New Technologies for Time Transfer with Picoseconds Precision and Accuracy

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Outline

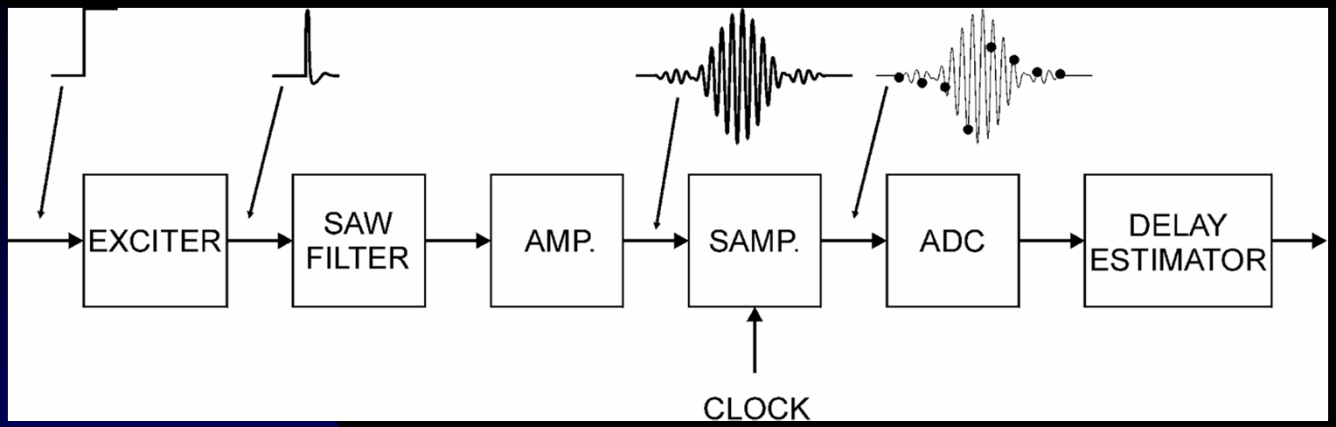
New Technologies for Time Transfer

- **New devices** with (sub) ps resolution and stability
- Timing system
- Optical switch for laser output time tagging
- Photon counting detector for optical time transfer
- Two Way Time Transfer via coax. cable module

- **Experiments**
- Laser time transfer ground – space
- Two Way Time Transfer (TWTT) via coaxial cable
- First results

- **Conclusion**

Timing based on SAW filter interpolation



P.Panek
Inst.of Phot.AS CR

- Time-interpolation by the Surface Acoustic Wave (SAW) filter signal processing in time domain, data process.requirements

- = > extreme (! fs !) resolution, linearity and stability

- *Review of Scientific Instruments, Vol. 78, No1, 2007*
- *U.S. Patent 7,057,978 B2, Jun. 2006.*
- *IEEE Trans. Inst. Meas, , Vol. 57, No.11, Nov 2008*
- *Review of Scientific Instruments, 2009*

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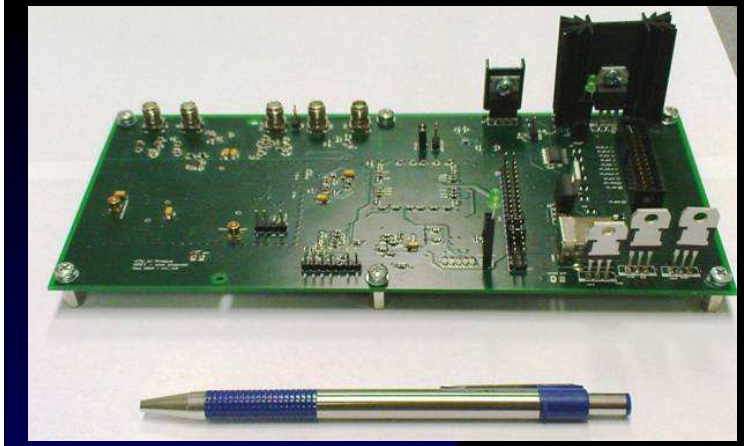
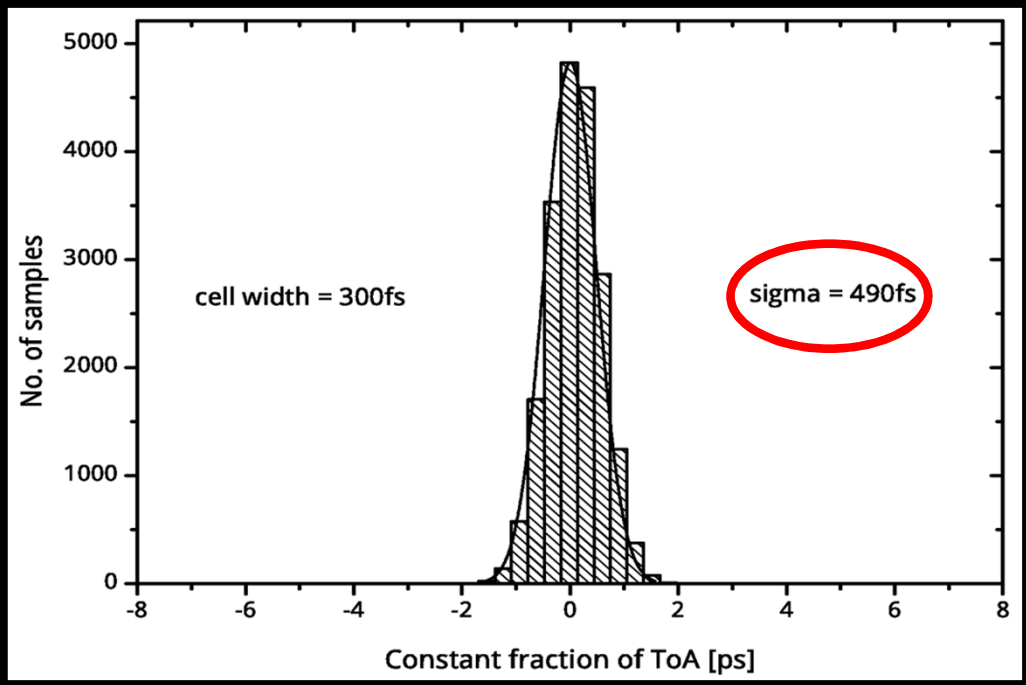
Sub-ps Timing system by CTU Prague



