SuperGPS through optical networks

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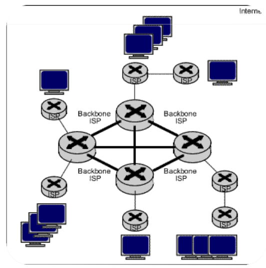
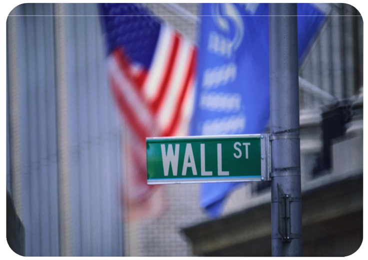
Partners

Funding

Objectives

- Optical methods to **back up GNSS timing** via fiber

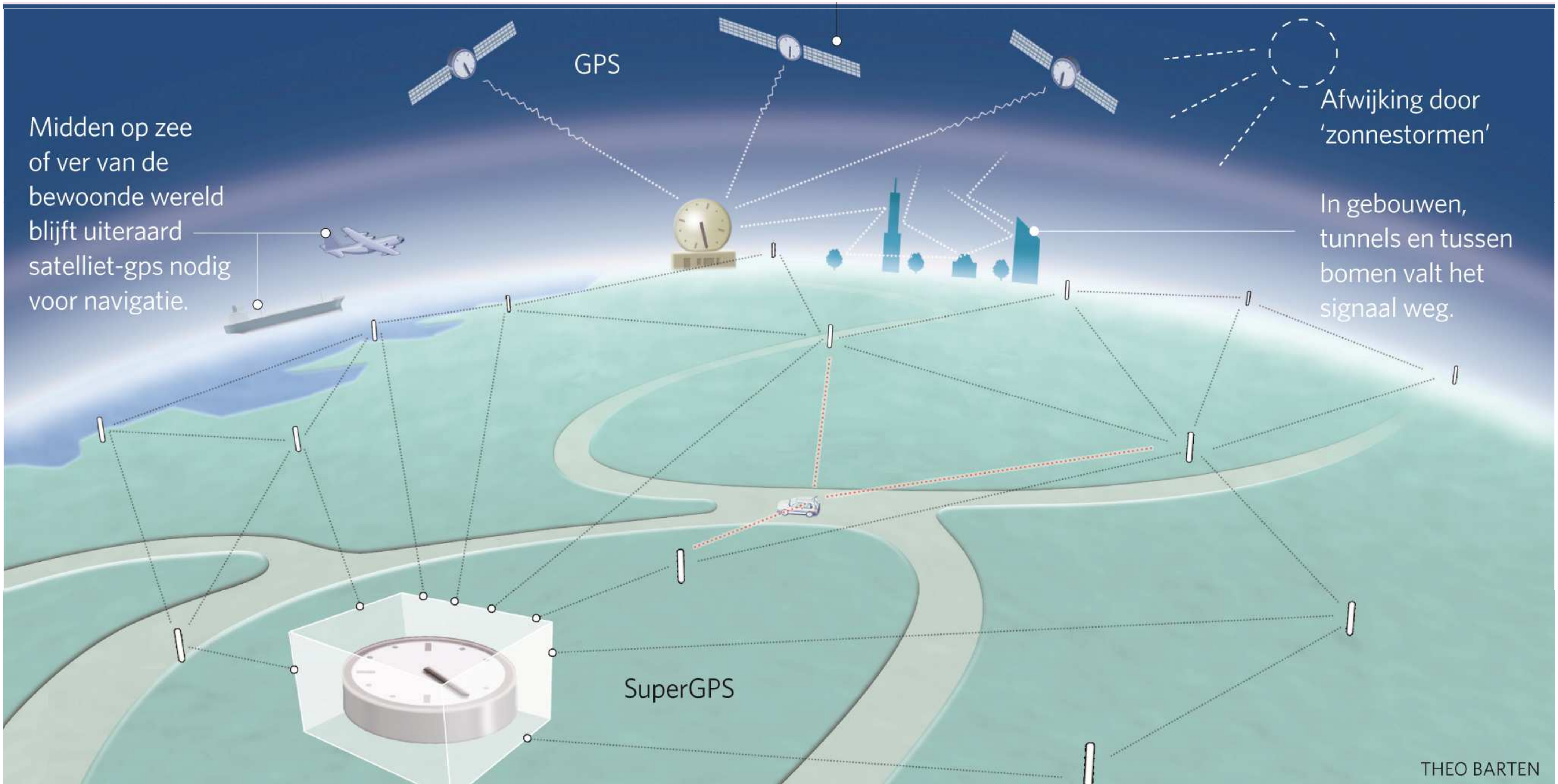




- **Next-generation timing** via live optical networks, T&F encoded in data streams

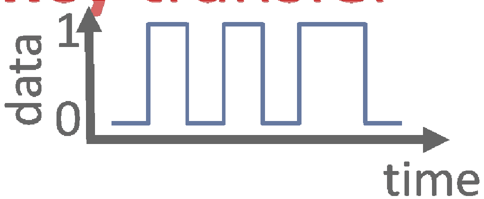
- **Next-generation positioning** (optical/radio)

Vision of SuperGPS



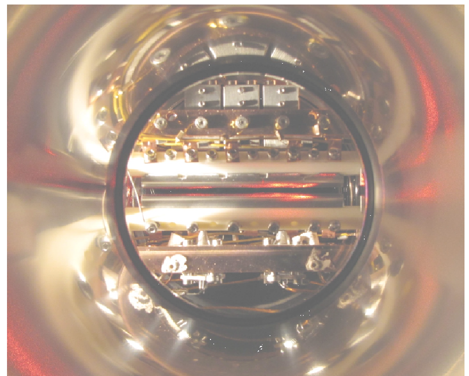
Activities at LaserLaB VU Amsterdam

- **Frequency transfer** through 2×317 km DWDM link (VU, SURFnet, KVI Groningen)
  - *Oct 2012: Menlo sub-Hz laser at 1542.14 nm (ITU #44) installed*
- Optical **data, time and frequency** transfer
  - *1 Gbps White Rabbit Ethernet*
    (VU, VSL, NIKHEF/WR project team)



