# 32-Channel WDM Transmitter based on a Single Off-the-Shelf Transceiver and a Time Lens

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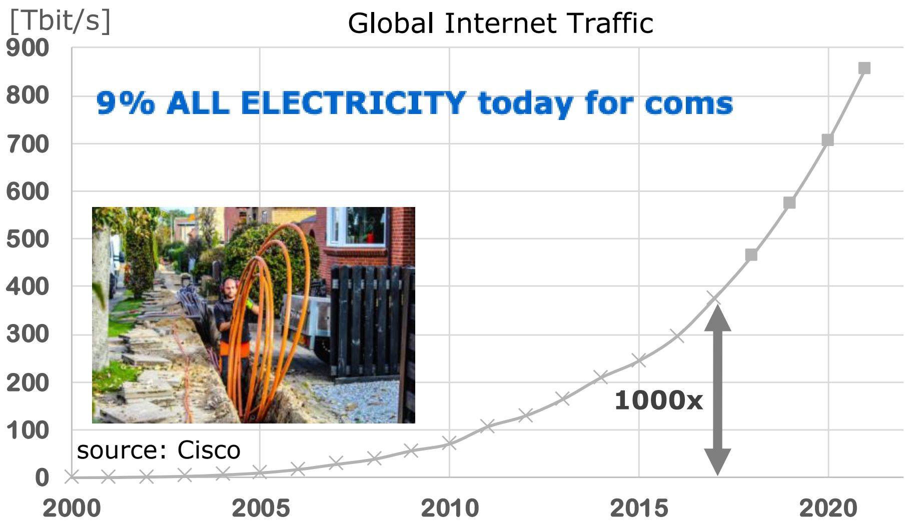
# Outline

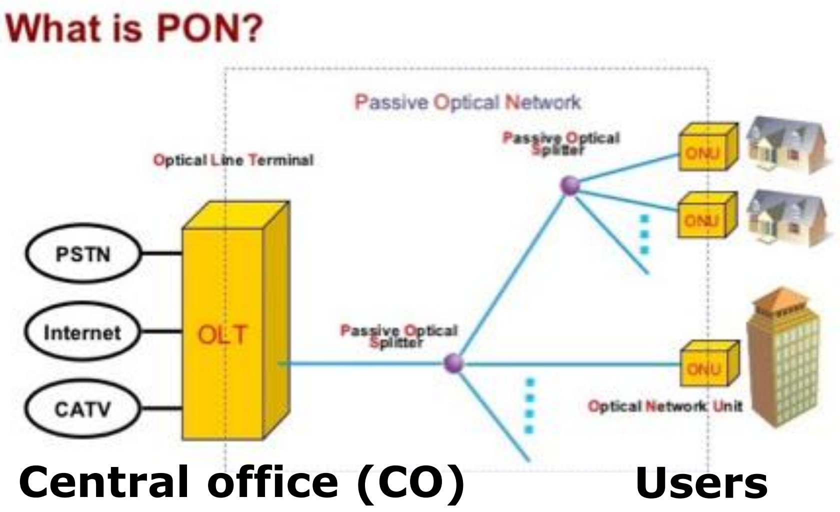
- On the internet energy consumption and passive optical networks
- Introduction to our single-laser WDM transmitter based on a time lens
- Principles of the four-wave-mixing-based time lens
- Presenting our work towards a more practical time lens WDM-transmitter
  - *Experimental setup and results*
- Conclusions

# Energy consumption and traffic of the internet

- Global traffic has increased by a factor 1000 since the year 2000 and counting…
- Communications consume ~9% of generated electricity