- Single PCB version (Kodet, Panek, 2012) built in data processing , FPGA
- Jitter & non-linearity < 500 fs
- temperature drift ~ 170 fs / K
- measurement rate > 4 / 20 kHz



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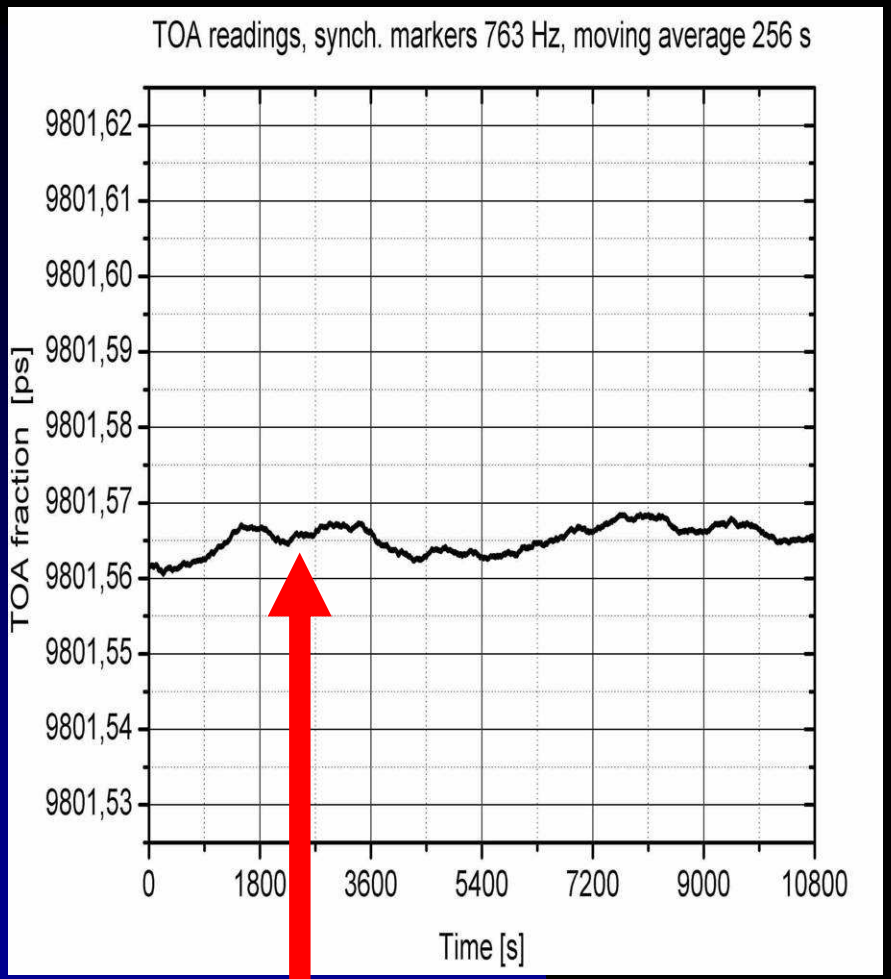
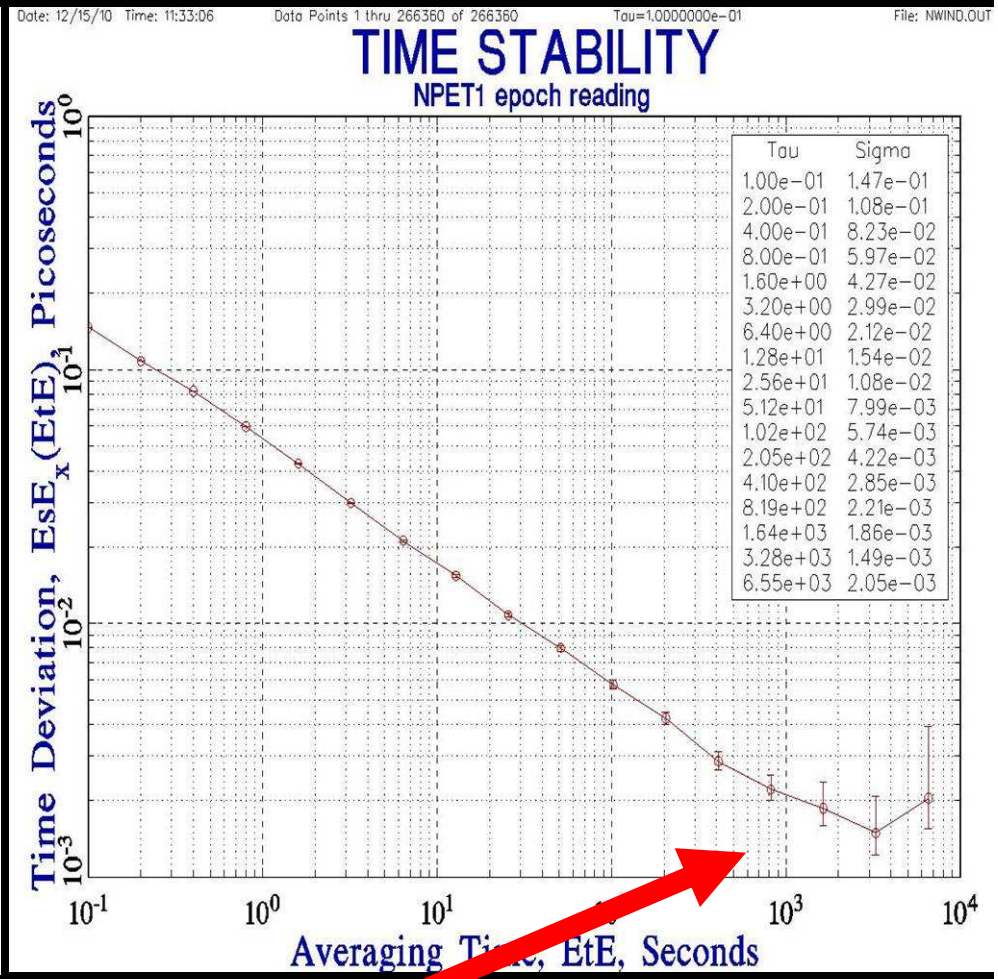
Sub-ps Timing system – Timing stability