  - *10 Gbps data streams and amplified bidir fiber links*
    (VU, TU Eindhoven, SURFnet)

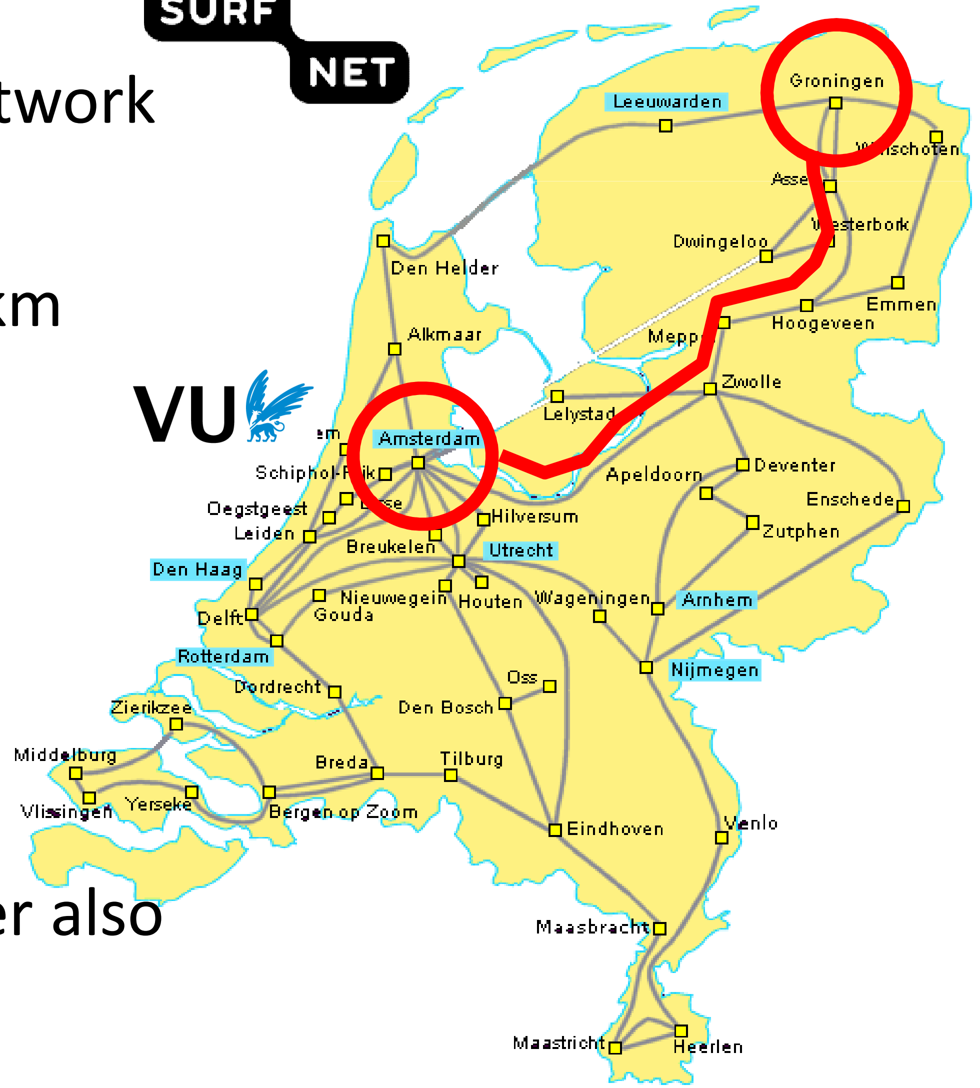
- Related: optical clocks under development
  - *Al^+ @ VU Amsterdam*
  - *Ra^+ @ KVI Groningen*



