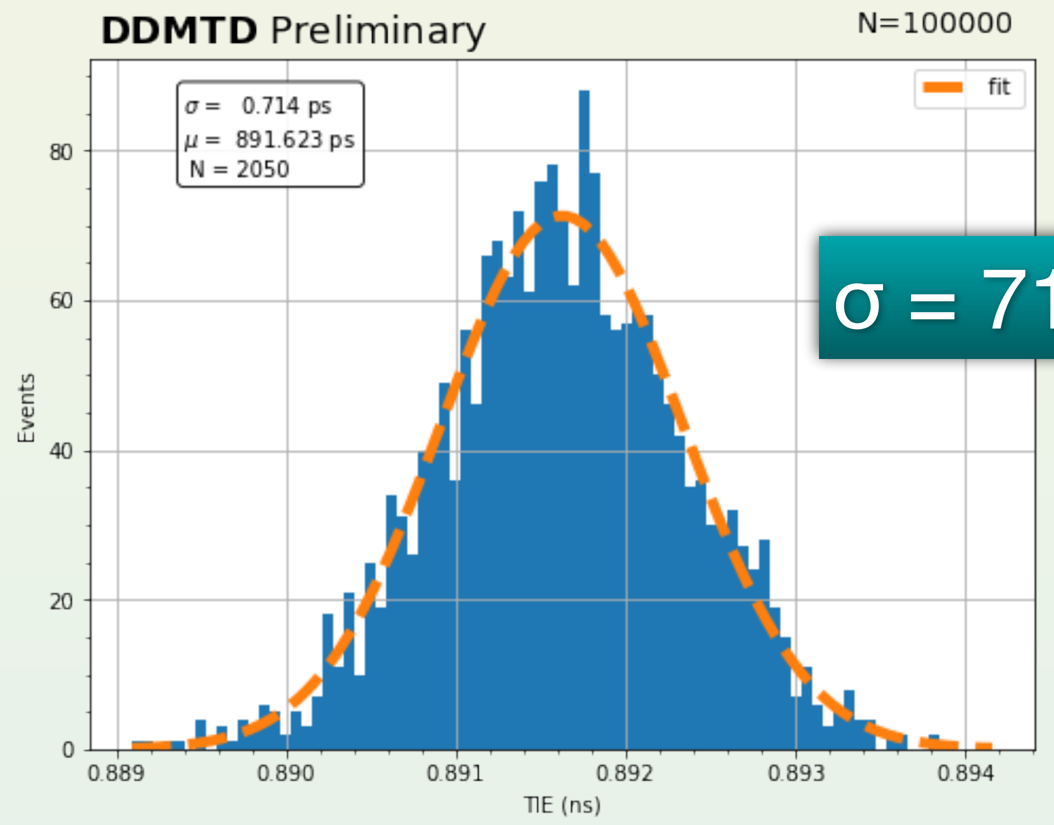


Multi-Channel Version

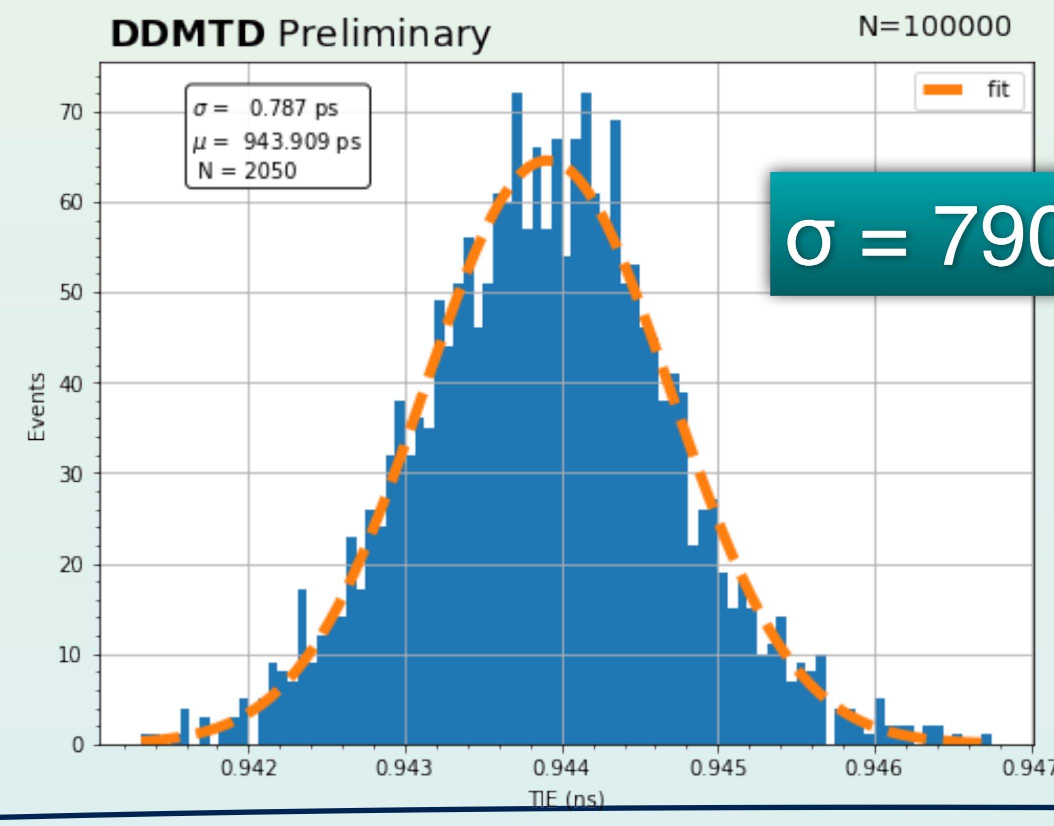