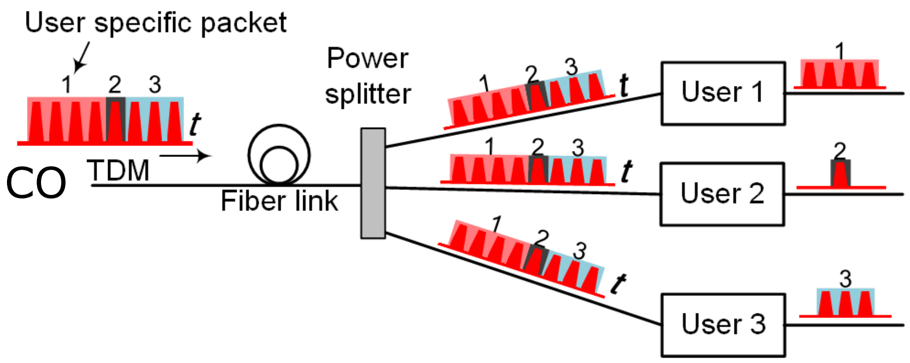

- The access networks are some of the largest energy consumers and expansion drivers
  - **Passive optical networks (PONs)**
    - Access to end users
    - Fronthaul e.g. for 5G




**Potential for high impact energy efficient solutions**

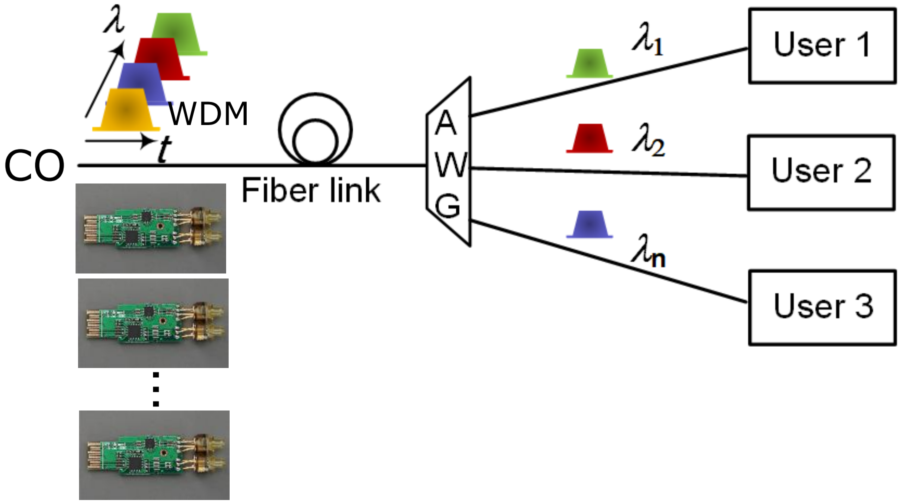
# Passive optical network solutions

- **TDMA-based PONs**
  - Single highspeed transceiver
    - Small space and energy footprint
  - Low dispersion tolerance
  - Power splitting *N* ways for *N* users
  - Low reach




**Single laser**: Low cost & energy consumption
**Single wavelength:** Low capacity & reach

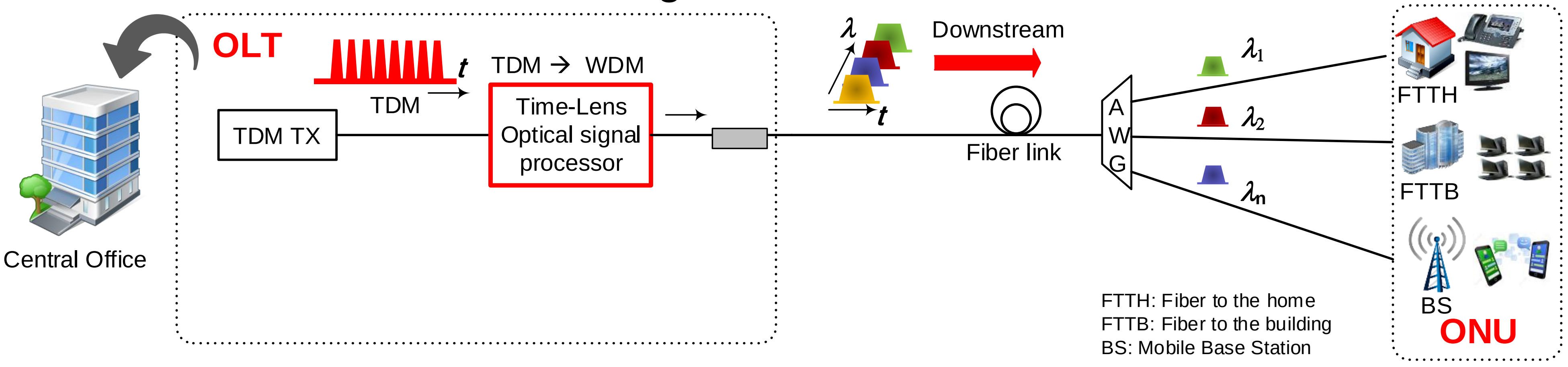
- **WDMA-based PONs**
  - *N* lowspeed transceivers needed at CO
    - Large space and energy footprint
  - High dispersion tolerance
  - Low splitting loss
  - High reach