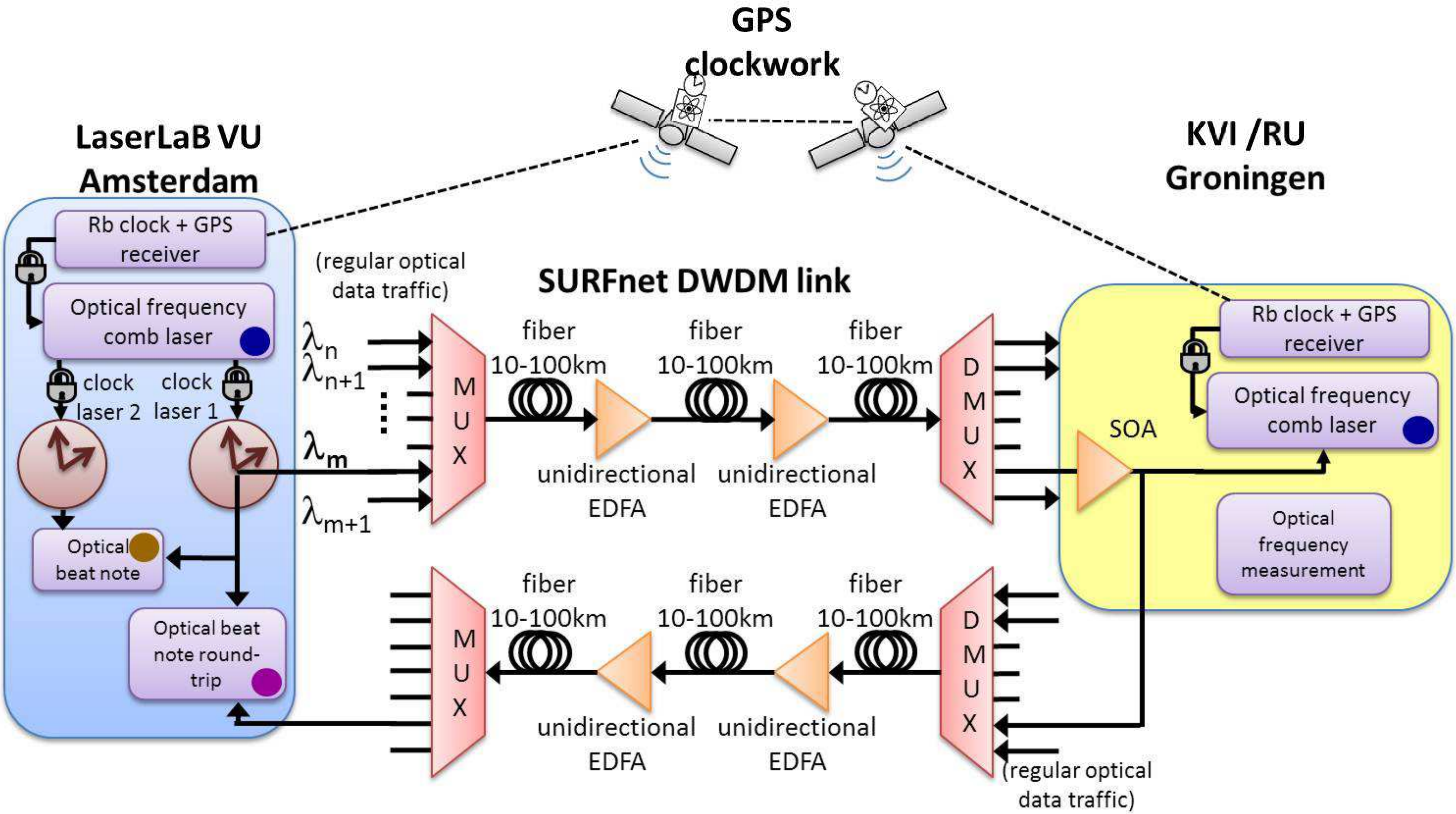
2×317 km DWDM link

2×317 km DWDM link

- Link part of SURFnet DWDM network
- Length 317 km, round trip 635 km
- Single λ-channel (1559.79 nm)
- Fiber carrying live data traffic
- Not (yet) bidirectional; dark fiber also available

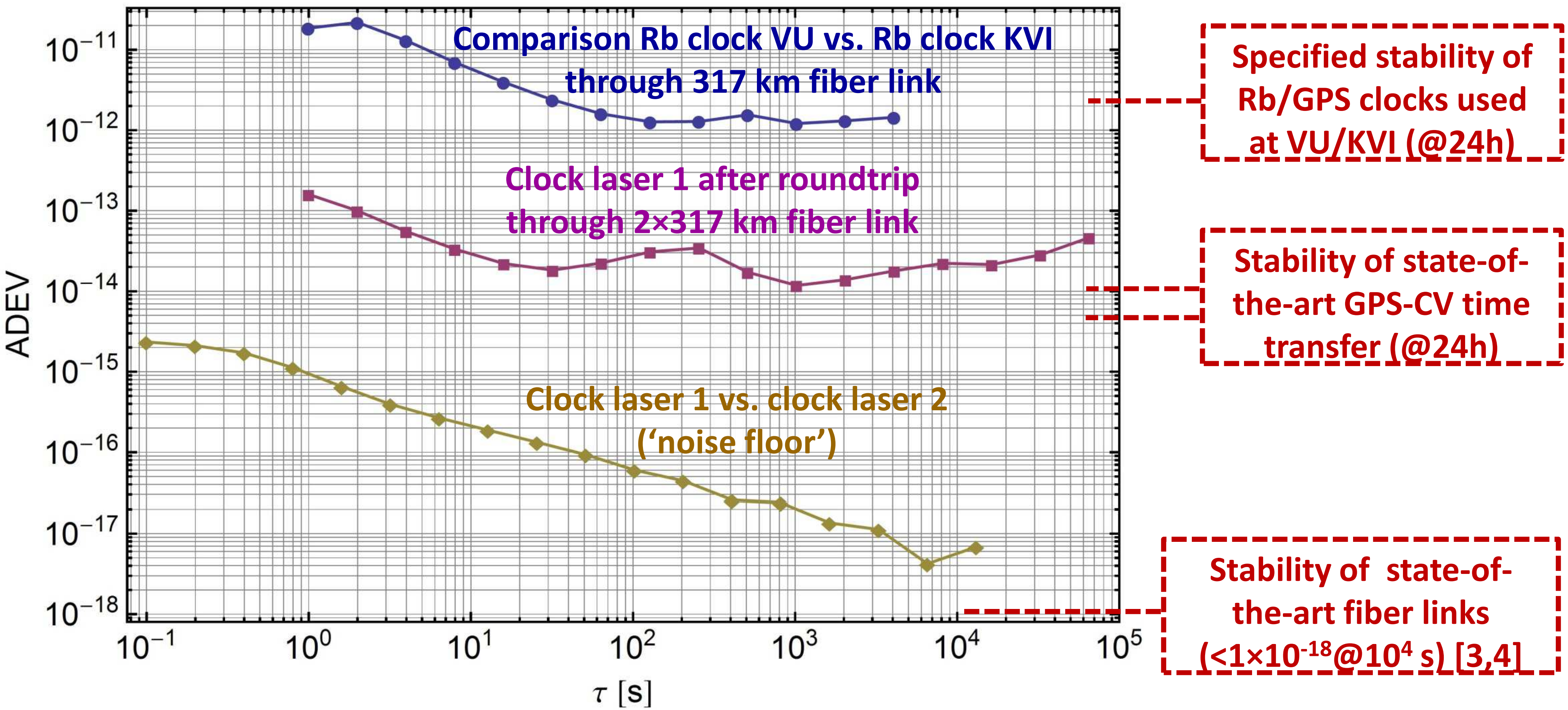


2×317 km DWDM link setup



2×317 km DWDM link stability

Results: stability measurements



Data suggest that one-way T&F transfer can back up GPS at least during short outages