Measurements of clock-to-clock variations after 30m optical fibers.



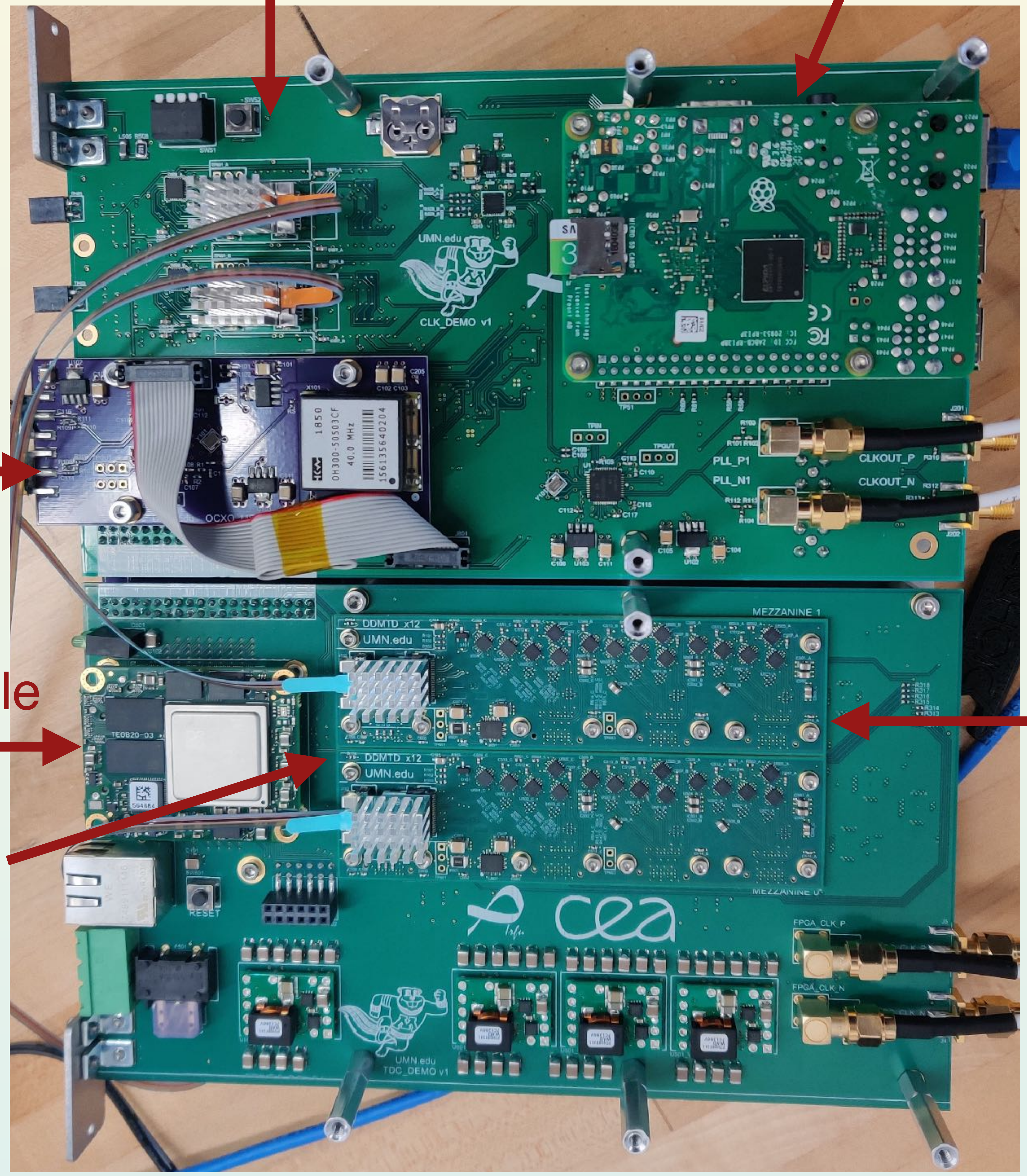
σ = 620 fs.