drift ± 4 fs within 10 000 s

Tdev < 2 fs

Metrologia 47 (2010) L13-L16

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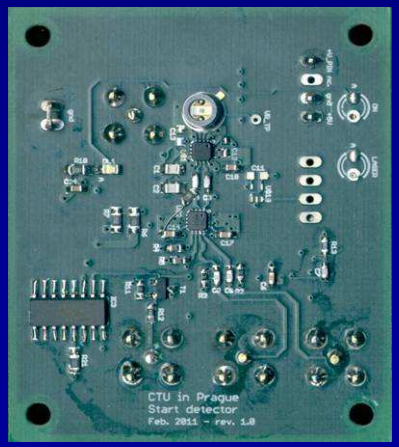
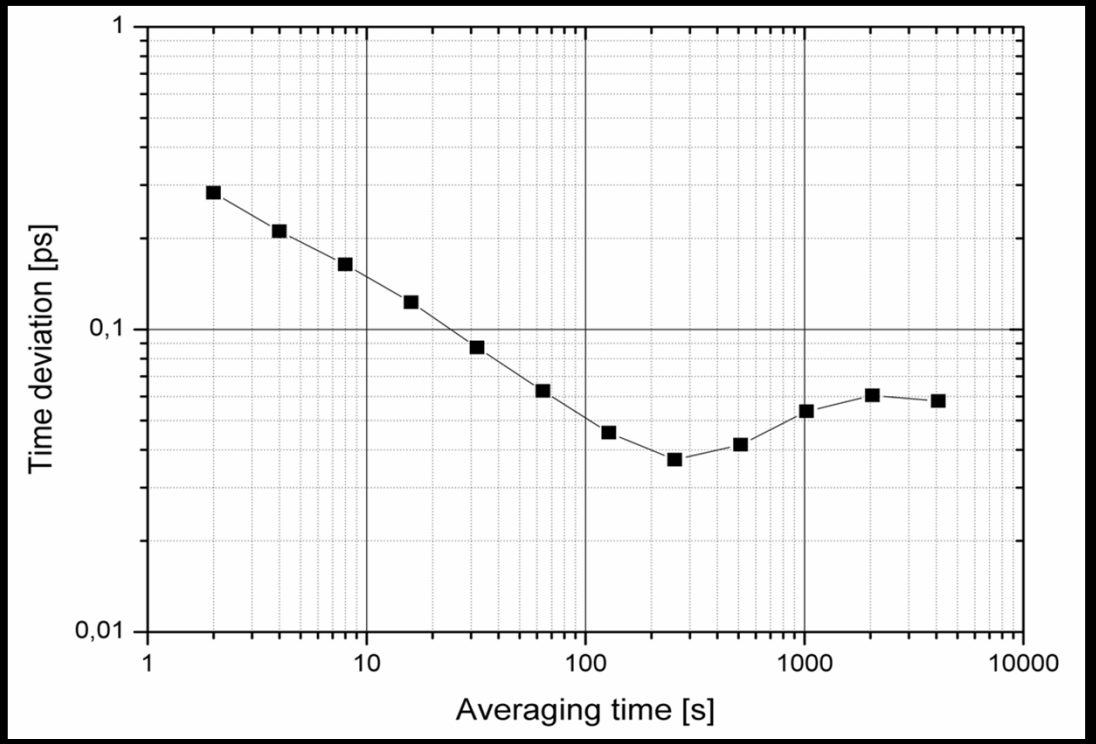
Time tagging of laser fire - Start detector



- Ultrafast components, high RF immunity
- Jitter < 900 fs
- Temperature drift ~ 350 fs / K
- Timing stability T_{DEV} < 50 fs / hours



Rev.of Sci.Instr. 2012, 12,Vol.83, No.3, 036101

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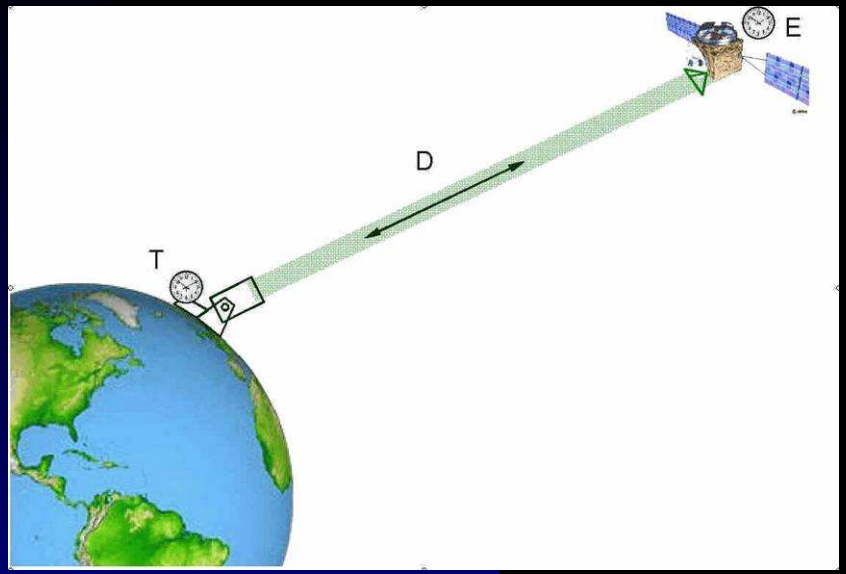
Photon counting detectors