**Multiple lasers**: High cost & energy consumption
**Multiple wavelengths:** High capacity & reach

# The Lens PON proposition

- Combine TDM/WDM benefits using a TDM-to-WDM converter

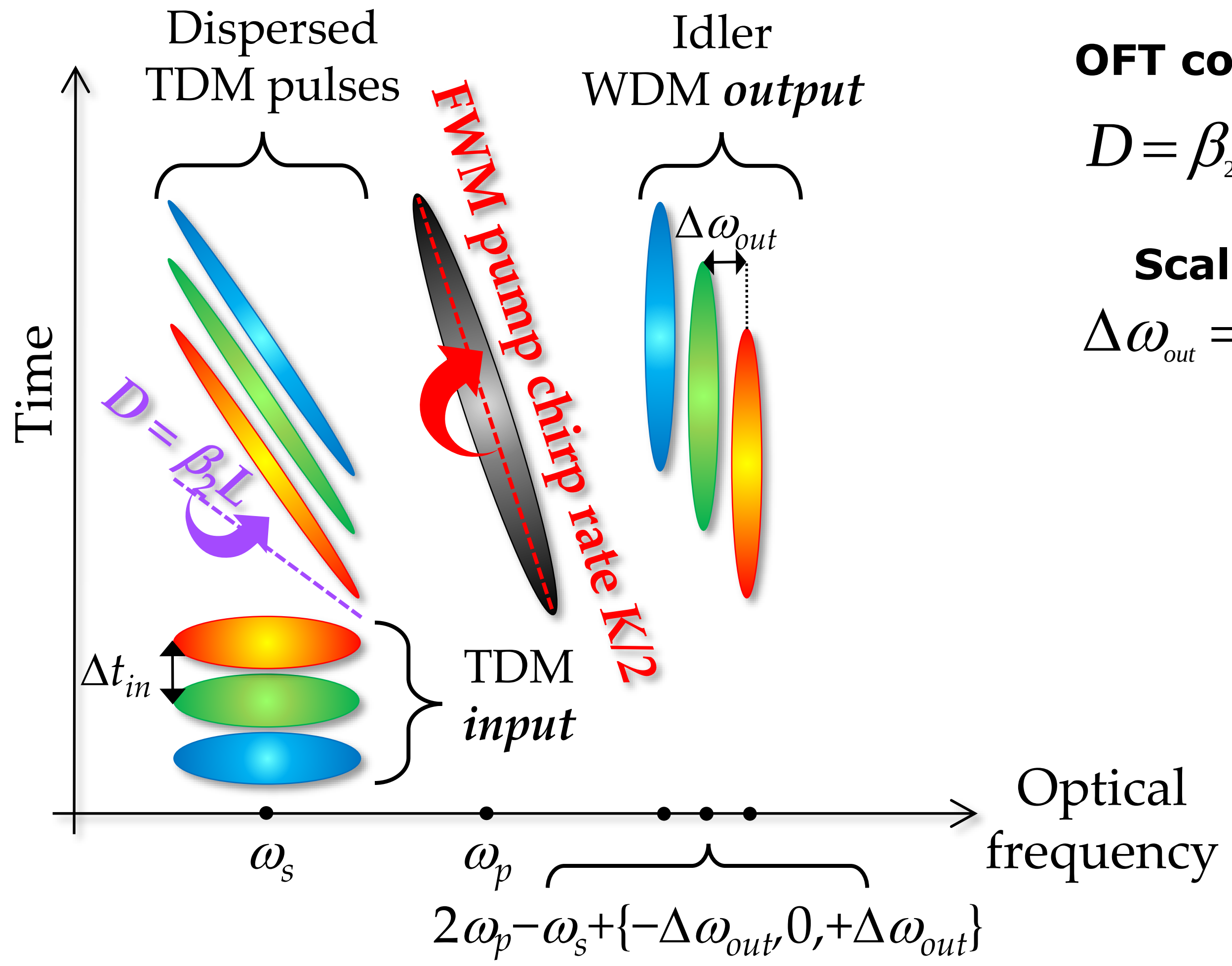



- Demonstrated flexible[1] 256 × 1 Gbit/s WDM generation[2] from OTDM transmitter
- TDM-to-WDM converter based on time-domain optical Fourier transformation
  - Parabolic phase modulation (time lens) and 2nd order chromatic dispersion

- Dispersion so far implemented using standard transmission fiber and DCF
