Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

SQuaD
Schirmprojekt Quantenkommunikation Deutschland

Niedersachsen Time-Frequency and Quantum Communications Testbed

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Content

SQuaD
Schirmprojekt Quantenkommunikation Deutschland

offers a central point of contact for expertise and infrastructure for the evolving quantum communications in Germany

QRX

over 40 partners from research & industry aimed to realize quantum repeater networks

SQuaD Project

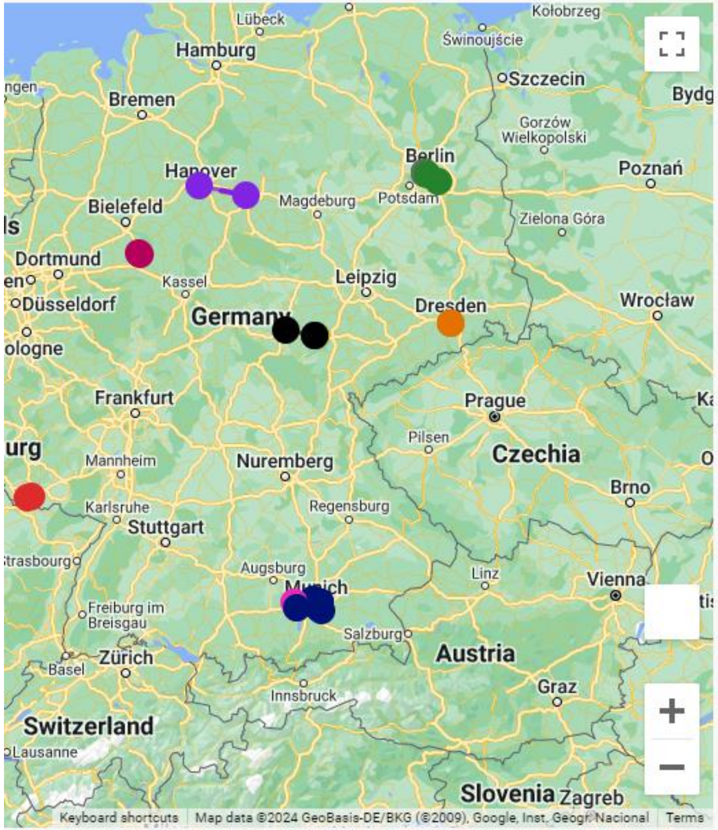
Testbed objectives:

- provide infrastructure
- knowledge and experience transfer

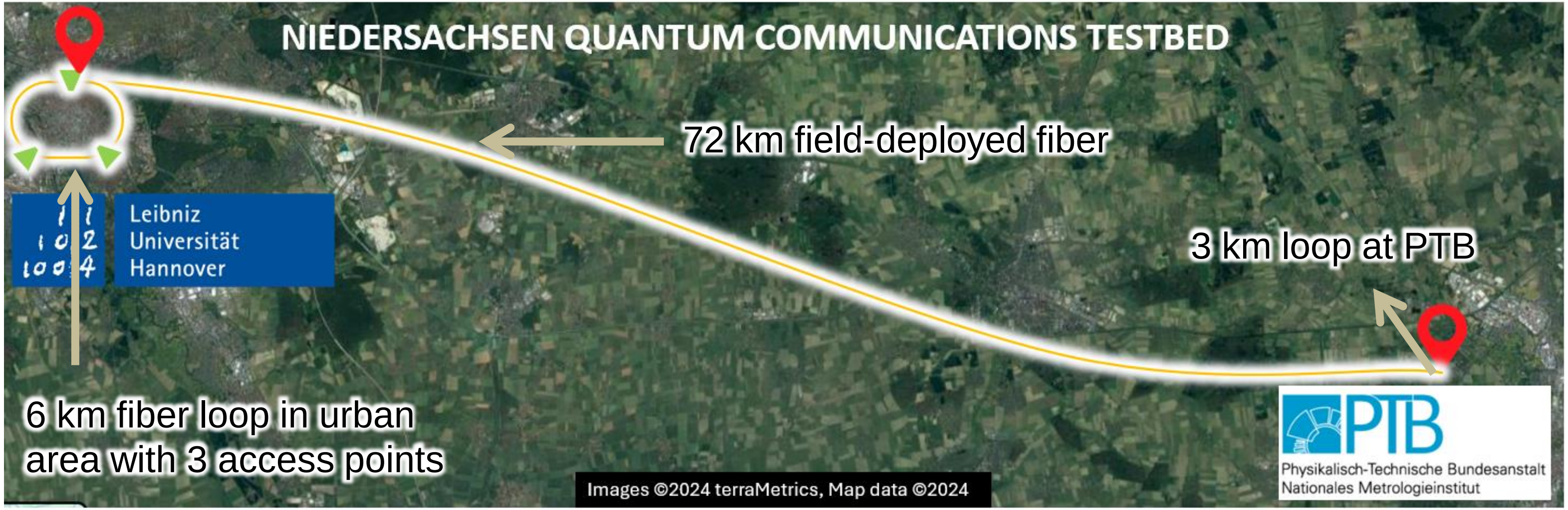
www.squad-germany.de

Testbeds map includes:

- fiber optic networks (so-called dark fibers)
- free-space links
- base stations for satellite transmission
- testbeds to characterize single-photon sources and detectors.