Laser Time Transfer & Satellite Laser Ranging



- Photon counting (ground & space) is minimizing systematic errors
- Compass GNSS (2007, ‘10, ‘11, ‘12)
- ESA mission ACES ELT (2015)

Space

Ground

- jitter < 20 ps rms
- delay drift +0.48 ps / K
- stability T_{DEV} 200 fs / day

- **<u>Delay absolute accuracy 12 ps</u>**
  photon -> electric

Metrologia 48 (2011) L13-L16

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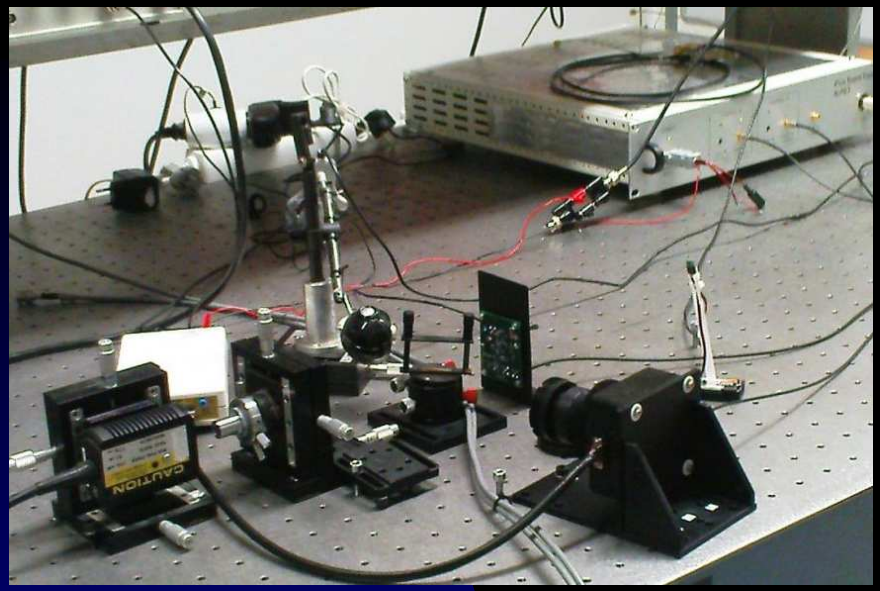
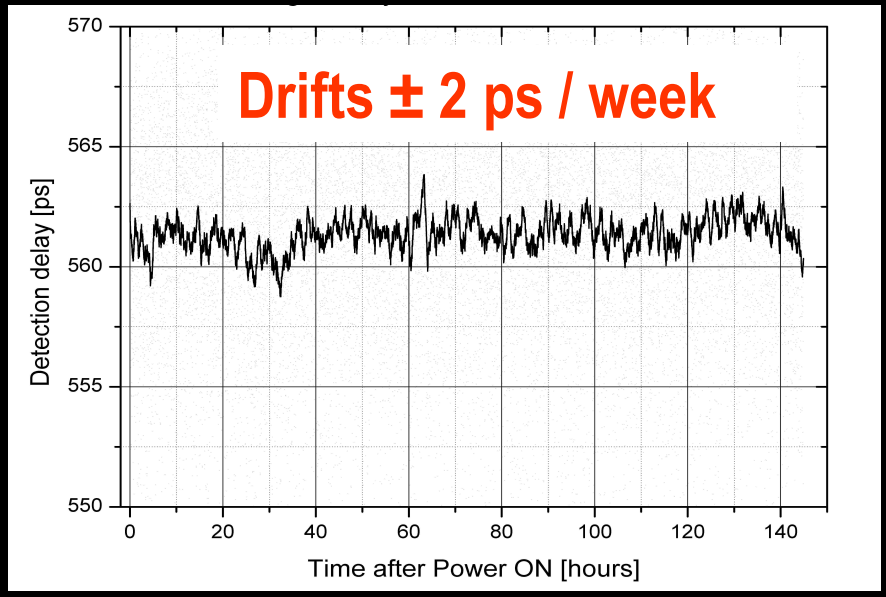
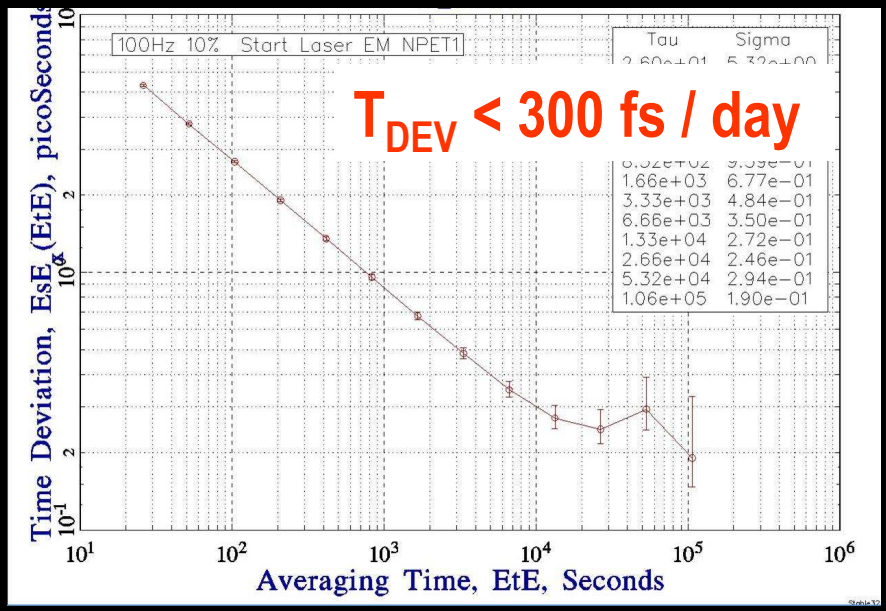
Laser Time Transfer chain stability