σ = 710 fs.



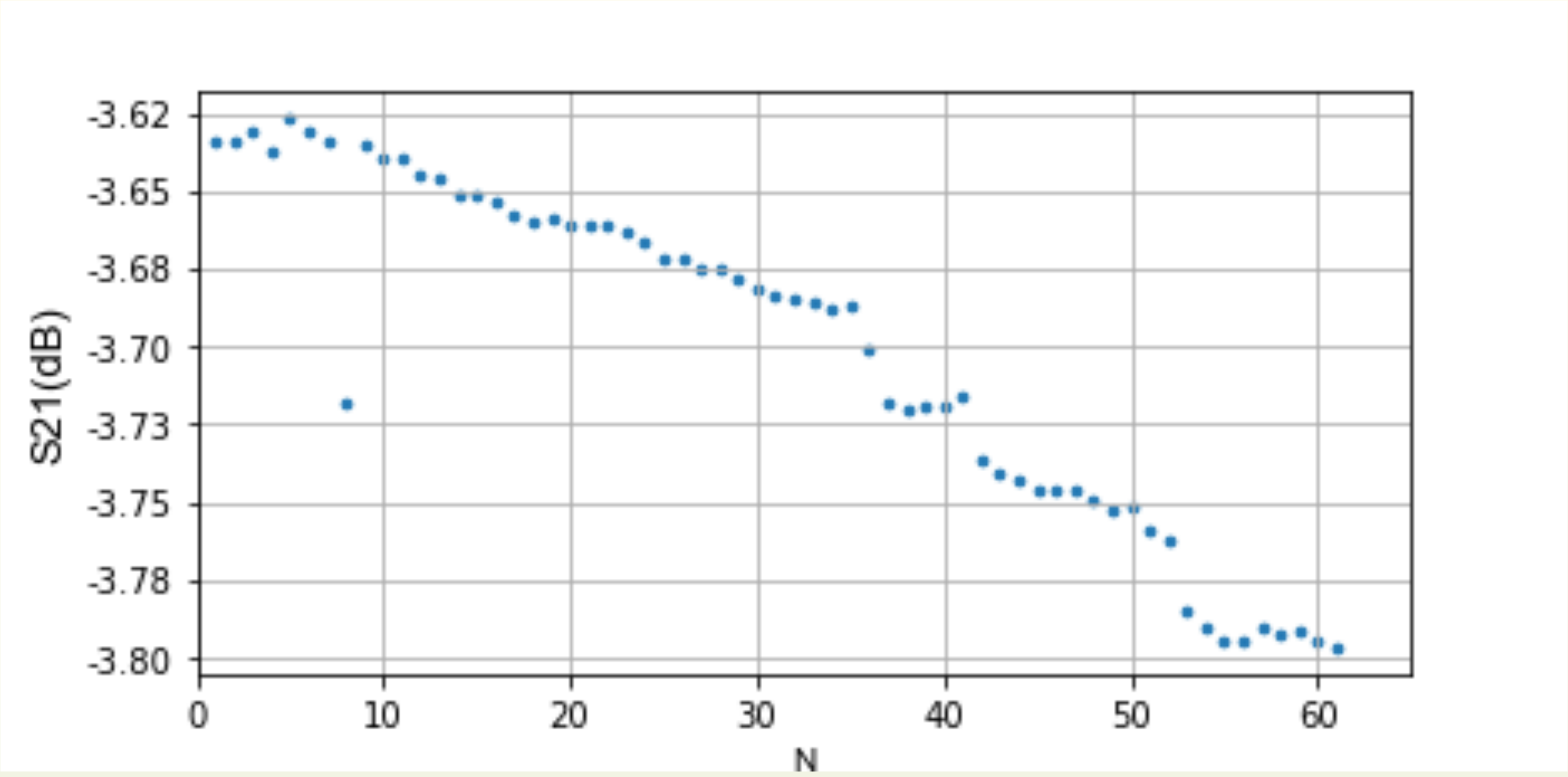
σ = 790 fs.

