Improving VLBI Station Performance

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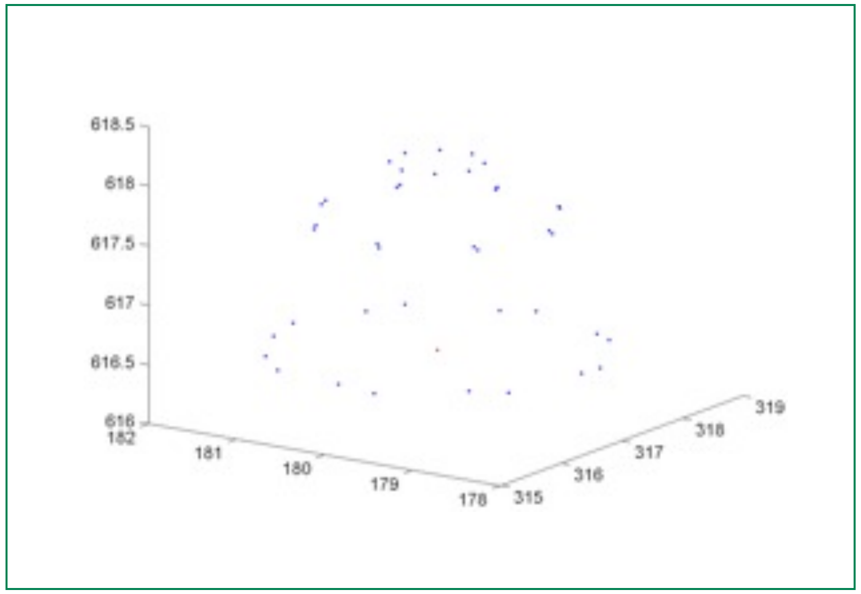
Higher Bandwidth and a vastly increased number of observed radio sources are basic elements of the roadmap into the future of VLBI. The new TWIN telescope system in Wettzell is in agreement with these basic goals. Systematic intra-technique biases are of equally high importance. Modern instrumentation of quantum optics and recent progress in high resolution event timing provide new tools for studying system behavior and the improvement of system stability. Compensated optical fibers may qualify as suitable tools for one-way system delay reduction. This talk will introduce current activities for system stabilization, inter- and intra- technique bias reductions in Wettzell.

WLRS Wettzell

campaign 09-23-2009:

Method	East	North	Up
geodetic 3D adjustment (PANDA)	316.92439	180.04240	616.51425
sphere adjustment (MatLab LSGE-bib.)	316.92438	180.04237	616.51454
circle adjustment	316.92438	180.04250	616.51454
max. difference	**0.01 mm**	**0.13 mm**	**0.29 mm**



Laser System Reference Point

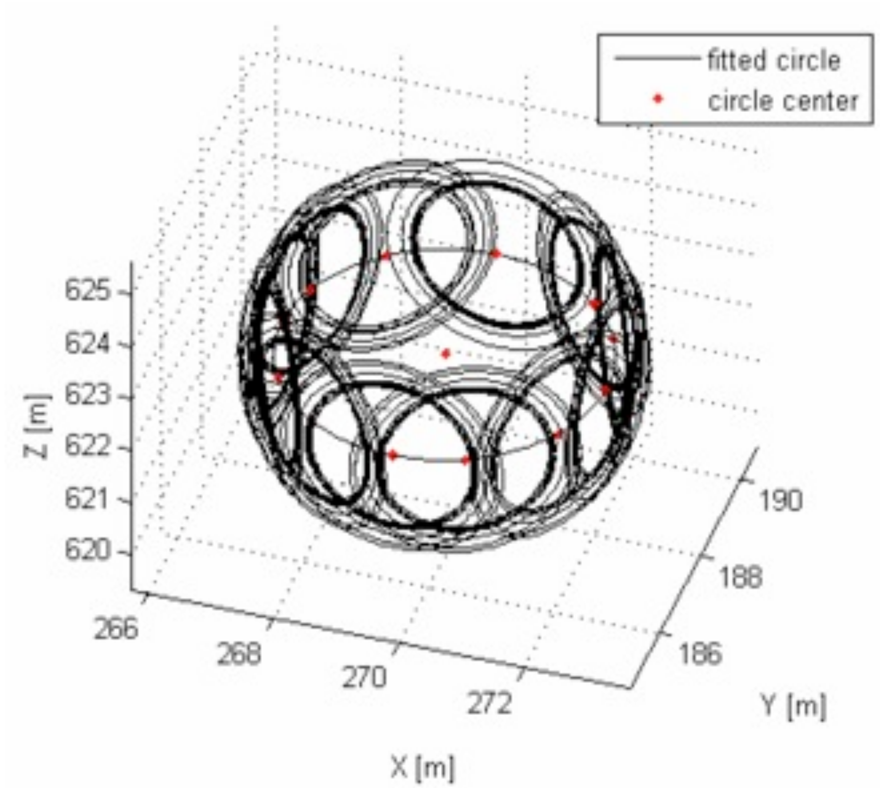
campaign 09-01-2009:

Method	East	North	Up
geodetic 3D adjustment	316.9253	180.0426	616.5134
Difference to above	**0.9 mm**	**0.1 mm**	**0.85 mm**

Mähler (2009), Klügel (2010)

RTW Wettzell

Method	East	North	Up
2D adjustment + height (NetzCG)	269.71713	187.69011	622.46484
3D adjustment (JAG3D)	269.71715	187.69011	622.46482
circle adjustment	269.71720	187.69008	622.46502
max. difference	**0.07 mm**	**0.03 mm**	**0.2 mm**



Laser tracker data:

Method	East	North	Up
3D adjustment (JAG3D)	269.71739	187.69056	622.46506
Difference to tachymeter data	**0.24 mm**	**0.45 mm**	**0.24 mm**

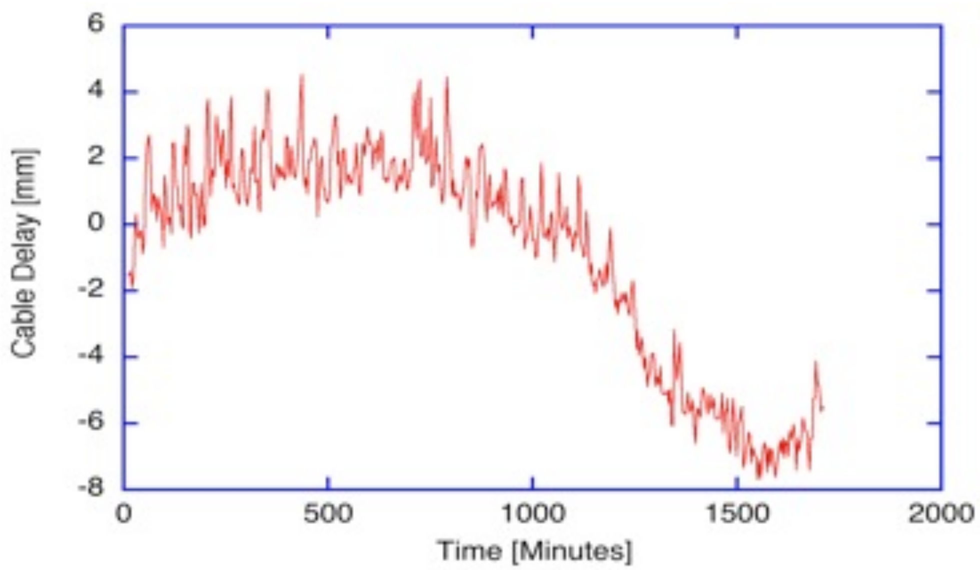
Lösler (2008), Klügel (2010)

Survey Errors are obtained consistently small

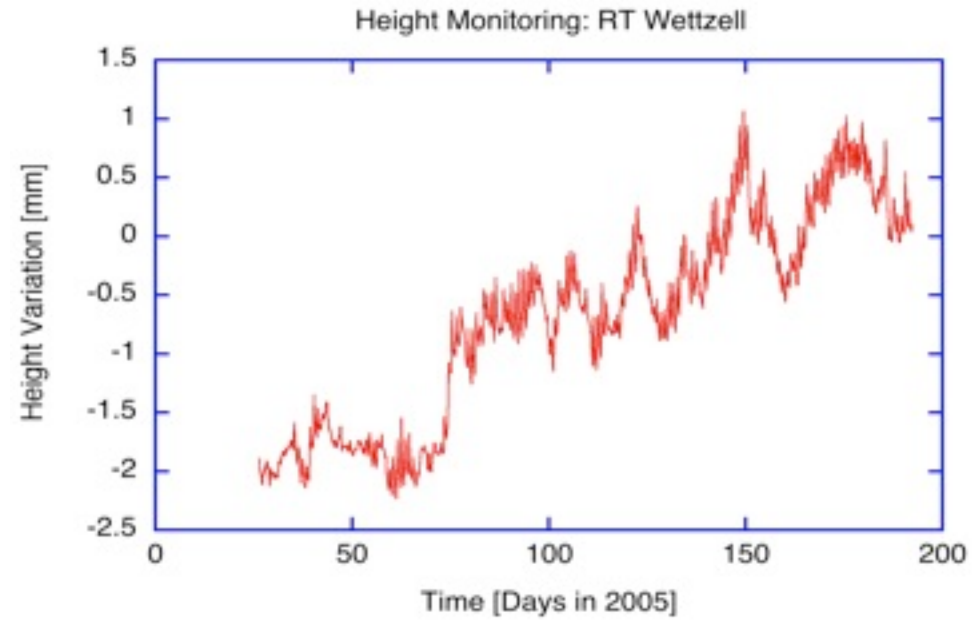
Conclusion from a series of surveys

- The space technique reference points show no significant displacements w.r.t. the local network
- Good repeatability, also when using different instruments -> small systematic errors
- The accuracy of the local ties in Wettzell are in the **order of 1-2 mm**
- **We certainly need a yet closer look at intra technique biases**