- Complete LTT / SLR chain laser + Start + Stop + timing
- Standard lab. conditions, +/- 2 K
- One week operation



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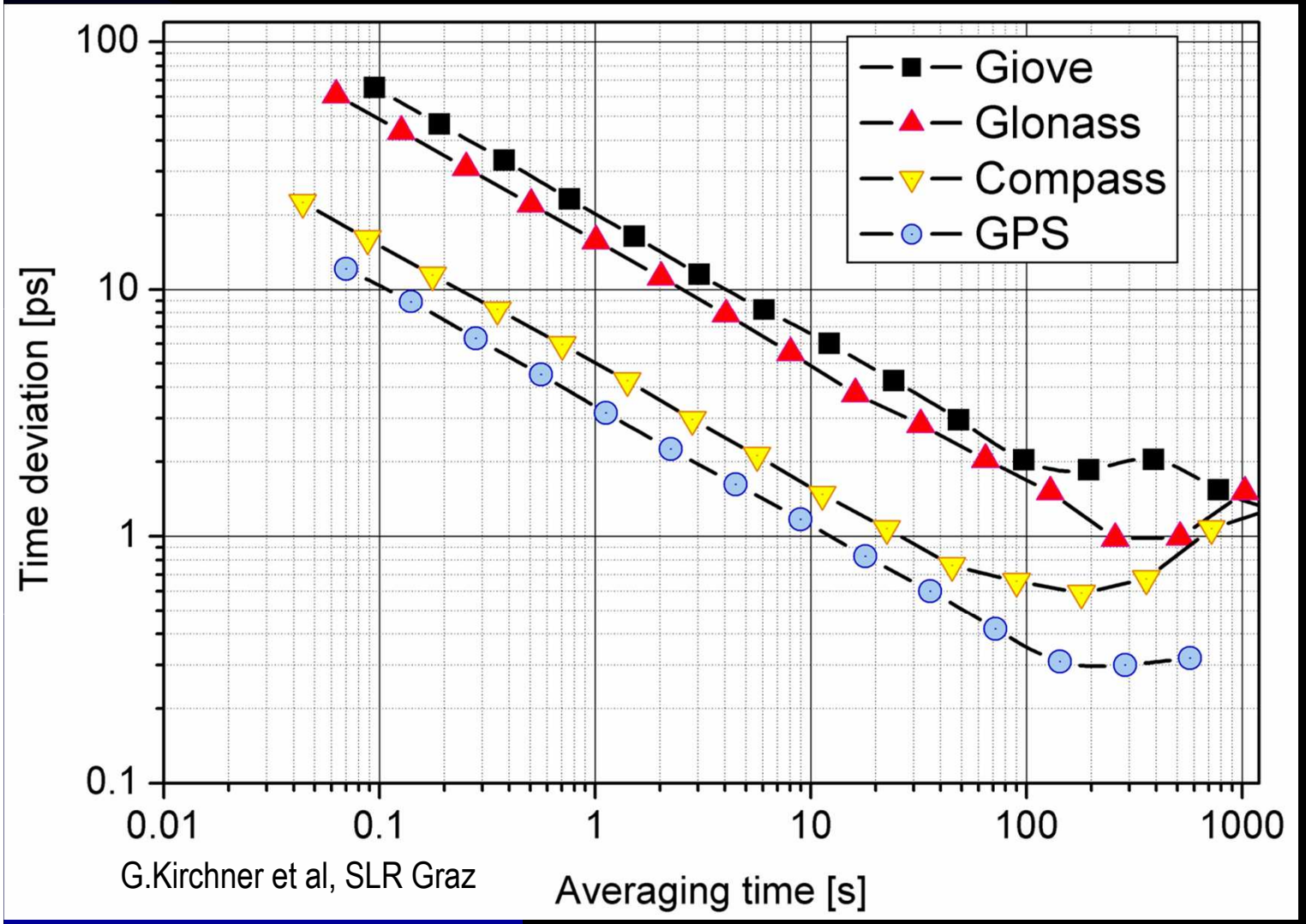
Ground to space time LTT precision

Experimental data - based on SLR of GNSS satellites



< 2 ps in 100 s

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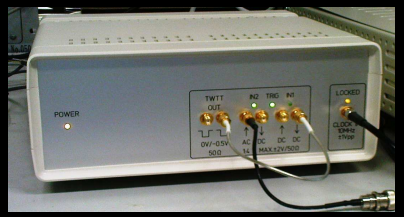
Two Way Time Transfer via single coaxial cable