Niedersachsen Q-Testbed

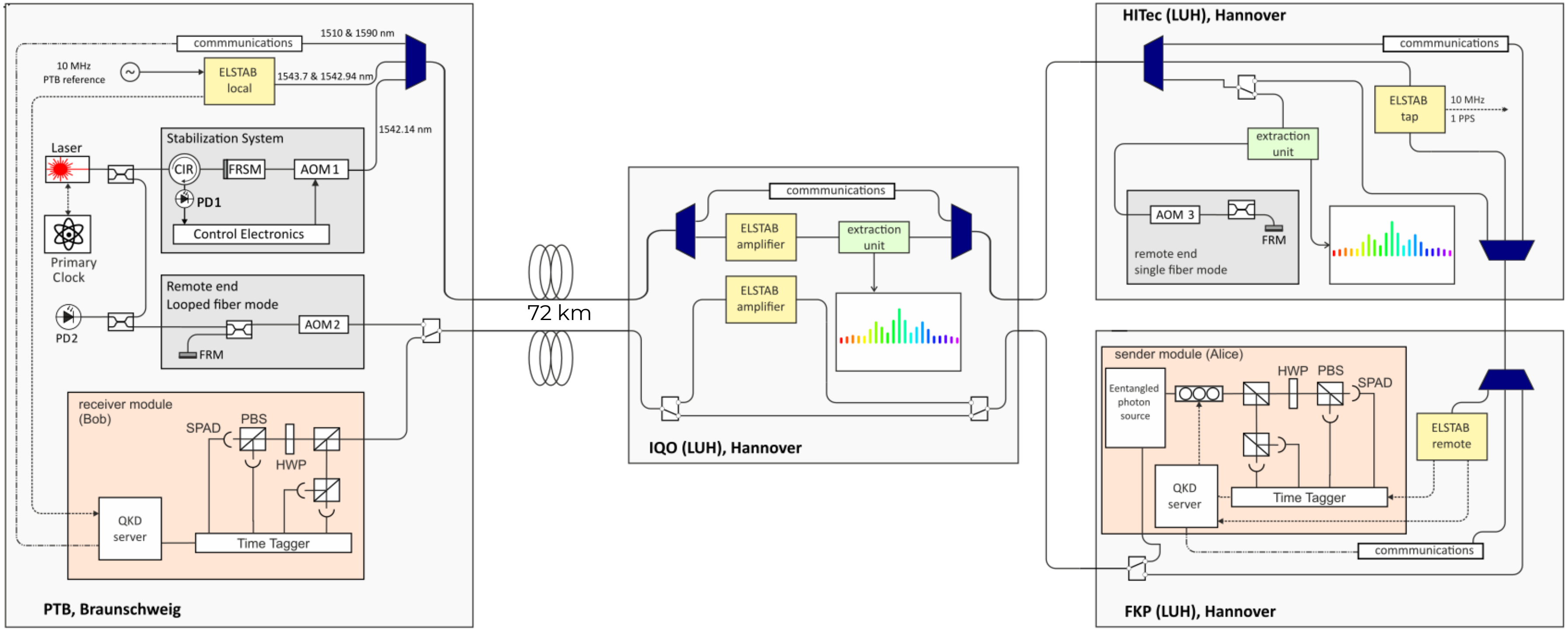


- Access points: Leibniz University of Hannover (LUH), Hannover – PTB, Braunschweig
- Field-deployed fiber length: about 72 kilometers
- Type of the fiber: Single-mode fiber
- Operator: PTB and LUH

Niedersachsen Q-Testbed

ELSTAB: 1543.73 nm , 1542.94 nm
Optical carrier: 1542.14 nm
Communications: 1490 nm , 1510 nm

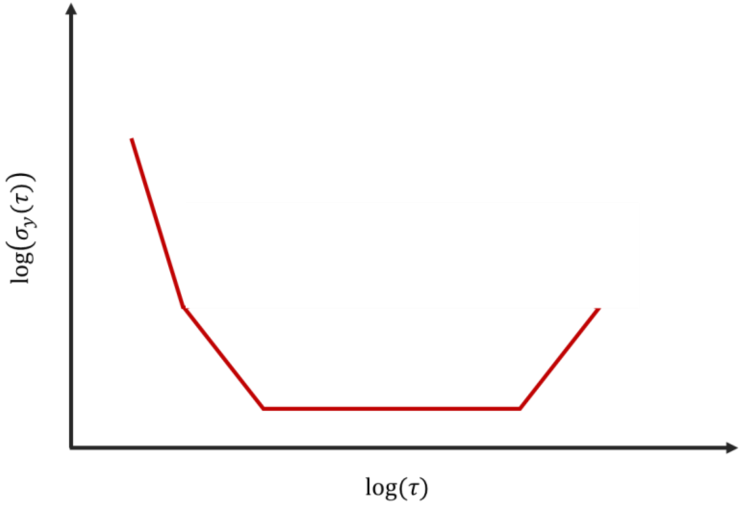
TFD fiber: PTB-IQO-HITec-FKP
QKD fiber: PTB-IQO-FKP



Dissemination Characterization

Stability indicates how well an oscillator can produce the same time or frequency offset over a given time interval.

- frequency stability is estimated by the Allan variance or deviation
- it is represented as a **function of averaging time**

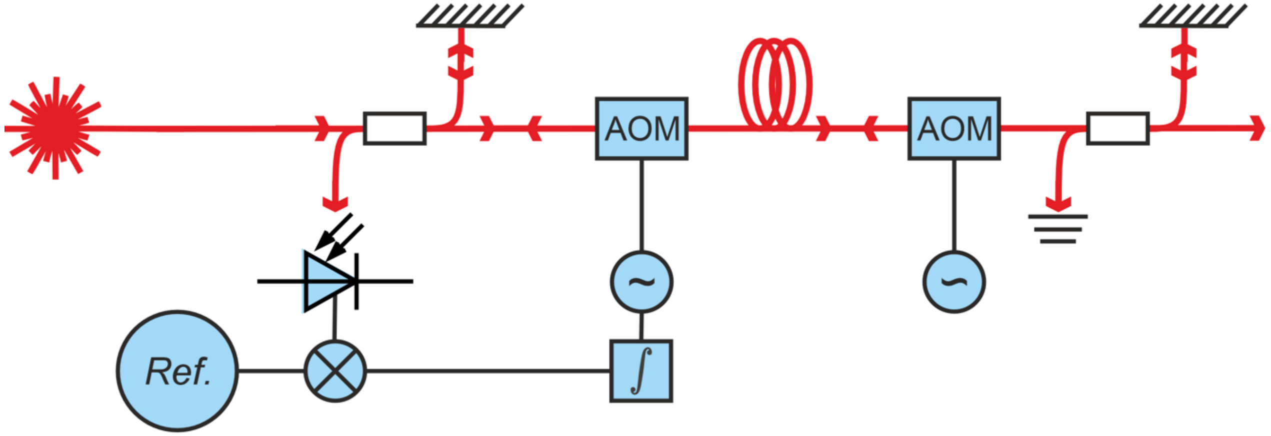


M. Lombardi: Fundamentals of Time and Frequency, NIST 2002

Optical Frequency Dissemination

Ultra-stable frequency dissemination via IFL

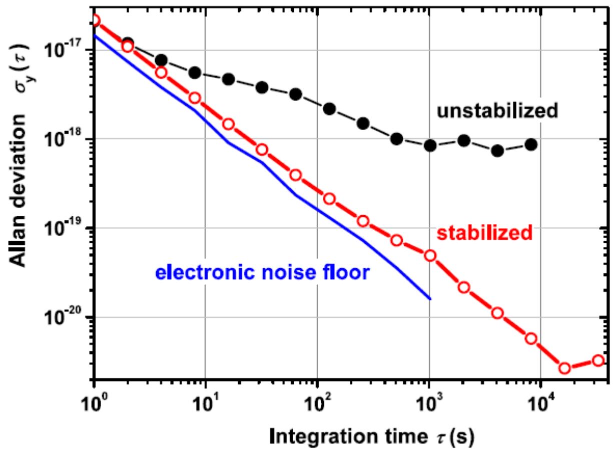
- environmental perturbations
  → optical path length variations (phase noise)
  → phase stabilization is required (Bi-directional transmission)