Laser	satellite signature, signal strength, asymmetry between satellite ranges and calibration
VLBI	system delay, phase-cal



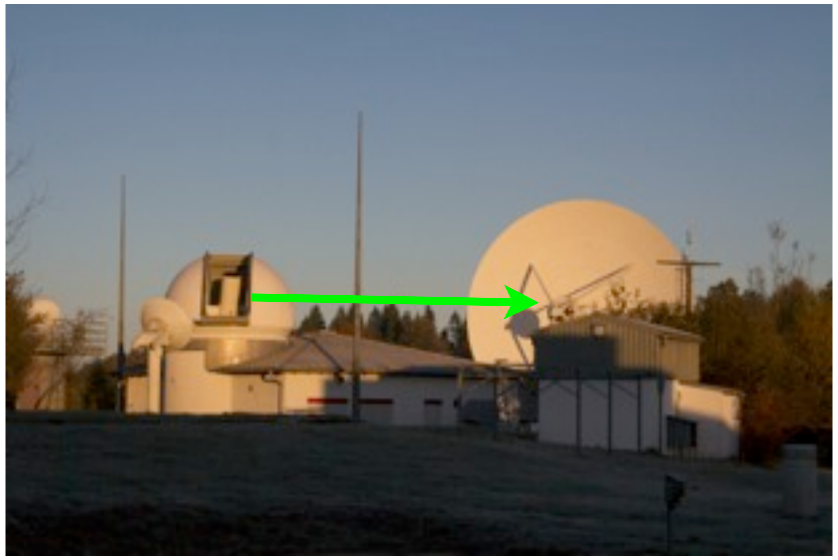
Instrumental biases (short term): cable delays in VLBI



Instrumental biases (seasonal): height changes of VLBI telescope

Present Status:

- Inaccurate, incomplete or missing local ties at many fundamental sites
- No use of co-location of instruments onboard satellites for ITRF
- Considerable technique-specific biases of the individual techniques



Prospect:

- Wettzell: 3 VLBI, 2 SLR telescopes and 5 GNSS antennas; common timing for all instruments
- Dedicated satellite missions for co-location of GNSS, SLR, VLBI (and DORIS) presently considered

Measurement device - Oscilloscope Tektronix - DPO 7254 - 2.5GHz / 40Gs/s

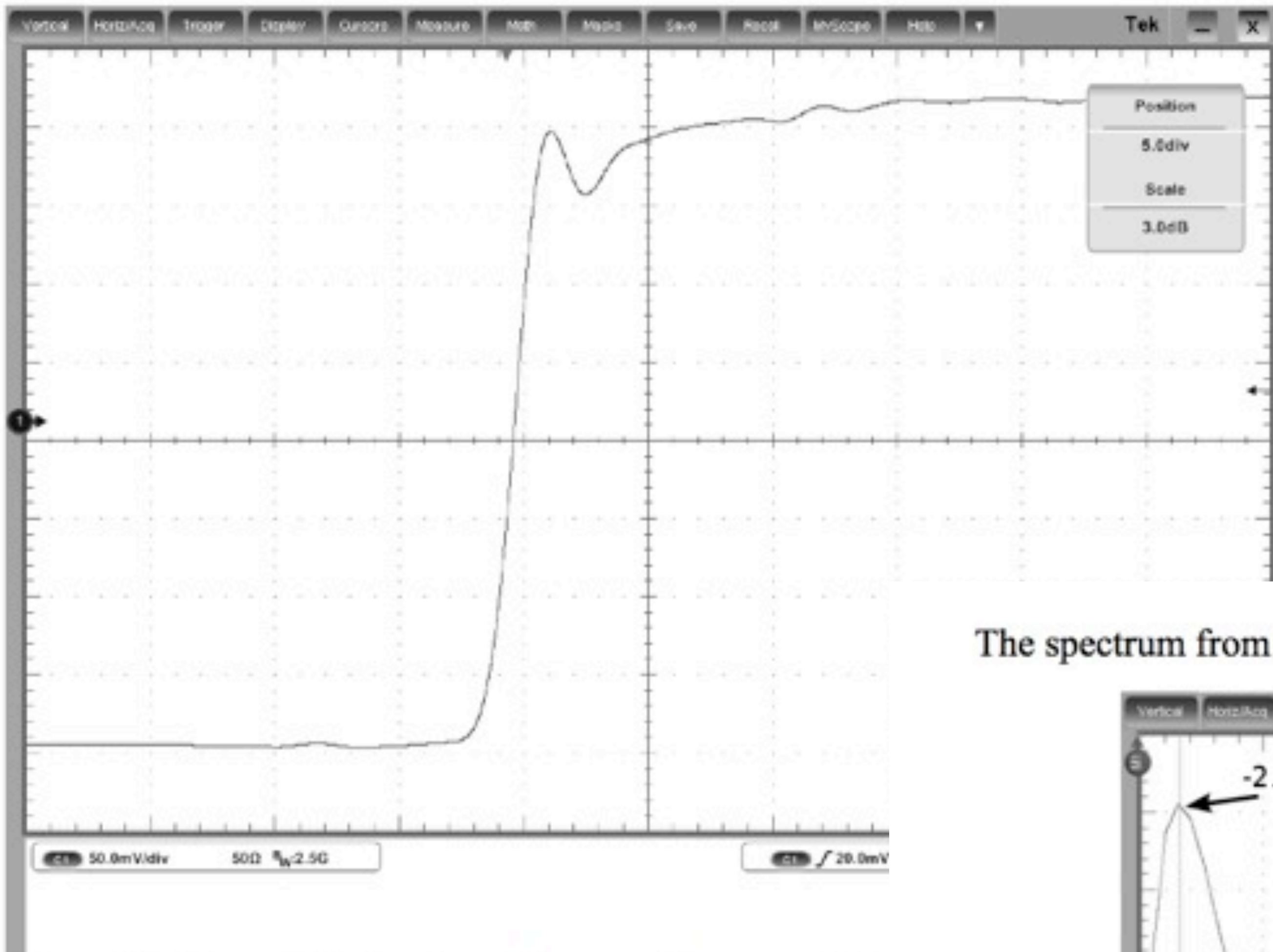


Figure 1: Edge with rice-time below oscilloscope BW, time = 35 ps.

Concept: Fire Laser at VLBI feedhorn, convert optical pulse to RF by high bandwidth detector and calibrate the entire geometry by timing the process

The spectrum from Figure 1:

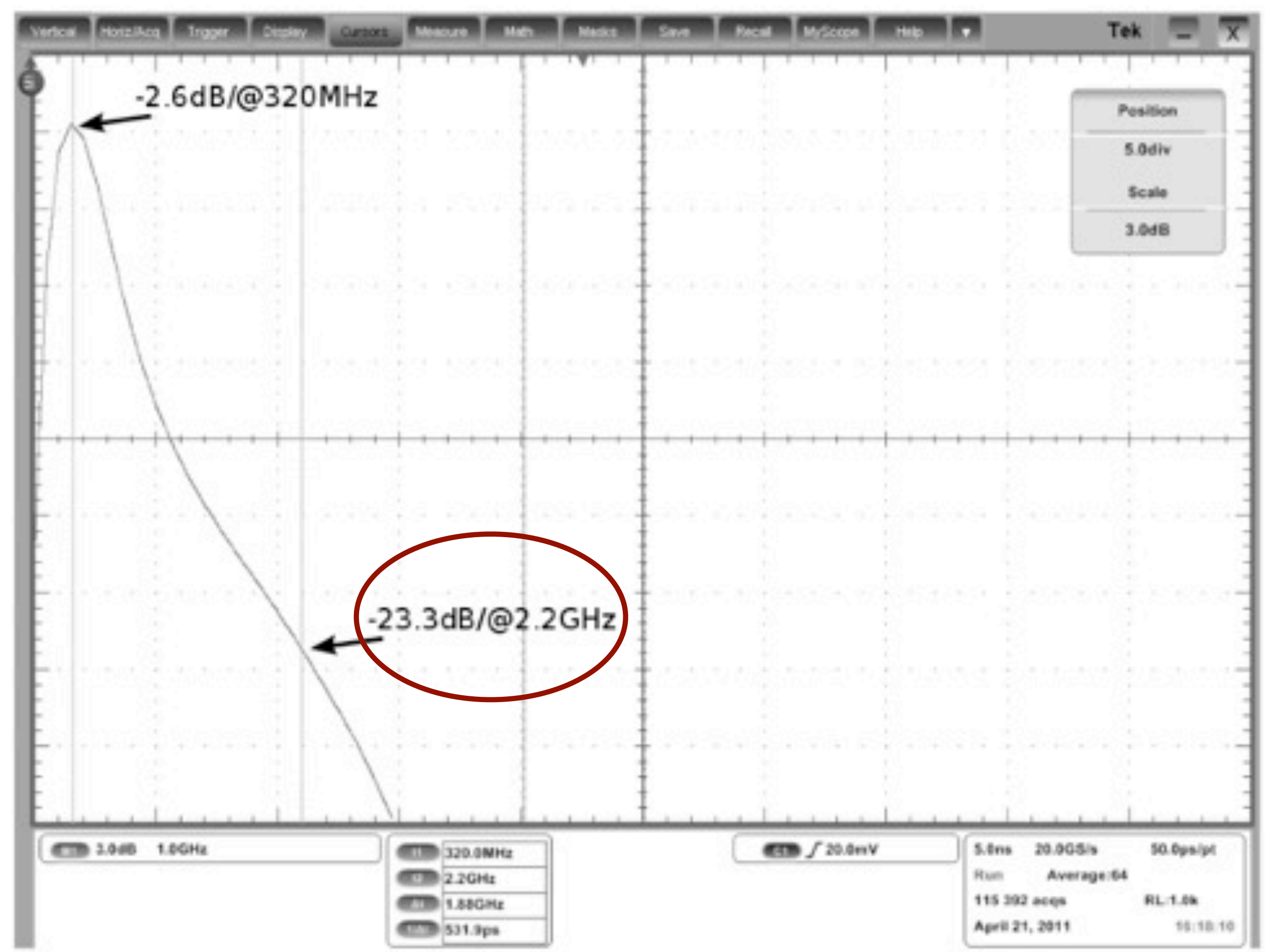
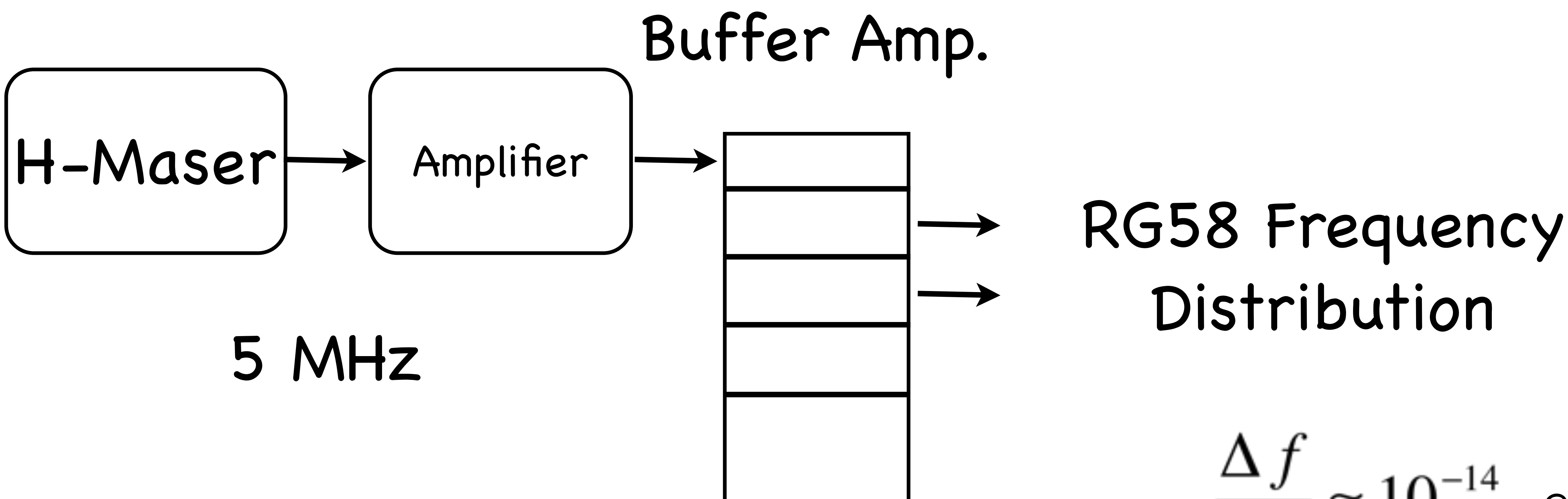


Figure 2: Edge spectrum.