- Time lens implemented using four-wave mixing with linearly chirped pump pulses


1. *P. Guan et al., OFC 2018, Th2A.54*
2. *P. Guan et al., ECOC 2019, M.1.A.6*

# Time-domain OFT based on four-wave mixing




**OFT condition**

$$D = \beta_2 L = \frac{1}{K}$$

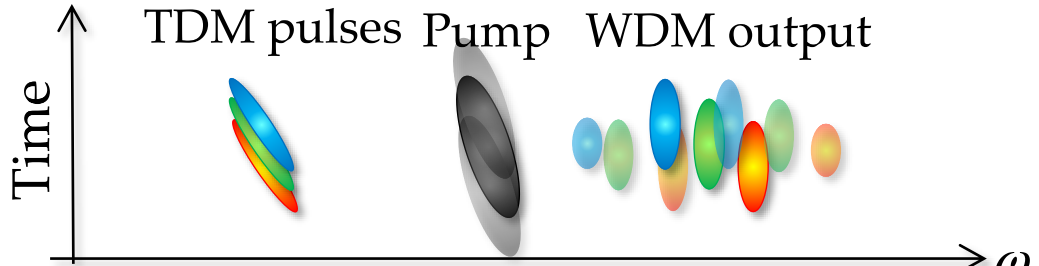
**Scaling**

$$\Delta\omega_{out} = K \Delta t_{in}$$

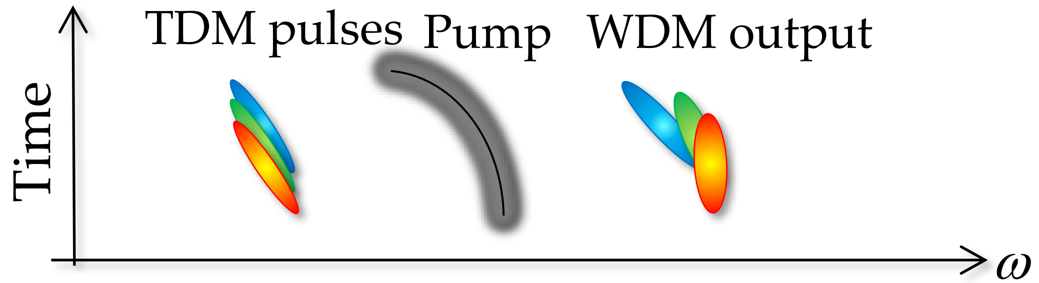
1. E. Palushani et al., IEEE J. Sel. Quantum Electron., 18(2), 2012.