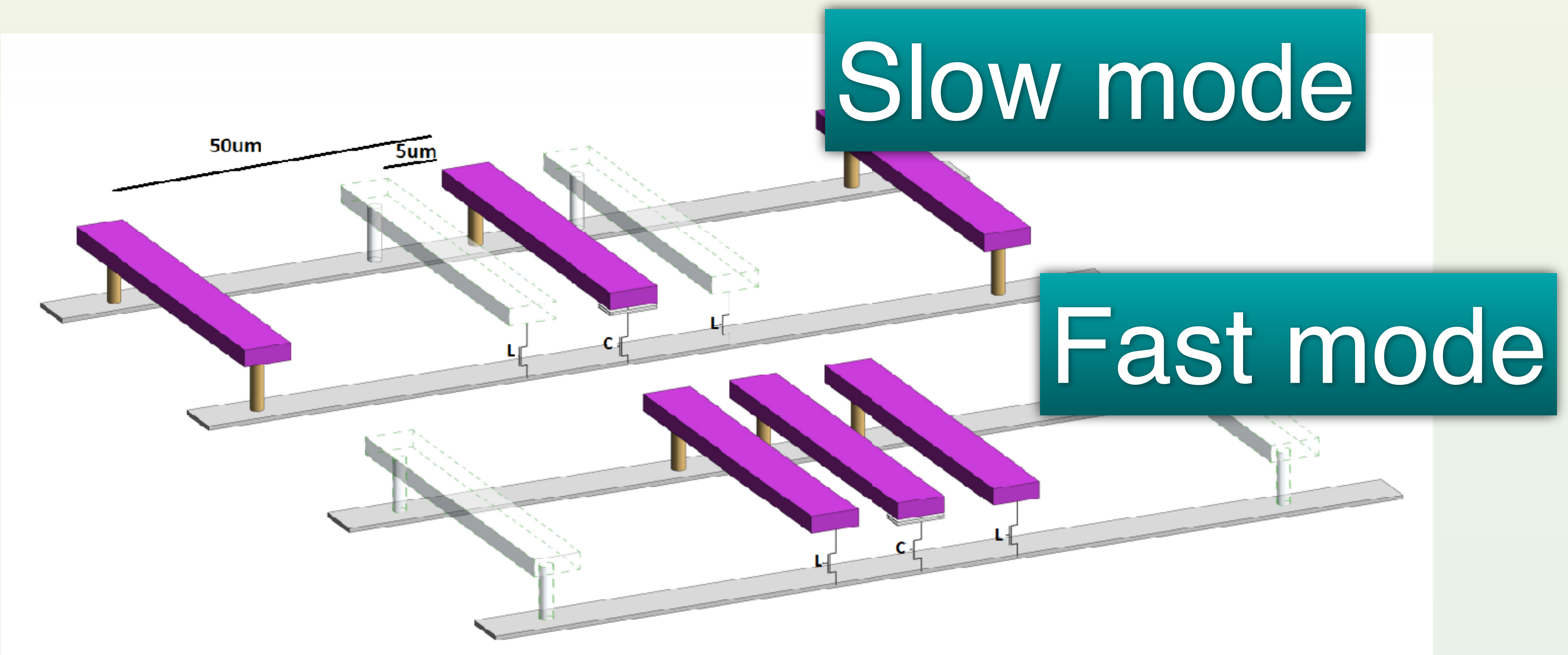