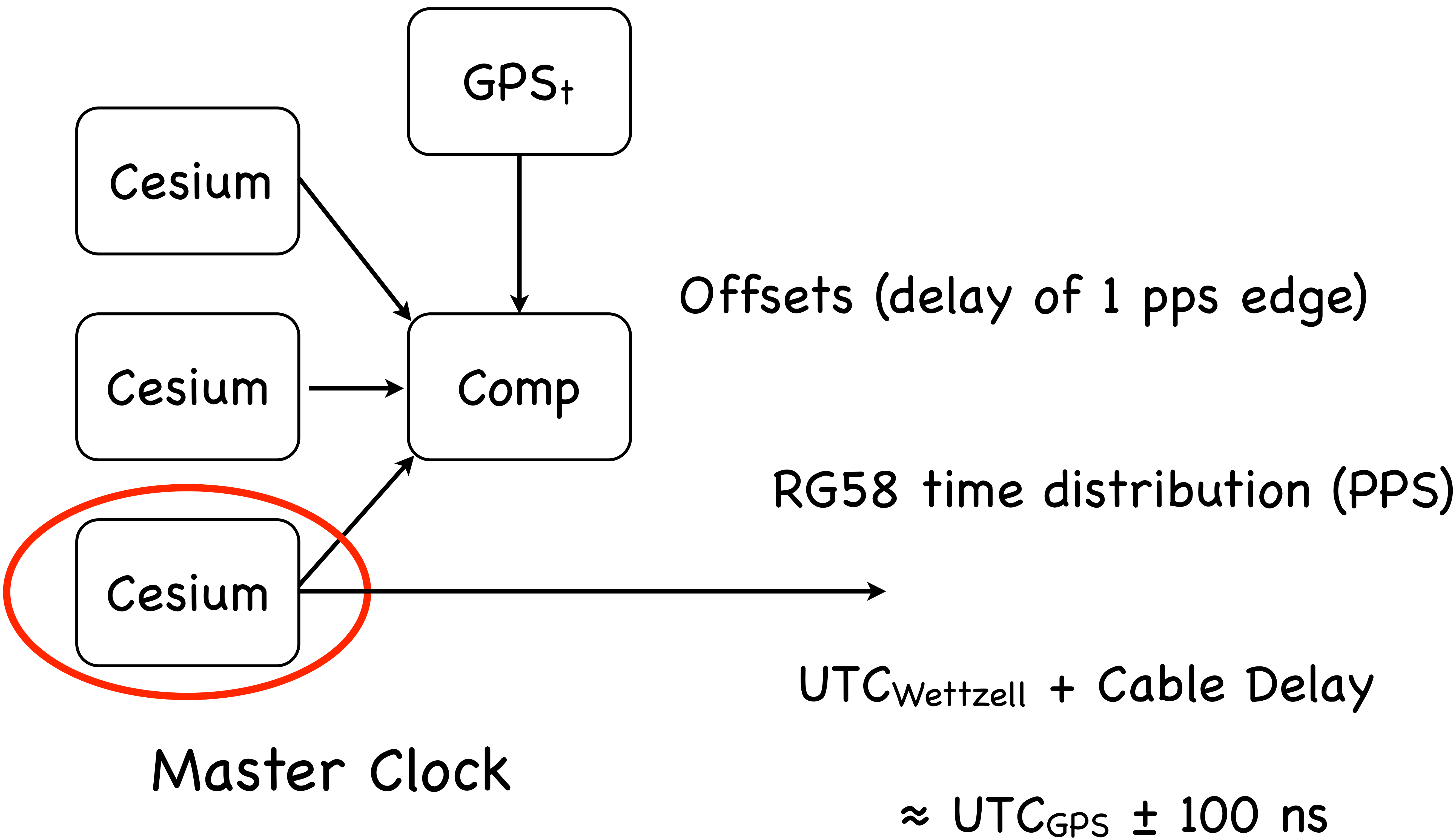
Preliminary experiment at CTU: J. Kodet

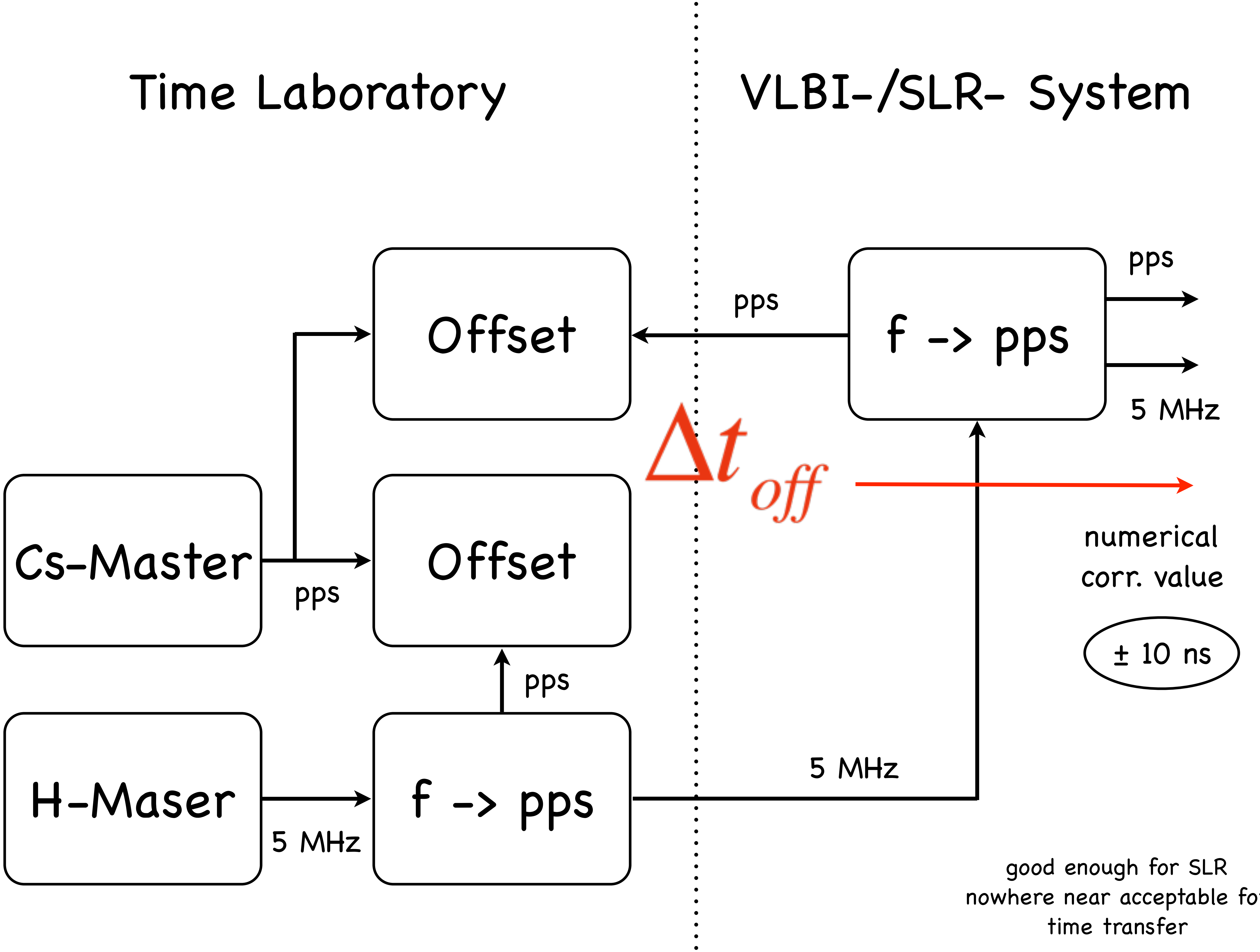
- light and RF not identical domain (cal.)
- SPAD not bad, more Bandwith needed
- Timing System needs consolidation
  (after all we are after 100 ps delay...)

Timing System Wettzell: Current State

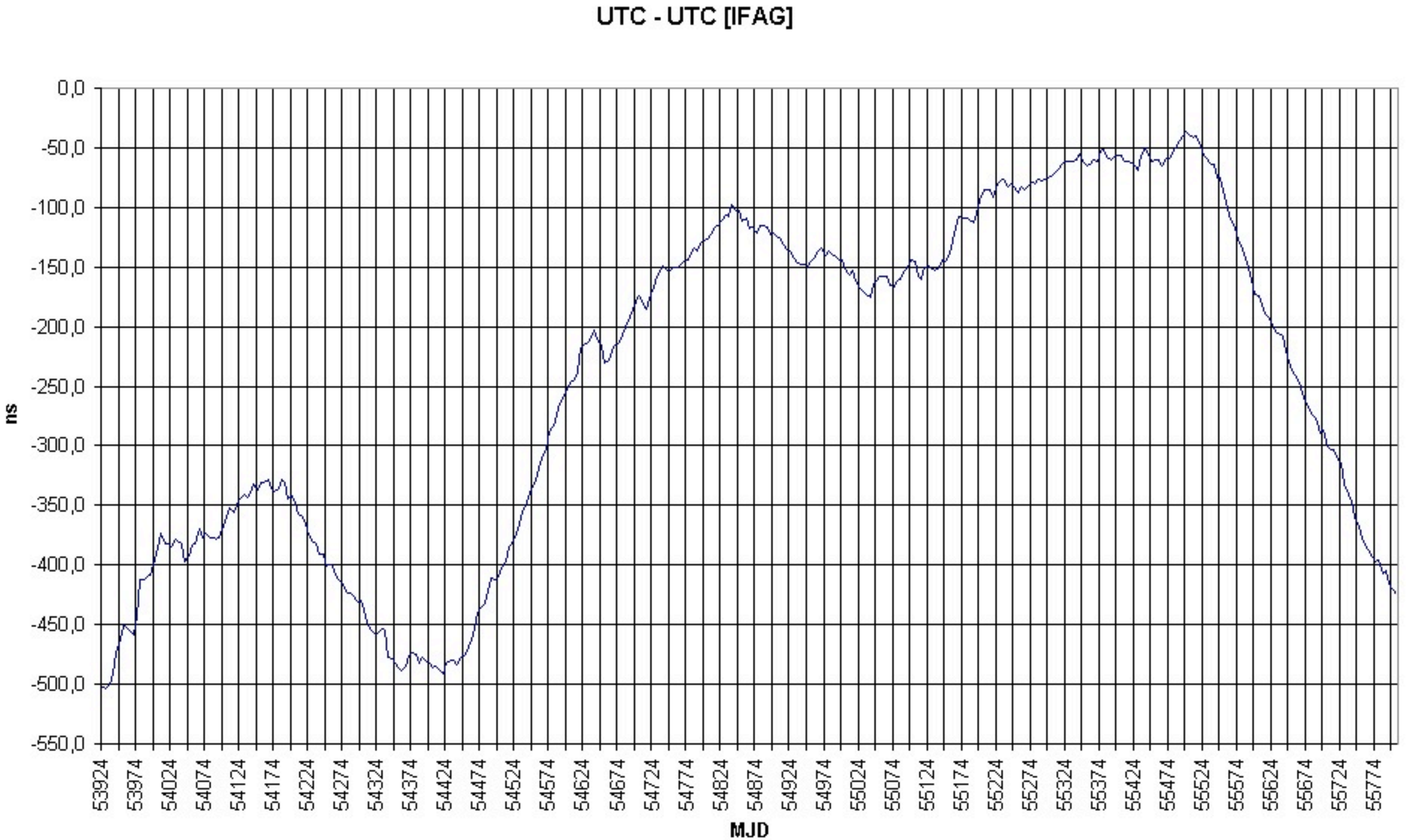


$$\frac{\Delta f}{f} \approx 10^{-14}$$ @ 1000 s


GPS$_t$
Cesium
Cesium
Comp
Cesium
Offsets (delay of 1 pps edge)
RG58 time distribution (PPS)
UTC$_{Wettzell}$ + Cable Delay
≈ UTC$_{GPS}$ ± 100 ns
Master Clock


Time Laboratory
VLBI-/SLR- System
Offset
Offset
Cs-Master
pps
H-Maser
5 MHz
f -> pps
pps
pps
f -> pps
pps
5 MHz
5 MHz
Δt_{off}
numerical corr. value
± 10 ns
good enough for SLR
nowhere near acceptable for time transfer