# Goals and challenges

- **Goals**
  - Stability → power and frequency stable WDM signal
  - Portability → compact and rugged components
  - Compatibility → interfacing with industry standard equipment
- **Challenges**
  - Pump-signal jitter due to thermal fiber length fluctuations



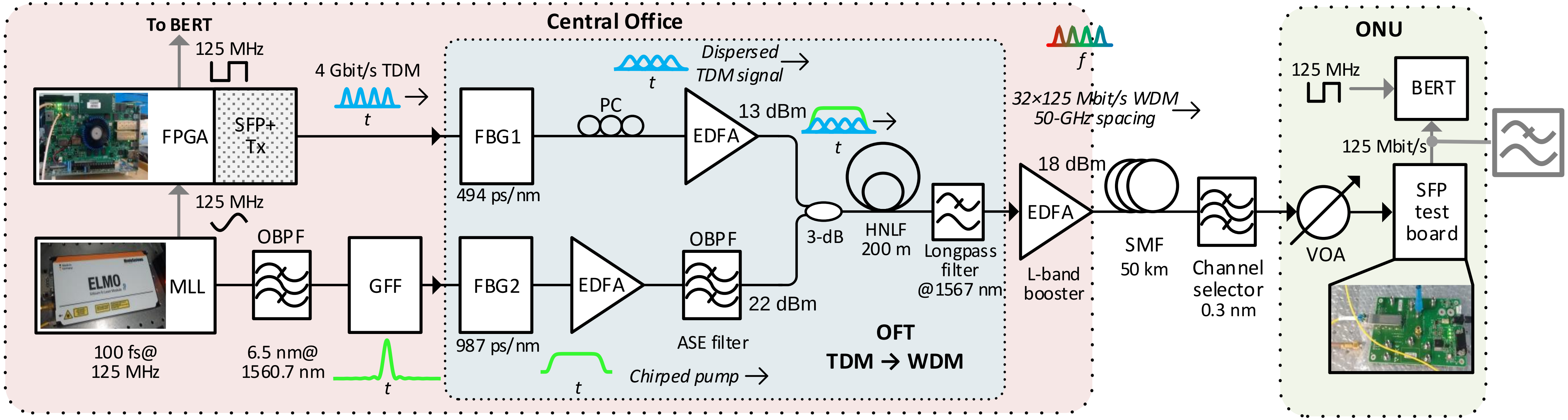

  - Residual third-order dispersion from chirped-pump generation



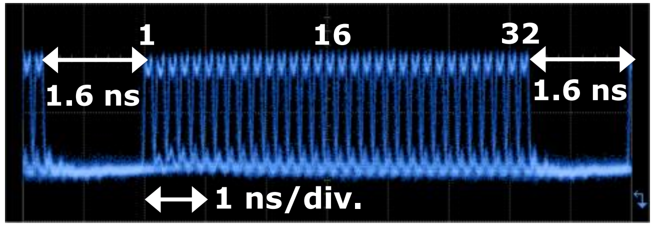
# This time lens based WDM transmitter

- **Fiber related stability and OFT distortion issues**
  - Compact dispersion designed fiber Bragg gratings with low TOD
- **Portability and potential compatibility**
  - Standard 10G SFP+ tranceivers controlled on FPGA board
  - Compact and rugged FWM pump comb source
- **Target output WDM signal**
  - 32 × 125 Mbit/s WDM channels with standard 50 GHz spacing
  - Suitable e.g. for 100BASE-TX ethernet with 4B5B encoding