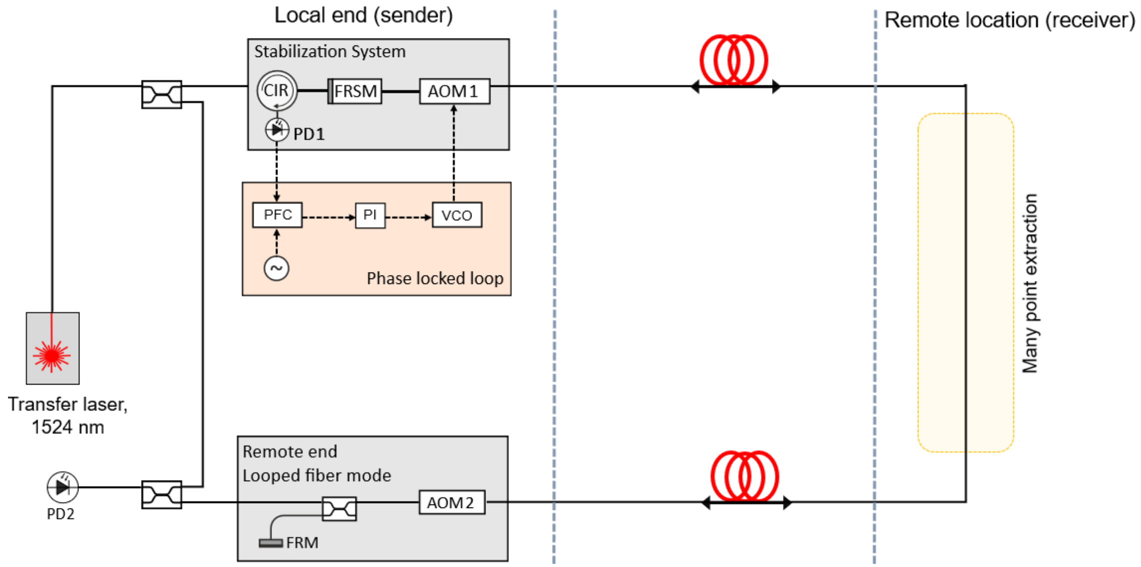


Optical Frequency Dissemination

- For assessing the frequency transfer performance:
  - out-of-loop characterization by looping back using another fiber
  - comparing the loop output signal to the input of the IFL.

O. Terra et al. DOI: 10.1007/s00340-009-3653-2

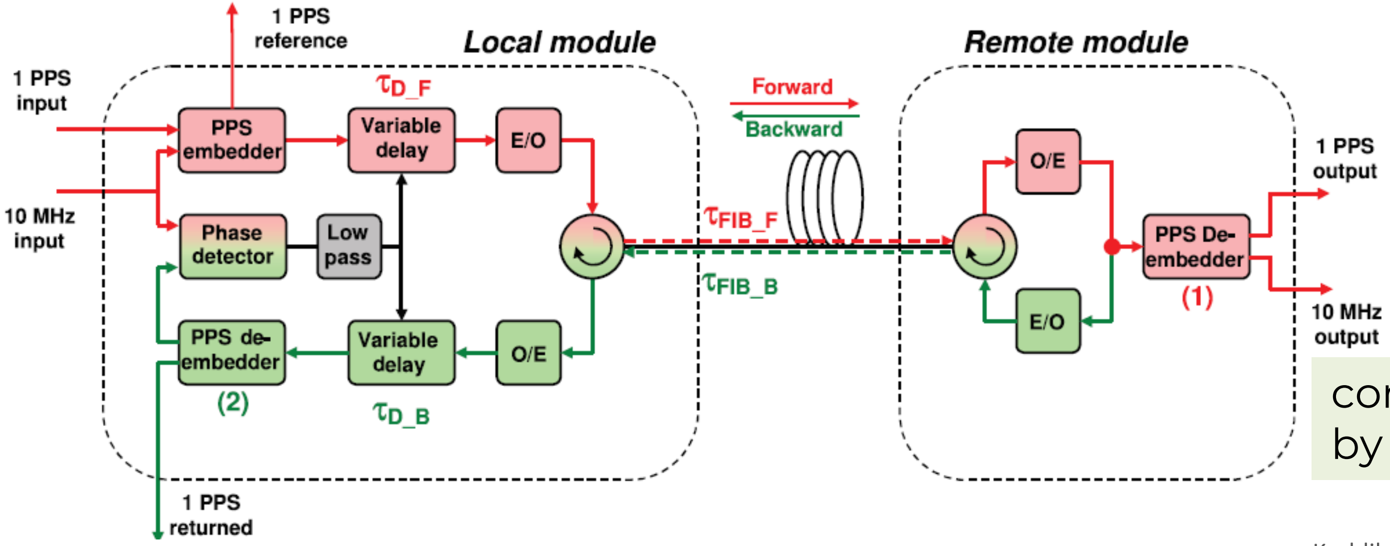




fractional frequency instability: $< 10^{-19}$

ELSTAB

- <u>El</u>ectronically <u>stab</u>ilized fiber-optic time and frequency distribution
- Electronic delay lines on chip for time & frequency transfer with AM light



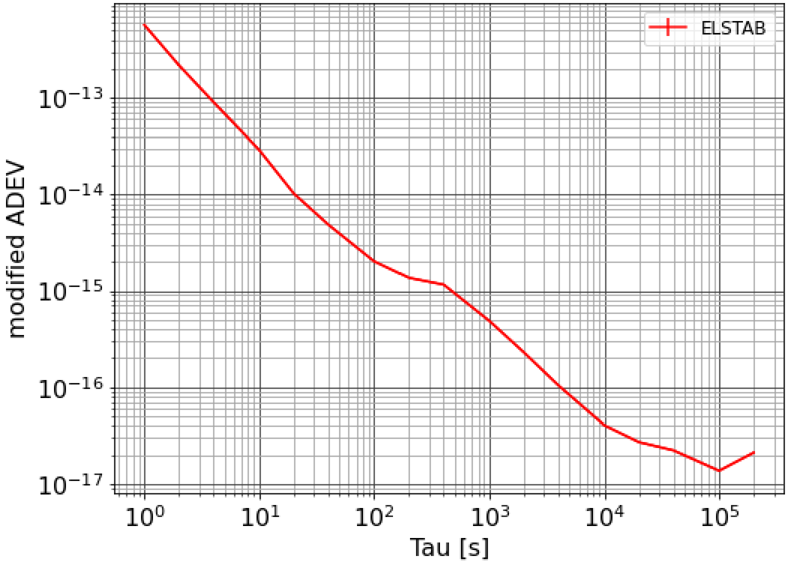
commercially available by PIKTime Systems