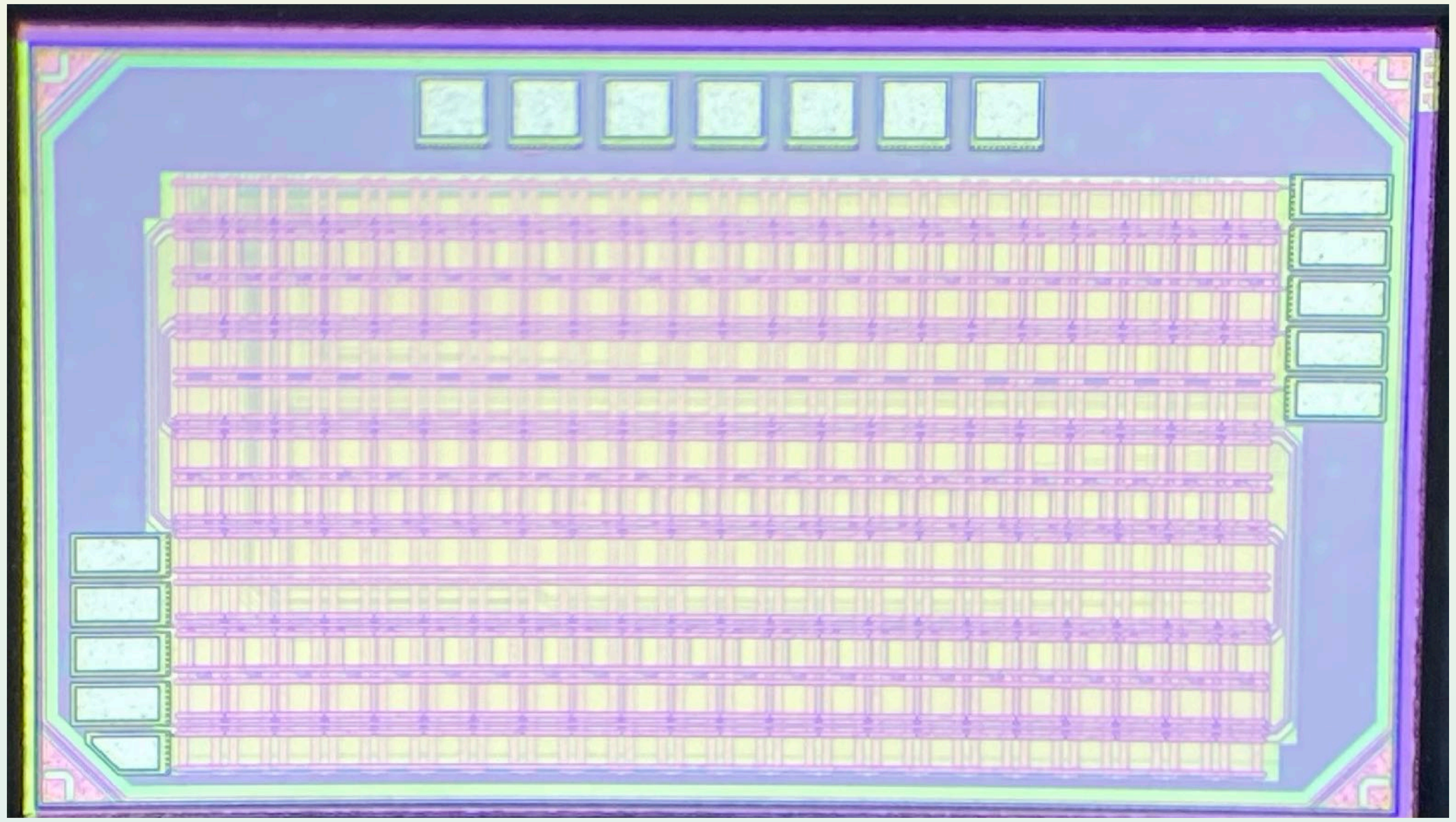
How Do We Correct For Drifts?