# Experimental Setup
## 4 Gbit/s TDM to 125 Mbit/s ×32 WDM channel generation

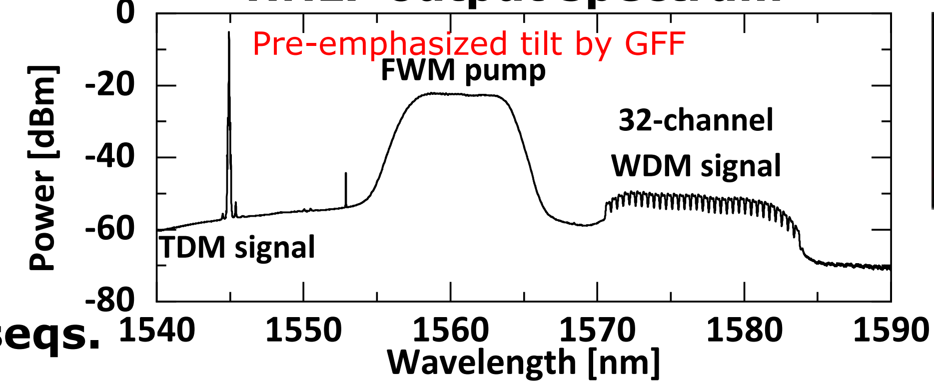



### 4 Gbit/s SFP+ Tx optical output

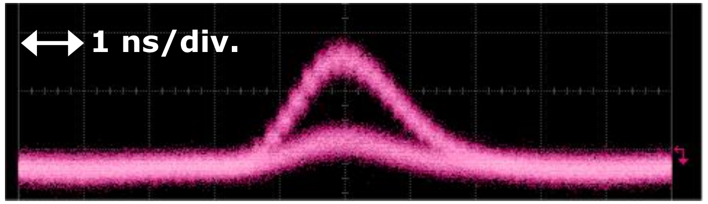



(10 Gbit/s SFP+ Tx)
TDM of 32 independent PRBS seqs.

### HNLF output spectrum



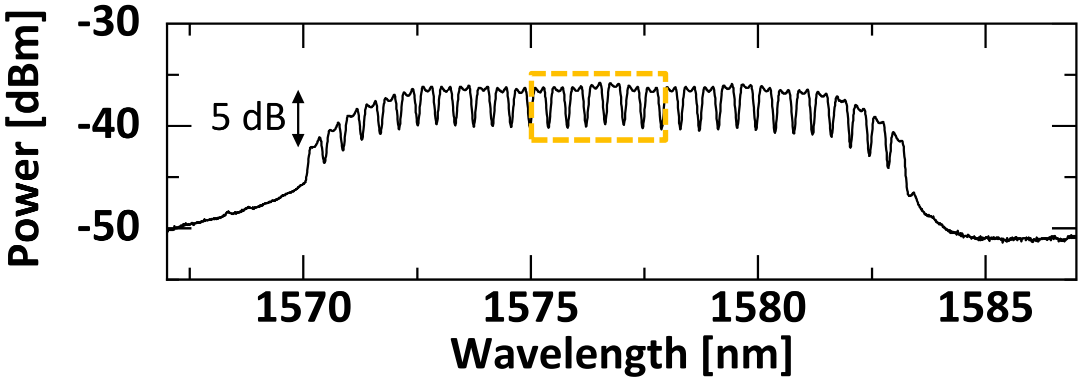

### Received WDM channel




(10 Gbit/s SFP+ Rx)