Krehlik et al. DOI: 10.1109/TUFFC.2015.2502547

ELSTAB

- Can be wavelength multiplexed with optical carrier.
- Delivers electronic 10 MHz & 1 PPS for the synchronization of instruments

A-K. Kniggendorf, IMEKO 2024



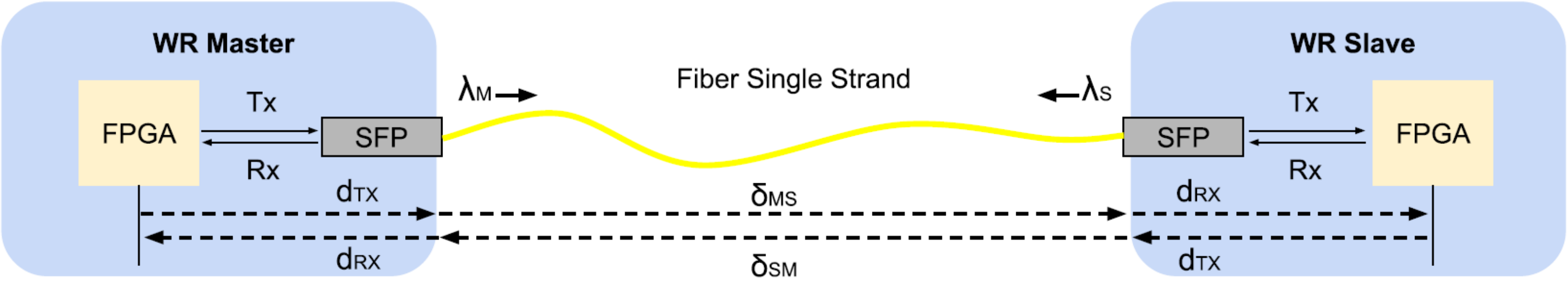
Fractional frequency instability $< 10^{-16}$

PTP White Rabbit

M. Lipinski et al., DOI: 10.1109/ISPCS.2011.6070148

Key Concepts

- sub-nanosecond synchronization developed at CERN
- standard ethernet infrastructure (making it cost-effective and easy to integrate into existing network setups)
    - Precision Time Protocol (PTP) for coarse synchronization
    - synchronous Ethernet (SyncE)



T-F Dissemination Techniques

Techniques

Optical carrier

- Instability:
  - 10^{-15} (short term)
  - $< 10^{-19}$ (one hour)
- Implementation: Complex
- No PPS signal

ELSTAB

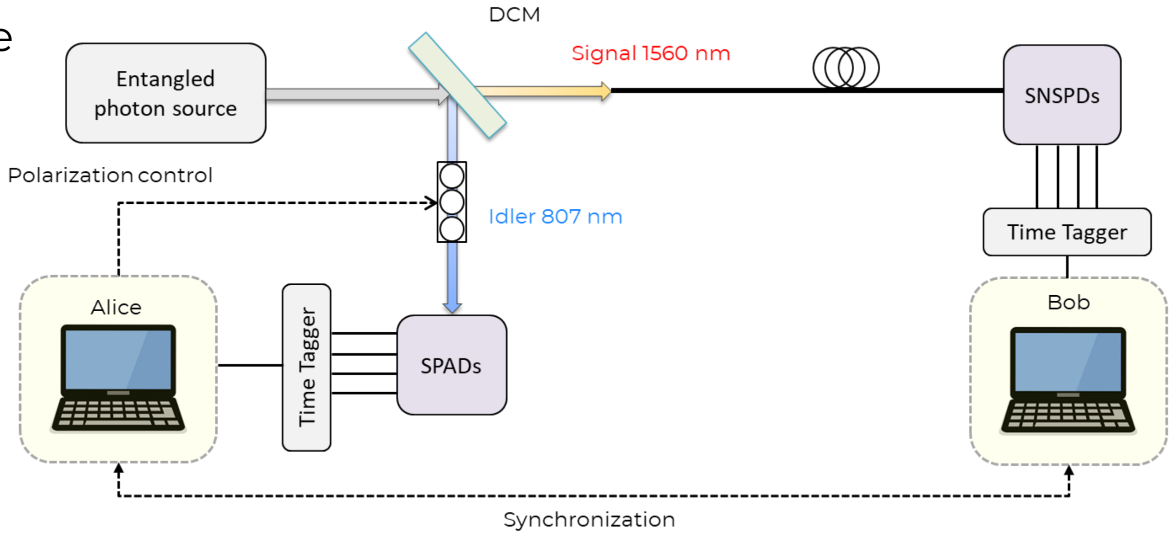
- Instability:
  - 10^{-13} (short term)
  - $< 10^{-16}$ (one day)
- Implementation: commercially available, fixed wavelength of the installed system.
- PPS

White Rabbit

- Instability:
  - 10^{-12} (short term)
  - $< 10^{-14}$ (one day)
- Implementation: commercially available, flexible wavelength
- PPS

Quantum Key Distribution

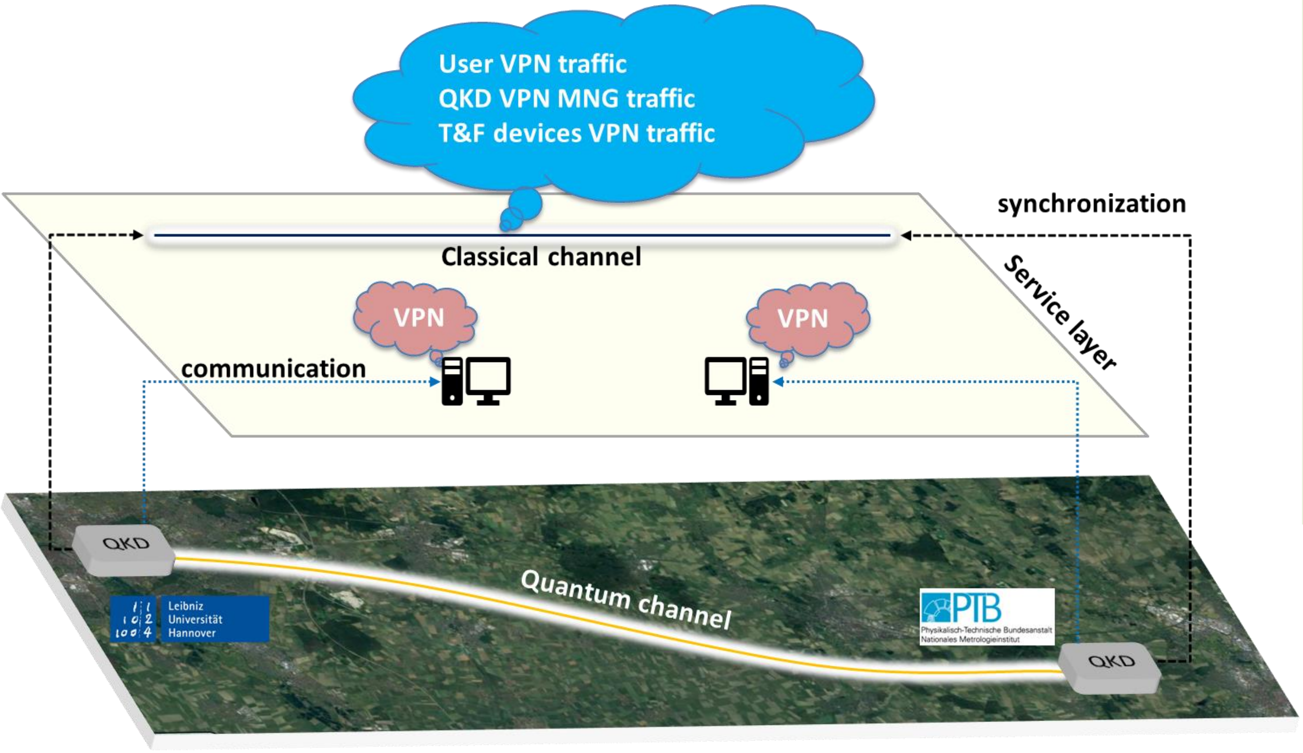
- The QKD system uses BBM92 protocol
- Entangled photon source based on spontaneous parametric down conversion
- polarization state at the far end is detected by superconducting nanowire single photon detectors