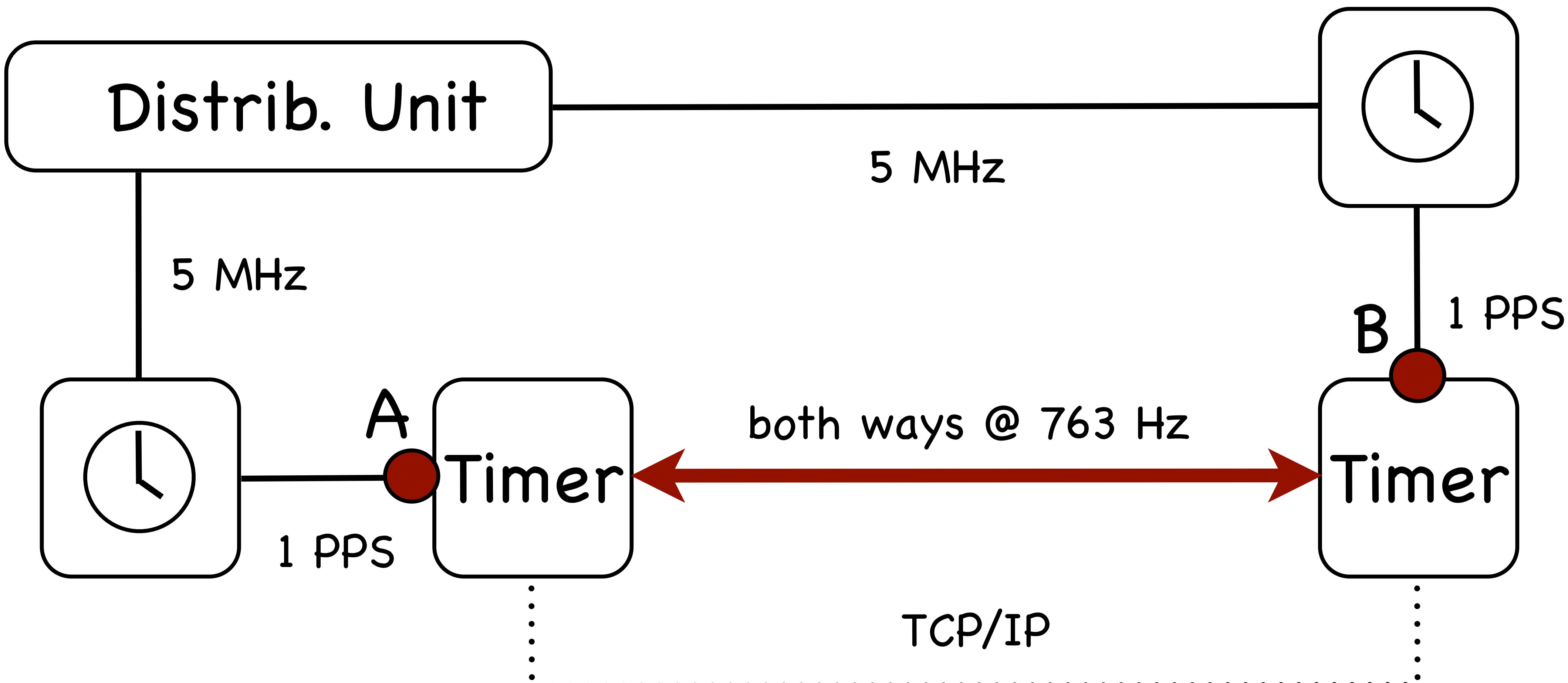
Comparison over 5 years



Known Issues in T&F

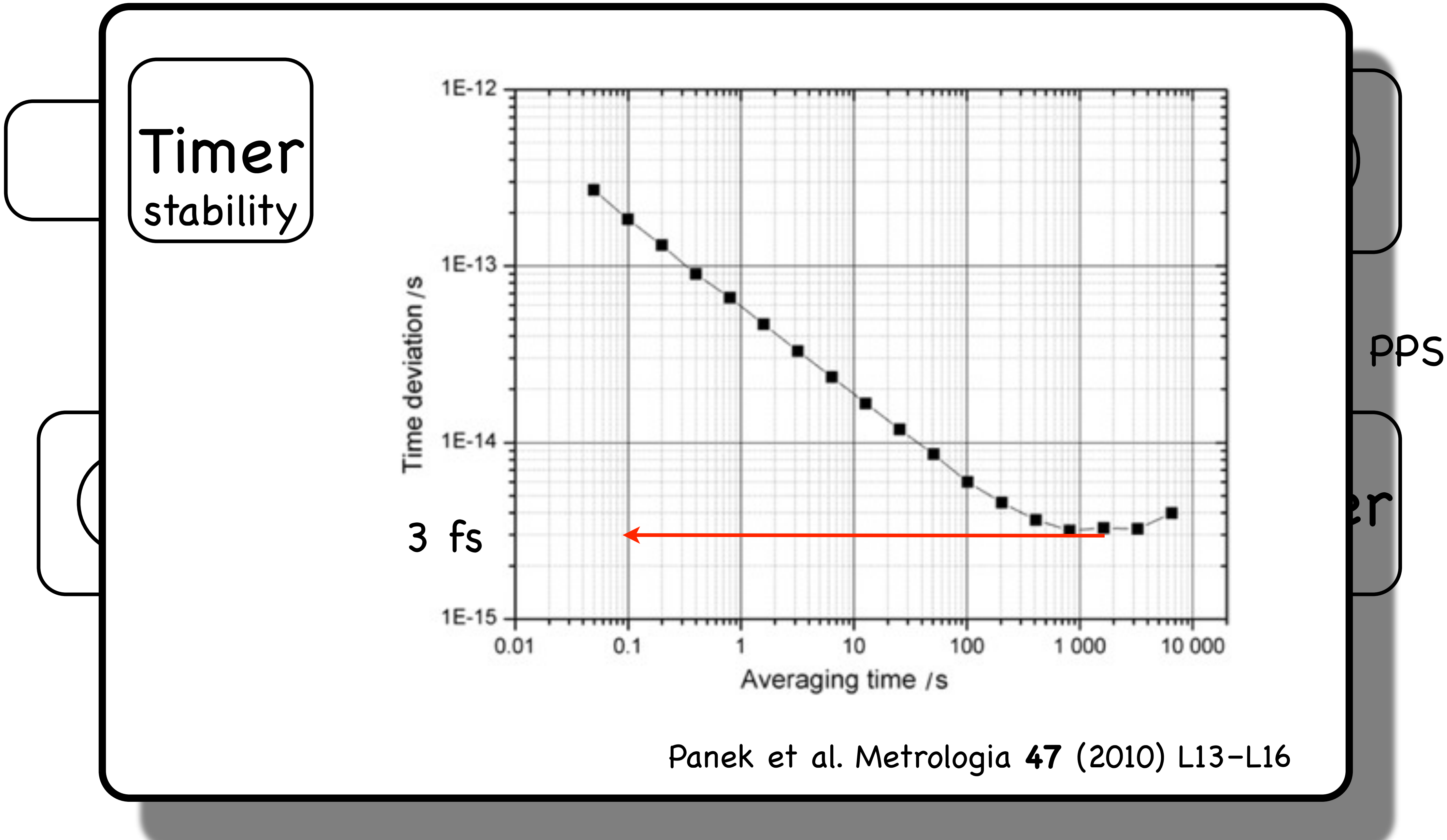
- PPS Pulse not sharp (bandwidth limited RG58)
- Cable delays sort of known (insufficient)
- Reference Frequency is low (5 MHz)
- 1pps jitters as ground potentials floats between systems
- simple Cable distribution (no 2-way-compensation)
- insufficient for the definition of space time (ART) on observatory

Practical Application



Measurement returns Offset between A and B
It also returns the variation in the length of the cable