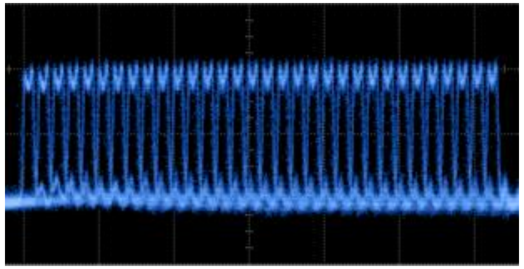
# Time lens based transmitter results

**Transmitter output after booster EDFA**
**32×125 Mbit/s WDM channels (50 GH spacing)**

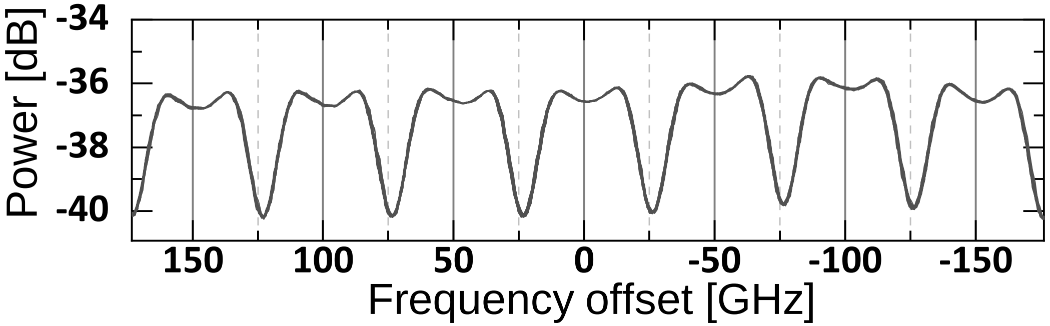



**OFT**

**SFP+ Tx output**
**Same characteristic troughs**



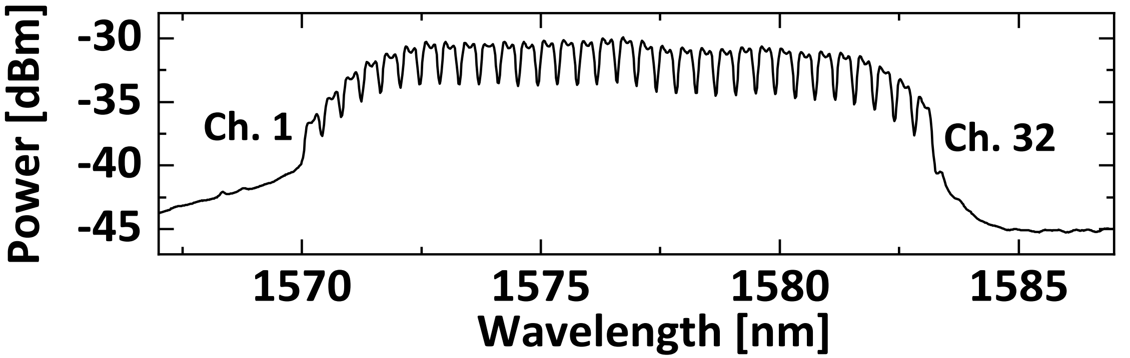
**Zoom-in of 7 channels**
**60 overlapping spectra, 1 spectrum/min over 1 hour**