(Cf. earlier data by SP/STUPI, CESNET/IPE :

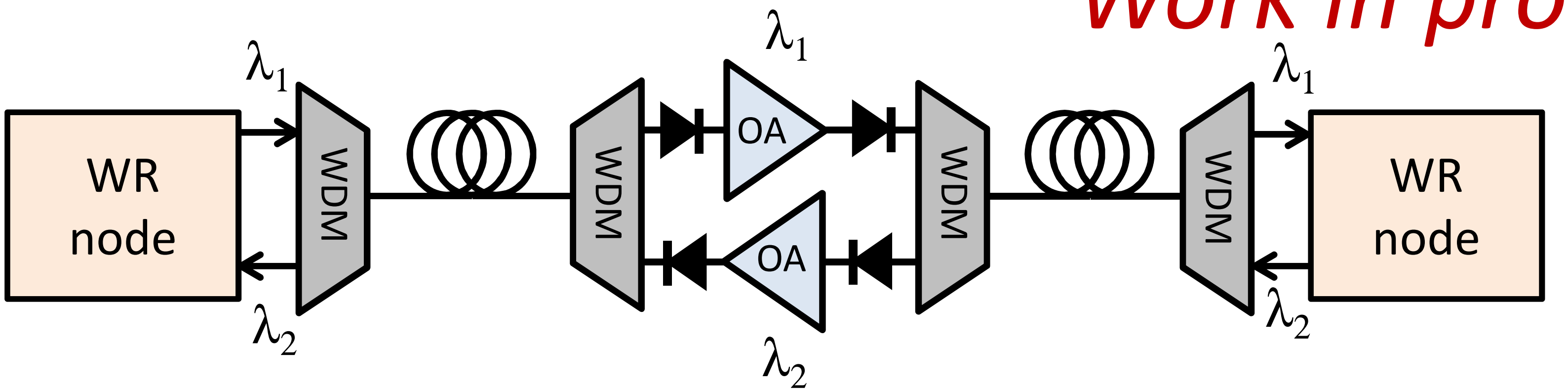
1-way TT at GPS level on timescales months – year)

Optical TFT through White Rabbit

Optical TFT through White Rabbit

- Collaboration VSL and VU with technical support from NIKHEF Amsterdam and WR project team
- WR: collaboration CERN, GSI, NIKHEF, universities, …
  Target: timing and synchronization through 1G Ethernet for accelerator facilities (using Synchronous Ethernet and PTP/IEEE1588v2)
- Aim 1: use WR equipment for dissemination of UTC(VSL) through installed telecom fiber link (u < 1 ns)
- Aim 2: demonstrate long-haul, scalable time transfer using quasi-bidirectional amplifiers (u < 1 ns)

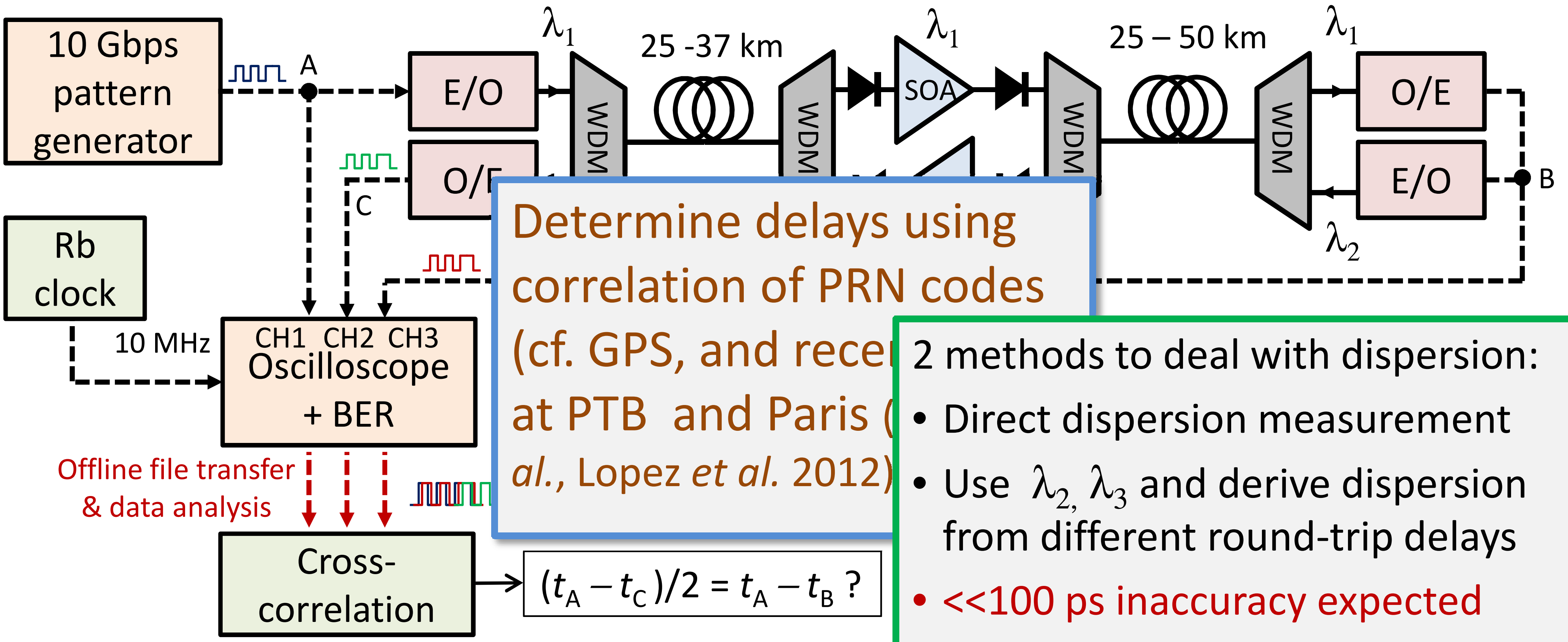
Work in progress…



Optical TFT through 10G data streams

Optical TFT through 10G data streams

- Metropolitan area networks moving towards 10G Ethernet
- 10G modulation offers better timing/frequency stability
- 10G more compatible than 1G but also more dispersion
- Collaboration VU, TU Eindhoven: laboratory test setup