Practical Application

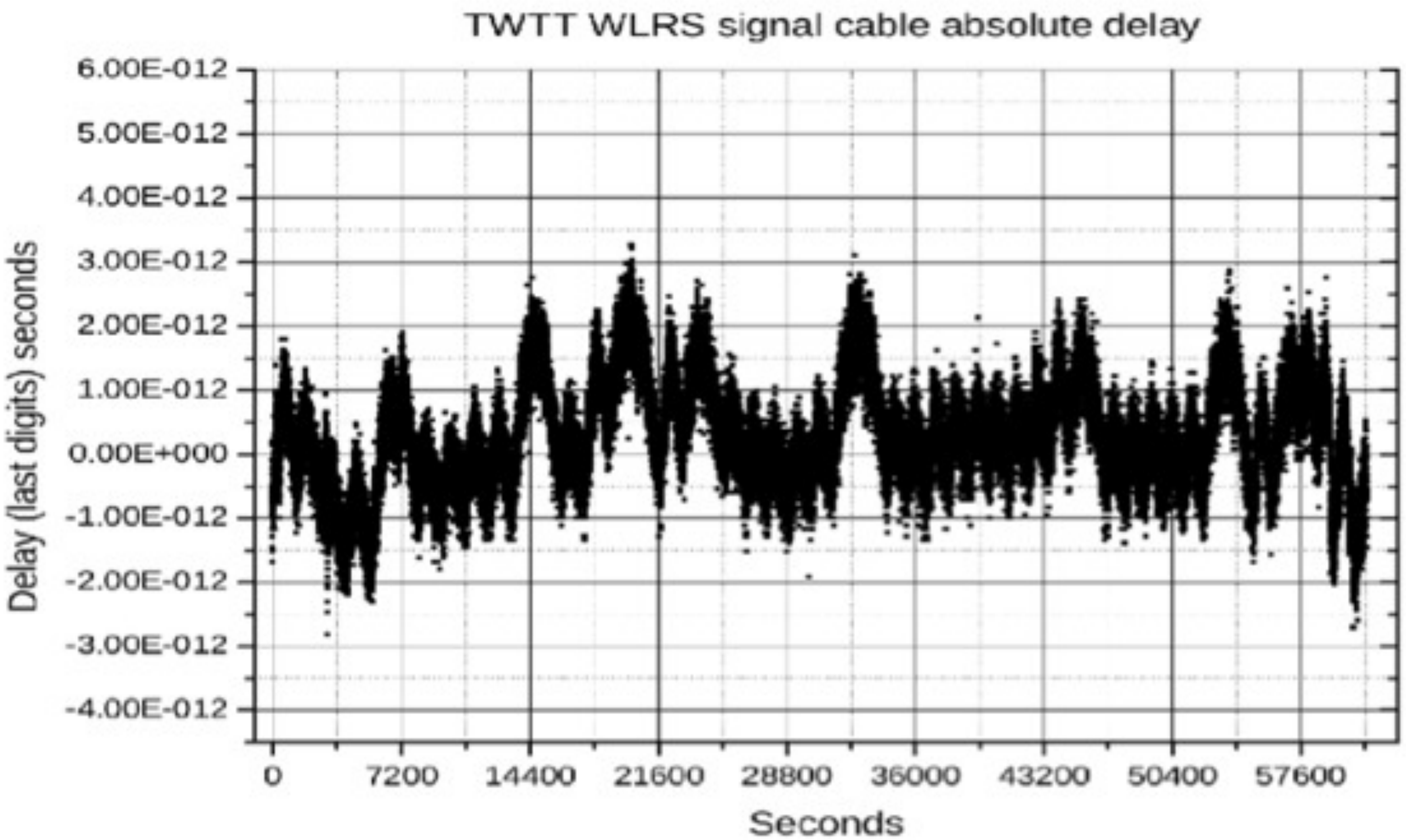


Panek et al. Metrologia **47** (2010) L13–L16

Measurement returns Offset between A and B

It also returns the variation in the length of the cable

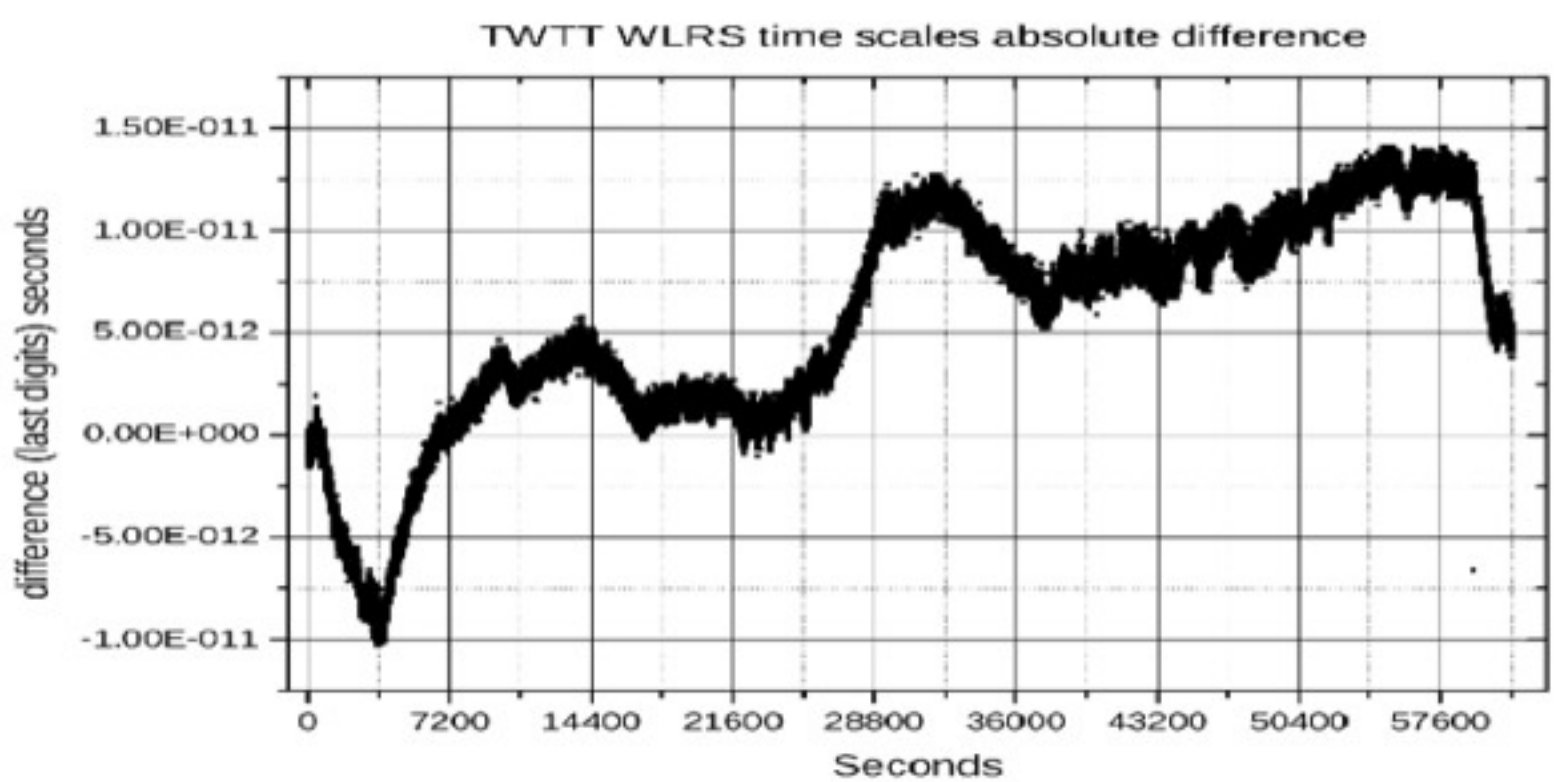
Clock Comparison inside a building



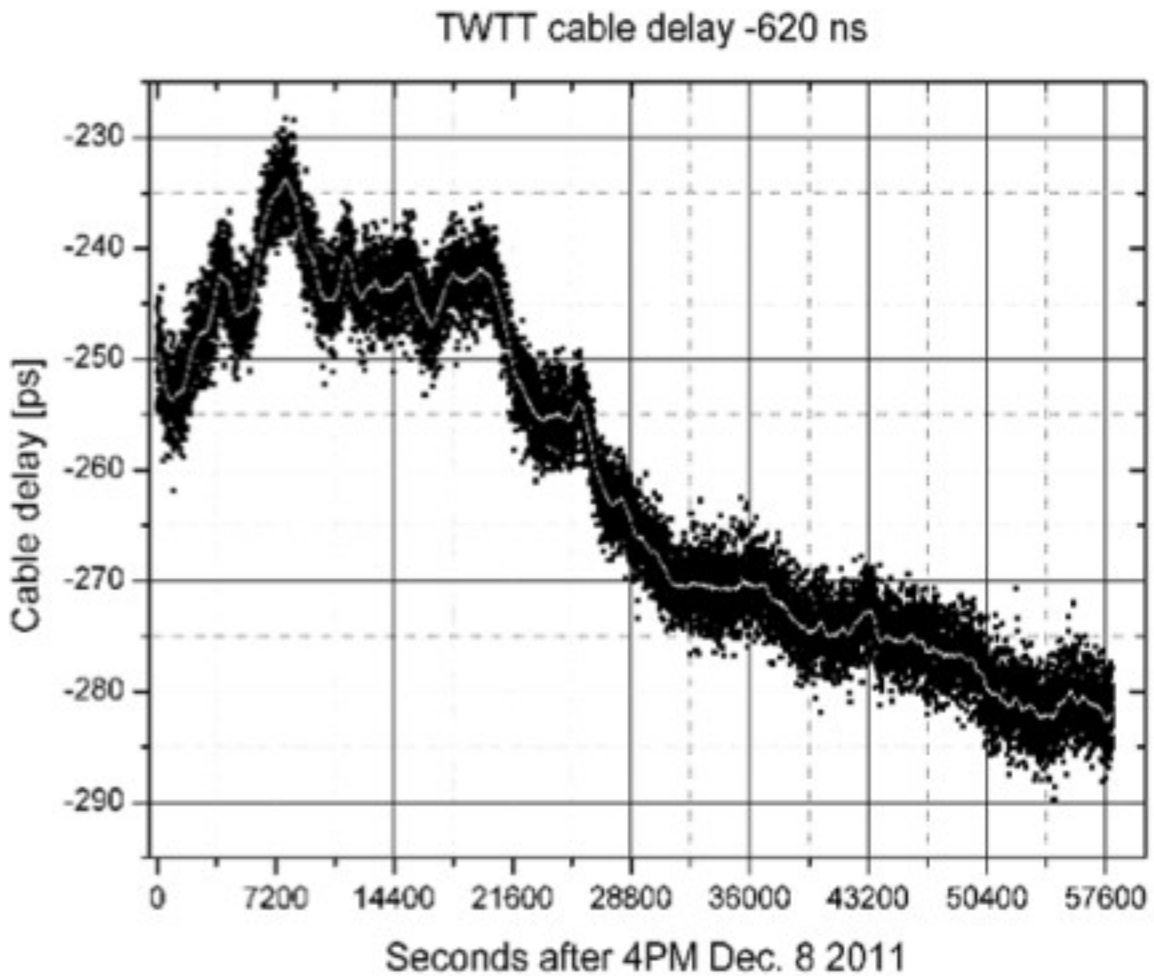
Variation of 2-way delay between clocks by rf-pulses in a cable