Developed by:

QUANTUM OPTICS JENA

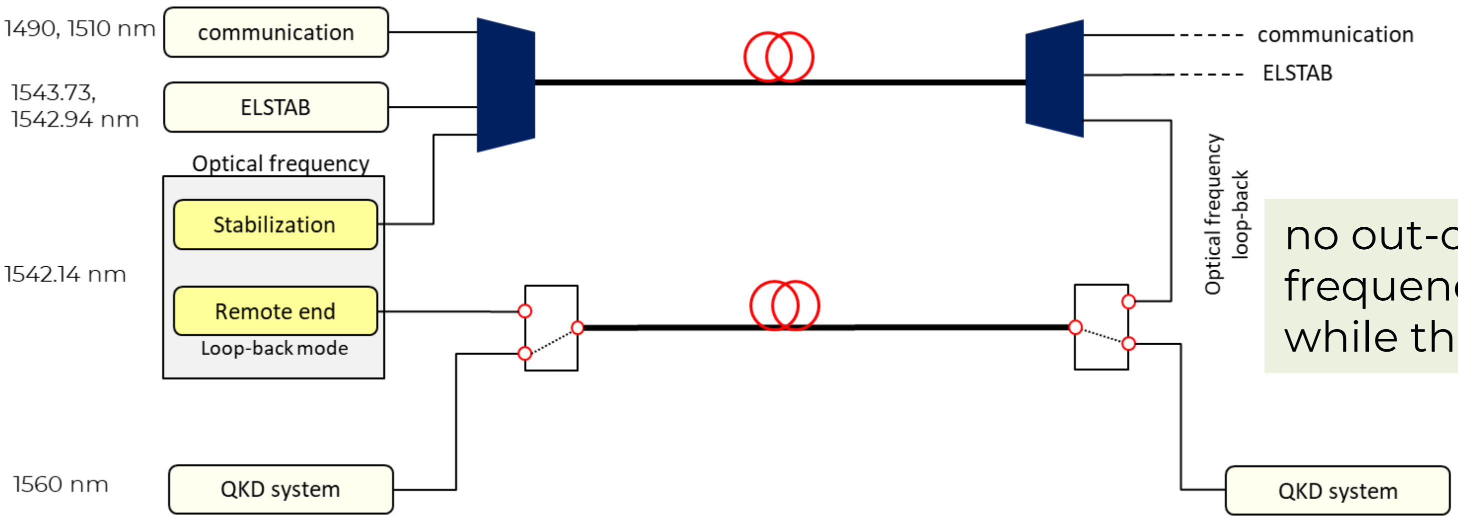
Communications Scheme



- Synchronization and communication signals are transmitted over separate classical channel
- QKD management communication is isolated in separate VPN
- QKD user traffic can also be isolated in a separate VPN

Mode of Operation: Separated Fibers

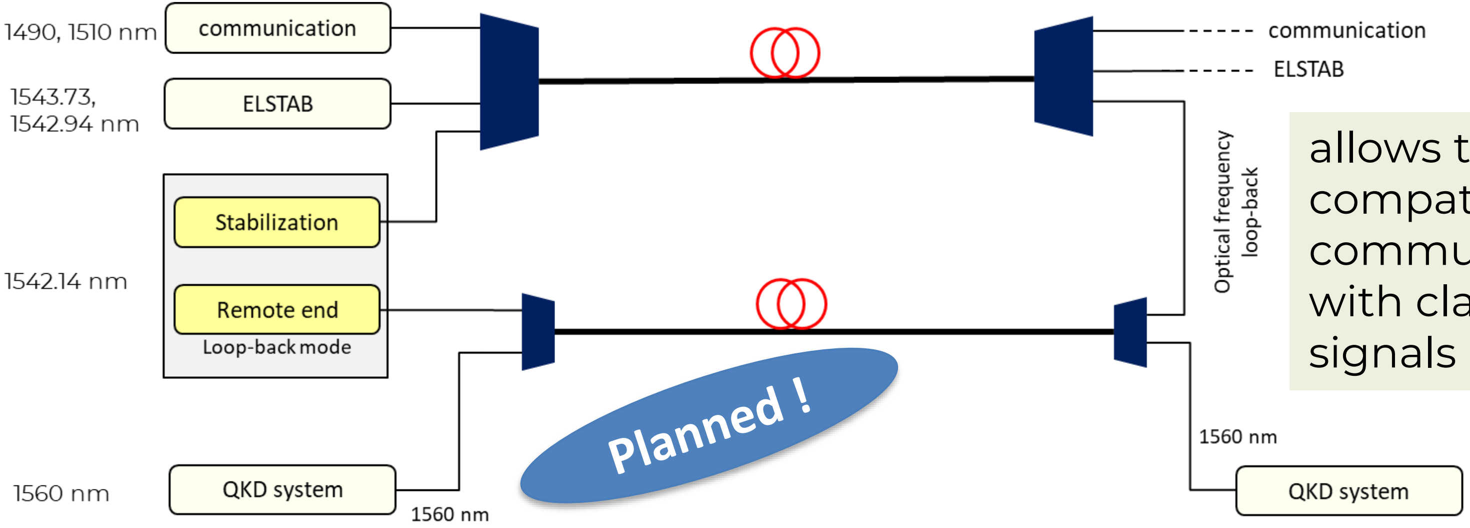
- Separate operation of QKD and TFD
- Better SNR for QKD in the absence of background photons
- Remote controlled optical switches for flexible management of QKD and TFD transmissions