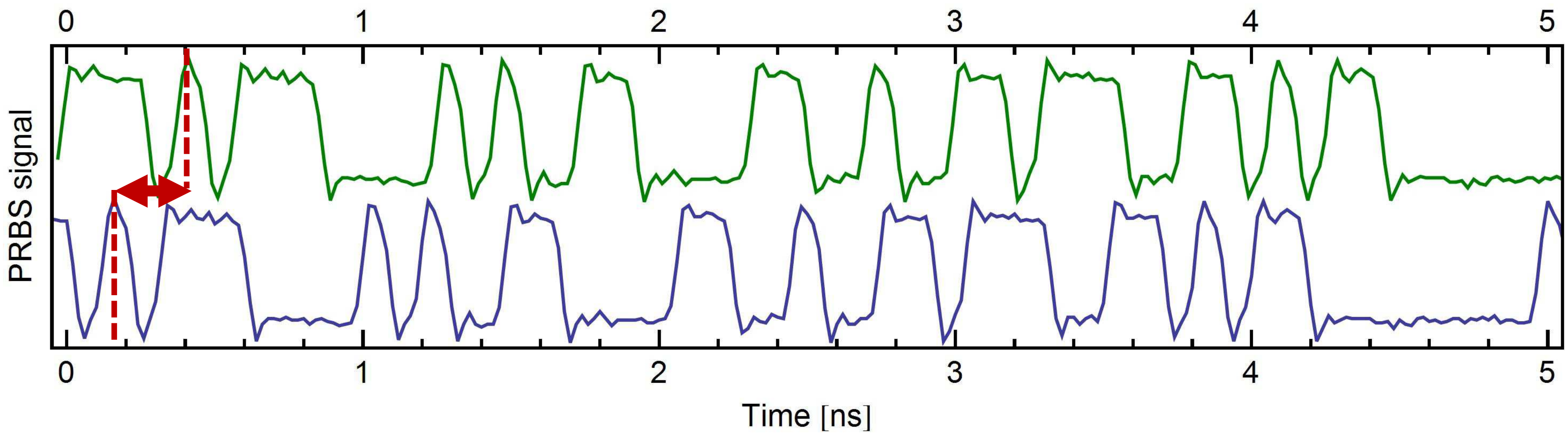


Determine delays using correlation of PRN codes (cf. GPS, and recen at PTB and Paris (al., Lopez *et al.* 2012)

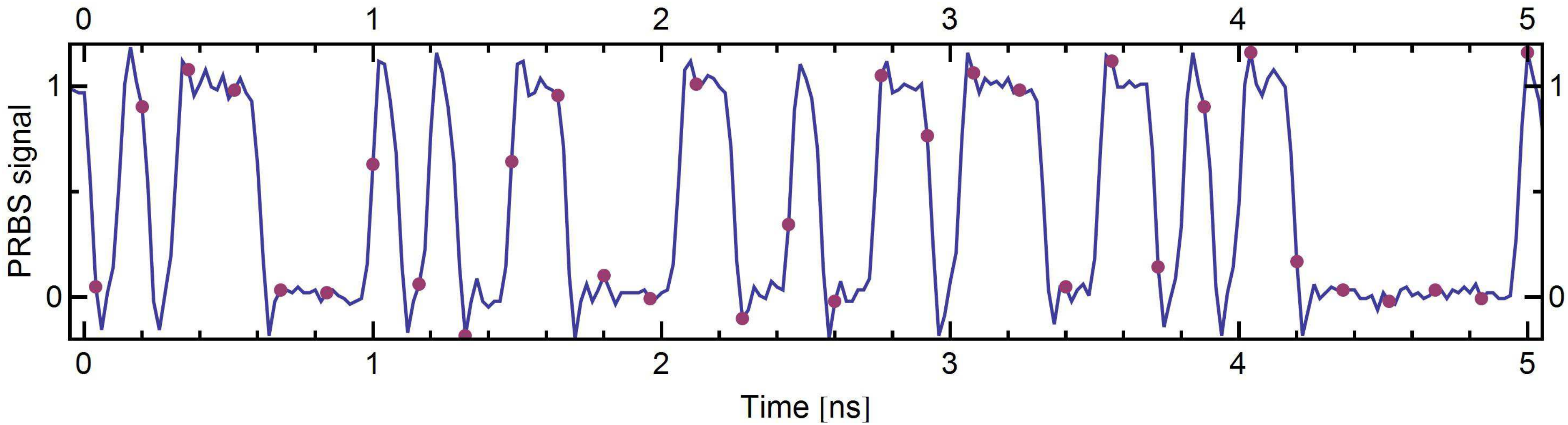
2 methods to deal with dispersion:

- Direct dispersion measurement
- Use λ_2, λ_3 and derive dispersion from different round-trip delays
- <<100 ps inaccuracy expected