Single coaxial cable, variable delay



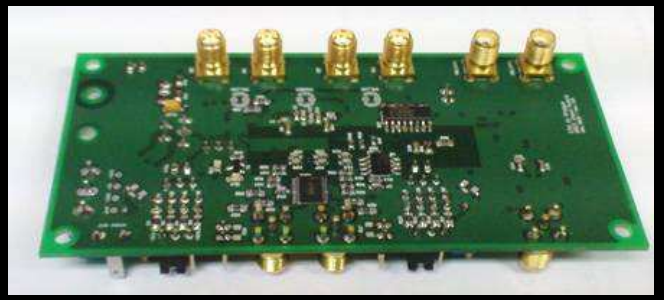
Time scale #1

Time scale #2

External events

External events

- Comparison of two independent time scales #1 and #2
- Sub-ps precision & few ps accuracy
- TWTT input boards

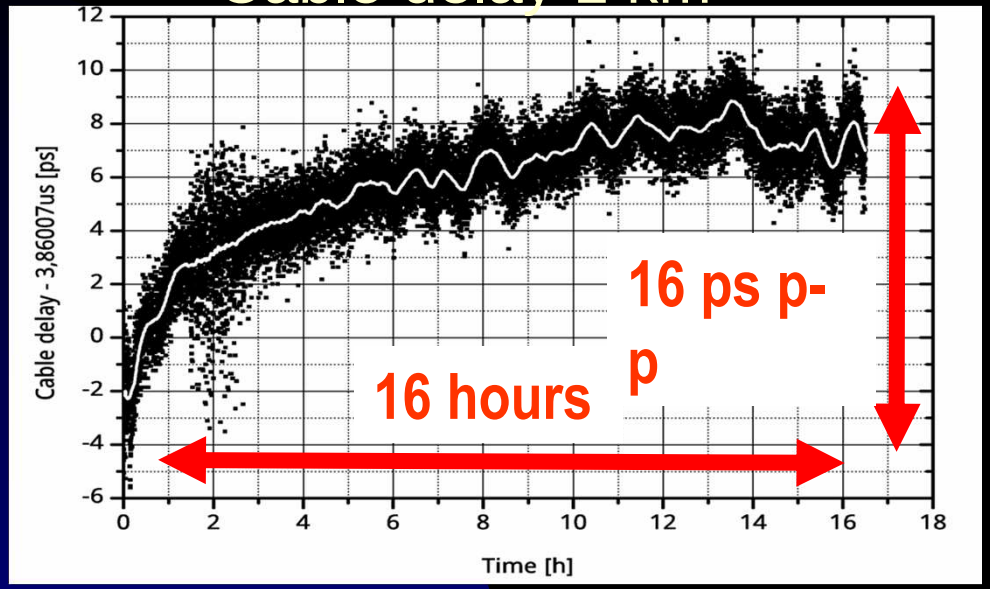


- Event timing function <u>in parallel to TWTT in the same device</u>

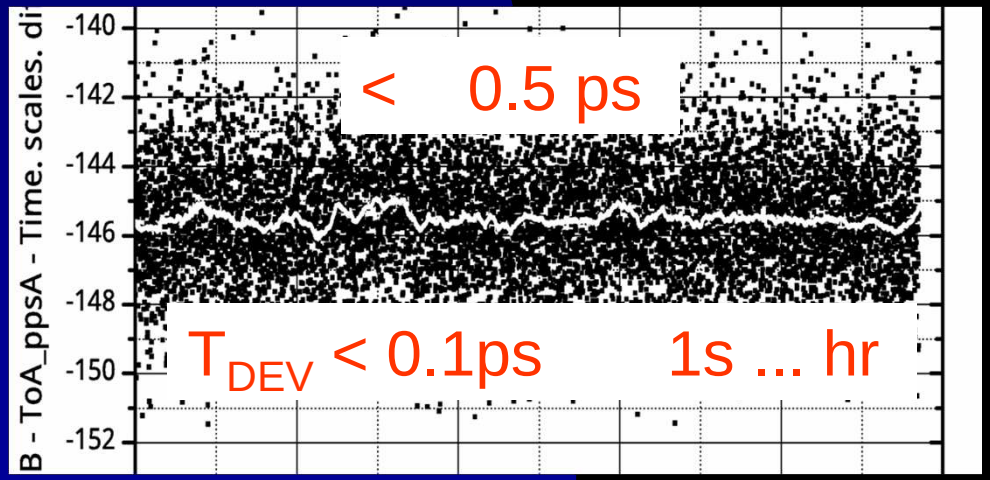
Rev.Sci. Instr. submitted, 2012

TWTT experiment PTB Braunschweig

Cable delay 1 km



Time scales difference



- Two TWTT timing systems
- Common frequency source
- Time transfer cable loops
  1 m ref.; 1 km, 2 km, 3 km