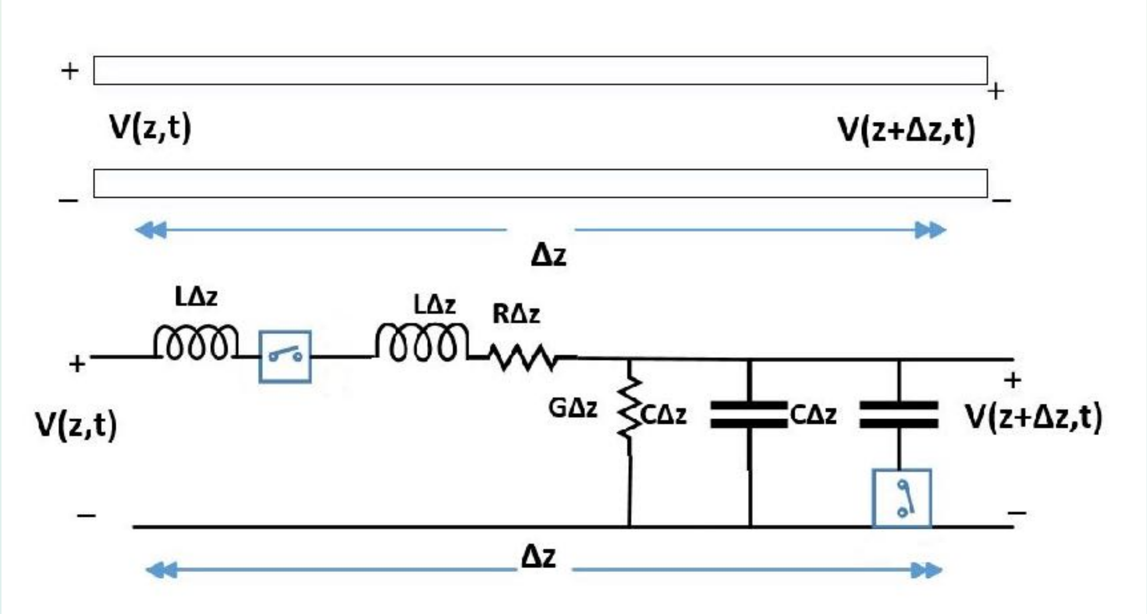
To solve the problem of how to align clocks that drift we have made a multi-cell planar wave guide in TSMC 65 nm process.

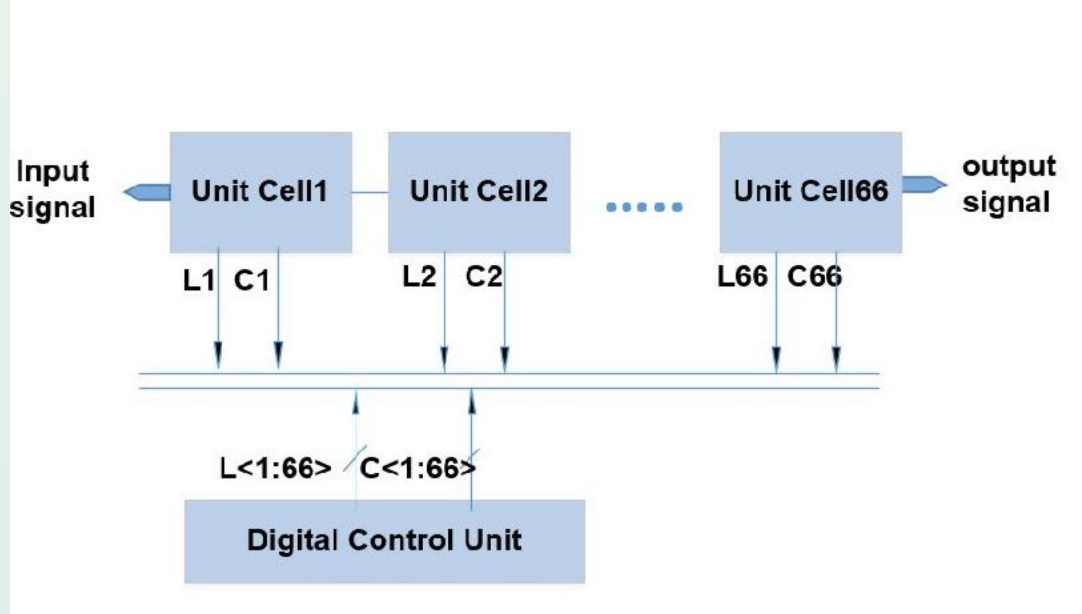
Digitally Controlled Phase Shifter — DCPS