no out-of-loop control for frequency dissemination while the QKD is operating

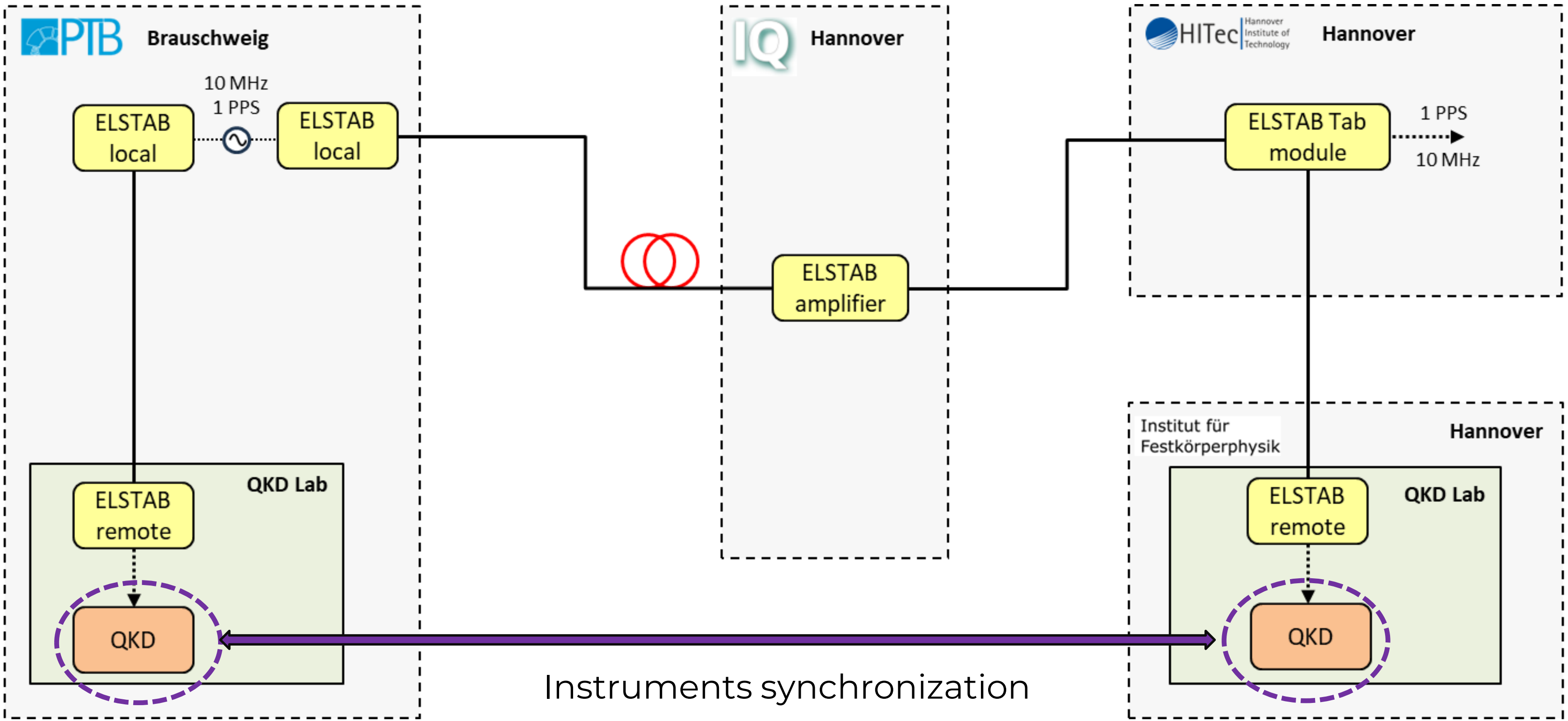
Mode of Operation: Shared Fibers

- Simultaneous operation of QKD and frequency dissemination via wavelength multiplexing
- Allows use of the existing clock-comparison fiber link network