Heliax LDF1 – 50, ~ 170 meters

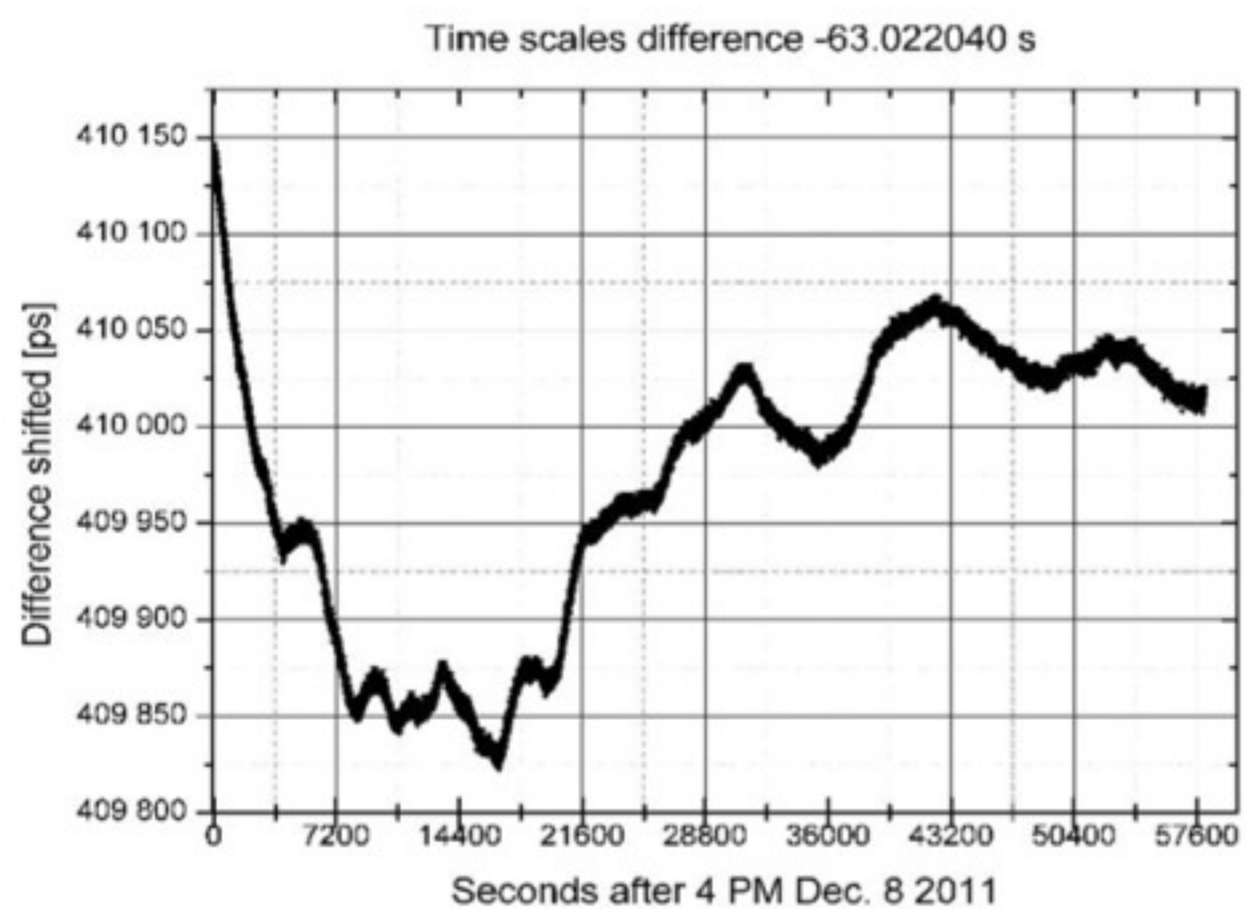
Offset between the two separate timescales



Clock Comparison between buildings 100 m apart



Variation of cable delay (Δt ≈ 60 ps)

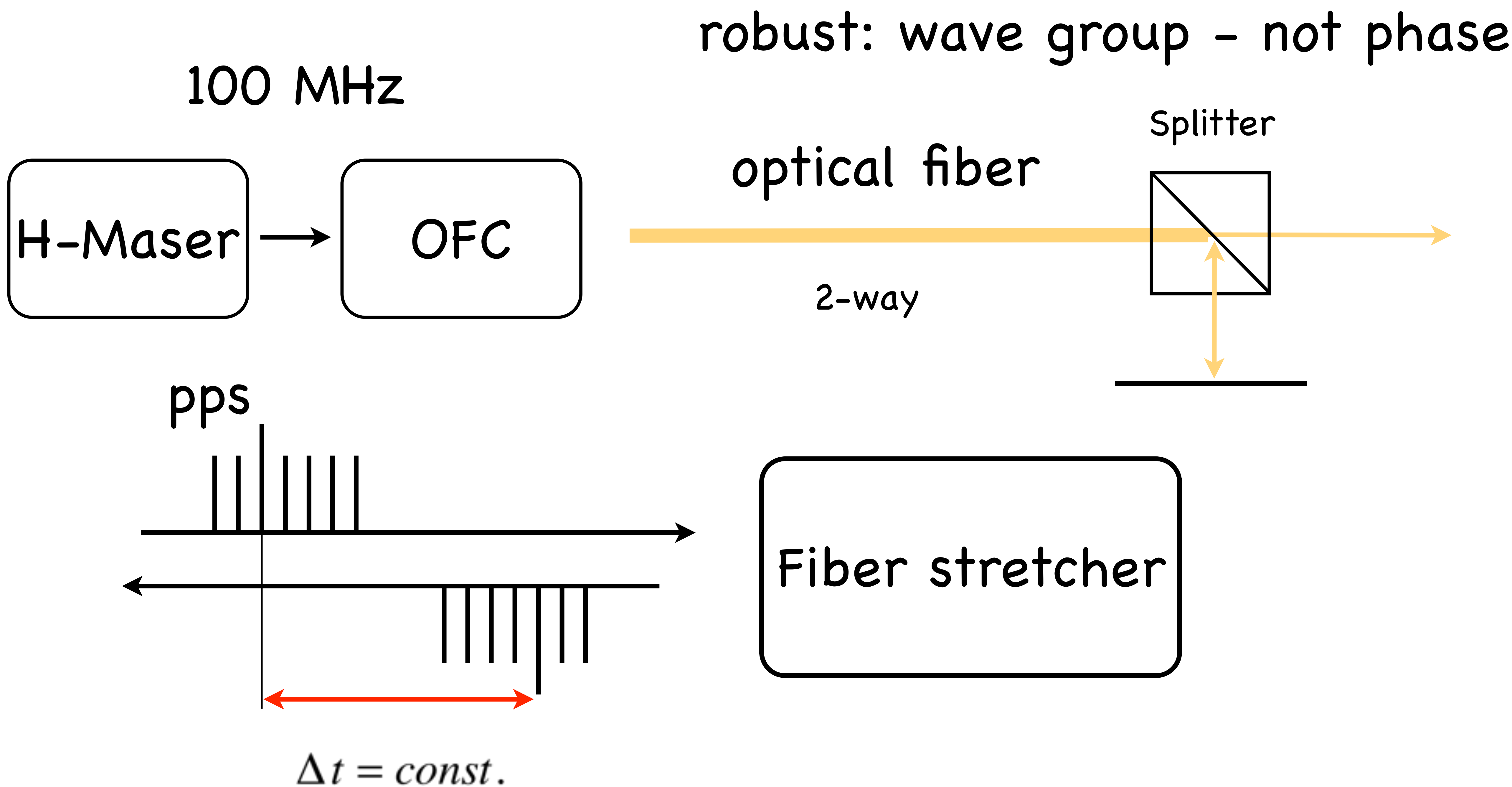


Variation between timescales (Δt ≈ 320 ps)

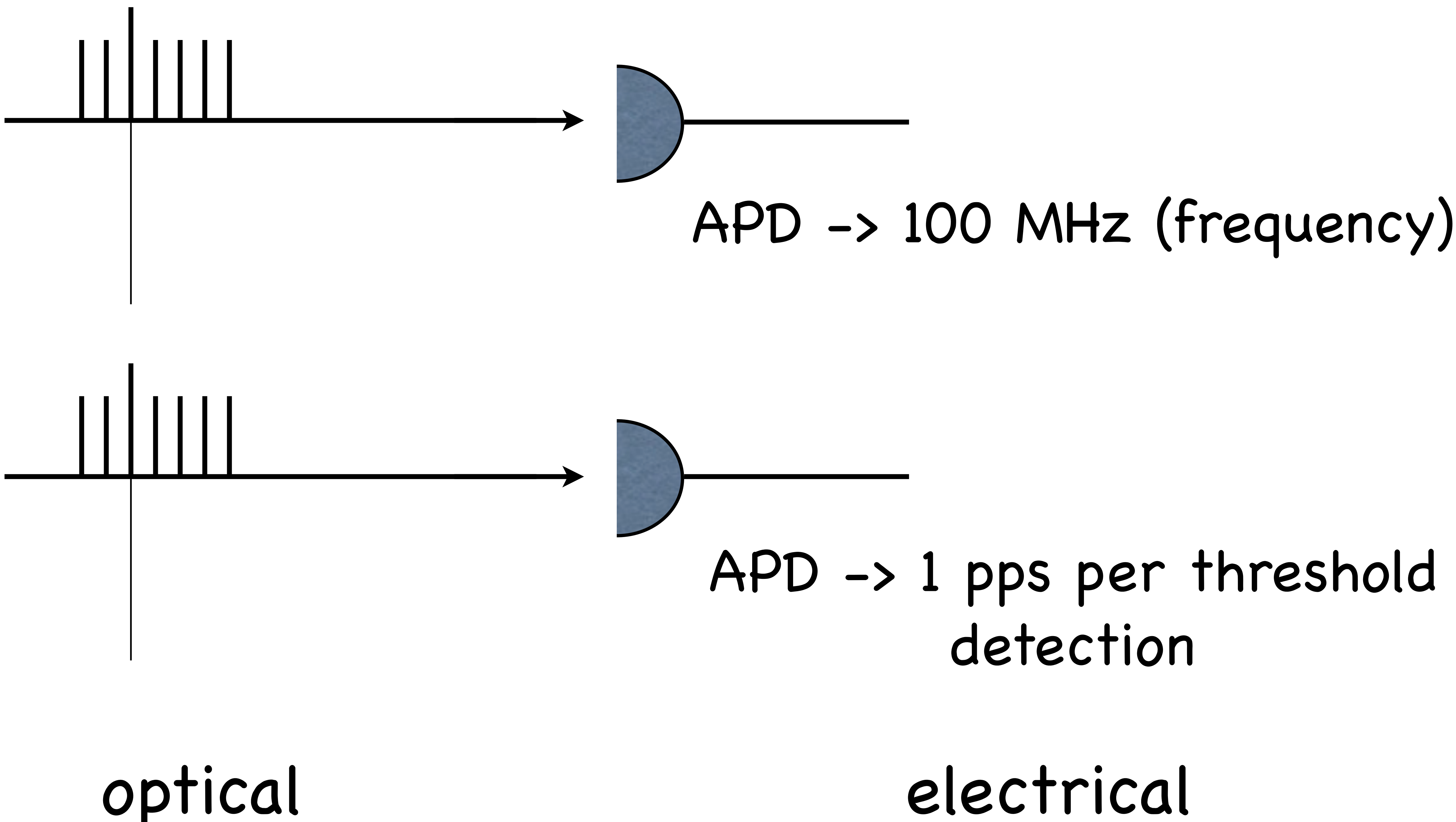
Goals for new Timing System

- Optical Frequency Distribution (Fiber)
- continuous precise 2-way-delay compensation
- Reference Frequency high (100 MHz)
- exact reference (±1 ns) relative to external source (PTB)
- T & F generated from same signal (OFC technology)
- Definition of Space Time (in anticipation of optical clocks)