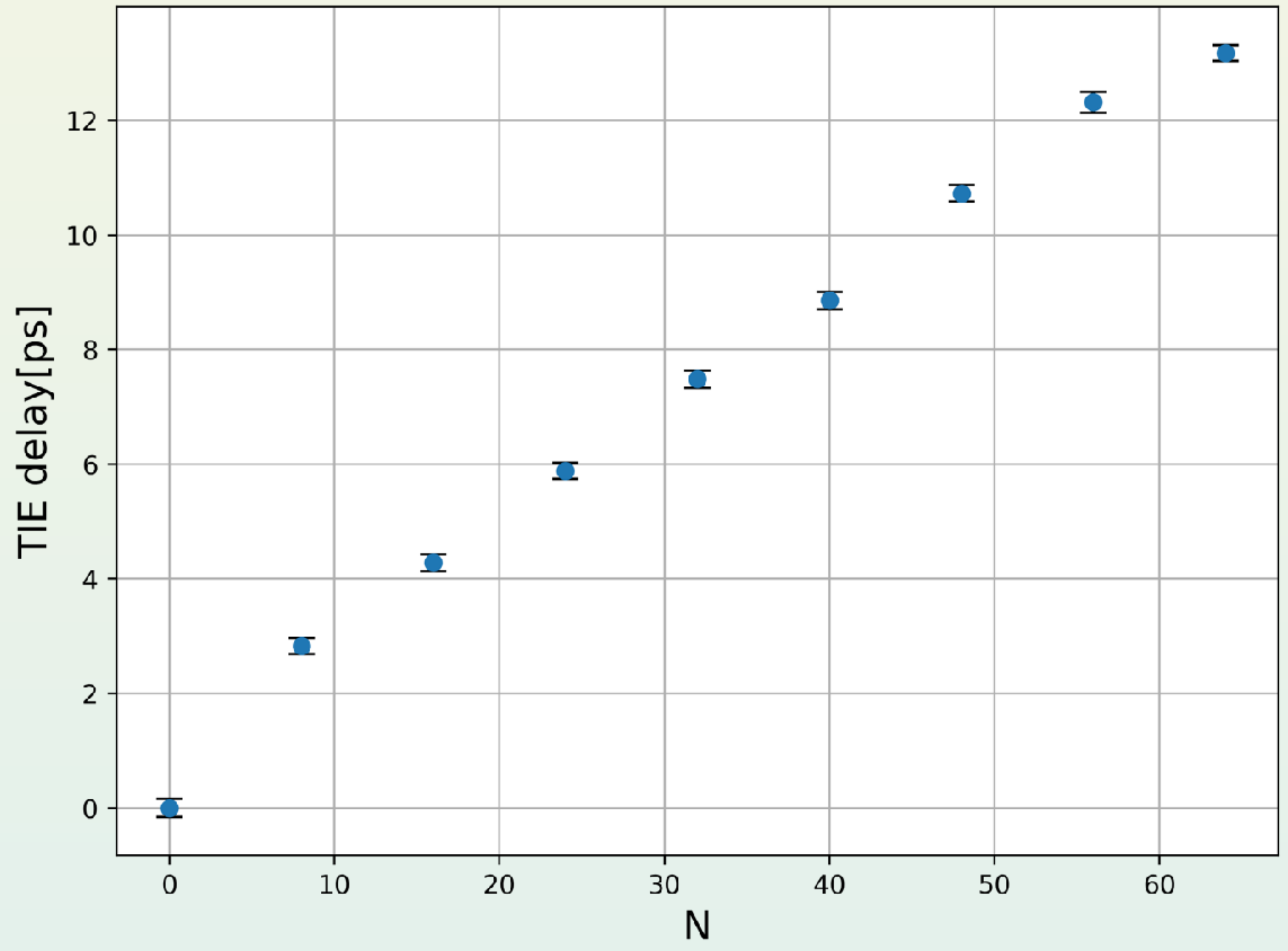




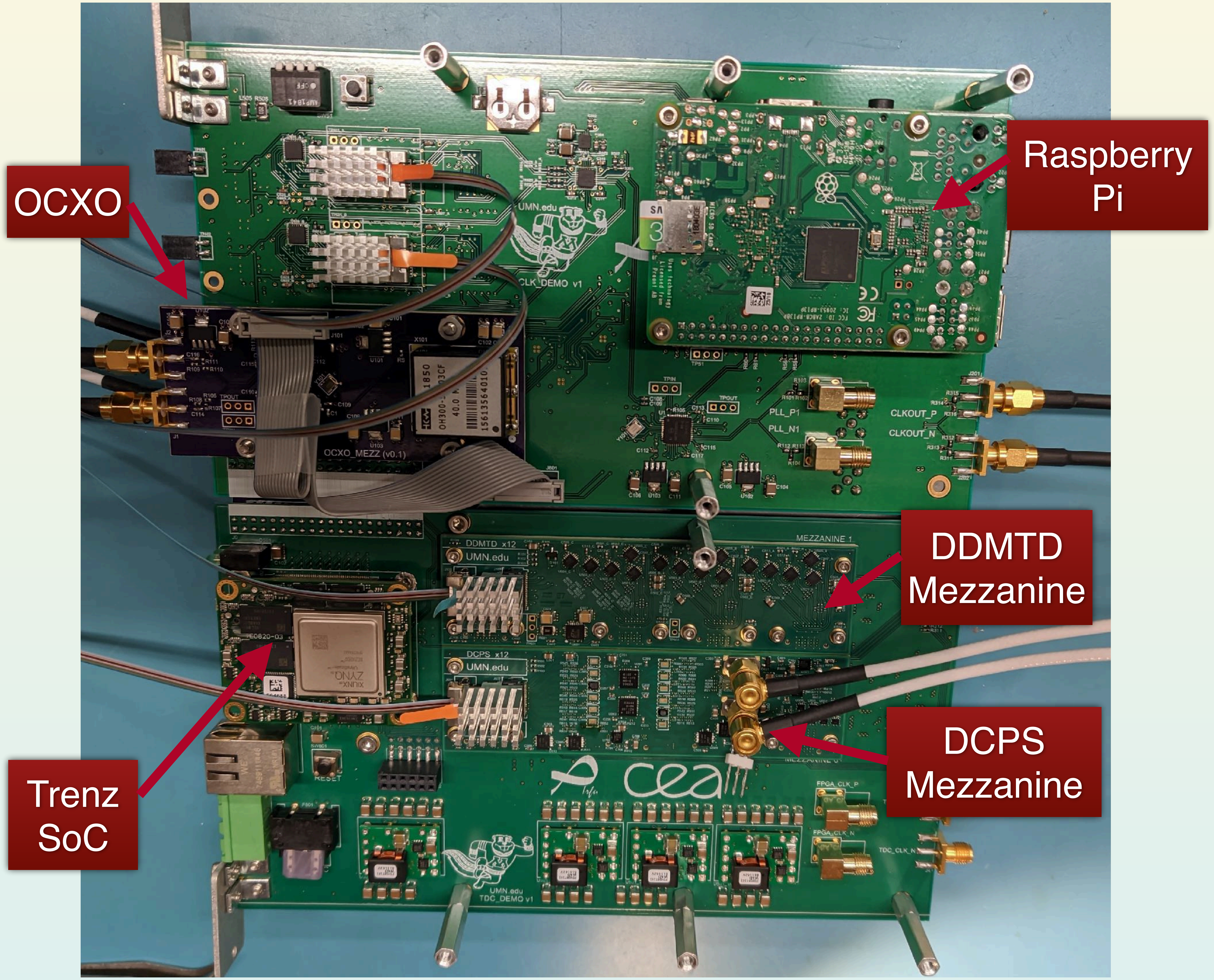
Measured delay step is 200 fs

Multi-channel DCPS Test bench

- Generate 160 MHz clock with OCXO
- Measure phase drifts with DDMTD
- Correct for phase drifts with DCPS.



Use the DCPS to control the clock phase in steps of 200 fs measured with DDMTD.



Summary

- To exceed current state of the art achievable with clock-recovery we have used a pure clock distribution system and demonstrated sub-picosecond jitter levels.
- We have demonstrated a low-cost circuit capable of tracking clock drifts at the sub-picosecond level.
- We have produced a digitally controlled planar waveguide ASIC in TSMC 65nm that can delay a digital clock signal in steps of 200 fs.
- With these tools we have shown that we can deliver a stable clock with low wander and low jitter.

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