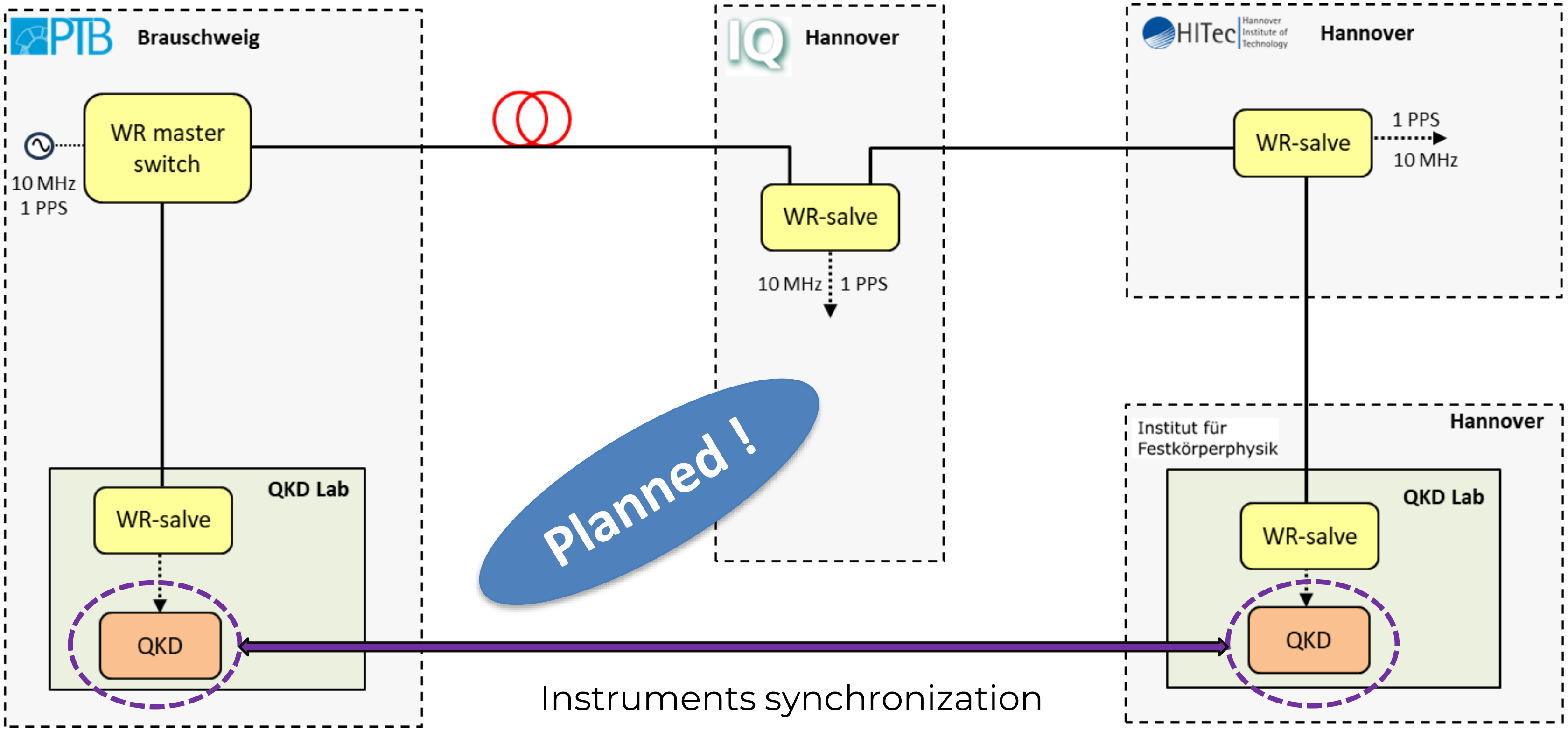


allows to test the compatibility of quantum communication systems with classical optical signals

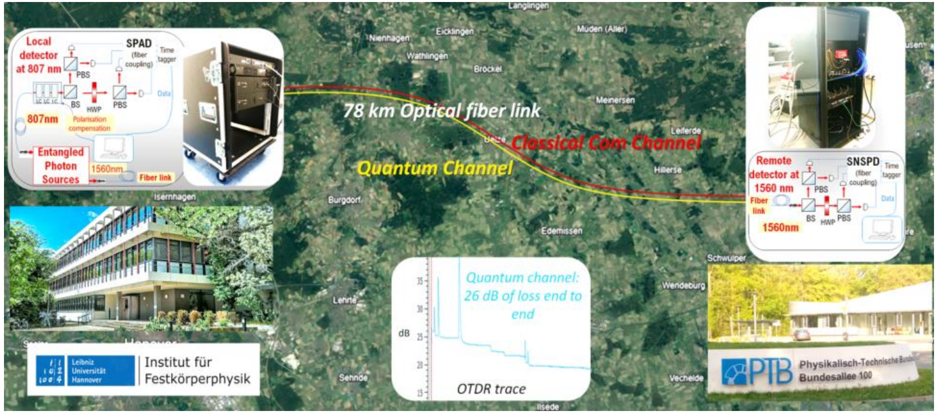
QKD Devices Sync: ELSTAB



QKD Devices Sync: White Rabbit



QKD Experiments



- The source module (Alice) set at LUH (FKP building) and the receiver at PTB (Bob)

- Transfer quantum encrypted signal
- Adapting of an existing fiber link for quantum communication
- Simultaneous transmission of QKD and T-F signals

Ali Hreibi https://www.ptb.de/

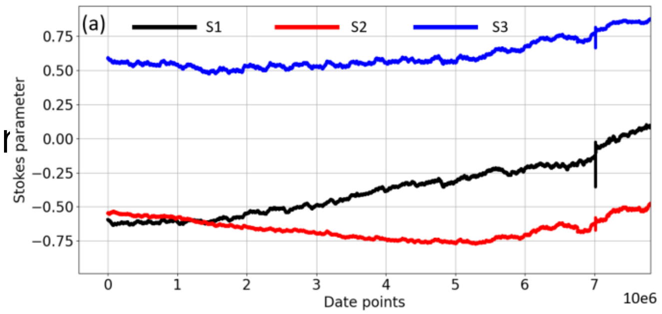
Quantum Channel Characterizations

- Quantum communications
  → maintain Quantum state of the photons during the transmission.
- Acoustic noise and thermal variations
  - polarization fluctuations
  - timing drift and phase fluctuations
  - Noise photons from classical channels
  → high QBER or Quantum communication failure.

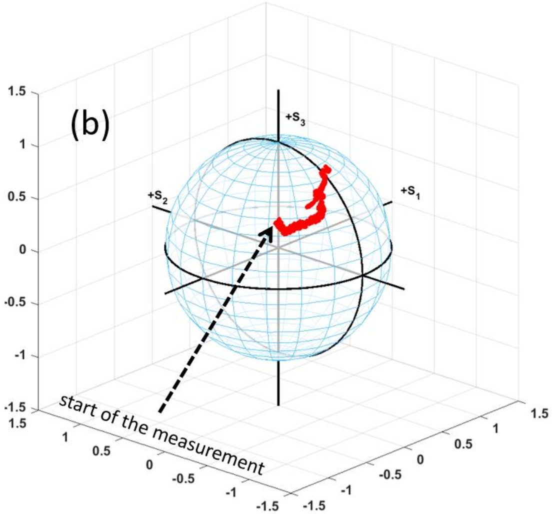
Network performance and stability, including phase, polarization, and loss MUST be monitored, evaluated and optimized

Polarization

- Induced birefringence in fibers
  → lead to polarization transformations drift over tir
  as the fiber environment changes

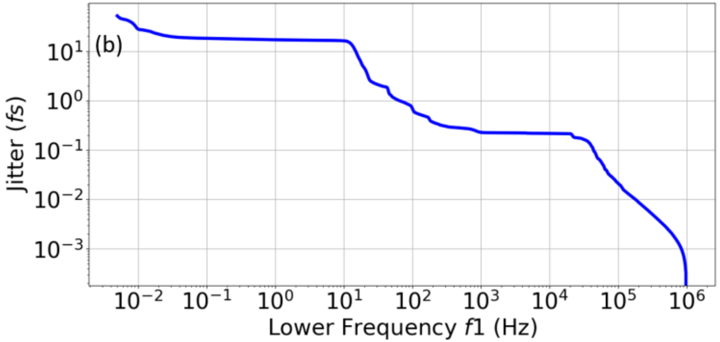


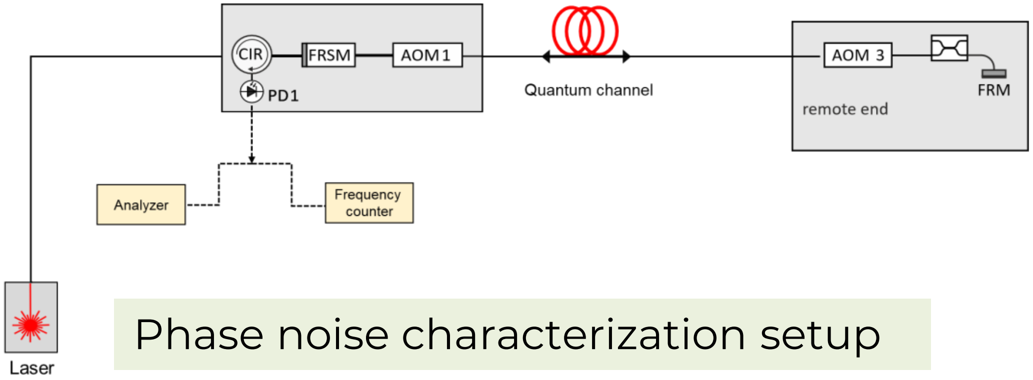
- Polarization Stokes parameters S1, S2, and S3
  are recorded at a rate of 95 Hz for several days.