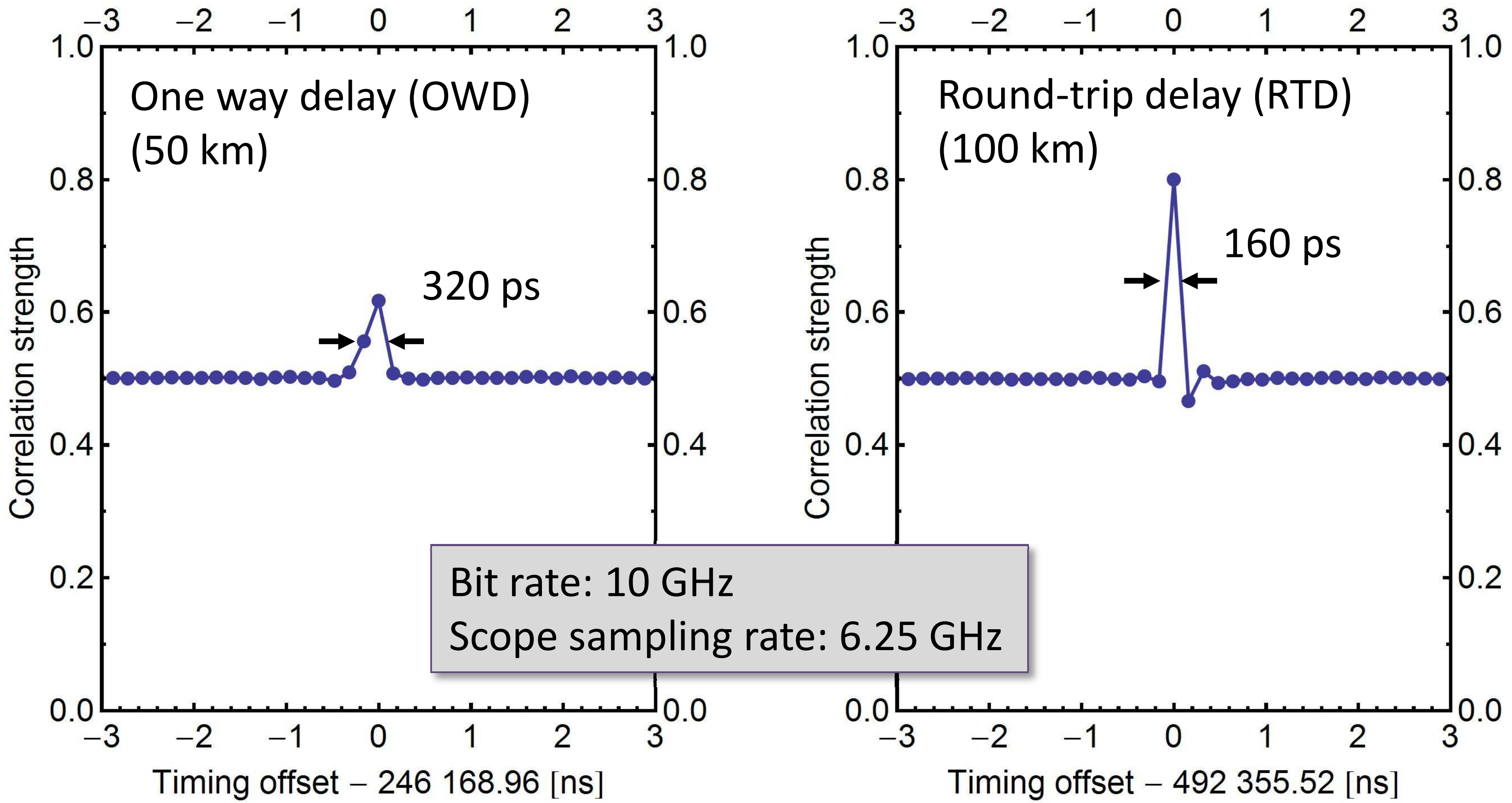
10G pseudo-random bit sequence



- Symbol length 100 ps
- Word length 2^{23}–1 is longer than ~1 ms round-trip time
- First test: sample 10 G PRBS at 6.25 GS to speed up correlation