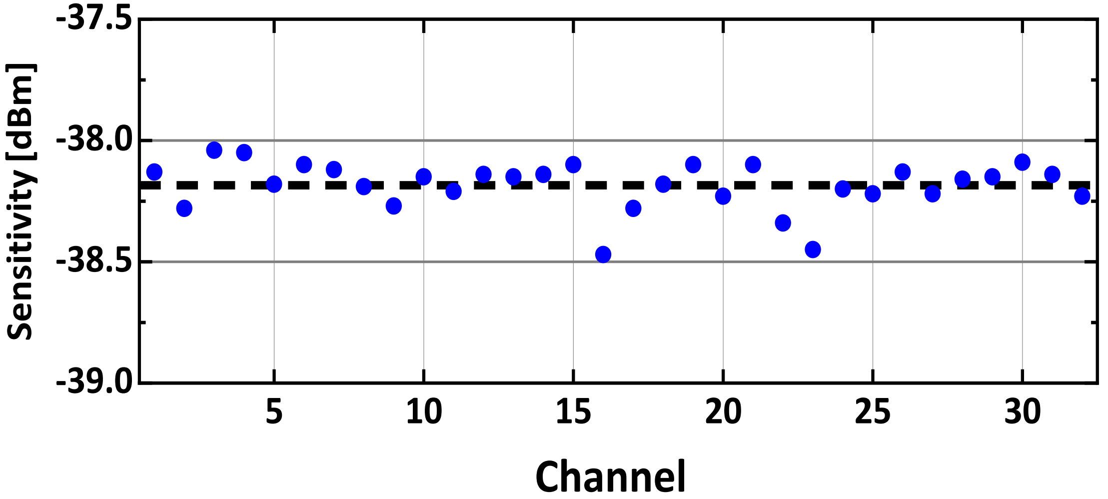

- **High fidelity transformation**
- **Highly stable system**
  - ➢ **Frequency**
  - ➢ **Power**
- **Frequency spacing according to design specifications**

# Transmission performance results

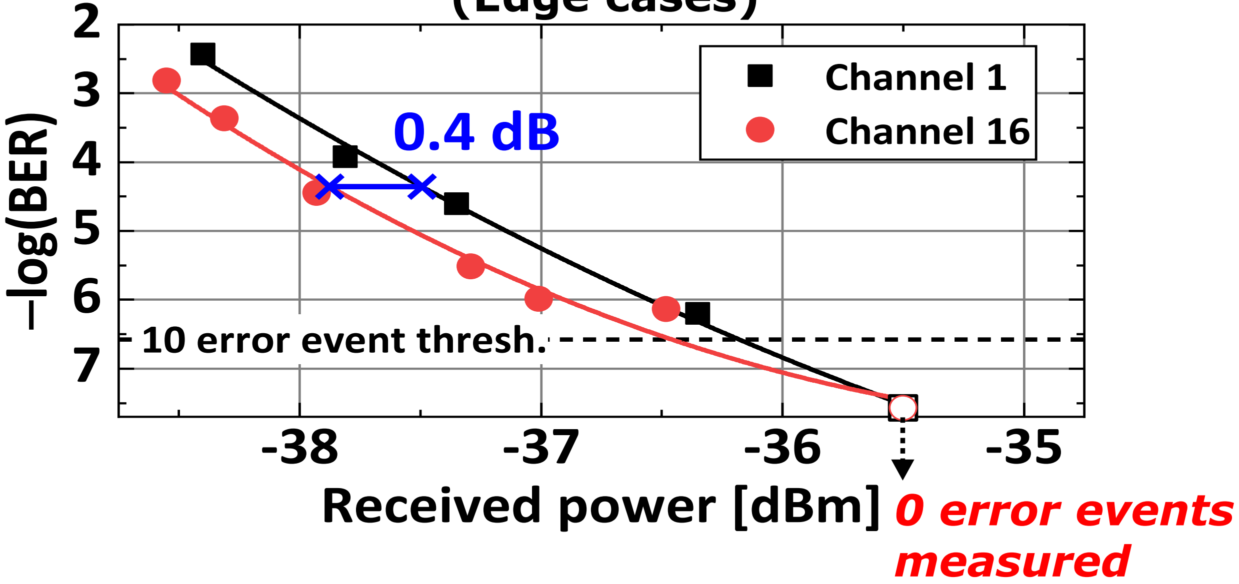
WDM spectrum after 50 km transmission




Receiver sensitivity at BER = $10^{-3}$ threshold




BER vs. received power
(Edge cases)




- **Uniform sensitivity for all channels (<0.5 dB variation)**
- **Good average sensitivity of −38.2 dBm using a standard commercial SFP+ transceiver**
- **26 dB average power budget**

# Conclusions

- Demonstration of 32$\times$125 Mbit/s WDM channel generation from single SFP+
- Excellent stability and OFT fidelity with FBGs instead of standard fiber
- Uniform channel performance after 50 km transmission w/SFP+ receiver
- 26 dB average power budget
- First WDM signal generated from a single off-the-shelf transceiver

# Acknowledgements

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VILLUM FONDEN

ofs
A Furukawa Company

# Questions?

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