General Idea



OFC pulse train and 100 fs pulse width



-> per 2-way comparison space time definition

Application: Time Transfer

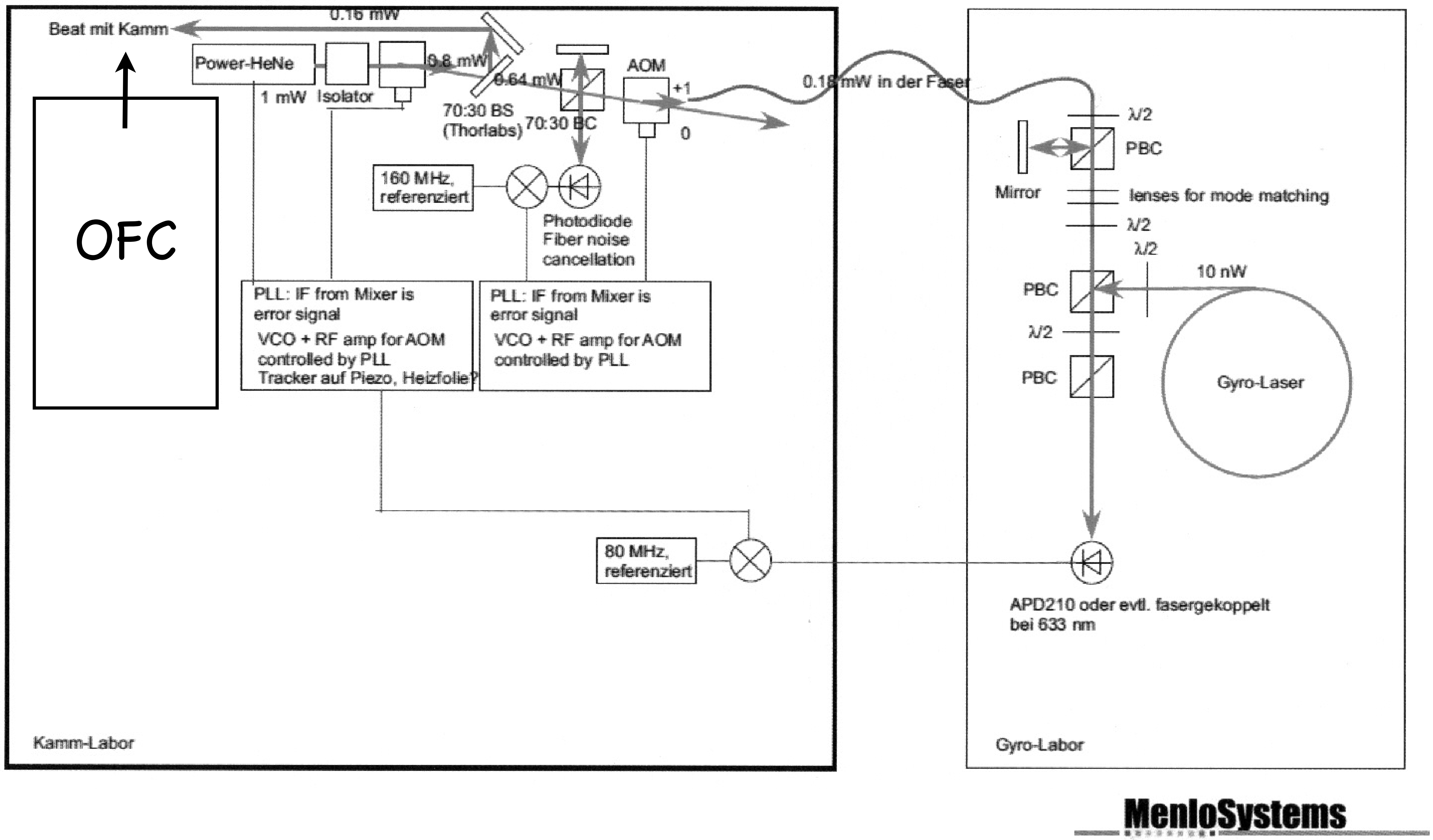
- optical (sub-)picosecond link between event timer - UTC_{Wtz}
- optical time transfer per laser link
- optical frequency (time) transfer by fiber link - PTB

Application: Frequency Stab.

- Application of optical pulses for system delay in VLBI
- 100 MHZ frequency ref. not 5 MHz for mixer
- direct conversion of 2 + 8 GHz from OFC?
- Inter-technique calibration SLR - VLBI

More OFC-Technique options for VLBI...?

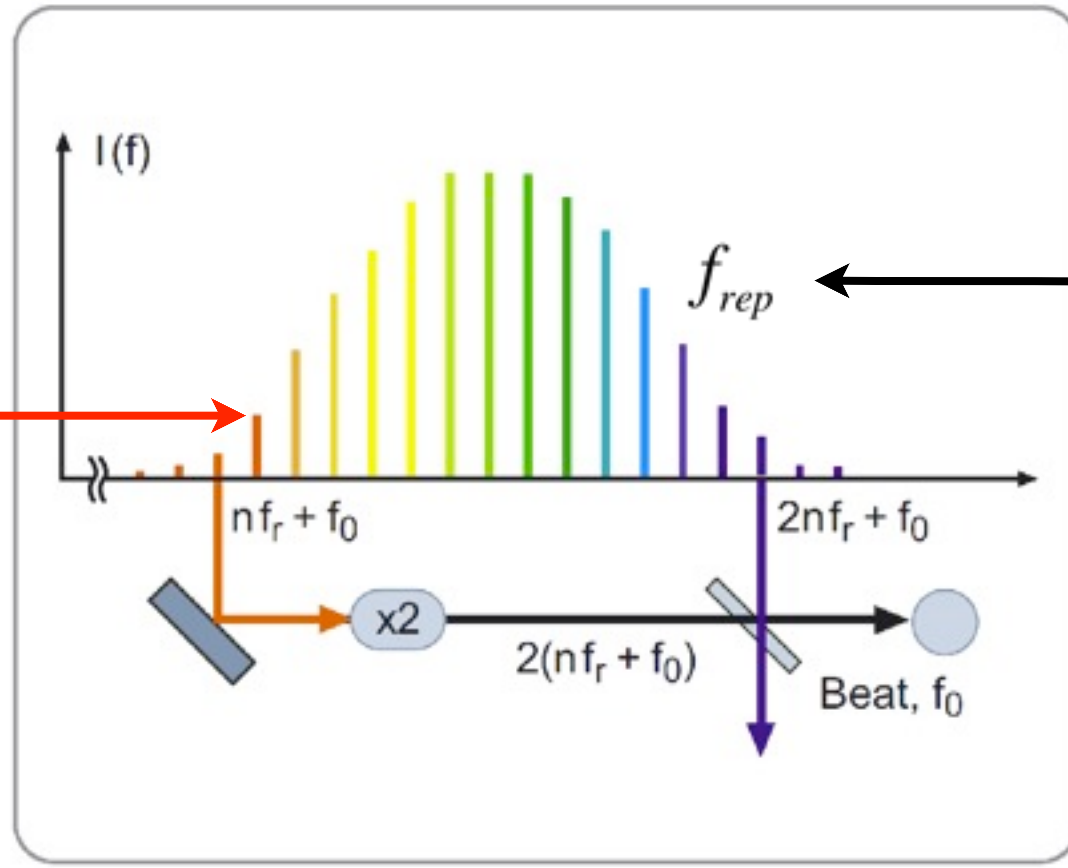
Ring Laser Cavity Q > 10^{12}



Schawlow – Townes Limit ≈ 300 μHz @ 474 THz

RLG as a flywheel for freq. stability

$Q > 10^{12}$



H- Maser

OFC as gearbox between optical and RF domain

∂f = 10 Hz -> 2e-14 (1s)
∂f = 3 Hz -> 6e-15 (1s)

+ surprises

Potential:

- New arena for intra- and inter-technique biases
- Common clock for VLBI (via PTB in the longterm?)
- New challenges and prospects for Time Transfer
- What is in with better space clocks with GNSS?
- Time a geodetic observable rather than a adjustment parameter?

Photo: U. Schreiber

Wettzell: 15.9.2011