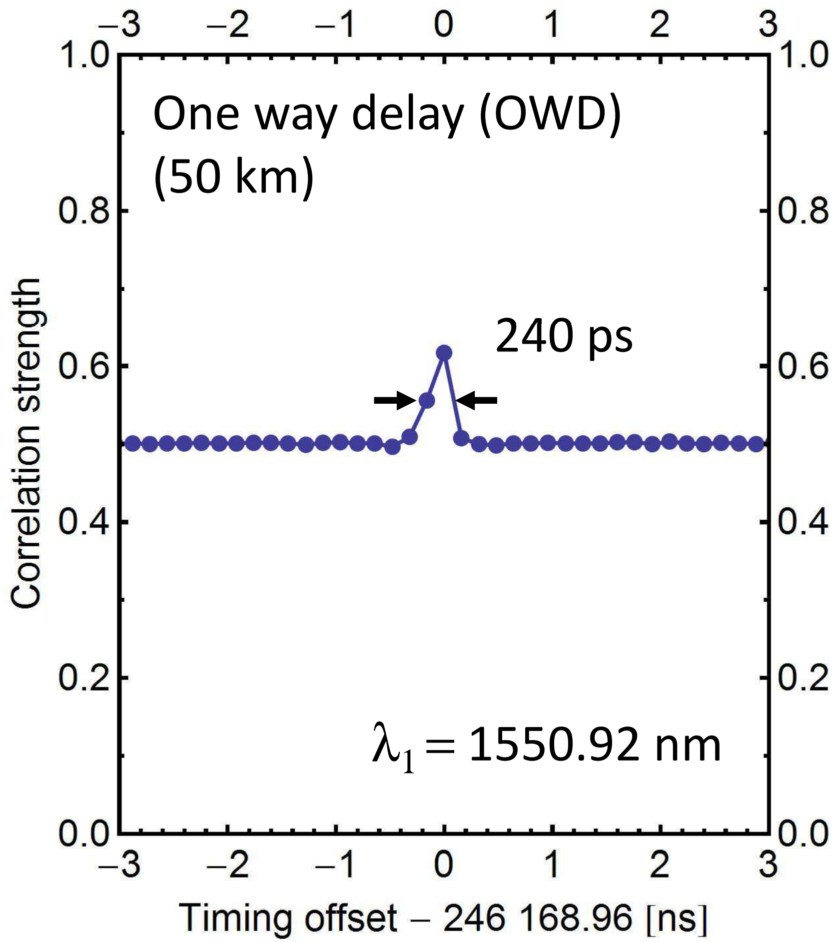


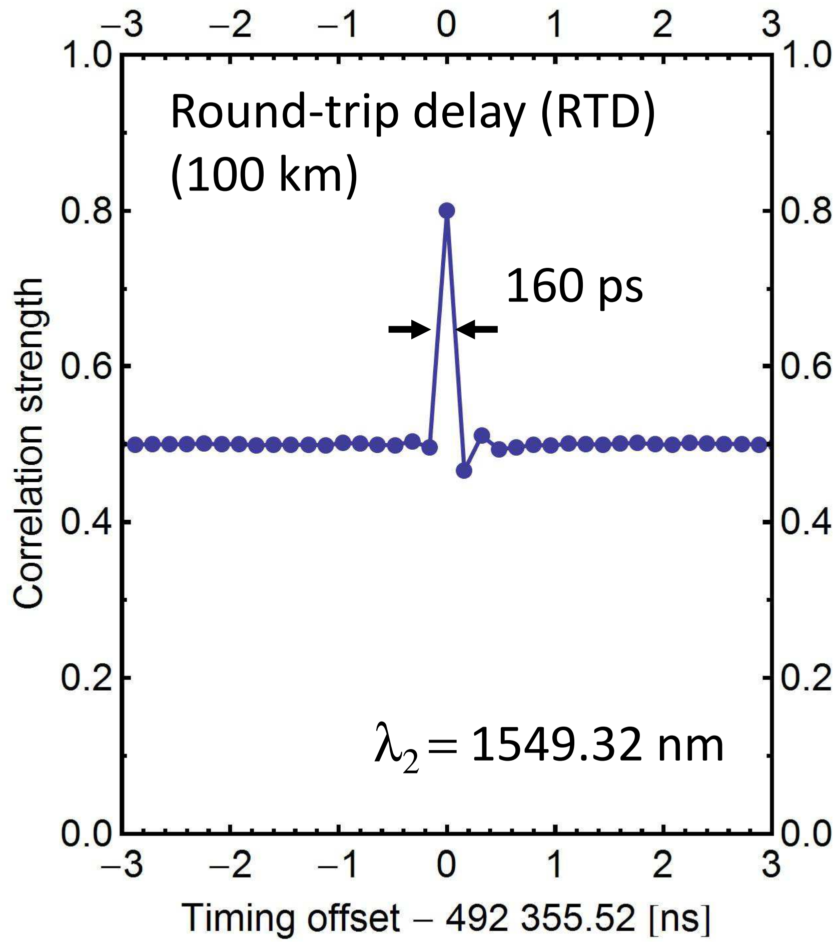
Preliminary results (last week)



- Intrinsic device delays not yet measured, rough estimate based on fiber/copper lengths ± 10 ns. Target <<100 ps
- **TFT *and* 10G communication possible with zero BER!**

Preliminary results (last week)





	Delay [ns]	Δ [ns]	Disp. asymm. [ns]	Device asymm. [ns]
OWD (direct)	**246 169.0(3)**		–	–
OWD (from RTD)	**246 173(10)**	**4(10)**	1.34(6)	13(10)
Sellmeier	246 222(50)	53(50)	–	–

To do list

- Measure device delays using correlation method
  - Target <<100 ps
- Compare the two methods for dispersion correction
  - Direct measurement
  - $\mathrm{OWD}(\lambda_1) \approx \frac{\lambda_1(\tau_{12}-\tau_{13}) + \lambda_2\tau_{13} - \lambda_3\tau_{12}}{2(\lambda_2-\lambda_3)}$
- (Hopefully) achieve <100 ps accuracy time transfer
- Measure frequency stability
- Implement lightweight correlation algorithm: correlate bit vectors (00110101010110...) rather than oscilloscope traces

Outlook: TWTT + one-way FT

- Assume 100 ps timing accuracy (via 10G or WR)
- Assume one-way frequency dissemination
- Typical stability of one-way fiber frequency transfer at 10G:
  - ADEV(1s) = 10^{-13} ⇔ TDEV = 60 fs
  - ADEV(2hrs) = 2×10^{-14} ⇔ TDEV = 80 ps

  ⇒ *every 2 hrs new synchronization required to maintain 100 ps timing accuracy*
- Possible technology for long-haul, sub-ns level **timing + data** link for OPERA experiment CERN-LNGS
- $c \times 100$ ps = 3 cm ⇒ 'SuperGPS' positioning

Thanks!

- Tjeerd Pinkert, Matthijs Jansen, Wim Ubachs, Kjeld Eikema (VU)
- Roeland Nuijts, Richa Malhotra, N.O.C. (SURFnet)
- Oliver Böll, Lorenz Willmann, Elwin Dijck, Bart Groeneveld, Klaus Jungmann (KVI/RU Groningen)
- Huug de Waardt, Chigo Okonkwo (TU Eindhoven)
- Erik Dierikx, Marc Pieksma (VSL)
- Henk Peek, Peter Jansweijer (NIKHEF), White Rabbit Team

Correlation PMD and path length?