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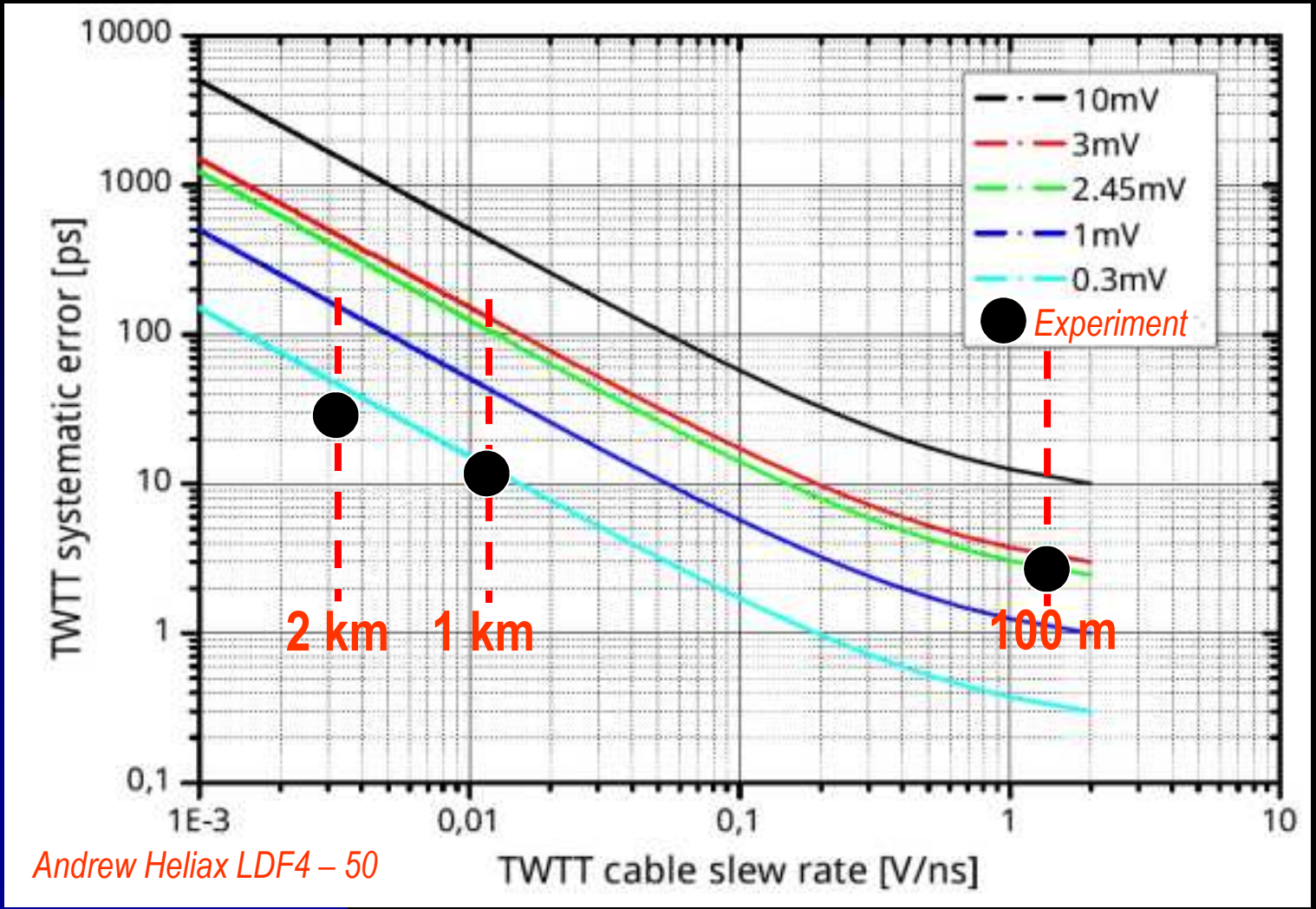
TWTT via coaxial cable ACCURACY



IEEE, 2012, p. 1-7. ISBN 978-1-4577- 1821-2

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Time biases and time scales comparison

Wettzell observatory , GPS, SLR, VLBI versus Master clock

- Local time scales are generated from distributed 5MHz H2 signal
- Time is related (1pps) to “Master clock”, Cs
- To solve pulses degradation on 30 – 150 m cables TWTT is implemented
  = > The absolute cable and instrumentation delays
  are easily referenced to the Master clock on ps level

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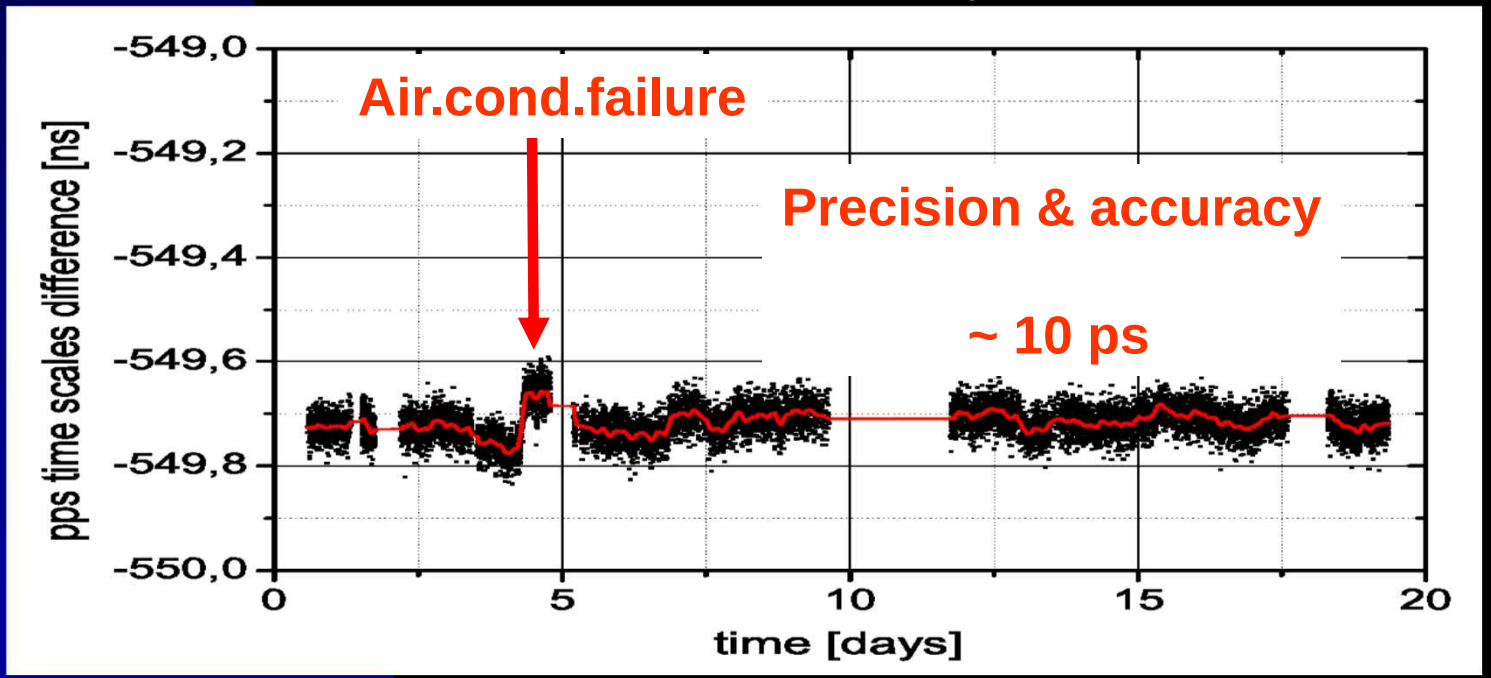
Time scales comparison TWTT Wettzell