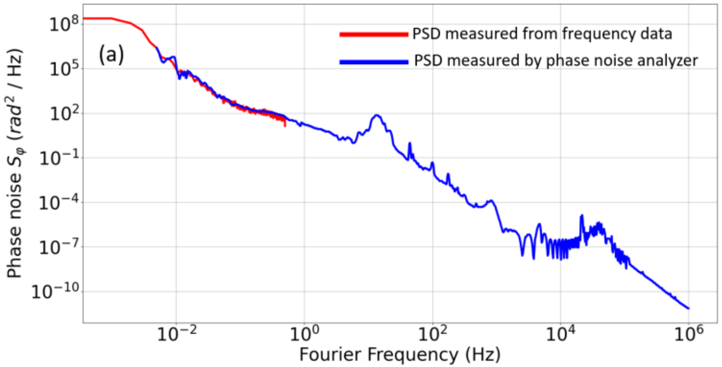
Phase Noise

- Acoustic noise and thermal variations cause phase fluctuations.



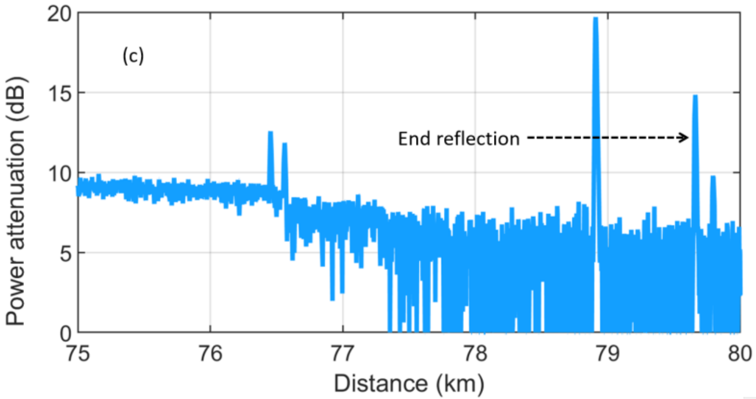


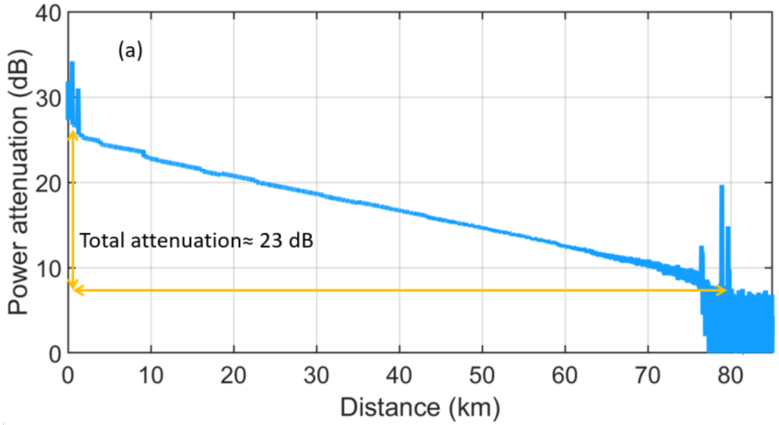
Phase noise characterization setup

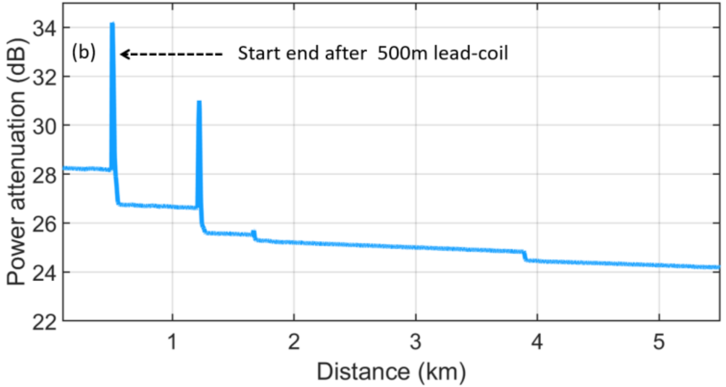


Attenuation

- Optical time reflectometry (OTDR) of the deployed quantum link to investigate the loss and reflections profile.
- The average attenuation coefficient of the fibre is 0.2 dB/km.



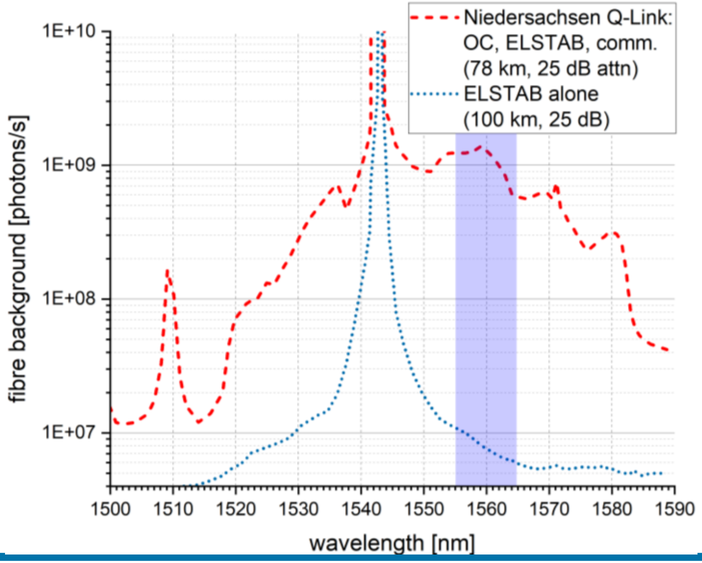




Noise Photons

- To test the compatibility of quantum communication systems with conventional optical networks
  → noise photons must be characterized
- The background photons from time and frequency signals are measured by single photon detector
- Bidirectional T&F signals generate photonic back-ground (noise photons) in the QKD channel

  → dominated by bidirectional Raman scattering



A-K. Kniggendorf, IMEKO 2024

Thank you !

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