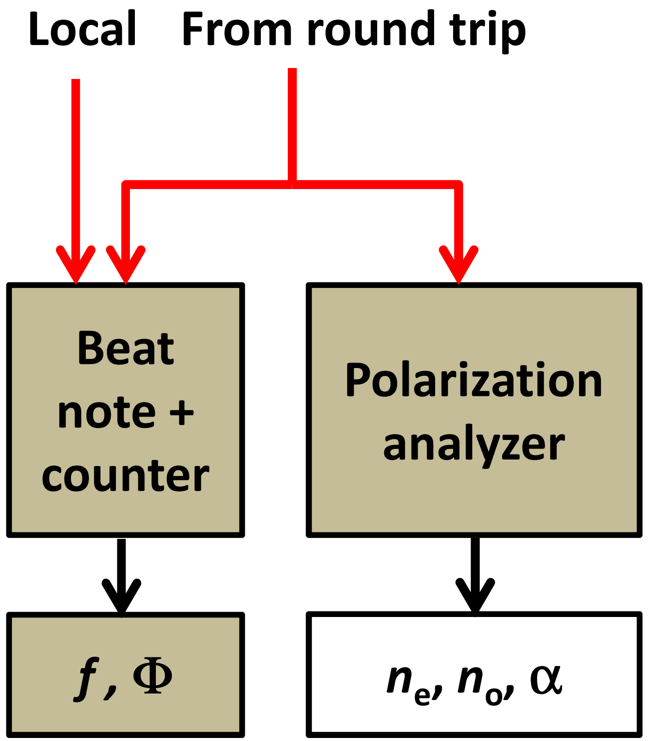
- One-way fiber frequency transfer limited by optical path length variations (acoustic, thermal origin)
- Polarization state fiber link output varies due to varying PMD (acoustic, thermal origin)
- Do PMD and length variations correlate? If so, improve one-way time transfer!
- Cf. two-color compensation based on chromatic dispersion SP (Ebenhag *et al.* 2010)
- Model fiber as uniaxial birefringent medium (L, n_o, n_e and α)
- Optical beat note after fiber transmission:

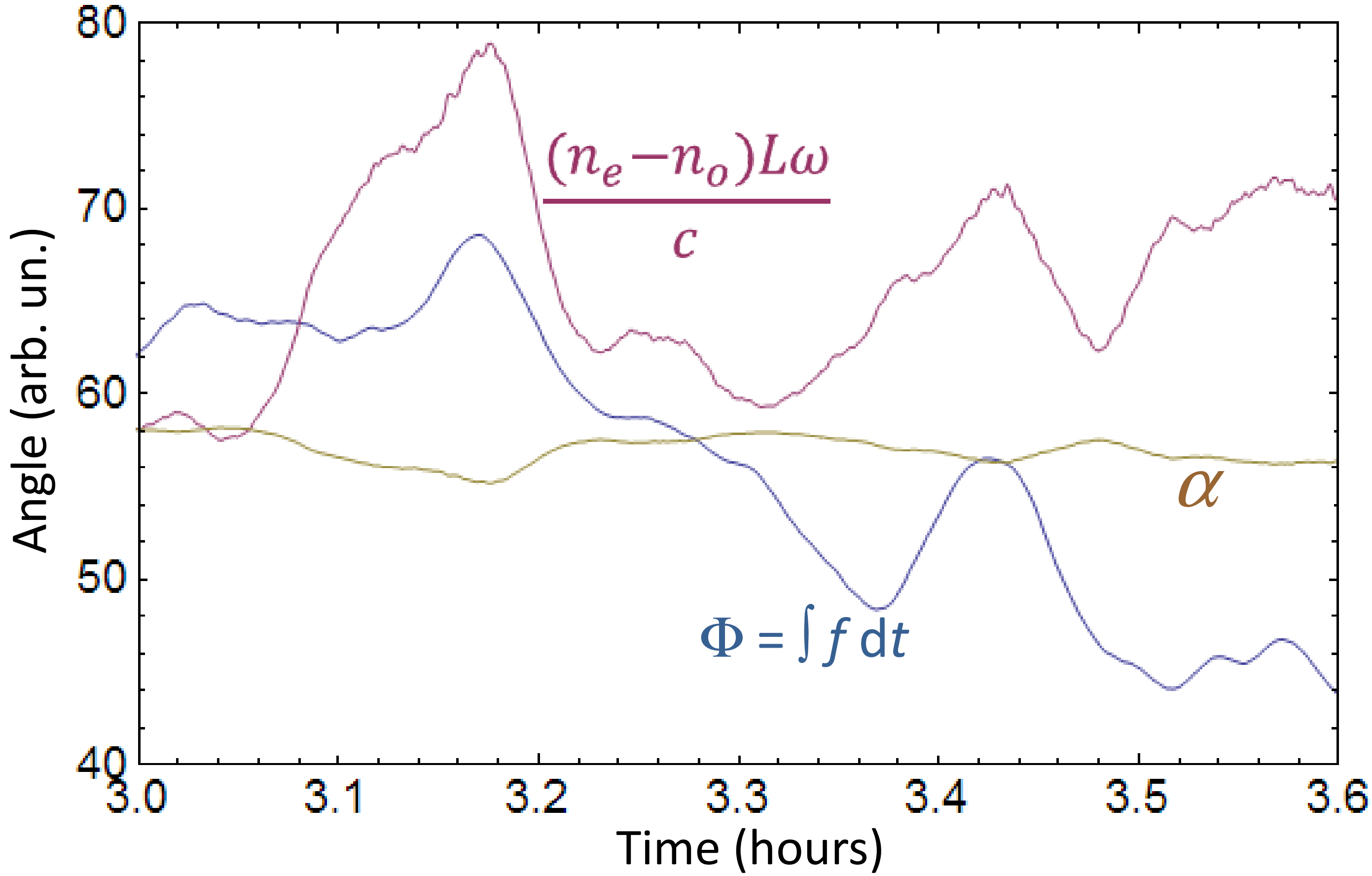
$$\Phi_{\text{beat note}} = \Omega t + \frac{n_o L\omega}{c} + \operatorname{arccot}\left[\cot\left(\frac{(n_e - n_o)L\omega}{c}\right) + \cot^2\alpha \csc\left(\frac{(n_e - n_o)L\omega}{c}\right)\right]$$

Frequency fluctuations

Infer from polarization

PMD versus frequency variation





- Polarization data: variation of n_o, n_e and α with time
- Frequency counter data: variation of L and n_{iso}
- Pol. and f time series show similarities, but no 1:1 correlation ☹
- PMD and length variations occur in different locations along fiber