GPS lab to Master Clock, 100 m cable



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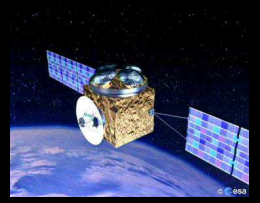
Conclusion

New technologies for ps precision and accuracy Time Transfer

- New timing system NPET
  Optical switch
  Photon counting receivers (ground,space)
  provide sub-ps stability, linearity

- Optical time transfer with 300 fs precision and 3 ps accuracy
  was demonstrated (ground experiment)

- The technology enables ground to space time transfer
  with 1 ps precision (demo via GNSS satellites)
  and < 10 ps accuracy (ground experiment)

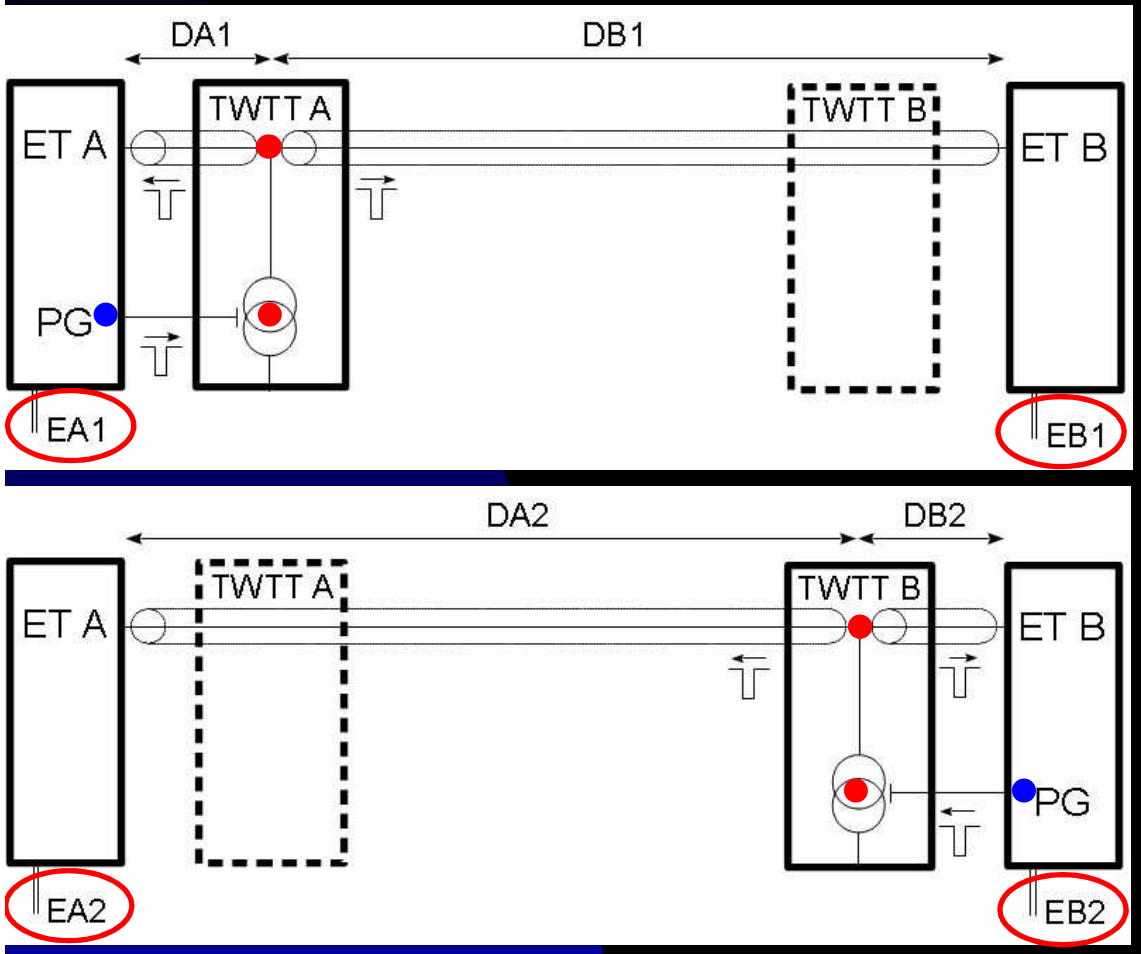


- Two way time transfer via a single coaxial cable technology
  ~ 1 ps precision and 3 / 15 ps accuracy over 0.1 / 1km demonstrated

- **Looking forward our future cooperation**

Operating Principle

Two Way Time Transfer via single coaxial cable



- TWTT modules activated alternately
- Resulting time scale diff.:
  DS = ((EB1 − EA1) + (EB2 − EA2)) / 2
- Cable delay
  DC = ((EB1 − EA1) - (EB2 − EA2)) / 2
- Optical analogy is possible photon counting, fiber
- Symetry of terminals #1, #2

TWTT in Wettzell Block Scheme